A STANDARD SIMULATION TESTBED FOR THE EVALUATION OF CONTROL ALGORITHMS & STRATEGIES RELATED TO VARIABLE AIR VOLUME HVAC SYSTEMS

by

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S.B., Mechanical Engineering (1980)

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Submitted to the Department of Architecture
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Building Technology

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ABSTRACT

The parameters for a dynamic, computer simulation model were developed. The parameters characterize the physical and geometric properties of a building shell, the internal and external building loads, the building's secondary systems, and the plant or primary energy source. The purpose of the model is to provide a standard testbed for the evaluation of control algorithms and strategies related to variable air volume HVAC systems. This work was conducted in collaboration with, and under sub-contract to, Loughborough University of Technology, Leicestershire, United Kingdom (LUT). The prototype building is a four level commercial, multi-use building. Activities in the building include classroom / educational space professorial and student offices, and office / administrative. The building contains three air-handling units; one unit and the volume it serves provides the basis for the testbed. The portion of the building serving as the testbed is divided into thirty-four zones, each with its own single duct, pressure independent VAV terminal box with hot water reheat. A perimeter heating system, composed of hot water convectors, radiators and baseboard heaters, augments the room comfort control system. Local-loop control in the mechanical room and for all but one zone is executed with microprocessor based, pneumatic actuators. One prototype direct-digital-control terminal box system was in use for a classroom zone. DDC control systems and motor driven actuators were substituted in the simulation for the pneumatic equipment. Zoning in the simulation was redistributed into six zones; the supply and return duct system was redesigned to accommodate the simplified zone configuration.

A survey was conducted to determine the availability of sub-one-hour solar and collateral weather data. Historically, data in this frequency have been collected, but not reported. A relatively new program called the Automated Surface Observing System (ASOS) and operated by the National Oceanic and Atmospheric Administration will eventually provide weather data at varying intervals down to one minute, depending on the type of information required. Daily and monthly summaries are available; however, resolution is reduced and averaged to one hour intervals. The SOLMET program, under the auspices of DOE, provides archived solar data at one hour intervals on CD ROM. Data are collected from twenty-six stations distributed around the United States. Collateral weather data are also provided with the solar data and for simulation purposes the SOLMET data provides the best resource.

Thesis Supervisor: Leslie K. Norford

Title: Associate Professor of Building Technology

Acknowledgments

This work is dedicated to the memory of my brother Philip Christian DeSimone and to my cousin Timothy Robert Cleeton. Their memory is an inspiration, and I aspire to attain only a small fraction of the wisdom, understanding, and courage they achieved in their short lifetime.

Ostensibly, this thesis represents the consummation of my graduate work; in reality, it represents twenty-five years of patient and thoughtful support from family, friends and colleagues, and I would like to acknowledge all who contributed to this quarter century effort. In particular, I must express my profound appreciation to Dr. Leslie K. Norford who, in the last two and a half years, emerged as a trusted guide and mentor for this work and all of which I endeavor to undertake in the future. My colleagues and friends Angelita Lotivio Altea, David Lorenzetti, Kachi Akoma, Leyla Tanaçan, and Sydney were a continuous, unwavering source of energy, studied advise, and intellectual support, most particularly appreciated at those fragile moments when the path appeared the most difficult and the obstacles insurmountable. To Philip Haves, I extend special appreciation for his dependable, serious, and accurate guidance, input and support during the accomplishment of this project, not uncommonly delivered with an understated and equally dependable sense of wit and humor.

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In the course of this project's development, my quest for information introduced me to the esoteric world of solar and collateral weather data acquisition and processing. The assistance provided by those at the National Climatic Data NCDC, Asheville, NC particularly Bill Skinner; the Federal Records Center, Waltham, MA; the National Archives, Washington, DC; the National Oceanographic and Atmospheric Administration, Camp Springs MD; the Blue Hill Meteorological Observatory (including the Harvard University Archives), Canton, MA - particularly Mr. Skilling; and the vast wealth of historical and technical knowledge provided by Bob Lautzenheiser all combined to make this task both extremely interesting and pleasurable, as well as being a true learning experience.

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1 Introduction

Heating, ventilating and cooling (HVAC) systems for buildings have become increasingly important. People are spending more time within buildings, as much as 90% in Western countries [McNall 1985]. Satisfaction with the thermal environment can affect productivity in ways that dwarf energy costs, which are about two orders of magnitude less than labor costs. But energy consumption itself is far from trivial in its cost. In the U.S. in 1990, buildings consumed 36% of the nation's total energy supply at a cost of $200 billion [Bevington and Rosenfeld 1990]. Energy consumption can be reduced through a combination of better lights, improved windows, more efficient motors and motor drives, and enhanced thermal insulation and air-tightness of building walls. Another factor is better control of space conditioning equipment. Bevington and Rosenfeld highlighted several examples of savings achieved through better controls with acceptably short (2-3 year) payback periods.

HVAC controls are inherently somewhat complex. The foundation of HVAC control is the single-loop proportional-integral-differential (PID) controller. While this device itself is well understood, its application for temperature and flow control often involves estimation of the thermal parameters of the controlled system, leading to the need for manual tuning of the controllers or on-line adaptive control. Further, assembling a system of single-loop controllers requires attention to the response time of the controlled systems, to ensure that the entire system is stable. For example, the common variable-air-volume ventilation system involves both local control of airflow to each thermal zone and central regulation of the pressure in the supply duct. Adjustments in the duct pressure must allow time for response by the local, thermostatically controlled dampers to prevent undue oscillation in pressure and accompanying wear on actuators. In addition, HVAC control systems increasingly include supervisory controllers to adjust set points to optimize system performance and are beginning to incorporate on-line diagnostics as well.

This growing complexity has prompted a need for improved methods for developing and testing control strategies and diagnostic methods. On-line testing in test rigs or real buildings provides perhaps the most information, but is expensive and not a good starting point. Simulation potentially offers the best efficient first step but only if the simulation tool can model a building and its HVAC system in sufficient detail to yield valuable results. The building energy simulation tools favored by energy analysts, including DOE-2 and BLAST, do not permit the user to describe and simulate HVAC systems and their controllers in the requisite detail. Time steps are too long and there is little flexibility in describing systems, which are described as a whole, with no opportunity to work at the component level. At this time, the simulation tools of choice are those that permit component-level simulation, including HVACSIM+, TRNSYS, IDA or SPARK [Haves 1995]. Indeed, HVACSIM+ and TRNSYS have been extensively used for tasting of HVAC control and diagnostic strategies [Haves 1995]. Andresen and Brandemuehl (1994) incorporated the TRNSYS building shell model into their study of the control of heat flows in and out of building thermal mass, as did Morris et al. (1994) for a study of optimal control of building thermal storage. Neither of these studies focused on duct systems or control of ventilation systems.

Component-level simulation work to date has been performed by experts for specific applications. Such simulations could potentially aid a much wider audience, including controls engineers working in research, training, and in field applications. Simulations can be used not only in a stand-alone configuration but as emulators to mimic the functions of a building and its HVAC system and communicate requested information to a control system, and respond to the controller's outputs. Inhibiting the use of component simulation programs has been the complexity of the programs, as manifested in the very substantial effort required to configure a simulation and ensure proper convergence of the numerical algorithms.

To make a component simulation program more accessible and more useful to practicing engineers. there is a need to prepare a simulation that is solidly based on a typical HVAC system installed in a building of typical construction and usage patterns. To date, there has been no systematic attempt to prepare such a simulation. Simulations of portions of a few buildings have been developed, with one notable example that of a U.S. government office building [Park et al., 1989]. However, these simulations were designed to demonstrate the viability of the simulation program itself rather than serve as a simulation testbed, and consequently lack the requisite documentation of the building, its systems, and the matching of equipment to simulation needed to develop parameters for the simulation of components of the HVAC system. This thesis, in conjunction with parallel work at Loughborough University of Technology, U.K., has the goal of developing an accurate, thoroughly documented simulation testbed suitable for development and testing of HVAC control algorithms.

"Computer simulation has the potential to play an important role in the development and testing of control algorithms and strategies. The main advantages of computer simulation are that it can produce reproducible conditions, provide accelerated testing, and be carried out more conveniently and inexpensively than the testing on a real plant especially when abnormal conditions or faulty operation is required. A standard testbed for HVAC controls will make these potential benefits more widely available in the industry. It will facilitate the inter-comparison of different algorithms and strategies,

and it can also be expected to simulate the development of objective standards for control system performance."[1]

My work as a Research Assistant for the ASHRAE Research Grant 825-TRP: A Standard Testbed for the Evaluation of Control Algorithms and Strategies serves as the basis for this thesis. This project was conducted by the interdisciplinary graduate program in Building Technology at the Massachusetts Institute of Technology, and was being undertaken to develop a standard computer simulation testbed for the evaluation of control algorithms and strategies in cooperation with Loughborough University of Technology, Leicestershire, UK (LUT) for the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., (ASHRAE).

"*The principles and objectives of this project are to provide and document a standard set of algorithms that model the performance of HVAC components and to demonstrate their use in simulating an HVAC system for the purpose of comparing control techniques under realistic conditions. The algorithms will model short-term dynamic characteristics and non-linearities of HVAC components and will be capable of being connected together to simulate the behavior of different types of HVAC-systems using the modular simulation programs HVACSIM+ or TRNSYS. The fabric and HVAC system of a selected variable air volume (VAV) office building [or model volume] will be documented in sufficient detail to allow it to be modeled using the testbed. The operation of the building will be simulated to illustrate how the testbed can be used to demonstrate the operation of HVAC control systems.*"[2]

This project has ten identifiable tasks:

1. Identify HVAC Component Models
2. Review Zone Models
3. Reformat Models
4. Selection of Real Building
5. Real Building Specification
6. Schedules of Occupancy and Internal Gains
7. Need For/Availability of Sub-One-Hour Weather Data
8. Identify and Implement Methods

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1 ASHRAE Application For Grant Funds: A Standard Testbed for the Evaluation of Control Algorithms and Strategies (825-TRP), Principle Investigators - Haves, Philip & Norford, Leslie, December 1993.

2 ASHRAE 825-TRP

9. Implement and Test the Building Specification
10. Final Reporting (on the MIT Tasks)

"The work will be carried out jointly by Loughborough University of Technology, UK (LUT) and Massachusetts Institute of Technology (MIT). LUT will be responsible for assembling and documenting the component models and identifying and documenting the methods of interfacing control systems algorithms and control hardware to a simulated building and plant. MIT will be responsible for detailed documentation of an example VAV office building for use in testing and demonstrating the testbed. LUT and MIT independently will use the example building documentation to model and simulate the example building. This will allow LUT to check the completeness and consistency of the building documentation and will allow MIT to test the ability of the component models individually and collectively to model a real HVAC plant and control systems."[3] Each of the ten tasks is described in detail in the referenced research grant proposal document.

My contribution to this project coincided with the areas of responsibility outlined for MIT in the research grant proposal, and consists of the following sub-sections:

4. Selection of Real Building;
5. Real Building Specification;
6. Schedules of Occupancy and Internal Gains;
7. Need for Availability of Sub-One-Hour Weather Data;
9. Implement and Test the Building Specification;
10. Final Reporting.

The selection process for the real building involved making some preliminary decisions regarding:

(1) what primary, essential physical characteristics must the a prototype structure possess;
(2) what secondary features would be desirable but would not necessarily essential;
(3) what kinds of buildings would meet certain the necessary qualitative and quantitative physical requirements, as well as having certain operational characteristics;
(4) where can such buildings be located to satisfy access requirements;
(5) what kind of access will be required;
(6) who needs to be involved in gaining the required access;

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3 ASHRAE 825-TRP

(7) what level of documentation will be required?

After making a preliminary selection, a final selection was made to optimize flexibility. Recognizing that *"achieving the ideal is difficult"*[4] trade-offs were made to gain the most benefit from the characteristics of each choice, and the building that scored the highest was selected.

The task identified as "Specifying the Real Building" was divided into two parts; the first part involved the specification of the real building, identifying all systems and sub-systems that make the prototype building which would eventually have to be modeled in order to create the testbed. This included: (1) siting the building geographically (location, compass orientation, and external obstructions; (2) quantifying the building's internal and external walls; (3) and detailing all mechanical systems including the air conditioning and distribution systems, both the primary and secondary control systems, and the perimeter heating system. The second part of this task involved mapping the real building specifications into the component models available with the chosen computer simulation package assigning the appropriate state variables and component parameters.

In order to evaluate the ability of the building's local, closed loop control systems (or localized automatic control systems[5]) to maintain a set point in a particular zone, realistic disturbances due to internal gain fluctuations are necessary. Identifying the internal heat gain components including occupancy, lighting, and equipment required a study of the occupancy schedules for the multi-use building, involved making site surveys and inspections to ascertain equipment and lighting types and densities. In addition, information obtained from the site surveys was augmented with a survey of studies both published and unpublished; these studies characterized internal gains by lighting and equipment with information gathered experimentally and through theoretical modeling.

The need for solar and collateral weather data is in concert with the need to quantify internal disturbances in the form of heat gains. Two objectives were to be met in this sub-task: (1) using the model, determine the highest frequency external excitation to which the HVAC system will respond; (2) ascertain the availability of solar and collateral weather data which is prescribed in the first part of this task. A survey of the historical development of solar and weather collection data was made. In addition, an assessment was made of the various types of data available in numerous formats from a

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4 ASHRAE 825-TRP

5 1991 ASHRAE Handbook - HVAC Applications, A41.33.

wide variety of sources. In conclusion, on the basis of the surveys and assessments, the sources appropriate for projects such as this were identified.

Implementation and testing of the computer model was specified as a sub-task in this project. The first part, implementation, involves mapping the building's geometric and physical characteristics into the components available with the selected computer simulation package. Testing involves subjecting the model to the variety of internal and external stimulations or disturbances and observing the resulting behavior. Real time interfaces were planned and developed by LUT to allow human interaction during a simulation run.

As outlined in the proposal, a final report was to be prepared and submitted. In addition, system model configuration files were to be prepared in machine readable form, (the exact specifications of which remain to be determined), and all drawings, tables, and data as stated in the work scope were to be provided. This document shall serve as the basis for much of the information and documentation which will be included in a final report to be prepared by others.

This thesis is organized in the following manner. The first part of Chapter 2 outlines the basic theory behind one-dimensional heat transfer analysis related to real-time performance testing and evaluation of control algorithms and strategies. A contrast is drawn between the two classes of analysis: (1) the energy estimating methods, including degree day analysis, variable degree day analysis, bin analysis, and correlation analysis; and (2) time dependent, transient analysis. The second part of Chapter 2 details the development of the global parameters for the multi-zone, lumped parameter, second order dynamic model on which the work accomplished for this thesis is based. In addition, an algorithm is presented for calculating effective sol-air temperatures as a function of insolation, ambient air temperature and the properties of the incident walls (roof).

Chapter 3 provides a detailed record of a buildings physical construction and mechanical system. Beginning with a brief outline of the buildings external shell including the foundation, external walls, internal partitions, ceilings and floor, and the HVAC system, Chapter 3 systematically catalogs the original engineering design specifications, and describes each piece of equipment in the HVAC system. A large part of the work for this project involved simplification of existing systems for computational purposes. The original thirty-four zone layout of the building was redesigned to six zones and a simplified supply and return duct system was designed to match the flow and thermal characteristics of the original thirty-four zone system. Re-zoning was accomplished while preserving the total floor area devoted to the various uses identified in the building. The Last part of Chapter 3 is devoted to mapping the real building structure (external shell, internal partitions, floors, ceilings, and roof) to the lumped parameter, second order model.

Chapter 4 examines the availability of sub-one-hour solar and collateral weather data. A number of sources were identified from which raw and processed (corrected) data can be obtained, however, no direct measurement insolation data was found to be available at the frequencies of interest, (sub-one-hour). One source was found to yield sub-one-hour weather data, and from this it may be possible to derive realistic insolation values at high frequencies, and it is left to further research to clarify and develop this concept.

Chapter 5 details the development of the parameters for the HVACSIM+ model type units required to model the subject building. The basis for the parameters described in this chapter is the information reproduced in Chapter 3. Some of the HVACSIM+ types required modification in order to accurately reflect the configuration of certain pieces of equipment in the building and in these cases the elements or sub-components from which the "new" types would eventually be constructed were provided. In addition to the parameters, profiles have been provided which detail the internal and external heat gains for a typical day of operation. The external gains consist of effective sol-air temperatures based on the ambient air temperature, solar flux, and external wall properties. Two methods were used to calculate the sol-air temperatures, and one method was finally chosen over the other on the basis of subjective judgement; the method not chosen was not producing values which could be considered reasonable. Internal gains were based on dissipation due operating equipment and electric lighting and that due to occupant densities. Gain profiles were developed on the basis of actual schedules for the various zones usages.

2 Theory

The transient response of a physical system model, comprised of ideal capacitors and resistors, to excitation from system inputs and control signals, in addition to model temperatures and the net energy flow required to maintain a set point, control system behavior and fluid flow temperatures are the desired outputs of this project.[6] Both open and closed loop control are possible, however, it is the response to closed loop control and the resulting behavior of the closed loop control systems that are of particular interest. The modeling process involves estimating the energy required to maintain a certain comfort level within a control volume when the volume is subjected to varying loads. Various methods of analysis are available for estimating energy in buildings. The various methods can be divided into two classes of analysis; (1) steady-state; and (2) transient. In either case, the fundamental, underlying principles governing the solutions are:

First, the principle of conservation of energy:

$$\begin{matrix}\textit{The change of internal energy}\\ \textit{within the system}\end{matrix} = \begin{matrix}\textit{Heat energy transfered}\\ \textit{into the system}\end{matrix} + \begin{matrix}\textit{Heat energy generated}\\ \textit{within the system}\end{matrix} \tag{1}$$

or

$$\Delta U = \dot{Q}\,\Delta t + \dot{Q}_v\,\Delta t\,; \tag{2}$$

which in differential form appears as

$$\frac{dU}{dt} = \dot{Q} + \dot{Q}_v\,; \tag{3}$$

and second, the phenomenological law governing heat flow known as "*... Fourier's law of heat conduction which states that in a homogeneous substance, the local heat flux is proportional to the negative of the local temperature gradient.*"[7] In Cartesian coordinates, this is stated as:

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6 *The analysis of a dynamic system always involves the formulation of a conceptual model made up of basic building-blocks that are idealizations of the essential physical phenomena occurring in real systems. An adequate conceptual model of a particular physical device or system will behave approximately like the real system. The best model is the simplest one which yields the information necessary for engineering action or decision.* (Shearer, et. al.)

7 Mills, A.F., Chapters 1 & 2.

$$q_x = -k\frac{\partial T}{\partial x}; \quad q_y = -k\frac{\partial T}{\partial y}; \quad q_z = -k\frac{\partial T}{\partial z} \tag{4}$$

or equivalently:

$$\boldsymbol{q} = -k\,\nabla T \tag{5}$$

"... where q_x is the component of the heat flux in the x direction, $\partial T/\partial x$ is the partial derivative of $T(x,y,z,t)$ with respect to x, and so on ...."[8] and where the thermal conductivity k is the same in all directions, ie. the material is considered to be isotropic. In addition, from the definition of constant-volume specific heat attributed to an incompressible solid, the change of internal energy for a solid in differential form is given by:[9]

$$dU = \rho V c_v dT \tag{6}$$

From the principle of energy conservation (Eq. 3), Fourier's Law of Heat Condtiction (Eq. 5), and the definition stated in Eq. 6 the **Heat Conduction Equation** is derived (note that the complete derivation is provided in Mills, Pp. 124 - 128):

$$\rho c_v \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \dot{Q}_v''' ; \tag{7}$$

where:

$$\rho c_v \frac{\partial T}{\partial t} \equiv \textit{transient component} ; \tag{8}$$

and, the rate of internal or volumetric heat generation is given by:

$$\dot{Q}_v''' \equiv \textit{rate of internal or volumetric heat generation} \quad [W/m^2]; \tag{9}$$

and : ρ = the density of the material through which the heat is passing; [kg/m³];
c = the physical characteristic of the material, the specific heat [J/(kg·K)].

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8 Mills, A.F., Chapters 1 & 2.

9 Ford, Kenneth W., §13.9

It should be noted that Eq. 7 does not account for radiation or convection. In this simulation model, these two modes of heat transfer equivalent resistances (or conductances) are calculated using various methods, and are then incorporated into the system of conduction equations, (refer to §3.3.3.7 for detailed development of equivalent resistances).

In the first class of analysis, the energy estimating methods include degree day analysis, variable base degree day analysis, bin analysis, and correlation analysis. They vary in degrees of complexity and accuracy, and hour-by-hour analysis or even a quasi-steady-state analysis can be performed using these methods. For steady-state, multi-dimensional analysis the transient component of the heat conduction equation for heat flow in isotropic media (Eq. 7) must be equal to zero, or equivalently:[10]

$$\rho c \frac{\partial T}{\partial t} = 0 \ . \qquad \textbf{(10)}$$

However, when real-time performance testing and evaluation of control algorithms and strategies or closed loop controls are involved, these methods are not sufficient, leading to the second class of analysis. The time dependent solutions found for closed loop control problems require time dependent system models (or dynamic models). The model or mathematical system for this project was designed to demonstrate the transient response of the building's control system to stimulation from internal and external loads, and therefore contains non-zero contributions from the transient component of the heat conduction equation. The model used for this project assumed one dimensional, transient heat flow with internal/external gains. Consequently, the y and z terms in Eq. 7 are equal to 0, which results in the one dimensional form of the heat conduction equation shown by Eq. 11, as follows:

$$\rho c \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2}\right) + \dot{Q}_v''' \ . \qquad \textbf{(11)}$$

The real building and its energy systems are represented in the mathematical model by the following three fundamental aspects: (1) the thermal behavior of the building structure (the loads model); (2) the thermodynamic behavior of the air-conditioning delivery system (the secondary systems model); and (3) a mathematical relationship for load versus energy requirements of the primary energy conversion equipment (the plant model).[11] It should be noted that these three elements are not unique to dynamic modeling, but also form the basis for each of the steady state methods as well.

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10 Anthony F. Mills, Heat Transfer (Boston, MA: Richard D. Irwin Inc., 1992), p.127.

11 1993 ASHRAE Fundamentals Handbook, Energy Estimating Methods, F28.14.

The loads model takes into account the physical and geometric characteristics of the building and the various load sources. It is in this step where the amount of energy, which must be added or extracted from the space in order to maintain a certain set point, is calculated. The secondary systems include heating and coiling coils, mixing box, VAV boxes, ducts, dampers, and all other components of the real HVAC system. This part of the model is comprised of mass and energy balances for each the systems components, and it is here where the requirements specified in the first step is translated into load requirements on the secondary system components.

In the ASHRAE Handbook the plant model *"relates the required input energy rate ... to the required energy rates of the secondary systems. Typically, the central plant model includes such relationships for chillers, boilers, cooling towers ...."* For this project, cooling power is supplied by a constant temperature source; a central plant provides cooling for a number of buildings in the vicinity of the subject building, similar to a district style system. It should be noted that heating energy comes from a hot water boiler system located in the building's basement. The system serves the three individually conditioned volumes, and for simplicity in the first stages of the model development, it was decided to model this as a constant temperature source. It is anticipated that future work by others will include the components required to model the water side of the heating system and include them in the dynamic model. Electric powered perimeter heating elements were substituted for the hot water convectors installed around the perimeter.

Local, closed loop control systems maintain control over the individual plants and also provide some links between the three. Each zone has its own temperature control monitoring system which modulates air flow through the VAV terminal box, water flow through the reheat coil, and water flow through the perimeter heating system. Three points within the model volume send temperatures to a comparator in the mechanical room. The supply air temperature for the entire building is reset to meet the highest cooling demand. A local, closed loop control system in the mechanical room maintains set points for supply air pressure and the mixture of return and fresh air that comprises the mixed air, later to become the supply air.

2.1 HVACSIM+ Simulation Program Structure

Presently, there are several simulation packages available which can run on a microcomputer based platform. For this project use the non-proprietary building system simulation program, HVACSIM+

(or HVAC SIMulation PLUS other systems), was selected. The program was originally developed in the mid-1980's at the United States National Bureau of Standards (NBS) (renamed and currently known as the National Institute of Standards and Technology), and has undergone many updates, revisions, and improvements since then. Quoting from a draft document prepared by the NBS team:

> *"... HVACSIM+ consists of a main simulation program, a library of HVAC system component models, a building shell model [or zone model] and an interactive front end program. The main simulation program employs a hierarchical, modular approach and advanced equation solving techniques to perform dynamic simulations of building/HVAC/control systems ...."*[12]

The program calculates instantaneous space sensible loads based on the heat balance method relying on the first law of thermodynamics and the principles of matrix algebra. Heat balance equations for the walls, floors and ceilings of each control volume (or zone) plus additional equations for the air contained in each of the volumes calculate the energy required to meet given set points. Mass and energy balance equations, characterizing both the transport equipment conveying energy in to or out of the volumes and the local loop control systems work together to satisfy the energy requirements demanded by instantaneous zone conditions. The essence of the simulation package is found in the MODSIM program. This program handles seven major functions:

(1) Input and Output;
(2) Block and State Variable Status Control;
(3) Integration of Stiff Ordinary Differential Equations;
(4) Solving of a System of Simultaneous Non-Linear Algebraic Equations;
(5) Models of HVAC Components and Controls;
(6) Building Loads Model;
(7) Supporting Utility and Fluid properties.

The model definition (component parameter values), solar and collateral weather information, and boundary data files are called by the MODSIM program. In addition, simulation control input data can be changed on a real time basis, and an output interface has been developed which provides real time

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12 Cheol Park, Daniel R. Clark, George Kelly. An Overview of HVACSIM+, a Dynamic Building/HVAC/Control Systems Simulation Program, Building Equipment Division, Center for Building Technology, National Bureau of Standards, Gaithersburg, Maryland, 1986.

simulation results in a colorful graphical interface.[13] More detailed summaries of the theory behind the HVACSIM+ simulation program structure can be found in the three manuals prepared by the NBS team and shipped with the program.[14,15,16]

Simulating a building and its comfort control systems using HVACSIM+ requires the disaggregation of the structure into discreet component parts. Each component is represented by an HVACSIM+ Unit Type comprised of one or more sets of differential and non-linear algebraic equations. The types are linked together by state variables. Parameters, detailing the physical and geometric characteristics of each components, capture the essence of the building and its sub-systems and provide the coefficients for the differential and algebraic equations. The components are grouped into sub-systems called blocks, and the blocks are grouped into larger groups called super-blocks. The basic intent behind grouping the units into blocks and super-blocks is to optimize the time required to execute a simulation while retaining the highest level of accuracy possible. The literature provided with the program (NBSIR 85-3243) states that "*... There are no highly specific rules for the division of super-blocks and blocks. The decisions involved must be based on knowledge of how the real system behaves and an understanding of how blocks and super-blocks are handled within the simulation program.*

A strong recommendation is made in the literature to *"keep tightly coupled sub-systems such as local closed loop control systems or closed loop flow streams within a single block...."* However, another method for grouping units into blocks and super-blocks places all units of a certain category into the same super-block.[17] The recognized logical breakdown forms the basis for the categories is found in Table 1. Grouping the components in this manner separates the necessarily stiff sets of differential equations resulting from grouping together equations with widely varying time constants into component groups with similar time dependent behavior. The intent of this philosophy is to decrease the real-time required to conduct a simulation, as well as to increase the accuracy of the results. Anecdotal evidence supports this contention, although no formal testing has been conducted which shows one method to be superior over the other. Within the super-block categories, units can be placed into blocks which group

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13 Phil Haves, LUT, 1995.

14 Clark, NBSIR 84-2996, Chapter 1.

15 Clark, et.al., NBSIR 85-3243, Chapter 2.

16 Park, et.al., NBSIR 86-3331, Chapter 5.

17 The method was proposed by Phil Haves, Loughborough University of Technology, Leicestershire UK, and is one of the bases for the sample simulation in Appendix AA.

the units in a more traditional manner, by tightly coupled sub-system, as outlined in the program manuals.

Table - 1: Super-Block Categories for Haves Simulation Method

Category	Super-Block Category Description
01	Technical and Administrative - used for some i/o activity during real time simulation and also for altering psychrometric characteristics of airflows w/i the simulation
02	Controllers and Control System Components - all controllers & accessories
03	Actuators - actuators for coil control valves and dampers are included in this section
04	Airflow Components - all components associated with the calculation of air flow rates and pressure through the system
05	Thermal Components - contains all components associated w/ temperature calculation
06	Sensors Devices - all sensors in the system are grouped in this category
07	Simulation Real-Time Input and Output Devices - real time interfaces

It should be noted that grouping similar components into separate superblocks works if, and only if, the time-step used is much shorter than the dominant time constant of each loop. This is the approach taken in this project. This approach is unavoidable if real controllers are to be combined with a simulated building and plant; a principle requirement of the Testbed which is to be the product of this research effort. This process also decreases the numerical difficulty associated with achieving solutions during the simulation, although there may be a significant associated increase in computational costs.

2.2 Theoretical Building Model

The multizone dynamic model of each zone is a lumped parameter model of 2nd order. Zones are connected by resistances, thus describing the dwelling by a polygonal network. The model has 5 degrees of freedom per zone. They are determined by respecting the zone:

- *overall resistance;*

- *ratios of loss through light structures to the total losses;*

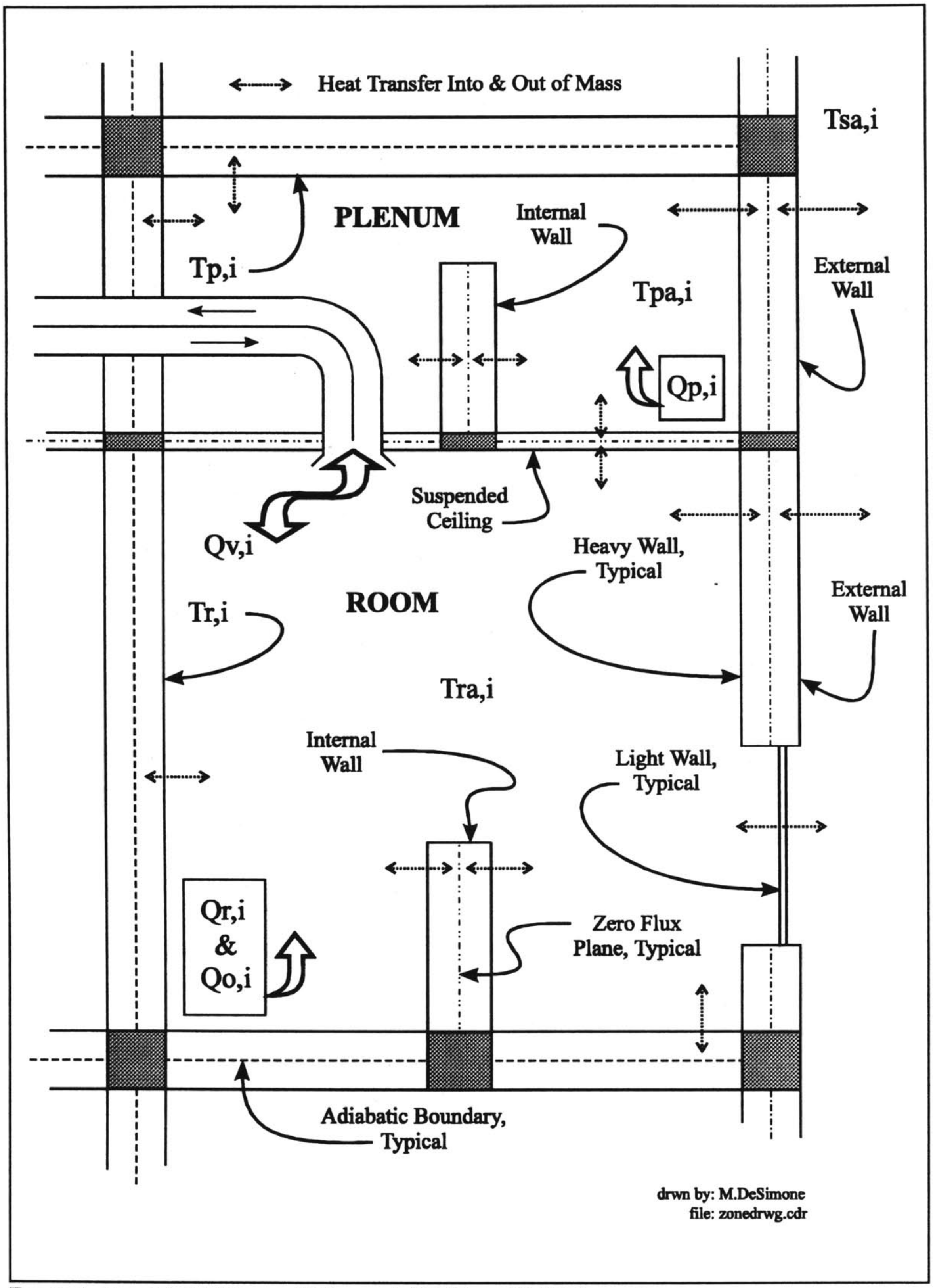
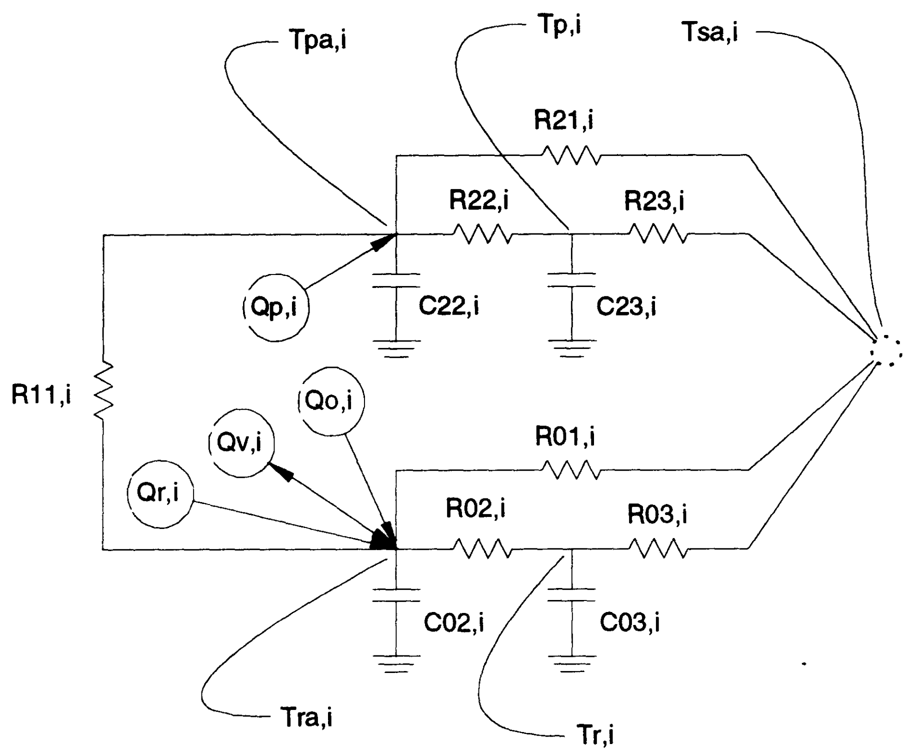


Figure 1: Zone Model Diagram W/Suspended Ceiling - 3R/2C Concept



Tr,i = temp, zone room structure

Tra,i = temp, zone room air

Tsa,i = temp, sol-air

Qo,i = heat gain, occupant

Qr,i = heat gain, room elements

Qv,i = HVAC heat gain, room

Tp,i = temp, zone plenum structure

Tpa,i = temp, zone plenum air

Qp,i = heat gain, plenum elements

R01,i = res, light external walls - room

R02,i = res, proportioned structural - room

R03,i = res, proportioned structural - room

R21,i = res, light external walls - plenum

R22,i = res, proportioned structural - plenum

R23,i = res, proportioned structural - plenum

C02,i = cap, internal - room

C03,i = cap, structural - room

C22,i = cap, internal - plenum

C23,i = cap, structural - plenum

C = capacitance [J/K]

R = resistance [K/W]

T = temperature [K]

Q = heat input [W]

drwn by: M.DeSimone
file: typzone.cfl

Figure 2: Schematic, Typical Arrangement for 2C3R Model of Zone "i"

- *characteristic response parameters to step changes. They are namely the sudden change of internal temperature at the moment when a unit step change in heat load is applied inside (a_i^q) and a similar change when a step change of outdoor temperature occurs (a_i^t);* [see Equations 50 and 51]

- *time constant.*[18]

Please note the following:

In the last stages of the development of the work for this thesis, confirmation was received which clarified suspicions raised earlier during the research effort and which gave rise to the Section 2.2.2 "Proposed Alternative 2C3R Lumped Parameter Model." The basic issue was whether or not the expressions defining the global parameters $R_{02,i}$ $R_{03,i}$ $R_{22,i}$ and $R_{23,i}$ were sufficient to describe the building accurately. As it happened, the confirmation received stated that the expression for the structural resistance had been copied incorrectly, and the inaccurate version had made its way into print. Time did not allow for the correction to be incorporated into this body of work, however, the error, its correction and the resultant impact on the calculations recorded in this thesis are presented in the Section 2.2.3 "Error Correction to 2C3R Model." Recalculation of the values effected by this change will be done by others and the simulation test runs will be made with the corrected values. The results of this additional work will be included in the final ASHRAE 825 TRP report.

2.2.1 Current Model

The theoretical model for the building consists of a large network of a second order, lumped parameter models (LPM) each representing a *space or combination of spaces* [zones in this model] *in the building that may be characterized by a uniform temperature and a perfectly mixed volume .... Conductive heat transfers through walls are one-dimensional. Radiative heat exchanges are linearized and surface exchanges are globalized and assumed to be constant with time. Consequently, temperatures are* <u>*resultant temperatures*</u>.[19] The IEA Annex 10 report is difficult to obtain, and for the reader's convenience, the majority of the equations and theory presented in the Annex 10 report has been

18 International Energy Agency [IEA], Report on Lumped Parameter Building Model Development

19 IEA Annex 10

reproduced in this document. The global parameters used to model E51 were derived wholly from the equations that follow in this section. Some modifications in definition were made to accommodate the real building configuration. Those modifications include the term for the "capacitive flow of infiltration" and the sol-air temperatures.

Some questions persist upon completion of the work ascribed to this thesis as to the validity of the construct of the 2C3R model applied to the building. Specifically, the fundamental question is that of the conductance between the inside and the outside through the structural node, (eg. $1/R_{02,i}$ and $1/R_{03,i}$ in Figure 2). It has been proposed that in order to respect the (low frequency) resistance between the inside and outside, the defining equations (34, 102, 103 and 35) specified in the Annex 10 need to be modified slightly by removing the θ_m term.[20] Development of this concept and verification of the proposed modification was being sought at the time this report was written, and a conclusion will be developed in the ASHRAE 825 TRP Final Report.

In accordance with the model theory presented in the Annex 10 report, each zone model is composed of two second order LPM's: one set representing the occupied volume and contents in a zone and one representing the unoccupied volume (or typically the plenum space above a suspended ceiling and contents of the same zone, refer to Figure 1. The second order LPM used in this study, commonly referred to as a 2 capacitor - 3 resistor (2C3R) model is shown in Figure 2. The model is comprised of two 2C3R LPM's: one representing the room volume and one representing the corresponding plenum volume. The two LPM's are linked together with a connecting resistance which represents the ceiling separating the two volumes. One set, as shown in the figure, is used to model one megazone. Correspondence of the variable names used in Figure 2 with the variable names used in the Annex 10 report is shown in Table 40 on page 161.

Three sets of general variables and parameters are defined in the Annex 10 report which characterize the 2C3R model structure. The first set describes each individual structural element in the building. The second set of parameters describes the real building in terms of the first set transformed and combined to produce the five parameters necessary for each 2C3R model. The third set represent computed values which characterize infiltration and convective flow between zones.[21] The procedure

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20 Phil Haves, LUT, 24 Jan 1996.

21 Heat transfer between zones was assumed to be zero to coincide with the HVACSIM+ zone model chosen for this study. It is anticipated that future versions of this model will account for heat and mass transfer through and across adjacent zone boundaries. All necessary geometric and physical material properties have been provided in the appendices in order that parameters for future more complete models can be

described by the Annex 10 report entails a three step procedure for developing the five parameters:

1. <u>Thermal Zone Definition</u>: select the building volume to be simulated and define the thermal zones in which different temperatures are expected to occur;
2. <u>Compute Wall Parameters for Each Zone</u>: for each external, internal, or connecting wall describe them by capacitances and resistances, encompassing all individually identifiable wall, floor and ceiling components;
3. <u>Define Global Parameters for Each Zone</u>: by the elementary networks developed in Step 2, define the five parameters for each of the 2C3R networks.

<u>External Walls:</u>

The individual external walls are represented by first order models consisting of one capacitor and two resistors each. These sub-models connect the outdoor temperature node to the indoor nodes. The thermal capacitance for each external wall is located between the two thermal resistors at a location in the wall specified by a weighting factor θ_m (referred to in the Annex 10 report as, the *Accessibility of Capacitance*). The walls are assumed to be comprised of "N" easily definable layers, each characterized by a resistive element and a capacitive element. Air boundary layers on both sides of the walls are accounted for as individual resistive elements (based on surface area and the appropriate film coefficient), adding two additional resistors to the "N" wall layers combines for a total of "N+2" series resistors in each external wall section. The "N+2" resistive elements are summed in series to obtain an overall resistance, Equation 12, and the "n" capacitances are summed to obtain and overall capacitance, Equation 13, and the *Accessibility of Capacitance* is calculated in Equation 14.

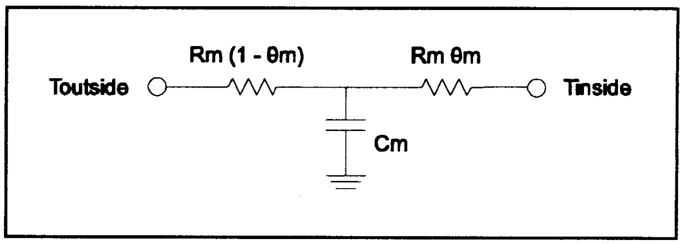

Figure 3: First Order 1C2R Model

$$R_m = \sum_{n=0}^{N+1} R_{m,n} \tag{12}$$

derived. Infiltration can be expressed as a capacitive flow rate which may implemented as a parallel resistance directly between the indoor and outdoor nodes of the 2C3R network according to the Annex 10 model.

$$C_m = \sum_{n=1}^{N} C_{m,n} \tag{13}$$

$$\theta_m = 1 - \sum_{n=1}^{N} \frac{(\sum_{p=0}^{n-1} R_{m,p} + \frac{R_{m,n}}{2}) C_{m,n}}{R_m \, C_m} \tag{14}$$

The two thermal resistances ($R_{m,\,outer}$ and $R_{m,\,inner}$) in the first order model are expressed as a function of the overall external wall resistance R_m and the weighting factor θ_m in Equations 15 and 16.

$$R_{m,outer} = R_m \, (1 - \theta_m) \tag{15}$$

$$R_{m,inner} = R_m \, \theta_m \tag{16}$$

The time constant, expressed as a function of R_m , C_m and θ_m in Equation 17 was used to differentiate between light and heavy walls and sub-walls or structures.

$$\tau_m = \theta_m \, (1 - \theta_m) \, R_m \, C_m \tag{17}$$

where: $\tau_m \leq \tau_{limit} \Rightarrow$ light structure;

$\tau_m > \tau_{limit} \Rightarrow$ heavy structure; and

the approximate limits for τ are 1 hour $\leq \tau_{limit} \leq$ 2 hour.

Internal Walls

Walls are considered to be internal if both sides are exposed to the same temperature. In this case, the wall is represented by a first order model, and parameters are calculated similarly to those for the external wall using the same equations. In a second step, a second order model is defined which utilizes the concept that there exists a plane somewhere within the wall through which no heat passes,

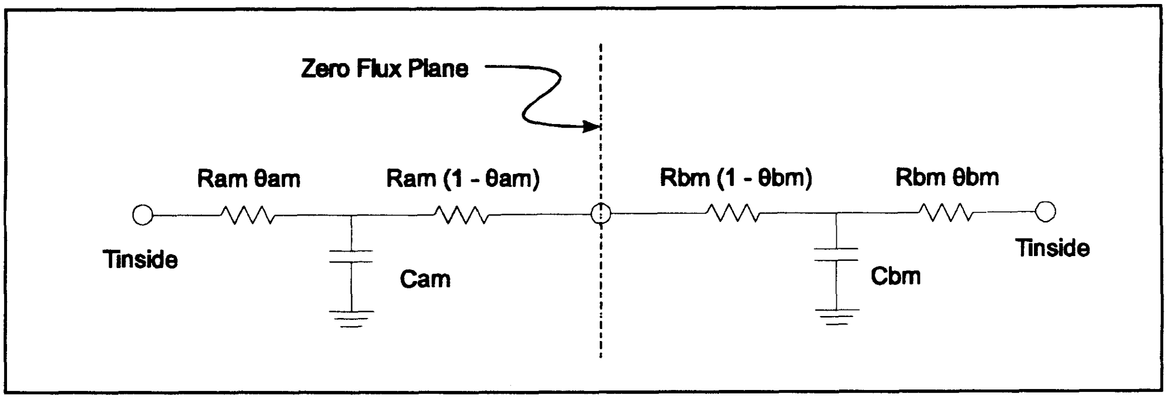

Figure 4: Second Order 2C4R Model for Internal Walls with Zero Flux Plane ·

ie. a zero flux plane as in Figure 4. Each of the two thermal resistances calculated in Equations 15 and 16 are subdivided into two sub-sets of two smaller, proportioned thermal resistances. These two resistor sub-sets are then combined with proportional parts of the overall thermal capacitance calculated using Equation 13 forming the second order system. The overall resistance for side "a" of the internal wall and the overall resistance for side "b" are expressed in the following equations:

$$R_{am} = R_m \, (1 - \theta_m) \; ; \; and \tag{18}$$

$$R_{bm} = R_m \, \theta_m \; ; \tag{19}$$

The location of the zero flux plane is found by satisfying the equation:

$$\sum_{n=0}^{n^*-1} R_{mn} < R_{am} < \sum_{n=0}^{n^*} R_{mn} \; ; \tag{20}$$

where the index value n^* is deduced. The fractional part y of the layer n^* which included in R_{am} is expressed by the following:

$$y = \frac{1}{R_{mn^*}} (R_{am} - \sum_{n=0}^{n^*-1} R_{mn}) \tag{21}$$

The capacitances C_{am} and C_{bm} are proportioned parts of the overall capacitance C_{mn} as follows:

$$C_{am} = \sum_{n=0}^{n^*-1} C_{mn} + y\, C_{mn^*} \tag{22}$$

$$C_{bm} = C_m - C_{am} \ . \tag{23}$$

The weighting factors θ_{am} and θ_{bm} used to proportion the resistances for the two first order sub-systems on either side of the zero flux plane is expressed as a function of the properties of the internal wall as follows:

$$\theta_{am} = \frac{\sum_{n=1}^{n^*-1} (\sum_{p=0}^{n-1} R_{mp} + \frac{R_{mn}}{2}) C_{mn} + (R_{am} - \frac{y}{2} R_{mn^*}) y\, C_{mn^*}}{R_{am}\, C_{am}} \ ; \ and \tag{24}$$

$$\theta_{bm} = \frac{\sum_{n=N}^{n^*+1} (\sum_{p=N+1}^{n+1} R_{mp} + \frac{R_{mn}}{2}) C_{mn} + (R_{bm} - \frac{z}{2} R_{mn^*}) z\, C_{mn^*}}{R_{bm}\, C_{bm}} \ ; \tag{25}$$

where: $z = 1 - y$.

The two internal resistances closest to the zero flux plane, nestled in between the two capacitances C_{am} and C_{bm} can be eliminated since there is no temperature potential across them. The result is a second order 2C2R model for the internal wall as shown in Figure 5. The time constants used to differentiate between heavy

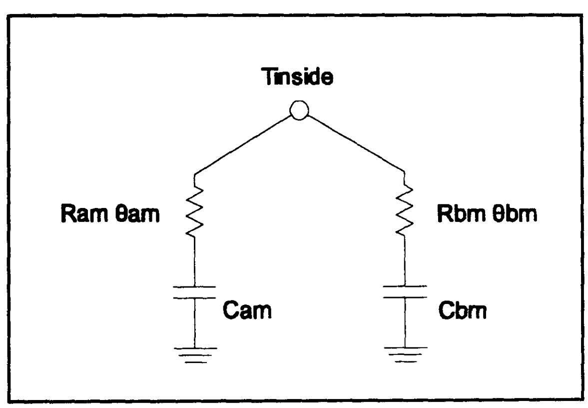

Figure 5: Internal Wall 2C2R Model

and light wall elements are expressed in the following equations:

$$\tau_{am} = \Re_{am} C_{am} \text{ ; and} \tag{26}$$

$$\tau_{bm} = \Re_{am} C_{bm} \text{ ;} \tag{27}$$

where the two capacitances C_{am} and C_{bm} are proportional parts of C_m, and the two resistances $\Re_{am}$ and $\Re_{bm}$ are expressed in the following:

$$\Re_{am} = R_m (1 - \theta_m) \theta_{am} \text{ ; and} \tag{28}$$

$$\Re_{bm} = R_m \theta_m \theta_{bm} \text{ .} \tag{29}$$

<u>Connecting Walls</u>

The basic model for a connecting wall is the same as that for internal walls. The proportional constant θ_m fractionalizes an overall resistance R_m, and establishes a virtual plane separating the wall, one part to zone i and one part to zone j. Capacitances are calculated as described for an internal wall, and assigned as heavy or light in their respective zones i and j according to the time constants calculated with Equations 26 and 27. The connecting resistance $R_{i,j}$ is then calculated by summing the sets of two resistances for each in series R_{am} and R_{bm} giving back the value R_m and then summing the m resistances in parallel as shown in the following equation:

$$\frac{1}{R_{i,j}} = \sum_m \frac{1}{R_{am} + R_{bm}} \text{ .} \tag{30}$$

Referring to Figure 4, values for R_{am} and R_{bm} are calculated as described for an internal wall in Equations 18 and 19. For this project half of each connecting wall was apportioned to the abutting zones or sub-zones. Then for each connecting wall, an internal wall with the same thickness but half the area was placed in the ascribable zone or sub-zone. For example, a suspended ceiling has an overall resistance R_m consisting of a conductive heat transfer coefficient and two film coefficients: one for the horizontal surface facing up into the plenum, and one for the horizontal surface facing down into the room. When calculating $\Re_{am}$ and $\Re_{bm}$ the area of the internal wall becomes half that of the ceilings projected area to obtain:

$$\Re_{am,connecting} = 2 R_m (1 - \theta_m) \theta_{am} \ ; \ and \tag{31}$$

$$\Re_{bm,connecting} = 2 R_m \theta_m \theta_{bm} \ . \tag{32}$$

The film coefficient for the suspended ceiling looking down into the room is used on both sides of the "internal wall" representing the half of the ceiling apportioned to the room. A similar construction is made for the half apportioned to the plenum, using the appropriate film coefficient.

Adiabatic Walls

Adiabatic walls are treated in exactly the same fashion as the connecting walls, except that no connecting resistance is calculated. Depending on the time constant, the mass of the adiabatic walls is included in one or the other of the global capacitance values.[22]

Global Parameters for Each Zone:

The global parameters representing the five elements shown in Figure 2, as proposed in the Annex 10, are described in Table 2. Two sets of these parameters are required to fully describe the zone, one for the room and one for the plenum; they are typically separated by a suspended ceiling. The two sets are thermally connected through the ceiling material by the resistive element $R_{11,i}$ in Figure 2. For those zones which do not have a suspended ceiling, only one set of parameters is used. The Annex 10 model requires the two heavy wall resistance parameters to be expressed as proportional amounts of some fraction of the resistance for the heavy structures. It is the author's opinion, however, that the resistance value apportionment described by the Annex 10 report, may not accurately model the actual heat flow paths through the heavy structures, refer to §2.2.2. Numerical calculations and parameters presented in the appendices of this report were developed in accordance with the theory and structure provided in the Annex 10 report. Initially the model in this study will assume adiabatic isolation between zones.

22 In the Annex 10 report, it is interesting to note that if any internal walls are considered to be of the light variety, then, although the associated mass is accounted for in the internal capacitance value C02, there is no corresponding heat transfer coefficient modeling heat flow through the mass implied.

Table - 2: Five Global Parameters for 2C3R Lumped Parameter Model (refer to Figure 2)

Parameter	Description
$R_{lite,ext}$ or $1/K_{lite,ext}$	resistance for internal structure directly to outside through light walls
$R_{hvy,inner}$ or $1/K_{hvy,inner}$	resistance of inner portion of heavy walls[23]
C_3	capacitance of heavy structures
C_2	capacitance of internal structures including indoor air and furniture
θ_i	weighting factor or global accessibility of structural capacitance

The additional parameters defined in Table 3 characterize resistances (or conductances) which follow directly from the definitions expressed in the Annex 10 report for the five global parameters expressed in Table 2.

Table - 3: Additional Parameters Associated with the 2C3R LPM

Parameter	Description
$1/K_{ext}$	overall resistance for external structure; includes both heavy and lite walls
$1/K_{int}$	overall resistance for internal structure; includes both heavy and lite walls
$1/K_{hvy,ext}$	resistance for the heavy external walls
$1/K_{hvy,ext,outer}$	resistance for the outer portion of the heavy external walls (see §2.2.2)
$1/K_{hvy,ext,inner}$	resistance for the inner portion of the heavy external walls (see §2.2.2)

Each of the global resistive elements within the individual LPM's is a composite of many sub-components, and are defined in terms of loss coefficients or conductances as follows:

$$R_{01,i} = \frac{1}{K_{lite,ext}} \; ; \tag{33}$$

$$R_{02,i} = \frac{1}{(K_{hvy,inner})} \, \theta_i \; ; \tag{34}$$

23 Refer to Section 2.2.2 for alternative proposal to allocate resistive and capacitive elements for the global parameters in the 2C3R model.

$$R_{03,i} = \frac{1}{(K_{hvy,inner})}(1 - \theta_i) \text{ ; and} \tag{35}$$

where the factor θ_i (*global accessibility of structural capacitance*) is defined in terms of the heat flux ratio ξ_i (see Equation 49) and the characteristic response parameter to step changes of internal heat flux $a_{i,q}$ as follows:

$$\theta_i = \frac{a_{i,q}(1 - \xi_i)}{(1 - \xi_i a_{i,q})} \text{ ;} \tag{36}$$

which, in the Annex 10 report, proportions the structural resistance to express the heavy structures inner and outer resistive components.[24] A similar set of global parameters can be defined for the plenum sub-zone. By substituting the Equations 49 & 50 into Equation 36 the coefficient θ_i can simplified into the ratio of conductances:

$$\theta_i = \frac{K_{hvy,ext}}{K_{hvy,inner}} \text{ .} \tag{37}$$

Equation 37 expresses θ_i in terms of the conductance for all the heavy, external wall sections (refer to Equation 41) divided by the conductance of all the heavy inner wall sections (refer to Equation 39) which includes contributions from all of the internal walls and only the inner portions of the external walls as defined in Equation 16.

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24 The characteristic response parameters to step changes of internal heat flux (ai,q) and outdoor temperature (ai,t) are defined as follows:

$$a_{i,q} = K_i R_{eq,i} \text{ ; and } a_{i,t} = \xi_i a_{i,q} \text{ .}$$

The expression of the global parameters as functions of conductances is a simplification of the presentation made in the Annex 10 report. In so doing, relationships between variables in the Annex 10 presentation became more apparent, and the decision was made to work as much as possible with conductances and revert to expressions in terms of resistances when detail or clarification was required. The conductances expressed in terms of composite resistance values are as follows:

$$K_{lite,ext} = \sum_m \frac{(1 - H_m)\, E_m}{R_m} \; ; \qquad (38)$$

$$K_{hvy,inner} = \sum_m \frac{H_m}{R_m\, \theta_m} \; ; \; and \qquad (39)$$

$$K_{hvy,ext} = K_{ext} - K_{lite,ext} \; ; \; or \qquad (40)$$

$$K_{hvy,ext} = \sum_m \frac{E_m}{R_m} - \sum_m \frac{(1 - H_m)E_m}{R_m} \, . \qquad (41)$$

where: $E_m = 0$ for each internal wall or connection sub-wall
$E_m = 1$ for each external wall
$H_m = 0$ for all wall or sub-walls with $\tau_m \leq \tau_{limit}$ (light walls)
$H_m = 1$ for all wall or sub-walls with $\tau_m > \tau_{limit}$ (heavy walls)

The time constant τ_i which characterizes the response to excitation for the global system ascribed to each zone is expressed in the following equation:

$$\tau_i = \frac{1}{K_i} \sum_m (1 - \theta_m E_m)\, H_m\, C_m \, . \qquad (42)$$

The conductance K_i is defined as the overall loss coefficient and is expressed in terms of $\dot{C}_{i,out}$ (the Capacitive Flow of Infiltration in zone i based on the volumetric flow rate $\dot{V}_{i,out}$ for infiltration) and K_{ext} (the overall loss coefficient for the heavy walls) in the following equations:

$$K_i = \dot{C}_{i,out} + K_{ext} \text{ ; where} \tag{43}$$

$$\dot{C}_{i,out} = \rho_a \, C_{pa} \, \dot{\forall}_{i,out} \text{ ; and} \tag{44}$$

$$K_{ext} = \sum_m \frac{E_m}{R_m} \; . \tag{45}$$

It should be noted that the introduction of the term $\dot{C}_{i,out}$ in the expression for the overall loss coefficient is an attempt to account for the influence infiltration has on the what is referred to in the Annex 10 report as the "structural capacitance," refer to Equation 47. The Annex 10 report recommends that if infiltration is to accounted for in the recommended model, then the conductance represented in the term $\dot{C}_{i,out}$ is to be added to the conductance for the light, external wall structures:

$$K_{\mathfrak{S},lite,ext,} = \dot{C}_{i,out} + K_{lite,ext} \text{ ;} \tag{46}$$

which would be used in place of $K_{lite,ext}$ in Equation 33. Documented studies suggest that infiltration occurs across the entire building shell surface, including both windows and external walls and roof, refer to sub-section Capacitive Flow of Infiltrations, page 55. In these cases, the conductances for the plenum and room walls would have to be modified in a similar fashion, using the appropriately calculated infiltration terms.

The structural capacitance parameter $C_{03,i}$ (refer to Figure 2) represents the heavy structures in the global model. It is expressed in terms of the overall heavy structure capacitance and a factor which characterizes the response of the 2C3R global network to step changes in internal heat flux and outdoor temperature:[25]

$$C_{03,i} = K_i \tau_i \frac{\left(1 - \frac{\xi_i K_i}{K_{eq,i}}\right)^2}{\left(1 - \frac{K_i}{K_{eq,i}}\right)} . \tag{47}$$

The conductance $K_{eq,i}$ is described in the Annex 10 report as the equivalent resistance for zone i and is expressed in the following equation:

$$K_{eq,i} = \dot{C}_{i,out} + K_{lite,ext} + K_{hvy,inner} ; \tag{48}$$

and the term ξ_i is described in the Annex 10 report as the ratio of heat loss through the light walls (with no phase change) to the total heat loss to the outside (and it is value should be less than 1):

$$\xi_i = \frac{\dot{C}_{i,out} + K_{lite,ext}}{\dot{C}_{i,out} + K_{ext}} . \tag{49}$$

Note that the characteristic response parameter to step changes in internal heat flux can be expressed in ratios of conductances by combining Equations 43 and 48 as follows:

$$a_i^q = \frac{\dot{C}_{i,out} + K_{ext}}{\dot{C}_{i,out} + K_{lite,ext} + K_{hvy,inner}} ; \; and \tag{50}$$

the characteristic response parameter to step changes in outdoor temperatures can be expressed in ratios of conductances by combining Equations 49 and 50:

$$a_i^t = \xi_i \, a_i^q . \tag{51}$$

The internal capacitance parameter $C_{02,i}$ represents the light structures and the air contained within the

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25 Characteristic response parameters are described in the Annex 10 report, and can be calculated from the data presented in the appendices of this report.

zone. It is simply the sum of the represented thermal capacitance values:

$$C_{02} = C_{a,i} + \sum_{m} C_m \left(1 - \theta_m E_m\right)\left(1 - H_m\right) . \qquad (52)$$

The term $C_{a,i}$ represents the capacitance for the air within zone i, ($\rho_{room\ air}$ x $C_{p,room\ air}$ x $V_{room\ air,i}$). The sum adds the entire contribution from the light, internal walls to a fractional contribution from the light, external walls.

With infiltration, the direct link between the inside and outside nodes is augmented by a parallel resistance, or conversely a parallel conductance representative of the infiltration flow rate. In this case, $R_{01,i}$ can be expressed in the modified form:

$$R_{01,i} = \frac{1}{\dot{C}_{i,out} + K_{lite,ex}} . \qquad (53)$$

The Annex 10 report proposes that the structural capacitance $C_{03,i}$ be expressed, in part, as a function of outside air infiltration. In doing so, it is recommended that a mean estimate of the infiltration flow rate be used in defining the structural capacitance. Further, when figuring the value of the direct coupled resistance $R_{01,i}$ the actual time varying value of the infiltration term be used. For this project the building is considered to be pressurized, and the effect of infiltration is assumed to be negligible.

Capacitive Flow of Infiltrations (this section for reference only - see §3.3.3.7.1)

The driving mechanism for the capacitive flow of infiltration $\dot{C}_{i,out}$ is assumed to emanate strictly from wind pressure; the effects of indoor and outdoor temperature differ (stack effects) and those induced by mechanical equipment are ignored. $\dot{C}_{i,out}$ is found as a function of an estimated, average air flow rate $\dot{V}_{i,out}$ and its physical properties as expressed in Equation 44. Determining $\dot{V}_{i,out}$ is an exercise in blending the laws of physics with some empirical relations derived by experiment and observation to determine flow characteristics for various physical building configurations. The average air flow rate may be expressed as function of mass flow rate $\dot{m}_{i,out}$ and local air density ρ_{air}:

$$\dot{\forall}_{i,out} = \frac{\dot{m}_{i,out}}{\rho_{air}} \text{ ; } where \tag{54}$$

the mass flow rate $\dot{m}_{i,out}$ is expressed as a function of the pressure difference across the wall ΔP_w and the air flow resistance R_l presented by the leakage paths in the wall:

$$\dot{m}_{i,out}^2 = \frac{\Delta P_w}{R_l} \text{ .} \tag{55}$$

The pressure difference ΔP_w as a result of wind impingement on a buildings side may is expressed by:

$$\Delta P_w = p_o + p_w - p_i \text{ ;} \tag{56}$$

where: p_o = outside static pressure at a reference height in undisturbed flow $\{\rho g(h_r - h_l)\}$;

p_w = wind pressure at location L $\{C_p \rho v_a^2 /2\}$;

p_i = interior pressure at location L $\{\rho g(h_r - h_L)\}$.[26]

Hence, Equation 56 can be re-expressed as:

$$\Delta P_w = C_p \, \rho \, \frac{v_a^2}{2} \tag{57}$$

where: C_p = surface pressure coefficient;

v_a = wind speed.

The surface coefficient C_p is a function of the building envelope's orientation to the prevailing wind direction, in addition to a wide variety of environmental influences, including but not limited to, a building's width to height ratio, surrounding topography, and shape. Averaged, empirically derived values for C_p related to low-rise buildings were used in this study. A low-rise building with a width W and height H is defined as one for which the ratio $H/W \leq 1$.[27]

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26 1993 ASHRAE Handbook - Fundamentals, F23.3.

27 1993 ASHRAE Handbook - Fundamentals, Figures 6 & 7, F14.5.

The flow resistance R_l is an expression of the leakage characteristics of a specific building in a unique set of circumstances. It is dependent on a *building's design, construction, seasonal effects, and deterioration over time*; a wide array of empirical data is available, generalizing the behavior for a variety of building configurations.[28] Equation 55 can be rewritten to express R_l as a function of leakage rate Q_l and the surface area through which the air is passing:

$$R_l = \frac{\Delta P_w}{\rho_a^2 \, Q_l^2 \, A_w^2} \tag{58}$$

For this project empirical results from two mutually supportive independent studies, tempered by historically accepted standards, were used to determine representative values for R_l, (refer to Figure 206). The studies suggest that Q_l for a typical commercial building envelope (excluding operable windows) are on the order of 1080 to 5220 $cm^3/(s\text{-}m^2)$ at a 75 Pa pressure differential. Values for tight, average, and leaky walls are proposed to be 500, 1500, and 3000 $cm^3/(s\text{-}m^2)$ at 75 Pa by one study.[29] These values are significantly higher than the value of 300 $cm^3/(s\text{-}m^2)$ at 75 Pa as proposed by the National Association of Architectural Metal Manufacturers. As a compromise, 1200 $cm^3/(s\text{-}m^2)$ at 75 Pa was selected to represent Q_l for the entire building shell, including the exterior walls and operable windows (in fully closed position).

Additional Comments

(1) The two variables $T_{pa,i}$ and $T_{ra,i}$ in Figure 2 represent the temperatures of the internal air and all light structures in the plenum and room models. The HVACSIM+ zone model used for this study (Type 272), calculates these temperatures as a weighted average, taking into consideration the influences of surrounding walls, the outside ambient air, leakage and infiltration from adjacent zones, and the supply air.[30]

(2) Initially, the model in this study will assume adiabatic isolation between zones. The zones are separated by solid walls and the HVACSIM+ zone model Type 272 used in the initial model development was designed to accommodate an open plan office zoning strategy, (refer to the sample

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28 1993 ASHRAE Handbook - Fundamentals, F23.12.

29 1993 ASHRAE Handbook - Fundamentals, F23.16.

30 HVACSIM+ Type 272, Source Code, §Heat Balances of the Nodes, February, 1994.

HVACSIM+ simulation ACREF2 in Appendix AA). Heat transfer between zones was limited to conduction through the walls of the duct work for a certain zone to the plenum air of other zones when that duct work was determined to pass through the plenums of other zones. In later stages of development, it is anticipated that a zone model which accounts for conduction heat transfer between zones will be implemented. The resistances $R_{11,i}$ (refer to 2C3R schematic) calculated to represent conductive connections between a zones plenum and a zones occupied volume were incorporated into the model.

(3) Heat sources to each zone include: $Q_{r,i}$ for lighting and equipment; $Q_{o,i}$ for occupant densities and schedules; $Q_{v,i}$ for ventilation, perimeter heating and infiltration, ; $T_{sa,i}$ for solar radiation and the external ambient air temperature.

Solar Gains and Sky Radiation

Solar gains and sky radiations are expressed through the definition of an equivalent "sol-air" temperature $t_{sa,i}$. The overall, equivalent temperature represents an estimate of the energy flux across the external zone barriers.[31] It is a weighted average taking into account the effect of all incident radiation on all surfaces for each individual zone. Normally, weighting is derived from ratios of the conductance for the surface(s) of similar optical characteristics and physical orientation within a given zone to the conductance for the entire external zone surface, refer to §2.2.3. In the Annex 10 report there is a slight variation. The weighting factors are "light" by the difference between K_i and $K_{ext,m}$ which is the capacitive flow infiltration flow rate $\dot{C}_{i,out}$. It should be noted that K_i includes a term for the capacitive flow for infiltration which has an unbalancing effect on the weighting; the factors do not sum to one, refer to Equation 43. The overall, equivalent sol-air temperature incorporating the effect of opaque surfaces, single pane windows, and general barriers of any configuration is expressed in the following equation, according to the Annex 10 report:

$$T_{sa,i} = \frac{\sum_m K_{ext,m}\, t_{sa,m,i,opaq}}{K_i} + \frac{\sum_m K_{ext,m}\, t_{sa,m,i,sing}}{K_i} + \frac{\sum_m K_{ext,m}\, t_{sa,m,i,any}}{K_i} \,. \qquad (59)$$

31 The Annex 10 report states that the procedure outlined for estimating solar and sky radiation gains is an approximation, and further that the approximation overestimates solar gains when the building has "large" glazed surfaces and high infiltration rates. The building used in this study has a window surface to wall surface ratio of approximately 0.25:1. The Annex 10 report does not define "large," however, it is assumed that the subject building is fitted with an average distribution of glazed external surfaces, not in "large" amounts.

The conductances K_i and $K_{ext,m}$ are previously defined, and the sol-air temperatures for the various barrier types are expressed as follows:

$$t_{sa,m,i,opaq} = t_{out} + \frac{1}{h_{out,m,i}} \left(\alpha_{m,i}\, Ir_{g,m,i} - \varepsilon_{m,i}\, Ir_{r,m,i} \right) ; \quad \textbf{(60)}$$

$$t_{sa,m,i,sing} = t_{out} + \frac{1}{h_{out,m,i}} \left(\alpha_{m,i}\, Ir_{g,m,i} - \varepsilon_{m,i}\, Ir_{r,m,i} \right) + \frac{\tau_{m,i}\, Ir_{g,m,i}}{U_{m,i}} \; ; \; and \quad \textbf{(61)}$$

$$t_{sa,m,i,any} = t_{out} - \frac{\varepsilon_{m,i}\, Ir_{r,m,i}}{h_{out,m,i}} + \frac{S_{m,i}\, Ir_{g,m,i}}{U_{m,i}} \; ; \quad \textbf{(62)}$$

where: $t_{sa,m,opaq}$ = the sol-air temperature for an opaque wall

$t_{sa,m,sing}$ = the sol-air temperature for a single pane window

$t_{sa,m,any}$ = the sol-air temperature for any wall type.

Note that the solar heat gain coefficient $S_{m,i}$ is a function of the heat transfer characteristics of the barrier for which the sol-air temperature is to be calculated, (refer to sub-section "Calculating the Solar Heat Gain Coefficient" this section for $S_{m,i}$ related to single and double pane windows.

The coefficients included in Equations 60, 61, and 62 are defined as follows:

$I_{r,m,i}$ = as the longwave heat transfer between the outer surface of wall m in zone i and the sky cover[32] [W/m^2]

$I_{g,m,i}$ = as the shortwave solar gain on the outer surface of wall m in zone i[33] [W/m^2]

$U_{m,i}$ = as the overall conductive heat transfer coefficient for wall m in zone i [W/°K·m^2]

$S_{m,i}$ = as the solar heat gain coefficient for wall m in zone i

$\alpha_{m,i}$ = as the outer surface absorptance of wall m in zone i

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32 Also the difference between long-wave radiation incident on a surface from the sky and surroundings and radiation emitted by a black body at the outdoor temperature [w/m2] (1993 ASHRAE F26.5).

33 Also the total solar radiation incident on the surface [w/m2] (1993 ASHRAE F26.6).

$\varepsilon_{m,i}$	=	as the emissivity of the outer surface of wall m in zone i
$\tau_{m,i}$	=	as the transmittance of the outer surface of wall m in zone i
$h_{out,m,i}$	=	film coefficient for exterior surface of wall m in zone i [W/°K·m²]
t_{out}	=	outdoor air dry bulb temperature [°C]

Calculating the Long-wave Heat Transfer

The heat flux $I_{r,m,i}$ across surface m can be expressed as a function of the longwave (infrared) sky radiative transfer of a horizontal surface to the celestial sphere and the angle s of surface m (measured from horizontal):

$$I_{r,m,i} = \frac{1 + \cos s_m}{2} I_{r,h} \qquad s_m < 90^\circ \; ; \tag{63}$$

where $I_{r,h}$ is defined as the long wave sky radiative transfer of a horizontal surface. Typical values for $I_{r,h}$ range between 100 W/m² for clear sky conditions to 45 W/m² for overcast conditions. When figuring what value to use, cloud cover data can provide a basis for fractionalizing the difference between the two extremes. For $s_m = 90°$ the value 0.5 $I_{r,h}$ was used. Refer to Annex 10 report for additional information.[34]

Calculating the Short-wave Heat Transfer

The total solar gain $I_{g,m,i}$ on the external surface of wall m is a the sum of the direct solar radiation E_D, the diffuse sky radiation E_{ds} and the solar radiation reflected from the surroundings E_r as follows:

$$I_{g,m,i} = E_D + E_d + E_r \; ; \tag{64}$$

where:

$$E_D = E_{DN} \cos \theta_v \; ; \; and \tag{65}$$

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34 It should be noted that for vertical surfaces net flux of long wave radiation between the outer surface of the wall and the sky is considered to be zero (1993 ASHRAE F26.5).

$$E_d = E_{ds} + E_{dg} . \tag{66}$$

with E_{DN} = the direct normal irradiance; and

θ_v = the incident angle of the sun to the surface of wall m;

E_d = total diffuse radiation from the sky and ground;

E_{ds} = diffuse radiation from the sky;

E_{dg} = diffuse radiation from the ground.[35]

Calculating the Reflected Solar Radiation E_r

E_r is considered to be negligible for Building E51 for two reasons. First, the building is open, with an unobstructed view to the south. Second, the west face is mostly shaded by trees, reducing the sun's reflection off of the adjacent building (refer to Figures 16) to minimal values. Diffuse radiation on the west end was assumed to be for open, unobstructed conditions in an effort to compensate for the complete elimination of reflected radiation E_r. It should be noted that the tree's shading on the west end does not obscure direct, early afternoon solar radiation, and that this fact is represented in the sol-air temperature calculations.

Calculating the Direct Normal Irradiance E_{DN}

For this project, solar data is drawn from a source which provides values for E_{DN}, (refer to §4) and θ_v can be calculated following the procedure outlined in this section.

In the case, when no solar data are available and a realistic, varying solar flux profile is required, it is proposed that a profile $E_{DN,varying}$ can be developed using the expression for E_{DN} calculated at the earths surface on a clear day multiplied by the percent of cloud cover at each applicable moment for which a value is required as follows:

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35 1993 ASHRAE Handbook - Fundamentals, F27.10.

$$E_{DN,varying} = A\ X(\beta)_{cc}\ e^{-\left(\frac{B}{\sin\beta}\right)} \qquad \textbf{(67)}$$

where: A = the apparent solar irradiation;
B = atmosphere extinction coefficient;
$X(\beta)_{cc}$ = percent cloud cover at time for each β.[36]

Use of Equation 67 to derive realistic, time varying values for the direct normal radiation is predicated on the availability of local cloud cover data or other similar surface or satellite based meteorological observations.

The factor is intended to derate the clear sky value. In addition to the cloud factor, real-time extinction coefficients can be used accounting for local atmospheric contaminants.[37]

Calculating the Total Diffuse Radiation from Sky and Ground E_d

Two methods were explored for determining total diffuse radiation. One method makes use of data sets which purport to capture local, time varying values, and which are made available through the National Climatic Data Center, (refer to the SOLMET data set in §4). The other method makes use of the equation set presented in the ASHRAE Handbook, F27 for calculating diffuse sky and ground radiation.

In the method based on SOLMET data directly, horizontal diffuse radiation is measured and recorded at various local SOLMET sites. These data are taken as they are to describe 100% of the incident sky diffuse radiation on a horizontal surface, and half of these values are taken for incident sky diffuse

36 Clear sky average values of apparent solar irradiance A and the coefficient B are provided in Table 7, F27.9, 1993 ASHRAE Handbook - Fundamentals. Real-time extinction coefficients are available from the ASOS program data records, (refer to §4.1.2). Values for C(β) would typically be taken from a source for surface meteorological observations.

37 Actual values of the atmosphere extinction coefficient for non-clear sky conditions and the impact of cloud cover are both heavily dependent on the suspended particulate matter (smoke, dust, and other pollutants as well as water vapor content in the air). Time constraints did not allow for complete exploration of this concept, and perhaps in a follow-up project some comparison can be made between actual measured values and those calculated using cloud cover.

radiation on a vertical surface. It was assumed that no ground diffuse radiation was incident on the upward facing horizontal surfaces, and the ground diffuse radiation incident on the vertical surfaces was calculated as a fraction of the horizontal sky diffuse. The fraction chosen for this project was based on the ratio of sky diffuse to ground diffuse radiation calculated using the ASHRAE algorithms, (refer to §5.3.2.1).

In the method based on the ASHRAE algorithms, the diffuse sky radiation E_{ds} for vertical and horizontal surfaces can be expressed in terms of E_{DN}, some trigonometric relations related to the orientation of the surface receiving the radiation, and a factor representing the degree of scatter induced by the atmosphere as a function of the earth's relative position to the sun:

$$E_{ds,vert} = C\,Y\,E_{DN} \;;\; and \qquad (68)$$

$$E_{ds,\Sigma \neq 90^\circ} = C\,E_{DN}\,\frac{(1 + \cos\Sigma)}{2} \;;\; where \qquad (69)$$

$$Y = 0.55 + 0.437\cos\theta + 0.313\cos^2\theta \quad \forall \quad \cos\theta > -0.2 \;; \qquad (70)$$

$$otherwise \quad Y = 0.45 \;; \qquad (71)$$

and: C = sky diffuse factor.[38]

The sky diffuse factor is a dimensionless ratio indicating the effect of the earth's relative position to the sun throughout the year, proportioning the effect of the direct normal irradiance as the seasons change. Values for C over the course of a year are provided in 1993 ASHRAE Fundamentals (SI), Table 7, F27.9. It should be noted that, as with the factors A and B in Equation 67, this coefficient is affected by local levels of smog, water vapor, and dust suspended in the atmosphere.

The diffuse radiation reflected from the ground is expressed as a fraction of the direct normal radiation:

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38 1993 ASHRAE Handbook - Fundamentals (SI), F27.28.

$$E_{dg} = \frac{E_{DN} (C + \sin\beta) \rho_g (1 - \cos \Sigma)}{2} ; \tag{72}$$

where: C = sky diffuse factor;

β = solar altitude;

ρ_g = ground reflectance; and

Σ = receiving surface tilt angle from horizontal.[39]

The coefficient C in this expression intensifies, to varying degrees, the effect of the direct normal irradiance as the seasons change. Again this effect is, in practice, subject to local variations in atmospheric conditions. The solar altitude β is calculated in Equation 77. The ground reflectance was assumed to be equal 0.20. This value represents an average for a variety of surfaces. If necessary, more precise values can be drawn from Table 19 in 1993 ASHRAE Fundamentals, F27.27. For this project, Σ is equal to either 90° for vertical surfaces or 0° for horizontal surfaces.

Incident Angles θ and Solar Altitude β [40]

The incident angle θ_v can be expressed, in general for any surface orientation, as a function of the solar altitude β, the surface solar azimuth γ, and surface tilt angle Σ as follows:

$$\cos \theta = \cos \beta \cos \gamma \sin \Sigma + \sin \beta \cos \Sigma . \tag{73}$$

For vertical surfaces ($\Sigma = 90°$) and with γ expressed in terms of the solar azimuth ϕ and the surface azimuth ψ Equation 73 becomes:

$$\cos \theta_v = \cos \beta \cos (\phi - \psi). \tag{74}$$

For horizontal surfaces ($\Sigma = 0°$) and with γ expressed in terms of ϕ and ψ Equation 73 becomes:

39 1993 ASHRAE Handbook - Fundamentals (SI), F27.11 & F27.27/8.

40 Refer to F27.11 1993 ASHRAE Fundamentals (SI) for drawing.

$$\cos \theta_h = \sin \beta \ . \tag{75}$$

The surface azimuth ψ is interpolated from Table 8 on F27.11 of the 1993 ASHRAE Fundamentals, and the solar azimuth ϕ (a function of the solar altitude β, local latitude L, and solar declination δ) must be calculated:

$$\cos \phi = \frac{\sin \beta \ \sin L - \sin \delta}{\cos \beta \ \cos L} \tag{76}$$

The solar altitude β is a function of local latitude L, solar declination δ, and apparent solar time expressed as an hour angle H:

$$\sin \beta = \cos L \ \cos \delta \ \cos H + \sin L \ \sin \delta \ ; \ with \tag{77}$$

$$H = 0.25 \ x \ M_{number\ of\ minutes\ from\ local\ solar\ noon} \ ; \ and \tag{78}$$

$$M_{number\ of\ minutes\ from\ local\ solar\ noon} = 720 - AST_{in\ minutes\ after\ midnight} \tag{79}$$

$$AST = LST + ET + 4 \, (LSM - LON) \ ; \tag{80}$$

where: LST = local standard time [minutes];

ET = the equation of time [minutes of time] 1993 ASHRAE F27.9, Table 7;

LSM = local standard time meridian, [degrees of arc];

LON = local longitude, [degrees of arc];

4 = minutes of time required for 1.0 degree rotation of earth.

Calculating the Overall Conductive Heat Transfer

The factor ($U_{m,i}$) defined in the following equation describes the overall conductive heat transfer coefficient for the external boundary m in zone i. Components of the factor include the internal and external surface film coefficients ($h_{out,m,i}$ and $h_{in,m,i}$), as well as physical construction characteristics of the external boundary (e_k the thickness of the layer of material with a thermal conductivity k_m).

$$\frac{1}{U_{m,i}} = \frac{1}{h_{out,m,i}} + \sum_k \frac{e_k}{k_m} + \frac{1}{h_{in,m,i}} \tag{81}$$

The components $h_{out,m,i}$ and $h_{in,m,i}$ represent the film coefficients for the outside and inside exposed surfaces, and the terms summed over k represent the conductive heat transfer coefficients for the layers from which wall m is constructed. In the case of the double glazed windows installed in Building E51, three elements comprise this sum: two for the glass panes and one for the air space. The effective heat transfer coefficient E for the air space can be calculated using the expression for the effective emittance between two gray surfaces:

$$E = \frac{1}{\frac{1}{\epsilon_2} + \frac{1}{\epsilon_3} - 1} ; \tag{82}$$

where ϵ_2 = hemispherical emittance of the air space side surface of the outside glass pane; and

ϵ_2 = hemispherical emittance of the air space side surface of the inside glass pane.[41]

With the value of E in hand, Table 4 in 1993 ASHRAE F27.5 can be used to select effective heat transfer coefficients for a range of temperature differences, air space temperatures, and air space thicknesses. Note that the heat transfer coefficient for the air-space in Equation 81 is equivalent to $h_{airspace,m,i}$ in Equation 84.

Calculating the Solar Heat Gain Coefficient

The coefficient ($S_{m,i}$) represents the windows solar heat gain coefficient (SHGC) as described in ASHRAE 1993 Fundamentals, F27.18, and solving Equations 61 and 62 for $S_{sing,m,i}$ the SHGC for a single pane glass can be expressed in terms of the previously defined parameters as follows:

41 Rohsenow, et.al., p.346.

$$S_{sing,m,i} = \frac{U_{m,i}\,\alpha_{m,i}}{h_{out,m,i}} + \tau_{m,i}\ . \qquad \textbf{(83)}$$

The SHGC for double glazed windows can be expressed in terms of the previously defined parameters and the as follows:

$$S_{dbl,m,i} = \frac{U_{m,i}\,\alpha_{external}}{h_{out,m,i}} + \tau_{m,i} + \left(\frac{U_{m,i}}{h_{out,m,i}} + \frac{U_{m,i}}{h_{airspace,m,i}}\right)\alpha_{internal} \qquad \textbf{(84)}$$

The solar heat gain coefficient is a dimensionless characteristic specific to each type of fenestration, and since the transmittance and absorptance of glazing materials depend on the incident angle, values vary. Representing the fraction of incident irradiance passing through fenestration as heat gain, the factor accounts for both radiation transmitted directly and radiation absorbed and reemitted. The calculation of the SHGC becomes increasingly more complicated for additional layers. Three methods for calculating the SHGC are offered in this section.

The first method begins with an estimate for the total, instantaneous heat gain through fenestration due to solar insolation and conduction.[42] In this procedure, the total instantaneous heat gain (or admission) through any glazing material or fenestration *other than double strength sheet glass, but with similar angular dependence* is expressed as the sum of the solar heat gain pus the conductive heat gain:

$$q_A = (SC)(SHGF) + U\,(t_o - t_i)\ . \qquad \textbf{(85)}$$

In this equation the solar heat gain is expressed as the product of the shading coefficient (SC) and the solar heat gain factor (SHGF). The shading coefficient *is defined as the ratio of solar gain q_i of the window to that of a standard reference window of single pane, double-strength clear glass, irradiated in the same way and under the same environmental conditions.*[43] Shading coefficients (SC) for single and insulated glass are provided in Table 11 of the 1993 ASHRAE Handbook (SI), F27.19. These

42 1993 ASHRAE Handbook - Fundamentals (SI), F27.18.

43 1993 ASHRAE Handbook - Fundamentals (SI), F27.15.

coefficients are based on still air inside and a 7.5 mph wind on the outside. A wide selection of alternate values for a variety of fenestration options with and without air movement and with and without some form of interior and/or exterior shading device(s).

Solar heat gain factors (SHGF) for various latitudes, compass directions, and times throughout the year are provided in 1993 ASHRAE Handbook (SI), F27.20 - F27.26 all of which makes calculating the solar heat gain relatively simple. To make the necessary connection with the solar heat gain coefficient consider the solar heat gain expressed as the product of the solar heat gain coefficient ($S_{m,i}$) and the incident irradiance ($I_{g,m,i}$):[44]

$$(SC)(SHGF) = S_{m,i} \, I_{g,m,i} \, . \tag{86}$$

By rearranging the preceding equation, direct calculation of approximate values for the solar heat gain coefficient $S_{m,i}$ is possible:

$$S_{m,i} = \frac{(SC)(SHGF)}{I_{g,m,i}} \, . \tag{87}$$

When solar heat gain factors for the local conditions are known to the degree of accuracy necessary to meet the requirements of the simulation being contemplated and the shading coefficients for the window types are known, sol-air temperatures can be calculated directly using Equation 62. For this project, the behavior of the system when driven by varying real-time solar insolation and outside air temperatures is a prime objective. For this project, the average, hourly SHGF's found in for example 1993 ASHRAE F27.20 are not acceptable. As an alternative, solar heat gain factors can be generated by following the procedure outlined in the section titled "Computer Calculation of Solar Heat Gain Factors" beginning on page F27.27 of 1993 ASHRAE Fundamentals. However, another option using the expression for the SHGC, expressed in Equation 84, for double pane glass is more desirable. In this equation, it is the transmittance τ, absorptance α, and overall conductive heat transfer coefficient $U_{m,i}$ which are critical and specific to the fenestration construction and material content.

In this second method, calculating the SHGC makes use of the knowledge that all windows in the model building are double glazed. An expression for the transmittance $\tau_{m,i}$ through both glass panes for

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44 1993 ASHRAE Handbook - Fundamentals. F27.18 - F27.19.

double glazed windows can be expressed in the following equation:

$$\bar{\tau} = \frac{\tau_o \; \tau_i}{(1 - \rho_2 \, \rho_3)} \; ; \tag{88}$$

where τ_o = transmittance through the outer glass pane;

τ_i = transmittance through the inner glass pane;

ρ_2 = reflectance of the inner surface of the outer glass pane;

ρ_3 = reflectance of the outer surface of the inner glass pane.[45]

The absorptance α for double pane windows is expressed as a function of the absorptances and reflectances of the two glass panes and the transmittance of the outside pane as follows:

$$\alpha_{outside} = \alpha_1 + \alpha_1 \, \tau_o \, \frac{\rho_3}{1 - \rho_2 \, \rho_3} \; ; \; and \tag{89}$$

$$\alpha_{inside} = \alpha_3 \, \tau_o \, \frac{1}{1 - \rho_2 \, \rho_3} \; ; \tag{90}$$

where: τ_o = transmittance of the outer glass pane;

α_1 = absorptance of the outer surface of the outer glass pane;

α_3 = absorptance of the air space side surface of the inner glass pane;

ρ_2 = reflectance of the air space side surface of the outer glass pane;

ρ_3 = reflectance of the air space side surface of the inner glass pane.[46]

The parameters in Equations 88, 89,and 90 and the remaining parameters for Equation 84 including the inner and outer surface film coefficients, the overall heat transfer coefficient for the airspace, and the overall conductive heat transfer coefficient for the window can estimated, drawn from manufactures catalogs, or calculated. Tables in the ASHRAE Handbook - Fundamentals Chapter 27 can provide very reasonable estimates for the most common construction components and materials.

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45 1993 ASHRAE Handbook - Fundamentals, F27.18.

46 1989 ASHRAE Handbook - Fundamentals, Example 7, §27.

The third, and possibly the simplest, method for calculating the SHGC depends on a standard reference glazing system and shading coefficients for the particular window in question as follows:

$$SC = \frac{SHGC_{subject\ window}}{SHGC_{reference\ window}} \quad . \tag{91}$$

Values for SHGC are typically provided with the energy performance data for most commercially available windows. In the case where the SHGC is not known, Equation 83 can be used with values selected from Chapter 27 in 1993 ASHRAE Fundamentals to calculate a reference $SHGC_{ref}$, along with an appropriate value for the SC. Then using the preceding equation values $SHGC_{subject}$ can be figured directly.[47]

2.2.2 Proposed Alternative 2C3R LPM (Based on IEA Annex 10 Second Order LPM)

Overall Resistance or Conductance for Global Parameterization

The external wall, outer resistance is taken into consideration in the calculation of global parameters by Equation 43, the expression for the overall loss coefficient K_i. The outer portion of the external walls is defined in the first order approximation of the external wall sub-system as $R_{m,outer}$ in Equation 16. The coefficient K_i is used in defining the structural capacitance and in the denominator of the weighting factors for the overall, equivalent sol-air temperature. In contrast to this, the resistances $R_{02,i}$ and $R_{03,i}$ specified for the global model in the Annex 10 report depend entirely on proportional parts of the conductance referred to as $K_{hvy,inner}$ in Equation 39. This conductance is comprised of contributions from all the internal heavy walls and only the inner portion of the external walls. The inner portion of the external walls is defined in the first order approximation of the external wall sub-system as $R_{m,inner}$ in Equation 16. It should be noted that this specifically excludes all contributions to the resistance (or conversely conductance) effecting heat transfer through the outer portion of the external walls $R_{m,outer}$.

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47 The Lawrence Berkeley Laboratory has developed a calculation procedure and a computer program which automates the required calculations for determining Solar Heat Gain Coefficients for complex glazing systems. Multi-pane systems with angle dependent, spectrally selective layers are becoming increasingly popular. As a result, the equations in ASHRAE F27 are inadequate for calculating SHGC for these systems, 1993 ASHRAE Fundamentals (SI), F27.15.

Though not directly related, the contrast is drawn to illustrate an inconsistency in the application and apportionment of various resistances to define a system of heat flow that should be representative of the real system. The global model is an attempt to bring together a large number of individual systems for the purpose of rendering a complex system into a simple network with realistic behavior, and as developed in the Annex 10 report, the author believes, the model fails to meet this objective. An alternative derivation of the global parameters would take into account the effect of $R_{m,outer}$ on the dynamics of the global system and place all of the contribution from the internal walls in a position acknowledging that heat transfer in the internal walls never occurs in direct contact with the outside as is implied by the Annex 10 report proposal.

A further complexity in the Annex 10 model is found in the proportioning constant θ_i. The Annex 10 report represents this factor as the ratio of conductances expressed in Equation 37. Defining θ_i in this way does not ensure that the ratio remain less than 1 since there is no reason why $K_{hvy,inner}$ should be greater than $K_{hvy,ext}$. The need for $0 \leq \theta_i \leq 1$ is a seemingly desirable requirement, based on the use of θ_i in defining $R_{02,i}$ and $R_{03,i}$. By this alone, it would seem that an alternative definition of θ_i may be required.

Alternative Parameterization of Global System

It is the authors opinion that the apportionment of conductances for the global system can be made on rational terms, and a separate, global proportioning factor is not indicated or required. An alternative apportionment of resistive elements for the global 2C3R model, replaces the resistances $R_{02,i}$ and $R_{03,i}$ with $Ralt_{02,i}$ and $Ralt_{03,i}$, and the resistance $R_{01,i}$ remains the same along with the structural and internal capacitances. The alternative arrangement is shown in Figure 6. In the case of $R_{02,i}$, the alternative expression is a function of the resistance for all the heavy internal walls in parallel with a resistance representing the inner portion of the heavy, external walls for zone i as follows:

$$Kalt_{02,i} = K_{hvy,int} + K_{hvy,ext,inner} \text{ ; or} \tag{92}$$

$$\frac{1}{Ralt_{02,i}} = \sum_{m} \frac{(1 - E_m) H_m}{R_m} + \sum_{m} \frac{E_m H_m}{R_m \theta_m} . \tag{93}$$

In the case of $R_{03,i}$, the alternative expression is a function of the resistance representing only the outer portion of the heavy, external walls for zone i as shown in the following equation:

$$Kalt_{03,i} = K_{hvy,ext,outer} \ ; or \tag{94}$$

$$\frac{1}{Ralt_{03,i}} = \sum_{m} \frac{E_m H_m}{R_m (1 - \theta_m)} . \tag{95}$$

The proportional factor θ_m is found using Equation 14, the term for the *accessibility of capacitance* found for the first order system 1C2R model for the external walls.

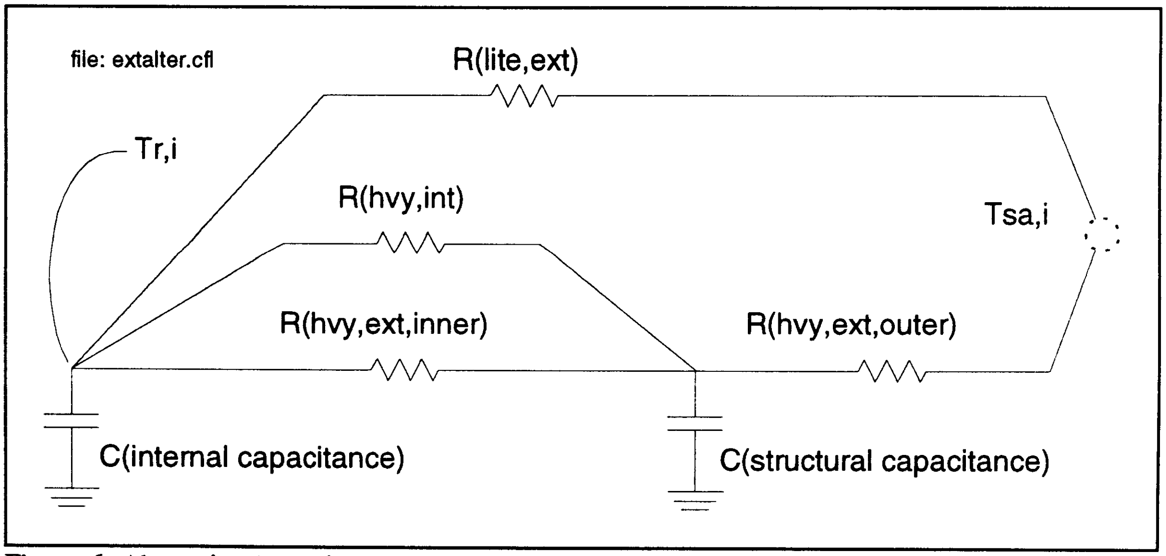

Figure 6: Alternative Apportionment of Resistive Elements for the Global 2C3R Model

<u>Additional Consequences to Modifying Global Resistance Parameters</u>

If the strategy for combining the LPM sub-systems is modified certain changes in some of the other defined variables must also be made. The primary change modification is made in the definition of the equivalent resistance $R_{eq,i}$ or conductance shown in Equation 48. The term representing the structural conductance $K_{hvy,inner}$ (defined in the Annex 10 report and shown in Equation 39) would be replaced with the term derived by combining the two Equations 92 and 94 ($Kalt_{hvy}$). The newly defined structural conductance would then be used in the definition for the equivalent resistance (conductance) shown in Equation 48 to obtain the following:

$$Kalt_{eq,i} = \dot{C}_{i,out} + K_{lite,ext} + Kalt_{hvy} \text{ ; where} \tag{96}$$

$$\frac{1}{Kalt_{hvy}} = \frac{1}{K_{hvy,int} + K_{hvy,ext,inner}} + \frac{1}{K_{hvy,ext,outer}} \text{ ;} \tag{97}$$

or alternatively, in terms of the first order sub-components, the modified equivalent resistance can be expressed as:

$$\frac{1}{Ralt_{eq,i}} = \dot{C}_{i,out} + \sum_m \frac{(1-H_m)E_m}{R_m} + \frac{1}{\dfrac{1}{\sum_m \dfrac{(1-E_m)H_m}{R_m} + \sum_m \dfrac{E_m H_m}{R_m \theta_m}} + \dfrac{1}{\sum_m \dfrac{E_m H_m}{R_m (1-\theta_m)}}} \text{ .} \tag{98}$$

Adopting the modification to the definition of $R_{eq,i}$ would not alter the overall loss coefficient K_i defined in Equation 43. However, the expressions for the global LPM characteristic response parameters, the accessibility (as defined in Equation 37), the time constant, and the structural capacitance would all be effected, and must be modified appropriately.

<u>Modification to the Overall, Equivalent Sol-Air Temperature Calculation</u>

The weighting coefficients in the sol-air temperature calculated in Equation 59 do not quite add up to 1. The offsetting component in this problem is the addition of the term for the capacitive flow of infiltration $\dot{C}_{i,out}$ which was added into the report by hand, apparently as an afterthought. Either this term should be eliminated from the coefficient denominator or the numerators need to be modified to correct the inconsistency. Reference is made at the end of the Annex 10 report sub-section 2.5 to the use of t_{out} in place of $t^*_{out,m,i}$ in the equivalent sol-air temperature ($t^*_{out,i}$) calculation when figuring a resistance for infiltrations. The solution to the inconsistency may lie with incorporation of an infiltration resistance term into $t^*_{out,i}$. However, since, infiltration is considered negligible in the real building, this feature was not implemented in the model. Consequently, the weighting coefficients used should be referenced to K_{ext} as proposed in the Annex 10 report prior to the hand drawn modification.

2.2.3 Error Correction to 2C3R Model

The structural resistance R_i is defined in a copy of the IEA Annex 10 report used by the MIT team as:

$$\frac{1}{R_i} = \sum_m \frac{H_m}{R_m \, \theta_m} \; . \tag{99}$$

This definition is also stated in Equation 39 expressing the sum as a conductance named appropriately for the portion of the physical structure it actually represents. It come to be known that this expression is inaccurate. The questions raised in the course of this researchers effort and summarized in Section 2.2.2 are a direct consequence of the inaccurate definition expressed in Equation 99. Further, the Equations 34, 102, 103 and 35 are defined in the Annex 10 report as:

$$R_{02,i} = R_i \, \theta_i \; ; \; and \tag{100}$$

$$R_{03,i} = R_i \, (1 - \theta_i) \; ; \tag{101}$$

and as a result of the incorrect definition expressed in Equation 99, the expression for $K_{ext,\ inner}$ found its way into the definitions for the structural resistance. It appears that R_i is used in the two expressions for the resistances $R_{02,i}$ and $R_{03,i}$ which are attached to the structural capacitance, and no where else. As a result, corrections to the calculations should be limited to recalculating these resistances.

The correct expression for the structural resistance R_i as a function of the overall loss coefficient K_i (Equation 43) and ratio of the heat flux through the light walls to the total heat losses to the outside ξ_i (Equation 49) is:

$$\frac{1}{R_i} = K_i \, (1 - \xi_i) \; . \tag{102}$$

The correct expression for $K_{ext,\ inner}$ as a function of R_i is:

$$K_{ext,inner} = \frac{1}{R_i\,\theta_i}\ ; \qquad (103)$$

accurately describing the physical arrangement which $K_{ext,inner}$ is intended to represent.

2.3 Preparing for and Executing an HVACSIM+ Simulation

The three major programs comprising the HVACSIM+ package all require advance preparation: (1) the "front end" program HVACGEN, used to configure a simulation; (2) the small utility program SLIMCON, used to convert input data developed by HVACSIM into a format compatible with MODSIM; and (3) the third, the main simulation program MODSIM used to compute a simulation. Additional programs are provided with the package which assist in pre-processing information used in conjunction with the building model, and are described in detail in the HAVCSIM+ document NBSIR 86-3331 [Park, et.al., 1986]. One utility, written to transform HVACSIM+ output data into a form compatible with MATLAB is particularly useful when the real-time user interface is not implemented [Lorenzetti, 1994].

The inter-linked system of components, each representing a piece of a building which has been identified for inclusion in the model, is developed through HVACGEN. Type input and output indices are assigned, and all non-time-dependent parameters are entered.[48] The units are grouped into logical categories called blocks, and the blocks are grouped into still more logically organized categories called super-blocks. The logic behind the development of the categories for each level of grouping is dependent on the type of simulation being considered. Recommendations for grouping units into blocks and super-blocks are discussed in §2.1 of this thesis and in HVACSIM+ document NBSIR 85-3243 [Clark, et.al., 1985].

HVACGEN

The HVACGEN module is used structure a simulation. The basic simulation components are organized into logical groupings, modeling each individual piece of the building. The HVACSIM+ type library contains many common and specialty models. In the event that alternate models are required, the

48 Reference to a building in this context refers to the building's shell and all internal components including, but not limited to, mechanical systems, walls, floors, ceilings, furniture, internal air, ducts, and control systems.

library is expandable; the code (written in Fortran 77) is accessible when modifications to existing types are necessary or require completely new, as yet undeveloped types; for example, the real-time interface was developed by LUT as a sub-task of the overall project.

The HVACGEN module must contain the information about all types which are to be simulated. If a type required to model a certain feature of a system does not exist in the current version of HVACGEN, then a new version of HVACGEN needs to be created. This entails including the new type information (stored in the form of *.for files) in the build statement for creating the HVACGEN executable and recompiling to include the new type(s) information.[49]

Preparation for running HVACGEN consists of identifying the component building parts and the corresponding HVACSIM+ types. Parameters for each unit must then be calculated or otherwise drawn from appropriate sources. These sources may include manufacturer's catalog cut sheets, local on-site measurements, and general references, manuals, and other industry accepted sources. Running HVACGEN produces a work file containing all model structure information.

SLIMCON

This small utility program converts output from HVACGEN into a format which can be used directly by the main simulation module MODSIM. Preparation for running SLIMCON consists of completing the input of all simulation units to create the model structure file. SLIMCON will automatically convert the work file. Output from SLIMCON consists of the model definition file, and a table is generated listing the number of critical elements and percentages of the maximum number of the critical components permitted in a simulation, [Clark, et. al., NBSIR 85-3243, p.36]

Time Dependent Input

Time dependent input to a simulation is implemented typically in a set of boundary files defined according to the requirements of the type to which they are to be fed. Solar and collateral weather data are typical examples of data input to a simulation in this manner. The type added to the library of HVACSIM+ capabilities which allows the operator to visualize a system of variables in "real" time as the simulation develops can be used to adjust control system parameters in "real" time, thus allowing

49 The windows based Microsoft Fortran Power Station compiler program was used for modifying the HVACSIM+ executable programs. MIT Research Assistant Dave Lorenzetti pioneered the use of this compiler program for this project.

the operator access to tuning and what-if scenarios. In general, the output for a simulation is collected in a file. The file contains a record of the values of variables as they evolve over the course of a simulation. The variables recorded can be selected from any used in the simulation. The reporting frequency can be adjusted for each super-block.

General 14 Step Procedure

The HVACSIM+ Users Guide, NBSIR 85-3243, suggests a 14 step procedure for developing, assembling, commissioning, and executing a simulation:

(1) Determine Systems and Components - Primary decisions are made at this point
(2) Determine Types Available and Select Types;
(3) Diagram Types and Connections;
(4) Select [derive and calculate] Parameters;
(5) Group Units into Blocks;
(6) Group Blocks into Super-Blocks;
(7) Select Boundary Variables;
(8) Select Reported Variables;
(9) Determine Initial Values;
(10) Run HVACGEN to Create a Simulation Work File;
(11) Run SLIMCON to Create a Model Definition File;
(12) Set-up Boundary Value File;
(13) Run HVACSIM; and
(14) Interpret Results.

For a simulation as large as the one contemplated for this project, it is advisable to prepare sub-assemblies which can be created and commissioned independently of each other and then incorporated into a final assembly of the entire system. The sub-assemblies would be logical groupings of, for example, mechanical room components, individual zone models, the return and supply air duct systems, or even individual components with these groups. A testbed can be set up which would simulate open or closed loop conditions which would enable one to bench test each major component or component group.

3 Model Development

The model development process was broken into three major task groups: (1) selecting the real building; (2) developing occupancy schedules, characterizing the system of internal gains including lighting and equipment, and selecting an appropriate zone simplification scheme; (3) collecting and identifying specifications, descriptions, and visualizations of every system component to be included in the model.

A number of building configurations were identified with the potential for providing the prototype required for this project, and based on a set of priorities an optimum selection was made. Following building selection, internal heat gains were divided into to major categories: occupancy related and lighting/equipment related. Studies and surveys were used to tabulate schedules and quantities. In the process of quantifying the internal gains, a formulation was developed to re-zone the building into a smaller number of zones than actually existed in the building. This simplification process was necessary in order to reduce the models complexity to a tractable level, recalling that "*...The best model is the simplest one which yields the information necessary for engineering action or decision....*"[50] Specification of the real building involved a detailed, comprehensive investigation of every component or system to be captured by the mathematical model. Information was drawn from architectural, structural, and mechanical drawings, catalog cut sheets, conversations with manufacturer representatives, visual inspections, occupancy records, and historical data. When systems or equipment were substituted, as in the case of the supply and return air ducting, every effort was made to maintain a basis for the substituted systems founded in the actual physical details of the item(s) being replaced.

3.1 Selection of Real Building

"The ideal building [or model volume] would include examples of all components to be modeled in this project. It would include a small number of thermal zones, enough to permit supervisory control strategies to be properly exercised, but not so many as to make preparation and execution of simulations unduly time consuming. For the purposes of the proposed work, the ideal building would not only

50 Shearer, Murphy, & Richardson, Introduction to System Dynamics, (Reading, Massachusetts: Addison Wesley, 2nd Printing, 1971), p. 151.

satisfy specific technical criteria, but [it] would also come with extensive documentation, primarily mechanical and structural specifications and control sequences, and a cooperative facilities manager."[51]

Selection and documentation of the building involved three phases. In the first, a limited number of buildings was selected for consideration on the basis of location, type or usage, size or geometric characteristics and orientation, approximate age, and known facts related to installed mechanical systems. In the second phase, surveys, interviews, and inspections were conducted to determine the availability and accessibility of the necessary specifications to sufficiently model the building envelope and HVAC system. In the third phase, field surveys were made to verify the information obtained in the second phase.

3.1.1 Desired Characteristics

Phase 1: Theoretically, the building could have been located anywhere, providing the building's documentation is sufficient to provide all technical details accurately, as installed: Practically, however, this was not a reasonable expectation, since equipment and construction details can often vary significantly between what was originally specified and what was actually installed. As-built drawings and specifications are designed to clarify these type of discrepancies, and usually do provide an accurate and thorough representation of the real building. It is this authors opinion, however, that in many instances an on-site, visual inspection can save many hours of tedious research looking for answers which may never have been well documented in the first place. Good examples of this can be found whenever specifications are augmented with the phrase "or equal to, or better." This implies that the builder, material and/or supplier, and/or field personnel have the option, at some point in the building delivery process, to provide something other than that which was specifically named. This is accepted practice in the industry, providing opportunities to meet cost and schedule objectives without sacrificing function. The implication for this project is that parameters for certain pieces of equipment and materials must be verified in the field.

One of the project's principle objectives is to *"model the short- term dynamic characteristics and non-linearities of HVAC components."*[52] Consequently, the values selected from the documentation of the

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subject building are critical; some examples of these critical data elements include parameters such as response times for actuators, motor and fan blade specifications, and valve body configurations. The accuracy of the model's behavior depends on faithful attention to detail, and this is possible only when verification of installed equipment and materials can be accomplished. As a direct consequence, the focus for selecting an appropriate building was confined to a fifteen or twenty mile radius of the MIT campus.

Beyond the essential and prime condition that the building ventilation system to be variable air volume (VAV), diversity was a factor in the selection process. Inside design conditions, air movement, circulation changes per hour, minimum outdoor air, noise, filtering efficiencies, energy budgets, and load profiles all contribute to the general design requirements for a buildings comfort air conditioning and heating system.[53] Examples of facilities that offer a wide range of various design criteria applicable to this project can be found in retail facilities, commercial and public buildings, places of assembly, and educational facilities. Each one of these building types make unique demands on a building's environmental control system, and combining two or more types into one building would provide the most interesting and ultimately useful testbed. A thorough compilation of design criteria for these building types can be found in the ASHRAE 1991 Handbook - HVAC Applications, Chapter 1. In selecting a building for this project an effort was made to find one that accommodated a range of activities. Facilities with unique or exotic environmental conditions such as health-care facilities or industrial applications were not included in consideration for this project although the concepts and technology developed in this project may be applied to such applications in the future.

Attention to the building's geometric characteristics automatically constrained the design criteria. Choosing a building within the 15,000 to 20,000 sqft range ensured that the building contained the requisite number of zones and a reasonable level of complexity. This size building allowed the possibility for the presence of a central plant supplying conditioned air through a single duct, variable air volume system. An alternative to central systems is provided by package systems - self contained air conditioning units, factory assembled in integral packages which include fan, filters, heating/cooling coils, refrigerant, compressor(s), controls and condenser. Although commonly applied to almost all classes of buildings, including the types considered appropriate for this project, the limitations inherent to package systems preclude them from consideration. The factors which result in the limitations are the limited performance options available due to fixed airflow, cooling coil, and condenser sizing, the general unavailability of air-side economizers, and reduced air distribution control. In addition,

53 ASHRAE 1991 Applications Handbook(SI), Commercial and Public Buildings, A3.2/3.

modeling is complicated by the unitary equipment design; individual components can not be isolated and accurately modeled.[54]

Orientation, shape and size contribute significantly to HVAC design considerations. *"... the exterior load may vary from 30 to 60% of the total air-conditioning load when fenestration area ranges from 25 to 75% of the floor area ... For example, a rectangular building with a four to one aspect ratio requires substantially more refrigeration than a square building with the same floor area."*[55] Hence, the impedance, and consequently, the dynamic range of the model can be manipulated significantly by shape factors. Intimately related to this design consideration is orientation. Solar load is dependent on fenestration area as well as compass orientation, and large south facing surfaces (for buildings located in the northern hemisphere) make good targets. These factors are not appropriate as a primary consideration in the building selection process. However as a secondary tool, understanding them can help to get the most out of a selection.

Age and known characteristics related to the installed mechanical system were considered together. A required feature in the chosen building was the use of computerized supervisory control of electro-mechanical systems or direct digital control (DDC). First appearing in the late sixties and early seventies, computer actuated supervisory control were often installed in parallel with pneumatic systems. As technology evolved, *"DDC eventually emerged as a stand-alone, and later, a distributed form of computerized control."*[56] Presently, the microcomputer technology used in DDC systems is often based on the Intel 80XXX or Motorola 68XXX families, both of which began to circulate into common use only after 1980.[57] Consequently, choosing a building that had been either constructed or renovated no earlier than 1980 helped to increase the chances of identifying proto-typical structures containing "modern" control systems.

Phase 2: Prior to approaching a building owner or operator for possible access to a candidate building, a menu of selection criteria was prepared together with a letter explaining the intentions of the project and the requirements for evaluation. Selection and documentation of the building involved compiling from the available specifications sufficient information to model the building envelope and

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54 1992 ASHRAE Handbook - HVAC Systems and Equipment (SI), Chapter 5.

55 1991 ASHRAE Handbook - HVAC Applications (SI), Chapter 3, A3.1.

56 ASHRAE Professional Development Seminar - DDC For HVAC Monitoring and Control. February, 1994.

57 ASHRAE PDS - DDC ..., 1994.

HVAC system. Once assembled, the building model envelope and its mechanical systems was to serve as the test-bed. The criteria for the building selection process is shown in Table 4.

For purposes of this study, the ideal building would not only satisfy the above technical criteria, but would also come with the full cooperation of building owner/management. Responses to the letter were collected and based on these, decisions were made to proceed to the third phase of the selection process.

Table - 4: Selection Criteria for Building Type

Criteria	Description
01	Office type - four to five stories, providing a simple, stand-alone envelope type
02	Well defined documentation - the building should be fully described by a complete set of building, equipment, and controls specifications, primarily mechanical and structural specifications and control sequences
03	VAV HVAC system
04	A small number of thermal zones; enough to permit supervisory control strategies to be properly exercised, but not so many as to make preparation and execution of simulations unreasonably time consuming; minimum number of zones - typically 25 terminal boxes to be grouped into 5 units for simplification
05	One control air handler
06	Dedicated mixing plenum
07	Draw through, as opposed to blow through, heating and cooling coils
08	One set of heating and cooling coils
09	One boiler
10	One chiller set digitally controlled terminal boxes with direct drive-control
11	Direct Digital Controls (DDC)
12	Direct drive-control, motor-driven electronic actuators
13	Adjustable or variable speed motor drives (VSD)
14	Accessibility - the building should be located within a 15 - 20 mile arc of Cambridge, Massachusetts

<u>Phase 3</u>: With the preliminary cut completed, field surveys and assessments were conducted in this final phase of the building selection process. More comprehensive inspections of plans and

specifications were made, and interviews were conducted. Verification of quantitative information regarding design details was sought in the process, in addition to qualitative information regarding accessibility to machine spaces, occupied areas, and occupancy rates. Then, with all available information compiled and analyzed, a final selection was made.

The building envelope and HVAC system configuration ultimately chosen was closely related to what may be considered the industry standard for a typical, medium-sized office building with a VAV HVAC system. This was be done in order to minimize accommodations necessary for non-standard installations and engineering practices, the result of which would weaken the integrity and compromise the utility of the model as a standard testbed. The ideal building was envisioned to have four to five floors, a VAV HVAC system with direct digital control system and motor driven electronic actuators. An acceptable alternative was an entire floor sub-section in a multi-story office building, provided that the volume serviced by the mechanical sub-systems for the subject area is limited to that area. Final selection was made in collaboration with LUT.

3.1.2 Candidate Building Characteristics

As stated in the research funding proposal ... *"Achieving the ideal is difficult. A building with a relatively small number of thermal zones will typically not have a rich set of equipment...."*[58] An additional consideration was to look for a building with an envelope and HVAC system configuration as close as possible to what may be considered the industry standard. This would help to minimize accommodations necessary for non-standard installations and engineering practices; the implication being that non-standard installations would weaken the integrity and compromise the utility of the computer model as a standard testbed. The ideal building was to be a free standing, four to five story office building with a VAV HVAC system.

An acceptable alternative is an entire floor sub-section in a multi-story office building each with its own isolated VAV HVAC system. In this case, the sub-section floor and ceiling would be treated as adiabatic boundaries and cooling energy would be provided by the core cooling system represented in the model as a temperature source. As an augmentation of those characteristics noted in Table 4, other major considerations for building selection included: adjustable (or variable) speed motor drives (VSD); direct digital control (DDC) controllers including digitally controlled terminal boxes with direct drive-

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control, motor-driven electronic actuators and microprocessor control; completeness of documentation; a reasonably limited number of thermal zones; a dedicated mixing plenum; draw through as opposed to blow through heating and cooling coils; one boiler; and one chiller.

Several buildings were considered: two originally included in the grant proposal (MIT Buildings E-18 and E-51, Cambridge, MA) and two identified afterward (75 State Street, Boston, MA and 222 Berkeley Street, Boston, MA). The two MIT buildings represent choices close to the ideal free standing model, and the more recently identified buildings represent choices as acceptable alternatives, sub-sections of multi-story office buildings.

The four buildings under consideration in the final phase of the selection process

A. **MIT Building E-51** - This building is a free standing structure. The HVAC system in this building is VAV with constant speed motor drives and inlet vanes. The terminal boxes are not DDC, and pneumatic actuators are used to operate the terminal box dampers and reheat coils as well as the AHU dampers and·cooing cooling control valve. Cooling for the building is provided via the campus cooling system. The length/width aspect ratio is approximately 2.4:1, and the fenestration area is close to 20 percent of the total floor area. The building is fully described in complete sets of building, equipment, and controls specifications. Full cooperation was available from the building owner and operator.

B. **MIT Building E-18** - This building is not a free standing structure. It is connected to two adjacent buildings. The intention with this building would be to model it as a free standing structure, making adjustments as required to accommodate anomalies. The HVAC system in this building is VAV with VSD motor drives. The terminal boxes are DDC, and electronic actuators are used to operate the terminal box dampers. Pneumatic actuators with transducers to the DDC system are used on the AHU and cooling control valve. Cooling for this building is provided by a system shared with the two connecting buildings. Several zones in the building are shared with the adjoining buildings. The mixing plenum is also shared with the adjoining buildings. The supply fan cooling coils are blow through rather then draw through.

The physical building boundaries are not clean; passage ways leading to the adjoining buildings are open which results in mingling circulation. The length/width aspect ratio is approximately 2:1, and the fenestration area is nearly 20 percent of the total floor area. The building is fully described in complete sets of building, equipment, and controls specifications. Full cooperation was available from the building owner and operator.

C. **75 State Street** - This is a high rise commercial office building. Each floor has its own self contained VSD VAV HVAC system. The entire system from the base building control system to the terminal boxes are DDC, and both the AHU and terminal box dampers are pneumatically actuated. The supply fan cooling coils are draw through. Cooling for each floor is provided by a central supply fed through the building's core. Perimeter reheat is provided by staged electric resistance elements. The length/width aspect ratio is approximately 1:1. Although the plan section is square, the total fenestration area is between 25 and 50 percent of the floor area. The building is fully described in complete sets of building, equipment, and controls specifications. Full cooperation was available from the building owner and operator.

D. **222 Berkeley Street** - This is a high rise commercial office building. Each floor has its own self contained VSD VAV HVAC system. The entire system from the base building control system to the terminal boxes are DDC, and the terminal box dampers have motor driven actuators. The supply fan cooling coils are draw through. Cooling for each floor is provided by a central supply fed through the building's core. Perimeter reheat is provided by staged electric resistance elements. The length/width aspect ratio is approximately 1.2:1, and the plan section is nearly square with the total fenestration area between 10 and 20 percent of the floor area. The building is fully described in complete sets of building, equipment, and controls specifications. Full cooperation was available from the building owner and operator.

IV. <u>Selection of Real Building - Detailed Comparison and Review</u>

A. **MIT Building E-51** - A review of the characteristics and features of this building and comparison with other possible choices may lead one to conclude that this building may not be an acceptable candidate. To date only one DDC terminal box with a motor driven damper actuator has been installed, and although a microprocessor is being used to process the control signals, pneumatic sensors and actuators are used throughout the building. However, this building has many strong physical or structural characteristics which tend to offset the negative features of the HVAC control system.

This building has two central plants servicing two adjoining volumes within the structure. Clearly defined, physical boundaries appear between the volumes, providing for separating structural and mechanical systems for each of the two volumes. Among the four selections, this building's aspect ratio is the highest, and except for the hallways, there are no interior spaces. The percentage of floor area to fenestration area is average for the typical commercial office building with a brick faced, CMU (concrete masonry units) block curtain wall.[59] Central plant cooling is augmented by an air-side economizer cycle. A point by point comparison with the characteristics of the other possible choices is presented in Appendix A.

B. **MIT Building E-18** - A review of the characteristics and features of this building and comparison with other possible choices removed it from serious consideration. Detractions include the blow through as opposed to draw through supply fan cooling coils, split zones, complicated physical boundary, shared mixing plenum, and shared cooling system. Additionally, the terminal box dampers are pneumatically actuated. The aspect ratio is high, and the percentage of floor area to fenestration area is average for the typical commercial office building with a brick faced, CMU.

C. **75 State Street** - With the exception of the pneumatically operated terminal box damper actuators and non-free-standing nature of this building, it is well suited for this research project. Although the aspect ratio is low, the percentage of fenestration area to floor area is unusually high. The building is faced with glass, resulting in a lower impedance and a potentially higher dynamic range with respect to solar flux and weather variations. A point by point comparison with the characteristics of the other high rise commercial office building is presented in Appendix A.

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59 This characterization is based on the author's experience in the construction industry.

D. **222 Berkeley Street** - With the exception of the non-free-standing nature of this building, it is generally well suited for this research project. The aspect ratio is low, and the percentage of floor area to fenestration area is also low. Usage in this building is highly diverse. This building contains retail, commercial office, and residential apartment spaces. Variable air volume and constant volume systems are in service for various parts of the structure, and the central cooling plant can benefit from the water-side economizer system tied to roof top mounted cooling towers. A point by point comparison with the characteristics of the other high rise commercial office building is presented in Appendix A.

3.1.3 Conclusion and Recommendation for Prototype Building Selection

The two high rise commercial office buildings (Selections C - 75 State Street & D - 222 Berkeley) provide very acceptable prototypes for use in this research project. Both provide easily identifiable building envelope boundaries, a rich set of DDC equipment, excellent documentation, and the full cooperation of owner and manager. For Selection C, the curtain wall impedance is relatively low which translates into potentially dramatic effects on the dynamic response from solar and weather excitation. For selection D, the curtain wall impedance is relatively high which translates into the potential for a somewhat more conservative dynamic response. Diversity for both buildings is low; the volumes available for consideration in each building are single use commercial office space. There is the usual mix of open plan interior and partitioned perimeter office areas.

The single outstanding feature separating the two high rise buildings is the terminal box damper actuator; motor driven damper actuators are installed in Selection D, and pneumatic driven damper actuators are installed in Selection C. Component models in the HVACSIM+ computer program currently exist to support the motor driven type actuators, and it is believed that motor driven actuators will eventually supplant pneumatic controls as an industry standard. Both buildings have a reasonably small number of zones, oriented in an orderly fashion which lend themselves very well to HVACSIM+ modeling requirements. Consequently, of the two high rise selections the building at 222 Berkeley Street has the preferred characteristics, and could easily serve as a prototype model for this research project.

The buildings (Selections A - MIT E51 & B MIT E18) have multiple uses with strong potential to bring occupancy diversity into the model. They represent nearly free standing structures, bringing these models very close to the desired ideal. In the case of E18, one central plant services this and an adjacent building. The building's physical boundaries are not separate and distinct, and in addition, the boundaries for the air circulation system in E18 are not clear. In the case of E51, two central plants provide cooling and fresh air. The physical boundaries between the two areas served by the two plants are separate and distinct, and the boundaries for the air circulation systems in E51 are maintained by fire-walls, doors, and a fully ducted return air system for both volumes. VSD drives are fitted in E18, where in E51 they are not. Pneumatic actuators are a negative feature for both buildings, however, central plant control are attended to by microprocessor, DDC based, supervisory energy management systems. One motor-driven actuated box has been installed in an E51 VAV terminal box for a beta-test case, and can be used as a proto-typical model for all VAV terminal box actuators in the testbed. No motor driven actuators have been installed in E18. The two MIT buildings also offer satisfactory mechanical and control systems, excellent documentation, and the full cooperation of owner/manager.

In conclusion, the two high-rise office buildings offer outstanding characteristics in regard to mechanical system characteristics. However, diversity, potential dynamic response, the absence of air-side economy cycles, and the open plan office structure do not lend themselves to the desired result. The MIT Building E18 can not be considered a serious contender due to the ill defined physical boundaries, split cooling system, and co-mingled air-flow patterns. The MIT Building E51 has the greatest potential of the four candidate structures. The strength of the clearly defined physical boundaries, the isolated cooling plant and air-flow patterns, the high occupancy and usage type diversity patterns, as well as the potential for dramatic dynamic responses to environmental influences combine to sufficiently over-shadow any deficiencies found in the HVAC control system.

These systems could easily and justifiably be replaced with the requisite class of equipment through a series of objective, analytical assessments, where modifications to the building structure, to suit the needs of this project, would be very subjective, not very analytical, and open to wide ranging criticism. One significant draw back to selection of this building is the large number of zones with many varied uses. Further complicating the issue is the fact that the zones with common usage and occupancy profiles are not all adjacent to each other. Simplification, in this case, for HVACSIM+ adaptation will be complicated, but not impossible. In support, clear objective, analytical assessments can be made for combing zones and re-orienting to suit HVACSIM+ adaptation.

In conclusion, of the four candidate selections, MIT Building E51 provides the best possible prototypical structure for the purposes of the proposed testbed.

3.2 Occupancy Schedules, Internal Gains, and Zone Selection

"Variations in the heat gains from the occupants, equipment, and lights make a major contribution to the variation in heating and cooling loads, particularly on the shorter time-scales (i.e. less than one hour). A major function of the loop controllers is to maintain the controlled variable at its set-point in the face of disturbances due to load variations. This becomes progressively more difficult as the time-scale of these variations gets smaller, approaching the dominant time-constant of the plant being controlled. The evaluation of local loop control, including interactions between loops, requires the use of realistic disturbances in order to assess the controlled performance under conditions representative of those occurring in a real system."[60]

Two methods were used to establish *"conditions representative of those occurring in a real system."* First a survey of information already available from other studies, published, and unpublished was made. *"Sources of existing information include: the National Research Council of Canada, which has studied usage patterns of office equipment; Pacific Northwest Lab, which monitored a large number of commercial buildings as part of Bonneville Power Administration's ELCAP (End-Use Load Consumer Assessment Program); Lawrence Berkeley Laboratory, which has recently analyzed building energy data from the Energy Edge program; and Pacific Gas & Electric."*[61] Second, a limited assessment of the equipment and activity in the proposed building was made.

The limited assessment captured the distribution and specifications of equipment and lighting throughout the selected building. In addition, thorough analysis of occupant usage in each area of the building produced a series of schedules for this source of heat input. Heat input to each of the individual zones in the HVACSIM+ Type 272 (reference Appendix Z, Type Models) is accomplished through three parameters: (1) number of occupants; (2) lighting heat gain; (3) equipment heat gain. This method limits heat input due to equipment, lighting, and occupants to a single value for the duration of a simulation.

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60 ASHRAE 825-TRP

61 ASHRAE 825-TRP

Modifications are under consideration by the LUT team to change the input method for these variables into a time varying input through an input variable similar to that for insolation. In preparation for the anticipated modifications, tables which reproduce the profiles of each of the three heat input categories were created. These tables represent a synthesis of the raw data, and are designed to provide realistic profiles for each heat input category for all megazones. The tables can be used directly as input for a modified HVACSIM+ Type 272 designed to accept time varying excitation.

The basis for lighting and equipment heat gains used in this project is them nameplate data. The studies cited in §3.2.1 clearly indicate that power usage per nameplate data differs substantially from actual power usage, and that estimated usage by nameplate data leads to overestimates. In this regard, a comprehensive monitoring program may be useful to gain insight into how power is consumed within Building E51. Such a program is beyond the scope of this project, and may constitute a separate project which could follow as an addendum to this report. Until such information is obtained, the profiles developed from the nameplate data can be tempered by scaling the data to percentage of the maximum.

3.2.1 Available Survey Information

The documents referenced in Table 5 were reviewed to identify sources of existing information which may capture the essence of the variations in the heat gains due to occupants, equipment and lights, and which make a major contribution to the variation in heating and cooling loads. When the document were reviewed, none demonstrated internal heat gain profiles with high frequency (near one minute) variations. Most quote power dissipation densities averaged over large quantities of data. One recently completed, unpublished paper came to this author's attention afterward which does report office equipment usage at one minute intervals. This report will be reviewed in the final report to ASHRAE regarding the model testbed project.[62]

Issues and concepts discussed in the various papers include actual values measured in the field and estimated or predicted values based on statistical analysis of accumulated data. Typical, measured, and actual energy consumption for several load categories are identified, including that for HVAC, lighting and various miscellaneous pieces of equipment (e.g. water coolers, office equipment, coffee makers,

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62 Norford, L.K., and K.L. Bosko, Performance of Energy Star Compliant Personal Computers and Monitors. Cambridge, Massachusetts Institute of Technology, 21 September, 1995.

Table - 5: Sources of Existing Information to Establish Realistic Heat Gain Conditions

Abbreviation Doc Date Type	Document
1 LBL <1992> Paper	Diamond, R., M.A. Piette, B. Nordman, O. deBuen, J. Harris, B. Cody. "The Study of the Energy Edge Buildings: Energy Use and Savings." Lawrence Berkeley Laboratory and Bonneville Power Administration, 1992. Published in the: ACEE 1992 Summer Study on Energy Efficiency in Buildings Proceedings "Commercial Performance: Analysis and Measurement 3" American Council for an Energy-Efficient Economy.
2 PNL <1994> Paper	Szydlowski, R.F., W.D.Chvála. "Energy Consumption of Personal Computer Work Stations." Pacific Northwest Laboratory February 1994. Document ID: PNL-9061/UC-350.
3 MAP <LBL 1991> Paper	Piette, M.A., J. Eto, and J. Harris. "Office Equipment Energy Use and Trends - Brief of Final Results to PG&E & CEC." Berkeley, California. Energy and Environment Division Lawrence Berkeley Laboratory. 1991. LBL-31308.
4 NOR <1990> Paper	Norford, L.K., A. Hatcher, J. Harris, J. Roturier, and Q. Yu. " Electricity Use in Information Technologies." Annual Review of Energy. Volume 15. 1990.
5 HAR <1988> Paper	Harris, J., J. Roturier, L.K. Norford, and A. Rabl. "Technology Assessment: Electronic Office Equipment." LBL Report Number 25558. November 1988.
6 ROA <1988> Paper	Roach, C. "Office Productivity Tools for the Information Economy: Possible Effects on Electricity Consumption." P/EM-6008. EPRI Research Project 2345-30. October 1988.
7 BPA1 <1991> Paper	Pratt, R. "ELCAP Connected Load Survey Data Summaries." Prepared for the Bonneville Power Administration by Pacific Northwest Laboratories. March 1991.
8 RMI <1990> Paper	Lovins, A., and H. Heede. "Electricity-Saving Office Equipment." Competitek. Rocky Mountain Institute. September 1990.
9 CBEMA <1991> Paper	Computer and Business Equipment Manufacturer's Association (CEBMA). "Information Technology Industry Data Book 1960 - 2001. Industry Marketing Statistics. CBEMA. Washington, DC. 1991.
10 MAR <1991> paper	Martin, E. personal communication concerning measurements of office equipment energy use at the PG&E Sunset Building. 30 August 1991.

and other common "plug loads"). Modern conservation standards are mentioned in the literature surveyed, as well as, the variations in loads which could be expected due to occupancy fluctuations. For comparison purposes, electric power consumption is expressed as an annual energy use rate, normalized over the area of the conditioned floor space in the building, and is known as the Energy Use Intensity (EUI).

3.2.1.1 Actual Values

Actual values for power consumption tend to differ significantly from those indicated on the nameplates attached to a given piece of equipment. Many studies with a focus on conservation, delineation, and market trend analysis for predicting future electric demand load have been done, and in conducting these studies it was necessary to determine actual values for electric power consumption related to a variety of office equipment.

In a study conducted by Szydlowski and Chvála from the Battelle Memorial Institute - Pacific Northwest Laboratory in February, 1994 (reference entry 2 PNL in Table 5 on Page 91), to characterize the "Energy Consumption of Personal Computer Work Stations" it is stated that the measured power density for workstation equipment in the commercial office buildings studied was an average 0.62W/ft^2 (w/ a standard deviation of 0.16W/ft^2); measured energy use intensity for all uses was found to be on average, 2.49kWh/ft^2 (w/ a std deviation of 0.53kWh/ft^2). Szydlowski and Chvála go on to assert that a hat shaped standard demand profile (SDP) for a standard building can be used to characterize the actual power demand over a 24 hour period, and that profile when normalized to the maximum possible energy consumption would show a baseload value of 18% and a peak load value of 76%. Additional analysis of the data collected showed that manufacturers' nameplate ratings typically over estimated actual power consumption by a factor of 4.3.

The PNL *"field monitoring study metered 222 personal computer workstations, network printers, facsimile machines, and photocopiers in six buildings at the Hanford Site in Richmond, Washington. A [non-metered] survey of another 1,231 workstations provided additional information about the number and type of installed equipment in each building."* Equipment monitored at the workstations included personal computers, printers scanners, external drives and modems, facsimile machines, photocopiers, coffee pots, clocks, and various other miscellaneous office automation equipment.

Energy Conservation Measures (ECM's) can be used in developing load distributions. Consumption patterns can be altered by variations due to conservation methods. The effects on power consumption (and conversely dissipation) by equipment changes and upgrades over extended time periods or on isolated areas within a building can be used in the decision making process for HVAC system design. In the PNL study, Szydlowski and Chvála conclude that three ECM's: (1) energy awareness program; (2) retrofit existing PC's w/ power controllers; and (3) purchase new energy efficient PC's will produce savings as follows:

> First, savings can be achieved only if permanent changes in habits are achieved. In the study, such a goal was deemed achievable at a cost of approximately $15/pc/yr. Actual savings for a given location will depend on the unit cost of electric power in the subject area.
>
> Second, savings can be achieved but at a high initial cost and with a comparatively high degree of complication. The initial cost of equipment that contains energy efficient components and features, in addition to the cost to replace energy inefficient equipment with improved models is high and can lead to many complications which may have a quelling effect on the desire to implement such a program.
>
> Third, cost savings can be achieved as old PC stock becomes obsolete and is replaced. An incremental cost will be incurred for those generic PC's replaced with name brands having Energy Star Ratings.

In a study conducted by Diamond, et al. for the Lawrence Berkeley Laboratory and the Bonneville Power Administration (reference entry 1 LBL in Table 5 on Page 91) power consumption for 28 buildings located in the Pacific Northwest corner of the united States was studied. The subject buildings were part of the Energy Edge Project (EEP); a program "initiated in 1986 to demonstrate cost effective energy savings in new commercial buildings..."[63] The EEP buildings were constructed to meet certain energy conservation standards, and the study was conducted to quantify the effectiveness of the measures. The statistics reported by LBL are based on billing records from twenty-seven of the buildings, hourly sub-metered end use data from of the ten buildings, and simulation models from five of the buildings. Although two of office buildings had back up gas-fired boilers, total electric power use was considered to represent the total building power consumption in all cases; the back boilers were rarely used, if at all.

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63 Diamond, R., et al., "The Study of the Energy Edge Buildings: Energy Use and Savings," <u>Commercial Performance: Analysis and Measurement 3</u>, ACEE 1992 Summer Study on Energy Efficiency in Buildings Proceedings American Council for an Energy-Efficient Economy.

The study analyzed energy performance in these buildings *"based on three types of comparisons: (1) comparisons of actual energy use to predicted use; (2) comparisons of actual energy use with energy use of similar new buildings in the region, based on end use metering and prototype simulation, and (3) comparisons of actual energy use with hypothetical baseline buildings that meet Model Conservation Standards (MCS) codes requirements,"* (note that energy simulation methods are fully described in ASHRAE 1993 Fundamentals Handbook, Chapter 28, "Energy Estimating Methods"). Energy consumption profiles for building types typical of the new commercial construction in the region including offices, schools, restaurants, clinics, and supermarkets were captured in the study. Floor areas for the subject buildings ranged between 2,000 and 1,000,000 sqft.

Diamond et al. states that for the limited number of Energy Edge office buildings, for which end use data was available, the average electrical power consumption rate was found to be 11 kWh/ft^2-yr; this average apparently takes into account all use categories. It was noted that this value was 50% less (both actual and predicted) than values for other new construction in the region. The actual consumption rate for heating, cooling, fans, and pumps alone is stated to be 7.6 kWh/ft^2-yr, and the predicted rate is stated to be approximately 6.8 kWh/ft^2-yr. The actual electric power consumption rate for lighting is stated to be 4.2 kWh/ft^2-yr, and the predicted rate is stated to be approximately 3.8 kWh/ft^2-yr. Electric power consumption by equipment falling into the other category which includes hot water, exterior lighting, plug loads and various miscellaneous end uses was stated to represent on average 22% of the actual total measured consumption.

Energy savings measures were determined to have a profound effect on overall electrical power consumption. Five buildings out of the twenty-eight were selected for a detailed study of the performance of certain energy conservation measures. The measures used in each building were selected according to the building's use. Measures implemented in four of the five subject buildings for the HVAC systems included high efficiency heat pumps, economizers, and exhaust ventilation heat recovery. Actual measured savings were stated to be 1.4 kWh/ft^2-yr, where predicted savings were set at approximately 2.7 kWh/ft^2-yr. Specifically, savings for economizers ranged from 0.02 kWh/ft^2-yr to 1.3 kWh/ft^2-yr.

Measures implemented for lighting in four buildings include various combinations of high efficiency lamps, ballasts, fixtures, occupancy sensors, and day-lighting control. The actual savings for these measures in the tuned buildings was stated to be 2.6 kWh/ft^2-yr, the predicted savings was stated to be approximately 2.4 kWh/ft^2-yr. Lighting Power Densities (LPD's) in Energy Edge office buildings ranged between 1.1 - 3.0 W/ft^2 with a mean of approximately 1.8 W/ft^2. The Model Conservation Standards Code (MCS) sets the LPD for this class of buildings at 1.5 W/ft^2.

Measures implemented in five of the building's shells included low-emissivity windows, wall and roof insulation, infiltration barriers, and vestibules. Actual savings realized for these measures in the tuned buildings was stated to be approximately 0.6 kWh/ft^2-yr; predicted savings was stated to be approximately 0.9 kWh/ft^2-yr. *"Among the five selected buildings, the predicted savings for the shell measures was about one third the savings for either the lighting or the HVAC measures. For comparison, among all twenty-eight Energy Edge buildings the average predicted savings for all three classes of measures were: 1.8 kWh/ft^2-yr (average of 26 HVAC measures), 1.8 kWh/ft^2-yr (23 lighting measures), and 1.3 kWh/ft^2-yr (33 shell measures)."*[64]

Some effort was made to quantify the effectiveness of various forms of lighting control. The normalized, peak average weekday hourly lighting load for occupant controlled lighting was found to be approximately 90%. The same value for Energy Management Control System (EMCS) controlled lighting was found to be approximately 85%, and not surprisingly, the same value for occupant sensor controlled lighting was found to be approximately 65%. Generally, it was found that lighting loads were very hard to predict when occupant dissatisfaction with lighting levels resulted in alteration of design lighting schemes.

Piette et al. (reference entry 3 MAP in Table 5 on Page 91) noted that in studies conducted by Harris, et al. and Norford et al. it was concluded that office equipment nameplate power consumption ratings were typically much higher then actual values. The study conducted by Szydlowski and Chvála supports this conclusion and indicates that this discrepancy could be as high as a factor of 4.3.

3.2.1.2 Estimated Values

Szydlowski and Chvála in the PNL study (reference entry 2 PNL in Table 5 on Page 91) state *"that the* [estimated power dissipation provided by the manufacturers Name Plate Dissipation (NPD) rating for the] *standard [personal computer] PC consumes approximately 144 W (CPU = 85W and monitor = 60W) and the [electric] power consumption of the standard workstation (PC plus peripherals) was 173W...,"* and further that ninety-three percent of all PC workstations fall into a 75W to 175W load

64 Diamond, R., et al., Page 3.56.

class. As mentioned in §3.2.1.1, the manufacturers' nameplate ratings typically over estimates actual power consumption by a factor of 4.3.

Diamond et al. concluded that although the Energy Edge buildings included in their study used, on average, typically 10% more energy than predicted, they were found to consume 30% less energy than the typical new construction in the region. See §3.2.1.1 for comparisons between actual values for electric power consumption and predicted values as determined in the study by Diamond et al.

In a Briefing of Final Results to PG&E & CEC - Office Equipment: Energy Use and Trends by Piette et al. (reference entry 3 MAP in Table 5 on Page 91) seven categories of office equipment are defined which relate to categories of office equipment found in utility surveys and industry reports. In the context of this report, the term "Office Equipment" is defined as meaning information processing equipment. The seven categories are: (1) mainframe and mini-computers; (2) personal computers; (3) printers; (4) copiers; (5) facsimile machines; (6) video display terminals; and (7) typewriters. data for the survey was drawn from a number of sources. Two sources of information - a Pacific Gas and Electric Company's 1985 on-site survey for 855 commercial buildings and a study conducted by Norford et al. (1990) - provided the majority of data and statistics used in this report. Nameplate power ratings and average energy use as a percent of nameplate ratings were combined to derive the electric power consumption rate estimates presented in this paper. Engineering estimates and, to a limited degree, component measurements provided the foundation for diversity factors.

Piette et al. estimates that in 1983 the total electric power consumption rate for information technology equipment, in what they refer to as the small office prototype, was 1.0 kWh/ft^2-yr. This estimate increases to 2.3 kWh/ft^2-yr in 1990, and in the year 2011, it is predicted that the rate will increase to 4.2 kWh/ft^2-yr. These predictions were based on an evolving equipment mix composition. In 1990, the total electric power consumption rate for information technology equipment in all buildings was 0.8 kWh/ft^2-yr, and in the year 2011, it is predicted that this rate will increase to 1.6 kWh/ft^2-yr. Piette et al. go on to state that, in 1990, *"Office equipment currently represents about 6% of the total commercial sector electricity use ... [and] Office equipment energy use [is] predicted to grow to about 10% of total commercial sector electricity use"* by the year 2011.

On a lower level, Piette et al. states that the total estimated Nameplate Power Dissipation in 1983 was 0.65 W/ft^2, and that of the total, 0.27 W/ft^2 was the result of mainframe and mini-computers. In the year 2011, it is estimated that personal computers will account for 2.24 W/ft^2 and printers will account for 2.31 W/ft^2; main-frame and mini-computer NPD is expected to rise to 0.54 W/ft^2.

Piette et al. refers to several studies and reports that contain relevant and definitive information pertinent to this topic: (1) Studies by Norford et al. (1990) and Lovins et al. contain discussions of the effect of swapping the heat load resulting from mainframe computers, located in special rooms with the dedicated space conditioning systems, with the heat load from personal computers in the general office spaces; (2) A paper by Lovins and Heede for the Rocky Mountain Institute in 1990 was referred to as containing the most notable and complete studies emphasizing the energy saving opportunities within office equipment technologies. In addition, summaries of other studies and forecasts are included in this paper; and (3) The Computer and Business Manufacturing Association (CBEMA, 1991) is one of the most complete sources of information for industry projections of several classes of hardware.

3.2.1.3 Occupancy

Diamond, et al states that occupancy variations are suspected as being responsible for high rates of change for energy consumption in certain buildings; insufficient information was available at the time of LBL's study to be certain what produced the high rates of change.

3.2.2 Building Loads Due to Occupancy Patterns and Variations

Occupancy patterns and variations for the maga-zone will have to be developed from the data presented in Appendix F and in the schedules shown in Appendix G. The tables in Appendix F show the maximum number of people for each office (administrative, professorial, and student) and refers to Appendix G for classroom occupancy statistics. It was assumed that professorial and student schedules were similar, following a pattern consistent with and complementing actual classroom usage schedules, since neither group could use both places at full capacity simultaneously. Administrative personnel schedules were assumed to cycle according to the typical MIT day work schedule; with the exception of lunch time, it was to be assumed that these personnel were within the confines of their respective office area for the work day established.

The data for Appendix G were obtained from records in the classroom schedules office for the academic years 1992/1993 & 1993/1994. The records were derived from preregistration enrollment numbers and do not necessarily represent the total number of students in a classroom for an entire semester. Occupancy for conference rooms was based on the number of faculty and staff typically in the room at the time indicated. Conference rooms are used for a variety of reasons, and it was necessary to speak with the individual responsible for scheduling each particular room to obtain occupancy, use and duration data.

3.2.3 Building Loads Due to Lighting and Installed Equipment

A schedule of lighting and installed equipment for the selected building - MIT E51 - is shown in Appendix F. The tables in the appendix are organized according to the final zoning configuration selected to group the thirty-four physically distinct zones into six megazones. The rationale for the procedure used for grouping the thirty-four individual zones into six megazones is discussed in §3.2.4.

Values for the quantity, type, duty, and nameplate power rating are tabulated for the lighting in each area. A majority of the lighting is provided by fluorescent tubes (32W T28 type) set in recessed, suspended ceiling enclosures. Tabulated quantities refer to the number of four foot tubes in the associated area. Other classes of lighting include incandescent spots lights and illumination for exit signs. The duty rating for the lighting is divided into four categories: (a) continuous; (b) standard office hours; (c) per class or conference room schedule; and (d) student or professorial office schedule, and it is proposed that a lighting schedule be tailored to match the appropriate occupancy schedule.

Values for the quantity, type, duty, and nameplate power rating are tabulated for the equipment installed in each area. Equipment types include personal computers, desk top printers (both large and small), micro-wave ovens, facsimile machines, copiers, refrigerators, and water coolers. In developing the equipment heat dissipation profiles the nameplate data ratings were used as a baseline value. These values may be adjusted for usage factors suggested in other studies, (reference §3.2.1 Available Information). These studies suggest that the nameplate power consumption rating for most pieces of equipment is typically significantly greater than the actual output. Maximum power dissipation levels quoted in the input schedules in Appendix Y are based on nameplate rating, and can be adjusted as necessary to reflect the findings of the studies reviewed.

3.2.4 Zone Number Reduction and Simplification

The building selected is a free standing structure. It is located on the East Side of the MIT campus at 70 Memorial Drive, Cambridge, Massachusetts, (referred to as MIT Building E51, see Appendix 16). Function serves to divide this building into two separate parts: (1) an auditorium; and (2) an office/educational facility. The auditorium area is physically isolated from the rest of the building, and is serviced by its own air conditioning and ventilation system. The balance of the building provides for office and educational uses in the form of classroom, data processing, conference rooms as well as administrative, professorial, and student offices. For the purposes of this study, E51 was considered to be oriented east to west by its long axis. Although the long axis is skewed from true east-west orientation by less than 10°, this approximation is considered to be adequate for solar flux calculations and heat loss/gain due to wind factors and shading.

The HVAC system is VAV with constant speed motors. With only one exception, an experimental prototype DDC, motor driven installation, the terminal boxes are not DDC or fan powered, and pneumatic actuators are used to operate the terminal box dampers. Cooling power for the office/classroom portion of the building is provided by campus cooling system, though two Trane Climate Changer supply air conditioning systems; heating is provided by an on-site, oil fired, forced hot water system through terminal box reheating elements and a perimeter heating system. The building is fully described in complete sets of building, equipment, and controls specifications.

The total floor area of this building is 58,200 square foot. For this project, one-half of the office / educational portion of the building is used. It consists of three floors plus a basement or ground floor (for a total of four floors) to constitute a total of 16,140 square feet, (reference Appendix 16). This volume is located at the west end of the building, and contains vertically oriented sections of each of the four floors. The model volume has north, south, and west facing walls, and for this project it is considered to be separated from the east end volume by an adiabatic boundary, (refer to Appendix D). The VAV ventilation and cooling systems for the office/educational portion of the building consist of two air handling units, each supplying two theoretically distinct and separate volumes within the building; partitions and fire doors effectively isolate the two volumes, and help to enhance the argument for assuming an adiabatic boundary between the two volumes. The subject volume is serviced by air-handler unit number one, (AHU1).

The zone configuration for the model volume consists of thirty-four zones supplied by AHU1: eight individually controlled VAV boxes on the basement level; nine on the first level; eleven on the second level; and six on the third level, (refer to Appendix D for supply and return duct drawings detailing VAV box and thermostat locations). A computer simulation using HVACSIM+ designed to reflect the thirty-four zone configuration represented in the model volume would be too large and unnecessarily complicated. The number of individual components required and the resultant variables, parameters and equations would choke the system. Model development would be severely hampered by the extremely fine breakdown of model volumes, and simulation times would be so slow as to severely diminish the value of the model for the stated purpose. Experience has proven that simplification by combing zones produces very acceptable results and also significantly enhances simulation performance, [P.Haves, LUT, 1994]; grounds for engineering simplifications are well established in the area of building system simulation.[65]

As a result, individual zones were combined into megazones by grouping them logically according to usage, compass orientation, occupancy schedules, and window area obstruction and shading by trees and shrubbery and adjacent buildings. When it became apparent that, even by this method, the number of zones would be too high, subjective judgement was used to further reduce the number to a more tractable level. Stairwells and utility closets and pipe/wire chases within the model volume boundary were not considered to be conditioned spaces, and were therefore not included in the model.

3.2.4.1 Zone Selection Criteria

Usage patterns provided the principle criteria for megazone selection. The model volume has five primary uses:: office, conference, classroom, data processing, and hallway. The three classes of office spaces (administrative, professorial, and student) were combined into one class to reduce complexity. Whenever possible adjacent rooms with similar patterns were combined, provided that the outside walls of the adjacent rooms had the similar compass orientations. The impact of solar and weather related loading on occupant comfort control for walls not containing fenestration is minimal. As a consequence, compass orientation was not considered critical for rooms with exterior walls and no fenestration. Window area obstruction and shading by trees, shrubbery, and adjacent buildings provided additional substantiation for placing a room with one group or another.

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65 Park, C., Simulation of a Large Office Building System Using the HVACSIM+ Program. National Institute for Standards, CH-89-6-4, 1989.

3.2.4.2 Zone Selection

For each level, several selection configurations were considered. The merits of each configuration were compiled, taking into consideration usage, occupancy schedules, fenestration, compass bearing, shading and other obstructions, and geometric location. The air distribution system for the subject volume is comprised of two main ducts (a supply and a return) oriented vertically through an insulated chase-way passing through each floor, from the roof-top mechanical room to the ground floor. Ducts branch off at each floor, and distribution and collection is accomplished through a series of multiple branches reaching across the individual floors; each floor is physically isolated as a separate volume by the structure of the building, fire doors, and partitions. The naturally occurring space segregation resulting from these design features provided the impetus for looking at zone simplification on a floor by floor basis. At the end of the process, a system of eleven well defined, contiguous areas representing each activity type conducted within the volume was identified.

BASEMENT LEVEL

Beginning with the Basement Level, which contains one hallway, a data processing center (or Athena Cluster) and number of areas used variously as student offices, conference rooms, and classrooms (reference Table 6), five configurations were considered.[66] The number of zones proposed in these choices range from 3 to 5.

Zoning Option 0A (Figure 34)

Zoning Option 0A combines office and conference space into a single zone. To do this, an assumption is made that heat gain through fenestration and from lighting, equipment, and occupancy is uniform in each room. A case can be made for Offices 003, 006, and 008. The windows for these spaces are located below ground level in planter wells The wells are densely with shrubbery and trees, and as a result shading on the windows is very heavy, almost completely blocking direct sunlight, (refer to Site Plan & Elevations, Appendix 16). The Conference Room 004, however, extends from the basement level to the top of the first level, and the south facing windows in this room extend from floor to ceiling. Consequently, heat gain through fenestration in 004 is uniquely different from that through the other spaces to be combined in this option, and therefore 004 must be treated separately from the other areas on this level, eliminating this option from consideration.

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66 An Athena Cluster is a group of computers and work stations which area accessible to students and other Institute personnel for computer and data processing on a 24 hour/day basis. Room air conditioning is served by the same system conditioning the other parts of the subject volume.

Zoning Option 0B (Figure 35)

Zoning Option 0B has merit. It identifies Conference Room 004 as an individual zone, and takes advantage of uniform heat gains from various sources cited in the description for Option 0A.

Table - 6: Basement Level Space Use Summary (refer to Appendix F)

	Admin. Offices	Prof. Offices	Student Offices	Data Process	Conf. Room	Class Room	Hallway
Number	0	0	4	1	1	1	1

Table - 7: Basement Level Zoning Option Summary (figures referenced are in Appendix E)

Option	Number of Zones	Refer to Figure	Comments (supporting use of the option)
0A	3	34	- heat gain through fenestration in 004 is not significant - heat gain through fenestration in 003, 006, & 008 is not significant - class room as individual zone - data processing as individual zone
0B	4	35	- heat gain through fenestration in 004 is significant - heat gain thru fenestration in 003, 006, & 008 is not significant - class room as individual zone - data processing as individual zone
0C	5	36	- heat gain through fenestration in 004 is significant - heat gain through fenestration in 003, 006, & 008 is not significant - class room as individual zone data processing as individual zone
0D	3	37	- conference room 004 zoned on 1st level - heat gain through fenestration in 003, 006, & 008 is not significant - class room as individual zone - data processing as individual zone
0E	3	38	- heat gain through fenestration in 004 is significant - heat gain through fenestration in 003, 006, & 008 is not significant - classroom 012 combined with office space - data processing as individual zone

Zoning Option 0C (Figure 36)

Zoning Option 0C is a variation of Option 0B. Fenestration in 003 has northerly and westerly exposure; while fenestration in 006 and 008 have southerly exposure. If heat gain through fenestration in 003, 006, and 008 was significantly different, there may be some merit in making the distinction represented in this option. This is, however, not the case; due to the heavy shading and comparatively small window sizes for all three office spaces, the argument for this arrangement is weak. As a result this option was to be eliminated from consideration.

Zoning Option 0D (Figure 37)

Zoning Option 0D requires moving the zone for Conference Room 004 to the first level. Moving a zone to another floor will not reduce the overall total unless it can be incorporated into a megazone on that floor. Since this can not be done Option 0D was to be eliminated from consideration.

Zoning Option 0E (Figure 38)

Zoning Option 0E takes advantage of the merits found in Option 0B, and in addition, combines Classroom 012 with the office areas. A reduction from the four zones of Option 0B to three is a positive step in reducing complexity. In support of turning a classroom into office space, it can be noted that classroom space in the model volume is well represented on the third level. Retaining an individual zone on the basement level as a classroom is redundant, not providing any additional variety, and, therefore, doing so represents an unnecessary complication.

FIRST LEVEL

The first level contains one hallway with administrative office, professorial office, conference room, and classroom areas. The distribution and numbers of space types are outlined in Table 8. Four zoning options were considered, and each one was chosen to optimize and accentuate the various features found on this level. Southerly, westerly, and northerly exposure are all possible, and keeping the two prime objectives in mind, simplification and diversity, the following options identified in Table 9 were considered.

Zoning Option 1A (Figure 39)

Zoning Option 1A depends on two factors: first, there must be uniform heat gain through fenestration along the west and north faces and along the south face; second, Conference Rooms 111 and 106 must be combined with general office space. For the "north" zone (1-1), the west facing windows in 101b are well shaded by trees extending above roof level and by the building located at 100 Memorial Drive. As a result, heat gain through fenestration in 101b is practically the same as that for the spaces with all north facing windows. For the "south" zone (1-2) all fenestration exists on the south building face. As for the conference rooms, this kind of space is well represented on the Basement Level in room 004 and isolating the conference rooms into individual zones on this level does not add to the utility of this model and doing so would impose unnecessary complications.

Table - 8: First Level Space Use Summary (refer to Appendix F)

	Admin. Offices	Prof. Offices	Student Offices	Data Process	Conf. Room	Class Room	Hallway
Number	7	5	0	0	2	0	1

Table - 9: First Level Zoning Option Summary (figures referenced are in Appendix E)

Option	Number of Zones	Refer to Figure	Comments (supporting use of the option)
1A	2	39	- divides space into north and south divisions - heat gain thru fenestration in 101b is uniform w/n.face - combines professorial and administrative office spaces - combines conference rooms with office spaces
1B	3	40	- divides space into north and south divisions - heat gain thru fenestration in 101b is not uniform w/n.face - combines professorial and administrative office spaces - combines conference rooms with office spaces
1C	3	41	- groups the office area 101, 101a, 101b, & 101c together - heat gain thru fenestration in 101b is uniform w/n.face - combines professorial and administrative office spaces - isolates one conference room into a separate zone
1D	4	42	- groups the office area 101, 101a, & 101c together - heat gain thru fenestration in 101b is not uniform w/n.face - combines professorial and administrative office spaces - isolates one conference room into a separate zone

<u>Zoning Option 1B</u> (Figure 40)

This option is similar to Option 1A plus one additional feature - the isolation of Office 101b into a separate zone. This option would have merit if heat gain through the west facing windows in 101b is significant. However, since this is not the case, this option can be eliminated from consideration.

Zoning Option 1C (Figure 41)
This option is similar to Option 1A plus one additional feature - the isolation of Conference Room 111 into a separate zone. This option can be eliminated from consideration, (see option 1A).

Zoning Option 1D (Figure 42)
This option has the same shortcomings as Zoning Options 1B and 1C, plus the additional complication incumbent with attempting to isolate one conference room into a separate zone. This option can be eliminated from consideration.

SECOND LEVEL
The second level contains one hallway and administrative office, professorial office, and conference room areas, (reference Table 10). Fenestration in the north and south facing exterior walls are exposed to nearly unobstructed solar gain. The south west corner is also unobstructed. Only the north west corner is shaded by the adjacent building, (100 Memorial Drive).

Table - 10: Second Level Space Use Summary (refer to Appendix F)

	Admin. Offices	Prof. Offices	Student Offices	Data Process	Conf. Room	Class Room	Hallway
Number	6	11	0	0	0	1	1

Table - 11: Second Level Zoning Option Summary (figures referenced are in Appendix E)

Option	Number of Zones	Refer to Figure	Comments (supporting use of the option)
2A	3	43	- divides space into north and south divisions - heat gain thru fenestration in 201c is uniform w/s. face - heat gain thru fenestration in 201d is uniform w/n. face - combines professorial and administrative office spaces - isolates classroom from office spaces
2B	5	44	- divides space into north and south divisions - heat gain thru fenestration in 201c is not uniform w/s.face - heat gain thru fenestration in 201d is not uniform w/n.face - combines professorial and administrative office spaces - isolates classroom from office spaces
2C	4	45	- divides space into north and south divisions - heat gain thru fenestration in 201c is not uniform w/s. face - heat gain through fenestration in 201d is uniform - combines professorial and administrative office spaces - isolates classroom from office spaces

Option	Number of Zones	Refer to Figure	Comments (supporting use of the option)
2D	3	46	- divides space into north and south divisions - heat gain thru fenestration in 201c is not uniform w/s.face - heat gain thru fenestration in 201d is uniform w/n. face - combines professorial and administrative office spaces - combines classroom with office spaces

Zoning Option 2A (Figure 43)

The proposal represented by Zoning Option 2A was designed to accommodate two factors: first, heat gain through fenestration must be uniform along the west and north faces and along the south face; second, the single classroom on this floor must be isolated into a separate zone. It can be noted that although the west facing windows in 201d are heavily shaded by trees and by the building located at 100 Memorial Drive, (refer to Appendix 16). As a result, heat gain through fenestration in 201d is practically the same as that for the spaces with all north facing windows. The west facing windows in 201c receive direct sunlight with almost no shading throughout the entire afternoon, and as a result heat gain through fenestration for this space will be significantly different then for any other space on this floor. Coincidentally, this condition is unique within the entire model volume, and therefore office 201c should be retained as a separate zone for the sake of diversity. This option can be eliminated from consideration.

Zoning Option 2B (Figure 44)

The proposal represented by Zoning Option 2B was designed to accommodate significant heat gain through fenestration in both rooms at the West End of the model volume, (201c & 201d). In addition, as in Option 2A, the single classroom on this floor, room 215, has been isolated into a separate zone. Closer examination of the probability of heat gain through fenestration into room 201d revealed that this portion of the building is heavily shaded by the building at 100 Memorial Drive (reference Site Plan, Appendix 16). As a result, separation of room 201d into a separate zone is not required. Hence, this option can be eliminated form further consideration. Refer to Zoning Option 2A for addition justification for rejecting this zoning option.

Zoning Option 2C (Figure 45)

The proposal represented in Zoning Option 2C was designed to accommodate significant heat gain through fenestration to room 201c. In addition, isolation of the single classroom on this floor, room 215, into a separate zone was considered a possibility. Classroom space is well represented on the third level, and retaining this area as a separate zone results in unnecessary complication and detail. By transforming this room into office space another zone is eliminated, moving closer to the goal to simplify the model. Hence, this option can be eliminated due to the inappropriate separation of the Classroom 215 into an individual zone.

Zoning Option 2D (Figure 46)

The proposal represented in Zoning Option 2D was designed to accommodate significant heat gain through fenestration to room 201c, and the transformation of the single classroom on this floor, Room 215, into office space. Refer to Zoning Option 2A & 2C for more detailed explanation of other features in this zoning option.

THIRD LEVEL

The third level contains six classrooms and has no other occupied spaces, (reference Table 12). One zoning option is offered for this level and is presented in Table 13. There is no fenestration on the west end exterior wall. Solar gain through fenestration on the north and south exterior walls is unobstructed.

Table - 12: Third Level Space Use Summary (refer to Appendix F)

	Admin. Offices	Prof. Offices	Student Offices	Data Process	Conf. Room	Class Room	Hallway
Number	0	0	0	0	0	6	1

Table - 13: Third Level Zoning Option Summary (figures referenced are in Appendix E)

Option	Number of Zones	Refer to Figure	Comments (supporting use of the option)
3A	3	47	- groups classrooms by compass orientation

Zoning Option 3A (Figure 47)

The proposal represented in Zoning Option 3A groups classrooms together according to the compass heading of the exterior walls. Room 302 does have south, west, and north facing walls, however, in the interest of diversity, it was assumed that north facing windows did not contribute significantly to the heating or cooling load in this area. This level can be divided into as many as six individual zones. In doing so, there would be no significant gain in occupancy schedules diversity, and there would be a significant increase in complexity. Adequate occupancy schedule representation for this type of usage can be achieved with a minimum number of zones on this floor. Classrooms sharing common exterior walls are joined in this option to reduce the total to three.

3.2.4.3 Preliminary Recommendation

Zone selection and discrimination resulted in a group of well defined, contiguous areas representing each type of activity conducted with the model volume. The result is a cross section of occupancy schedules, equipment and lighting densities, and usages that take advantage of each attribute offered by

Table - 14: Model Volume Space Use Summary (based on zoning selection simplifications)

	General Offices	Data Process	Conf. Room	Class Room	Hallway	Other
0th Level	5	1	1	0	1	1
1st Level	14	0	0	0	1	0
2nd Level	17	0	0	0	1	0
3rd Level	0	0	0	6	1	0
Total Area (ft^2)	6,661	607	1,192	5,519	2,018	142
Grand Total Floor Area in Model Volume Served by AH1 (ft^2)					16,139	

Table - 15: Window Area Summary & Compass Orientations (based on Table 16)

Compass Orientation	General Offices	Data Process	Conf. Room	Class Room	Hallway	Other
North	569	40	40	472	0	0
West	292	0	0	0	0	0
South	630	0	436	292	0	0
Total Area (ft^2)	1,491	40	476	764	0	0
Grand Total Window Area in Model Volume Served by AH1 (ft^2)					2,771	

the model volume. Shaded and unshaded north, south and west facing fenestration are also represented. The basement level is to be divided into three zones. Level one is to be divided into two zones. Level two is to be divided into three zones, as is level three for a grand total of eleven zones to be modeled in the simulation. Tables 14 provides a qualitative usage summary for various areas within the subject volume. A detailed accounting of floor areas and usage can be found in Appendix F. Note that the column labeled "Other" is not represented in the preceding analysis. An infrequently used kitchen is attached to Conference Room 004, and its volume was considered as being part of the conference room volume; it is recognized in Table 14 for the record, and also to maintain a correct floor area inventory. Table 15 summarizes the amount of window area facing each compass orientation for each area use type.

Table 16 summarizes the selection details by floor and includes the comments supporting the selection of each zoning option. Appendix F details the specific room assignments to each megazone according to the particular zoning option scheme chosen for each floor. See Appendix E for the physical locations of each room within each megazone for the selected zoning option. As a result of the process presented in §3.2.4, it was possible to reduce the number of zones from the original thirty-four to eleven megazones. The resulting configuration faithfully preserves the self imposed boundaries formed by the qualities of diversity and geometry.

The diversity represented in the building through occupancy schedules, compass orientations of exterior walls, usage patterns, and volume variations was maximized at every opportunity. In addition, the geometry or physical distribution of the floor plan layout has been preserved. The transformation of classroom space on the basement and first levels does not compromise the diversity factor and

Table - 16: Zoning Option Selection Recommendation Summary (refer to Appendix E)

Level	Option	Refer to Figure	Num of Zones	Comments (supporting use of the option)
0	0E	38	3	- heat gain through fenestration in 004 is significant - heat gain through fenestration in 003 is not significant - classroom 012 combined with office space - data processing as individual zone
1	1A	39	2	- divides space into north and south divisions - heat gain through fenestration in 101b is uniform w/ north face - combines professorial and administrative office spaces - combines conference rooms with office spaces

Level	Option	Refer to Figure	Num of Zones	Comments (supporting use of the option)
2	2D	46	3	- divides space into north and south divisions - heat gain through fenestration in 201c is not uniform w/ south face - heat gain through fenestration in 201d is uniform w/ north face - combines professorial and administrative office spaces - combines classroom with office spaces
3	3A	47	3	- groups classrooms by compass orientation
Total Number of Zones			11	

significantly enhances the simplification factor. The eleven zone configuration does represent the absolute minimum number of megazones which can be obtained without crossing the boundaries described. This number, however, was felt to be still too high. A maximum number of six zones with a preference for four was prescribed by one of the authorities for a simulation of a building or structure this size using HAVCSIM+.[67]

3.2.4.4 Zone Selection Re-evaluation

Re-evaluation of the selection and reduction criteria was necessary to reduce the eleven megazone configuration proposed in the §3.2.4.3 to at or below the six megazone configuration required by system and administrative constraints. Diversity preservation in occupancy schedules, zone volume, and compass orientation was essential. Preservation of the diversity represented by the occupancy schedules was accomplished through subjective analysis after the megazone geometry problem was solved, (see §3.2.3). Preservation of the diversity represented by the zone volume and compass orientation established the framework which was used to eventually create the desired megazone configuration.

The floor area use summary tabulated in Table 14 shows the relative areas devoted to each use category, and Table 15 shows the window areas and associated compass orientations for each use category. The first step in the final simplification process was the definition of three types of spaces: (1) office space, which included all types of offices; (2) classroom space; and (3) data processing. The

67 P. Haves, Loughborough University of Technology, Loughborough, England, October, 1994.

next step involved distributing the available volumes to the three space types. Referencing Table 14 the decision was made to allocate 5,519 ft^2 to classroom use, 607 ft^2 for data processing, and the balance of the 16,139 ft^2 or equivalently 10,013 ft^2 to use as office space.

An attempt to preserve the classroom space was felt to be important to the final results; occupancy schedules for these areas have a much greater impact on cooling and heating demand than does any other occupancy variation in the building. The data processing center was also deemed to be sacred ground. Cooling loads in this area are expected to be significant and vary substantially, providing a good source for excitation input in the model. It can be noted that each room for both classroom and data processing areas are all provided with individual, dedicated thermostat control. Designating the balance of the space for office use combines the hallways, conference rooms and other categories under one heading. All these spaces are conditioned in a similar manner; one thermostat usually controls several rooms and includes the hallways as well.

The third step in the process entailed grouping already well-defined areas into ones that were equal in size to those represented by the three use types defined above. Taking into consideration potential solar loading, shading, geometry, partitions, and design flow rates for the ventilation system the building was divided into six megazones representing a total classroom area of 4,666 ft^2, a total data processing area of 607 ft^2, and a total office area of 10,866 ft^2. This is very close to the original distribution of space. Appendix D shows the physical distribution of the megazones, and Appendix F provides a detailed breakdown of how the distribution relates to the original make-up of the building. It should be noted that any attempt to reduce the number of zones below six would result in a loss of realism. It is recognized that only three space types are required to characterize the entire building volume; however, environmental influences vary significantly on the three external walls and diluting the zone structure below six would sacrifice the diversity represented by these variances.

<u>Zone 1</u>

Zone 1 is designated office space and consists of basement level areas with minimal solar impact expected; in addition to being small, the windows are shaded by shrubbery and trees for the entire cooling season. The areas included do have north, west, and south facing windows, however, due to the shading and size factors, it was assumed that compass direction would have very little impact on the comfort control requirements for these spaces.

Zone 2

Zone 2 is dedicated to the data processing room. No qualifications were required to justify this choice. it is isolated as a separate zone in the real building, and the doors are kept closed at all times.

Zone 3

Zone 3 is designated as office space, and is distinguished from other zones designated as office space by the very large exposure on the building's south face.

Zone 4

Also designated as office space, Zone 4 is distinguished from the pack by its shaded west facing and fully exposed north facing exterior walls.

Zone 5

Zone 5 was designated as classroom space. The entire exterior surface of this zone faces north. Although some classrooms in the real building do have south facing windows, window shades are almost always drawn closed; solar loading in these rooms is minimal and can be considered approximately equivalent to the load expected as if they were facing north.

Zone 6

This zone is unique among all other office zones in two ways: (1) it is very small - 188 ft^2; and (2) it has west and south facing windows. Heat gain through fenestration for this zone was anticipated to be very high by the original designer, as evidenced by the very high design supply air flow rate specified, (see Figure 30, Room 201c). This is the only room in the building with such a high anticipated demand.

3.2.4.5 Final Recommendation

In conclusion, the original thirty-four zones can be grouped into six megazones preserving the rich diversity represented by the varied occupancy schedules, external wall and fenestration compass orientations, and use categories actually existing in the real building. Figures 26 - 33 (Appendix D) capture the layout for the final recommended zoning configuration Zoning Option F superimposed on the supply and return ducting actually installed in the real building.

Physical boundaries are preserved, and the design specifications for each the megazone VAV sub-systems can be met with existing HVAC components selected directly out of vendor catalogs, (reference §3.3 Real Building Specification). This feature helps to standardize and validate the design of the systems for the megazone system. The original intent of this project was to produce a model which faithfully reproduces the physical characteristics of an actual building. In the simplification process, some of the one-to-one correspondence of the model to the real thing is expected to be lost, and in the case of the zone number reduction requirement, a very large fraction of realism has the potential for being buried in unfounded assumptions and subjective judgements. Being able to quantify VAV system components from industry available standards is very helpful in mitigating potentially weakening elements in this process.

3.3 Real Building Specification

In conformance with the objects specified in the ASHRAE Contract, documentation was prepared in three phases. Following the development of the megazone simplification scheme (refer to §3.2.4), the first phase documented the building together with all installed equipment. This documentation procedure consisted of obtaining the floor plans, elevations, sections, plant room layout, and layout of the duct and pipe systems. Manufacturers catalog cut sheets were used, whenever obtainable, to provide performance and physical characteristics data for equipment, actuators, and sensors. Site inspections and surveys were conducted to verify data whenever possible or practical. Additional information was obtained as necessary by inquiries to manufacturers, designers, and contractors. The control system specifications have been documented in narrative form and a block diagram has been prepared.

In the second phase of the documentation process, a model structure was developed which mapped the individual component models representing the various parts of the physical building shell and HVAC system to components in the testbed forming a system simulation model. Individual components used to form the system simulation model were chosen from a library of components available in the HVACSIM+ program. At times, the structure of the program dictated how the physical structure was to be modeled, and at times it was the other way around. Development of this program is a continuing project, and some modifications were made to HVACSIM+ components to enhance their adaptability to real systems.

In the third phase of this project, values of the parameters associated with each component modeled by HVACSIM+ type models were specified. Every physical and geometric characteristic of every element or component in the real building and mapped into the simulation model was named, calculated, or estimated.

"*... The documentation of the building and system model will include a block diagram of the components and their connections, and a list of parameter values for each component and a description of how they were derived from the delivered description of the actual building. The documentation will also include a full description of how the control system can be modeled and included in the simulation.*"[68] The components required to mapping the control system into the structure of the HVACSIM+ simulation program were not available at the time this report was prepared. The control system has been documented; schematics and full descriptions have been prepared relating the function of the system in the building. Some modifications were made to transform the pneumatic components found in the actual building into DDC, electrically powered devices.

The components for mapping the control system into the structure of the HVACSIM+ simulation program were developed by the HVACSIM+ team at LUT. The real building control system components were mapped into the HVACSIM+ simulation, and accompanying documentation has been prepared.

3.3.1 Description of Building Shell and HVAC System

The building which serves as the prototype for the testbed is a four story, (including basement level) multi-use structure. The building's physical characteristics are described in §3.2.4 Zone Number Reduction and Simplification. The 16,140 square foot model volume is approximately 50 ft high, 85 ft long (east to west), and 53 ft wide (north to south). The interior spaces are, in general, fitted with suspended ceilings. Hallway areas have no suspended ceiling, and are open to the underside of the concrete slab above. For rooms with suspended ceilings the ceiling height is 9.5 ft, and the plenum height is 2.5 ft.

The floors are six inch reinforced concrete, and the roof deck is concrete decking as well, covered with a built-up asphalt water proofing system. The external shell wall is concrete block with a brick veneer,

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(see Figure 11). The inside face is lined with gypsum wallboard mounted over a system of steel studs, pine furring strips and fiberglass insulation. Windows are steel frame double glazed with swing out panels for occupant adjustment. Internal partitions are comprised of steel studs, gypsum wallboard and fiberglass insulation for sound deadening. Office doors are standard, commercial grade, solid core wood with no vision panels. Fire doors are standard commercial grade metal doors with automatic closers required by the building code.

The HVAC system is VAV with constant speed motors. With only one exception, an experimental prototype DDC, motor driven installation, the terminal boxes are not DDC or fan powered, and pneumatic actuators are used to operate the terminal box dampers. Cooling power for the office/classroom portion of the building is provided by campus cooling system, though two Trane Climate Changer supply air conditioning systems; heating is provided by an on-site, oil fired, forced hot water system through terminal box reheating elements and a perimeter heating system. Central plant cooling is augmented by an air-side economizer cycle. The fresh air dampers is divided into two parts: (1) A minimum air damper which is open at all times during operation, except during cold start conditions;[69] and (2) an economizer damper which is normally closed, opening when the outside air enthalpy is less then the return air enthalpy. The return air and exhaust air dampers are identical in size and specification.

The VAV ventilation and cooling systems for the office/educational portion of the building consist of two air handling units, each supplying two theoretically distinct and separate volumes within the building; partitions and fire doors effectively isolate the two volumes, and help to enhance the argument for assuming an adiabatic boundary between the two volumes. The volume of interest is serviced by air-handler unit number one, (AHU1). The supply and return air distribution system is fully ducted.

The zone configuration for the model volume consists of thirty-four zones supplied by AHU1: eight individually controlled VAV boxes on the basement level; nine on the first level; eleven on the second level; and six on the third level, (refer to Appendix D for supply and return duct drawings detailing VAV box and thermostat locations). Individual zones were combined into megazones by grouping them logically according to usage, compass orientation, occupancy schedules, and window area obstruction and shading by trees and shrubbery and adjacent buildings. Some subjective judgement was used make the final megazone configuration selection. Stairwells, utility closets, and pipe/wire/air-duct

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69 Normally, the supply fan can not start until the minimum air damper is open. For safety purposes (prevent cooling coil freezing) there is a freeze stat by-pass feature in the control system. This feature keeps the minimum air damper closed until the mixed air temperature is above a preset level.

chases, within the model volume boundary, were not considered to be conditioned spaces, and were therefore not included in the model. Refer to §3.2.4.4 Zone Selection Re-evaluation for a detailed description of how this configuration was derived.

3.3.2 Design Specifications & General Arrangement for Mechanical Systems

Engineering design specifications for the building volume served by AH1 are detailed in Appendix H, and the general arrangement of the mechanical room, including sketches of the air conditioning equipment and mechanical room duct work is provided in Appendix I. Floors plans, detailing the individual zone boundaries of megazone scheme Option F and the existing supply/return duct system layout, are provided in Appendix D. A schematic of the air distribution system for the volume served by AH1, configured to megazone Option F, is presented in Figure 64. The building mechanical systems were divided into two major parts; (1) the air handler and air conditioning equipment, located in the mechanical room; and (2) the VAV terminal boxes and perimeter heating systems, located in the individual zones. Each of these systems have their own control strategy. Temperature and pressure sensors provide the signals which link the two systems effecting the control systems output. The third system, comprised of the physical building structure, is a passive element providing thermal resistance and capacitance to the dynamic model.

3.3.3 Equipment Descriptions and Engineering Specifications

This section outlines the specific equipment descriptions, the associated engineering specification, and provide a commentary on how the equipment functions in regard to the entire system. The two major mechanical systems represented by the Air Handling Unit and Air Distribution System were sub-divided into six categories: (1) supply and return air handlers; (2) mixing box, including dampers and actuators; (3) intake and exhaust air grills and louvers; (4) zone components (VAV boxes, reheat coils, perimeter heating, and room temperature control system; (5) supply and return air distribution system; (6) air handler control system.

Information provided in this section was obtained from four sources: first, from the detailed mechanical design drawings;[70] second, from manufacturers catalog cut sheets; third, from physical, on-site inspections; and fourth, from simplification and/or substitution of certain key existing systems and components. Simplification was done to mitigate the complexity of the air distribution system, and substitutions were made to both accommodate the simplifications and to standardize the control system and damper/valve actuators to specifications consistent with direct digital control and electronic components. Design specifications for the supply and return duct systems are based on re-engineering the original duct system to conform with the six megazone configuration.

3.3.3.1 Supply & Return Air Handlers

Supply Air Handler - AH1

The supply air is handled by a Trane Central Station Climate Changer CLCH-MN-2A, Size 41 fitted with inlet vanes. The model number for the unit contains the unit type, basic unit design, primary coil, assorted accessories, and electric preheat information, see Figure 67. The Climate Changer Nameplate model number is M/N: CCDB41KG0A-HSSSLISL0BP-10CA2E000000-210100J0000000-000000. The position of each number in the model number is shown in Table 16.

Table - 16: Trane CLCH Climate Changer Model Number

Trane Climate Changer Model Number Key															
Position	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**					
Number	C	C	D	B	4	1	K	G	0	A					
Position	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**				
Number	H	S	S	S	L	1	S	L	0	B	P				
Position	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**			
Number	1	0	C	A	2	E	0	0	0	0	0	0			

70 Courtesy of Phil Green, Senior Office Assistant, MIT Physical Plant Office of Drawings and Records, E18-207

Trane Climate Changer Model Number Key															
Position	**34**	**45**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**45**	**46**	**47**	**48**	**49**
Number	2	1	0	1	0	0	J	0	0	0	0	0	0	0	0
Position	**50**	**51**	**52**	**53**	**54**	**55**									
Number	0	0	0	0	0	0									

Table - 17: Trane Central Station Climate Changer CLCH-MN-2A Model Number Coding

Figure/ Page	Portion of Model Number	Description
68 / 294	Digits 1 - 10 CCDB41KG0A	a development sequence 'B' climate draw-thru changer unit, size 41, with a 27" diameter, air foil (AF) type fan wheel; it has a type 'D' coil of design sequence 'A' in the first position and no coil in the second position;
71 / 297	Digits 11 - 21 HSSSLISL0BP	the unit is horizontally oriented with a custom motor voltage specified; the casing is special as well as the fan discharge; the motor location is left hand and the unit is fitted with inlet vanes; the drain pan is special, the first coil supply is left hand, and there is no second coil supply, 1.5 lb insulation is used, and the motor is 20 hp;
72 / 298	Digits 22 - 33 10CA2E000000	the coil height is full, there are no coil circuits, the coil fin series is 18,58 aluminum, the coil tube material is standard copper, there are Sigma Flow turbulators, and there are 4 rows, there is no coil height or any other features for the non-existent second coil;
74 / 300	Digits 34 - 49 210100J0000000	there is a standard drive with a 1.5 overload factor, a standard non-UL belt guard was provided, there is no damper section, there is a right hand fan access door, and no access door for the coil section, the mixing box and filter section are separate, a high capacity filter was provided, and nothing else beyond this point was specified;
77 / 303	Digits 50 -55 000000	including no electric preheat.

The decoded number indicates that Unit AH1 in Building E51 is as described in Table 17. Copies of the manufacturers catalog pages containing the information necessary to decode the model number are presented in Appendix J.

Fan curves and RPM tables developed by the Trane Company for installed the equipment are provided in Figures 83 and 84.The fan curves plot static pressure (in.wg) as a function of volumetric flow rate (1000's of cfm). The curves are for the Size 41 Climate Changer without inlet vanes since supply air flow control in the simulation will be accomplished with a variable speed drive rather then with inlet vanes. For verification of the megazone duct system design, the fan performance data for the Size 41 Climate Changer fitted with inlet vanes is presented in Figures 85. Inlet vane performance curves are presented in Figure 86. These curves are to be used to determine the modulated performance for both the supply and return fan units. The modulated performance information may be used to compare actual computer model performance with expected inlet vane position.

The pressure represented in the curves is referred to as the *fan static pressure* (P_{sf}) as defined in ASHRAE *Standard* 51 and AMCA *Standard* 210 in terms of the fan total pressure P_{tf} and fan velocity pressure P_{vf} :[71]

$$P_{sf} = P_{tf} - P_{vf} \;; \tag{104}$$

where the net rise in total pressure across the fan, from point 1 to point 2 is given by:

$$P_{tf} = P_{t2} - P_{t1} \;;\; with \tag{105}$$

$$P_{t2} = P_{s2} + P_{v2} \;; \tag{106}$$

$$P_{t1} = P_{s1} + P_{v1} \;; \tag{107}$$

and the net rise in fan velocity pressure:

71 ASHRAE 1992 HVAC Systems and Equipment, S18.5, §Fan and System Pressure Relationships.

$$P_{vf} = P_{v2} - P_{v1} \ . \qquad (108)$$

The Trane fan performance curves are developed in accordance with ASHRAE *Standard* 51 and AMCA *Standard* 210, and various test configurations are described in the standard. As implemented by Trane, the test setup for a particular fan includes the cabinet in which the fan is to be installed and delivered to the customer. The test set up also includes a section of duct installed at the fan cabinet's exit point. The duct's area is similar those of the cabinet's exit port. A pitot tube arrangement, installed three diameters from the exit point, measures both static and velocity pressure relative to dry air conditions at 101.325 kPa and 20°C (1.20 kg/m^3). It is believed that sufficient velocity profile smoothing occurs over the three diameter distance to allow accurate measurements.

Pressures are measured, recorded, and plotted for various restrictions to produce one fan performance curve. The family of curves presented by Trane is developed using the Fan Laws referred to in ASHRAE 1992 Fundamentals, F18.4.[72] In the case of draw through fan units, only the fan, cabinet, and internal fan support structural component along with the exit duct are included in the test setup. It can be noted that for blow through systems, the test configurations include the fan, cabinet, coils and filters used in the specific equipment arrangements offered by Trane. The draw through system described in this model was selected for the superior flow characteristics through the cooling coil over the blow through configuration, refer to §3.1 Selection of Real Building.

For the unique fan-duct configuration specified in the defining standards, the velocity pressure and the static pressure at the fan entrance are both equal to zero, $P_{s1} = P_{v1} = 0$. Therefore, referring to the preceding equations, the fan velocity pressure P_{vf} for the test fan-duct configuration is simply the velocity pressure at the fan outlet P_{v2} (or in ASHRAE terminology $P_{v,o}$)[73] and the total fan pressure rise is equivalent to the total pressure across the fan $P_{tf} = P_{t2}$. Furthermore, the fan static pressure can be expressed as:

$$P_{sf} = P_{s2} - P_{s1} \qquad (109)$$

72 Engineering Division, Trane Company, La Crosse, WI

73 ASHRAE 1993 Fundamentals, F32.4, Equation (18).

Hence, the data presented in the fan curves are equal to the static pressure rise across the fan. It must be noted that this is true only when the fan is operating in the same conditions under which the fan curve data was taken.

This is not necessarily true for a fan installed in a duct system with alternative inlet and outlet duct configurations. However, what makes the fan performance curves useful, in these situations, is that for any arrangement the total pressure rise across the fan ($P_{tf} = P_{t2} - P_{t1}$) will be the same as that for the defining test conditions. Furthermore, if the exit conditions (straight duct, three diameters in length) of the alternative duct arrangement are similar to those in the defining test conditions, then the velocity pressure at the exit point of the alternative arrangement (as defined in the test) will be the same as it was for the defining conditions, ie:

$$P_{tf} = P_{sf} + P_{v,o} \ . \qquad (110)$$

Therefore, in practice, the net total pressure loss calculated for a system can be equated to the total pressure rise across the fan. Then knowing the velocity pressure at the "outlet" of the fan $P_{v,o}$ one can calculate the fan static pressure P_{sf}. The fan static pressure is then used to select the appropriate fan from the fan curves generated by the fan manufacturers.

In the case where an alternative duct arrangement exit conditions are not the same, the resulting "losses" must be "deducted" from the total pressure rise P_{tf}; the net effect can either be positive or negative depending on whether or not the alternative arrangement leading away from the fan cabinet exit point represents more or less air flow resistance then the length of duct used in the defining test configuration *"which smooths the flow of the fan and provides stable, uniform flow conditions at the plane of measurement."*[74] Consequently, the total pressure rise for a fan installed in any system can be determined by summing the fan static pressure with the velocity pressure (calculated at a location selected to ensure a smooth velocity profile) less any losses due to duct conditions from the exit point to the selected location which deviate from the test set-up:

$$P_{tf} = P_{sf} + P_{v,o} - P_{losses} \ ; \qquad (111)$$

where: P_{losses} = total pressure losses for duct conditions deviating from the fan curve test conditions .

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74 ASHRAE 1992 HVAC Systems and Equipment, S18.4, §Fan Testing and Rating.

Return Fan - RF1

The return air is handled by a Trane FAN-IM-4 Centrifugal fan unit, size 24. The model number for the unit contains coded specifications for detailing fabrication and operational information, see Figure 100. The model number for RF1 is:

S/N: C-F-44-A-1-SW-3-CCW-TAU.

Referencing Appendix K, the decoded number reveals that the unit is a centrifugal style 24" fan with a counter clockwise rotation. Additional decoding information is found in Figure 100; the arrangement, width, and height can be obtained from this figure. No other coding information was available at the time this report was written, and field inspections were required to obtain motor size, discharge area size, and all other pertinent information required to for this project. Field inspection revealed a 5hp motor installed on the return air fan. In addition it was determined that the unit is fitted with inlet vanes operated with pneumatic actuators.

As with the supply fan, in this simulation, the return fan will be controlled by a variable speed drive. The manufactures fan curves, performance tables and additional information for the return fan without inlet vanes are provided in Figures 101 and 102. The 44.5 inch wheel is fitted with air foil blades. The outlet area is 13.48 sqft and the blast area is 11,15 sqft. These data are required in the design of the megazone return duct system.

3.3.3.1.1 **Supply and Return Centrifugal Fan Motors**

Specifications for the centrifugal fan motors are provided in Appendix H. The supply fan is operated by a 20 hp, 208 volt ac, 3 phase motor. The return fan is operated by a 5 hp, 208 volt ac, 3 phase motor. Performance curves and RPM Tables for the supply fan without inlet vanes are shown in Figures 83 & 84, and performance curves and RPM Tables for the return fan without inlet vanes in Figures 101 & 102. Performance data is also provided for the supply and return fans fitted inlet vanes, refer to §3.3.3.1 for discussion of these data.

3.3.3.1.2 Housings and Wheels

Dimensions for the Trane Central Station Climate Changer can be found in the Specification and Product Information Catalog CLCH-MN-2A. Excerpts from this Trane Publication reference are provided in Appendix J and a complete explanation of the model coding is provided in §3.3.3.1 Supply and Return Air Handlers. Dimensional data for the fan box, filter box, mixing box, and coil connections are provided in Figures 79 through 82.

3.3.3.1.3 Filtration

The Trane High Capacity filter box consists of replaceable fiber-glass elements mounted at a angles to the flow. The effective surface of the filter set is approximately 88 ft^2, more then twice the surface area, normal to the flow, exhibited by the cooling coil ($\sim$41 ft^2). Refer to Figure 87 for air pressure drop performance data. The values given in this figure are low - between 0.01 and 0.11 in-wg for the expected typical range of air flow rates. These values correspond to the pressure loss across clean elements. The Trane Data Table 79-2 in Figure 87 indicated that dust and dirt particle accumulation results in an estimated increased pressure loss across the filter of 0.2 to 0.5 in-wg, depending on the application. In practice, pressure losses as high as 0.75 - 1.00 in-wg across a typical filter system are not uncommon. Effects due to fouling and aging will vary depending on local conditions including air quality, maintenance schedules, and duty cycle. Values suggested in the Trane catalog cut sheets for air filter pressure drop will be used in the commissioning phase of the testbed development. Later, the value can be changed to reflect fouling and aging.

3.3.3.1.4 Cooling Coil

The coil is a Trane Type D double coil unit - a 24" coil stacked above a 30" coil. It is has four rows transverse to air-flow direction. The tubes are cooper, and the fins are aluminum. Engineering design specifications for the cooling coil are provided in Appendix H, page 279. Although not recorded in this report, a separate model number, in addition to that for the Climate Changer (see §3.3.3.1), is generally used to characterize the cooling coil; Figure 88 provides a key to the cooling coil model number coding. The manufacturers statement of engineering specifications identifies the coiling coil system as being comprised of the following elements:

Table - 18: Trane CLCH Chilled Water Cooling Coil Specifications (Refer to Figure 65)

Coil	Coil Type	Size		Tubes		Fins		Face Area [sqft]
		Width	Length	Rows	Mat'l	fins/ft	Mat'l	
1	D	24"	108"	4	Copper	144	Aluminum	28.9
2	D	30"	108"	4	Copper	144	Aluminum	36.1

The Climate Changer Model Number referred to in §3.3.3.1 corroborates these data. Figure 89 describes the various configurations for a Type D coil and gives the dimensions for the standard copper tubing indicated in §3.3.3.1 per model number digit 25: 5/8 inch outside diameter - with a 0.020 inch wall thickness.[75] The coil fin series specified by digit number 24 in the model number is *18, 58 aluminum*. In conversation with Trane representatives, this translates into a fin spacing equal to 144 fins per foot and a fin thickness of 0.085 inches.[76] Referring to Figure 90 a 4 row, Type D coil with outlets on the same side is shown in pictorial. Figure 91 shows the dimensions for the 30 inch and 24 inch Type D coils.

Figure 92 shows the results of the Trane CDS simulation for air-side and water-side flows.[77] The simulation results are based the original engineering design specifications for Building E51 as listed in Appendix H, although the heat exchanger tube thickness was changed from 0.020 to 0.024 inches, as discussed in the preceding paragraph. This simulation provides air and water side pressure drops at design flow rates. These results were used in the development and verification of the HVACSIM+ cooling coil model component parameters.

3.3.3.1.5 Cooling Coil Control Valve

The cooling coil water flow is controlled by a Powers VF 591-SD 2" IPS Single Seat, Tight Closing, Bronze Body Valve. It is operated by a Powers 8" Diameter Flowrite Pneumatic Actuator. The

75 The 0.020 inch wall thickness specified is what was provided for the unit installed in Building E51. The Trane simulation software **CDS Chilled Water Coil Selection Program Ver.12.12**, however, does not recognize this value as a valid selection, offering instead 0.024 inches for copper tubing and others for brass tubing. The program was required for independent corroboration of air pressure water pressure drops across the coil. As a result the wall thickness selected for use in the HVACSIM simulation was 0.024 inches.

76 Bob Alexy & Chris Bogart, Trane Company, Wakefield, Massachusetts.

77 Trane, CDS Chilled Water Coil Selection Program, ver: 12.12.

actuator description and model number is included in Table 19. Manufacturer specifications and catalog cut sheets are provided in Figures 93 through 98. The flow coefficient, Cv, for the Powers valve is 38, (refer to Equation 114, Page 134 for definition of Cv).

A Honeywell Direct Coupled Actuator Model ML6161 is used in place of the pneumatic actuator for the HVACSIM+ simulation model. Manufacturers specifications for this piece of equipment are provided in Figure 99.

Table - 19: Powers Pneumatic Actuator Specification, E51 Mechanical Room

Designated Use	Model Number	Description
Exhaust	332-2785	Powers IU2 Vortex Damper Motor with 4" Diameter Diaphragm
Return	332-2785	Powers IU2 Vortex Damper Motor with 4" Diameter Diaphragm
Minimum Air	332-2785	Powers IU2 Vortex Damper Motor with 4" Diameter Diaphragm
Economizer	332-2785	Powers IU2 Vortex Damper Motor with 4" Diameter Diaphragm
Supply Inlet Vane	332-2799	Powers IU2 Vortex Damper Motor with 6" Diameter Diaphragm
Return Inlet Vane	332-2799	Powers IU2 Vortex Damper Motor with 6" Diameter Diaphragm
Cooling Coil	579-7879	Powers 1TI0 2" Two Way Valve w/ 8" Diameter Diaphragm

3.3.3.2 Mixing Box - Dampers and Actuators

The mixing box is fitted with "opposed" blade Arrow, Series 1770 steel dampers. Manufacturer specifications and catalog cut sheets providing graphic illustration of the damper blades and housing along with performance curves and leakage rates are presented in Figures 103 through 104. Sizes of the minimum air, economizer and return dampers are given in Figure 61. Note that the exhaust air damper is identical to the return air damper.

Powers pneumatic actuators are used to operate the exhaust, return, minimum air, and economizer dampers, as well as for the supply and return inlet vanes and cooling water supply valve, and are cataloged in Table 19. The pneumatic actuators are to be replaced with the DDC motor driven actuators for the HVACSIM+ simulation, and three possible selection methods are proposed in this section for this purpose. First, for development purposes, a set of fictitious DDC actuators can be designed on the basis of the results of the time and dimensional study presented in Table 20. The dynamic response of the model, under these conditions, would not be realistic. However, the intent would be to mimic the behavior of the pneumatic actuators, providing a set of "reasonable" parameters until suitable DDC replacements have been identified.

Table - 20: Powers Pneumatic Actuator Dimension and Time Study, E51 Mechanical Room

Designated Use	Model Number	Actuator Lever Length [in]	Actuator Stroke Length [in]	Actuate to Open		Actuate to Close	
				Time [sec]	Delay [sec]	Time [sec]	Delay [sec]
Exhaust	332-2785	2 1/8	3	4	1	5	2
Return	332-2785	2 1/8	3	4	1	5	2
Minimum Air	332-2785	2 1/8	3 1/16	4	1	4	1
Economizer	332-2785	2 1/8	3 7/8	5	1	5	2
Supply Inlet Vane	332-2799	3 5/8	4 1/8	9	1	12	2
Return Inlet Vane	332-2799	2 3/4	3 3/4	9	1	10	4
Cooling Coil VV	579-7879	0	1	2	1	6	3

More realistic behavior can be derived by using the parameters for the DDC actuators installed in the sample HVACSIM+ simulation (ACREF2) cited in Appendix AA can be used. ACREF2 is a functioning explicit air flow simulation for a system having similar characteristics to the prototype building used for this simulation. At the time this report was written, the manufacturer and model for the actuators specified in the sample simulation was not available. Introduction of the DDC actuators from ACREF2 into this simulation can be done in the development phase in place of the fictitious actuators, or following the development phase in anticipation of specifying alternative DDC units. A third option would be to identify the specifications for a commercially available set of DDC actuators which would actually be used to replace the pneumatic units installed in E51. This is the ideal condition, and at the time this report was written, efforts were in progress to implement this option.

3.3.3.3 Intake & Exhaust Grills and Louvers

The intake and exhaust openings into and out of the building are protected by the bird screen and louvre arrangement shown in Appendix M. Figure 106 in the appendix shows the assembly in detail.

Precise information for the grill installed was not available at the time this report was written, however, an approximate facsimile was found in a catalog for Airolite products. Figures 107 and 108 provide pressure drop and water penetration data for the Airolite 638-C-100 Stationary Blade Louver; blade geometry and spacing details for the Airolite Louvre are very close to those of the installed grills.

3.3.3.4 Zone Components

The six zone air distribution system, outlined in Figure 64, provides the structure for the redesign of the zone components including: (1) VAV Terminal Boxes; (2) VAV Terminal Box Reheat Coils; (3) Reheat Coil Control Valves. In addition to those components directly related to the design air flow rates, VAV damper actuators and reheat water flow control valve actuators were changed from pneumatic function to all DDC, electric motor driven types. While many manufactures provide equipment which is appropriate for this project, specifications for prototypical electronic actuators were chosen from the actuators in use in another MIT building. Building E18 has been used by members of this research project in other projects related to the control of HVAC system, and the familiarity and convenience of the readily available experience and data prevailed.

The perimeter heating system in the original design was used as guide for establishing the parameters for the HVACSIM+ type which will be used for this function. It is intended to eventually design and implement a water side model for perimeter heating system, however, until this is done an explicit system with maximums, minimums, and some lag will be used to input the heat required from the perimeter heating system.

3.3.3.4.1 VAV Boxes & Zone Diffusers/Louvers

VAV Boxes

VAV terminal box design was based on the results of the re-design of the supply and return duct system to accommodate the six megazone simplification scheme. For each individual megazone, the data in Table 21 represents a baseline for the design flow of the conditioned air supply and exhaust air return, together with appropriately sized VAV terminal box sizes. These data represent the sum total of the design flows shown on the supply and return duct drawings presented in Figures 26 - 33 and recorded in Figures 109 - 112.

The engineering design supply and return flow rates shown at the bottom of Table 21 reflect a 15% reduction for the supply air and a 9% reduction for the return air. Design flow rate calculations are based on maximum anticipated loads in each individual area of the building. In practice, there will never be a time in the building's operation when all of the anticipated loads will act in concert, and it would be extravagant to size a system on this basis. Hence, the introduction of diversity factors or peak loading calculations to reflect realistic peak loading. Peak load calculations take into consideration the buildings characteristics, configuration, outdoor design conditions, indoor design conditions, and operating schedules all in relation dates and times selected to reflect maximum anticipated conditions.[78] It is not known what dates and times were selected in calculating the peak load for E51.

Table - 21: Megazone VAV Design Volumetric Flow Rate Summary

Megazone Designation	Conditioned Area [ft^2]	Maximum Demand Supply Flow [cfm]	Titus Single Duct Terminal Box Size [in x in]	Maximum Demand Return Flow [cfm]
I	2,369	2,060	16 dia	1,951
II	607	340	7 dia	310
III	6,799	10,772	48 x 16	8,880
IV	1,510	1,990	16 dia	1,710
V	4,666	5,890	24 x 16	5,590
VI	188	760	10 dia	720
Totals	16,139	21,812	-------	19,161
Flows per Engineering Design Specifications (ref: Appendix H)		18,590	-------	17,480

Titus single duct VAV terminal boxes were selected for the megazone model. Performance data, design features, dimensions for the Titus boxes are included in Figures 117 - 119. Selection of the box for each zone was based on flow rates, duct size and noise. Duct sizes were chosen to reflect decisions based engineering and design considerations encountered in the megazone design sequence, see

78 1993 ASHRAE Handbook -Fundamentals, F26.4.

§3.3.3.5 for details on the design process. It can be noted that Titus VAV box sizes 16 inch and under have round entry and exit openings, and the large 24 x 16 inch VAV box has rectangular openings. Hence, square duct work and round duct work were used as a matter of convenience, where-ever indicated.

Flow requirements for all megazones with the exception of Megazone III were met by stock Titus equipment. In the case of Megazone III, flow requirements exceeded the specifications of the largest stock box by 100%. As a consequence, two possible solutions were proposed: (1) to use two 24" x 16" boxes in parallel; or (2) to use the pressure drop and flow characteristics for the two 24" x 16" boxes in parallel to characterize the behavior of an ideal 48" x 16" box. The second solution was chosen. Two factors contributed heavily to this decision. First, due to complications in modeling the parallel system with currently available HVACSIM+ components use of a single large box was almost mandatory. Second, the pressure drop for a 24 x 16 box when subjected to half the design flow of Megazone III will be the same as that for a box that has twice the cross section carrying twice the flow. The ability to scale the box sizes simplified the substitution, eliminating the need to identify additional equipment manufactures.

Table - 22: Megazone VAV Single Duct Terminal Box Pressure Difference (ref: Figure 196)

Megazone Designation	Peak Demand Supply Flow [cfm]	Titus Single Duct Terminal Box Size [in x in]	Titus Single Duct Terminal Box Pressure Difference	
			Static [in-wg]	Total [in-wg]
I	1,773	16 dia	0.154	0.234
II	280	7 dia	0.082	0.141
III	9,180	48 x 16	0.304	0.435
IV	1,697	16 dia	0.141	0.214
V	5,020	24 x 16	0.364	0.521
VI	640	10 dia	0.144	0.214
Totals	18,590	-------		

Values for the minimum static pressure difference and the corresponding total pressure difference for the Titus boxes selected for the megazone design are presented in Table 22. The values recorded in the table correspond to a wide open damper or attenuator with a single row reheat coil installed in the terminal box. Since the exact flow rates in the design fell somewhere in between the values presented in the Titus catalog, a linear interpolation was used to estimate the value within the smallest possible interval. These calculations are documented in Figure 196.

Diffuser and Louvers

Table 23 shows the average design flow velocities for the original thirty-four zone system. The individual for the each of the diffusers and collectors in the corresponding megazones were averaged together to obtain the values presented in the table. These values were then used in support of the selection of return and supply grill and louvre dimensions in the megazone design.

Table - 23: Average Megazone Flow Velocity Based on 34 Zone Configuration (*)

Megazone Designation	Supply Flow Velocities [ft/min]		Return Flow Velocities [ft/min]	
	Diffuser	Duct	Collector	Duct
I	412	541	390	505
II	320	429	413	349
III	422	616	376	476
IV	393	547	428	517
V	396	540	399	594
VI	507	684	461	741
Average	408	560	411	530

(*) Refer to Figures 109 - 112: VAV Flow Tally - 34 Zone Configuration for origin of velocities shown in this table. The velocities cited are averages over the individual zone elements in the 34 zone configuration common to each of the megazones. The duct velocities are for the duct sections nearest the diffusers and collectors.

The catalog cut sheets for these components are shown in Figures 125 - 129. A standard square/rectangular style diffuser type was selected. Table 24 summarizes the megazone supply diffuser specifications. The noise criteria rating (NC) used as the basis for selection of diffuser face velocity. The rating was chosen to be below the maximum level specified in the range of typical values recommended by ASHRAE,[79] and also to be consistent with the velocities specified in the original thirty-four zone configuration, see Table 23. A deeper understanding, leading to a refinement of this

79 ASHRAE 1991 Applications Handbook, A6.3.

criteria, can be obtained in Chapter 42 of the 1991 ASHRAE Applications Handbook, (refer to Figures 120 - 124 for detailed sound application data for Titus VAV boxes).

Table - 24: VAV Room Supply Diffuser Specification Summary (ref: Figures 125 - 129)

Megazone Designation	Nominal Duct Size Diffuser [in x in]	Design Flow Rate [cfm]	Titus Catalog Page Number	Neck Velocity [ft/min]	Total Pressure Drop [in.wg]	NC Value
I	21 x 24	1,773	B108	500	0.117	27
II	9 x 9	280	B98	500	0.117	19
III	30 x 96	9,181	B110	500	0.117	31
IV	21 x 24	1,696	B108	500	0.117	27
V	30 x 48	5,020	B110	500	0.117	31
VI	12 x 15	640	B103	500	0.168	29

The return grill specifications are shown in Table 25. Selection for the grill sizes and specifications was based on design flow rates and ASHRAE sound criteria. By adjusting the grill size to keep face velocities at or below approximately 500 ft/min, it was possible to make selections for grills in Zones I, II, IV, and VI with appropriate NC levels. In the case of Zone II, the NC rating was below 10. No

Table - 25: VAV Room Return Grill Specification Summary

Megazone Designation	Nominal Duct Size Diffuser [in x in]	Nominal Duct Size Area [ft^2]	Design Flow Rate [cfm]	Titus Catalog Page Number	Neck Velocity [ft/min]	Total Pressure Drop [in.wg]	NC Value
I	22 x 22	3.36	1,663	E13	500	0.046	18
II	9 x 9	0.56	266	E13	500	0.046	nr
III	48 x 48	16.00	7,568	E13	500	0.046	----
IV	20 x 20	2.78	1,457	E13	500	0.046	20
V	40 x 40	11.10	4,764	E13	500	0.046	----
VI	14 x 14	1.36	613	E13	500	0.046	11

stock grills were found in the catalog with a core area larger then 6.25 ft^2. However, since the total pressure depends only on the velocity at this point in the system, it is reasonable to assume that the total pressure lose through grills of similar design for similar flow velocities would be similar to the loses reported in the tables for smaller grills.

Recall the total pressure is given by:

$$P_t = P_s + P_v \tag{112}$$

where

P_s = the static pressure, defined as the pressure equally exerted in all directions at the point of interest, [in.wg];

and the P_v is called the velocity pressure, and is calculated at the point of interest by:[80]

$$P_v = \rho \left(\frac{V}{1097}\right)^2 \tag{113}$$

where: ρ = density, [lbm/ft^3]

V = flow velocity, [ft/min].

3.3.3.4.2 Reheat Coils

A summary of the Titus hot water coil reheat elements chosen is presented in Table 26. The physical and engineering characteristics for the Titus single duct terminal box reheat coils are provided in Figures 130 through 137. The coils chosen for zones I, II, and IV are described as being single row / single circuit, and the coils chosen for Zones III, V, and VI are described as being single row / multi-circuit. The single-circuit coils have one continuous loop from inlet to outlet, making a serpentine trajectory across the face of the heat exchanger. The multi-circuit coils have, in the case of the coils chosen for this project, two loops essentially running parallel to each other across the heat exchanger's face, (refer to the Titus shop drawing presented in Figure 135, Water Coil: 1 Row - 2 Circuit Size 10). The rated capacity of the coil exceeds the design requirement in all zones. The basis for choosing the VAV box size is found in the megazone supply duct design philosophy, (see §3.3.3.5 Air Distribution

80 Patrick J. Brooks, "Duct Design Fundamentals," ASHRAE Journal , (April 1995), p.73.

Duct Design). Control valves with relatively small flow coefficients were chosen to compensate for the high capacity coils. The high authority of the valves will allow finer water flow modulation below the 1 gpm level, (refer to §3.3.3.4.3).

Table - 26: VAV Reheat Coil Output Summary

Megazone Designation	VAV Box Size [in x in]	Air-Side Design Flow Rate [cfm]	Design Reheat Coil Heat Output [Btuh]	Water-Side Flow Rate [gpm]	Approx. Rated Capacity [Btuh]
I	16	1,773	19,100	1.0	33,000
II	7	280	1,700	1.0	11,000
III	48 x 16	9,181	64,100	1.0	94,000
IV	16	1,696	15,700	1.0	33,000
V	24 x 16	5,020	32,900	1.0	47,000
VI	10	640	6,600	1.0	16,000
Totals		18,590	140,100		

3.3.3.4.3 Reheat Coil Control Valves

Powers VE VMP electronic valves were selected for use in the megazone VAV reheat control system. Catalog cut sheets provided by Landis & Gyr are shown in Appendix N, Figures 139 and 140. Valves ranging in sizes from 1/2" to 3/4" are offered with varying capacities. Table 27 summarizes the VAV reheat coil control valves specifications. Valve selection was based on the original design water side flow rates taken from Figures 113 and 114. Using Equation 114 and an assumed pressure drop of 5 psi across the wide open valve, values for the desired valve flow coefficient were calculated. These values were used to select valves with flow characteristics as close as possible to the ones indicated in the calculations.

The basic formulas for the flow coefficients Cv and Kv, defining the relationship between the pressure drop across the valve and the flow through the valve, are given in Equations 114 and 115.[81] The

81 Eur. Ing. R. C. Whitehouse, The Valve and Actuator User's Manual, (London: Mechanical Engineering Publications Limited, 1993). p. 121-123.

coefficient Cv is used primarily in the United States and United Kingdom. The coefficient Kv is also used in the UK and other parts of Europe. They differ by a factor of approximately 0.86.

Table - 27: VAV Reheat Coil Control Valve Summary

Mega-zone Number	Design Reheat Coil Heat Output [Btuh]	Water Side Design Flow Rate, Reheat Coil [gpm]	Design Value for Cv	Powers Control Valve Size [in]	Powers Control Valve		Powers Control Valve Part Number
					Cv	Kv	
I	19,200	2.1	0.94	1/2"	0.74	0.63	VMP42.11(2)
II	1,700	0.2	0.09	1/2"	0.29	0.25	VMP42.09(2)
III	64,100	6.8	3.04	3/4"	2.92	2.50	VMP42.14(2)
IV	15,700	1.8	0.80	1/2"	0.74	0.63	VMP42.11(2)
V	32,900	3.6	1.61	3/4"	1.87	1.60	VMP42.13(2)
VI	6,600	0.7	0.31	1/2"	0.47	0.40	VMP42.10(2)
Total	140,100						

The basic formula for Cv is:

$$C_v = Q \frac{\sqrt{G}}{\sqrt{(\Delta P)}} \tag{114}$$

where: Q = flow rate in US gal/min;
G = specific gravity of liquid (SG water = 1)
ΔP = pressure drop across valve in lbf/in^2;

and the basic formula for Kv is:

$$K_v = Q \frac{\sqrt{G}}{\sqrt{(\Delta P)}} \tag{115}$$

where: Q = flow rate in m^3/h;
G = specific gravity of liquid (SG water = 1)
ΔP = pressure drop across valve in bars.

Both of the equations 114 and 115 assume that the flow is neither viscous, cavitating, nor flashing.

3.3.3.4.4 Perimeter Heating

Perimeter heating is by forced hot water through a mixture of natural and forced convection units comprised of fin tube radiation or wall mounted. The design heat output for the perimeter heating system is shown in Figures 141, 142. The tables in these figures specify the type, size and output rating for each unit in every room. The list is sorted to show how the outputs add up in each of the six megazones. In addition, this list shows how the heat is distributed over each floor level. A total of

Table - 28: Perimeter Heat Tally Summary (ref: Figure 7)

Megazone Designation	Conditioned Area [ft^2]	Design Perimeter Heat Output [Btuh]
I	2,369	19,200
II	607	4,800
III	6,799	97,900
IV	1,510	23,600
V	4,666	56,900
VI	188	10,000
Totals	16,139	212,400

212,400 Btuh is specified for the 16,139 sqft area occupied by the selected portion of Building E51. Individual output capacities for the fin tube radiation vary from 700 to 1,200 Btuh/ft. Hot water convector capacities range from 1,600 to 9,600 Btuh. A summary of the perimeter heat requirements is shown in Table 7. Referring to Appendix H Building E51 Mechanical System Design Specifications, the column denoted 'Unit ID' names the unit specified in the locations indicated in the Supply and Return Duct System Drawings, Appendix D.

It has been proposed that an optional configuration for the perimeter heating system may be comprised of electric resistive elements rated at the same output as the forced hot water system. Identification and Parameterization of the HVACSIM+ types to model both the electric and forced hot water perimeter heating systems is by LUT.

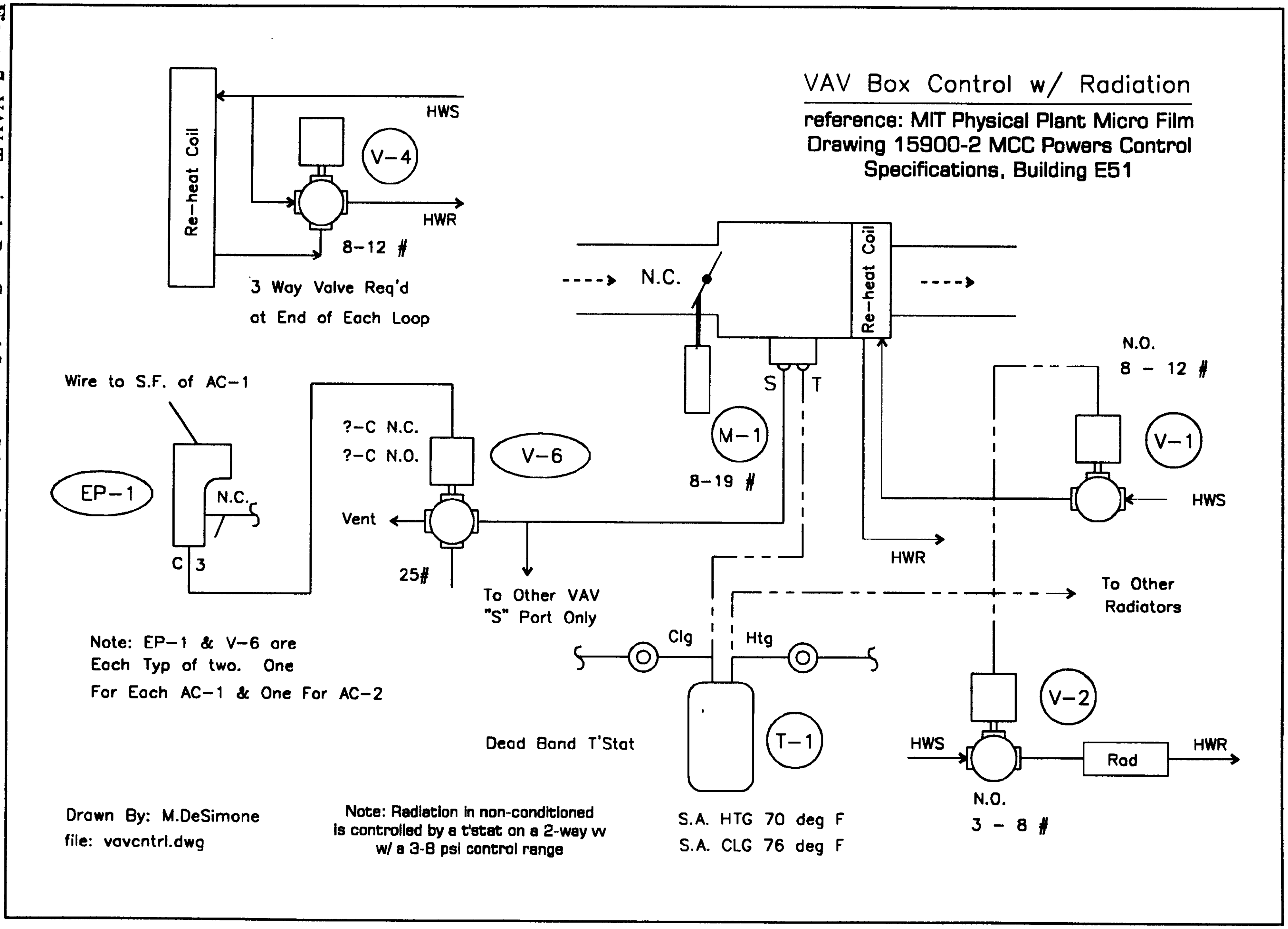

Figure 7: VAV Terminal Box Control System - Schematic, Pneumatic Controls

3.3.3.4.5 Room Temperature Control System

The room temperature control system installed in the real building is pneumatically operated. A schematic of the system is provided in Figure 7. Quoted from the mechanical specifications for Building E51, provided by MCC Powers, the control sequence is described as follows:

VAV Box Control
On a rise in space temperature, the space temperature thermostat will modulate the reheat coil valve closed. On a continued rise in temperature, the space thermostat will modulate the damper open.

VAV Box Control with Radiation
On a rise in space temperature, the space thermostat will modulate the radiation valves closed. On a continued rise in temperature, the space thermostat will modulate the reheat coil valve closed. On a still further rise in temperature, the space thermostat will modulate the volume damper open.

Radiation Control
On a rise in space temperature, the space thermostat will modulate the radiation valves closed.

3.3.3.5 Air Distribution Duct Design

The design of the supply and return air distribution system for the megazone configuration was based on the known flow requirements for each zone, the total static pressure drop across the two systems identified in the engineering design specifications, the supply air design static pressure set point, and some key industry accepted design standards. The need to match the thermal behavior of the megazone system with that of the real building imposed additional constraints. This was addressed by matching the surface area of the duct work with the effective surface area of the included zones.

Several design methods were considered: (1) equal friction; (2) static regain; (3) constant velocity; and (4) velocity reduction.[82,83,84] There are no economic or geometric constraints to optimize the design for

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82 Sauer et al., Principles of Heating Ventilating and Air Conditioning, §9.1.9 Design Methods.

83 1993 ASHRAE Handbook - Fundamentals (SI), Chapter 32, F32.16 Duct Design Methods.

84 Patrick J. Brooks, "Duct Design Fundamentals," ASHRAE Journal , (April 1995), p.73.

smallest possible sizes. There are no constraints to maintain constant velocity (as in for example a suspended particle exhaust system). There is a reason to design a balanced system, and under normal conditions the static regain method would be the most logical choice. However, since there are few geometric constraints the task to design a balanced system is simply to make sure that the pressure drop through all the paths are themselves equivalent to the pressure drop along the critical path without violating the boundary conditions.

The velocity reduction method allowed direct and immediate application of the known engineering specifications (or boundary conditions) with only the provision being that the flow rates and pressures had to meet certain minimums at specific points, typically at the reheat coil, diffusers and grills. Hence, the velocity reduction method provided the most direct means to meet design criteria and at the same time develop a system with realistic, tangible characteristics.

[For the supply air system] *This method consists of selecting the velocity at the fan discharge, and designing for progressively lower velocities in the main duct at each junction or branch duct .... The return air ductwork is sized similarly, starting with the highest velocity at the fan suction and decreasing progressively in the direction of the return air intakes. With the duct sized and the fittings known, the total pressure losses can be calculated, the pressure gradients plotted, and the maximum pressure loss or critical path of the system established.*[85]

The dimensions of the supply and return duct systems in the mechanical room portion of the real building were preserved in the megazone design. This feature, in conjunction with the real building engineering design specifications for supply and return air flow rates, established the velocity in both ducts at the mechanical room/main building interface. Similarly, overall pressure losses for both the supply and return systems were fixed by the need to match the operating points of the megazone design with those of the supply and return fans installed in the real building.

With the exception of duct surface area, there were no restrictions on the physical dimensions, cross sectional size or shape, or physical configuration of the megazone system. The surface area of each branch was designed to represent an effective surface calculated using the dimensions of the ductwork in the real building and the design flows for each of the individual supply and return grills and louvers.

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85 Sauer et al., Page 9.9.

Table - 29: Effective Surface Area Summary for Megazone Duct Systems (ref: Figure 146)

Megazone Designation			Total Effective Surface Area [ft2]	Required Megazone Duct Length	
				[ft2/ft]	[ft]
I	Supply	16" dia	215	4.19	51
	Return	16" dia	168	4.19	40
II	Supply	7" dia	75	1.83	41
	Return	8" dia	18	2.09	8
III	Supply	48" x 16"	1,369	10.67	128
	Return	26" x 30"	993	9.33	106
IV	Supply	16" dia	519	4.19	124
	Return	16" dia	515	4.19	123
V	Supply	24" x 16"	931	6.67	140
	Return	26" x 20"	450	7.67	59
VI	Supply	10" dia	266	2.62	102
	Return	11" dia	199	2.88	69

The lengths of duct required in each megazone to produce the necessary surface area were determined on the basis of the total effective surface area and branch duct diameters selected for the individual megazones. The effective surface areas and resulting duct lengths are summarized in Table 29. The total effective area for each duct leg was calculated as the sum of all fractional contributions from each of the ducts that carry any quantity of air destined for the associated zone. In many instances the subject ductwork passes through multiple megazones in route. In addition, the subject ductwork carries air destined for more than one megazone, and since the megazones were distributed over multiple floors it was necessary to access contributions on a zone by zone - floor by floor basis.

Effective Surface Areas for Supply and Return Duct Systems

The design flow designated for each return grill or supply louver in the real building passes through ductwork distributed across any number of zones. The ductwork distribution may or may not be shared with other flows, intermingling a specific flow with flow designated for various other destinations serviced by the common ductwork.[86] Taking the sum of the actual surface areas attributed to each design flow as the surface area of the ductwork for the aggregated flows in the megazone system would have produced inaccurate, oversized representations, since only fractions of the flows in the aggregated flows actually come in contact with any particular portion of the actual duct surface areas in the real building. As a consequence, a weighted area was calculated based on the proportion of the individual design flows for each grill and louvre to the total, aggregated flow for the associated megazone. The resulting general expression for the total effective area A_i for either the supply or return duct systems in zone i is expressed in the following equation:

$$A_i = \sum_{l=0}^{\Lambda} \sum_{z=1}^{\Omega} \sum_{q=1}^{\Phi} \frac{\sum_{k=1}^{K} Q_{i,l,z,q,k}}{\sum_{\beta=1}^{B} Q_{i,l,\beta}} \frac{\sum_{k=1}^{K} Q_{i,l,z,q,k}}{\sum_{k=1}^{K} Q_{i,l,z,q,k} + \sum_{\alpha=1}^{A} Q_{i,l,z,q,\alpha}} \Pi_q \, \nu_q \; ; \qquad (116)$$

where: Λ = the number of levels l over which zone i may be distributed;

Ω = the number of zones z on level l through which the duct system for zone i may pass;

Φ = the total number of individually identifiably and distinct duct sections in zone z on level l through which fractional portions of air ascribed to zone i may pass;

$Q_{i,l,z,q,k}$ = the individual design flows contributing to the total flow associated with zone i and which is ascribed to the duct section q in zone z and on level l;

K = the total number of design flows associated with zone i contributing to the total flow which can be ascribed to the particular section q through which the flow is passing in zone z and on level l;

$Q_{i,l,\beta}$ = the individual design flows contributing to the total flow passing through all ductwork on level l associated with either the supply or return duct system of zone i;

B = the total number of grills or louvers on level l associated with either the supply or return duct in zone i;

$Q_{i,l,z,q,\alpha}$ = design flow at the grill or louver for each contribution to the total flow passing through duct section q in zone z and on level l but which is not associated with zone i;

A = the total number of contributions to the flow in duct section q in zone z and on level l not associated with zone i;

Π_q = the perimeter measurement of duct section q;

ν_q = the length of duct section q.

86 The design supply and return air flow rates are specified in Figures 26 - 33.

The effective surface area was calculated by first finding the actual duct surface area attributed to each individual design flow. The actual surface area attributed to a particular design flow for a given duct section in the real building was considered to be proportional to the ratio of the design flow to the total flow passing through the particular duct section. The effective surface area for each individual design flow was then considered to be proportional to the ratio of the individual design flow to the total flow on the relevant level attributed to the associated megazone. The sum of the individual contributions from each design flow was used as the total effective area attributed to the entire flow for each megazone. The effective surface areas attributed to each zone are tabulated in Figure 146. The table shows a breakdown of the contribution from each portion of the supply and return systems, level by level and zone by zone. A summary of the calculations for the actual surface, detailing the weights and proportions assigned to obtain the effective areas is provided in the spreadsheet files area_sup.wq2 and area_rtn.wq2 in Appendix ?.

Design Velocities

Benchmarks for typical design velocities were obtained from several sources: (1) Table 8 and Figure 11 in Chapter 32, 1993 ASHRAE Fundamentals; (2) discussions with industry professionals;[87] (3) the flow rate and flow velocity analysis performed on the E51 HVAC system, (see Tables 22 & 23). Fittings were chosen from those listed in the Fitting Loss Coefficient Selection Guide, 1993 ASHRAE Fundamentals, Chapter 32, pages F32.27 - F32.52. Typical ranges for flow velocity are presented in Table 30. These values served only as a guide to begin the design procedure. As the design process developed, the actual velocities selected were dictated by the design specifications of manufactures equipment, noise criteria limitations, available duct and fitting sizes, and the requirement that velocity was to decrease or increase.

Table - 30: Design Velocity Ranges for HVAC Components (ref: ASHRAE Fundamentals §32)

Duct Element	Suggested Design Range [fpm]
Intake Louvers	300 - 600
Exhaust Louvers	400 - 700
Straight Duct	500 - 1800
Heating Coils	200 - 1500

87 Bob Leber, Cosentini Associates, Cambridge, Massachusetts, April 1995.

3.3.3.5.1 Supply Duct System

The velocity reduction method served as the basis for the design of the megazone supply duct system depicted in Figure 150, refer to §3.3.3.5 for discussion of design philosophy strategy. Elements of the supply system located in the mechanical room are shown in Figures 148 and 149. The order of appearance for the individual megazones along the path of the main duct was designed to place the zones requiring the highest flow rates nearest the supply fan outlet. The sizes of the ducts comprising each branch were selected to impose flow velocities which fell within the suggested flow velocity ranges cited in Table 30. Additional considerations for duct size were imposed by available Titus VAV terminal box sizes, and the output of the accompanying hot water reheat coil selections.

Each megazone branch consists of six basic elements: (1) a wye fitting to divert flow from the main trunk into the megazone branch; (2) a length of straight ductwork leading away from the wye fitting interspersed with; (3) a selection of fittings and bends; (4) a VAV box leading into a; (5) divergence providing a transition into; (6) a louver located somewhere inside the megazone.

The design process was devised to produce a nearly balanced system. The static pressure set point for the real building provided the necessary design point, and the total pressure loss for each branch from the static pressure sensor out to the exit point inside the individual zones was adjusted to equal the total pressure at the sensor. Selection of the wye's, VAV terminal boxes, diverging adapters, and louvers and straight duct lengths imposed a fixed series of losses in the system. Balance was accomplished by adjusting the number of fittings proposed to be installed in the branches according to the value of the fitting loss coefficient of the fitting selected and the amount of loss that was necessary to create. Some effort was made to select fittings for which pressure loss coefficients had been determined as in the ASHRAE Fitting Loss Coefficient tables.[88] However, this was not considered to be an essential feature of the design and individual coefficients were adjusted to produce whole values for numbers fittings required.

Balance was achieved in each branch by Equation 117. The values corresponding to each zone which satisfy this equation are summarized in Table 31.

$$P_T = l_{f,i}\, L_i + P_i + P_{mr} + \sum_q (n_q\, C_{l,i,q})\, P_{v,i,q} \tag{117}$$

88 1989 ASHRAE Handbook - Fundamentals, F32.27 - F32.52

where: P_T = the total pressure required at the static pressure set point [89] [in-wg]

$l_{f,i}$ = the friction loss per 100 feet of duct based on flow rate [90] [in-wg/ft]

L_i = the length of straight duct in zone i [ft]

P_i = total pressure loss imposed by fixed elements in zone i including wye, VAV box, divergence, and louver [in-wg]

P_{mr} = total pressure loss as a result of duct work from static pressure sensor to exit from mechanical room [91] [in-wg]

q = fitting types required to balance branch for zone i ------

n_q = the number of type q fittings required to balance branch for zone i ------

$C_{l,i,q}$ = fitting loss coefficient for fitting q selected to balance branch ------

$P_{v,i,q}$ = velocity pressure for flow passing through balancing fittings q [92] [in-wg]

Table - 31: Megazone Supply Duct Design Details (ref: Figures 144 & 151)

Zone	P_T	$l_{f,i}$	L_i	P_i	P_{mr}	n_q	$C_{l,i,q}$	$P_{v,i,q}$
I	1.411	0.00140	51	0.465	0.129	6	1.23	0.101
II	1.406	0.00255	41	0.382	0.129	3	1.25	0.069
	-----	-----	-----	-----	-----	1	7.70	0.069
III	1.410	0.00150	128	0.681	0.129	4	0.55	0.185
IV	1.390	0.00130	124	0.465	0.129	6	1.15	0.092
V	1.394	0.00200	140	0.786	0.129	2	0.45	0.221
VI	1.401	0.00205	102	0.534	0.129	5	1.23	0.086

The total pressure at the static pressure set point varies slightly from zone to zone. It is not possible to match the exact pressure loss requirements necessary to perfectly balance a branch using commercially

89 This value must be very close to the design value based on the Building E51 Engineering Design Specifications - MIT Physical Plant. Variances from the design value are in practice the result of manufacturing constraints and the impracticality of building an precisely balanced system with factory ready components. Precise balance is typically achieved in the field using balancing dampers or depending on the VAV boxes to make the necessary adjustment.

90 SMACNA HVAC Duct Design Calculator

91 reference Figure 145

92 based on Equation 113

available, standard duct fittings. In a real system, the VAV box dampers will reposition from the theoretical, ideal design position compensating for these irregularities.

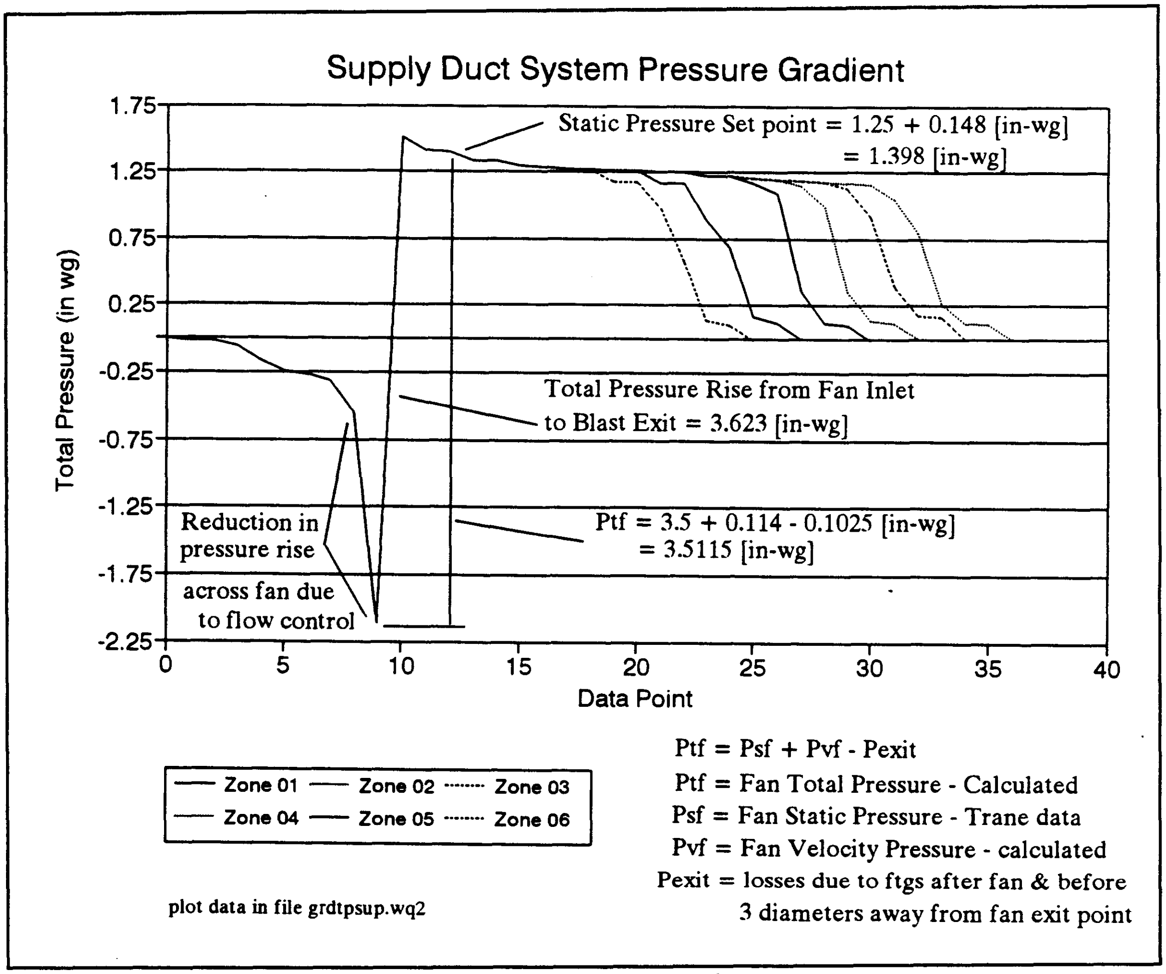

Figure 8: Megazone Supply Air System Total Pressure Grade Line

The supply duct system pressure grade line is shown in Figure 8 (refer to Figure 153 for plot data). Total pressure at the supply fan static pressure set point is 1.398 in-wg, and the design fan total pressure is specified to be 3.614 in-wg. The installed system varies from the conditions for which the fan performance curve is intended.[93] Referring to Figure 148, a 90 deg reducing bend plus a small offset combines to produce a pressure loss of approximately 0.1025 in-wg. This amount, subtracted from the fan total pressure, gives the total pressure available at the static pressure sensor location. Subtracting the total pressure rise across the fan, 3.5115 in-wg, from the total pressure at the static pressure sensor location fixes the total pressure value at the fan inlet.

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93 Fans in Air Conditioning (La Crosse, Wisconsin: The Trane Company, 1982), p. 4.

The pressure losses for the elements in front of the fan, back out to the fresh air intake are shown in Figure 145. The 0.549 in-wg total pressure loss is calculated up to a point just in front of the fan cabinet. Not included in this number is the loss due to the inlet vanes. The operating point for the fan is with the inlet vanes open to approximately 65%. The loss across the partially open vanes is represented in the grade line plot as the difference between the inlet total pressure and the total pressure at the point just in front of the fan cabinet.

3.3.3.5.2 Return Duct System

The velocity reduction method served as the basis for the design of the megazone return duct system depicted in Figure 158, refer to §3.3.3.5 for discussion of design philosophy strategy. Elements of the return system located in the mechanical room are shown in Figure 157. The order of appearance for the individual megazones along the path of the main duct was designed to place the zones requiring the highest flow rates nearest the return fan inlet. The duct sizes comprising each branch were selected to impose flow velocities which fell within the suggested flow velocity ranges cited in Table 30.

Each megazone branch consists of six basic elements: (1) a wye fitting to merge flow from the megazone branch into the main trunk; (2) a length of straight ductwork leading into the wye fitting interspersed with; (3) a selection of fittings and bends; (4) convergence providing a transition from; (5) a grill located somewhere inside the megazone.

The design process was devised to produce a nearly balanced system. The total static pressure loss for the critical path through the return system is specified in the Building E51 Engineering Specifications to be P_s = 0.75 in-wg. Adding to that, the velocity pressure at the fan outlet, $P_{v,o}$ = 0.07 in-wg, the overall total pressure loss for the return system is fixed at $P_{T,r}$ = 0.82 in-wg. The total pressure loss for each branch from the return grill out through the path of highest resistance in the mechanical room was adjusted to equal the total pressure rise across the return fan. Selection of the wye's, converging adapters and grills, and straight duct lengths imposed a fixed series of losses in the system. Balance was accomplished by adjusting the number of fittings proposed to be installed in the branches according to the value of the fitting loss coefficient of the fitting selected and the amount of loss that was necessary to create. Some effort was made to select fittings for which pressure loss coefficients had been determined as in the ASHRAE Fitting Loss Coefficient tables.[94] However, this was not

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94 1989 ASHRAE Handbook - Fundamentals, F32.27 - F32.52

considered to be an essential feature of the design and individual coefficients were adjusted to produce whole values for numbers fittings required.

Balance was achieved in each branch by using Equation 118. The values corresponding to each zone which satisfy this equation are summarized in Table 32.

$$P_T = l_{f,i}\, L_i + P_i + P_{mr} + \sum_q (n_q\, C_{l,i,q}\,)\, P_{v,i,q} \qquad \textbf{(118)}$$

where: P_T = the total pressure rise required across the return fan [95] [in-wg]

$l_{f,i}$ = the friction loss per 100 feet of duct based on flow rate [96] [in-wg/ft]

L_i = the length of straight duct in zone i [ft]

P_i = total pressure loss imposed by fixed elements in zone i including wye, convergence, and louver [in-wg]

P_{mr} = total pressure loss as a result of duct work from the mechanical room entry point to mixing box [97] [in-wg]

q = fitting types required to balance branch for zone i ------

n_q = the number of type q fittings required to balance branch for zone i ------

$C_{l,i,q}$ = fitting loss coefficient for fitting q selected to balance branch ------

$P_{v,i,q}$ = velocity pressure for flow passing through balancing fittings q [98] [in-wg]

Table - 32: Megazone Return Duct Design Details (ref: Figures 155 & 159)

Zone	P_T	$l_{f,i}$	L_i	P_i	P_{mr}	n_q	$C_{l,i,q}$	$P_{v,i,q}$
I	0.812	0.00120	40	0.098	0.523	3	0.540	0.088
II	0.829	0.00120	8	0.071	0.523	6	0.540	0.036
	-----	-----	-----	-----	-----	1	3.000	0.036
III	0.810	0.00075	106	0.049	0.523	5	0.260	0.122

95 This value must be very close to the design value based on the Building E51 Engineering Design Specifications - MIT Physical Plant. Variances from the design value are in practice the result of manufacturing constraints and the impracticality of building an precisely balanced system with factory ready components. Precise balance is typically achieved in the field using balancing dampers or depending on the VAV boxes to make the necessary adjustment.

96 SMACNA HVAC Duct Design Calculator

97 reference Figure 156

98 based on Equation 113

Zone	P_T	$l_{f,i}$	L_i	P_i	P_{mr}	n_q	$C_{l,i,q}$	$P_{v,i,q}$
IV	0.818	0.00095	123	0.097	0.523	10	0.120	0.068
V	0.841	0.00095	59	0.066	0.523	5	0.362	0.108
VI	0.812	0.00120	69	0.071	0.523	6	0.420	0.054

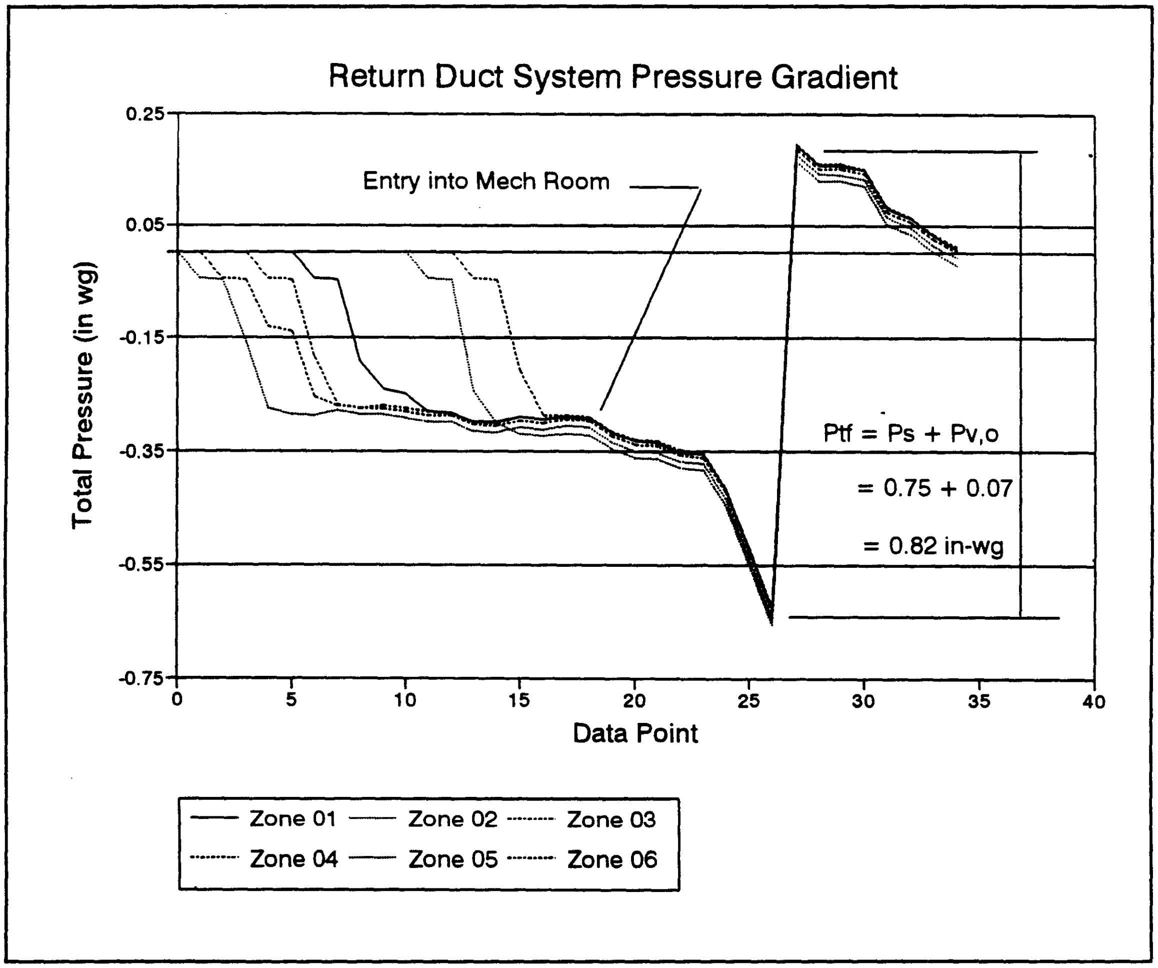

Figure 9: Megazone Return Air System Total Pressure Grade Line

The total pressure losses for each one of the branches slightly from zone to zone. It is not possible to match the exact pressure loss requirements necessary to perfectly balance a branch using commercially available, standard duct fittings. In a real system, the VAV box dampers will reposition from the theoretical, ideal design position compensating for these irregularities. The return duct system pressure grade line is shown in Figure 9 (refer to Figure 161 for plot data). The total pressure rise across the return fan is 0.082 in-wg.

3.3.3.6 Air Handler Control System - General Description w/ System Diagram

Control for the air handler is accomplished through a Johnson Metasys Network Control System. The Johnson system provides a Graphical Programming Language (GPL) for design and assembly of the control strategy used in Building E51.[99] Users have access to full control over the air handlers function through a remote operator workstation. A system drawing detailing the elements controlled through the Johnson System in Building E51 is shown in Figure 162. The Metasys program controls the signals received at various points in the diagram according to the strategy residing in the graphic program structure and the input received from sensors. A Metasys GPL control strategy consists of three primary levels. The first level is a dedicated file which contains the overall strategy for the control of Air Handler 1 in Building E51. This file is one of many available to the operator at a PC based workstation which maintains central control over a large number of buildings on the MIT campus. The second level captures the essence of the control strategy in a matrix of blocks, each referred to as compounds.

The compounds for Building E51 are shown in Figure 163. The compounds are sub-strategies which represent the control of an individual control signal. Typical control signals include damper adjustments, valve settings, and fan speeds as detailed in the system diagram. Behind each compound resides the third level consisting of the programming functions necessary to calculate the control of the state variables named in each compound. Metasys pre-programmed and user defined functions are linked together diagrammatically generating the code necessary to accomplish the desired calculations. The graphic program diagram for the static set point function in Building E51 is shown in Figure 164. Compounds can be found at the function level to characterize a control variable required for a certain function calculation.

Control System Details

Feedback from the building comes from three temperature sensors, one each located in Rooms E51-012, E51-110D, and E51-201, refer to drawings in Appendix D. These sensors signals are used by the Metasys Discharge Air Temperature Setpoint Reset Controller. The highest value is among the three is selected and processed by a proportional/integral reset algorithm which calculates a new setpoint for the chilled water valve. The Metasys system controls the supply fan output based on a supply air static air pressure set point. The feedback signal for this loop emanates from a pitot tube located three diameters down stream from the first bend coming off of the supply air fan in the mechanical room.

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99 Metasys, GPL Programmer's Manual, Johnson Controls, Inc., June 1992.

The return fan is controlled by the results of a differential comparator and tries to maintain a preset minimum differential flow. The return system flow rate calculation is based on the air flow velocity pressure measured in the return duct just up stream of the return fan. The mixed air damper is controlled in part by an economizer function which calculates and compares outside air enthalpy with inside air enthalpy. A freeze stat by-pass keeps the fresh air dampers closed at start-up if conditions are such that the coil is threatened with freezing. The air handler control system was modeled and tested by the group at Loughborough University of Technology.[100] Additional details for this system are available in the documentation accompanying the LUT model.

3.3.3.6.1 Sequence of Operations

Refer to section 3.3.3.6.

3.3.3.6.2 Point Schedule

Refer to section 3.3.3.6.

3.3.3.6.3 Mode Table

Refer to section 3.3.3.6.

3.3.3.6.4 Control Logic Diagram

Refer to section 3.3.3.6.

3.3.3.7 Building Zone Modeling 2 C - 3 R Components

The section provides a description of the procedure used to capture the essence of the subject building in terms of variables compatible with the HVACSIM+ component type used to model the individual

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100 Phil Haves, Loughborough University of Technology, Leicestershire UK.

megazones. The building's volume was divided into six megazones each consisting of two sub-zones: one for the occupied volume and one for the volume above the suspended ceiling referred to as the plenum.[101] A total of twelve LPM 2C3R models (described in §2.2 Theoretical Building Model) are used to describe the entire building, or similarly, six sets of two linked models. Each set requires eleven parameter sets as shown in Figure 2: two resistive and capacitive parameter groups containing five components and one resistive parameter linking the two groups. Thermal communication between megazones is limited to interzone air leakage which was modeled in a separate HVACSIM+ type (see §5.2.3.8 Inlet Constant Flow Resistances).

In conformance with the Annex 10 report modeling strategy, the building's structural elements were separated into three principle categories: external walls; internal walls; and connecting walls, and resistance and capacitance values were calculated per unit area for each structural element. The ceilings connecting each group of two sub-zones were treated as a connecting walls. The floors and ceilings separating the megazones were treated as internal walls. They were divided in half, each of which was individually ascribed to the adjoining megazones. The principle work in preparing the global parameter values was performed by Paul Balun. The work performed by P.Balun is documented in his report A Building Thermal Zone Model of VAV HVAC System, Massachusetts Institute of Technology, Undergraduate Research Opportunity Program, Summer 1995. All calculations shown in the interim and final results are included in Appendix R.

3.3.3.7.1 **Resistances & Capacitances**

Wall Types for Lumped Parameter Model

Seven wall types were identified for modeling refer to Table 33. The term wall is used in the Annex 10 report to characterize all structural and non-structural components in the real building which contribute to the global parameters for the 2C3R LPM building model. This includes floors, ceilings, windows, partitions, and miscellaneous door and internal window wall styles.[102]

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101 Return air in the subject building is ducted. As a result, the volume above the suspended ceiling was not used as a plenum, but only as a chaseway for distributed utilities and services.

102 The structural steel frame for Building E51 was not considered in calculating external or internal thermal resistances or capacitances. In addition, all internal partitions were modeled as homogeneous gypsum and steel stud composites, ignoring doors and window walls. Floor slabs were modeled with out any covering including carpet, vinyl tiles or other materials typically found in commercial office buildings.

Table - 33: Wall Types - Building E51

Code	Wall Types		
	External	Connecting	Internal
Horizontal Surfaces (refer to Figure 176)			
A	-------	-------	Ground Floor/Wall Concrete Foundation Slab
B	-------	Fire Rated Suspended Ceiling	-------
C	-------	-------	Concrete Floor/Ceiling without Carpeting
D	Roof, Built Up Asphalt	-------	-------
Vertical Surfaces			
1	External Shell Wall, Concrete Block/Brick Face	-------	-------
2	Double Pane, Steel Frame, Standard Glass Windows	-------	-------
3	-------	-------	Internal Partition & Adiabatic Walls, Steel Stud and Gypsum

EXTERNAL - External walls are categorized with three types: (1) vertical external wall; (2) roof; and (3) double glazed, aluminum framed fenestration with thermal breaks. The structure of the vertical external wall is shown in Figure 11 and discussed at the beginning of this section. The roof construction consists of 2" lightweight insulating cement deck on 14 gage, corrugated galvanized steel sheeting, supported by manufactured steel roof joists.[103,104] Waterproofing for the roof consists of two thicknesses of industry standard built-up roofing less one sub-layer of gravel weathering surface.[105] Characterization of the aluminum frame, double glazed windows was taken from the type described in Table 5 of 1993 ASHRAE Handbook - Fundamentals F27.6. Standard glass was assumed. Specific references are made to the example provided on page F27.19 when developing sol-air temperature profiles.

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103 Mark's Standard Handbook for Mechanical Engineers, 7th Edition, US Steel Wire Gage Standard, p. 6-48.

104 Ching, et.al., P. 8.24.

105 1993 ASHRAE Handbook - Fundamentals, F22.7. Two layers to account for a re-roofing that required removing the loose gravel weathering surface from the layer to be covered.

CONNECTION - The only "zone to zone" connections considered for which there would be connecting walls were for the suspended ceilings separating a megazone's two sub-zones: the room and plenum. A suspended ceiling's construction consisted of 5/8" x 24" x 48" fire proof ceiling tiles suspended in an aluminum frame matrix. Material properties for the ceiling tile was estimated from the tables of material properties in 1993 ASHRAE Handbook - Fundamentals, F22.7 and 0.0625" x 3/4" aluminum bar stock.

INTERNAL - Internal partition wall construction consisted of 5/8" gypsum wall board on 1 1/2" x 3 1/2" steel studs with fiberglass batt insulation, see Figure 10. Although 6" concrete block wall partitions exist in Building E51, the steel stud and gypsum wall board type wall construction was used in all locations. In these cases, the thermal resistances are calculated using Equations 28 and 29. Values for the thermal capacitance in these cases were calculated to be consistent with the physical construct of the thermal resistances.

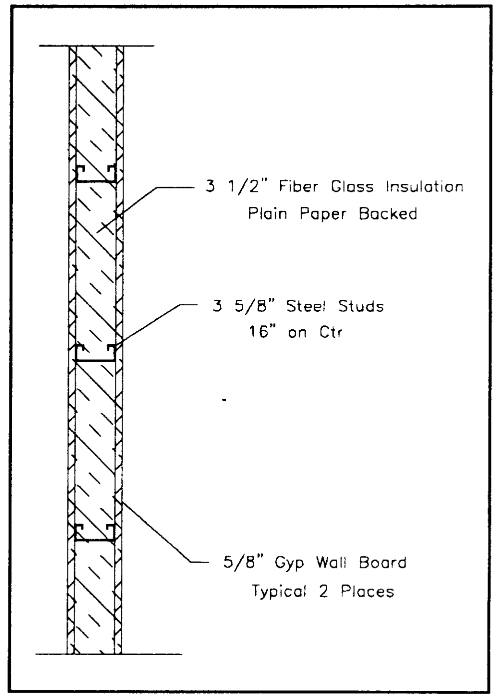

Figure 10: Detail, Building E51 Internal Partition Walls

The adiabatic walls separating the model volume from other portions of Building E51 are modeled as internal walls. These walls were divided in half apportioning half of the mass and corresponding thermal resistance to the adjoining zones. The resulting pieces were, in essence, folded over and placed within the zone volumes. The resulting wall sections were then treated as internal walls with half of the total surface area (or twice the resistance) and half the mass of the separating wall, (refer to Equations 31 and 32).

The foundation floor and wall slabs were treated as connecting walls. However, a fraction less then half of the actual thickness was taken to represent the mass affected by temperature changes, since only a small fraction of the total thickness responds to these changes over the course of a day.

<u>Overall External Wall Thermal Resistance</u>

A calculation of the overall external wall thermal resistance was prepared. The R-value calculated in this way was used to provide independent corroboration for the values calculated using the Annex 10 modeling strategy. The external shell wall for E51 is a composite, multilayered structure typical for the age and type of building, refer to Figure 11. The thermal resistance calculation for the curtain wall was based on the assumption that heat flow through the wall is one dimensional in a direction transverse to the layer planes. Consequently, the resistance is equal to the sum of the resistances for the n individual layers:

$$R_{total} = \sum_{n} \frac{1}{U_n} . \tag{119}$$

Certain layers are composed of multiple components presenting parallel heat paths through materials with different conductances. In these instances, the average conductance through the layer is given by:

$$U_{n,av} = \sum_{m} a_{n,m} \, U_{n,m} \; ; \tag{120}$$

where the coefficients $a_{n,m}$ are the respective fractional areas corresponding to the parallel paths composed of material with transmittance (or conductance) $U_{n,m}$.[106]

By combing the two preceding equations and applying the result to the wall shown in Figure 11, an expression for the overall resistance through the external shell wall was derived as follows:

$$R_{ext\ wall} = R_{brick} + \frac{1}{\frac{a_{oas}}{R_{oas}} + \frac{a_{sc}}{R_{sc}}} + R_{\substack{vapor \\ barrier}} + R_{\substack{concrete \\ block}} + \frac{1}{\frac{a_{ias}}{R_{ias}} + \frac{a_{fs}}{R_{fs}}} + \frac{1}{\frac{a_{ss}}{R_{ss}} + \frac{a_{fi}}{R_{fi}}} + R_{\substack{gypsum \\ wall\ board}} \; ; \tag{121}$$

where: a_{oas} = fractional area of outside air space

a_{sc} = fractional area of steel clip ($1 - a_{oas} = a_{sc}$)

a_{ias} = fractional area of inside air space

a_{fs} = fractional of furring strip ($1 - a_{ias} = a_{fs}$)

a_{ss} = fractional of steel stud

a_{fi} = fractional of fiber glass insulation ($1 - a_{ss} = a_{fi}$)

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106 1993 ASHRAE Handbook - Fundamentals, F20.8.

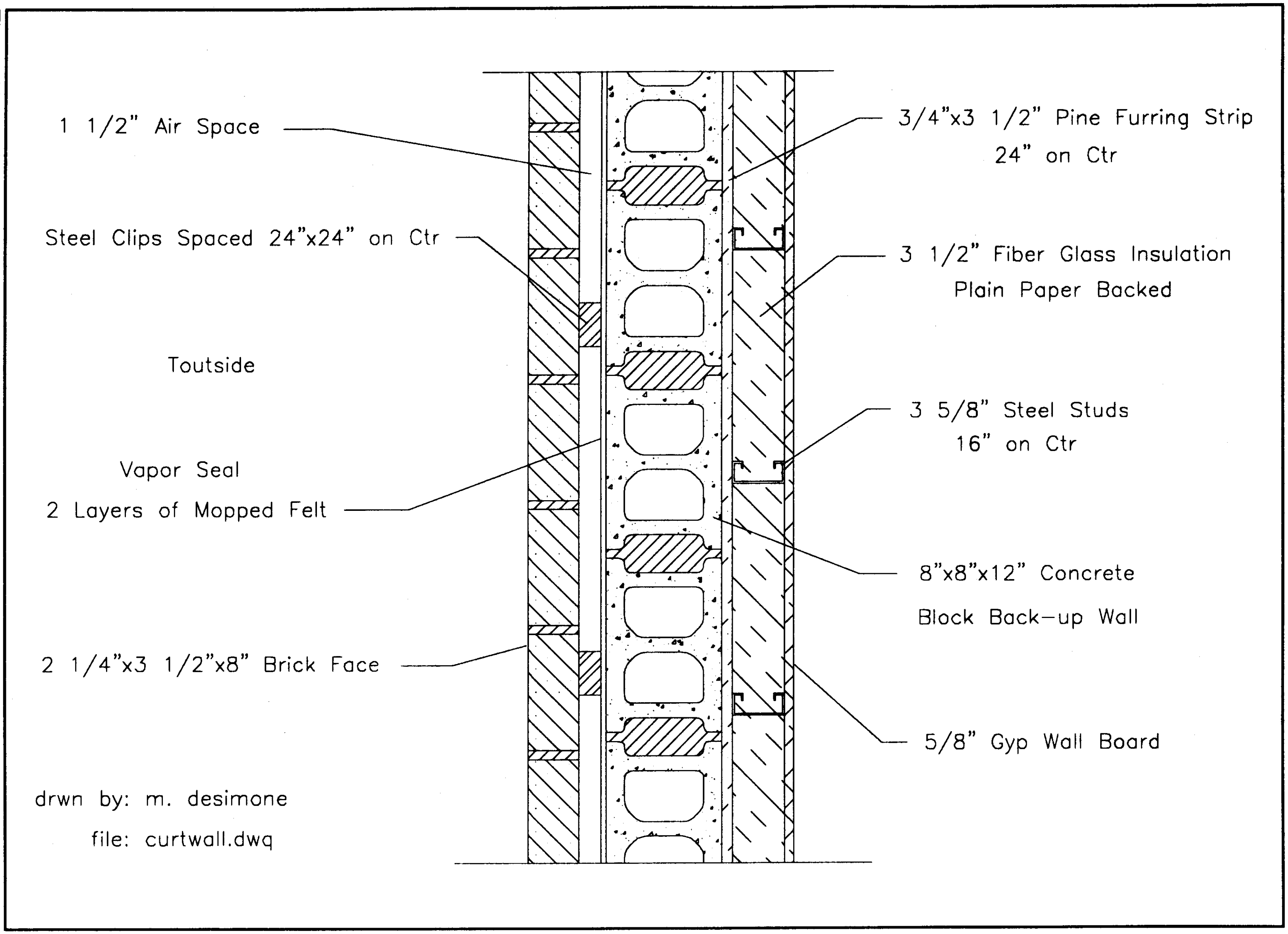

Figure 11: Detail, Building E51 External Shell Wall

Table - 34: Thermal Resistance Calculation, External Shell Wall (refer to Equation 121)

Material		Thermal Resistance [°F·hr·ft²/Btu]		Reference
Description	Code	Value	Calculation	
brick face	R_b	0.6000	0.17 [°F·hr·ft²/Btu·in] x 3.5 [in]	ρ_{brick} = 120 lbf/ft³ [Sauer, et.al.]
outside air space	R_{oas}	0.3600	0.24 [°F·hr·ft²/Btu·in] x 1.5 [in]	[Stein]
steel clip	R_{sc}	0.0075	0.005 [°F·hr·ft²/Btu·in] x 1.5 [in]	NAVSHIPS 900,190
felt vapor barrier	R_f	0.1200	------------------	ASHRAE F22.6 (SI) 2 layers mopped 15 # felt
concrete block	R_{cb}	1.1100	------------------	ASHRAE F22.8 (SI) 8" block ρ_{block} = 130 lbf/ft³
furring strip	R_{fs}	0.8000	1.06 [°F·hr·ft²/Btu·in] x 0.75 [in]	ASHRAE F22.9 (SI) Douglas Fir $\rho_{doug\ fur}$ = 34 lbf/ft³
inside air space	R_{ias}	0.1800	0.24 [°F·hr·ft²/Btu·in] x 0.75 [in]	[Stein]
steel stud	R_{ss}	0.0175	0.005 [°F·hr·ft²/Btu·in] x 3.5 [in]	NAVSHIPS 900,190
fiber glass insulation	R_{fi}	11.0000	------------------	ASHRAE F22.6 (SI) 3.5" fiber glass batt $\rho_{fiber\ glass}$ = 0.3 lbf/ft³
gypsum wall board	R_{gyp}	0.5600	------------------	ASHRAE F22.6 (SI) 3.5" fiber glass batt $\rho_{fiber\ glass}$ = 0.3 lbf/ft³

Table - 35: Thermal Resistance Calculation, Fractional Surface Areas

Coefficient	Value	Coefficient	Value	Coefficient	Value
a_{oas}	0.9987	a_{ias}	0.8542	a_{ss}	0.0100
a_{sc}	0.0013	a_{fs}	0.1458	a_{fi}	0.9900

Values for the individual wall components are detailed in Tables 34 and 35, and a value for overall resistance of the external shell wall $R_{ext\ wall}$ is calculated based on Equation 121 as follows:

$$R_{ext\ wall} = 0.60 + \frac{1}{\frac{0.9995}{0.36} + \frac{0.0005}{0.0075}} + 0.12 + 1.11 + \frac{1}{\frac{0.8542}{0.18} + \frac{0.1458}{0.80}} + \frac{1}{\frac{0.01}{0.0175} + \frac{0.99}{11.0}} + 0.56 \qquad (122)$$

$$R_{ext\ wall} = 4.5 \ [\,{}^{\circ}F \cdot hr \cdot ft^2 / Btu\,] \qquad (123)$$

Area of Each Wall Type and the Associated Unit Area Parameter Values

AREA - The areas for all internal wall types in each megazone, including room and plenum, are summarized in Figures 171 and 177. The tables in these figures contain individual take off quantities and total quantities of each variety. Take offs were derived by scaling linear measurements from the drawings shown in Figures 26 - 33, and using a 9.5 foot room ceiling height and 2.5 foot plenum height. The total external building surface area is shown in Figure 184 and includes all surfaces in direct contact with the outside air. The areas were calculated from measurements scaled directly from the Building E51 elevation drawings shown in Figures 19, 20, 21. External surfaces below grade were considered adiabatic boundaries, and a fraction of the total thickness of these surfaces were included in the parameter calculations.[107]

UNIT AREA PARAMETERS - Parameter values ascribed to each sub-megazone for the various wall types were calculated using the unit area values calculated by various means and the equations expressed in §2.2.1. Unit area parameters were calculated using the methods proposed in ASHRAE Fundamentals Chapter 2. The unit area parameters were obtained by combining the conduction components with the appropriate values of surface film coefficients. Film coefficients were taken from Table 1, 1993 ASHRAE Fundamentals, F22.1 and account for surface orientation, slope, and average local air movement, as well as, to some degree, for radiative heat transfer between internal surfaces; although there is no explicit accounting for radiative heat transfer between internal zone surfaces. The actual values may differ slightly from those values proposed in the ASHRAE tables due to variances in the behavior of specific material used in construction. In support of the ASHRAE tabulated values,

107 The full thickness of the foundation slab cannot respond fully (by attaining a steady state condition) to variations in temperature over the course of a twenty-four hour period. Concrete slabs with thickness closer to 3 - 4 inches are more representative, having time constants in the order of 3 - 5 hours.

they were obtained by accepted ASTM test methods and can be considered representative and consistent with common building practices.[108]

Long-wave and short-wave radiation heat transfer is accounted for explicitly in calculations modeling net solar heat flux on the external surfaces, and between the panes of the double glazed windows (refer to section concerning sol-air temperature calculations).

Annex 10 Global Parameters for Room and Plenum Volumes in Each Megazone

On the basis of the equations presented in §2.2.1 Current Model, and using the unit area parameter values, global parameters were calculated for each of the room and plenum volumes in the megazones. These values summarized in Tables 36 and 37, are explicitly detailed in Appendix R. Quality control was maintained continuously throughout the development of these values to ensure the validity of these numbers. In the case of the capacitances, approximate mass values were back-calculated using average specific heat values. The average specific heat values selected were based on relative quantities of each material contained in the composite capacitance values. In the case of the resistances, two methods were used: first, the value or its inverse, the conductance, must fall within known reference values; and second, by calculating a time constant using the corresponding capacitance and then comparing this with known reference values.[109] In both cases, effective surface areas and volumes were back calculated and compared with the values originally used as an additional verification.

Infiltration and the Effect on Lumped Parameter Model Values

Values for the Capacitive Flow of Infiltration $\dot{C}_{i,out}$ are calculated in Figure 185. This value is always positive. The direction of heat flow due to this component of the total heat flow into, or out of, the zone is determined by the temperature difference of the air in the zone and the air flowing through the zone due to all possible air flow paths. A list of air flow paths include that due to stack effects, infiltration and exfiltration through external and internal walls, ceilings, and floors and that due to mechanical ventilation. A fully detailed mathematical description of air flow through the megazones is complicated and the values are dependent on variables which change frequently throughout the course of a typical 24 hour period. For example sol-air temperatures and VAV flow rates. Stack effects are

108 1993 ASHRAE Handbook - Fundamentals, F22.1.

109 Reference values for these comparisons originate primarily from the authors personal experience as an engineer and in consultation with others associated with the industry.

Table - 36: Global Parameter Summary for Megazone I - III (refer to Figure 165)

Parameter	Megazone - Global Parameters (rounded)					
	I		II		III	
	Room	Plenum	Room	Plenum	Room	Plenum
$1/R_{wi}$ [W/°K]	30	0	10	0	220	0
$1/R_i$ [W/°K]	4,230	1,540	880	790	10,060	2,970
θ_i	0.011	0.011	0.016	0.006	0.038	0.076
$Cdot_{i,out}$ [W/°K]	0	0	0	0	0	0
K_i [W/°K]	80	20	20	5	600	220
ξ_i	0.39	0	0.34	0	0.36	0
$1/R_{eq}$ [W/°K]	4,270	1,540	890	790	10,280	2,970
C_{si} [J/°K]	5.85e+07	4.81e+07	1.07e+07	1.63e+07	2.79e+08	1.25e+08
τ_i [hr]	210	750	140	910	130	160
C_i [J/°K]	9.41e+06	2.18e+06	2.03e+06	7.03e+05	2.58e+07	6.87e+06

Table - 37: Global Parameter Summary for Megazone IV - VI (refer to Figure 165)

Parameter	Megazone - Global Parameters (rounded)					
	IV		V		VI	
	Room	Plenum	Room	Plenum	Room	Plenum
$1/R_{wi}$ [W/°K]	56	0	147	0	20	0
$1/R_i$ [W/°K]	1,853	1,356	5,490	3,861	257	179
θ_i	0.058	0.028	0.033	0.022	0.118	0.064
$\dot{C}_{i,out}$ [W/°K]	0	0	0	0	0	0
K_i [W/°K]	164	38	327	86	50	11
ξ_i	0.34	0	0.45	0	0.4	0
$1/R_{eq}$ [W/°K]	1,900	1,360	5,640	3,860	280	180
C_{si} [J/°K]	7.60e+07	5.18e+07	5.14e+08	1.52e+08	2.08e+07	1.08e+07
τ_i [hr]	130	370	180	490	120	260
C_i [J/°K]	7.24e+06	7.24e+06	1.78e+07	5.49e+06	6.77e+05	2.32e+05

Alert: New thermal parameter tables that correct the errors identified in §2.2.3 are presented in Appendix BB.

also another variable which will vary remarkably. The effect of capacitive flow cannot be ignored in developing the global parameters, and the simulation package in its present form cannot accommodate variable global parameters. As a compromise it is proposed that a value of 50% of the supply air flow in each megazone be used as trial numbers for $\dot{C}_{i,out}$, and as the simulation is fine tuned, these values can be adjusted to the most representative and accurate levels.

Table - 38: Global Time Constant τ_i (refer to Equation 42 & Figure 165, global01.wq2 - Page 6)

Zone Number	Global Time Constant τ_i [hrs]	
	Room	Plenum
I	13	71
II	14	137
III	12	31
IV	17	71
V	17	73
VI	12	40

Additional Comments

The values for τ_i presented in Table 38 are close enough to being acceptably accurate that there may be no need to examine the construct of the time constant detailed in Equation 42. However, as the model is fine tuned, and adjustments are made to the capacitive flow, the time constant may be distorted out of character, and the following observations concerning the time constant construct may be applicable in making modifications which produce more realistic results.

The formula combines values for resistance (or conversely conductance) and capacitance which do not have the same physical origins. The conductance calculation for K_i shown in Equation 43 (referred to in the Annex 10 report as the overall loss coefficient) and used in Equation 42 is based on contributions from only resistances in the external shell and fenestration in combination with the infiltration term. In contrast, the capacitance calculation shown in Equation 42 is based on contributions from both internal and external components heavy structures, none of the external light structures, and no part of the infiltration. More specifically, the capacitance used in this calculation is determined on the basis of a 100% contribution from the internal heavy structures and only a fractional part of the external heavy structures.

It is this author's contention that if the time constant is to be representative of the system's dynamic behavior, then the construct must recognize and characterize heat transfer by all paths to the mass represented by the capacitance value used in the calculation. In reality, heat transfer to the mass modeled by the capacitance in Equation 42 occurs through two routes: first, through the convective and conductive heat transfer paths for surfaces presented by the included internal components; and second, through the convective and conductive heat transfer paths for the external components.[110]

In the case of Building E51, surface areas for heavy internal structures constitute a very high percentage of the total surface area attributed to the mass included in the time constant calculation, and heat transfer through the associated internal paths are ignored in Equation 42, referring specifically to the fact that K_i is a function of the external heat transfer paths only according to Equation 43. From the summary of surface areas related to heavy structures provided in Table 39 it is surmised that omitting internal heat transfer paths ascribed to internal surfaces significantly underrates the total heat transfer characterization intended when calculating a time constant. In fact, by augmenting Equation 43 with additional heat transfer paths the ratio τ_i would decrease.

Table - 39: Heavy Structure Surface Area Comparison (refer to Figures 177 & 184)

Zone Number	Heavy Structure Surface Areas			
	Horizontal Internal		Vertical External	
	[ft²]	% of Total	[ft²]	% of Total
I	5,076	86	834	14
II	1,245	84	234	16
III	13,746	68	6,501	32
IV	3,020	63	1,810	37
V	9,332	73	3,398	27
VI	376	41	539	59

Heat transfer is also affected by infiltration through internal and external walls and by mechanical ventilation. The model for τ_i represented in Equation 42 takes into account heat transfer through

110 Radiative heat transfer for internal surfaces is ignored. A case could be made to include this as another path since, in practice, the temperature of the inside surface of an external wall may often be significantly different then the temperatures of the internal wall surfaces.

infiltration and conduction through the external walls; heat transfer though the connecting and internal walls by any means is ignored. In addition, no accounting is made for heat transfer by mechanical ventilation. It is the author's opinion that additional investigation, beyond the scope of this project, is necessary to clarify the inconsistencies related to the infiltration term.

It is understood that the Annex 10 model equations were not intended to be all encompassing, generalized equations for every zone configuration and ventilation system. However, the intent to include a capacitive flow term is well taken and one simply needs to insure that this term accurately describes the total flow through a zone.

2C3R Lumped Parameter Model Parameters

The parameters for the 2C3R LPM's are shown in Table 40. They were calculated using the equations in §2.2.1 on the basis of the global parameters in Tables 36 and 37. The values presented in Table 40 are used directly as the parameters values for the HVACSIM+ type modeling the megazone thermal characteristics. The entire calculation is summarized in Appendix R in a series of fully linked spreadsheets.[111] If recalculation or modification is required, this may be done in Quattro or the sheets may be converted into a format compatible with either the Lotus 123 or Microsoft Excel spreadsheet programs; for this process, it is recommended the *.wks format be used.

Table - 40: 2C3R Lumped Parameter Model Characteristics (refer to Figure 2 & 165)

Parameter	**2C3R Lumped Parameter Model Characteristics for Each Zone i ***					
	I	**II**	**III**	**IV**	**V**	**VI**
$R_{01,i}$ [°K/kW]	3.27e+01	1.37e+03	4.64e+00	1.79e+01	6.82e+00	5.00e+00
$R_{02,i}$ [°K/kW]	2.64e-03	1.80e-02	3.76e-03	3.15e-02	5.99e-03	4.61e-01
$R_{03,i}$ [°K/kW]	2.34e-01	1.12e+00	9.56e-02	5.08e-01	1.76e-01	3.43e+00
$C_{02,i}$ [kJ/°K]	9.41e+03	2.03e+03	2.58e+04	7.24e+03	1.78e+04	6.77e+02
$C_{03,i}$ [kJ/°K]	5.85e+04	1.07e+04	2.79e+05	7.60e+04	2.14e+05	2.08e+04
$R_{11,i}$ [°K/kW]	3.26e+00	9.47e+00	1.14e+00	3.81e+00	1.33e+00	3.06e+00

111 Novell's spreadsheet program Quattro Pro V5.5 was used to accomplish the calculations. Soft copies of the sheets presented in Appendix R are included in Appendix ?. An index cross referencing the file names to the figures in which the information is presented in hard copy form is presented at the beginning of this thesis.

Parameter	2C3R Lumped Parameter Model Characteristics for Each Zone i *					
	I	II	III	IV	V	VI
$R_{21,i}$ [°K/kW]	infinite	infinite	infinite	infinite	infinite	infinite
$R_{22,i}$ [°K/kW]	7.45e-03	7.97e-03	2.54e-02	2.09e-02	5.77e-03	3.57e-01
$R_{23,i}$ [°K/kW]	6.41e-01	1.26e+00	3.12e-01	7.17e-01	2.53e-01	5.23e+00
$C_{22,i}$ [kJ/°K]	2.18e+03	7.03e+02	6.87e+03	2.36e+03	5.49e+03	2.32e+02
$C_{23,i}$ [kJ/°K]	4.81e+04	1.63e+04	1.25e+05	5.18e+04	1.52e+05	1.08e+04

* The parameters in Table 40, expressed in terms of the variable names used in the Annex 10 report, are shown in the following list:

$R_{01,i} = R_{wi,room}$ $R_{02,i} = R_{i,room}\theta_{i,room}$ $R_{03,i} = R_{i,room}(1 - \theta_{i,room})$
$C_{02,i} = C_{i,room}$ $C_{03,i} = C_{si,room}$
$R_{21,i} = R_{wi,plenum}$ $R_{22,i} = R_{i,plenum}\theta_{i,plenum}$ $R_{23,i} = R_{i,plenum}(1 - \theta_{i,plenum})$
$C_{22,i} = C_{i,plenum}$ $C_{23,i} = C_{si,plenum}$
$R_{11,i} = R_{i,j,connecting}$.

Alert: New thermal parameter tables that correct the errors identified in §2.2.3 are presented in Appendix BB.

4 Requirement for Sub-One-Hour Solar and Collateral Weather Data

"Variations in meteorological conditions also impose variations in heating and cooling loads. Since variations in ambient dry bulb temperature and humidity are generally quite slow (time-scales of hours), variations in solar radiation account for the main load changes on time scales that effect the closed loop behavior. The greatest high frequency variations occur under partly cloudy skies with high wind speed. As with variations in internal gains, the thermal characteristics of the zone have a major effect in determining how much of the high frequency variations in the heat gain to the room are passed on to the HVAC system as load variations. No experimental work in this area appears to have been reported in the literature, so the most suitable of the zone models identified ... [in other phases of this study conducted by LUT] ... *will be used to assess the sampling rate for solar data that is required to ensure that the higher frequency components of the load are calculated with reasonable accuracy.*

A further effect of meteorological conditions that has no first order effect on heating and cooling loads, but [which] does affect HVAC control loops, is the effect of wind pressure changes on fan control and building pressurization, especially in VAV systems. Proper investigation of this effect would require a study using the completed testbed .... However, consideration of the dynamics of the fan static pressure control loop and the flow control loop in pressure independent VAV boxes suggests that a sampling interval of one minute for wind velocity data represents an upper limit for the study of such effects.

The availability of one minute solar and wind velocity data from such sources as NOAA, the National Climatic Center (Ashville, NC), and the national labs will be investigated and reported. Sample data for extreme day (in terms of short fluctuations) will be obtained to facilitate further studies of these effects, and will be delivered together with a report on the availability of short term data for different sampling intervals and different climates."[112]

4.1 Available Solar Radiation & Collateral Meteorological Observations

The search for solar data in any form followed a course which researched the holdings of the Federal Records Center in Waltham MA, the National Archives in Washington DC, the National Climatic Data Center (NCDC) in Asheville, NC, the NOAA reference library in Camp Springs, MD, the Blue Hill Weather Observatory in Canton MA, the Harvard University and the National Renewable Energy

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Laboratory (NREL) in Golden Colorado. Aside from discovering that the history of solar data collection is extremely interesting, filled with amusing and fascinating anecdotes, the net result of the investigation was that four references for solar radiation and collateral surface meteorological observations originating in the United States are available: (1) SOLMET - Hourly Solar Radiation & Surface Meteorological Observations; (2) SOLDAY - Daily Solar Radiation & Surface Meteorological Data; (3) SAMSON - Solar and Meteorological Surface Observational Network CD-ROM; and (4) ASOS - Automated Surface Observing System. These references, prepared by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) for the Department of Energy under interagency agreement No. E(49-26)-1041, provide a broad base of corrected data in a standard format.

The two programs, SOLMET and SOLDAY, produced corrected and reformatted data and information in a common format with all known procedural and instrument errors removed. Correction was necessary because much of the data existing in the historical data bases from which the SOLMET and SOLDAY programs drew information suffered from neglect and contained serious errors resulting from a number of calibration and instrument problems.[113] Further, data was not all referenced to the same scale. The SAMSON CD-ROM is a National Solar Radiation Data Base V1.0 (NSRDB V1.0), which is the result of a development project sponsored by the National Climatic Data Center (NCDC) and implemented by the National Renewable Energy Laboratory's (NREL) Analytical Studies Division under the Solar Radiation Resource Assessment Project (SRRAP). The ASOS program, in contrast, is an ongoing and currently expanding NOAA program to deploy and activate 900 to 1,700 automated surface meteorological observing system at airports around the United States. The ASOS system does not collect or record solar insolation data.

Two additional resources for meteorological and solar insolation data records are found in guides to all United States weather records in the custody of the National Climatic Weather Service. The first guide is available through NOAA Meteorological Records Document No. 4.11, Selective Guide to Climatic Data Sources. This comprehensive guide includes synopses of Data Bases and Digital Files, Satellite Digital Files, Statistical and Special Studies, Manuscript and Autographic Records, Microfilm and Microfiche Files, Historical Publications, Decennial and Periodic Publications, and Subscription Publications. The second guide is also published by NOAA National Climatic Data Center - Products and Services, and includes information regarding on-line systems, CD-ROM products, summaries of

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113 SOLMET Volume 1 - User's Manual, p. i.

digital datasets, and another list of related publications. This catalog and all other NOAA publications can be obtained by phone, fax or e-mail.[114]

4.1.1 SOLMET - Hourly Solar Radiation & Surface Meteorological Observations

The SOLMET program was developed to collect information into a *"common tape format that is designed to provide, in a single Fortran compatible tape, quality controlled hourly solar insolation and collateral meteorological data...."* The SOLMET program was sponsored by the United States Department of Energy, Division of Solar Technology, Environmental and Resources Assessments Branch in an effort to provide the solar heating and cooling industry with comprehensive, conveniently organized, accessible information. SOLMET tapes are available for 249 stations distributed around the United States.[115] Most data sets extend over the period from 1951 to 1976. A small number of the stations did not have complete data for the entire twenty-five year period.

The program was the result of recommendations by Working Group 1 of the National Oceanic and Atmospheric Administration (NOAA) Solar Energy Data Workshop (1973) to *"rehabilitate the pyranometer data for the United States network of stations to at least five percent accuracy for all possible stations for a period of ten years, or longer where possible."*[116] The key features of the program were to:

1. merge all available insolation and meteorological data into a single source;
2. present all data in SI units;
3. provide time information in true solar and/or local standard time;
4. provide for augmentation to accommodate additional solar radiation parameters and allow for supplemental fields for additional measurements e.g. spectral, ultraviolet, etc.;
5. eliminate undesirable format features that were inherent in the past data sources such as over-punches, blanks, etc.

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114 NCDC / Climate Services Division (as of 07 Oct, 1994) Tel: (704)271-4800 Fax: (704)271-4876 e-mail: orders@ncdc.noaa.gov

115 SOLMET Volume 2 - Final Report, Table 11, p. 184.

116 SOLMET Volume 2 - Final Report TD9724, P. 1

6. code missing observations and those observations that were estimated via models (e.g. sunshine and cloud regression models);
7. provide the user with global radiation data as they were originally observed corrected for all known scale, instrument, and calibration problems, and, in addition provide a data set corrected via a standard year irradiance (or radiant flux density) model.

Solar radiation data sets for twenty-seven stations were from direct measurement. Twenty-five of these stations were considered control data stations (dividing the contiguous United States into twenty-five climatologically consistent regions). Since rehabilitated hourly direct measurement solar radiation data was not available from the 222 additional stations, solar radiation data sets for these sites were derived through a series of regression equations *"which relate measured hourly global solar radiation to commonly reported weather elements [cloud and sky cover conditions] as described in SOLMET Volume 1 -User's Manual."*[117] The equations were initially derived to fill in missing data from the control data stations. Later, the equations were used to extend the SOLMET data set inventory to the 222 additional stations.

Pyranometer data from the direct measurement stations were rehabilitated to at least five percent accuracy. The rehabilitation process was an attempt to remove the effect of all known procedural and instrumentational errors, and its application was limited to hourly global solar radiation data. All solar radiation data was presented as integral hourly values in true solar time, and the collateral meteorological data was presented as instantaneous hourly values in local standard (or GMT) time.[118]

SOLMET data tape contain information formatted into the fields shown in Table 41 (refer to SOLMET Volume 2 - Final Report for a more detailed explanation of each field).

Table - 41: SOLMET Data Tape Records

LN	Record Description
1	Tape Deck Number
2	WBAN Station Number
3	Solar Time Day [solar year/month/day/hour/minute]

117 SOLMET Volume 2 - Final Report TD9724, P. 168

118 SOLMET Volume 2 - Final Report TD9724, P. 2

LN	Record Description
4	Local Standard Time [hr - minute]
5	Extraterrestrial Radiation [kJ/m^2] : Amount of solar energy received at the top of the atmosphere during the solar hour ending at the time indicated in the field .... based on solar constant 1377 $J/(m^2\text{-}s)$ .... includes night values for a limited number of stations only
6	Direct Radiation [kJ/m^2] : Portion of radiant energy received at the pyrheliometer directly from the sun during the solar hour ending at the time indicated in the field
7	Diffuse Radiation [kJ/m^2] : Amount of radiant energy in received at the instrument indirectly from reflection, scattering, etc. during the solar hour ending at the time indicated in the field
8	Net Radiation [kJ/m^2] : Difference between the incoming and outgoing radiant energy in kJ/m^2 during the solar hour .... a constant of 5000 has been added to all net radiation data
9	Global Radiation on a Tilted Surface [kJ/m^2] : Total of direct and diffuse radiant energy in kJ/m^2 received on a titled surface (tilt angle indicated in station - period of record list) during the solar hour ending at the time indicated in the field
10	Global Radiation on a Horizontal Surface (GRHS) - Observed Data [kJ/m^2] : Total of direct and diffuse radiant energy in kJ/m^2 received on a horizontal surface by a pyranometer during the solar hour ending at the time indicated in the field
11	GRHS - Engineering Corrected Data [kJ/m^2] : Observed value corrected for known scale changes, station moves, recorder and sensor calibration changes etc.
12	GRHS - Standard Year Corrected Data [kJ/m^2] : Observed value adjusted to the Standard Year Model. This model yields expected clear sky irradiance received on a horizontal surface at he elevation of the station.
13	Minutes of Sunshine : for Local Standard Hour most closely matching solar hour
14	Observation Time [time of collateral surface observation] : Local Standard Hour of TD 1440 Meteorological Observation that comes closest to mid-point of the solar hour for which solar data are recorded
15	Ceiling Height [dekameters] : Ceiling height defined as the height of sky cover of 0.6 or greater
16	Sky Condition : Identifies observations after 01 June 51. Coded by layer in ascending order; 4 layers are described; if less than 4 are present the remaining positions are coded 0 .... Layer codes are expressed on a scale from 0 to 8. The code breaks down as follows: 0 = clear or less then 10 % cover; 1 = thin scattered 10 - 50 % cover; 2 = opaque scattered 10 - 50 % cover; 3 = thin broken 60 - 90 % cover; 4 = opaque broken 60 - 90 % cover; 5 = thin overcast 100 % cover; 6 = opaque overcast 100 % cover; 7 = obscuration; 8 = partial obscuration.
17	Visibility [hectometers] : prevailing horizontal visibility
18	Weather : none, rain, t-storm etc. with lots of codes for variations of the same theme
19	Pressures (kPa) : local station pressure and pressure reduced to sea level

LN	Record Description
20	Dry Bulb Temperature [°C to tenths]
21	Dew Point Temperature [°C to tenths]
22	Wind Speed and Direction [m/s + deg]
23	Clouds : includes sky cover defined as the amount of celestial dome covered by clouds or obscuring phenomena and is expressed in 10ths .... other data available in this category includes cloud types, height, and layer
24	Snow Cover : indicates presence of snow cover on ground

Typical Meteorological Years

In addition to the SOLMET tapes, data sets referred to as Typical Meteorological Years (TMY) are available for twenty-six stations. Twenty-five of these stations are direct measurement control stations. TMY data represents hourly data, averaged over many years. Each data set is a one year composition of the most representative or typical months for that station over the course of the twenty-five year period. The TMY tapes contain the same data fields as the SOLMET tapes except that the cloud layer information was omitted. Also, since the typical months were most likely chosen from different calendar years, discontinuities between months were smoothed with a cubic spline function covering six hourly points on either side of the interface.

Two other tape formats are available which may also be used in HVACSIM+ simulations: Weather Year for Energy Calculation (WYEC); and NOAA Test Reference Year (TRY).[119] All four data tape formats tapes may be ordered from the National Climatic Data Center (NCDC), Ashville, North Carolina. In the event a custom configuration is required, the desired input may be configured to mimic any of the aforementioned formats and used in the simulation accordingly. The most useful format for accessing the

CDROM Formatted SOLMET Data

Recently, SOLMET data has become available on CDROM. The data available is a synthesis of the data formerly distributed as a result of the SOLMET and SOLDAY programs. *The 1961-1990*

119 SOLMET Volume 2 - Final Report TD9724, P.65

National Solar Radiation Data Base Version 1.0 was developed by the National Renewable Energy Laboratory's (NRELS) Analytical Studies Division under the Solar Radiation Resource Assessment Project (SRRAP). NRSDB 1.0 is available on CDROM as the Solar and Meteorological Observational Network (SAMSON) from the [NCDC].[120] The data set used for this project was taken from the CDROM set entitled "Solar and Meteorological Surface Observation Network (SAMSON) 1961 - 1990" Version 1.0, September 1993.[121] Table 42 lists the data available in a SAMSON record.

Table - 42: SAMSON CDROM Data Records

Data Field	Description
Day - Date - Time	Local Standard Time
Location	Longitude and Latitude for station location
Extraterrestrial Horizontal Radiation	Amount of solar radiation in Wh/m^2 on a horizontal surface at the top of the atmosphere during the 60 minutes preceding the hour indicated
Extraterrestrial Direct Normal Radiation	Amount of solar radiation in Wh/m^2 on a surface normal to the sun at the top of the atmosphere during the 60 minutes preceding the hour indicated
Global Horizontal Radiation	Total amount of direct and diffuse solar radiation in Wh/m^2 on a horizontal surface during the 60 minutes preceding the hour indicated
Direct Normal Radiation	Amount of solar radiation in Wh/m^2 received within a 5.7 degree field of view centered on the sun during the 60 minutes preceding the hour indicated
Diffuse Horizontal Radiation	Amount of solar radiation in Wh/m^2 received from the sky (excluding solar disk) on a horizontal disk during the 60 minutes preceding the hour indicated
Total Sky Cover	Amount of sky dome covered in 10ths by clouds
Opaque Sky Cover	Amount of sky dome covered in 10ths by clouds that prevent observing the sky or higher cloud layers
Dry Bulb Temperature	Dry bulb temperature in °C
Dew-Point Temperature	Dew point temperature in °C
Relative Humidity	Relative humidity in percent
Station Pressure	Station pressure in millibars

120 Rymes, Martin, "Beyond Version 1.0 of the National Solar Radiation Data Base," National Renewable Energy Laboratory, Golden, Colorado, 1994.

121 NOAA, U.S.Department of Commerce, National Climatic Data Center, Ashville, NC. (704)271-4272.

Data Field	Description
Wind Direction	in degrees
Wind Speed	in m/s
Visibility	Horizontal visibility in km's
Ceiling Height	in meters
Present weather	see SOLMET weather codes
Precipitable Water	measured in millimeters
Broadband Aerosol Optical Depth	broadband aerosol optical depth (broadband turbidity) on the day indicated
Snow Depth	depth in cm
Days Since Last Snow Fall	days
Hourly Precipitation	inches and hundredths for each hour that precipitation is reported

This version was completed in 1992 and contains hourly measured and modeled solar radiation and collateral meteorological data for 239 stations across the United States for a 30 year period. The data was processed an screened for all known problems at the time V1.0 was prepared. Subsequently, three problems were identified in the data from 30 of the 239 site. These problems included the incorrect assignation of time zones for 23 sites, quality problems effecting daytime global horizontal solar irradiance for 8 sites, and inaccurate daily temperature statistics effecting temperature based daily statistics in all 30 sites. These errors were corrected, and an updated revision was released Version 1.1, [Rymes, 1994]. Data used for this project originated at the Blue Hill Observatory, and was not included in the list of 30 deviant sites.

Historical Background and Future Data Quality in the NSRDB

Most of the data in the NSRDB was modeled from meteorological data with only 7% derived from measured solar data. Future plans propose increased usage of solar irradiance information surmised from satellite observations. The resulting images and derived data can be used to produce more uniform and wide ranging data sets providing usable data for even the most remote sites. Most meteorological-based solar irradiance models rely heavily on surface cloud observations, and with the implementation of the National Weather Service Modernization Program cloud observers are being replaced by the Automated Surface Observing System (ASOS), see §4.1.2. These data in combination with satellite based irradiance data promise to yield more accurate results.

4.1.2 ASOS - Automated Surface Observing System

The ASOS is designed to support aviation operations and weather forecast activities and, at the same time, support weather observation needs of the hydrometeorological, climatological and meteorological research communities. The ASOS will provide continuous, minute by minute observations and perform the basic observing functions necessary to generate Surface Aviation Observation (SAO) and other aviation weather information, [ASOS, June 1992]. Basically, this system is designed to gather weather data only, (ie. no readings of solar intensity direct or otherwise).

Although no solar insolation data is recorded in this data set, it is believed that the real-time weather data and observations recorded in this format can be used to produce believable values for the direct normal solar radiation that would have been otherwise recorded during the same time the weather data was recorded. The resulting data would then provide the sought after high frequency solar excitation discussed in the proposal for this project.[122]

In 1992, NOAA began to implement a program called the Automated Surface Observing System (ASOS). The equipment developed for the program is designed to sample and record one minute temperature data and five second wind data. Forty-five to fifty primary sites located at airports around the United States were chosen for initial development of the ASOS program. Additional sites will be operational by March 1995, and the maximum number of sites will be operational by 1997. The information gathered and recorded are outlined in Table 43. Quality control (QC) is addressed in the ASOS manual. Three levels of control are described: (1) local; (2) regional; and (3) national. QC at the national level is accomplished by the NCDC, and is done on all data prior to archive.

For the purposes of this and similar projects, the primary source for ASOS data should be the archive records at the NCDC. The NCDC downloads ASOS data from all stations directly through computer links. These data are processed in a quality control procedure which looks for anomalies (data that falls outside normal expected ranges). Attempts are made to reconcile inconsistencies as they are

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122 ASHRAE 825-TRP, Sub-Task 7, Need for Availability for Sub-One-Hour Data (MIT/LUT).

Table - 43: ASOS Data Records

LN	ASOS High Resolution Data	Sample Frequency
1	cloud height reading (ceilometer data)	30 second
2	visibility extinction coefficient	1 minute average
3	photometer reading	1 minute
4	ambient temperature	1 minute average
5	dew point temperature	1 minute average
6	wind speed and direction (reported every minute)	2 minute average
7	wind speed and direction for each minute	max 5 second avg
8	precipitation identification sensor data	1 minute
9	lightning data *	1 minute
10	precipitation amount	1 minute
11	incremental precipitation amount stored every 15 minutes	15 minute
12	sunshine data *	1 minute
13	frozen precipitation water equivalent *	1 minute
14	snow depth *	1 minute
15	freezing rain occurrence	1 minute
16	average pressure for each pressure cell	1 minute

* Anticipated data collection when sensors become available, [ASOS, June 1992].

encountered by various means. Included in the bag of tricks for fixing data are collateral human observations and reports submitted according procedural guide lines by local on-site personnel to record equipment failures, calibration problems, or any other disturbing influence which may result in anomalous readings.

Data from the ASOS program has been generally of high quality.[123] When problems are discovered it has usually been with precipitation, visibility, and sky coverage. It was proposed in conversation with the NCDC representative that the reason for these phenomena is in the way this kind of information is

123 Conversation with a representative of the Surface Observation Data Operations Branch of the NCDC, Asheville, NC, December, 1995.

gathered by the ASOS equipment. Overall, actual conditions may be obscured by localized, narrow fields of view for the sensing devices capturing this information. No problems have been reported with values for the extinction coefficient, although it may be wise prior to drawing upon this resource that some additional investigation be made to learn more about how this piece of data is measured and what effects its quality.

Presently sunshine is not part of the ASOS equipment gathered data set. However, it is the intention of the program to eventually make this an ASOS function. Collateral sunshine data is reported in archived ASOS reports for those stations which have the capability to record sunshine. The device used to measure is the standard pyrheliometer used in other observation programs. Sunshine recorders are relocated from time to time, and a list of current locations can be obtained from the NCDC. The sunshine data received is checked and matched with the ASOS data on site at the NCDC.

Cloud cover data for observations above 12,000 feet are made by satellite. These data, like the sunshine data, is received at the NCDC where they are "Q" checked and then linked with the appropriate ASOS data set, adding another data feature to the total data package.

ASOS Data Set Availability

The best source for ASOS data is the National Climatic Data Center (NCDC) in Asheville, North Carolina, and they may be ordered by contacting the NCDC. Data sets obtained from the NCDC are quality controlled and corrected for all known errors. In addition, these data sets will contain the collateral data not collected directly by the ASOS equipment, but obtained simultaneously through other local sensors, (for example sunshine and cloud cover above 12,000 feet). Normally, the data sets obtained from NCDC are daily or monthly summaries with data averaged and reported at one hour intervals. The raw data on which the one hour interval reports are based is received by NCDC and it is surmised that data sets with resolutions finer than one hour may be obtained on special request.

There is a chance that raw data sets may be obtained directly from ASOS sites or through the ASOS data network. The frequency of reporting being exactly what is advertised in Table 43. However, due to the absence of collateral data collected by other instrumentation and the high likelihood of random errors (calibration, malfunctions, or other), there is little advantage to obtaining raw, uncorrected data.

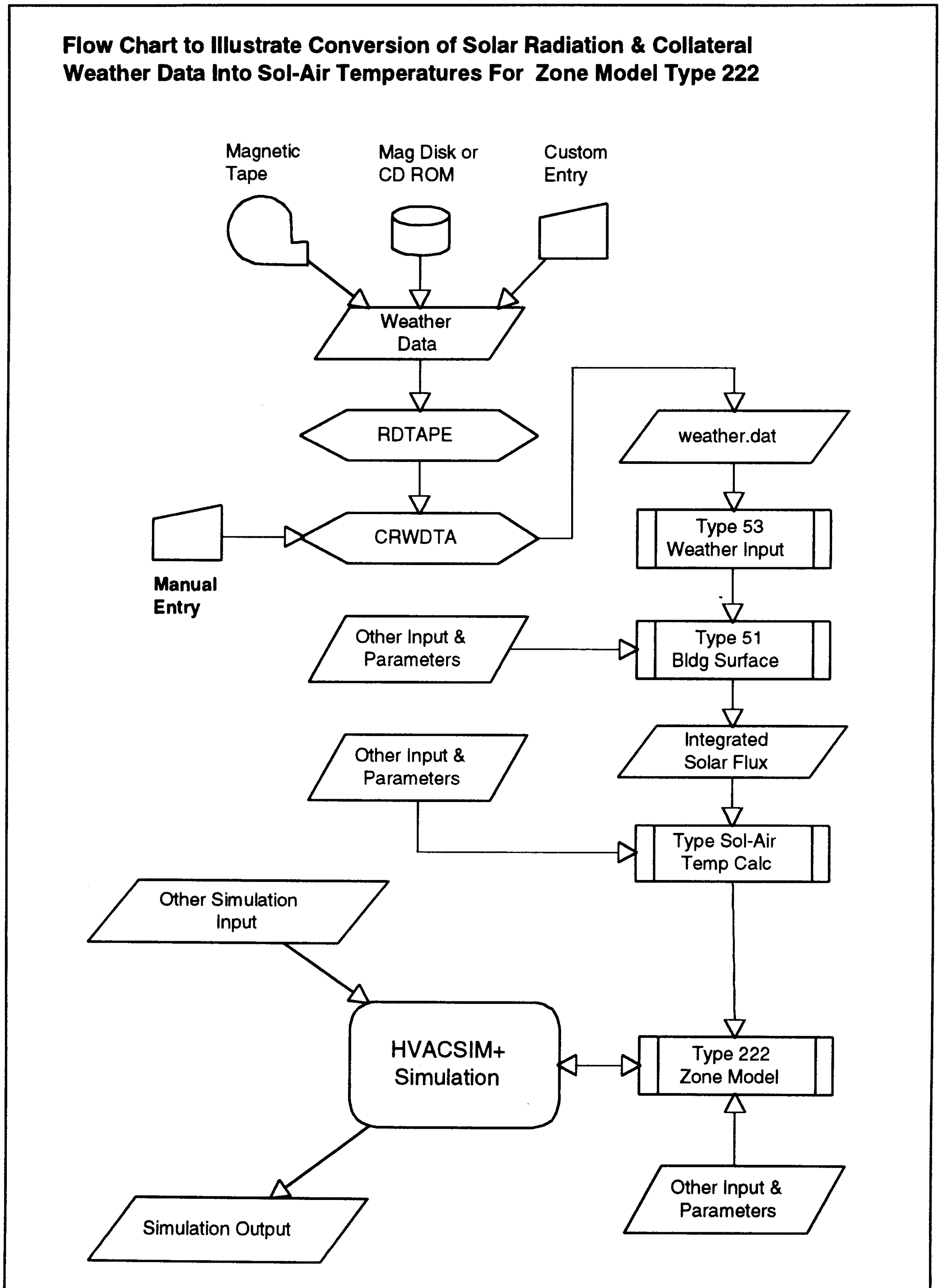

Figure 12: Flow Chart for Solar and Weather Data Compilation

4.2 Solar Radiation & Collateral Weather Data Preparation

There are a number of possible ways, automated and manual, to use data from the standard sources mentioned in §4.1. These sources include SOLMET; TMY; TRY; WYEC; SAMSON; ASOS; or Custom Configuration. An automated method draws data directly from the media on which it is provided from NOAA, and processes the data to yield the necessary sol-air temperatures. Manual entry may be used if the data in any of these forms does not meet a given set of requirements. In this case, one may go directly to generating the HVACSIM+ input file weather.dat.

4.2.1 Automated Data Reading and Sol-Air Temperature Calculation

HVACSIM+ Assisted Data Procurement and Processing

A semi-automated system for in-putting solar and collateral weather data into an HVACSIM+ simulation can be implemented in a sequence similar to that outlined in Figure 12. The system makes use of data available in a standard format from several sources and converts these data into a format compatible with the automated processing available through specific HVACSIM+ simulation types. In this scheme, each zone is modeled as a system of walls with or without windows (including floor, ceiling, vertical walls), and for each wall, the net energy flux due to solar radiation would be calculated. The incident energy for each wall would then be integrated over all walls for each zone to calculate an average, weighted sol-air temperature. A review of current HVACSIM+ types revealed that the specific formats required to implement an automated scheme were not available in the context of this project, and a manual scheme for generating of sol-air temperatures was used, see §4.2.2. This does not preclude the development of an automated system for generating the required parameters in the context of similar future projects. If this is to be accomplished, additional development work is necessary to modify existing HVACSIM+ types and possibly to add new types. For reference, the steps to be followed for a proto-typical automated input scheme are reviewed in the following sub-sections.

Reading & Writing - Data are read from the selected media by a stand alone utility program available in the HVACSIM+ package called *rdtape.exe*. The source code is provided to allow the program to be compiled for the immediate requirements. This program is designed to read selected information from the taped format and write it in a file called *wtpout.dat*. This intermediate process is required to gather the required input data into a form which is compatible with the computer equipment being used for the simulation, [Clark, et.al., NBSIR 85-3243, p. 40].

Creating the Weather Data File - In this step, the selected data are processed into a format which is required for all further calculations. If standard or custom data are not available, or it is desirable to have solar and collateral weather data generated according to some pre-ordained guidelines then the HVACSIM+ stand-alone utility *crwdta.exe* can be used to "generate smooth 'design day' solar radiation and temperature data for clear or cloudy" conditions; as with *rdtape.exe*, source code is also provided with this program to allow customization to local requirements. The latitude, longitude, and time zone must be entered at the start of the conversion process. An output data file, *weather.dat*, is created which contains month, day, hour, dry-bulb temperature (°C), barometric pressure (kPa), wind speed (m/s), humidity ratio (-), direct beam solar radiation (W/m^2), sky diffuse radiation (W/m^2), and total horizontal radiation (W/m^2). Assuming constant relative humidity, the humidity ratio is calculated using expressions found in the ASHRAE 1981 Handbook §6, and the three items relating to solar radiation flux are calculated from geographic location and sun position.

Indexing Input Data - Data in *weather.dat* are further prepared for use by HVACSIM in Type 53 - Weather Input. The Type 53 unit places the input data into a state vector which is used by a utility subroutine.

Calculating Integrated Normal Solar Flux Values - A building surface simulation type calculates integrated solar flux values normal to the surface. In the prototype automated system Type 51 is used for this purpose and the calculation of the corresponding sol-air temperatures. In addition, Type 51 goes one step further an calculates an inner surface temperature. It takes into account compass orientation, wall surface area, tilt angle, the relevant qualities of the immediate surrounding environment including shading, ground reflectivity, and the conductive heat transfer properties of each wall. In the context of this project, only outside equivalent surface temperatures are required. Consequently, the only relevant information provided in this step using for example a Type 51 would be the integrated normal solar flux.

Calculating Equivalent Sol-Air Temperatures - An HVACSIM+ type would then be used to calculate equivalent sol-air temperatures for each individual exterior surface based on equations in ASHRAE 1993 Fundamentals §26 and §27. In the context of this project, an additional step is necessary to calculate an equivalent sol-air temperature characterizing environmental effects distributed over the entire exterior surface of a zone.

4.2.2 Manual Data Reading and Sol-Air Temperature Calculation

Data from NSRDB V1.0 was used to develop sol-air temperatures for this project. The data for a selected day was taken from the SAMSON CDROM database and imported to a spreadsheet. A spreadsheet based calculation scheme, based on the equations presented in §2.2.1, was used to produce weighted, average sol-air temperatures for each sub-zone exterior surface. It is proposed that future simulations include an HVACSIM type which can take the input data used in the spreadsheet calculations and automatically generate the necessary sol-air temperatures.

5 Implementation of the Real Building Specification

The building and HVAC system specification prepared in §3.3 is mapped into the HVACSIM+ computer simulation package in this section. The system model may be organized from two points of view. The first view point may consider the physical system, a building and its mechanical system divided into discreet, logical parts - the mechanical room containing the air conditioning and control systems and the conditioned space containing the duct distribution system and associated equipment, the zone volumes, and input components. Superblocks in this scheme would contain all the components needed to model each logical grouping. Such groupings are demonstrated in the two schematics depicted in Figures 186 and 187, (refer to Table 44 for type names). The second view point may consider the actual HVACSIM+ component types which would be used in a simulation, and organize them according to the category of component by which they can be described.[124]

In the sample simulation provided by Haves (and reproduced for reference in Appendix AA) the model was organized into ten categories:

(1) Simulation Real-Time Input Devices - used for input activity in real time during a simulation, in addition psychrometric characteristics for airflows may be altered within the simulation;

(2) Controllers and Control System Components - contains all controllers and associated devices in the simulation;

(3) Actuators - actuators for coil control valves and dampers are included in this section;

(4) Airflow Components - all components associated with the calculation of air flow rates and pressure through the system;

(5) Place Holder for Future Expansion;

(6) Thermal Components - contains all components associated with the calculation of temperatures;

(7) Place Holder for Future Expansion;

(8) Sensors Devices - all sensors in the system are grouped in this category;

(9) Simulation Real-Time Output Devices - another grouping of real time interfaces;

(10) Place Holder for Future Expansion.

124 Simulation prepared and executed by Phil Haves, Loughborough University of Technology, Loughborough England, 1995.

Three additional categories are provided for in the sample simulation, and it is intended that future simulations will include components requiring category designations not included in the current seven.[125] The categories not currently used include Both points of view are helpful in the process of model conceptualization. However, the latter is mathematically more efficient in the context of the HVACSIM+ program package.[126] Consequently, the modeling philosophy used in this project coincides with the grouping by similar component types mentioned above.

There are two methods available for modeling air flow. The "Implicit Flow" develops volumetric flow rates on an as needed basis. The model adjusts automatically the amount of air flowing in the system according to the demand requirements from the zone(s) being conditioned. Leakage is made up by adding the appropriate amount of air at exterior ambient conditions to the flow at the mixing box. In an explicit simulation, the volumetric flow rates in the system are specified by the demand requirements from the zone(s) being conditioned and the supply fan and return fan are manipulated in an effort to accommodate the demanded flows. Although the explicit method is more desirable for the purpose of this project in producing a testbed, the implicit method can be useful. During development and testing, implicit simulations provide the utility of being able to run unencumbered by airflow component problems.

Test and Verify Sub-Systems in HVACSIM Model - Testing and verification of the systems developed will be accomplished by LUT. Once tested and certified operable by LUT, the simulated plant and controls will be commissioned and comprehensive graphical output will be produced to demonstrate the operation of both the simulation and control strategies.

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125 The simulation detailed in Appendix AA is an attempt to set a standard format for superblock categories. The current version of HVACSIM+ limits the number of superblocks in a simulation to 10, and in addition, the numbering of superblocks, blocks and units is sequential and consecutive. This forces superblocks, blocks, or units added after a simulation is input to be numbered out of sequence. By naming three superblocks to act as place holders, some semblance of standardization is implemented and may be maintained for future additions.

126 The reader is directed to the National Bureau of Standards Document NBSIR 85-3243 HVACSIM+ Building Systems and Equipment Simulation Program Users Guide. by Daniel Clark & William May, September 1985, for a detailed discussion regarding model development philosophy and the mathematical solver.

5.1 HVACSIM+ Schematic

The components listed in Table 44 were selected by LUT from the large assortment of component type models available in the HVACSIM+ Program Library. The table identifies components used in the simulation of Building E51 and the corresponding quantities. Two sets of type numbers are given in the table: the "old" set refers to the type numbers used in this thesis for developing the HVACSIM+ parameters describing Building E51; the "new" set refers to a modified set of HVACSIM+ type models which more accurately describe the complexities of the model building. The selected components are arranged in the simulation according the superblock groupings suggested in §5, as proposed by the LUT team. A schematic showing the airflow components is presented in Figure 188, and prototype arrangements outlined in the schematics presented in Figures 186 and 431 show how thermal components in a mechanical room model and a zone model might be arranged.

Table - 44: HVACSIM+ Component Model Type Summary

HVACSIM+ Type Number		Bldg E51 Simulation		Component Class	Description
Old	New	Used	Quantity		
007	301	yes	as req'd	Sensor	Temperature sensor
026	(026)	yes	as req'd	Place Holder	Control signal inverter
087		yes	1	Actuator	8-way patchboard
102	327	yes	1	Airflow	Mixing box + dampers
109		no	----	Airflow	Addition of 3 moist air streams
110		no	----	Airflow	Mixing of 3 moist air streams
133		yes	1	Input	Psychrometrics
134	525	yes	6	Airflow	Pressure-independent vav box (Belimo controller)
135	(511 - 518)	yes	1	Output	Write 16 reals to Unix socket
167		no	----	Control	VAV ideal flow control
168		no	----	Control	VAV Rate limit actuator w/deadband and hysteresis
169	(365)	yes	34	Thermal	Moist air duct, heat loss as output, humidity delayed

HVACSIM+ Type Number		Bldg E51 Simulation		Component Class	Description
Old	New	Used	Quantity		
189	303	yes	as req'd	Sensor	First order velocity sensor model
196	504	yes	1	Input	Read 16 reals from Unix socket
197		yes	1	Output	Graphs of pressure, flow and control
200	333;481; 482	yes	1	Control	Fan controller with tracking (P.Haves - lut - 7.9.93)
201	347	yes	2	Airflow	Fan or pump model
203	305	yes	as req'd	Sensor	First order static pressure sensor model
204	346	yes	5	Airflow	Flow merge model
205	366	yes	2	Thermal	Fan or pump model, power and temperature rise only
207	345	yes	6	Airflow	Flow split model - different resistances, treats near-zero flow (P.Haves - LUT - 4/8/93)
210a		yes	6	Airflow	Mixing of multiple air flows with leakage
211	367	yes	as req'd	Thermal	Mixing of moist air streams
212	368	yes	as req'd	Thermal	Mixing of Moist Air Streams
228	341	yes	20	Airflow	Constant flow resistance model linearised at low flow (P.Haves - University of Oxford - August 1992) modified 20/9/93 to use function dpturlam
229	342	yes	5	Airflow	Inlet constant flow resistance model
272	403	yes	12	Thermal	2 node room/plenum Model - rs and cs as parameters, ducted return
275	485	yes	1	Control	C-1-1 simple reversing control for mixing dampers w/ cooling demand - separate manual control of each damper

HVACSIM+ Type Number		Bldg E51 Simulation		Component Class	Description
Old	New	Used	Quantity		
276	490	yes	6	Control	VAV terminal box with reheat
281	489	yes	1	Control	Supply temp sp for vav ahu w/ heating
282	486	yes	1	Control	Generation of AHU plant demands with boost over-ride on clg coil
283		yes	1	Control	Component on/off controller - uses up to six demands to switch component on and off - includes delay and hysteresis
299	522	yes	7	Thermal	Heating/cooling coil w/ 1 &g 3 port valve
300	321	yes	as req'd	Actuator	Rate limit actuator model with "deadband" and hysteresis (adapted from type100 by P.Haves - LUT - 16.6.94)

The schematics detail a simulation in which the airflow is implicitly determined, and the components used to model airflow in the implicit model are not the ones used in the Building E51 explicit flow model. However, the thermal components in the B51 simulation are similarly arranged, and the schematics show the juxtaposition of the relevant components. It can be noted that there will be some variation from the schematics in the final E51 model, particularly in the areas showing thermal contact between zones. The complexities of thermal contact between zones in the original thirty-four zone configuration were preserved in the six megazone simplified system significantly increasing the number of thermal components and resulting connections. When the E51 model is finalized, a more comprehensive schematic may be developed showing the relationship between all components, detailing the individual variable connections and information paths.

Table 44 summarizes the list of candidate HVACSIM+ component types chosen for inclusion in this project at the time this report was written, and Appendix Z provides a concise listing of all inputs, outputs, and parameters for the candidate types. In the next phases of this projects development additional types will be added to this list; the list of types to be added or updated includes some control system types, airflow components, and thermal components.

5.1.1 Air Flow Component Network

The airflow component network depicted in Figure 188 is modeled on the basis of the flow paths outlined in Figure 64 depicting the supply and return duct systems, the various inter-zone connections identified in the original thirty-four zone configuration, and paths due to infiltration and exfiltration. The pressure difference between a zones room and plenum volumes is considered to be equal to zero, hence, mass flow across the suspended ceiling, if any, is ignored.

Much of the HVACSIM+ flow network is comprised of individual components or sub-systems are designed to model specific parts of the real system. An economy in the total number of units required to model a system is achieved by such groupings. An example is found in the supply duct system. Here duct lengths and fittings are divided into pieces which are mapped directly into HVACSIM+ types. The pieces are composed of one or more parts, and the parameters for the corresponding HVACSIM+ type represented by the individual flow resistance values which describe the flow characteristics of each part. The Type 207 Flow Split discussed in §5.2.3.5 is an example of this construct, and is a composite of one flow resistance splitting into two; a fitting in the supply system and a five foot section of duct leading up to the fitting provided the basis for the model. Referring to resistance values Rs1, Rs2 and Rs4 depicted in Figure 199 and named in Figure 204, Rs1 represents the flow resistance in a 5 foot duct section and Rs2 and Rs4 represent the flow resistances in the branch and main legs of a wye type duct fitting.

Other elements of the flow network are modeled as the individual pieces themselves rather then as the sub-systems previously discussed. This was necessary when a discreet, unique component part of the flow system could not be modeled by an existing HVACSIM+ type, and in addition, the part could not be subdivided into parts that could be easily mapped into other existing HVACSIM+ types. Designing a new HVACSIM+ type was an option which may still be viable. However, at the time this work was completed, the most feasible method for handling these unique circumstances was to construct the discrete component as a composite of basic components.

An example of this is illustrated in the elements representing the mixing box. Referring to Figure 188, 192 and 193, the mixing box is comprised of fixed and variable flow resistances. Providing for the opportunity to assemble a configuration of HVACSIM+ elements to exactly resemble the mixing box allows the highest flexibility in adapting the techniques developed in this project to other systems in the future. This technique adds to the complexity and unwieldiness of a simulation and should be limited to the least number of sub-systems as possible.

5.1.2 Thermal Component Network

The thermal component network was assembled from existing HVACSIM+ types, and accounts for heat transfer throughout the building. The major components in the network include the individual zone models, the reheat coils and perimeter heating system, heat flow characteristics of the supply and return duct systems related to air flow and conductive transfer through the duct walls , the cooling coil in the mechanical room. Heat input to the air stream as a result of the supply and return fans is also accounted for in this network.

5.2 HVACSIM+ Components

The following sections detail the parameters for the components used to model Building E51, and how the parameters were developed. Parameter value sources included manufacturers specifications, visual inspections, analysis, educated guesses and design. The format used to present the parameters is divided into three parts; typically a summary of what types are being discussed in a particular section is followed by a summary of the associated parameters, which in turn is followed by all relevant substantiation. The substantiation includes all references, analysis, educated guesses, and design work required to generate the parameters, and is found in the Appendices T through X.

Each of the sub-sections under §5.2 correspond to one of the categories into which the simulation components have been organized. Each of these subsections are divided further according to the HVACSIM+ types corresponding to each category. The type information is organized in ascending numerical order according to the HVACSIM+ type numbers. The appendices are organized in the same order in the same fashion, providing a one to one correspondence with the text.

5.2.1 Simulation Real-Time Input Devices

5.2.1.1 Type 133 - Psychrometrics

The HVACSIM+ Type 133 model computes relative humidity, air humidity ratio, air enthalpy, and dew point temperature from input dry and wet bulb air temperatures, refer to p. 493 for type model outline. LUT will provide parameters for the Type 133 unit used in this simulation.

5.2.1.2 Type 196 - Read From Unix Socket (16 Reals)

Parameters for units included in the simulation which come under this category were prepared by the LUT team, refer to p. 495 for type model outline.

5.2.2 Controllers - Types per LUT

HVACSIM+ controller model types were designed and implemented by the LUT team. This includes the control system for the mechanical room equipment and the control system for the individual zones, including the perimeter heating systems, VAV dampers and reheat control valves. The proposed method for modeling the Building E51 control system was to use individual HVACSIM+ components designed to mimic the function of the components in the Metasys GPL system and assembled them into compounds matching the strategy in the existing system. Refer to the LUT report for details regarding how the solution was actually implemented.

5.2.3 Type 300 - Actuators

Actuators for controlling the following systems in the model of E51 are named in the following list:

(1) Damper - Mixing Box Minimum Air
(2) Damper - Mixing Box Economizer Air
(3) Damper - Mixing Box Return Air
(4) Damper - Mixing Box Exhaust Air
(5) Valve - Climate Changer Cooling Coil
(6) Damper - Zone I VAV Box
(7) Valve - Zone I VAV Box Reheat Coil
(8) Damper - Zone II VAV Box
(9) Valve - Zone II VAV Box Reheat Coil
(10) Damper - Zone III VAV Box
(11) Valve - Zone III VAV Box Reheat Coil
(12) Damper - Zone IV VAV Box
(13) Valve - Zone IV VAV Box Reheat Coil
(14) Damper - Zone V VAV Box

(15) Valve - Zone V VAV Box Reheat Coil

(16) Damper - Zone VI VAV Box

(17) Valve - Zone VI VAV Box Reheat Coil

Values for the parameters associated with the seventeen actuators named in the preceding list are tabulated in Figure 189, refer to p. 504 for type model outline. Sixteen parameter set are listed in the table, and it is intended that the set identified for the mixing box fresh air be used for both the minimum air damper and the economizer damper. The damper motors chosen for this project are direct digital controlled. The mixing box dampers rotate 90 degrees and specifications for the associated motors were taken from information provided by the LUT in the sample simulation ACREF2 included in Appendix AA. Specifications for the other motors are drawn from the proposed alternatives for the existing pneumatic units mentioned in §3.3.3.1.5 and §3.3.3.4.3.

5.2.4 Airflow Components

5.2.4.1 Type Various - Mixing Box

A single HVACSIM+ type was not used to model the mixing box in Building E51. Instead the mixing box was modeled as an assemblage of smaller, discreet elements. The elements characterize the fresh air dampers, exhaust damper, return damper, and high capacity filter and cooling coil combination. In addition, minor elements consisting of air flow resistances for the bends and transitions in and around the immediate vicinity of the box are also included to complete the connections between the major elements. A diagram of the mixing box is shown in Figure 192, and dimensions are shown in Figure 148. The values of these components are summarized in Table 45. For reference, and possible future development, a twenty-two parameter HVACSIM+ Type XXX which includes the elements identified in Table 45 is presented in Figure 190. An outline of HVACSIM+ Type 102 Mixing Box is provided for reference on page 492.

The resistances for the Arrow dampers are calculated with the blades in a wide open condition based on areas noted in Figure 61. According to the manufacturers specifications the loss coefficient varies as the flow rate through the Arrow units. Referring to Figure 191, a series of resistances were calculated based on the pressure drop vs. flow speed curve in Figure 104. The values selected for this project are underlined in the figure, and correspond to the design flow rates specified in the Building E51 Engineering Design Specifications shown Appendix H.

Table - 45: Type XXX Mixing Box Element Parameter Values

Resistance Designation	Value [1/kg-m]	Reference
Rr1	1.64e-01	see Figure 201
Rr2	0.00e+00	see Figure 201
Rr3	3.80e-01	see Figure 201
Rr4	2.85e-01	see Figure 201
Rr5	1.18e-01	see Figure 201
RsA	4.12e-01	see Figure 198
Rmb	1.09e-02	see Figure 198
RsF	6.25e-01	see Figure 198
RrE	4.78e-01	k=1.25 Arrow cut sheet @ 1600 fpm face velocity, Figure 104
RrR	4.78e-01	k=1.25 Arrow cut sheet @ 1600 fpm face velocity, Figure 104
RsMin (1)	3.26e+00	k=1.25 Arrow cut sheet @ 1600 fpm face velocity, Figure 104
RsEcon (1)	2.75e-01	k=1.25 Arrow cut sheet @ 1600 fpm face velocity, Figure 104

These values are calculated on the basis of the following two formulas relating hydraulic resistance to mass flow rate:

$$R_{hydraulic\ resistance} = \dot{m}^2 \Delta P \ ; \tag{124}$$

and pressure drop and a pressure loss coefficient to the ration of pressure drop to velocity pressure:

$$k_{loss\ coefficient} = \frac{2\,\Delta P}{\rho\, v^2} \ ; \tag{125}$$

or equivalently:

$$R_{hydraulic\ resistance} = \frac{k_{loss\ coefficient}}{2\,\rho A^2} \ . \tag{126}$$

Loss coefficients and pressure losses for manufactured equipment were obtained from catalog cut sheets. Resistance values for common duct sections and fittings are based on technical information from the SMANCA Duct Design Calculator and 1898 ASHRAE Handbook Fundamentals, Fitting Loss Coefficient Reference Guide, F32.27 - F32.52.

5.2.4.2 Type 134 - Pressure Independent VAV Box

HVACSIM+ Type 134 is used to model the six VAV boxes required for this project, refer to Figure 188. Titus Single Duct Pressure Independent Terminal Boxes were chosen to match the megazone design requirements. Technical specifications for the box including damper and actuator, reheat coil and control valve, and sound attenuation can be found in Figures 117 through 140. All boxes except the one applied to Megazone III (MZIII) is a standard commercially available size. The box for MZIII

Table - 46: Type 134 VAV Terminal Box Parameters (refer to Figure 194)

Parameter Num		1a	1b	2	3	4	5	6	7
Mega-Zone	Size	Flow Rate		Damper Area	Air Press Drop	Actu-ator Time	Frac Motor Speed	Hyst-eresis	Cont-roller Gain
[---]	[---]	[cfm]	[m³/s]	[m²]	[Pa]	[sec]	[---]	[---]	[---]
I	16	1,773	0.837	0.128	38	30	1	---	10
II	7	280	0.132	0.024	20	30	1	---	10
III	48x16	9,180	4.330	0.490	76	30	1	---	10
IV	16	1,696	0.801	0.128	35	30	1	---	10
V	24x16	5,020	2.369	0.245	91	30	1	---	10
VI	10	640	0.302	0.049	36	30	1	---	10

is configured to equal two commercially available 24" x 16" boxes side by side, see §3.3.3.4.1 for related details. The parameters for the six Type 134 models used in this simulation are presented in Table 46, refer to p. 493 for the type model outline.

The stock version of HVACSIM+ Type 134 was modified by the LUT team to calculate the pressure drops based on the manufacture specification for pressure drop across box, coil, and damper when damper is wide open. Also include parameter for wide open resistance. Note that the resistance parameter is calculated on the basis of a pressure drop stated in the manufactures specification for ΔP across the box, coil, and wide open damper, for a specified flow rate, so it may be redundant to have the resistance as a separate parameter. A more expedient method would be to input the manufactures specifications as they appear in the cut sheets and let the HVACSIM+ type calculate the required values. An automated procedure would help reduce the likelihood of errors.

5.2.4.3 Type 201 - Centrifugal Fans

The supply and return fans are modeled HVACSIM+ Type 201. The HVACSIM+ fan model chosen computes a pressure rise and efficiency based on the mass flow rate through the system, refer to p. 497 for the type model outline. The fan diameter, the identity of the fluid being moved by the fan, and the dimensionless performance curves (pressure vs. flow and efficiency vs. flow), represented by 4th order polynomials, are required inputs. The dimensionless function coefficients are presented in Table 47.

Table - 47: Type 201 Supply and Return Fan Parameters

Num	Description	Supply Fan	Return Fan
1	1st Pressure Coefficient	8.534e-01	9.816e+00
2	2nd Pressure Coefficient	-3.929e+00	-2.396e+01
3	3rd Pressure Coefficient	4.229e+00	1.221e+01
4	4th Pressure Coefficient	-1.387e+00	-1.634e+00
5	5th Pressure Coefficient	4.290e+00	4.194e+00
6	1st Efficiency Coefficient	-1.971e-01	-3.375e+00
7	2nd Efficiency Coefficient	7.664e-01	6.168e+00
8	3rd Efficiency Coefficient	-1.483e+00	-5.755e+00
9	4th Efficiency Coefficient	1.540e+00	3.142e+00
10	5th Efficiency Coefficient	1.162e-01	6.190e-02
11	Diameter [m]	0.686	1.12
12	Mode: air=1 water=2	1	1
13	Lowest Valid Normalized Flow*	1.00e-05	1.00e-05
14	Highest Valid Normalized Flow	1	1

* This number must be set to a value greater than 0, [Hill, June 1995].

The polynomials representing the fans characteristics in the form a dimensionless pressure head function and efficiency are expressed in the following equations:

$$\Delta\bar{\Pi}(\dot{M}) = a_4\,\dot{M}^4 + a_3\,\dot{M}^3 + a_2\,\dot{M}^2 + a_1\,\dot{M} + a_0\ ;\ and \tag{127}$$

$$\eta_t(\dot{M}) = e_4\,\dot{M}^4 + e_3\,\dot{M}^3 + e_2\,\dot{M}^2 + e_1\,\dot{M} + e_0\ ; \tag{128}$$

and the dimensionless pressure head and dimensionless mass flow variable are given by:

$$\Delta\bar{\Pi}(\dot{M}) = \frac{1000\ \ \Delta P(\dot{M})}{\rho N^2 D^2}\ ;\ and \tag{129}$$

$$\dot{M} = \frac{\dot{m}}{\rho N D^3}\ ;\ and \tag{130}$$

$$\eta_t(\dot{M}) = \frac{W_o(\dot{M})}{W_i(\dot{M})}\ ; \tag{131}$$

where: $\Delta\bar{\Pi}(\dot{M})$	=	pressure rise (P_{outlet} - P_{inlet}) across the fan for flow rate $\dot{V}$	[kPa]
ρ	=	fluid density	[kg/m^3]
N	=	fan rotational speed	[rev/s]
D	=	fan diameter	[m]
$\dot{m}$	=	mass flow rate for pressure $\Delta P(\dot{M})$ ($\rho\ \dot{V}$)	[kg/s]
$\dot{V}$	=	volumetric flow rate for pressure $\Delta P(\dot{M})$	[m^3/s]
$\eta_t(\dot{M})$	=	total fan efficiency for flow rate $\dot{V}$ [127]	
$W_o(\dot{M})$	=	total power output based on flow rate and fan total pressure	[W]
$W_i(\dot{M})$	=	total power input based on measured power at the shaft	[W]

127 1992 ASHRAE Handbook - Systems and Equipment, E18.1.

The coefficients a_0 - a_4 and e_0 - e_4 for the dimensionless curves $\Delta\bar{\Pi}(\dot{M})$ and $\eta_t(\dot{M})$ were obtained by applying the MATLAB[128] polyfit function to digitized and smoothed fan curves constructed from the manufactures equipment performance curves for the supply and return fans presented in Figures 83 and 101. The rotational speeds specified in the Building E51 Engineering Design Specifications are not explicitly mapped in the manufacturer's performance curve plots.[129] Hence, it was necessary, through the use of the fan laws, to create them. This was accomplished in a three step process: first, curves for speeds close to the speed indicated and which are explicitly mapped were digitized;[130] second, the MATLAB polyfit function was applied to the digitized data to smooth local irregularities caused during the digitizing process; and third, the fan laws [1992 ASHRAE Handbook, HVAC Systems and Equipment, E18.4] were used to map the smoothed digitized data into the new curve space.[131]

The equations representing the smoothed and digitized curves of the supply and return fans were found to be:

$$P_{\frac{supply}{1300}} = -0.1772\,\dot{\forall}^6 + 1.860\,\dot{\forall}^5 - 7.347\,\dot{\forall}^4 + 13.44\,\dot{\forall}^3 - 12.04\,\dot{\forall}^2 + 4.918\,\dot{\forall} + 4.070\ ;\ and \qquad \textbf{(132)}$$

$$P_{\frac{return}{400}} = 0.134\,\dot{\forall}^4 - 0.719\,\dot{\forall}^3 + 0.803\,\dot{\forall}^2 - 0.236\,\dot{\forall} + 1.326\ . \qquad \textbf{(133)}$$

Then by using the fan laws, followed by the application of Equations 129 and 130 and the MATLAB polyfit function, the following dimensionless equations were obtained for the supply and return fan expressing pressure rise as a function of flow rate:

$$\Delta\bar{\Pi}(\dot{M})_{\frac{supply}{1340}} = 0.853\,\dot{M}^4 - 3.93\,\dot{M}^3 + 4.23\,\dot{M}^2 - 1.39\,\dot{M} + 4.29\ ;\ and \qquad \textbf{(134)}$$

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128 MATLAB, The MathWorks, Inc. Natick, Massachusetts, 1991.

129 1,340 rpm for the supply fan and 430 rpm for the return fan, refer to Appendix H.

130 The performance curve chosen as a basis for the supply fan parameter calculations was for the speed 1300 rpm. The 400 rpm curve was chosen for the return fan

131 This work was performed by Mit Student Paul Balun and is written up in his report titled Parameter Delineations of the Supply Fan and the Return Fan of a VAV HVAC System, Massachusetts Institute of Technology, Undergraduate Research Opportunity Program, Spring 1995

$$\Delta \bar{\Pi} (\dot{M})_{\frac{return}{430}} = 9.82 \ \dot{M}^4 - 24.0 \ \dot{M}^3 + 12.2 \ \dot{M}^2 - 1.63 \ \dot{M} + 4.19 \ . \qquad (135)$$

By combining the fans laws with Equations 130 and 131, values for efficiency as a function of dimensionless flow were calculated. Then by applying the MATLAB polyfit function to the resulting plot, the coefficients for Equation 128 were obtained, resulting in the following expressions for the dimensionless efficiency curves of the supply and return fans at the corresponding design speeds:

$$\eta_{t,\frac{supply}{1340}} = - \ 0.197 \ \dot{M}^4 + 0.766 \ \dot{M}^3 - 1.48 \ \dot{M}^2 + 1.54 \ \dot{M} + 0.116 \ ; \textit{and} \qquad (136)$$

$$\eta_{t,\frac{return}{430}} = - \ 3.37 \ \dot{M}^4 + 6.17 \ \dot{M}^3 - 5.76 \ \dot{M}^2 + 3.14 \ \dot{M} + 0.062 \ . \qquad (137)$$

5.2.4.4 Type 204 - Flow Merge

The HVACSIM+ Type 204 is a fluid flow merge model. A merge model consists of two inlet fluid flow resistances and one outlet resistance, refer to p. 498 for the type model outline. Five units are represented by this type to model the various flow merge points in the megazone return duct system, refer to Figure 188. The resistances assigned to each unit of the Type 204 variety and the corresponding values are shown in Figure 203, the placement of the resistances comprising each unit is shown in Figure 202. Calculations for the resistance values are shown in Figure 201.

5.2.4.5 Type 207 - Flow Split

The HVACSIM+ Type 207 is a fluid flow split model. A split model consists of one inlet fluid flow resistance and two outlet resistances, refer to p. 498 for the type model outline. Five units are represented by this type to model the various flow split points in the megazone supply duct system, refer to Figure 188. The resistances assigned to each unit of the Type 207 variety and the corresponding values are shown in Figure 204, and the placement of the resistances comprising each unit is shown in Figure 199. Calculations for the resistance values are shown in Figure 198.

5.2.4.6 Type 210a - Mass Balance for Multiple Air Streams

The intent of the HVACSIM+ Type 210a model is to balance the mass flow rates across the various megazone boundaries, and derives its structure from HVACSIM+ Type 210. Included in the model are flows related to flows due to mechanical ventilation, leakage through walls from megazone to megazone, leakage across the external shell, and system loss due the presence of extract fans such as lavatory or kitchen exhausts. Type 210 was designed to account for flow from three sources and calculate the resulting air mass flow rate of the mixed stream, refer to p. 499 for the type model outline. However, the Building E51 model requires a prototype which can handle up to five incoming streams. As a result, modification of the Type 210 model was necessary.[132] The designation Type 210a is used in this report for clarity to distinguish the unit required for this project and its namesake.

Table - 48: Type 210a Mass Balance for Multiple Air Streams (refer to Figure 206)

Parameter		Zone					
#	Description	I	II	III	IV	V	VI
1	External Shell Leakage [1/(kg-m)]	5.83e+03	7.40e+04	9.59e+01	1.24e+03	3.52e+02	1.40e+04
2	Local Extract Fan Mass Flow [kg/s]	0	0	0	0	0	0

Six Type 210a units are required for Building E51, one for each megazone, refer to Figure 188. The parameter list for Type 210a requires the resistance values for leakage across the external shell and the local extract fan flow rates. Air flow due to leakage between zones is calculated in a separate unit, and resultant flows are fed to the Type 210a units as an input value, consequently, parameters for air flow resistance modeling inter-zone leakage are not found in this type, see §5.2.4.7 Type 228. No extract fans are present in the areas of the building selected for inclusion in this model, and all corresponding parameter values are set to zero. The values for the parameters of the six Type 210a units are presented in Table 48. These values are based on the total area presented by the entire external shell surface of each individual zone, and are calculated in Figure 206.

132 Modification of Type 210 accomplished by LUT team.

5.2.4.7 Type 228 - Constant Flow Resistance - Linearized at Low Flow

The HVACSIM+ Type 228 units represent the constant flow resistances used to model various elements in the airflow network; included are the duct bends and straight duct lengths, grills and louvers, and miscellaneous duct transitions changing size or shape, (refer to Figure 188). Parameter values for Type 228 consists of the single hydraulic resistances shown in Figure 208, refer to p. 500 for the type model outline. Calculations for each individual element comprising the units are detailed in Figure 201.

5.2.4.8 Type 229 - Inlet Constant Flow Resistance + Negative O/P

The HVACSIM+ Type 229 units represent the hydraulic resistance to airflow between zones as depicted in Figure 188, refer to p. 500 for the type model outline. The airflow resistance is based on the expression for hydraulic resistance in terms of a loss coefficient k and the opening area transverse to the air flow:

$$R_{hydraulic} = \frac{k}{2\,\rho\,A^2}\ . \tag{138}$$

The loss coefficient in this case is expressed in terms of a dimensionless discharge coefficient C_D which depends entirely on the opening geometry and the flow's Reynolds number.[133] The flow through an opening can be expressed as:

$$Q = C_D A \sqrt{\frac{2\,\Delta P}{\rho}} \tag{139}$$

where: Q = airflow mass flow rate [m³/s]

- C_D = discharge coefficient for opening
- A = opening cross sectional area [m²]
- ρ = air density [kg/m³]
- ΔP = pressure difference across opening [Pa]

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133 1993 ASHRAE Handbook - Fundamentals (SI), F23.7.

Combing these equations with the expressions for $R_{hydraulic}$ and k in terms of the pressure difference across the opening:

$$R_{hydraulic} = \frac{\Delta P}{\dot{m}^2} \text{ ; and} \tag{140}$$

$$k = \frac{\Delta P}{P_v} \text{ ;} \tag{141}$$

the loss coefficient can be expressed as a function of the discharge coefficient:

$$k = \frac{1}{C_D^2} \text{ .} \tag{142}$$

Parameters values for interzone leakage hydraulic leakage resistance are presented in Table 49.

Table - 49: Type 229 Inlet Constant Flow resistance (refer to Figure 25, 209 & 188)

Parameter		Type 229 Unit				
#	Description	1	2	3	4	5
1	Flow Resistance [1/(kg-m)]	1.92e+02	8.55e+01	3.08e+01	5.35e+00	7.70e+02

The origin for inter-zone leakage in this model was assumed to be in the form of cracks around the doors located in the partitions separating the zones. Hence, the discharge coefficients were all set to 0.6 in accordance with a value proposed for a sharp edged orifice.[134] An alternative for determining interzone leakage would have been to use the empirical data presented in Table 4 and Figures 10 & 11 of 1993 ASHRAE (SI), F23.16. The data in Table 4 assumes a 75 pa pressure differential and a C_D = 0.65, and apply to internal partitions without doors, and the data in the figures apply to elevator shaft and door crack leakage. Discharge coefficients based on these data range between 0.4 and 0.8 depending on the crack width and wall construction chosen. These data indicate that contributions due to leakage through partitions without doors is approximately 5% of the leakage through a partition with

134 1993 ASHRAE Handbook - Fundamentals (SI), F23.12.

a few doors. Consequently, leakage through the partition wall material itself was entirely ignored in calculating a hydraulic resistances for interzone leakage presented in Table 49.

5.2.5 Type 026 - Control Signal Inverter

This HVACSIM+ Type 026 Control Signal Inverter is used as a place holder for future expansion.

5.2.6 Thermal Components

5.2.6.1 Type 169 - Moist Air Duct - Heat Loss as Output (Supply & Return)

The HVACSIM+ Type 169 is used in this simulation to calculates the heat lose of a duct section to the surrounding environment due to convection and conduction; radiative heat lose is neglected, refer to p. 495 for the type model outline. This type can calculate airflow pressure drop as a function of a hydraulic resistance and mass flow rate, however, in this simulation, the airflow network is used for this purpose. Thermal contact by the duct runs for each grill and louver in the thirty-four zone configuration is complex. An equivalent surface area was calculated to ensure that thermal contact in the megazone system was similar in character to the original thirty-four zone system, refer to §3.3.3.5. An equivalent diameter is calculated based on the following expression:

$$D_e = 1.3 \frac{(a\, b\,)^{0.625}}{(a + b\,)^{0.250}} \; ; \qquad \textbf{(143)}$$

where: a = side a of rectangular duct [in] or [mm]; and
b = side b of rectangular duct [in] or [mm].[135]

A network of Type 169 units was assembled to model the multiple heat paths from a ductway to the zones through which it passes in the original system, see Figure 210. In the case of Zone I, heat paths for the supply side are identified to Zone II, Zone III, and Zone I in series; on the return side heat paths are identified to Zone I and Zone II. Heat paths for the other five zones are similarly identified. Values for the first six parameters in each of six megazones are given in Figure 211. The seventh and eighth parameter values pertain to airflow pressure drop calculations are set to zero in this simulation.

135 Sauer, et.al., 1993.

5.2.6.2 Type 205 - Fan: Power and Temperature Rise Only

This component was included for its superior algorithm over the one in Type 201 for calculating power consumption and temperature rise across a fan, refer to p. ? for the type model outline. However, this component will not be required following the modification of Type 201 to accommodate both thermal and airflow requirements.[136]

5.2.6.3 Type 211 - Mixing of Moist Air Streams

The HVACSIM+ Type 211 simulates the thermal mixing of two moist air streams. Inputs consist of the dry bulb temperature, air humidity ratio, and dry air mass flow rate for each entering stream; the corresponding properties of the mixed stream is output, refer to p. 499 for the type model outline. No parameters are required for this type.

5.2.6.4 Type 212 - Mixing of Moist Air Streams

The HVACSIM+ Type 212 simulates the thermal mixing of five moist air streams. Inputs consist of the dry bulb temperature, air humidity ratio, and dry air mass flow rate for each entering stream; the corresponding properties of the mixed stream is output, refer to p. 499 for the type model outline. No parameters are required for this type.

5.2.6.5 Type 272 - Two Node Room/Plenum - Interzone and Leakage

The HVACSIM+ Type 272 calculates zone air and structure temperatures based on the 2C3R model presented in §2.2.1. The schematic in Figure 187 shows the Type 272 zone model installed in a typical thermal network. Nineteen parameters are required by the model to characterize a zone including a room volume and a plenum volume, refer to p. 500 for the type model outline. Parameter values for the six Type 272 units are presented in Figure 213, (refer to Figure 165 for origin of values).

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136 Modification to be accomplished by LUT team.

Modes of heat transfer across the boundaries of the model include radiation through fenestration, conduction through the exterior walls, and mechanical ventilation through the supply and return duct systems. Heat input is set in the parameters as fixed values representing the number of occupants, lighting heat and equipment heat gain, and a fraction of lighting heat gain to plenum (assuming the lighting units are set in a suspended ceiling). The need to modify the internal heat gain entry method was identified in the course of this projects development. The time varying profiles which reflect actual usage patterns established in the occupancy and equipment schedules are more appropriately entered into the simulation as an input in a way similar to the heat gain due to time varying insolation. In the case of occupancy and equipment, it was proposed that profiles be entered as a percent of maximum heat load, with the maximum heat loads being entered as parameters. Thus providing maximum flexibility for future simulation requirements.[137]

5.2.6.6 Type 299 - Liege Coil L&G Valve

The HVACSIM+ Type 299 is used to model the supply air cooling coil and the six VAV terminal box reheat coils. Twenty three parameters are required to model this unit, characterizing the geometric and physical properties of the coil and control valve, refer to p. 503 for the type model outline. Most of the parameters were taken directly from the manufacturers equipment catalog cut sheets, and the balance were calculated based on information obtained from the same cut sheets, refer to §3.3.3.1 and §3.3.3.4. The parameter values for the cooling coil and six reheat coils are presented in Figure 214 and 215. The control valve in Type 299 is modeled as a three-way type, and all control valves are modeled as two-way in this simulation.[138] Hence, parameter 23 is set to a very high value, effectively turning the three-way model into a two-way model.

Parameter 19, Valve Characteristic Component ngl, characterizes the valve flow behavior based on the following expressing flow as a function of valve lift:

$$\frac{\dot{m}}{\dot{m}_{\max}} = e^{[ngl\,(s\,-\,1)]} \quad (144)$$

137 In collaboration with Les Norford, MIT and Phil Haves, LUT, 1995.

138 When the water side of the VAV reheat coils is modeled in future versions of this simulation testbed, the last control valve in the loop must be changed to a three-way type, as pictured in Figure 7. In accordance with the megazone duct layout (Figure 150), the last coil in the loop should be assigned to megazone II.

The value ngl was calculated by identifying the percent flow predicted by the valve manufacturer for 50% valve lift, or when:

$$ngl = -2 \ln \frac{\dot{m}}{\dot{m}_{\max}} \Big|_{50\ \%} \quad . \tag{145}$$

Two valve styles are used in the model; one for the air handling unit cooling coil, and one for the VAV reheat coils. The cooling coil control valve flow at 50% lift is approximately 17% (see to Figure 96), and the flow for the VAV reheat coil control valve at 50% lift is approximately 20% (see to Figure 139).

5.2.7 Type 026 - Control Signal Inverter

This HVACSIM+ Type 026 Control Signal Inverter is used as a place holder for future expansion.

5.2.8 Sensors

5.2.8.1 Type 007 - Temperature

Parameters for units included in the simulation which come under this category were prepared by the LUT team, refer to p. 492 for type model outline.

5.2.8.2 Type 189 - Velocity Sensor

Parameters for units included in the simulation which come under this category were prepared by the LUT team, refer to p. 495 for type model outline.

5.2.8.3 Type 203 - Static Pressure Sensor

Parameters for units included in the simulation which come under this category were prepared by the LUT team, refer to p. 497 for type model outline.

5.2.9 Simulation Real-Time Input and Output Devices

5.2.9.1 Type 135 - Real Time Graphs of Pressure, Flow and Control Signals

Parameters for units included in the simulation which come under this category were prepared by the LUT team, refer to p. 494 for type model outline.

5.2.9.1 Type 197 - Write to Unix Socket

Parameters for units included in the simulation which come under this category were prepared by the LUT team, refer to p. 496 for type model outline.

5.2.10 Type 026 - Control Signal Inverter

This HVACSIM+ Type 026 Control Signal Inverter is used as a place holder for future expansion.

5.3 Internal and External Heat Gains

Heat gain to the simulation model is from a combination of internal and external sources. All gains are given as step changes in one hour increments over a twenty-four hour period. The internal gains are divided into three categories: (1) heat loss by human occupants; (2) electrical resistance dissipation due to the operation of office equipment and miscellaneous appliances; and (3) electrical resistance dissipation due lighting. These input variable values are presented as percentages of a maximum value set as a fixed parameter. External gains are the result of the combined effect of the external ambient air temperature and insolation. These two variables are combined into one excitation variable: the sol-air temperature. Heat dissipation by the supply and return fan electric motors is accounted for in the HVACSIM+ type used to model the fans.

Representative profiles were developed for each input category, and one day's data was chosen for inclusion in this report. Although one representative cold days data and one representative hot days data together, together with a couple of median days data (one for each transitional season) should be used in proving the model. The single days data sets, originating on 20 July, 1990 and included in this report, are representative of the data sets required to perform a simulation. The changes required to distinguish a data set from one season to another is the adjustment of the sol-air temperatures for each compass face. This is accomplished by selecting the required data from the SAMSON CDROM data set and entering the data into the appropriate spreadsheet. Calculation of corresponding sol-air temperatures is automatically achieved when the new solar and collateral weather data is entered.

Occupant schedules and consequently lighting and equipment usage schedules do vary seasonally. However, for the data sets included with this report the maximum levels of occupant, lighting and equipment loads is considered to be representative for all periods throughout the year. Adjustments to internal gains can be easily made by modifying the percentage profiles or by resetting the maximum value parameters.

For this purpose, tabulated input gain data are presented as spreadsheet printouts in Appendix Y, and soft copies of the spreadsheets are provide in Appendix ?. The six linked files sa*.wq2 are provided in Novell's Quattro Pro V5.5 spreadsheet format *.wq2. These files can be converted to other formats, however, care must be taken, when doing so, to ensure that all links are renamed properly. A popular format which minimizes the manipulation required to preserve links is found in the Lotus *.wk2 type. It has been the authors experience that converting to other formats is problematic, and should be avoided.

5.3.1 Internal Heat Gains

A plot of the total internal heat gains for each zone is presented in Figure 13; data for this plot can be found in Figure 216. The internal gain heat load is estimated to peak at 1100 reaching 34.6 kW. A baseline internal heat gain level is estimated at 4.0 kW, refer to Figure 216. The baseline is established by averaging the total internal load during the hours from 2200 - 0600.

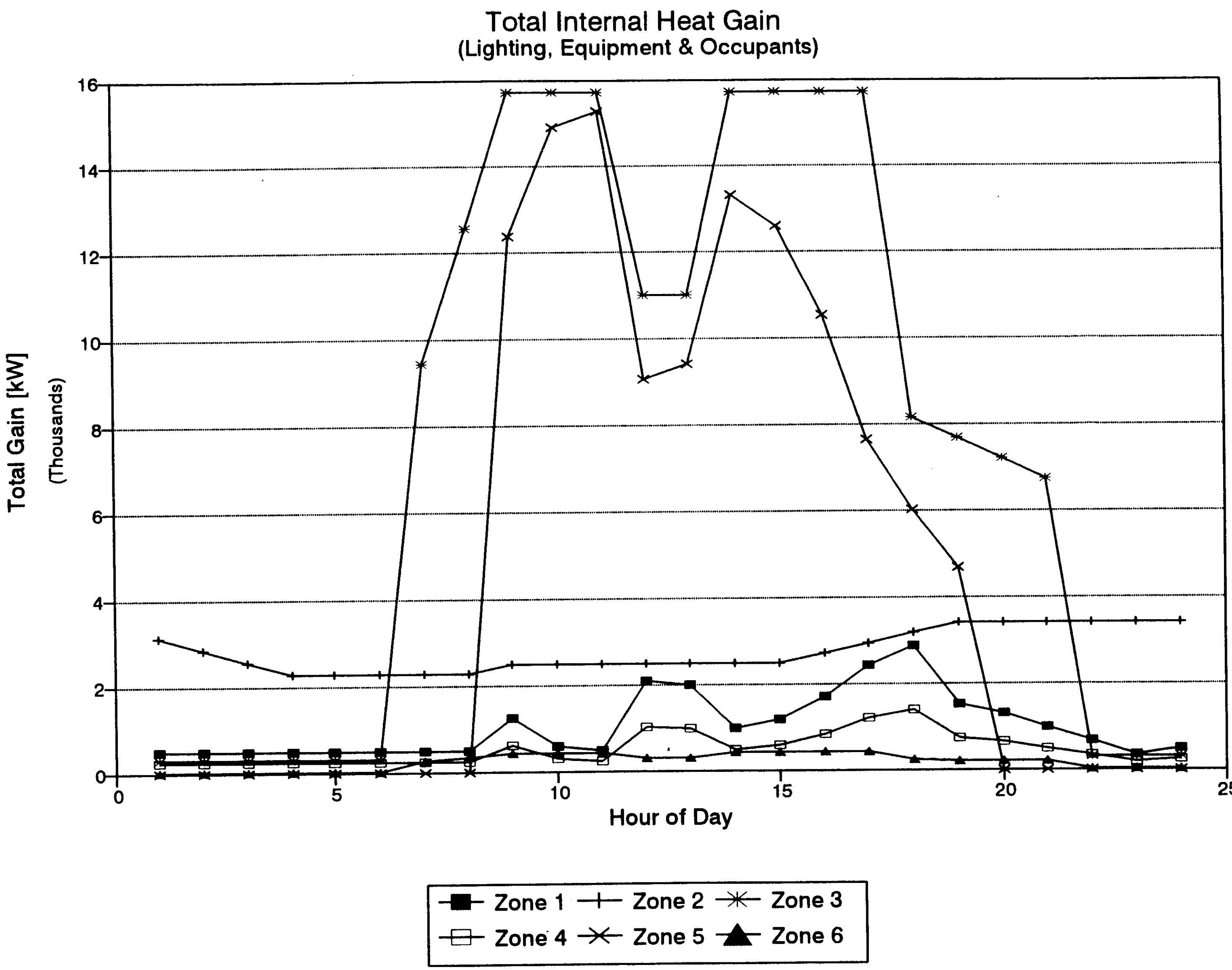

Figure 13: Total Internal Heat Gain for Each Megazone

Megazone 3, designated as an administrative area, has the highest internal heat gain, peaking for a few hours at 15.7 kw during mid-morning and mid-afternoon. The average total gain density (ATGD) for occupants, equipment and lighting in Megazone 3 is 1.14 W/ft^2. The peak load for Megazone 5, designated as a classroom-conference room area, is 15.3 kW, which occurs at 1100. The ATGD for occupants, equipment and lighting in Megazone 5 is 1.03 W/ft^2. The peak load for Megazone 2, designated as a personal computer/data processing center, is 3.4 kW, which occurs between 1900 and 2400. The ATGD for occupants, equipment and lighting in Megazone 2 is 4.5 W/ft^2. The ATGD for occupants, equipment and lighting in Megazone 2 is 4.5 W/ft^2. The peak load for Megazone 1, designated as a professorial and student offices, is 2.9 kW, which occurs at 1800. The ATGD for occupants, equipment and lighting in Megazone 1 is 0.44 W/ft^2. The peak load for Megazone 4, also designated as a professorial and student offices, is 1.4 kW, which occurs at 1800. The ATGD for occupants, equipment and lighting in Megazone 4 is 0.34 W/ft^2. The peak load for Megazone 6, designated as administrative offices, is 0.4 kW, which occurs during mid-morning and mid-afternoon similar to the load profile for Megazone 3. The ATGD for occupants, equipment and lighting in Megazone 6 is 1.1 W/ft^2.

5.3.1.1 Occupants

Profiles were developed capturing the essence of the varied occupancy schedules in this multi-use building. The occupancy densities represented in the actual thirty-four zone configuration were preserved in developing the distributions within the six megazone configuration. Four classifications were defined in the six megazone configuration: (1) student professorial offices; (2) administrative offices; (3) computer center; and (4) classrooms/conference rooms. Figure 217 shows the occupant densities for each zone classification as determined from survey data developed for the original thirty-four zone configuration. These densities were used to calculate the maximum number of people which may likely occupy each megazone. These maximums were then used to calculate a maximum anticipated heat input to each megazone based on a value of 75 watts per person.

The occupant usage percent profile for each megazone was designed to match usage profiles which actually exist in the original thirty-four zone configuration. Professorial and student office schedules were designed to mirror classroom occupancy, except during off hours when students are working in their offices into late hours of the evening. During these times, the professorial community is almost certainly enjoying other activities away from the university, while a small percentage of students are considered to be toiling away at all times during the twenty-four hour period.

Classroom occupancy profiles are based on survey data from actual classroom usage schedules for an academic year.[139] The schedules are presented in Figures 52 through 56. They show the number of occupants scheduled for each classroom throughout the week on a half-hourly basis and the maximum number of occupants permitted in each room. The daily schedules for the entire week were combined to determine a maximum total number of occupants which may be present in all classrooms during a the five day period Monday through Friday. This number was divided into the total number of occupants scheduled to be in each room over the five day week for each half hour period. Each two consecutive half hour periods were averaged together to produce an entry to the hourly stepped percentage profiles.

The computer center operates twenty-four hours a day, and usage was assumed to follow, to a certain degree, a track reflecting classroom and professorial/student office usage. A steady ramp starting after classroom usage peaks, leads to peak usage in the computer room at 100% beginning in early evening, after the dinner hour, and continuing until near mid-night. Usage falls off steadily after midnight, until the facility is empty of people at around 0400. Usage begins to pick up steadily at breakfast time, reaching a median usage of 20% which is sustained until classes begin to break when the cycle repeats.

Administrative use follows standard office use patterns. Workers begin to arrive at 0600, peaking at 100% at 0800. This level is sustained until 1100 when the lunch cycle begins. At least fifty percent of the occupants are assumed to be in situ at all times during due to staggered schedules and brown baggers. Occupant density returns to 100% by 1400 until 1700 when workers begin to leave. Occupancy falls off at a higher rate and some are assumed to linger until late hours of the evening; but, they do all eventually leave.

5.3.1.2 Equipment

Profiles were developed capturing the essence of the varied equipment usage schedules in this multi-use building. Care was be taken to distribute equipment usage within the megazones, preserving the same densities represented in the actual thirty-four zone configuration. A survey of the actual equipment existing in each room provides the basis for the densities quoted in Figure 218. Survey data is recorded in Figure 48. These data together with the associated floor areas yielded average power

139 MIT Classroom Scheduling Office, E19-334.

dissipation densities. These average densities were compared with densities reported in the surveys reviewed in §3.2.1 for verification and validation.

Usage profiles parallel occupant presence in the professorial/student and administrative offices. Equipment usage in the computer room is at 100% form 0000 - 2400. No equipment is assumed to be used in the classroom areas. Nameplate data is used to calculate the maximum dissipation values.

5.3.1.3 Lighting

Lighting usage patterns follow occupancy patterns with slight variations. All lights are assumed to be on during the working day in the office and classroom areas, and the lights are never turned off in the computer room. Densities are based on the total lighting load averaged over the entire building floor area. A survey recorded in Figure 48 captures a bulb count including every fixture in the entire building volume. All power consumed by the bulbs was assumed to add heat to the building.

5.3.2 External Heat Gains

The external heat gains to the individual megazones represented by insolation are modeled in the sol-air temperatures presented Figure ?. Two sets of temperatures are shown: one for the room sub-megazone and one for the plenum sub-megazone. These temperatures were calculated using the formulae found in 1993 ASHRAE Handbook - Fundamentals, §27. External ambient temperatures vary from 21.9 °C, recorded during late evening and early morning, to over 42 °C, recorded at 1200. Heat loss to the environment due to radiation is calculated to lower the sol-air temperature by 2 - 3 °C depending on the surface: either glass, brick, or asphalt. No account was made for radiative heat transfer due to reflection from surrounding buildings.

5.3.2.1 Solar and Collateral Weather Conditions

Two options were explored for calculating the total diffuse radiation E_d (refer to Equation 66). One method makes use of the value for diffuse radiation provided in the SAMSON data (see §4), and the other method is based on the direct normal radiation making use of the algorithms expressed in 1993 ASHRAE F27, (refer to Equations 68 - 72). For horizontal surfaces using either method, ground diffuse radiation is considered zero. For vertical surfaces, in the case of the SAMSON based calculations, half of the data value taken from the data set is used. This assumes that the vertical surface can only see half of the celestial sphere. For vertical surfaces, in the case of the ASHRAE based calculations, values for the incident diffuse radiation are based on the Equation 68. Incident angles are calculated using Equations 73 - 80.

Two equivalent temperatures are provided in Appendix Y: one calculated using ASHRAE formulae and one calculated using SAMSON solar flux data directly. The factors causing the difference between the results of two methods reside in the sky E_{ds} and ground E_{dg} diffuse radiation values, see Equation 66. Calculating the horizontal and vertical diffuse radiation from the SAMSON data leads to significantly higher values than does calculating the same values using the ASHRAE formulae. Time permitting, the discrepancies noted between the two data sets should be investigated, and a final data set should be selected.

Plots of the effective sol-air temperature profiles, one for each sub-volume represented by the plenum and room portions of the megazones, are presented in Figures 14 & 15. These effective sol-air temperatures are calculated as weighted averages based on the net effect of the sol-air temperature for each compass heading and the outside surface types ascribed to each megazone. Three surface types are defined: (1) external shell wall; (2) double pane insulating windows; (3) roof. Compass headings include south, west, and north faces.

In determining the effective temperatures, sol-air temperature profiles unrelated to the specific characteristics of each megazone were calculated for each compass heading according to Equations 60 and 62. This yielded seven temperature sets; one for the roof; three sets for the opaque external shell wall surfaces (one set for each compass heading); and three sets for the fenestration (also, one set for each compass heading). These profiles are presented in Figures 221 through 223.

Insolation and ambient air temperature data is presented in Figure 225, and sun incident angles for each of the three compass faces are presented in Figure 224. These data are calculated for the building assuming that long axis of the building is approximately 15 degrees off of a true east-west axis. Hence, the south face is actually facing 15 degrees to the east of south, the west face is facing 15 degrees to the south of west, and the north face is facing 15 degrees to the west of north.[140]

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140 The spreadsheet sa5_suna.wq2 calculates incident angles for any three sided structure at any latitude and longitude in any orientation. The constants at the top of the sheet may be changed as necessary for other applications, and other columns can be easily added to include as many sides as required to accommodate

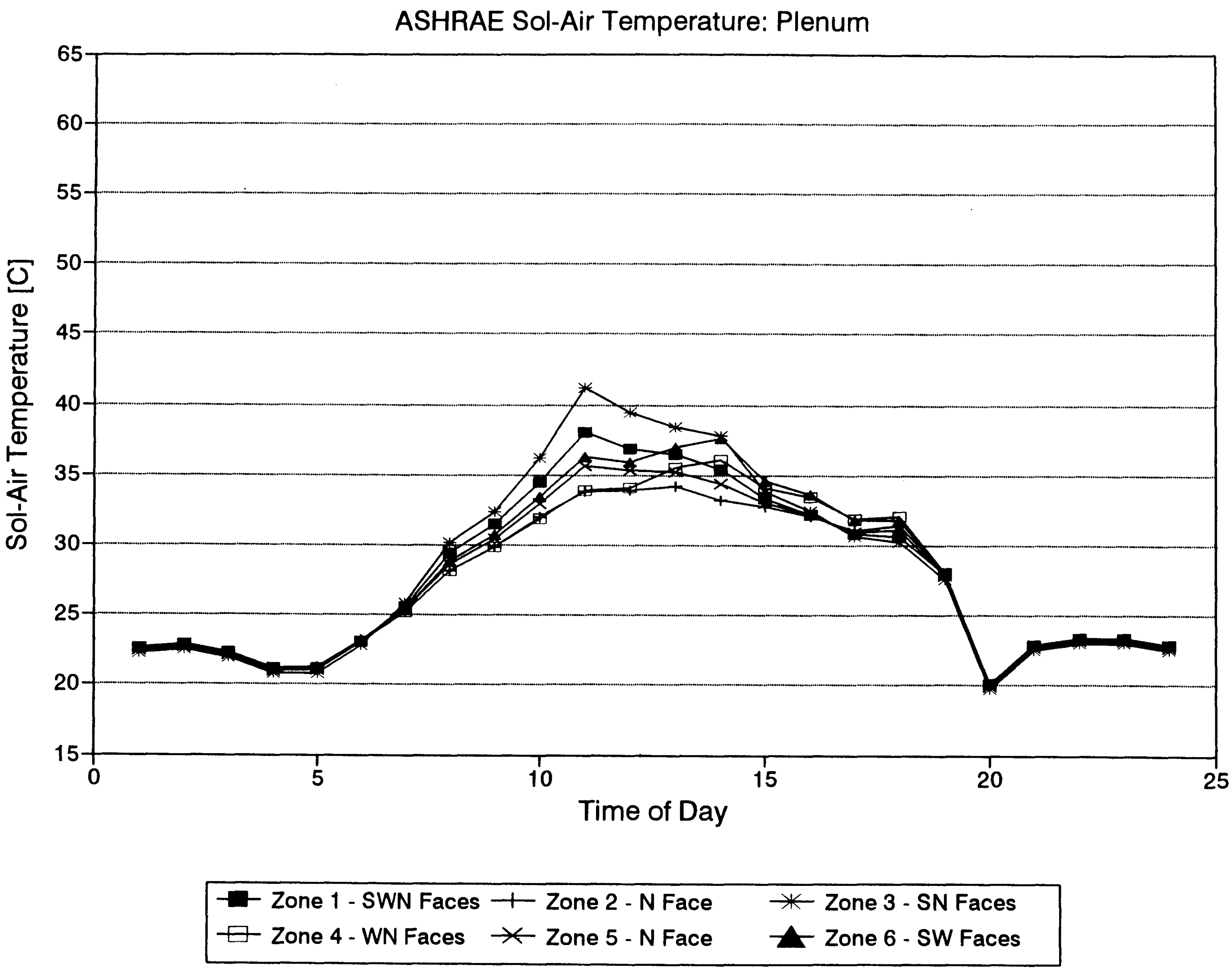

Figure 14: Sol-Air Temperatures for Plenum

other building configurations. Data for this report was developed for 20 July 1990, in Boston, Mass, @ 71W longitude - 42N latitude, a solar declination of 20.6° and the local standard time meridian @ 67.5W longitude, [Pasachoff, 1977].

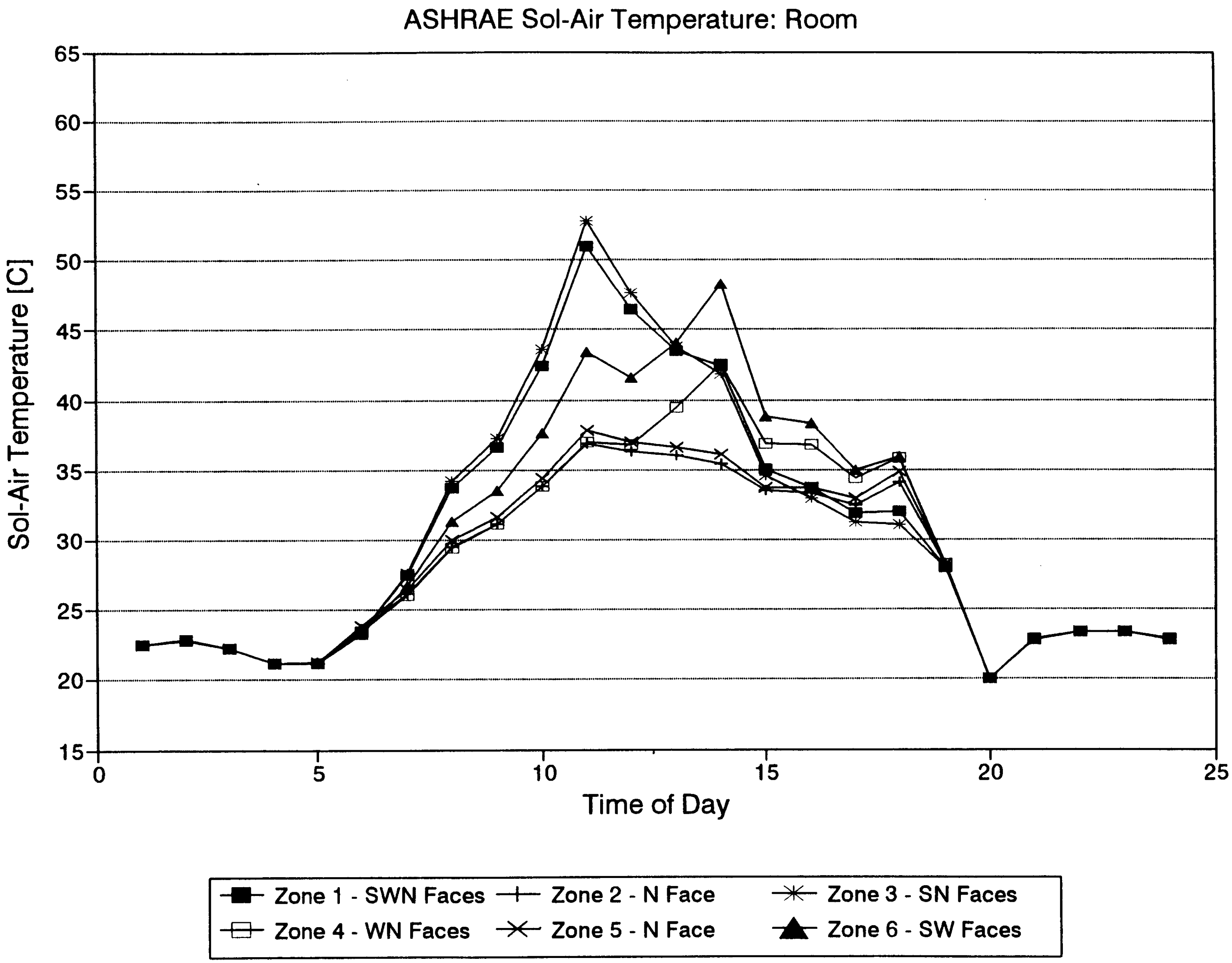

Figure 15: Sol-Air Temperatures for Room

Equivalent sol-air temperatures $T_{sa,i}$ were calculated according to Equation 59. These temperatures are weighted averages based on the ratios of the thermal conductances of each section of a sub-megazone (either room or plenum), identified by surface type, to the total thermal conductance of the entire surface area of the same sub-megazone. The capacitive flow of infiltration was not included in these calculations as indicated in Equation 59; instead of K_i in the denominator, K_{ext} was substituted. If K_i was to be used, then the appropriate contributions to the capacitive flow of infiltration for each component being combined to generate the equivalent temperature.

5.4 Simulation

Inputting the model parameters to the HVACSIM+ program and running a simulation is tasked to LUT. For reference Table 50 shows a sample set of output values from the E51 Johnson Metasys Network control system. The data shown in the table represents a sampling taken mid-afternoon on 17 January, 1995. It is not expected that simulation will duplicate the values for the real building control system, however, the report data presented can be used as a baseline for comparison.

Table - 50: MIT Building E51 Johnson Metasys Control System Output[141]

Line Num	Status	Item	Description	Value	Units
1		SEQUENCE	Sequence of Operation		
2		FRZ-BYPS	Freezstat Bypass Control	OFF	
3		SF-C	Supply Fan Control	ON	
4		SF-S	Supply Fan Status	ON	
5		RF-S	Return Fan Status	ON	
6		MIN-DPR	Minimum Air Damper Control	OPEN	
7		ECON	Economizer Status	MOD-A	
8		MALL-PID	Mixed Air Lower Limit Control Set Pt	48.0	DEG F
9	SWO	MA-DPR	Mixed Air Dampers	0.0	%OPEN
10		MA-T	Mixed Air Temperature	71.2	DEG F

141 Data transcribed from a Standard Summary - Requested from: MIT-FMS\OWS-101 for System: MIT-FMS\BLDG-E51\SYSTEMS_\E51-AH1 on 17 January 1995 @ 15:47:10. Reference Eric Epstein, MIT Physical Plant, Project Engineer.

Line Num	Status	Item	Description	Value	Units
11		SF-PID	Discharge Static Control Set Point	1.25	INWG
12		SPHL-PID	Discharge Static High Limit Cntrl Set Pt	2.50	INWG
13		SF-VN	Supply Fan Inlet Vanes	48.70	%OPEN
14		SA-F	Supply Air Flow	12,962.5	CFM
15		RF-SET	Return Volume Differential Set Point	1,000.0	CFM
16		RF-PID	Return Volume Differential Cntrl Set Pt	1,000.0	CFM
17		RF-VN	Return Fan Inlet Vanes	100.0	%OPEN
18		RA-F	Return Air Flow	9,755.8	CFM
19		DA-PID	Discharge Air Control Set Point	57.3	DEG F
20		CH-VLV	Cooling Coil Valve	19.5	%OPEN
21		DA-T	Discharge Air Temperature	57.2	DEG F
22		DA-SP	Discharge Air Static Pressure	1.24	INWG
23		RM-SET	Room Temperature Set Point	73.0	DEG F
24		RM012-T	Room 012 Temperature	69.2	DEG F
25		RM110D-T	Room 110D Temperature	73.5	DEG F
26		RM201A-T	Room 201A Temperature	71.5	DEG F
27		RA-T	Return Air Temperature	71.3	DEG F
28		RA-H	Return Air Humidity	47.0	% RH
29		RA-E	Return Air Enthalpy	25.75	BTU/LB
30		OA-E	Outdoor Air Enthalpy	18.99	BTU/LB
31		MA-PTP	Mixed Air Control Pass Thru	0.00	

6 Conclusion and Summary

The purpose of the model is to provide a standard testbed for the evaluation of control algorithms and strategies related to variable air volume HVAC systems. This work was conducted in collaboration with, and under sub-contract to, Loughborough University of Technology, Leicestershire, United Kingdom (LUT). The prototype building is a four level commercial, multi-use building. Activities in the building include classroom / educational space professorial and student offices, and office / administrative. The building contains three air-handling units; one unit and the volume it serves provides the basis for the testbed. The portion of the building serving as the testbed is divided into thirty-four zones, each with its own single duct, pressure independent VAV terminal box with hot water reheat. A perimeter heating system, composed of hot water convectors, radiators and baseboard heaters, augments the room comfort control system. Local-loop control in the mechanical room and for all but one zone is executed with microprocessor based, pneumatic actuators. One prototype direct-digital-control terminal box system was in use for a classroom zone. DDC control systems and motor driven actuators were substituted in the simulation for the pneumatic equipment.

The principle work associated with this thesis involved the amalgamation of real building specifications with the theoretical model to produce a highly refined composite of approximations and simplifications. The extreme, unprecedented high detail level achieved in this effort produced a model which effectively reduced the thirty-four zone structure to a level which was both physically and numerically manageable, while at the same time preserving the primary thermal and airflow characteristics of the building. The simplification procedure involved three primary steps: (1) a review and critical analysis of the theoretical basis for the simulation and the building model; (2) the model development and component identification; (3) and the implementation of the real building specifications mapping the building's components into the HVACSIM+ simulation package.

In the first step, the structure and procedure for parameter identification for the IEA Annex 10 second order, 2C3R lumped parameter zone model was studied. Some inconsistencies were identified with respect to the applying the Annex 10 model to the subject building, and an effort is currently in progress to clarify these inconsistencies and make the necessary modifications. The conclusion of this effort will appear in the ASHRAE 825 TRP Final Report. The inconsistencies identified relate to the development of the global parameters and affect the model's response to low frequency, diurnal frequency, and high frequency excitation.

Model development and component identification was accomplished in three categories: (1) real building selection; (2) occupancy schedule and internal gain identification linked to zone selection and simplification; (3) real building specification. A number of buildings were surveyed and a selection was made on the basis of the physical and operational constraints. The complex structure of the thirty-four zone building was simplified to a six megazone system. The procedure executed in this work made use of the occupancy schedules, the physical orientation of the buildings external walls to diurnal solar flux, and the natural physical boundaries within the building to establish the simplified megazone configuration. Another criteria used in the zone simplification procedure entailed maintaining the total area ascribed to each of the four basic uses identified in the building; (1) administration offices; (2) professorial-student offices; (3) classroom and conference rooms; and (4) computer/data processing. In addition, uniquely defined areas were preserved, or at least the conditions which give rise to the uniqueness of these areas were preserved. Unique characteristics considered in the zone simplification process include the unusually high insolation incident on isolated areas of the external shell, the lack of exposure to the external ambient characteristic of the ground floor wall and floor surfaces, and the specialized individual use represented in the data processing - computer room area.

As a direct consequence of the six megazone simplification, it was necessary to redesign the supply and return air duct systems. The procedure developed to redesign the two air duct systems preserves the air-flow and thermal characteristics intrinsic to the as built system. A procedure was developed for matching the surface areas of the modified air duct systems with the actual surfaces in the as built systems. In addition, a procedure was developed which matches the total pressure drop through each leg in the modified system with the pressure drop in each critical path specified for the original thirty-four zone system in the Engineering Design Specifications.

Internal and external heat gains for the thirty-four zone configuration were analyzed. An inventory of internal gains was made which captures the heat input values to the zones due to equipment, lighting, and occupants. In the case of equipment and lighting, heat dissipation densities (per area) were calculated for the original thirty-four zone configuration, and this information was translated into total heat dissipation densities for each megazone. In the case of the heat load due to classroom occupancy schedules, actual classroom occupancy schedules for an academic year were used to develop profiles and maximum input levels. Heat load due to occupancy schedules in the administrative, professorial, student offices were designed to reflect typical cycles in accordance with ordinary work schedules and classroom occupancy.

External heat gains were accounted for in sol-air temperatures developed for each of the two sub-zones comprising each megazone. Three methods were identified for determining insolation: (1) using direct measured values of direct normal and diffuse radiation; (2) using measured values of direct normal radiation and then using commonly accepted expressions to calculate diffuse values based on direct normal values; and (3) using measured values of the solar extinction coefficient, calculating direct normal radiation an then using the commonly used expressions for method 2, calculate diffuse radiation. The first and second procedures are codified in the spreadsheets attached to his document, and the results are presented. The highest frequency input which could be developed using either of these two methods was at one hour intervals. The desired frequency per contract requirements was closer to the order of one to five minutes, and the third procedure outlined in this thesis proposes a method which may yield the desired results. Due time constraints it was not possible to fully explore the third method and produce some proto-typical values, and the subject may serve as the basis for future research.

Each of the three methods required solar incident angles to the subject surface. A procedure was developed using standard ASHRAE formulae for calculating these incident angles on vertical and horizontal surfaces located at any latitude and longitude; the procedure is codified in the spreadsheets attached as an appendix to this thesis. The incident angles were used in combination with locally measured data and the buildings thermal properties to produce the hourly averaged sol-air temperatures included in this report. The procedure identified to calculate sol-air temperatures for short intervals using the high frequency measurements of the extinction coefficient was not proven, and it was not known at the time this report was written if the data required for the calculation is available, accurate, or reliable.

The availability and quality of insolation and collateral weather data was researched. Several sources were identified, all of which provide data in various formats. In total, these data are collected at hundreds of government maintained and operated locations scattered across the continental United States. All of the data are screened and corrected for errors, and a large percentage of these data are derived from observed values using commonly known relations. Typically, the insolation and collateral data are presented as one hour averages, and no solar data at frequency intervals less then one hour were found to be available. Although, it was determined that weather data is being measured and recorded at intervals between 30 seconds and 5 minutes, depending on the data type. Unfortunately, these data, ordinarily available in a condensed format, represent one hour averages. However, the data in uncondensed format may be obtained by special request from the NCDC in Asheville, NC.

The SOLMET program, under the auspices of DOE through a program known as SAMSON, provides archived solar data at one hour intervals on CDROM. Data are collected from twenty-six stations distributed around the United States. Collateral weather data are also provided with the solar data, and for simulation purposes, the SOLMET data provides the best resource providing the data is accurate and true. In the course of developing sol-air-temperatures it was observed that the diffuse radiation values for read directly from the SAMSON records did not agree with the diffuse radiation values calculated using the ASHRAE formulae found in F27. Sol-air temperatures were calculated using both methods, a determination was made to use the values calculated with the ASHRAE formulae. Additional research is required beyond the scope of this work to correct the inconsistencies discovered between the two methods of determining the diffuse radiation.

A relatively new program referred to as the Automated Surface Observing System (ASOS) was identified. This program is operated by the National Oceanic and Atmospheric Administration and will eventually provide weather data at varying intervals down to one minute, depending on the type of information required. Historically, ASOS program data at this frequency have been collected, but not reported. Daily and monthly summaries are available; however, resolution is reduced and averaged to one hour intervals. Special arrangements will be necessary if processed data from the ASOS program at higher frequencies is to be obtained. The extinction coefficient is provided with this data, and is the only part directly related to insolation. It is detected and recorded at one minute intervals. However, as previously mentioned, one hour averages are all that are generally reported.

Parameters were developed for the HVACSIM+ components corresponding to the elements comprising the model building. The parameters characterize the physical and geometric properties of a building shell, the internal and external building loads, the building's secondary systems, and the plant or primary energy source. An airflow network and thermal network provide the two key structural elements in the HVACSIM+ simulation. The third key structural element in the simulation is the control system which was handled entirely by the LUT Team. The airflow network models the complex airflow connections intrinsic to the six megazone approximation of the real building. Interzone leakage is accounted for as well as exfiltration. The model structure for the mixing box uses a open modeling concept which allows the user to adapt basic components into the precise configuration existing in the subject system. This method for mixing box modeling is a modification over the previous method which relied upon an individual, specialized model limited to applications to one configuration.

Consisting primarily of the zone models, cooling and reheat coils, space heating elements, and air flow duct conduction surfaces, the thermal network models the complex thermal connections also intrinsic to the six megazone approximation of the real building. The supply and return air in the real building pass through a complex system of ductwork, exchanging heat with multiple zones along the way to the intended destination. This feature of the as built system was successfully captured in a procedure which respected the percentage of the total duct surface area exposed to each zone in the real building. The control system was modeled by the LUT team and will be fully described in their report. Parameter input for the HVACSIM+ model types has been completed, and some simulation testing has been done by the Lut team. The results of the testing and the final simulation runs will be in the final report for this project in accordance with the contractual requirements described in ASHRAE 825 TRP.

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Appendices

Appendix A - Building Selection Comparison

Selection Comparison

Building A

Location:	Building E51 - Massachusetts Institute of Technology Memorial Drive, Cambridge, MA
Floors:	4 levels (includes ground level or basement)
Usage:	Office/Educational - Classroom/Computer Laboratory/Conference Room
Constructed:	Renovated 1980
HVAC Type:	Variable Air Volume to all areas of building
Air Handler:	Trane - Supply & Return fans; supply motor size 20 hp/208VAC/3 ph constant speed & return motor 5 hp/ 208VAC/3 ph constant speed; typical maximum supply flow rate approximately 18,590 cfm; total cooling capacity 736 MBH; pressure controlled set point
Outside Air:	Through central plant via ducting direct to outside
Mixing Plenum:	Dedicated - attached to the back end of each central plant is a fabricated sheet metal mixing box
Exhaust:	Through Bathroom Venting and Exfiltration
VAV Terminal Units:	Single Duct, pressure independent; flow range 80 - 2200 cfm
TB Damper Actuators:	Pneumatic (one test VAV box fitted with Motor Driven Electronic)
Reheat:	Single row, single circuit hydronic coils fed by hot water boiler within the building; perimeter heating is fed by same system
Control System:	microprocessor control connected to pneumatic transducers; one DDC controller and VAV box is fitted in a zone for test purposes
Instrumentation:	Flow, Temperature, Humidity, Damper Positions, Outside Air Temperature, etc. as required by control system for total automated operation and manual override
Cooling:	Central Supply from MIT Campus cooling system
Documentation:	Excellent
Number of Zones:	Typical approximately 30 - 40 per central plant

Selection Comparison (continued)

Building C

Location:	75 State Street Boston, MA
Floors:	31
Usage:	Commercial Office
Constructed:	1989
HVAC Type:	Variable Air Volume
Control System:	Mixed Direct Digital Control and Pneumatic - DDC for base building and supply fans and pneumatic for individual terminal box damper control
VAV Terminal Units:	Fan Powered
TB Damper Actuators:	Pneumatic
Reheat:	Electric Coils
Instrumentation:	Flow, Temperature, Humidity, Damper Positions, Outside Air Temperature, etc. as required by control system for automated operation and manual override
Mixing Plenum:	Dedicated - Mechanical room on each floor is used for this purpose
Cooling:	Central Supply Through Core Piping
Outside Air:	A central supply via core ducting
Exhaust:	Through Bathroom Venting and Infiltration
Documentation:	Excellent
Number of Zones:	Variable (less than 25)
Air Handler:	Draw Through

Selection Comparison (continued)

Building D

Location:	222 Berkeley Street Boston, MA
Floors:	23
Usage:	Commercial Office
Constructed:	1989
HVAC Type:	Mixed Constant Volume for the common areas and first floor retail spaces and Variable Air Volume for the commercial office spaces
Air Handler:	Carrier - Supply fan only; motor size 20 hp/480 VAC/3 ph; VSD; typical maximum flow rate approximately 17,130 cfm; total cooling capacity 682 MBH; pressure controlled set point
Outside Air:	A central supply via core ducting - Typical volume flow rate approximately 2500 cfm
Mixing Plenum:	Dedicated - Mechanical room on each floor is used for this purpose
Exhaust:	Through Bathroom Venting and Infiltration
VAV Terminal Units:	Fan powered type by Aire Systems of Houston Texas; centrifugal fan type; max flow primary 760 - 1900 cfm; min flow primary 190 - 475 cfm; max flow total 900 - 2000 cfm; min flow total 601 - 1751 cfm
TB Damper Actuators:	Motor Driven
Reheat:	Multi-stage electric resistance coils; max 10 kw; min 3.5 kw
Control System:	DDC for all Controllers - Control for this building is entirely automated through the use of DDC control. Any aspect of the control system can be monitored and controlled from a central location.
Instrumentation:	Flow, Temperature, Humidity, Damper Positions, Outside Air Temperature, etc. as required by control system for total automated operation and manual override
Cooling:	Central Supply Through Core Piping
Documentation:	Excellent
Number of Zones:	Typical approximately 18 - 20

Appendix B - Site Plan & Elevations for the West End of Building E51 [142]

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142 Based on MIT Drawings: EA51 A06.0004
EA51 A07.0004
EA51 A24.0001

Architectural layouts for Building E51, in the form of Autocad compatible *.dxf files, were obtained from the MIT Facility Management Systems Office in Building E28. The *.dxf files were modified using Coreldraw 5.0 to reflect the supply and return duct layouts, the perimeter heating unit sizes and distribution, and the megazone boundaries. The drawings are in proportion to the scale bar depicted in each figure.

MIT BUILDING DATA REPORT

-- BUILDING E51 -- Revised 02/87

IDENTIFICATION DATA

BUILDING NUMBER	E51
BUILDING NAME	
PERSON FOR WHOM NAMED	
STREET ADDRESS	70 MEMORIAL DRIVE
MAILING ADDRESS	77 MASSACHUSETTS AVENUE
OCCUPANCY CLASS	ASSEMBLY (A-4)

ARCHITECTURAL INFORMATION

ARCHITECT	PERRY, SHAW, & HEPBURN *
CONSTRUCTION COMMENCED	1944
INITIAL OCCUPANCY	1980
MAJOR RENOVATION DATE	1979

FINANCIAL/REAL ESTATE DATA

CONSTRUCTION COST	
PROJECT COST	
OWNERSHIP	MIT
PURCHASE DATE	1945
EFFECTIVE LEASE DATE	N/A
LEASE/OPTIONS EXPIRE	N/A
LEASED FROM	N/A
LENGTH OF LEASE	N/A
OPTIONS	N/A
RENT	N/A
BUILDING INVESTMENT	
SOURCE OF FUNDS (MAJ)	
SOURCE OF FUNDS (MIN)	

PHYSICAL DATA

GROSS AREA (SQ. FT.)	57708
NET USEABLE AREA (SQ. FT.)	52152
NET ASSIGNABLE AREA (SQ. FT.)	34793
GROSS ROOF AREA (SQ. FT.)	15343
BUILDING HEIGHT FROM GRADE	53 FEET
NUMBER OF FLOORS	3
NUMBER OF BASEMENTS	1
NUMBER OF PENTHOUSES	1
TYPE OF CONSTRUCTION	REINFORCED CONCRETE

Figure 16: MIT Building E51 Data Report Rev 02/87 - Facility Management Systems

MIT BUILDING DATA REPORT

-- BUILDING E51 -- Revised 02/87

<u>BUILDING SERVICES</u>

SAFETY SYSTEMS	MANUAL FIRE ALARM SYSTEM AUTOCALL SYSTEM FIRE HOSES, FIRE PUMP FIREFIGHTER ELEVATOR CONTROL
HANDICAPPED ACCESS	RAMP (2)
NUMBER OF PASSENGER ELEVATORS	1
NUMBER OF FREIGHT ELEVATORS	0
F.E. WT, LGTH, WDTH, DR, OPN	N/A
SHIPPING/RECEIVING PLATFORM	
ROOF REPAIR DATES	1981
ELECTRICAL SERVICES	MIT SYSTEM - HIGH VOLTAGE MIT SYSTEM - LOW VOLTAGE
BUILDING HEAT	MIT CENTRAL STEAM SYSTEM
HEATING SYSTEM	CENTRAL AIR & PERIMETER HOT WATER
AIR CONDITIONING	CENTRAL CHILLED WATER SERVICE
OTHER UTILITY SERVICES	NO
ENVIRONMENTAL CONTROL	UNIT CONTROLLER W/CENTRAL MONITOR
EMERGENCY LIGHTING	
DATA SYSTEMS CONNECT	
PERMITS	

<u>REMARKS</u>

BUILDING WAS PREVIOUSLY LEASED TO ELECTRONICS ~~CORPORATION OF AMERICA BEFORE RENOVATION FOR~~ ACADEMIC USAGE.

* RENOV: WALLACE, FLOYD, ELLENZWEIG, & MOORE, INC.

NATIONAL RESEARCH CORP.

Figure 17: MIT Building E51 Data Report Rev 02/87 - Facility Management Systems (cont'd)

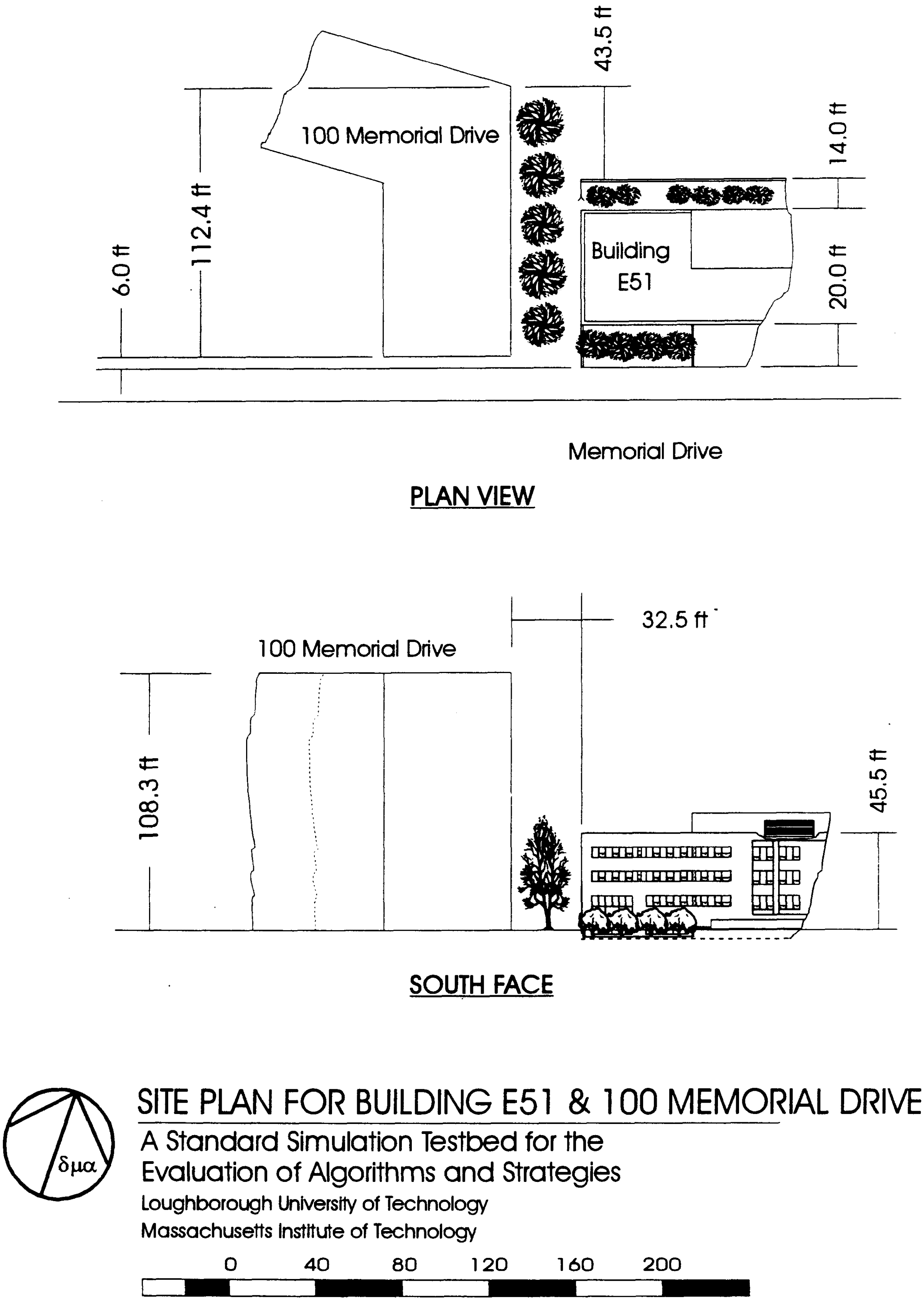


Figure 18: MIT Building E51 - Site Plan

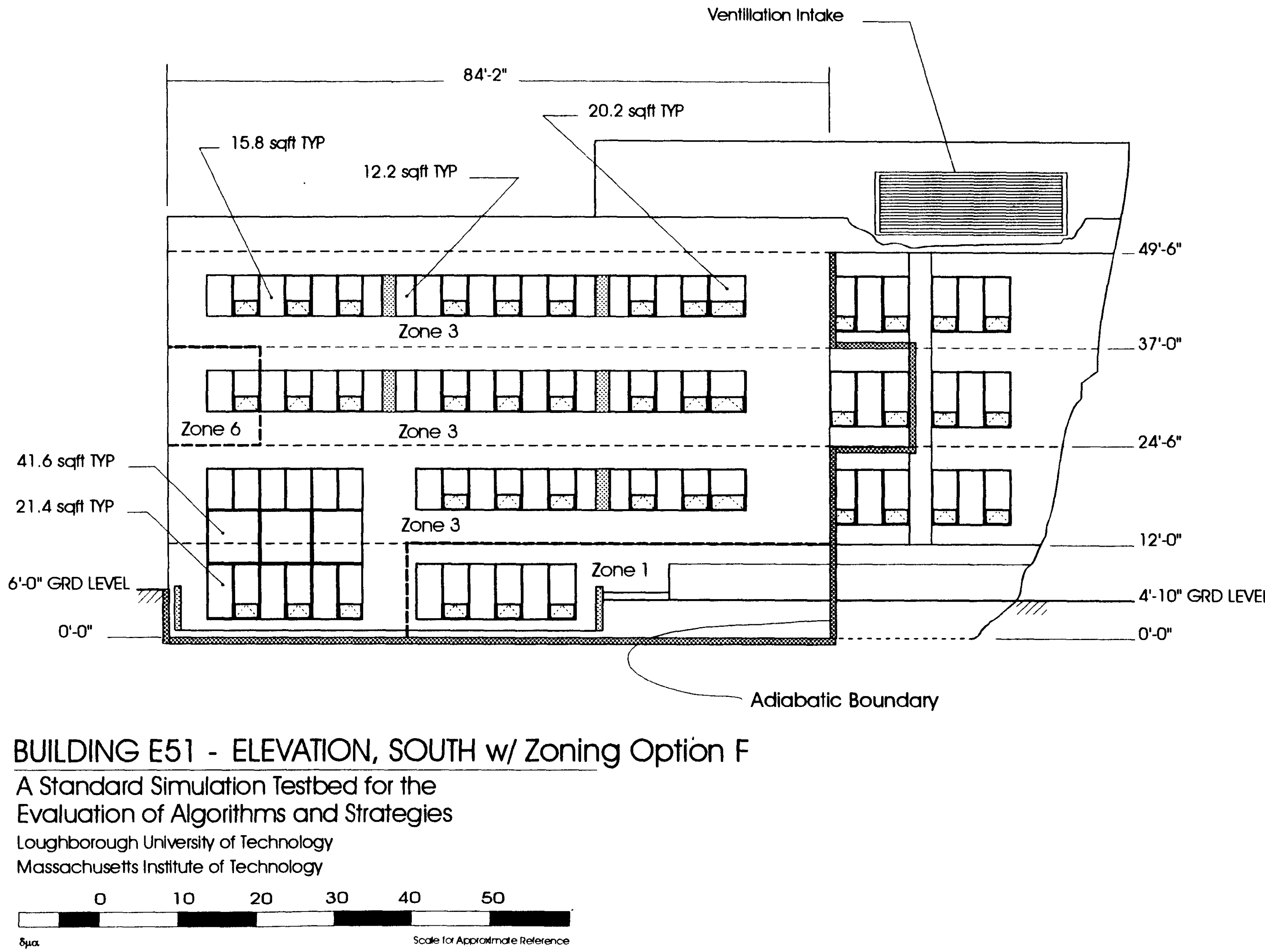
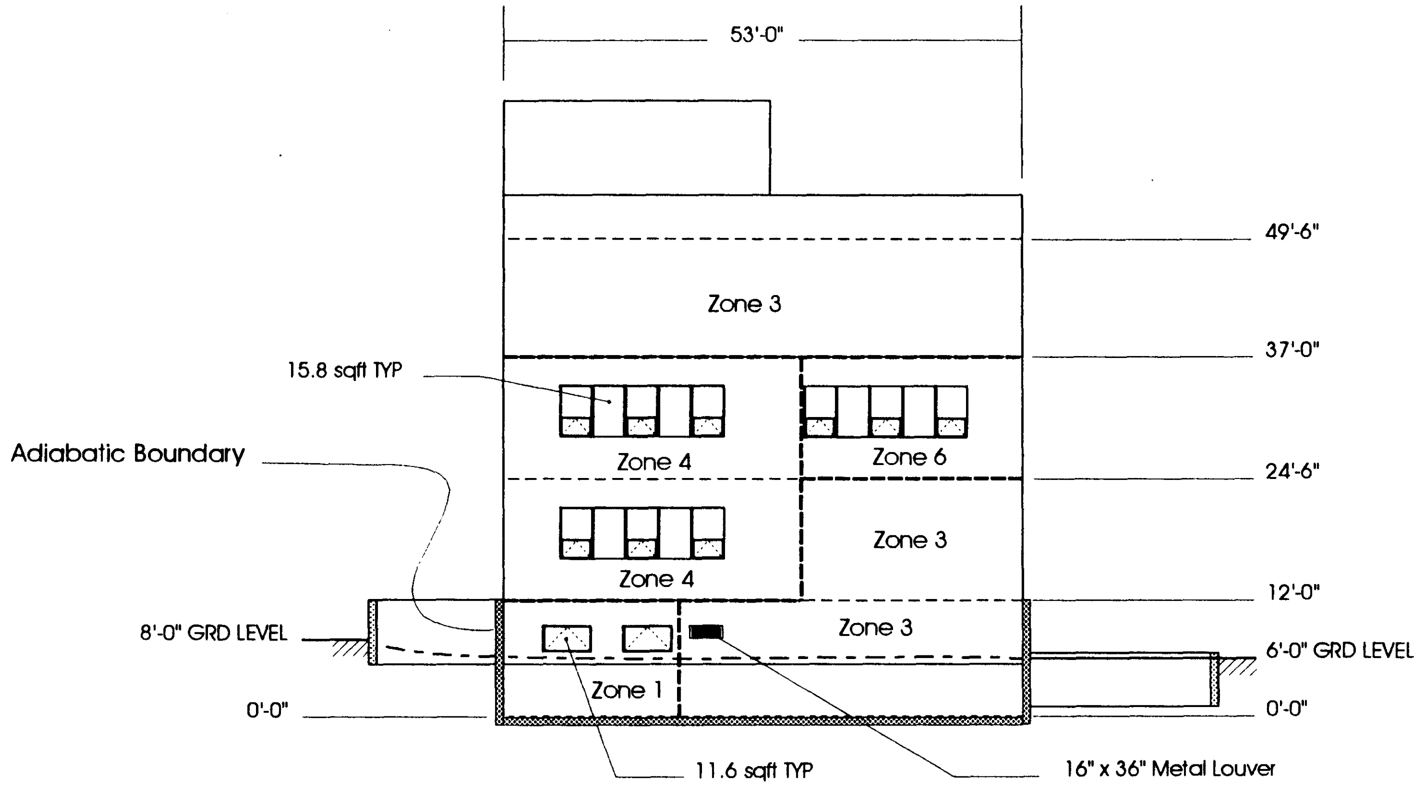


Figure 19: MIT Building E51 - South Elevation



BUILDING E51 - ELEVATION, WEST w/ Zoning Option F

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

Loughborough University of Technology
Massachusetts Institute of Technology

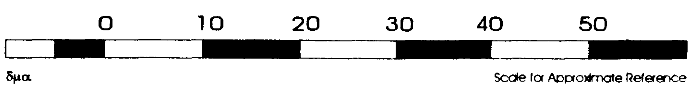
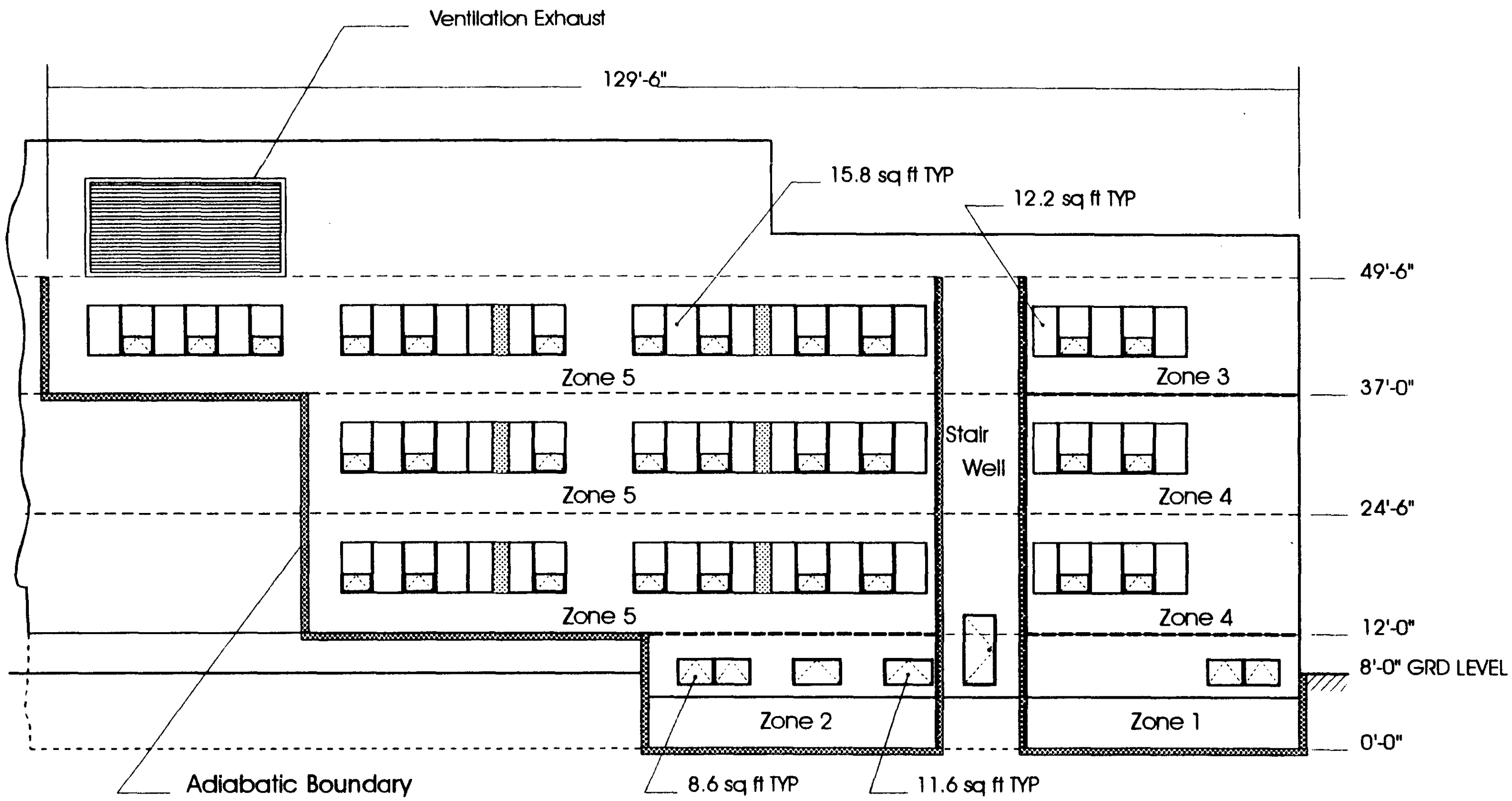


Figure 20: MIT Building E51 - West Elevation

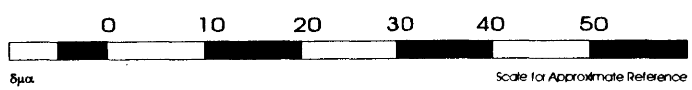
Figure 21: MIT Building E51 - North Elevation



BUILDING E51 - ELEVATION, NORTH w/ Zoning Option F

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

Loughborough University of Technology
Massachusetts Institute of Technology



Appendix C - Building Envelope & Shared Internal Wall Surface Areas

Figure 22: Building Envelope Wall and Window Areas - Zoning Option F

External Windows & Wall Surface Areas plus Resistance Values for Air Flow Leakage to Outside

a	b	c	d	e	f	g	h	i	j	k	l	m
Type 210 Parameter Nu												
Zone Number	External Surface Compass Heading	External Surface Area			Tot Ext Surface Area [ft2]	Window Area					Hdg Ext Wall Area [ft2]	Tot Ext Wall Area [ft2]
		Heading Room [ft2]	Heading Plenum [ft2]	Heading Total [ft2]		Unit Area per Hdg [ft2]	Number of Units per Hdg	Unit Total per Hdg [ft2]	Hdg Win-dow Area [ft2]	Tot Win-dow Area [ft2]		
I	South	386	107	493		21.4	6	128	128		365	
I	West	96	27	123		11.6	2	23	23		100	
I	North	171	47	218	834	8.6	2	17	17	169	201	665
II	North	183	51	234	234	11.6	2	23				
						8.6	2	17	40	40	194	194
III	South	3,567	991	4,558		21.4	6	128				
						41.6	3	125				
						15.8	43	679				
						12.2	10	122				
						20.2	3	61	1,115		3,443	
III	West	1,181	328	1,509		0.0	0	0	0		1,509	
III	North	340	94	434	6,501	15.8	4	63				
						12.2	1	12	75	1,191	359	5,310
IV	West	737	205	942		15.8	10	158	158		784	
IV	North	679	189	868	1,810	15.8	8	126				
						12.2	2	24	151	309	717	1,501
V	North	2,659	739	3,398	3,398	15.8	42	664				
						12.2	12	146	810	810	2,588	2,588
VI	South	146	40	186		15.8	2	32	32		154	
VI	West	276	77	353	539	15.8	5	79	79	111	274	428
Chk Sums		10,421	2,895	13,316	13,316			2,629	2,629	2,629	10,687	10,687
			13,316						10,687		13,316	13,316

file: extwall.wq2 12/27/95 Page 1

External Windows & Wall Surface Areas plus Resistance Values for Air Flow Leakage to Outside

a	b	c	d	e	f	n	o	p	q	r	s	t	u
Type 210 Parameter Nu													P1
Zone Number	External Surface Compass Heading	External Surface Area (Wall & Window)			Tot Ext Surface Area [ft2]	Leakage Resistance w/rate=1200 cm3/s-m2 @ 75 Pa ASHRAE Fundamentals, F23.16.							
		Heading Room [ft2]	Heading Plenum [ft2]	Heading Total [ft2]		Compass Heading Room		Compass Heading Plenum		Hdg Zone Leakage [1/(lbm-ft)]	Tot Zone Leakage [1/(lbm-ft)]	Hdg Zone Leakage [1/(kg-m)]	Tot Zone Leakage [1/(kg-m)]
						Leakage [1/(lbm-ft)]	Leakage [1/(kg-m)]	Leakage [1/(lbm-ft)]	Leakage [1/(kg-m)]				
I	South	386	107	493		3.77E+03	2.72E+04	4.89E+04	3.53E+05	2.31E+03		1.67E+04	
I	West	96	27	123		6.06E+04	4.38E+05	7.86E+05	5.67E+06	3.71E+04		2.68E+05	
I	North	171	47	218	834	1.93E+04	1.39E+05	2.50E+05	1.81E+06	1.18E+04	8.08E+02	8.53E+04	5.83E+03
II	North	183	51	234	234	1.67E+04	1.21E+05	2.17E+05	1.57E+06	1.03E+04	1.03E+04	7.40E+04	7.40E+04
III	South	3,567	991	4,558		4.41E+01	3.19E+02	5.72E+02	4.13E+03	2.70E+01		1.95E+02	
III	West	1,181	328	1,509		4.03E+02	2.91E+03	5.22E+03	3.77E+04	2.47E+02		1.78E+03	
III	North	340	94	434	6,501	4.87E+03	3.51E+04	6.31E+04	4.55E+05	2.98E+03	1.33E+01	2.15E+04	9.59E+01
IV	West	737	205	942		1.03E+03	7.46E+03	1.34E+04	9.67E+04	6.33E+02		4.57E+03	
IV	North	679	189	868	1,810	1.22E+03	8.79E+03	1.58E+04	1.14E+05	7.46E+02	1.71E+02	5.38E+03	1.24E+03
V	North	2,659	739	3,398	3,398	7.94E+01	5.73E+02	1.03E+03	7.43E+03	4.86E+01	4.86E+01	3.51E+02	3.51E+02
VI	South	146	40	186		2.65E+04	1.91E+05	3.44E+05	2.48E+06	1.62E+04		1.17E+05	
VI	West	276	77	353	539	7.36E+03	5.31E+04	9.54E+04	6.88E+05	4.51E+03	1.93E+03	3.25E+04	1.40E+04
Chk Sums		10,421	2,895	13,316	13,316								
			13,316										

Basic Formula: R = delP/[rho^2*(Ql*A)^2] where rho = 1.22 kg/m3; Ql = 1200 cm3/s-m2; delP = 75 Pa

Figure 23: Building Envelope Wall and Window Areas - Zoning Option F (continued)

Figure 24: Building Envelope Wall and Window Areas - Zoning Option F (continued)

a = zone number designation
b = compass heading of wall within a particular zone
c = room external curtain wall surface area for zone heading
d = plenum external curtain wall surface area for zone heading
e = total external curtain wall surface area for zone heading [c+d]
f = total exterior curtain wall surface area for the zone (includes walls and windows)
g = unit area of a specified window configuration type (reference E51 Elevation Drawings)
h = unit quantity for the window type
i = total area for each window type for each heading [g*h]
j = total window area, including all types, for each compass heading
k = total window area for the zone
l = exterior wall surace for each heading [e-j]
m = total exterior wall surface area for the zone (excluding glass area)
n = air leakage resistance for room per heading and zone (english) derived from SI calculation [o/(3.2808*2.2)]
o = air leakage resistance for room per heading and zone (SI) ref 1993 ASHRAE F23.14 & F23.16
R = [75/((1.22*1.22)*(1200/1000000)*(1200/1000000)*(c/10.7636)*(c/10.7636))]
p = air leakage resistance for plenum per heading and zone (english) derived from SI calculation [q/(3.2808*2.2)]
q = air leakage resistance for plenum per heading and zone (SI) ref 1993 ASHRAE F23.14 & F23.16
R = [75/((1.22*1.22)*(1200/1000000)*(1200/1000000)*(d/10.7636)*(d/10.7636))]
r = air leakage resistance (for room & plenum as one volume) per heading and zone (english) derived from SI calculation [t/(3.2808*2.2)]
s = air leakage resistance for entire zone (considering room & plenum a single volume) (english) derived from SI calculation [u/(3.2808*2.2)]
t = air leakage resistance (for room & plenum as one volume) per heading and zone (SI) ref 1993 ASHRAE F23.14 & F23.16
R = [75/((1.22*1.22)*(1200/1000000)*(1200/1000000)*(e/10.7636)*(e/10.7636))]
u = air leakage resistance for entire zone (SI) considering room and plenum as one volume (type_210: P1)
R = [75/((1.22*1.22)*(1200/1000000)*(1200/1000000)*(f/10.7636)*(f/10.7636))]

Figure 25: Internal Shared Wall Areas and Air Flow Resistances - Zoning Option F

Interzone Shared Wall Area and Air Flow Resistance Values

a	b	c	d	e	f	g	h	i	j		k	l
Type 229 Parameter Number												P1
Level	Zone A	Zone B	Shared Wall Area Linear Dim [ft]	9 ft Room Height [ft2]	2.5 ft Ceil'g Height [ft2]	Number of Doors	Crack Length [ft]	Loss Coefficient 1/Cd2	Crack Area [ft2]	[m2]	flow resis [1/lbm*ft]	SI convert [1/kg*m]
0th	I	II	36	324	90	2	40	2.78	0.83	0.077	2.67E+01	1.92E+02
	I	III	72	648	180	3	60	2.78	1.25	0.116	1.19E+01	8.55E+01
1st	III	IV	40	594	100	2	40	2.78	0.83	0.077	4.27E+00	3.08E+01
	III	V	66	594	165	5	100	2.78	2.08	0.194	7.41E-01	5.35E+00
2nd	III	IV	33	297	83	3	60	2.78	1.25	0.116	see first level	
	III	V	58	522	145	5	100	2.78	2.08	0.194	see first level	
	III	VI	30	270	75	0	----	----	----	----	no openings	
	IV	VI	12	108	30	1	20	2.78	0.42	0.039	1.07E+02	7.70E+02
3rd	III	V	72	648	180	2	40	2.78	0.83	0.077	see first level	

door size: 7'0" x 3'0"
crack width: 0.25 inches

rho: 0.075 lbm/ft3
1.220 kg/m3

a = level shared wall area & air flow resistance is evaluated
b = zone sharing contact area and air flow
c = zone sharing contact area and air flow
d = linear dimension of shared wall area
e = ceiling height [ft]
f = height of volume above suspended ceiling [ft]
g = number of doors in shared wall

h = resulting crack length based on the number of shared doors
i = loss coefficient (k) based on commonly accepted discharge coefficient for airflow thru cracks in a bldg envelop (93 ASHRAE Fundamentals F23.12) Cd=0.60 & k=1/Cd2
j = effective crack area based on a 0.25 inch crack width
k = air flow resistance [English Units] R = k / (2 * rho * A * A)
l = air flow resistance [SI Units] type_229: P1 R(SI) = R * 3.2808 * 2.2

Appendix D - Supply & Return Duct Layouts for AH1 in Building E51 w/ Zoning Option F [143]

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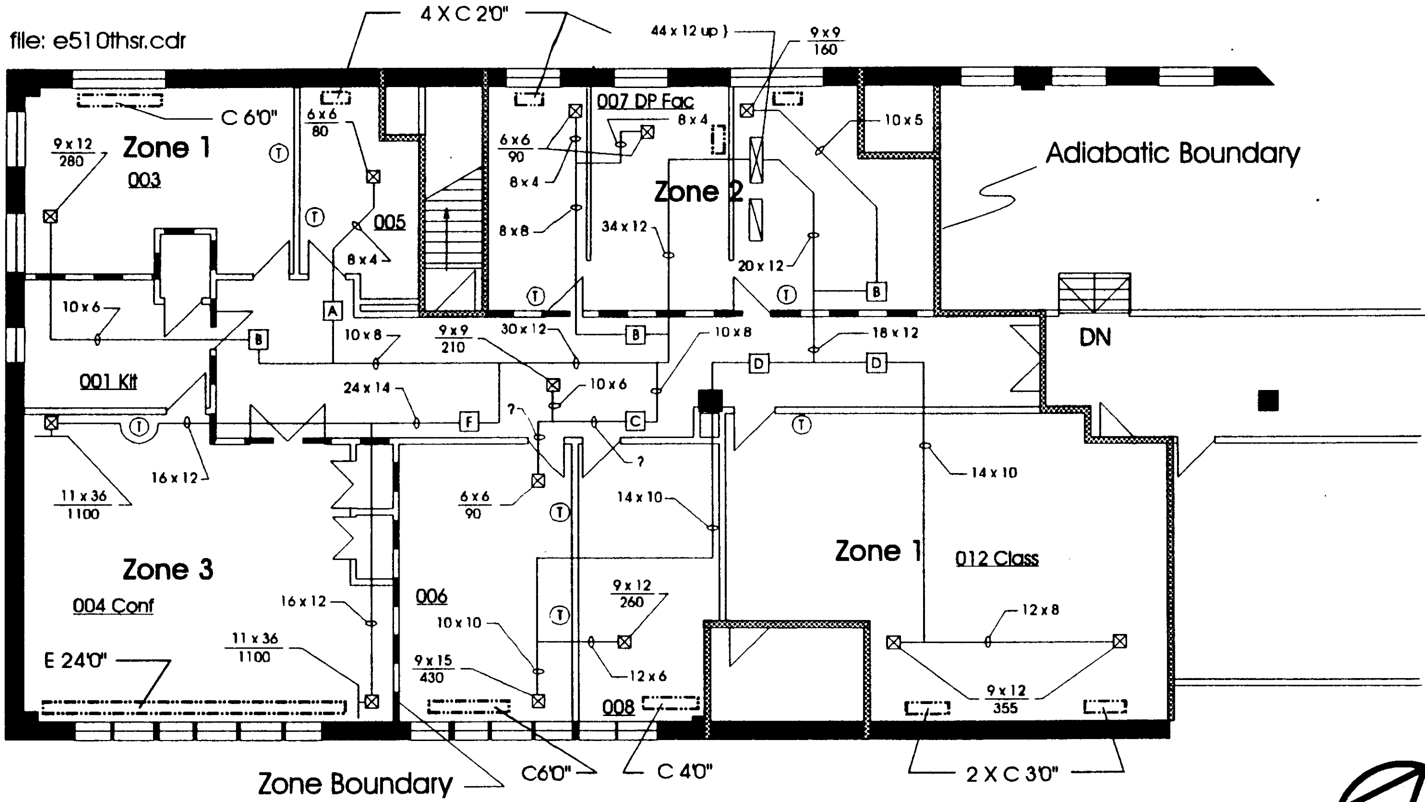
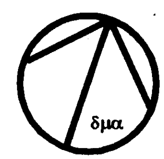
143 Based on MIT Drawings: EA51 M07.0002
EA51 M01.0002
EA51 M01.0003
EA51 M02.0004
EA51 M03.0003
EA51 M03.0002
EA51 M04.0002
EA51 M05.0002
EA51 M06.0002

Architectural layouts for Building E51, in the form of Autocad compatible *.dxf files, were obtained from the MIT Facility Management Systems Office in Building E28. The *.dxf files were modified using Coreldraw 5.0 to reflect the supply and return duct layouts, the perimeter heating unit sizes and distribution, and the megazone boundaries. The drawings are in proportion to the scale bar depicted in each figure.





BUILDING E51 - Basement Level Supply Ducting w/ Zoning Option F

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

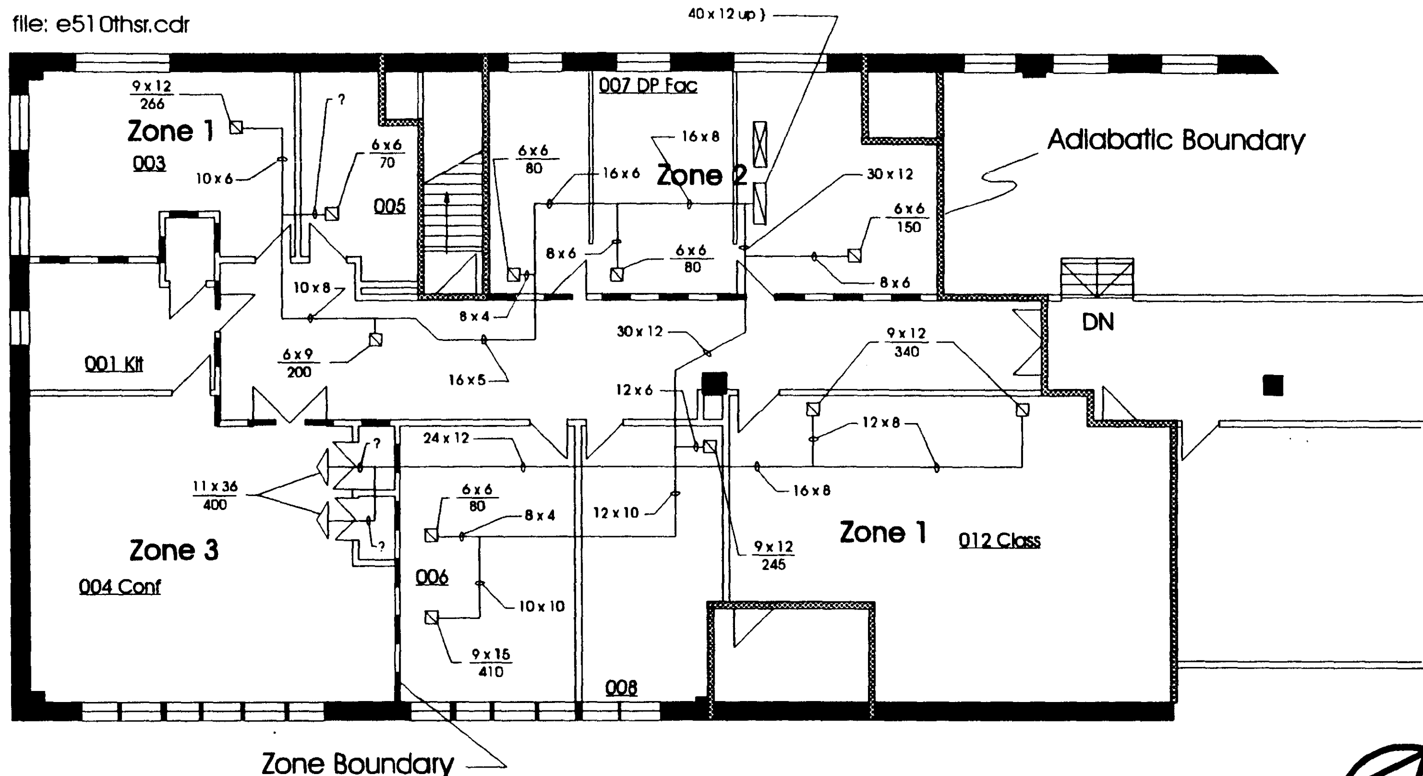
Loughborough University of Technology
Massachusetts Institute of Technology

0 5 10 20 40 FEET

F	VAV Box (see other for descriptions)
T	Thermostats
⊠	Supply Register
9 x 12 / 355	Register Size & CFM

Figure 26: Building E51 - Basement Level Supply Ducting w/ Zoning Option F

Figure 27: Building E51 - Basement Level Return Ducting w/ Zoning Option F



BUILDING E51 - Basement Level Return Ducting w/ Zoning Option F

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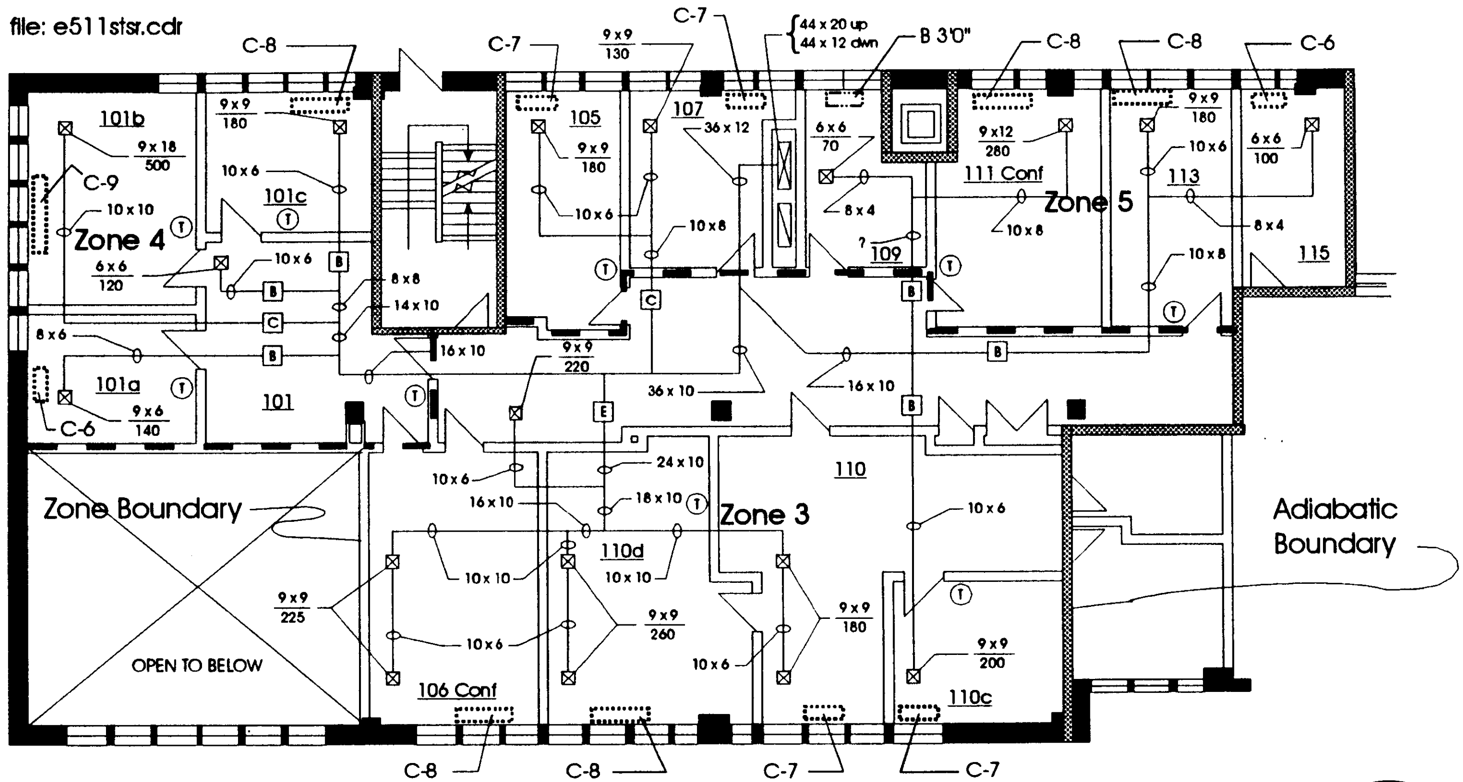
Massachusetts Institute of Technology

0 5 10 20 40 FEET

Return Register

9 x 12 / 245 Register Size & CFM

Figure 28: Building E51 - First Floor Level Supply Ducting w/ Zoning Option F



BUILDING E51 - First Floor Level Supply Ducting w/ Zoning Option F

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0 5 10 20 40 FEET

E VAV Box (see other for description)

Supply Register

(T) Thermostat

9 x 9 / 260 Register Size & CFM

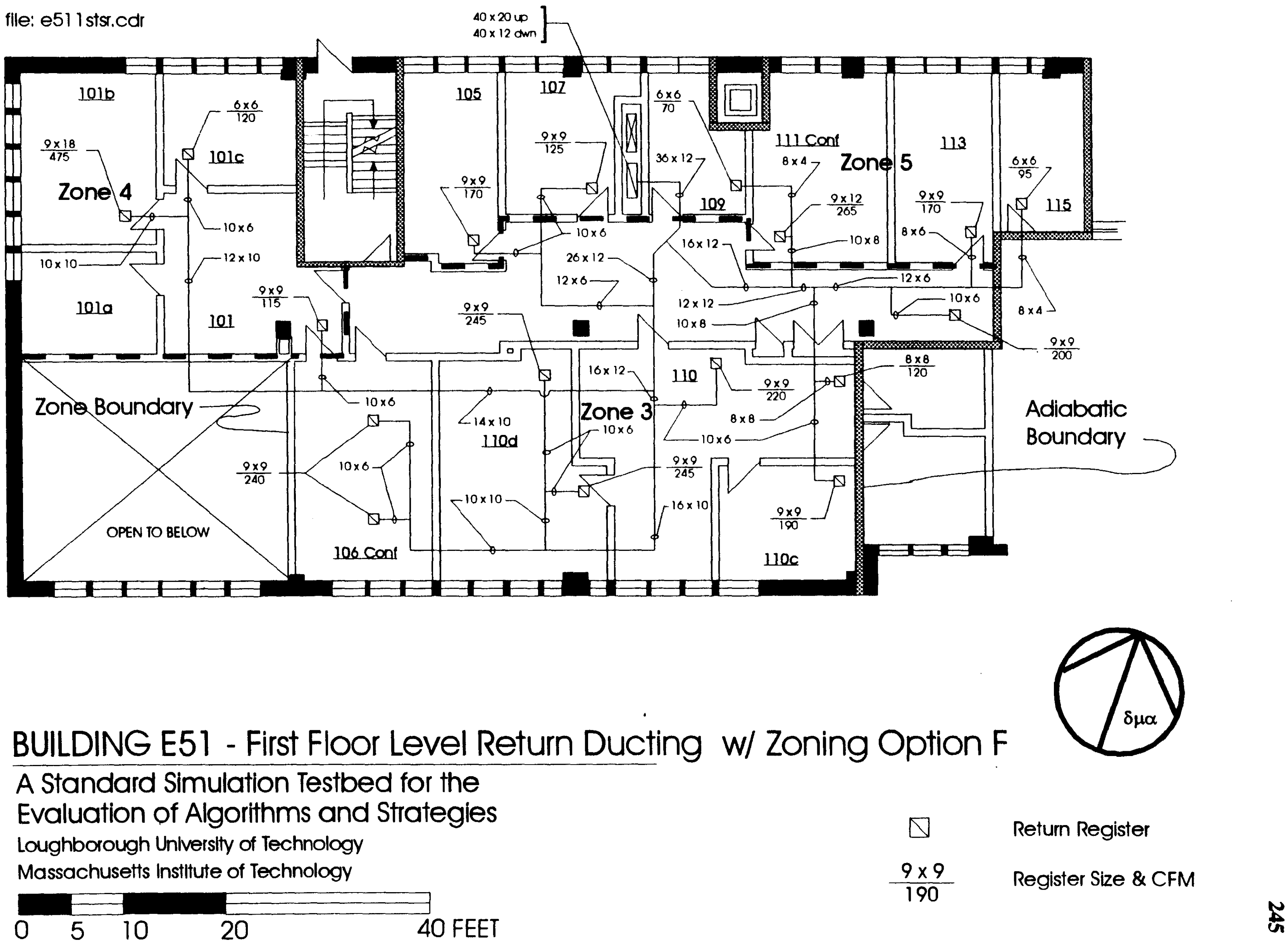
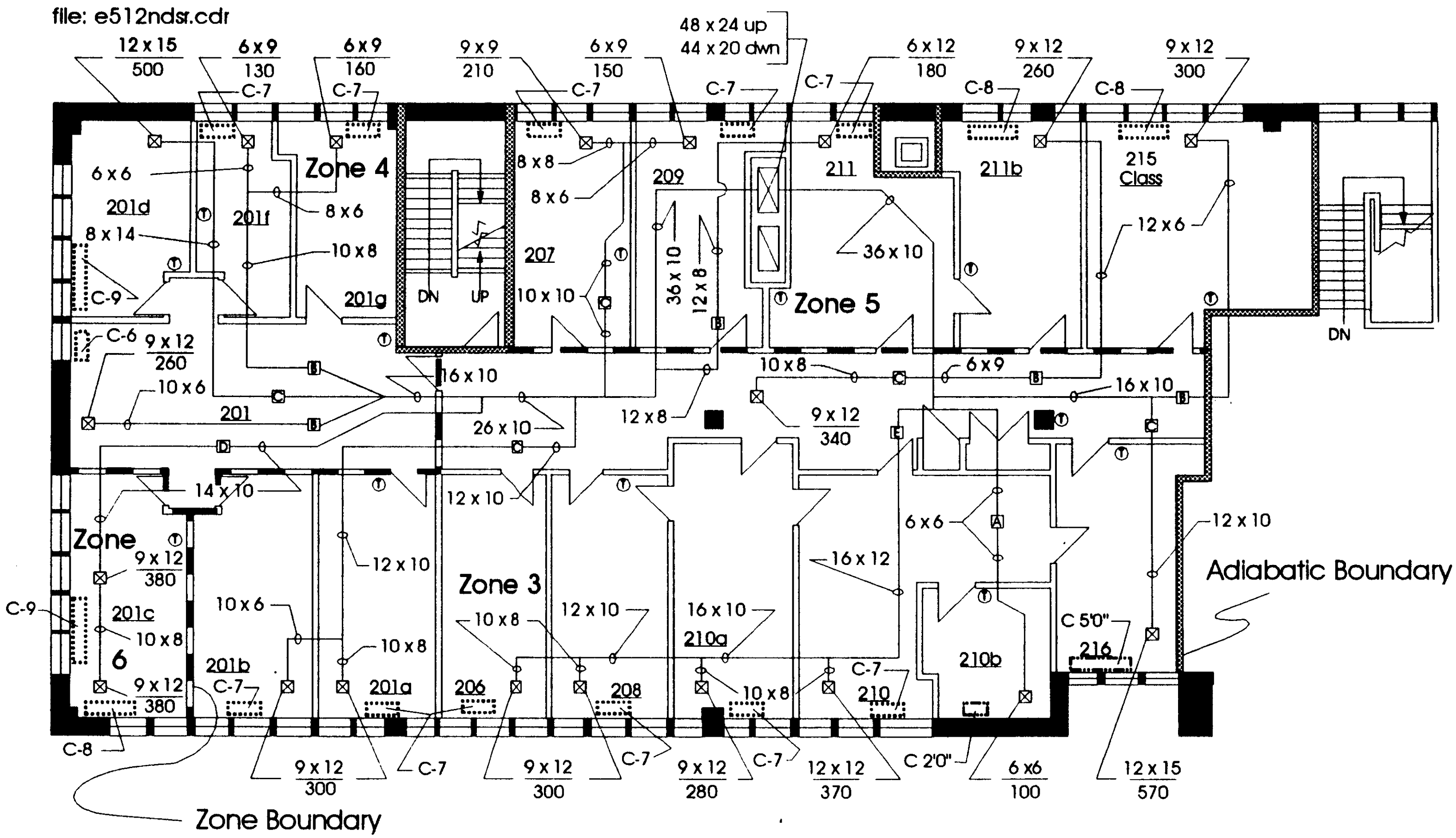


Figure 29: Building E51 - First Floor Level Return Ducting w/ Zoning Option F

Figure 30: Building E51 - Second Floor Level Supply Ducting w/ Zoning Option F



BUILDING E51 - Second Floor Level Supply Ducting w/ Zoning Option F

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

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Massachusetts Institute of Technology

0 5 10 20 40 FEET

D VAV Box (see other for description)

Supply Register

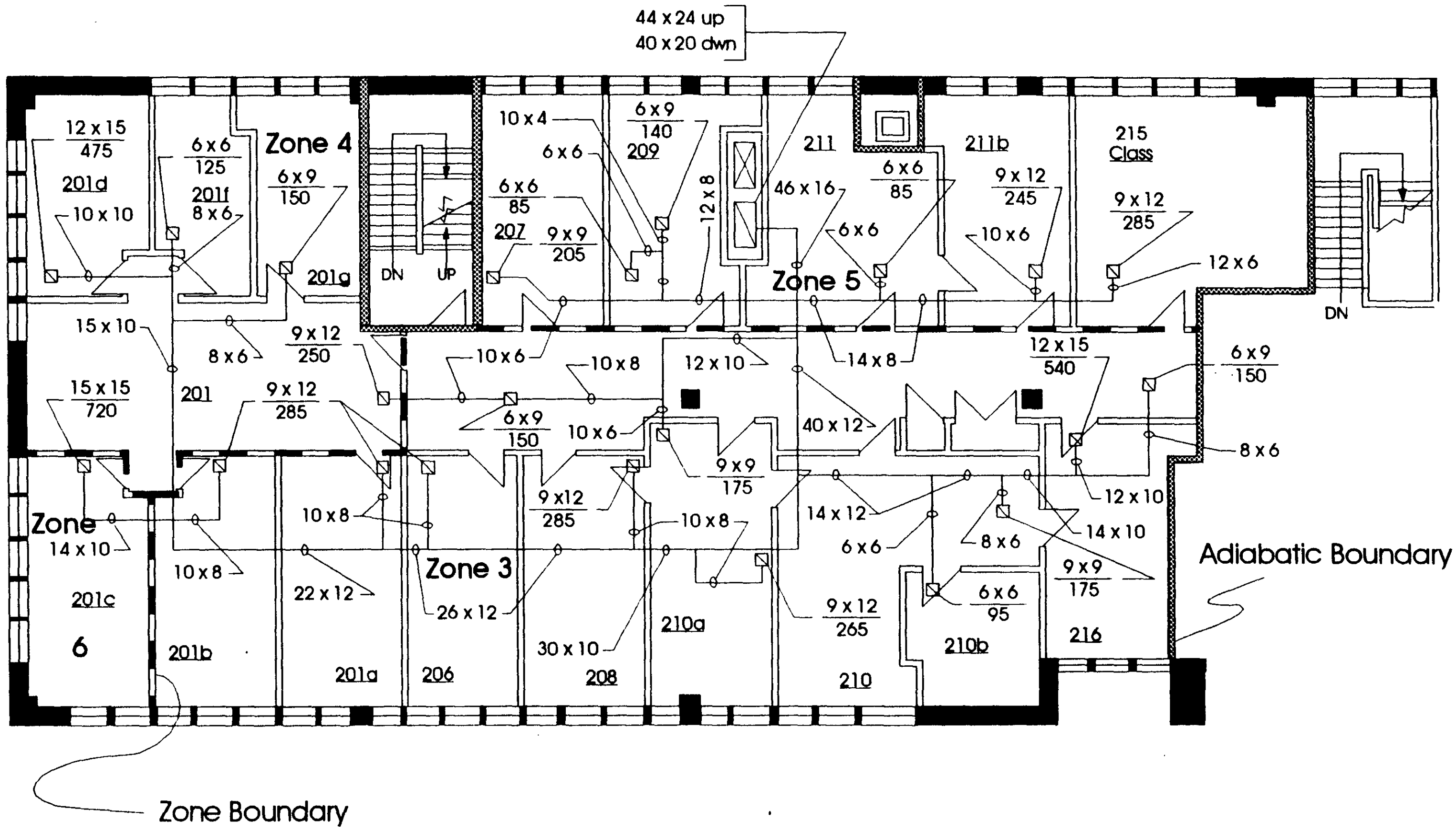
T Thermostat

9 x 12 / 300 Register Size & CFM

δμα

Figure 31: Building E51 - Second Floor Level Return Ducting w/ Zoning Option F

file: e512ndsr.cdr



BUILDING E51 - Second Floor Level Return Ducting w/ Zoning Option F

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

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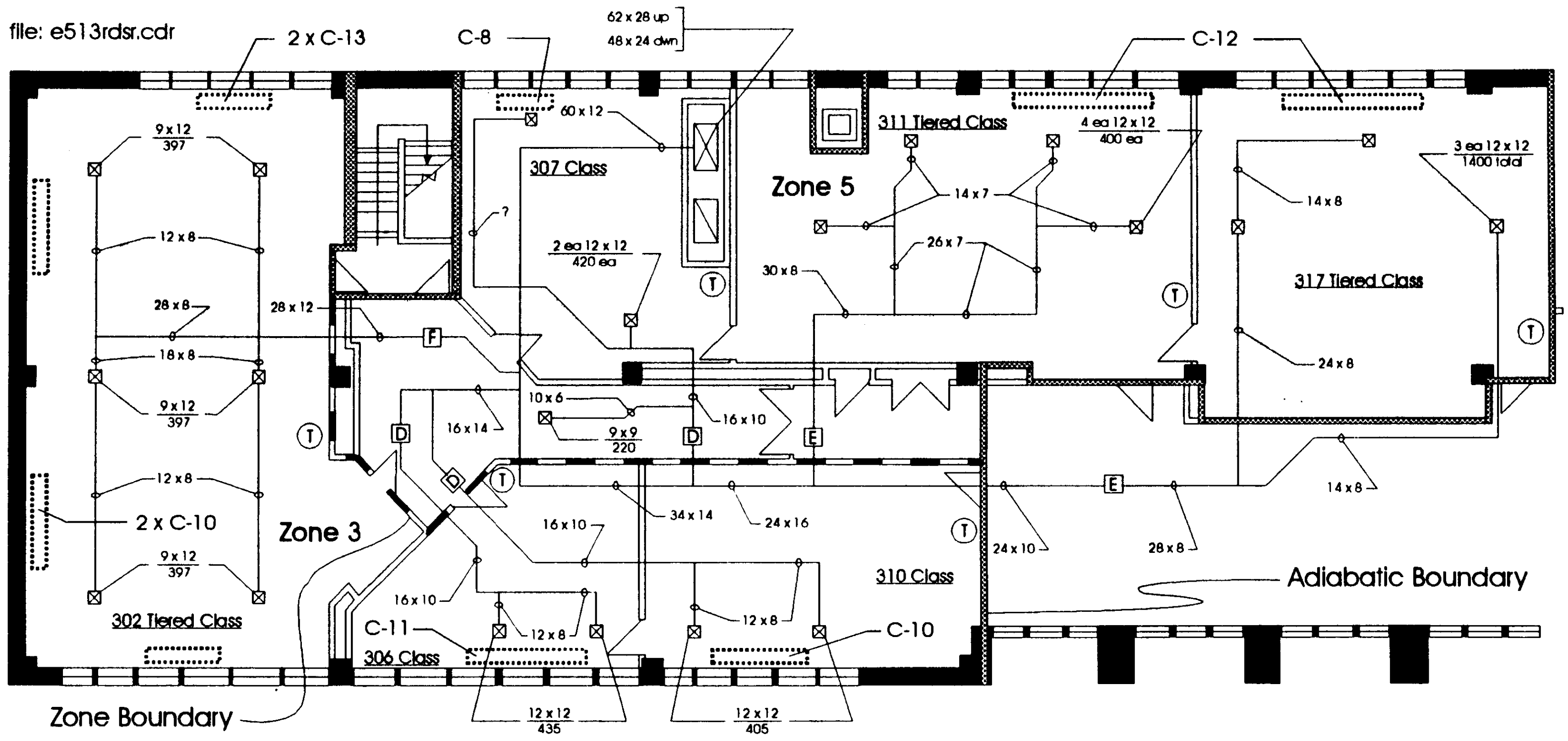
Massachusetts Institute of Technology

Return Register

9 x 12 / 300 Register Size & CFM

0 5 10 20 40 FEET

δμα



BUILDING E51 - Third Floor Level Supply Ducting w/ Zoning Option F

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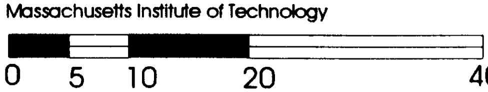


E VAV Box (see other for description)

⊠ Supply Register

12 x 12 / 405 Register Size & CFM

(T) Thermostat

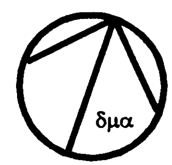
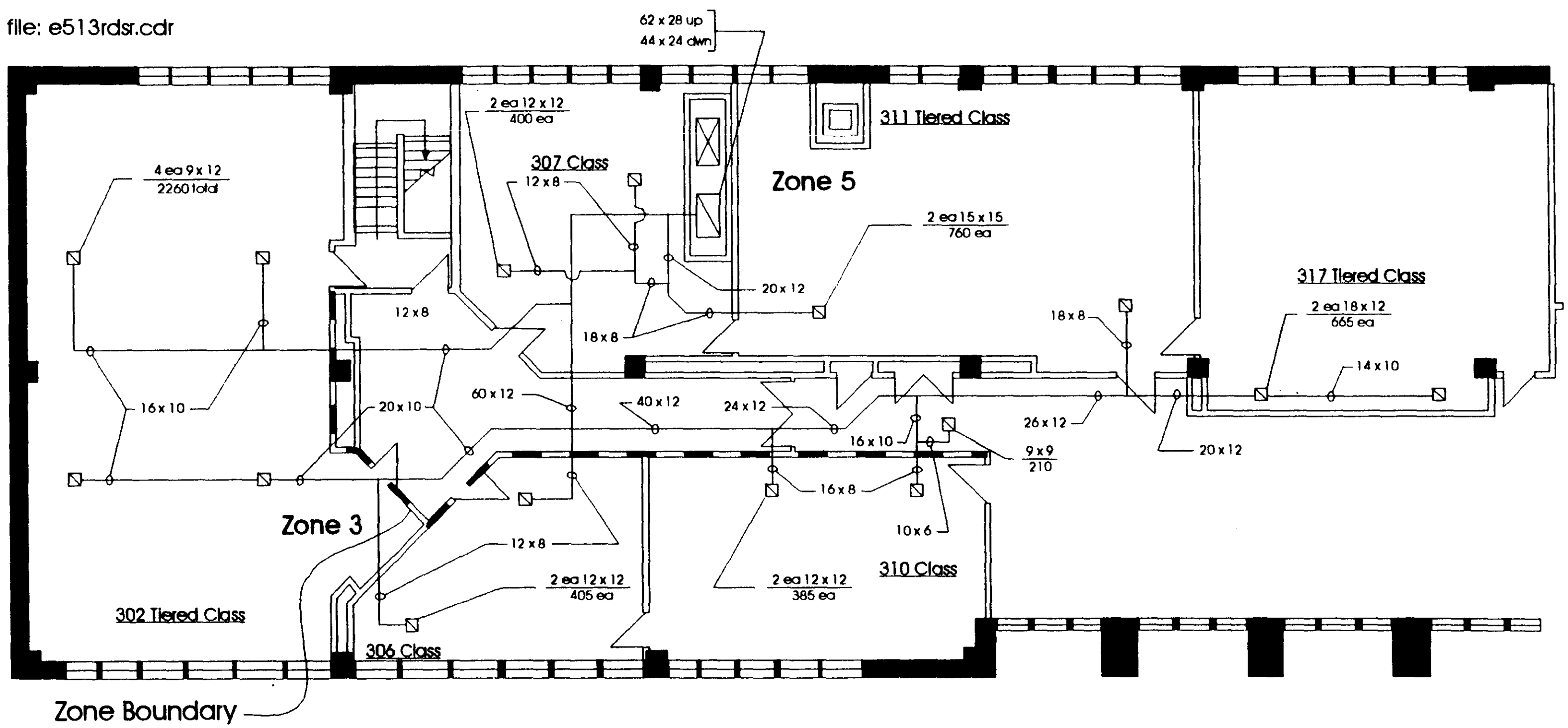


Figure 32: Building E51 - Third Floor Level Supply Ducting w/ Zoning Option F

Figure 33: Building E51 - Third Floor Level Return Ducting w/ Zoning Option F



BUILDING E51 - Third Floor Level Return Ducting w/ Zoning Option F

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Loughborough University of Technology
Massachusetts Institute of Technology

0 5 10 20 40 FEET

Return Register

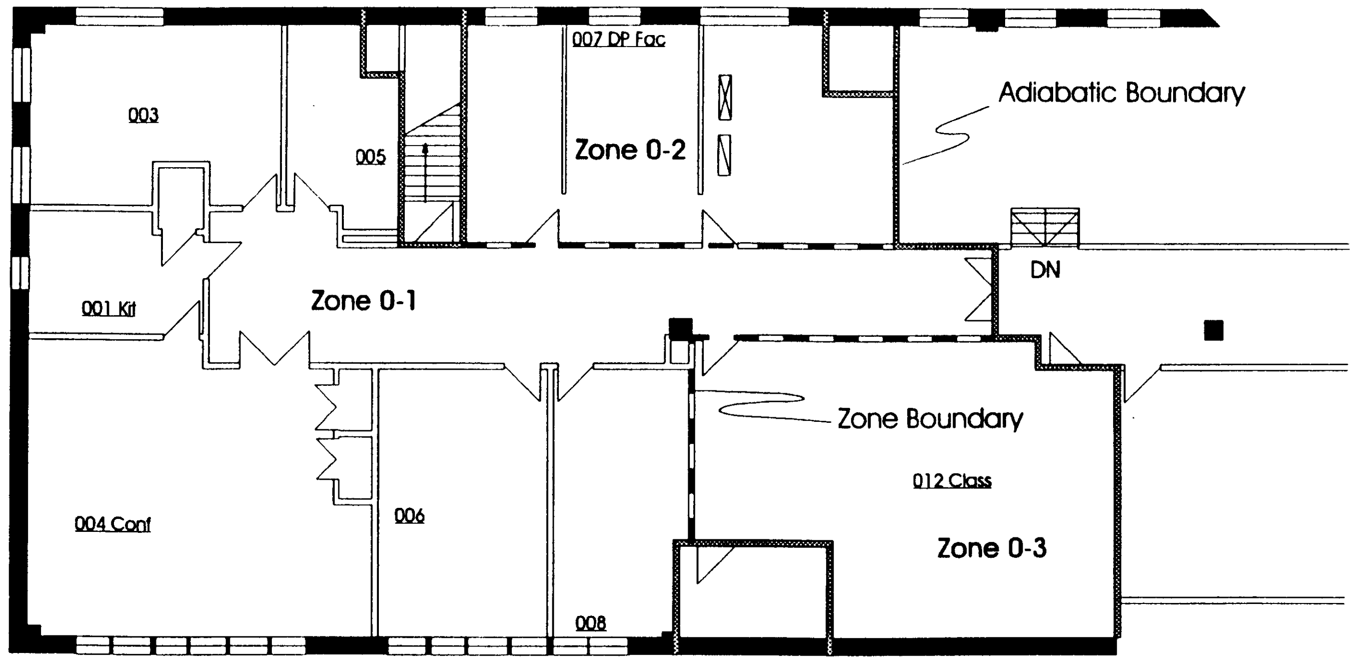
2 ea 12 x 12 / 385 ea — Register Size & CFM

δμα

Appendix E - Proposed Zoning Options for the West End of MIT Building E51 [144]

144 Based on MIT Drawings: EA51 M01.0002
EA51 M02.0004
EA51 M03.0002
EA51 M04.0002

Architectural layouts for Building E51, in the form of Autocad compatible *.dxf files, were obtained from the MIT Facility Management Systems Office in Building E28. The *.dxf files were modified using Coreldraw 5.0 to the megazone boundaries. The drawings are in proportion to the scale bar depicted in each figure.



BUILDING E51 - Basement Level Zoning Option 0A

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

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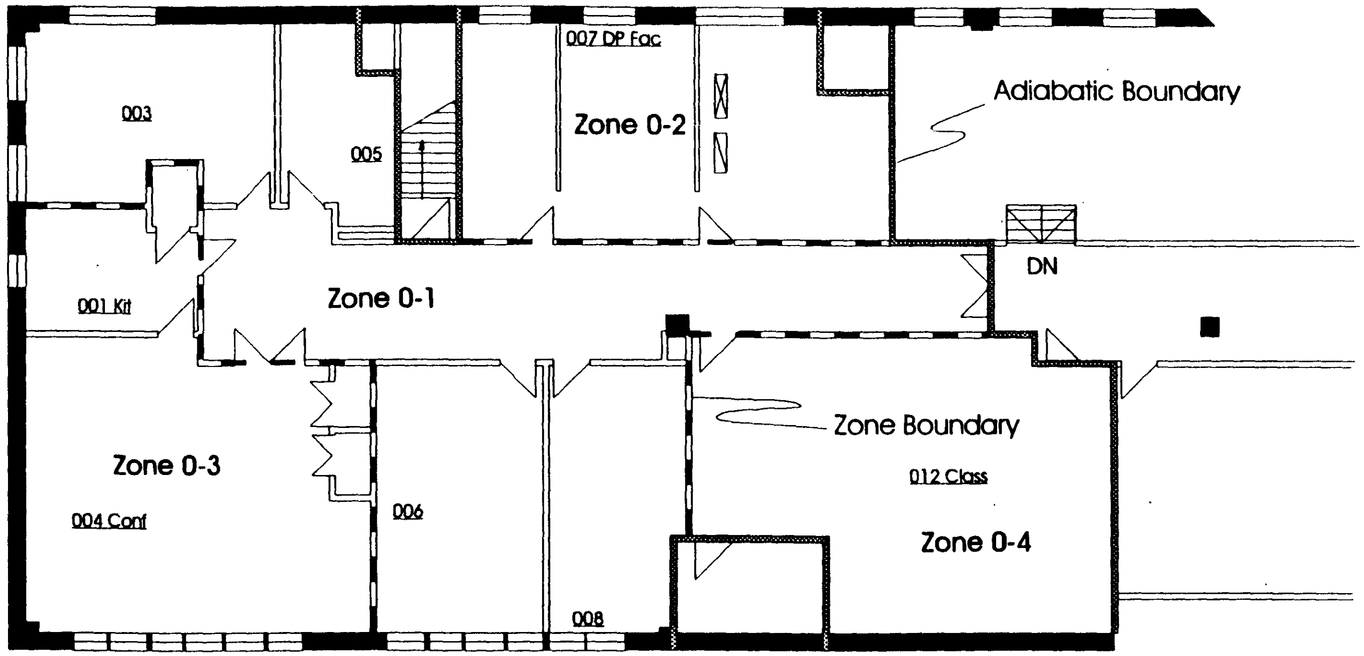
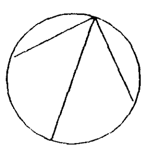
Figure 34: Building E51 - Basement Level Zoning Option 0A

Figure 35: Building E51 - Basement Level Zoning Option 0B





BUILDING E51 - Basement Level Zoning Option 0B

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

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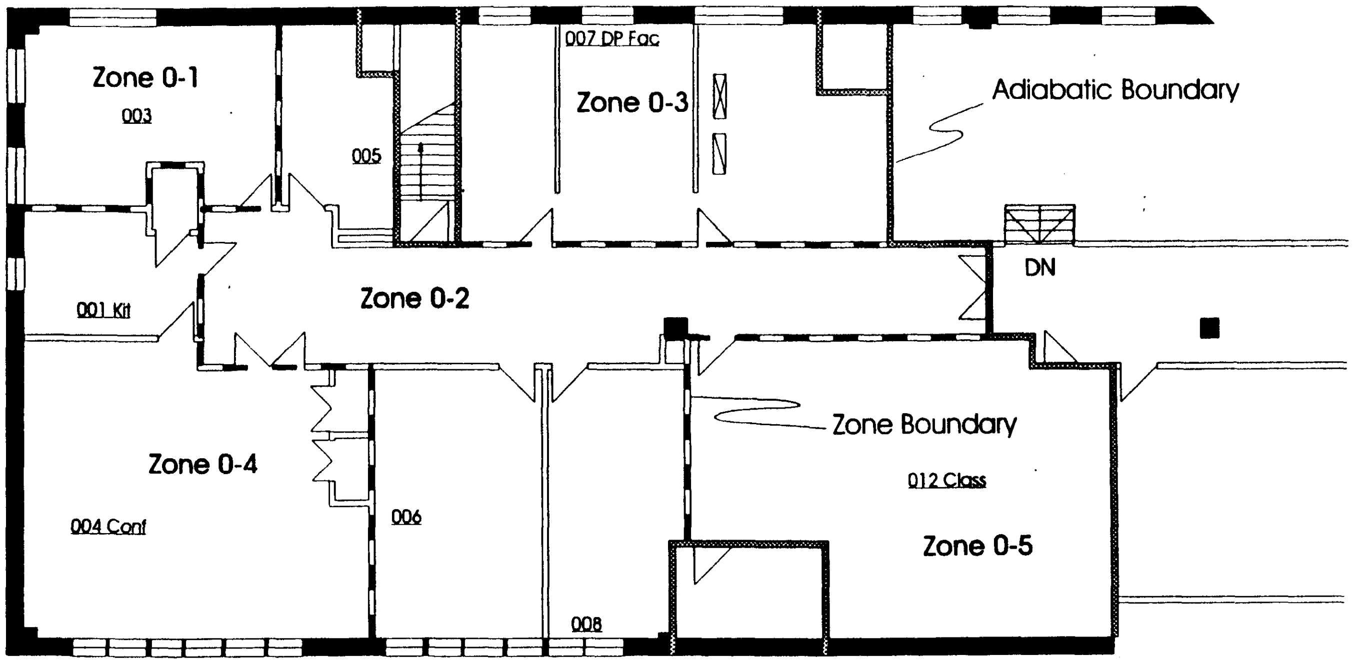
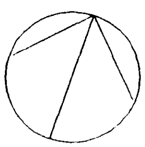
Figure 36: Building E51 - Basement Level Zoning Option 0C





BUILDING E51 - Basement Level Zoning Option 0C

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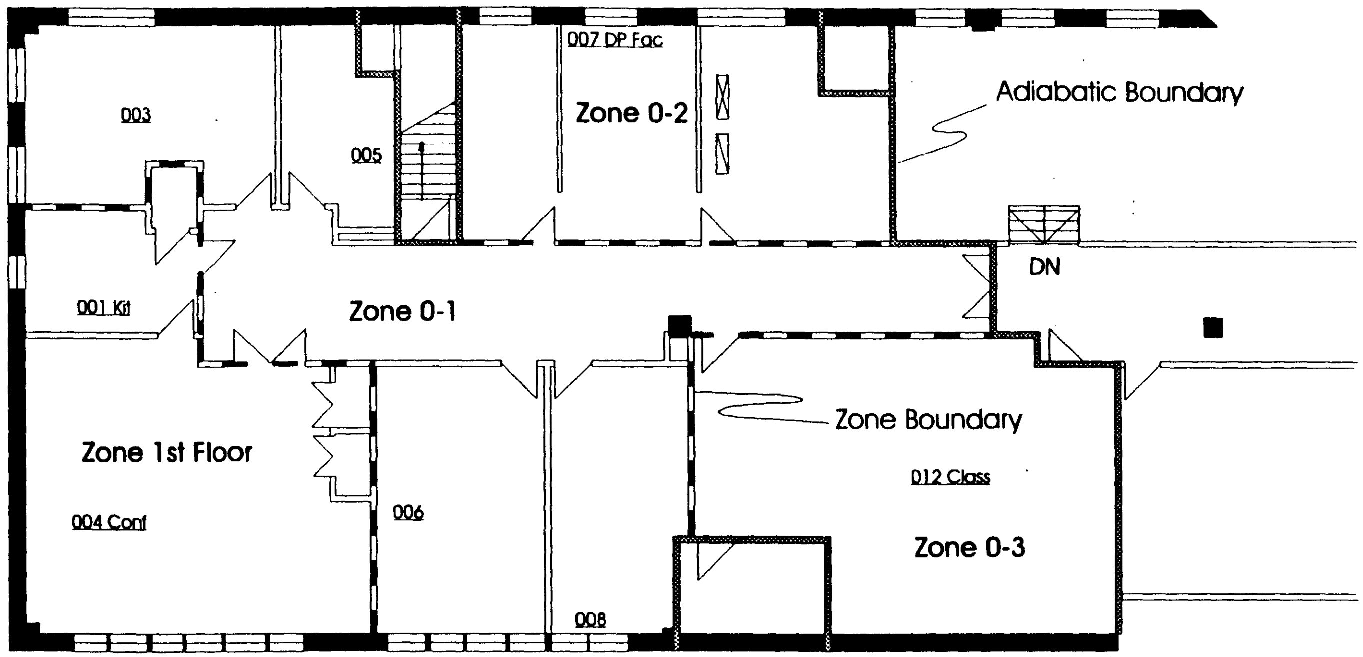


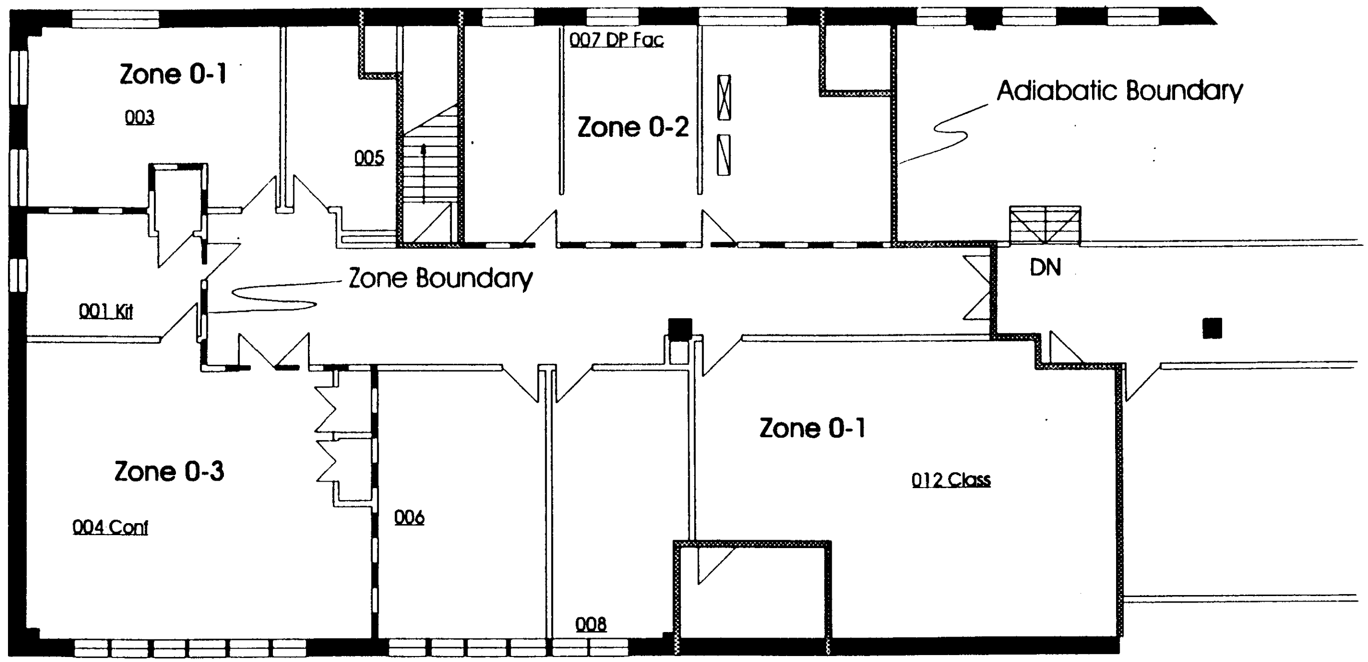
BUILDING E51 - Basement Level Zoning Option 0D

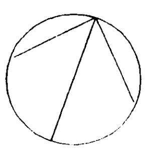
A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

Loughborough University of Technology
Massachusetts Institute of Technology

0 5 10 20 40 FEET

Figure 37: Building E51 - Basement Level Zoning Option 0D





BUILDING E51 - Basement Level Zoning Option 0E

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

Loughborough University of Technology
Massachusetts Institute of Technology

0 5 10 20 40 FEET

Figure 38: Building E51 - Basement Level Zoning Option 0E

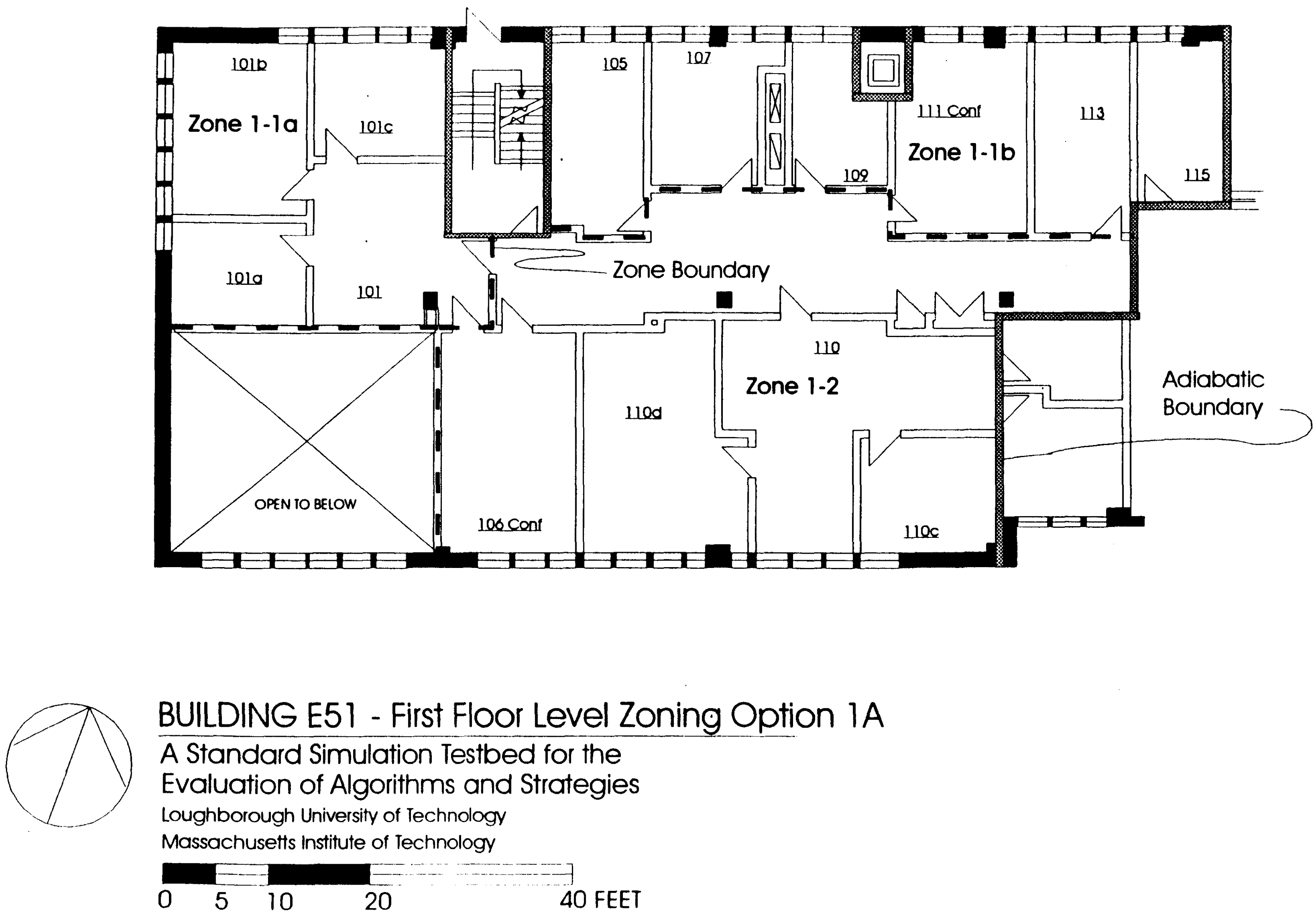
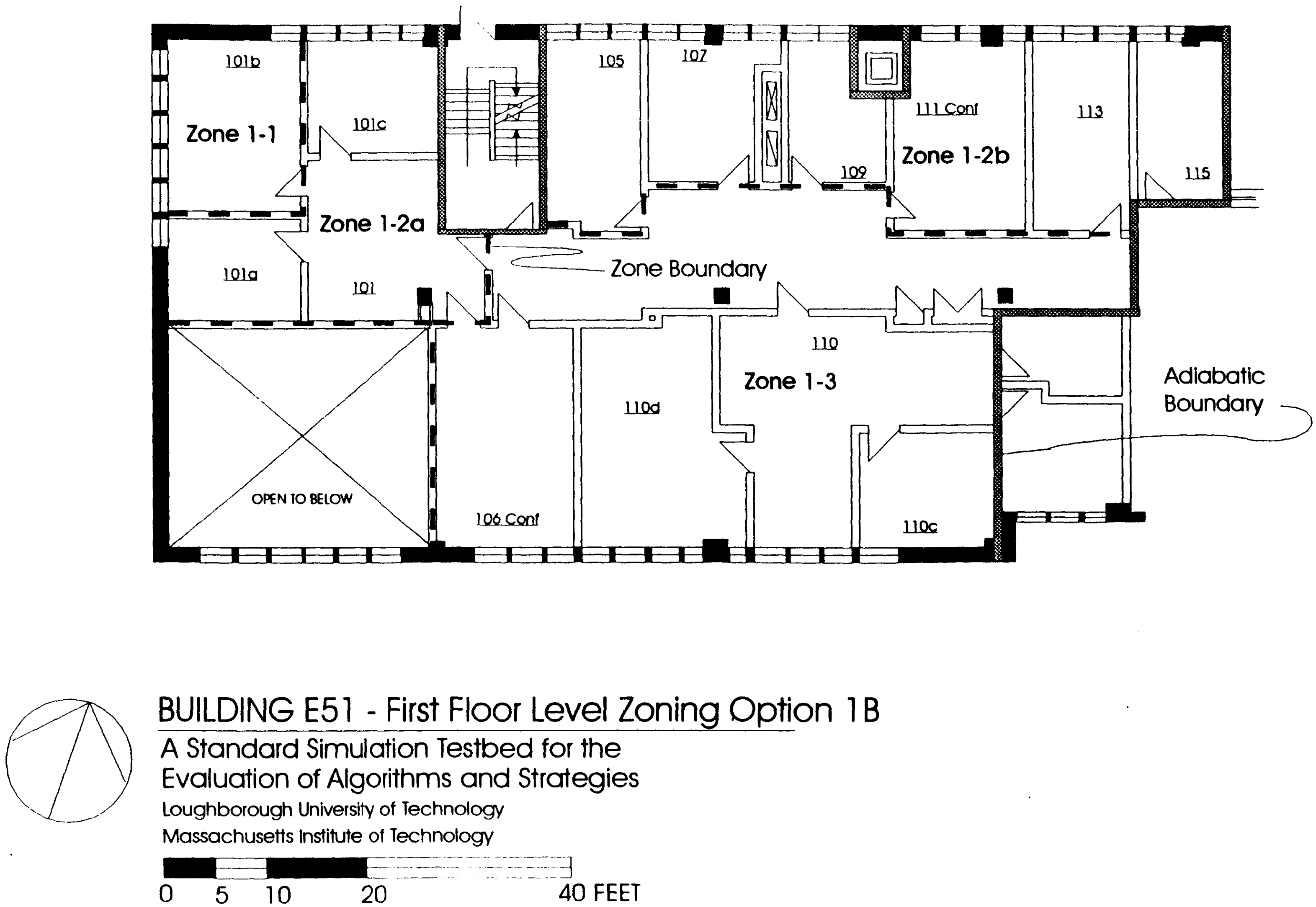
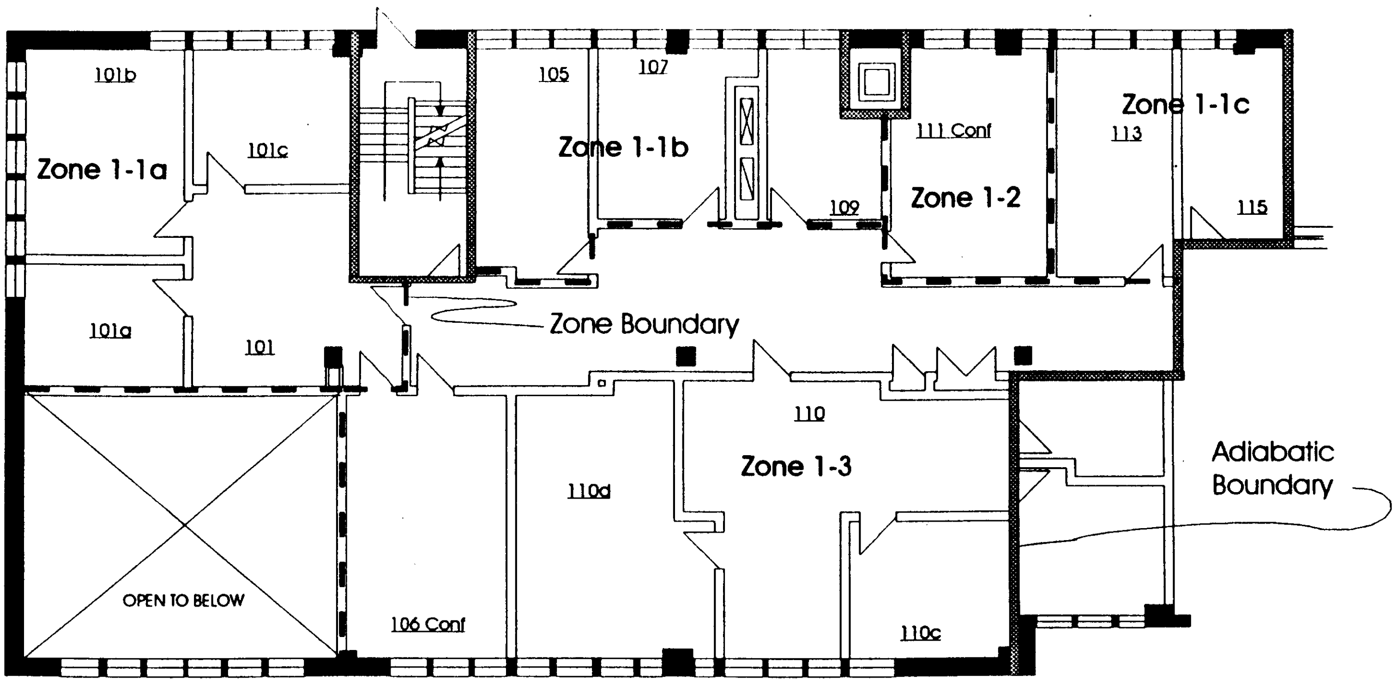
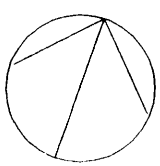


Figure 39: Building E51 - First Floor Level Zoning Option 1A

Figure 40: Building E51 - First Floor Level Zoning Option 1B







BUILDING E51 - First Floor Level Zoning Option 1C

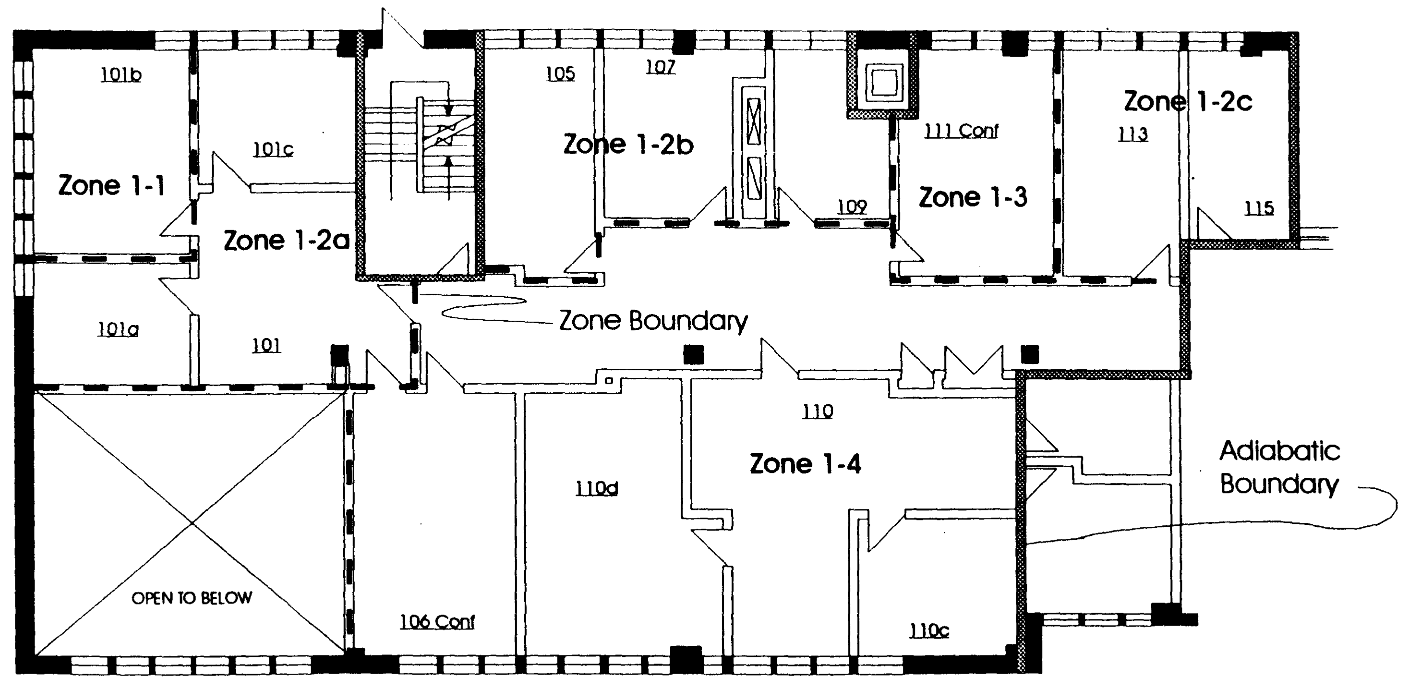
A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

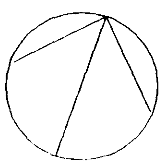
Loughborough University of Technology
Massachusetts Institute of Technology

0 5 10 20 40 FEET

Figure 41: Building E51 - First Floor Level Zoning Option 1C

Figure 42: Building E51 - First Floor Level Zoning Option 1D





BUILDING E51 - First Floor Level Zoning Option 1D

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Evaluation of Algorithms and Strategies

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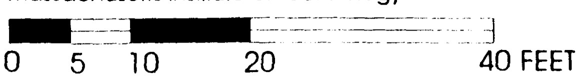
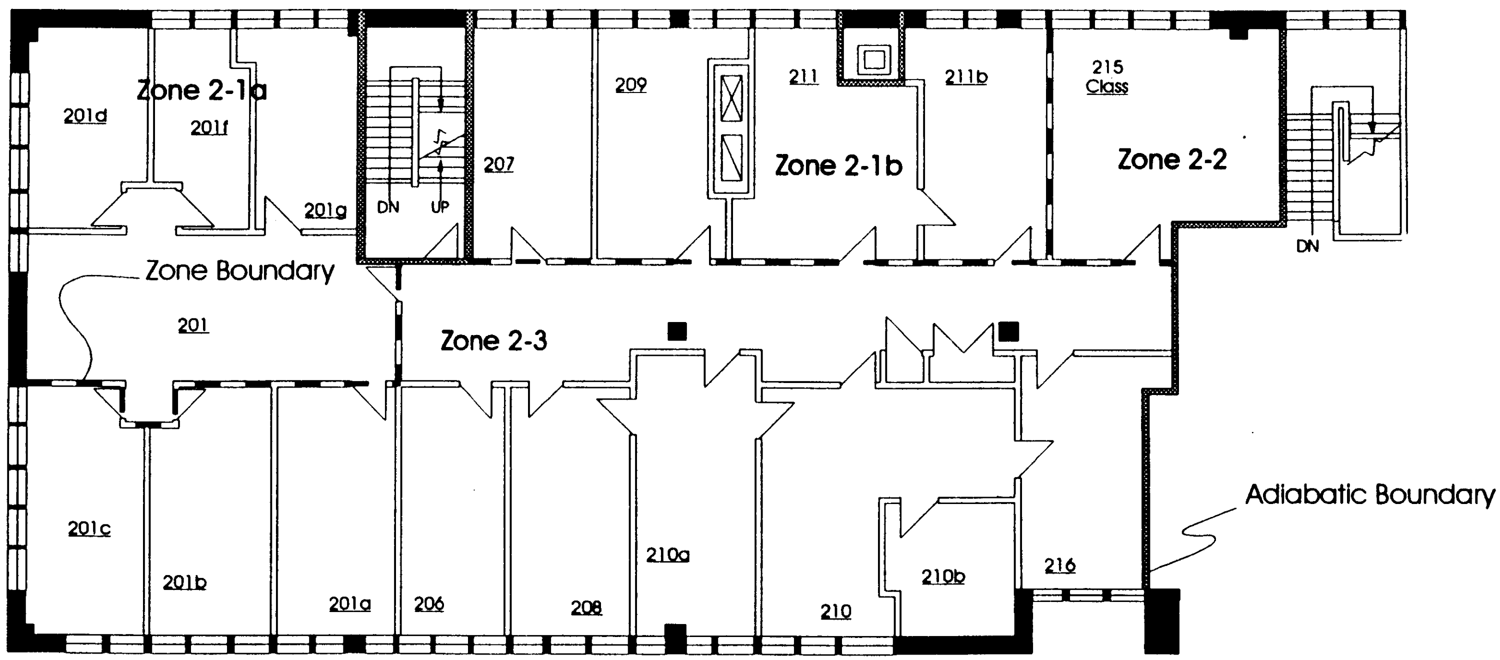
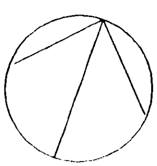






BUILDING E51 - Second Floor Level Zoning Option 2A

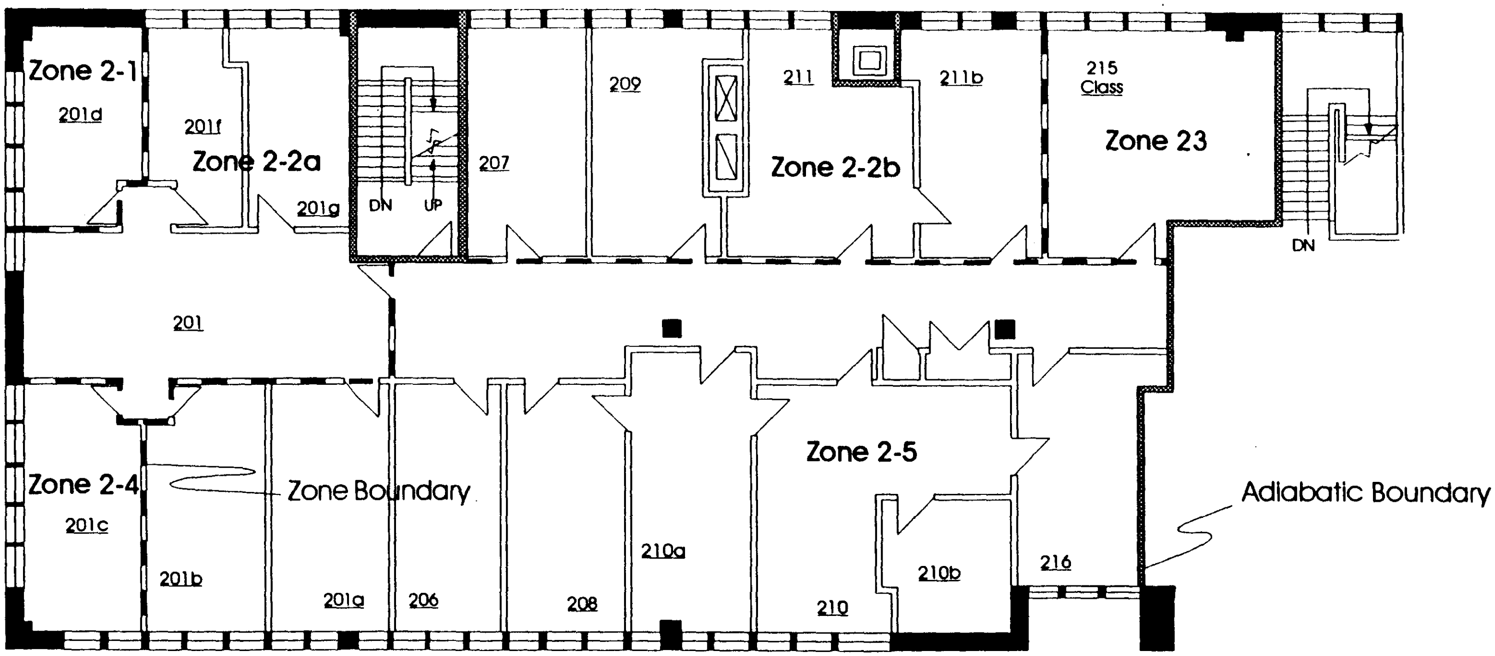
A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

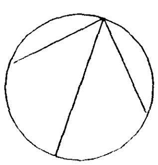
Loughborough University of Technology
Massachusetts Institute of Technology

0 5 10 20 40 FEET

Figure 43: Building E51 - Second Floor Level Zoning Option 2A

Figure 44: Building E51 - Second Floor Level Zoning Option 2B



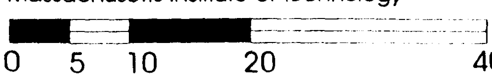


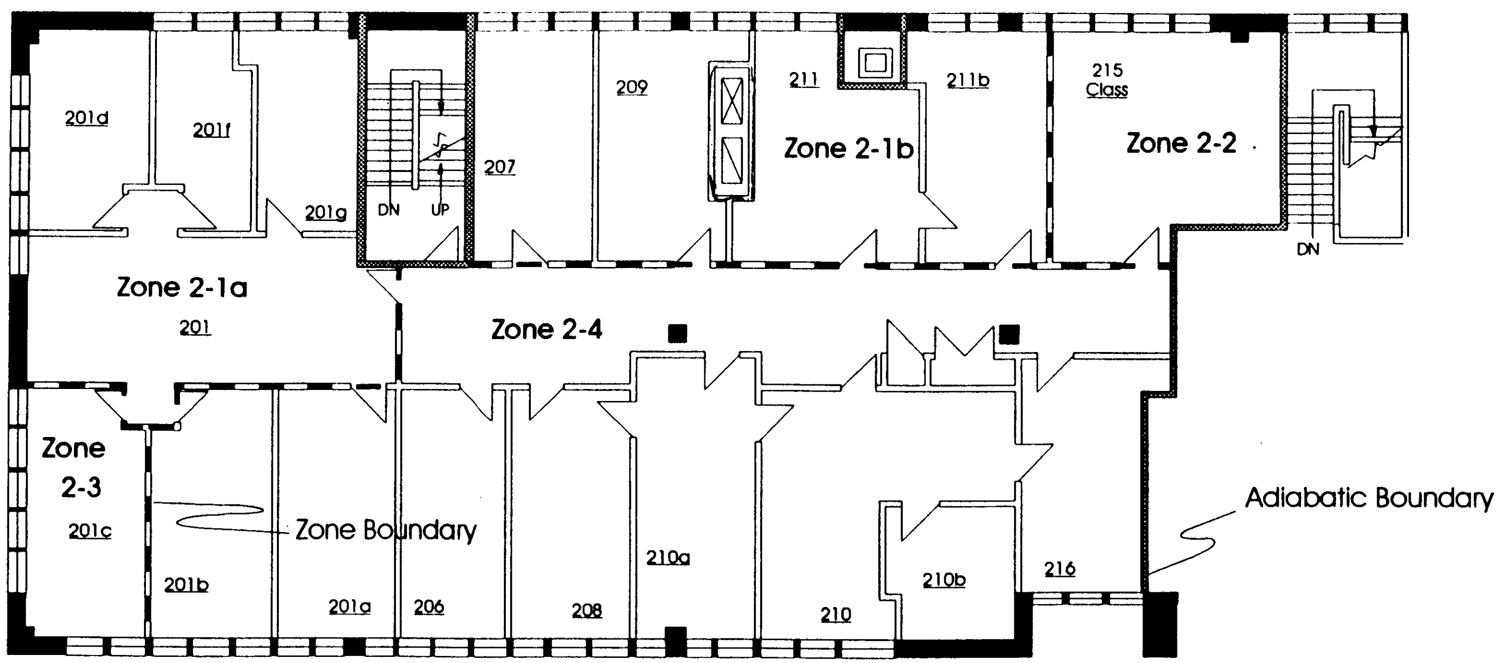
BUILDING E51 - Second Floor Level Zoning Option 2B

A Standard Simulation Testbed for the Evaluation of Algorithms and Strategies

Loughborough University of Technology

Massachusetts Institute of Technology





BUILDING E51 - Second Floor Level Zoning Option 2C

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

Loughborough University of Technology
Massachusetts Institute of Technology

0 5 10 20 40 FEET

Figure 45: Building E51 - Second Floor Level Zoning Option 2C

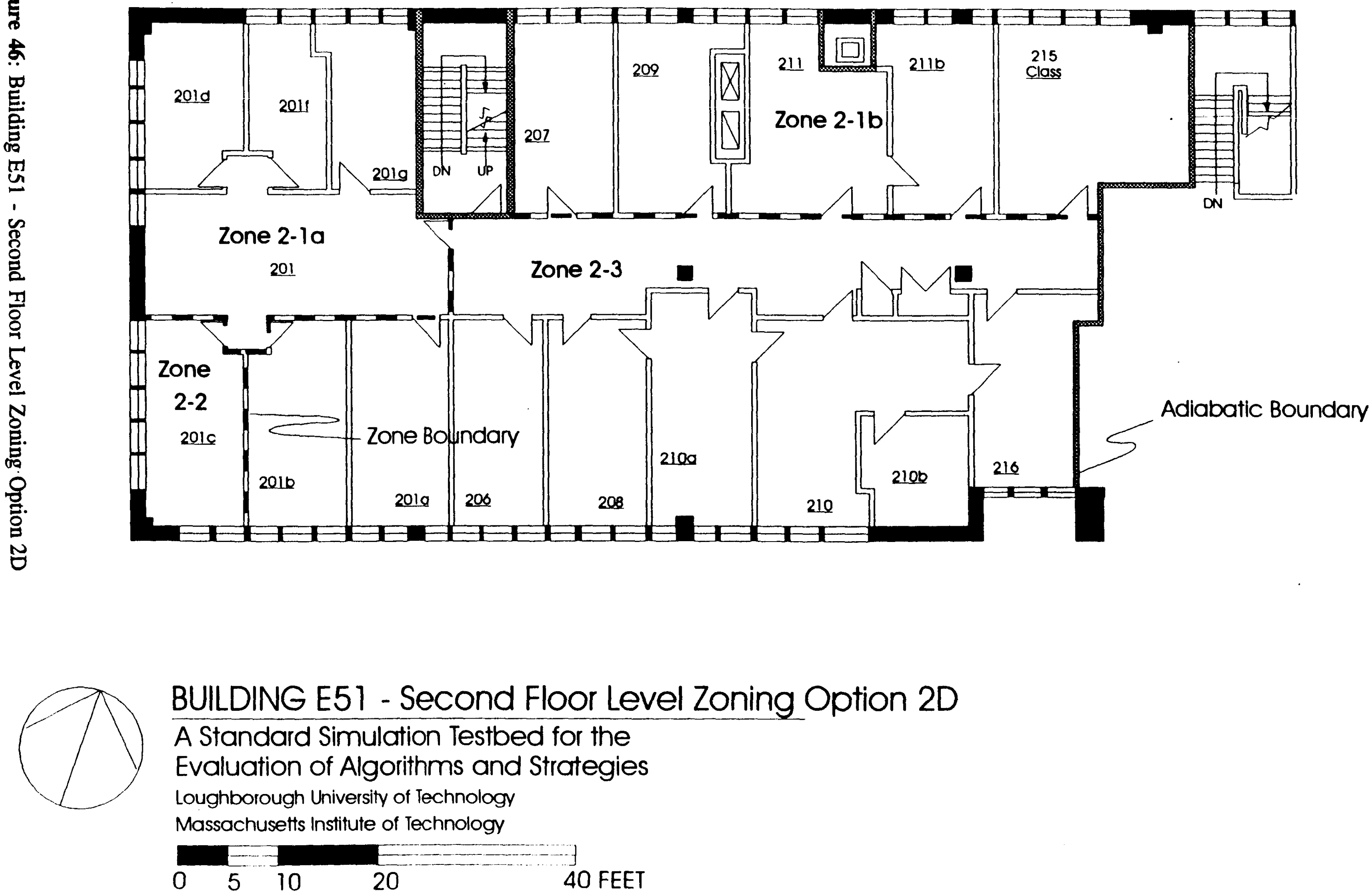
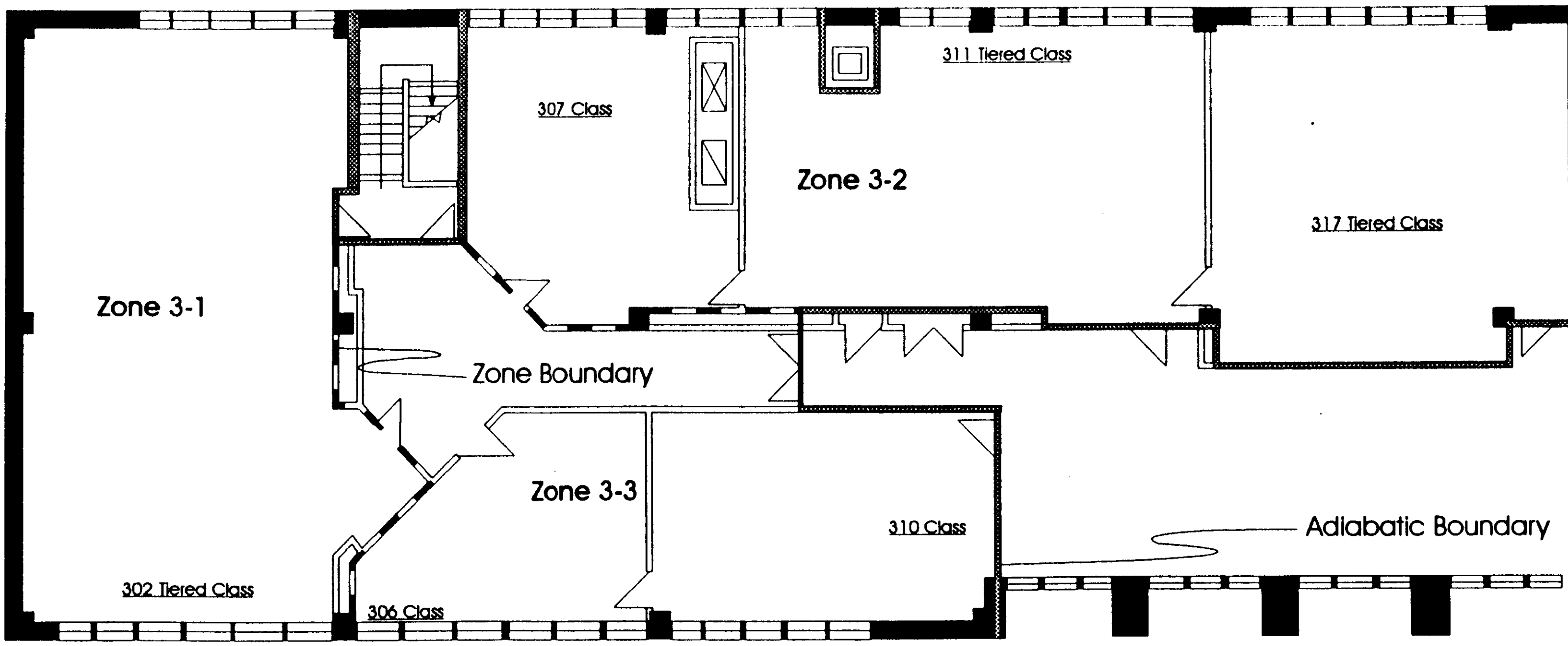
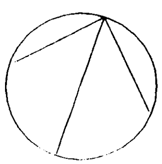


Figure 46: Building E51 - Second Floor Level Zoning Option 2D





BUILDING E51 - Third Floor Level Zoning Option 3A

A Standard Simulation Testbed for the
Evaluation of Algorithms and Strategies

Loughborough University of Technology
Massachusetts Institute of Technology

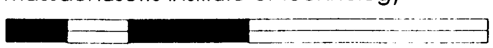


Figure 47: Building E51 - Third Floor Level Zoning Option 3A

Appendix F - Critical Data Summary for Zoning Option F in the West End of Building E51

Figure 48: Occupancy, Lighting, and Office Equipment Survey and Area Schedule

Occupancy, Lighting and Office Equipment Survey & Area Schedule

(1) - 75 Watts per Person
(2) - See Classroom & Conference Room Occupancy Schedule
(3) - a=continuous; b=standard office hours; c= per class/conference schedule; d=student/prof office schedule
(4) - MIT Registra's Office
(5) - Site Survey
(6) - MIT Office of Facilities Mngt Systems Insite Space Inventory 30 Jun 93
(7) - Zoning Selected to Reflect Occupancy and Physical Constraints where Z-I = 11 Zone Option & Z-II = 6 Zone Option
(8) - Name Plate Data
(9) - MIT Drwgs: EA51-A07.0004; A06.0004; A24.0001; S02.0001
(10) - (a)=administrative (p)=professorial (s)=student

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v
							Floor Area [sqft] (6)		Window												
Line	Rm	Use (7,10)			Zoning(7)		Room	Zone	Area(9)	Comp	Occupancy(1)(4)			Lighting(5)				Equipment(5)			
Num	Num	Z-I	Z-II	Opt	Z-I	Z-II	Area	Total	[sqft]	Head'g	Qty	Duty (3)	Pwr [w]	Qty	Type	Duty (3)	Pwr [w]	Qty	Type	Duty (3)	Pwr [w](8)
1	000	Hall	Office	0E	0-1	1	606	606	0.0	-	0	-	0	8	F32T28	a		0	None		
2	000	Hall	Office	0E	0-1	1				-				2	Exit	a	80				
4	003	Office (s)	Office	0E	0-1	1	299	1,763	23.2	W	7	d	525	7	F32T28	d		1	Computer		
5	003	Office (s)	Office	0E	0-1	1			17.2	N								1	Printer, Sm		
7	005	Office (s)	Office	0E	0-1	1	138		0.0	-	3	d	225	2	F32T28	d		1	Computer		
8	005	Office (s)	Office	0E	0-1	1				-								1	Printer, Sm		
9	006	Office (s)	Office	0E	0-1	1	316		85.6	S	4	d	300	4	F32T28	d		1	Computer		
12	008	Office (s)	Office	0E	0-1	1	243		42.8	S	1	d	75	2	F32T28	d		1	Computer		
13	012	Class	Office	0E	0-1	1	767	2,369	0.0	-	(2)	c	-	40	F32T28	c		0	None		
10	007	Computer	Computer	0E	0-2	2	607	607	40.4	N	(2)	c	-	11	F32T28	c		12	Computer		
11	007	Computer	Computer	0E	0-2	2		607		N								1	Printer, Lg		
3	001	Kitchen	Office	0E	0-3	3	142	142	0.0	-	(2)	c	-	3	F32T28	c		1	M-Wave		
6	004	Conf	Office	0E	0-3	3	680	680	348.0	S	(2)	c	-	14	spots	c		0	None		
14	100	Hall	Office	1A	1-2	3	539	539	0.0	-	0	-	0	11	F32T28	a		0	None		
15	100	Hall	Office	1A	1-2	3				-				2	Exit	a	80				
26	106	Conf	Office	1A	1-2	3	284	1,121	47.4	S	(2)	c	-	8	F32T28	c		0	None		
29	110	Office (a)	Office	1A	1-2	3	378		47.4	S	2	b	150	7	F32T28	b		2	Computer		
30	110	Office (a)	Office	1A	1-2	3				S								1	Printer, Sm		
31	110	Office (a)	Office	1A	1-2	3				S								1	Fax		
32	110	Office (a)	Office	1A	1-2	3				S								1	Copier		
33	110	Office (a)	Office	1A	1-2	3				S								2	Type		
34	110	Office (a)	Office	1A	1-2	3				S								1	1/2 Fridge		
35	110	Office (a)	Office	1A	1-2	3				S								1	H2O Cool		
36	110c	Office (a)	Office	1A	1-2	3	147		22.2	S	1	b	75	2	F32T28	b		1	Computer		
37	110d	Office (a)	Office	1A	1-2	3	312		59.6	S	1	b	75	3	F32T28	b		1	Computer		
41	200	Hall	Office	2D	2-3	3	519	519	0.0	-	0	-	0	10	F32T28	a		0.	None		
42	200	Hall	Office	2D	2-3	3				-				2	Exit	a	80				
47	201a	Office (p)	Office	2D	2-3	3	202	1,611	40.2	S	1	d	75	2	F32T28	d		1	Computer		
48	201b	Office (p)	Office	2D	2-3	3	192		47.4	S	1	d	75	2	F32T28	d		1	Computer		
54	206	Office (p)	Office	2D	2-3	3	181		47.4	S	1	d	75	2	F32T28	d		1	Computer		

Figure 49: Occupancy, Lighting, and Office Equipment Survey and Area Schedule (continued)

Occupancy, Lighting and Office Equipment Survey & Area Schedule

(1) - 75 Watts per Person
(2) - See Classroom & Conference Room Occupancy Schedule
(3) - a=continuous; b=standard office hours; c= per class/conference schedule; d=student/prof office schedule
(4) - MIT Registra's Office
(5) - Site Survey
(6) - MIT Office of Facilities Mngt Systems Insite Space Inventory 30 Jun 93
(7) - Zoning Selected to Reflect Occupancy and Physical Constraints where Z-I = 11 Zone Option & Z-II = 6 Zone Option
(8) - Name Plate Data
(9) - MIT Drwgs: EA51-A07.0004; A06.0004; A24.0001; S02.0001
(10) - (a)=administrative (p)=professorial (s)=student

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v
Line	Rm	Use (7,10)		Zoning(7)			Floor Area [sqft] (6)		Window	Comp	Occupancy(1)(4)			Lighting(5)				Equipment(5)			
Num	Num	Z-I	Z-II	Opt	Z-I	Z-II	Room Area	Zone Total	Area(9) [sqft]	Head'g	Qty	Duty (3)	Pwr [w]	Qty	Type	Duty (3)	Pwr [w]	Qty	Type	Duty (3)	Pwr [w](8)
56	208	Office (p)	Office	2D	2-3	3	197		47.4	S	1	d	75	2	F32T28	d		1	Computer		
58	210	Office (a)	Office	2D	2-3	3	303		53.8	S	3	b	225	3	F32T28	b		2	Computer		
59	210	Office (a)	Office	2D	2-3	3				S								1	Printer, Sm		
60	210	Office (a)	Office	2D	2-3	3				S								1	Fax		
61	210	Office (a)	Office	2D	2-3	3				S								1	Copier		
62	210a	Office (a)	Office	2D	2-3	3	226		40.2	S	1	b	75	3	F32T28	b		1	Computer		
63	210b	Office (a)	Office	2D	2-3	3	112		0.0	-	1	b	75	2	F32T28	b		1	Computer		
67	216	Office (a)	Office	2D	2-3	3	198		64.2	S	1	d	75	2	F32T28	d		1	Computer		
70	302	Class	Office	3A	3-1	3	1,339	2,187	91.2	S	(2)	c	-	76	F32T28	c		0	None		
71	302	Class	Office	3A	3-1	3			75.4	N											
72	306	Class	Office	3A	3-3	3	353		119.2	S	(2)	c	-	19	F32T28	c		0	None		
74	310	Class	Office	3A	3-3	3	495	6,799	81.8	S	(2)	c	-	23	F32T28	c		0	None		
16	101	Office (a)	Office (a)	1A	1-1a	4	238	720	0.0	-	2	b	150	2	F32T28	b		2	Computer		
17	101	Office (a)	Office (a)	1A	1-1a	4				-								1	Printer, Sm		
18	101a	Office (a)	Office (a)	1A	1-1a	4	128		15.8	W	1	b	75	2	F32T28	b		1	Computer		
19	101b	Office (a)	Office (a)	1A	1-1a	4	213		79.0	W	1	b	75	2	F32T28	b		1	Computer		
20	101b	Office (a)	Office (a)	1A	1-1a	4			15.8	N											
21	101c	Office (a)	Office (a)	1A	1-1a	4	141		75.4	N	1	b	75	2	F32T28	b		1	Computer		
22	101c	Office (a)	Office (a)	1A	1-1a	4				N								1	Printer, Sm		
23	101c	Office (a)	Office (a)	1A	1-1a	4				N								1	Fax		
24	101c	Office (a)	Office (a)	1A	1-1a	4				N								1	Copier		
43	201	Office (a)	Office (a)	2D	2-1a	4	384	790	15.8	W	2	b	150	8	F32T28	b		2	Computer		
44	201	Office (a)	Office (a)	2D	2-1a	4				W								1	Printer, Sm		
45	201	Office (a)	Office (a)	2D	2-1a	4				W								1	Fax		
46	201	Office (a)	Office (a)	2D	2-1a	4				W								1	Copier		
51	201d	Office (p)	Office (p)	2D	2-1a	4	151		79.0	W	1	d	75	2	F32T28	d		1	Computer		
52	201f	Office (p)	Office (p)	2D	2-1a	4	112		31.6	N	1	d	75	2	F32T28	d		1	Computer		
53	201g	Office (p)	Office (p)	2D	2-1a	4	143	1,510	43.8	N	1	d	75	2	F32T28	d		1	Computer		
25	105	Office (p)	Class	1A	1-1b	5	164	949	47.4	N	1	d	75	2	F32T28	d		1	Computer		
27	107	Office (p)	Class	1A	1-1b	5	149		56.0	N	1	d	75	2	F32T28	d		1	Computer		

Occupancy, Lighting and Office Equipment Survey & Area Schedule

(1) - 75 Watts per Person
(2) - See Classroom & Conference Room Occupancy Schedule
(3) - a=continuous; b=standard office hours; c= per class/conference schedule; d=student/prof office schedule
(4) - MIT Registra's Office
(5) - Site Survey
(6) - MIT Office of Facilities Mngt Systems Insite Space Inventory 30 Jun 93
(7) - Zoning Selected to Reflect Occupancy and Physical Constraints where Z-I = 11 Zone Option & Z-II = 6 Zone Option
(8) - Name Plate Data
(9) - MIT Drwgs: EA51-A07.0004; A06.0004; A24.0001; S02.0001
(10) - (a)=administrative (p)=professorial (s)=student

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v
							Floor Area [sqft] (6		Window												
Line	Rm	Use (7,10)		Zoning(7)			Room	Zone	Area(9)	Comp	Occupancy(1)(4)			Lighting(5)				Equipment(5)			
Num	Num	Z-I	Z-II	Opt	Z-I	Z-II	Area	Total	[sqft]	Head'g	Qty	Duty (3	Pwr [w]	Qty	Type	Duty (3	Pwr [w]	Qty	Type	Duty (3)	Pwr [w](8)
28	109	Office (p)	Class	1A	1-1b	5	109		31.6	N	1	d	75	2	F32T28	d		1	Computer		
38	111	Conf	Class	1A	1-1b	5	228		40.2	N	(2)	c	-	8	F32T28	c		0	None		
39	113	Office (p)	Class	1A	1-1b	5	173		47.4	N	1	d	75	2	F32T28	d		1	Computer		
40	115	Office (p)	Class	1A	1-1b	5	126		28.0	N	1	d	75	2	F32T28	d		1	Computer		
55	207	Office (p)	Class	2D	2-1b	5	184	1,123	47.4	N	1	d	75	2	F32T28	d		1	Computer		
57	209	Office (p)	Class	2D	2-1b	5	184		56.0	N	1	d	75	2	F32T28	d		1	Computer		
64	211	Office (p)	Class	2D	2-1b	5	233		31.6	N	1	d	75	4	F32T28	d		1	Computer		
65	211b	Office (p)	Class	2D	2-1b	5	197		40.2	N	1	d	75	2	F32T28	d		1	Computer		
66	215	Class	Class	2D	2-1b	5	325		63.2	N	(2)	c	-	15	F32T28	c		0	None		
68	300	Hall	Class	3A	3-3	5	354	354	0.0	-	0	-	0	6	F32T28	a		0	None		
69	300	Hall	Class	3A	3-3	5				-				2	Exit	a	80				
73	307	Class	Class	3A	3-2	5	535	2,240	103.4	N	(2)	c	-	22	F32T28	c		0	None		
75	311	Class	Class	3A	3-2	5	894		135.0	N	(2)	c	-	54	F32T28	c		0	None		
76	317	Class	Class	3A	3-2	5	811	4,666	94.8	N	(2)	c	-	47	F32T28	c		0	None		
49	201c	Office (p)	Office	2D	2-2	6	188	188	31.6	S	1	d	75	2	F32T28	d		1	Computer		
50	201c	Office (p)	Office	2D	2-2	6		188	79.0	W											
		Total Area For All Zones	[sqft]					16,139			Totals [w]		3,675				320				0
		Check Sum	[sqft]				16,139														

Figure 50: Occupancy, Lighting, and Office Equipment Survey and Area Schedule (continued)

Figure 51: Occupancy, Lighting, and Office Equipment Survey and Area Schedule (continued)

Occupancy, Lighting and Office Equipment Survey & Area Schedule

(1) - 75 Watts per Person
(2) - See Classroom & Conference Room Occupancy Schedule
(3) - a=continuous; b=standard office hours; c= per class/conference schedule; d=student/prof office schedule
(4) - MIT Registra's Office
(5) - Site Survey
(6) - MIT Office of Facilities Mngt Systems Insite Space Inventory 30 Jun 93
(7) - Zoning Selected to Reflect Occupancy and Physical Constraints where Z-I = 11 Zone Option & Z-II = 6 Zone Option
(8) - Name Plate Data
(9) - MIT Drwgs: EA51-A07.0004; A06.0004; A24.0001; S02.0001
(10) - (a)=administrative (p)=professorial (s)=student

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v
							Floor Area [sqft] (6		Window												
Line	Rm	Use (7,10)		Zoning(7)			Room	Zone	Area(9)	Comp	Occupancy(1)(4)			Lighting(5)				Equipment(5)			
Num	Num	Z-I	Z-II	Opt	Z-I	Z-II	Area	Total	[sqft]	Head'g	Qty	Duty (3	Pwr [w]	Qty	Type	Duty (3	Pwr [w]	Qty	Type	Duty (3)	Pwr [w](8)

a = data entry record line number (coincides with ascending order of room numbers)
b = room number designation per MIT Facilities Management Systems Drawings
c = room use designation per MIT Facilities Management Systems Drawings
d = reallocated room use as required in 6 megazone re-zoning Option F
e = applicable zoning option designation contributing to the 11 megazone re-zoning plan
f = zone number designation for 11 megazone re-zoning option
g = zone number designation for 6 megazone re-zoning option
h = floor area attributed to each room number per MIT Facilities Management Systems Report
i = total floor area for each zone per 6 megazone Option F
j = window area attributed to each room number per take offs from E51 architectual drawings
k = compass heading for each window set by room number
l = number of occupants per room or indicates varied occupancy per classroom or conferencing requirements
m = indicates how the room or area is occupied
n = indicates the toatl heat input for the occupancy schedule
o = number of lighting elements
p = type of lighting element
q = indicates how the lighting element is used
r = maximum heat input due to the lighting indicated
s = number of pieces of equipment
t = type of equipment in the room or area
u = indicates how the equipment is operated
v = indicates the maximum heat dissaption per nameplate data

Appendix G - Occupancy Schedules for Classrooms in West End of MIT Building E51 [145]

145 Data taken from classroom use schedules provided by the MIT Schedules Office, Room E19-334.

Building E51 Classroom Occupancy Data 09/93 - 12/93

MONDAY	004	007	012	106	111	215	302	306	307	310	311	317
Rm Capacity	60	12	50	14	15	25	80	25	25	18	59	55
0800 - 0830												
0830 - 0900							56				31	47
0900 - 0930				12*			56	16			31	47
0930 - 1000				12*			56	16			31	47
1000 - 1030		3*	26	12*			56	16	27	17	30	47
1030 - 1100		3*	26	12*			56	15	27	17	30	47
1100 - 1130		3*	26				56	15	27	17	30	47
1130 - 1200		3*					56	15				47
1200 - 1230		2*									12	
1230 - 1300		2*									12	
1300 - 1330		2*	38	6*	2	14*	58	7	26			41
1330 - 1400		5*	38	6*	2	14*	58	7	26			41
1400 - 1430		6*	38	6*	2	14*	58	7	26			41
1430 - 1500		7*	22	6*	2	14*	58	7	25	11	59	58
1500 - 1530		8*	22		2	4*	58	7	25	11	59	58
1530 - 1600		8*	22		2	4*	58	7	25	11	59	58
1600 - 1630	50	8*								13	50	
1630 - 1700	50									13	50	
1700 - 1730	50											
1730 - 1800	50					4*						
1800 - 1830		6*				4*			20*			
1830 - 1900		6*				4*			20*			
1900 - 1930		6*				4*			20*			
1930 - 2000		6*							20*			
2000 - 2030		6*							20*			
2030 - 2100		6*							20*			
2100 - 2130		5*							20*			
2130 - 2200		4*							20*			
2200 - 2230		3*							20*			
2230 - 2300		2*										

* - Estimated (actual data unavailable)

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Figure 52: Building E51 Classroom Occupancy Schedule - Monday

Figure 53: Building E51 Classroom Occupancy Schedule - Tuesday

Building E51 Classroom Occupancy Data 09/93 - 12/93

TUESDAY	012	111	215	302	306	307	310	311	317
Rm Capacity	50	15	25	80	25	25	18	59	55
0800 - 0830									
0830 - 0900				57					46
0900 - 0930				57				28	46
0930 - 1000		6		57				28	46
1000 - 1030		6	20*	57		27		28	46
1030 - 1100		6	20*	57		27			46
1100 - 1130		6	20*	57	6	27			46
1130 - 1200		6	20*	57	6		13		46
1200 - 1230		6	20*		6		13		
1230 - 1300		6	20*				13		
1300 - 1330			15*			26		51	27
1330 - 1400			15*			26		51	27
1400 - 1430		2	15*		1	26		51	27
1430 - 1500		2	15*		1	25	7		36
1500 - 1530	7	2	15*		1	25	7		36
1530 - 1600	7	2	15*			25	7		36
1600 - 1630	7	2		51			7	?	
1630 - 1700	7	2		51				?	
1700 - 1730	7			51			6	?	
1730 - 1800	7			51			6	?	
1800 - 1830				51		20*	6		
1830 - 1900				51		20*	6		
1900 - 1930		1				20*			
1930 - 2000		1				20*			
2000 - 2030		1				20*			
2030 - 2100		1				20*			
2100 - 2130		1				20*			
2130 - 2200						20*			
2200 - 2230						20*			
2230 - 2300									

* - Estimated (actual data unavailable)

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Figure 54: Building E51 Classroom Occupancy Schedule - Wednesday

Building E51 Classroom Occupancy Data 09/93 - 12/93

WEDNESDAY	012	111	215	302	306	307	310	311	317
Rm Capacity	50	15	25	80	25	25	18	59	55
0800 - 0830									
0830 - 0900				56				31	47
0900 - 0930				56	16			31	47
0930 - 1000				56	16			31	47
1000 - 1030	26			56	16	27	17	30	47
1030 - 1100	26			56	15	27	17	30	47
1100 - 1130	26			56	15	27	17	30	47
1130 - 1200				56	15				47
1200 - 1230								12	
1230 - 1300			20*					12	
1300 - 1330	38		20*	58		26			41
1330 - 1400	38		20*	58	3	26			41
1400 - 1430	38		20*	58	3	26			41
1430 - 1500	22		20*	58	3	25	11	73	58
1500 - 1530	22			58	3	25	11	73	58
1530 - 1600	22			58		25	11	73	58
1600 - 1630	50					2		50	
1630 - 1700	50					2		50	
1700 - 1730	50					2			
1730 - 1800	50					2			
1800 - 1830	50				?	20*			
1830 - 1900					?	20*			
1900 - 1930					?	20*			
1930 - 2000						20*			
2000 - 2030						20*			
2030 - 2100						20*			
2100 - 2130						20*			
2130 - 2200						20*			
2200 - 2230						20*			
2230 - 2300									

* - Estimated (actual data unavailable)

file: classocc.wq2 12/27/95

Figure 55: Building E51 Classroom Occupancy Schedule - Thursday

Building E51 Classroom Occupancy Data 09/93 - 12/93

THURSDAY	012	111	215	302	306	307	310	311	317
Rm Capacity	50	15	25	80	25	25	18	59	55
0800 - 0830									
0830 - 0900				57					47
0900 - 0930	43			57				28	47
0930 - 1000	43	6		57				28	47
1000 - 1030	43	6		57				28	47
1030 - 1100	43	6		57		12			47
1100 - 1130	43			57	6	12			47
1130 - 1200	43			57	6	12	13		47
1200 - 1230					6	12	13		
1230 - 1300							13		
1300 - 1330	43							51	27
1330 - 1400	43							51	27
1400 - 1430	43				1			51	27
1430 - 1500	43				1				27
1500 - 1530	43		20*		1		5		27
1530 - 1600	43		20*				5		27
1600 - 1630			20*			?	5	42	
1630 - 1700			20*			?	5	42	
1700 - 1730						?		42	
1730 - 1800						?			
1800 - 1830						20*			
1830 - 1900						20*			
1900 - 1930						20*			
1930 - 2000						20*			
2000 - 2030						20*			
2030 - 2100						20*			
2100 - 2130						20*			
2130 - 2200						20*			
2200 - 2230						20*			
2230 - 2300									

* - Estimated (actual data unavailable)

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Building E51 Classroom Occupancy Data 09/93 - 12/93

FRIDAY	012	111	215	302	306	307	310	311	317
Rm Capacity	50	15	25	80	25	25	18	59	55
0800 - 0830									
0830 - 0900				46					37
0900 - 0930				46				28	37
0930 - 1000	9			46	9	9		28	37
1000 - 1030	9	1		46	9	9	?	28	37
1030 - 1100	9	1		46	9	9	?	18	37
1100 - 1130	9	1		46	9	9	?	18	37
1130 - 1200		1		46			?	18	37
1200 - 1230		1						28	
1230 - 1300		1						28	
1300 - 1330				93	29	26	15		
1330 - 1400				93	29	26	15		
1400 - 1430				93		26	15		
1430 - 1500							15		
1500 - 1530			20*				15		
1530 - 1600			20*				15		
1600 - 1630			20*						
1630 - 1700			20*						
1700 - 1730									
1730 - 1800									
1800 - 1830						20*			
1830 - 1900						20*			
1900 - 1930						20*			
1930 - 2000						20*			
2000 - 2030						20*			
2030 - 2100						20*			
2100 - 2130						20*			
2130 - 2200						20*			
2200 - 2230						20*			
2230 - 2300									

* - Estimated (actual data unavailable)

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Figure 56: Building E51 Classroom Occupancy Schedule - Friday

Appendix H - Building E51 Mechanical System Design Specifications [146]

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146 Based on MIT Drawings: EA51 M07.0002
EA51 M01.0002
EA51 M02.0004
EA51 M03.0002
EA51 M04.0002

Air Handling Unit Schedule

Fan Data					Motor		
Design Flow [cfm]	Minimum Outside Air Flow [cfm]	Total Static Pressure [in wg]	Wheel Diameter [in]	Wheel Speed [rpm]	Power Rating [hp]	Speed Rating [rpm]	Electric Spec's [V-Ph-Hz]
18,590	4,000	3.5	27	1,340	20	1,750	208-3-60

Cooling Coil							
Total	Sensible	Entering Air		Leaving Air		Maximum	Clg Coil
Coil Output [MBH]	Coil Output [MBH]	Dry Bulb [deg F]	Wet Bulb [deg F]	Dry Bulb [deg F]	Wet Bulb [deg F]	Face Velocity [fpm]	Design Flow [gpm]
736.3	518.0	81.8	62.8	56.0	55.0	500	74

Special	
Filters	Mfr or Equal
30 x 35 x 2 Very High Capacity	Trane # 41

VAV Box Schedule

General				Reheat Coil				
					Air Side	Water Side		
VAV Box ID Designation	Rated Design Flow Range [cfm]	Minimum Volume Setting [%]	Maximum Allowable Inlet SP [in wg]	Minimum Output [MBH]	Temperature Enter/Leave [deg F]	Flow Rate [gpm]	Temperature Enter/Leave [deg F]	Pressure Drop [ft H2O]
A	0 - 100	30	0.14	0.6	55 / 72	0.06	180 / 160	0.1
B	101 - 300	30	0.34	1.7	55 / 72	0.17	180 / 160	0.1
C	301 - 650	30	0.33	3.6	55 / 72	0.37	180 / 160	0.2
D	651 - 1200	30	0.34	6.6	55 / 72	0.68	180 / 160	0.5
E	1201 - 1600	30	0.32	8.9	55 / 72	0.91	180 / 160	0.3
F	1601 - 2400	30	0.34	13.3	55 / 72	1.36	180 / 160	2.1

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Figure 57: Mechanical System Design Specs - MIT Physical Plant Drwg: EA51 M07.0002

Return Fan Unit Schedule

Fan Data					Motor			
Fan Type n/a	Design Flow [cfm]	Total Static Pressure [in wg]	Wheel Diameter [in]	Wheel Speed [rpm]	Power Rating [hp]	Speed Rating [rpm]	Electric Spec's [V-Ph-Hz]	Mfr or Equal
centrifugal	17,480	0.75	44.5	430	5	1,750	208-3-60	Trane # 44 AFSW

Fin Tube Radiation Schedule

Unit ID Designation	Unit Type	Temperature Enter/Leave [deg F]	Capacity @ 160F AWT [Btu/ft]	Copper Pipe Size [in]	Fin Density [fpi]	Manufacturer	Remarks
B	floor mounted	170 / 150	700	1	40	Vulcan	pedestal monuted
C	slant top	170 / 150	800	1.25	48	Vulcan DS	12" cover, 4" A.F.F.
D	bare element	170 / 150	1,200	1.25	33	Vulcan SX	w/ diamond mesh enclosure & slope top
E	slant top	170 / 150	1,200	1.25	40	Vulcan DS	18" cover, 4" A.F.F.

Hot Water Convector Schedule

Convector ID Designation	Rated Design Flow Rate [gpm]	Capacity @ 160F AWT [MBH]	Temperature Enter/Leave [deg F]	Convector Dimensions l x h x d [in]	Manufacturer & Type	Remarks
C-1	0.7	7	170 / 150	80 x 32 x 4	Sterling MH	----
C-2	0.6	6	170 / 150	44 x 32 x 6	AAF FRG	Provide Wall Guard & Enclosing Frame
C-3	0.9	9	170 / 150	56 x 32 x 6	AAF FRG	Provide Wall Guard & Enclosing Frame
C-4	0.6	5.6	170 / 150	64 x 32 x 6	AAF FRG	Provide Wall Guard & Enclosing Frame
C-5	0.6	6	170 / 150	44 x 32 x 6	AAF FRG	Provide Wall Guard & Enclosing Frame
C-6	0.2	1.6	170 / 150	28 x 20 x 4	AAF FRG	Provide Wall Guard & Enclosing Frame
C-7	0.3	2.4	170 / 150	32 x 32 x 4	AAF FRG	Provide Wall Guard & Enclosing Frame
C-8	0.4	4	170 / 150	48 x 32 x 4	AAF FRG	Provide Wall Guard & Enclosing Frame
C-9	0.6	5.6	170 / 150	64 x 32 x 4	AAF FRG	Provide Wall Guard & Enclosing Frame
C-10	0.7	6.4	170 / 150	80 x 32 x 4	Sterling MH	----
C-11	0.9	8	170 / 150	104 x 32 x 4	Sterling MH	----
C-12	----	9.6	170 / 150	124 x 32 x 4	Sterling MH	----
C-13	----	5.6	170 / 150	62 x 14 x 4	Trane RG	----

file: dsgnspec.wq2 01/31/96 Page 2

Figure 58: Mechanical System Design Specs - continued

Appendix I - Building E51 Mechanical Room Layout & Air Conditioning Equipment Sketches [147]

147 Based on MIT Drawings: EA51 M05.0002

Note: Equipment detail drawings are based on visual inspection and site measurements.

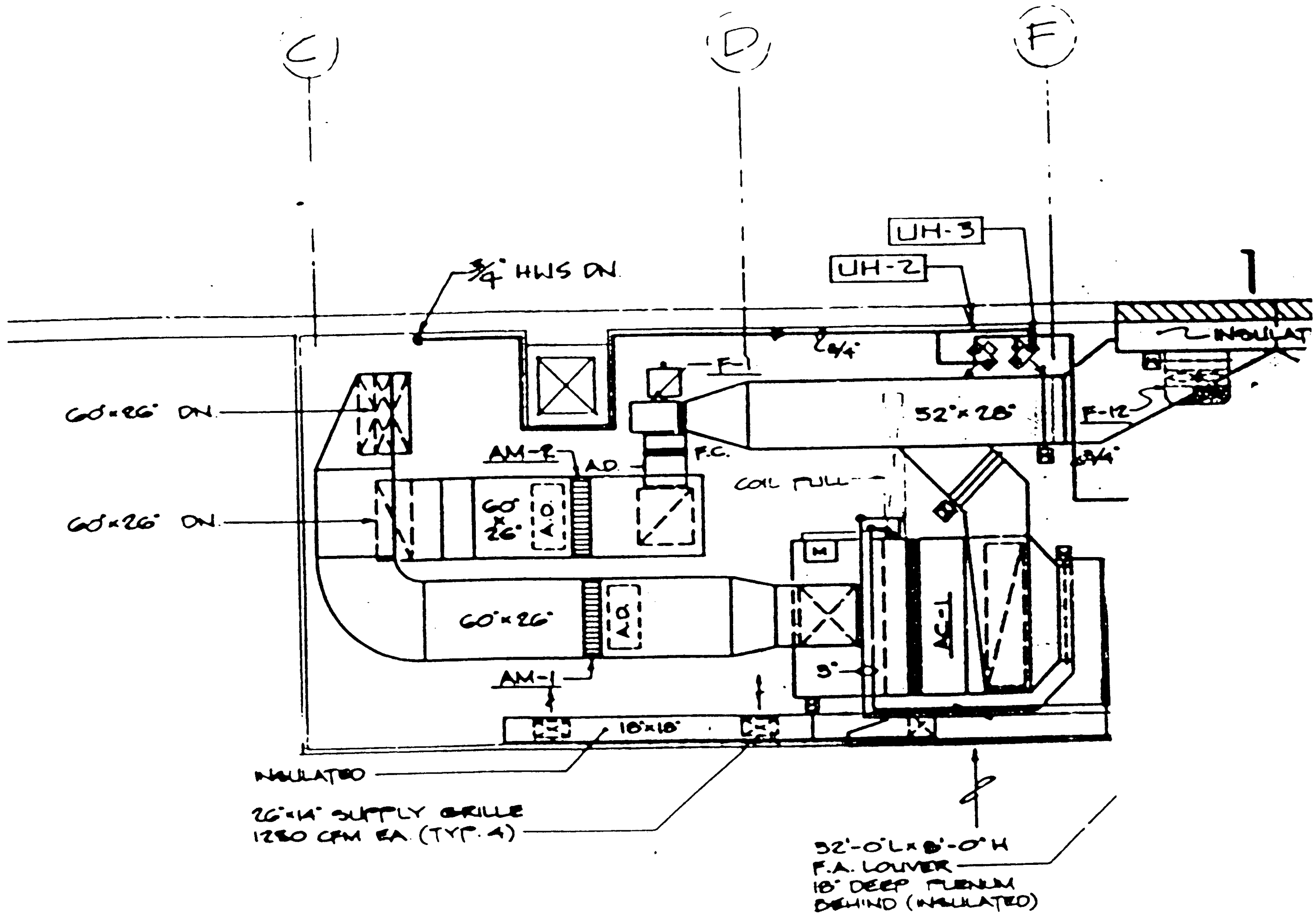


Figure 59: Building E51 Mechanical Room General Arrangement

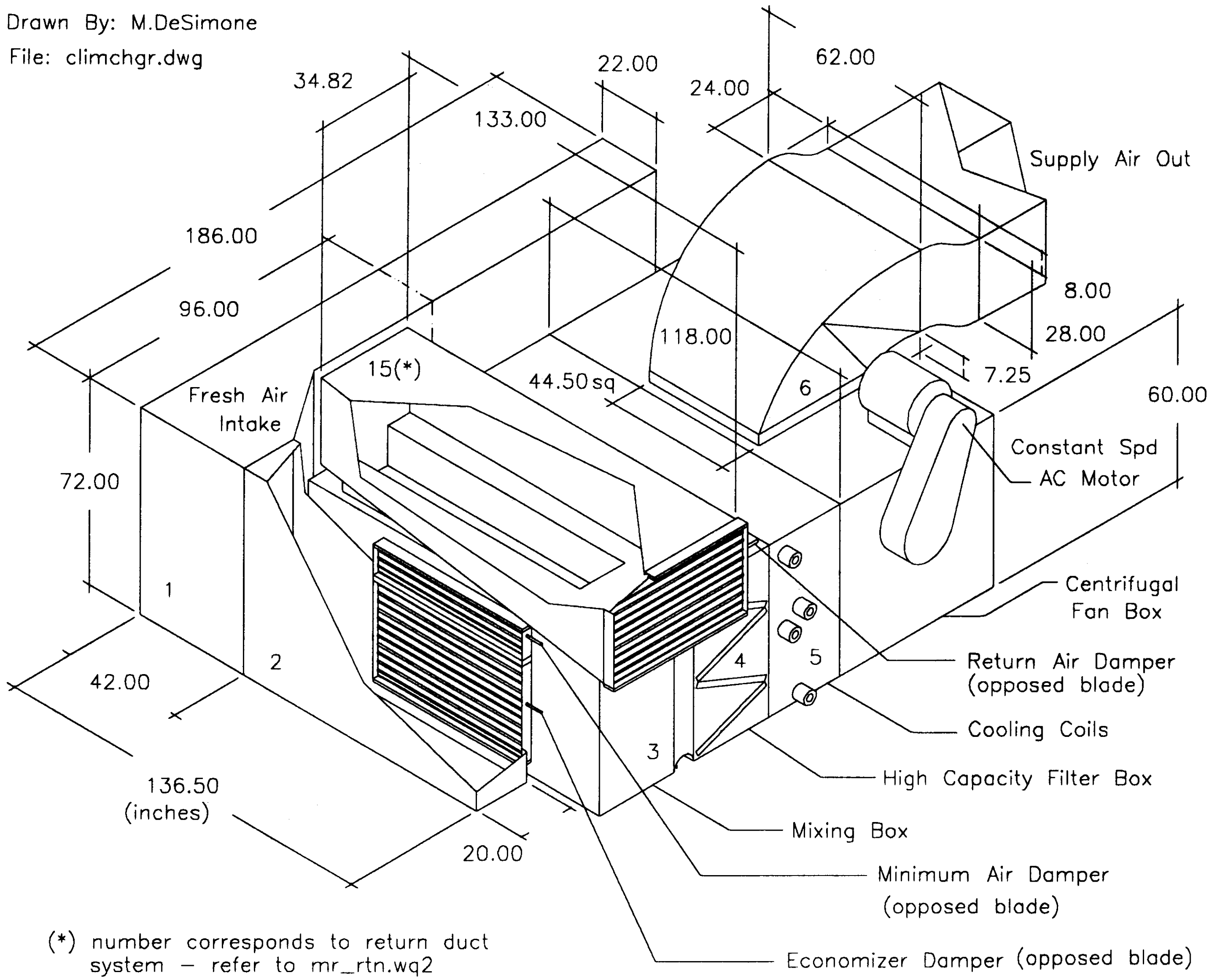


Figure 60: Building E51 Supply Air Conditioning Equipment (AH1)

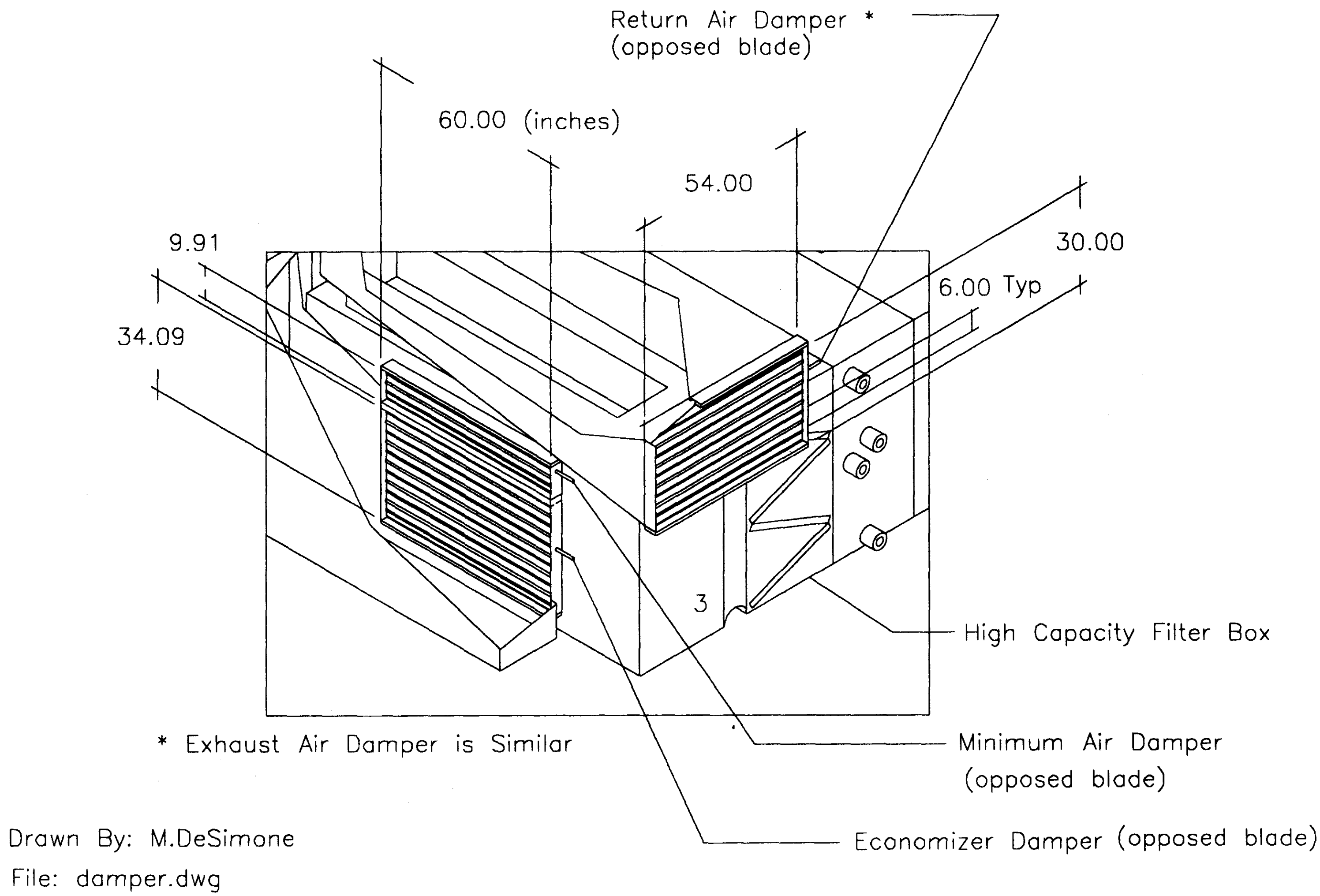


Figure 61: Detail of Mixing Box Return and Fresh Air Dampers

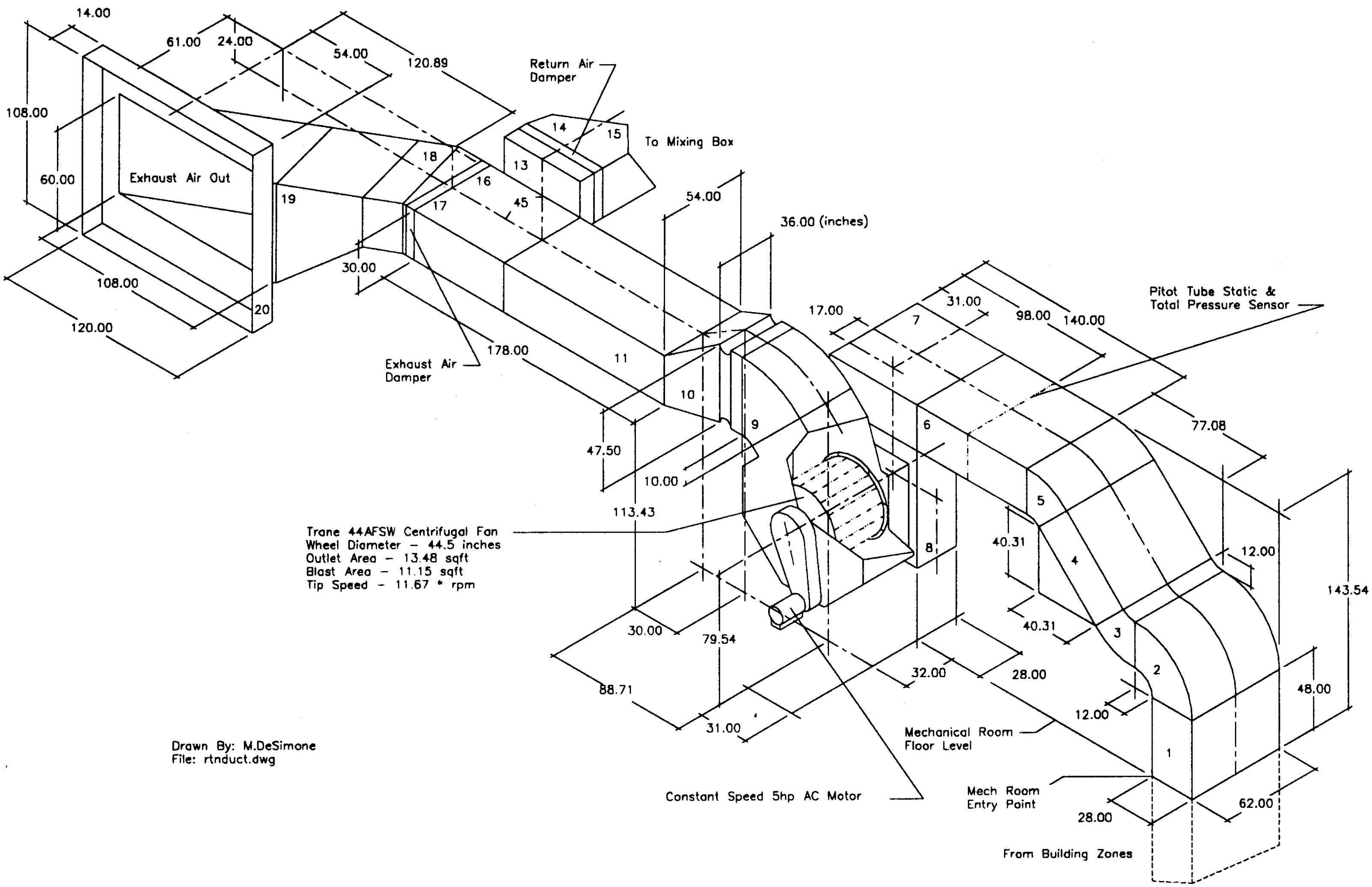


Figure 62: Building E51 Return Air Fan & Duct System (Mechanical Room)

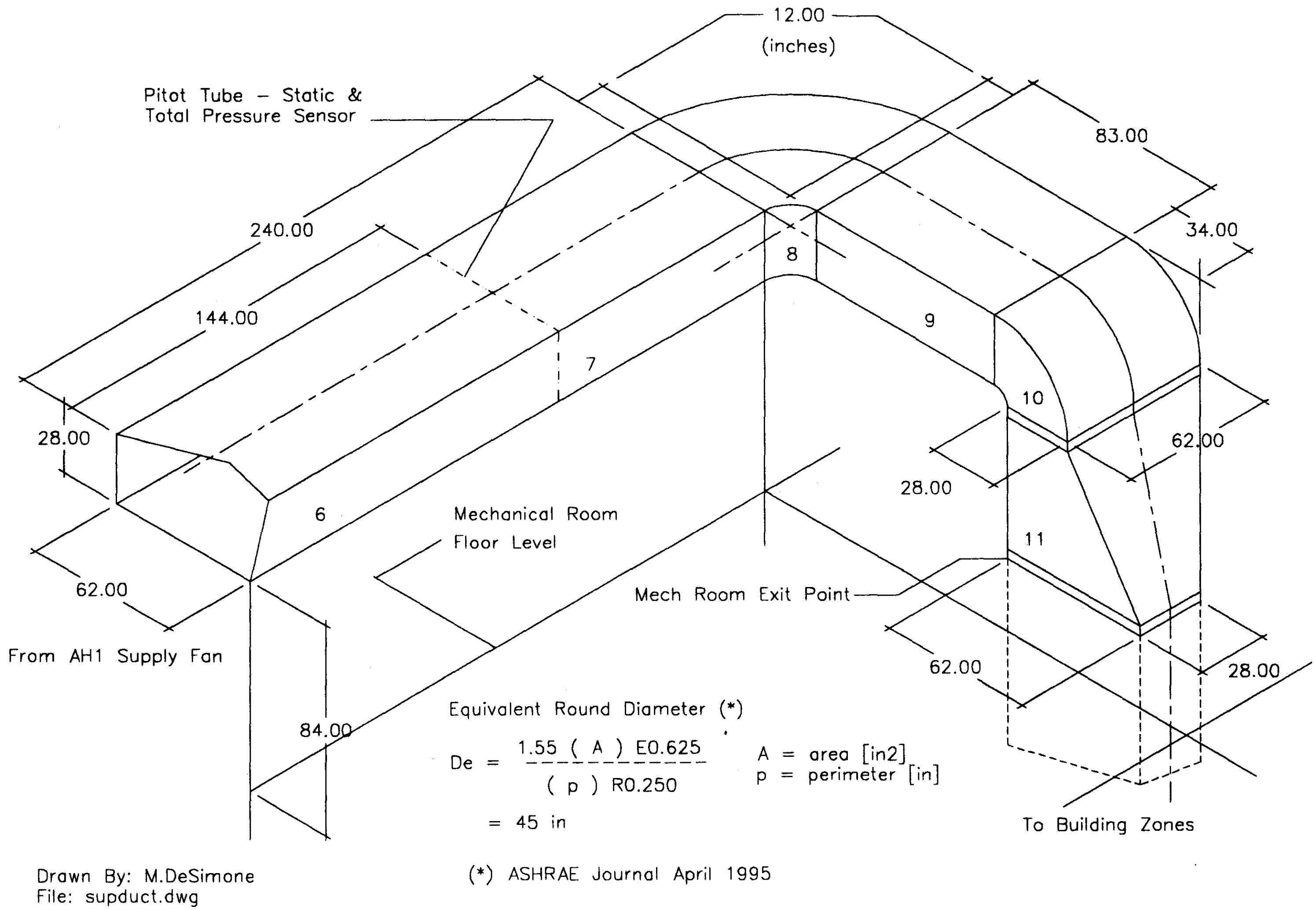


Figure 63: Mechanical Room Supply Air Duct System

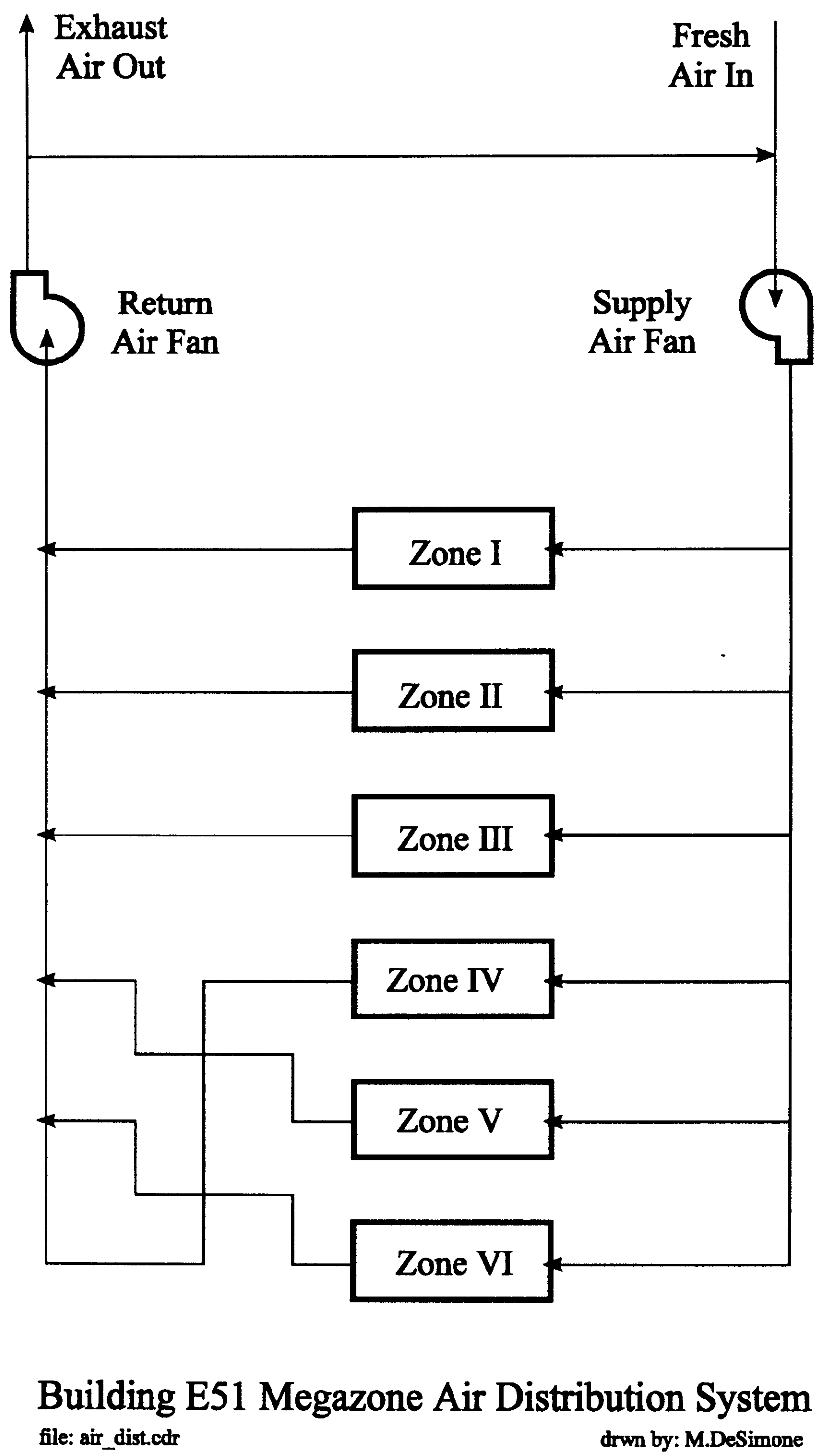


Figure 64: E51 Megazone Air Distribution System

Appendix J - AH1: Trane Central Station Climate Changer CLCH-MN-2A

JUL-18-1994 16:58 TRANE CO 787 2166 P.02

[redacted]

MANUFACTURING ENGINEERS OF AIR CONDITIONING, HEATING, VENTILATING, HEAT TRANSFER AND AIR FILTRATION EQUIPMENT.

NET 30 | LEXINGTON F/A

CALL NO.: 617-497-1992
NO HRS. BEFORE DELIVERY.
ATTN: JACK DESMOND

ORDER DATE	CUSTOMER ORDER NUMBER	CUSTOMER ACCOUNT NO.	SHIP VIA	COLLECT
06/27/80	02235	A1-35-6075-2		D

Sold to: M.J. FLAHERTY COMPANY, 430 CENTRE STREET, NEWTON, MASSACHUSETTS 02158

Ship to: M. J. FLAHERTY CO., 2 BLDG. E51-M.I.T., 70 MEMORIAL DRIVE, CAMBRIDGE, MA 02139

K80K17375

Ship with: CLCH30

QTY	TYPE	MODEL	
01	K	MODEL	HORIZONTAL DRAW-THRU CLCH WITH 27" AF WHEEL
		DISCHARGE	BACK VERTICAL

Model number: [illegible]

QTY PER UNIT	COIL BANK	COIL TYPE	SIZE WIDE	SIZE LONG	FIN SERIES	TUBES ROWS	TUBES MATERIAL	TUBES W WO	COIL SUP	CIRC PER COIL	COIL DIST.	CIRCS PER DIST.	H C	STP #
1	1ST IN		24											0018
1	CASING	D	30	108	18	4	A	T	L				U	0018

30FTM INCREASE
INLET VANES
1" 1.5 LB COATED INSULATION (UNIT ONLY)
1 HIGH CAPACITY FILTER BOX LESS FILTERS — HIGH CAPACITY
1 ACCESS DOOR FAN SECTION RIGHT

2895-6899

[redacted]

1959a
DRIVE 1299 RPM D FIXED 1.50
1 MOTOR 20.00 HP 200 V. 60 CY. 3 PH 1750 RPM
ISOLATORS

831.

BOSTON | BOSTON

1 of 2

Figure 65: Manufacturers Statement of Engineering Specifications for AH1

TRANE® AIR CONDITIONING

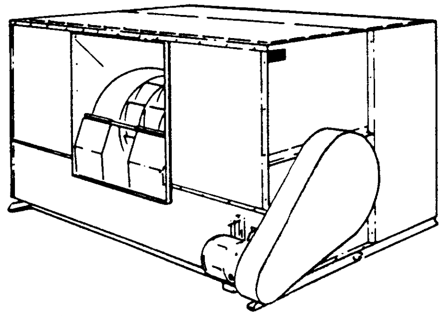
FILE INFORMATION
DIVISION TAB - TRANE AIR HANDLING PRODUCTS
PRODUCT TAB - CENTRAL STATION UNITS Climate Changers
MODEL TAB - CLCH
LITERATURE ITEM - Model Number

LITERATURE FILE NO.

CLCH-MN-2A

MODEL NUMBER

SEPTEMBER, 1980
Supersedes CLCH-MN-2A
Dated February, 1980



CENTRAL STATION CLIMATE CHANGERS ®

DRAW-THRU UNITS
B DEVELOPMENT SEQUENCE
B DESIGN SEQUENCE

RELATED LITERATURE

Model Number Booklets

Climate Changer Draw-Thru Units	CLCH-MN-2A
Climate Changer Blow-Thru Units	CLCH-MN-2B
Torrivent Draw-Thru Units	CLCH-MN-2C
Cabinet Fan Draw-Thru Units	CLCH-MN-2D
Coil Module Units	CLCH-MN-2E

Installation and Maintenance Booklets

Climate Changer Draw-Thru Units	CLCH-IM-7
Climate Changer Blow-Thru Units	CLCH-IM-7
Climate Changer Sprayed Coil Units	CLCH-IM-7
Climate Changer High Pressure Units	CLCH-IM-7
Torrivent Draw-Thru Units	TORR-IM-1
Cabinet Fan Draw-Thru Units	TORR-IM-1
Electric Heat Climate Changer Units	CLCH-IM-8
Roll Filters	RF-IM-1

TRANE PRODUCTS ARE IDENTIFIED BY A MULTIPLE CHARACTER MODEL NUMBER THAT PRECISELY IDENTIFIES A PARTICULAR TYPE OF UNIT. AN EXPLANATION OF THE DRAW-THRU CLIMATE CHANGER MODEL NUMBER IS LISTED WITHIN TO ENABLE THE OWNER OR SERVICE ENGINEER TO DEFINE THE SPECIFIC OPERATION, COMPONENTS AND ACCESSORIES OF HIS UNIT.

Figure 66: Trane CLCH-MN-2A Climate Changer - Related Literature Guide

TRANE

CLIMATE CHANGER

DRAW-THRU

SERIAL NO.

MODEL NO. — UNIT TYPE | BASIC UNIT | PRIMARY COILS | ACCESSORY | ELECTRIC PREHEAT

MAX. RATED PRESSURE — PSIG 1ST COIL — PSIG 2ND COIL

DESIGN TEST STATIC PRESSURE — IN. H_2O — REFRIGERANT

FAN MOTOR — HP — VOLTS — PHASE — HZ — AMPS

THE TRANE COMPANY, LA CROSSE, WISCONSIN 54601

MADE IN U.S.A.

MODEL NUMBER DESCRIPTION
CLIMATE CHANGER DRAW-THRU

UNIT TYPE

1 □ CLIMATE
2 □ CHANGER
3 □ DRAW-THRU
4 □ DEVELOPMENT SEQUENCE
5,6 □□ UNIT SIZE
7 □ FAN AND SHAFT TYPE
8 □ COIL TYPE - FIRST IN CASING
9 □ COIL TYPE - SECOND IN CASING
10 □ DESIGN SEQUENCE

BASIC UNIT

11 □ UNIT STYLE
12 □ MOTOR VOLTAGE
13 □ CASING LENGTH
14 □ FAN DISCHARGE
15 □ MOTOR LOCATION
16 □ INLET VANES
17 □ DRAIN PAN
18 □ COIL SUPPLY - FIRST IN CASING
19 □ COIL SUPPLY - SECOND IN CASING
20 □ INSULATION
21 □ MOTOR HORSEPOWER

PRIMARY COILS

22 □ COIL HEIGHT - FIRST IN CASING
23 □ COIL CIRCUITS - FIRST IN CASING
24 □ COIL FIN SERIES - FIRST IN CASING
25 □ COIL TUBE MATERIAL - FIRST IN CASING
26 □ TURBULATORS - FIRST IN CASING
27 □ COIL ROWS - FIRST IN CASING
28 □ COIL HEIGHT - SECOND IN CASING
29 □ COIL CIRCUITS - SECOND IN CASING
30 □ COIL FIN SERIES - SECOND IN CASING
31 □ COIL TUBE MATERIAL - SECOND IN CASING
32 □ TURBULATORS - SECOND IN CASING
33 □ COIL ROWS - SECOND IN CASING

ACCESSORIES

34 □ DRIVE AND OVERLOAD FACTOR
35 □ BELT GUARD
36 □ DAMPER SECTION
37 □ ACCESS DOOR - FAN SECTION
38 □ ACCESS DOOR - COIL SECTION
39 □ COMBINATION FILTER/MIXING BOX
40 □ FILTER BOX
41 □ HIGH EFFICIENCY PREFILTER BOX
42 □ HIGH EFFICIENCY FINAL FILTER BOX
43 □ HUMIDIFIER
44 □ MIXING BOX
45 □ ACCESS SECTION
46 □ PREHEAT SECTION
47 □ COIL FIN SERIES - PREHEAT COIL
48 □ COIL TUBE MATERIAL - PREHEAT COIL
49 □ TURBULATORS - PREHEAT COIL

ELECTRIC PREHEAT

50 □ ELECTRIC COIL VOLTAGE AND STEP CONTROLLER
51 □ ELECTRIC CONTROL PANEL
52 □ CONTROL SYSTEM SUPPLIER
53 □ ELECTRIC PREHEAT OPTION
54 □ CONDUIT LENGTH
55 □ MISCELLANEOUS

2

CLCH-MN-2A

Figure 67: Trane CLCH-MN-2A Climate Changer Model Number Description

UNIT TYPE
DIGITS 1 THROUGH 10

1 ☐ CLIMATE

2 ☐ CHANGER

3 ☐ DRAW-THRU

4 ☐ DEVELOPMENT SEQUENCE
B - Second

5,6 ☐☐ UNIT SIZE DIGIT DESCRIPTION
03 - 3
06 - 6
08 - 8
10 - 10
12 - 12
14 - 14
17 - 17
21 - 21
25 - 25
31 - 31
35 - 35
41 - 41
50 - 50
63 - 63

7 ☐ FAN AND SHAFT TYPE DIGIT DESCRIPTION
A
B
C
D
E
F
G
H
J
K
L
M
N
P
S - Special
Note: Refer to Table 1 for Fan and Shaft Type Digit Description.

8* ☐ COIL TYPE - FIRST IN CASING DIGIT DESCRIPTION
0 - None
A - F (F1)
B - F (F2)
C - F (F1) Two Sets of Connections
D - F (F2) Two Sets of Connections
E - W (Cooling)
F - K
G - D
H - DD
J - P
K - AW
L - WC
M - TT
N - A
P - NS
R - N
T - W (Heating)
U - H (HB)
V - H (HA)
S - Special

9* ☐ COIL TYPE - SECOND IN CASING DIGIT DESCRIPTION
0 - None
A - F (F1)
B - F (F2)
C - F (F1) Two Sets of Connections
D - F (F2) Two Sets of Connections
E - W (Cooling)
F - K
G - D
H - DD
J - P
K - AW
L - WC
M - TT
N - A
P - NS
R - N
T - W (Heating)
U - H (HB)
V - H (HA)
S - Special

* NOTE FOR DIGITS 8 AND 9
Digit "J" is not available on unit sizes 12, 14, 25 and 50 (full coil) or on unit sizes 31, 50 and 63 (modified coil).
Digit "M" is not available on unit sizes 21 through 63.
Digit "M" (1 row) is not available on unit sizes 12 and 14 (full coil).

10 ☐ DESIGN SEQUENCE
B - Second

Figure 68: Trane CLCH-MN-2A Model Number Code - Unit Type / Digits 1 - 10

TABLE 1 - Fan and Shaft Type Digit Description

UNIT SIZE	FAN & SHAFT TYPE	FAN WHEEL SIZE & TYPE	MAX. RPM	MAX. HP
03	A	9" FC	1,910	2
	B	7½" FC	3,310	5
06	A	12¼" FC	1,403	5
	B	10½" FC	1,548	5
	C	10½" FC	2,237	7½
08 & 08X	A	15" FC	1,109	5
08	B	13½" FC	1,611	5
	C	13½" FC	1,839	7½
	D	12¼" FC	1,350	5
	E	12¼" FC	2,027	7½
10	A	16½" FC	1,042	7½
	B	15" FC	1,146	7½
	C	15" FC	1,655	10
	D	13½" FC	1,273	7½
	E	13½" FC	1,839	10
12 & 12X	A	18¼" FC	942	7½
12	B	16½" FC	1,042	7½
	C	16½" FC	1,505	10
	D	15" FC	1,146	7½
	E	15" FC	1,655	10
14	A	20" FC	859	7½
	B	18¼" FC	942	7½
	C	18¼" FC	1,360	10
	D	16½" FC	1,042	7½
	E	16½" FC	1,505	10
17	A	20" FC	859	10
	B	20" FC	1,200	10
	C	20" FC	1,241	15
	D	18¼" FC	942	10
	E	18¼" FC	1,360	10
	F	18¼" FC	1,360	15
	G	16½" FC	1,505	10
	H	16½" FC	1,505	15
21	A	22" FC	728	10
	B	22" FC	1,150	15
	C	20" FC	859	10
	D	20" FC	1,241	15
	E	18¼" FC	1,360	15
25	A	25" FC	700	7½
	B	25" FC	960	20
	C	25" FC	1,000	30
	D	22" FC	834	7½
	E	22" FC	1,200	20
	F	22" FC	1,200	30
31	A	25" FC	700	7½
	B	25" FC	960	20
	C	25" FC	1,000	30
	D	22" FC	834	7½
	E	22" FC	1,200	20
	F	22" FC	1,200	30

Figure 69: Trane CLCH-MN-2A Model Number Code - Unit Type / Digits 1 - 10 (cont'd)

TABLE 1 - Continued

UNIT SIZE	FAN & SHAFT TYPE	FAN WHEEL SIZE & TYPE	MAX. RPM	MAX. HP
35	A	30" BI	1,050	15
	B	30" BI	1,200	20
	C	30" AF	1,100	15
	D	30" AF	1,334	25
	E	27" AF	1,300	15
	F	27" AF	1,481	25
	G	27" AF	1,650	30
	H	24" AF	1,500	15
	J	24" AF	1,638	20
	K	24" AF	1,900	30
41	A	33" BI	900	15
	B	33" BI	1,050	25
	C	33" AF	900	15
	D	33" AF	1,100	25
	E	33" AF	1,218	40
	F	30" AF	1,100	15
	G	30" AF	1,300	25
	H	30" AF	1,450	40
	J	27" AF	1,300	15
	K	27" AF	1,481	25
	L	27" AF	1,650	30
	M	24" AF	1,500	15
	N	24" AF	1,638	20
	P	24" AF	1,800	30
40	A	36" BI	750	15
	B	36" BI	900	25
	C	36" AF	750	15
	D	36" AF	950	25
	E	36" AF	1,103	40
	F	33" AF	925	15
	G	33" AF	1,100	25
	H	33" AF	1,350	40
	J	30" AF	1,050	15
	K	30" AF	1,250	25
	L	30" AF	1,500	40
	M	27" AF	1,300	15
	N	27" AF	1,450	20
	P	27" AF	1,650	30
63	A	40" BI	750	25
	B	40" BI	900	40
	C	40" AF	780	25
	D	40" AF	900	40
	E	36" AF	950	25
	F	36" AF	1,100	40
	G	36" AF	1,250	60
	H	33" AF	1,100	25
	J	33" AF	1,300	40
	K	30" AF	1,300	25
	L	30" AF	1,500	40

Figure 70: Trane CLCH-MN-2A Model Number Code - Unit Type / Digits 1 - 10 (cont'd)

BASIC UNIT
DIGITS 11 THROUGH 21

11 ☐ UNIT STYLE DIGIT DESCRIPTION
H - Horizontal (Unit Sizes 03 through 63)
V - Vertical (Unit Sizes 03 through 50)

12 ☐ MOTOR VOLTAGE DIGIT DESCRIPTION
0 - None
1 - 115V Single Phase
2 - 230V Single Phase
3 - 200V Three Phase
4 - 230V Three Phase
5 - 460V Three Phase
S - Special

13 ☐ CASING LENGTH DIGIT DESCRIPTION
A - Standard Length (03 through 50)
B - 8" Extra Length (03 through 50)
C - 8" Extra Length With Space Between Coils (03 through 50)
D - Standard Length (63, BI Wheel)
E - Standard Length (63, AF Wheel)
G - 8" Extra Length (63, AF Wheel)
H - 8" Extra Length With Space Between Coils (63, BI Wheel)
J - 8" Extra Length With Space Between Coils (63, AF Wheel)
S - Special

14 ☐ FAN DISCHARGE DIGIT DESCRIPTION
1 - Top Horizontal - Horizontal Unit (03 through 63)
2 - Bottom Horizontal - Horizontal Unit (03 through 63)
3 - Front Vertical - Horizontal Unit (03 through 25)
4 - Back Vertical - Horizontal Unit (03 through 25)
5 - Back Vertical - Vertical Unit (03 through 50)
6 - Front Vertical - Vertical Unit (03 through 50)
7 - Back Horizontal - Vertical Unit (03 through 25)
8 - Front Horizontal - Vertical Unit (03 through 31)
S - Special

15 ☐ MOTOR LOCATION DIGIT DESCRIPTION
R - Right Hand
L - Left Hand
S - Special

16 ☐ INLET VANES DIGIT DESCRIPTION
0 - None
1 - Inlet Vanes (Except 03)
S - Special

17 ☐ DRAIN PAN DIGIT DESCRIPTION
1 - Standard
2 - With Liner
S - Special

18 ☐ COIL SUPPLY - FIRST IN CASING DIGIT DESCRIPTION
0 - None
R - Right Hand
L - Left Hand
S - Special

19 ☐ COIL SUPPLY - SECOND IN CASING DIGIT DESCRIPTION
0 - None
R - Right Hand
L - Left Hand
S - Special

20 ☐ INSULATION DIGIT DESCRIPTION
A - Standard (Unit Only) 3/4 lb.
B - Optional (Unit Only) 1-1/2 lb.
C - Standard (Unit and Accessories) 3/4 lb.
D - Optional (Unit and Accessories) 1-1/2 lb.
S - Special

21 ☐ MOTOR HORSEPOWER DIGIT DESCRIPTION
0 - None
A - 1/6
B - 1/4
C - 1/3
D - 1/2
E - 3/4
F - 1
G - 1-1/2
H - 2
J - 3
K - 5
L - 7-1/2
M - 10
N - 15
P - 20
R - 25
T - 30
U - 40 (35 through 63 only)
V - 50 (63 only)
W - 60 (63 only)
S - Special

Figure 71: Trane CLCH-MN-2A Model Number Code - Basic Unit / Digits 11 - 21

PRIMARY COILS
DIGITS 22 THROUGH 33

22 ☐ COIL HEIGHT - FIRST IN CASING DIGIT DESCRIPTION
0 - None
1 - Full
2 - Modified
S - Special

23 ☐ COIL CIRCUITS - FIRST IN CASING DIGIT DESCRIPTION

0 - None							
B - 2 D - 4 H - 8		Digits 8 &9 Selection J (Type P Coil)					
	Digits 8 & 9	Coil Height 12	18	24	30	33	
A	A, B	8	12	16	20	22	Type F Coil
	C, D	8	12	16	20	22	
C	A, B	4	6	8	10	11	
	C, D	4	6	8	10	11	
E	A, B	2	3	4	5	7	
	C, D	2	—	4	—	7	
F	A, B	1	2	2	4	3	
	C, D	—	2	2	4	—	
G	A, B	—	1	—	2	—	
	C, D	—	—	—	2	—	
S - Special							

24 ☐ COIL FIN SERIES - FIRST IN CASING DIGIT DESCRIPTION
0 - None
A - 15, 55 Aluminum
B - 16, 56 Aluminum
C - 18, 58 Aluminum
D - 25, 65 Copper
E - 26, 66 Copper
F - 28, 68 Copper
G - 33 Aluminum
H - 34 Aluminum
J - 35 Aluminum
K - 36 Aluminum
L - 37 Aluminum
M - 38 Aluminum
N - 43 Copper
P - 44 Copper
R - 45 Copper
T - 46 Copper
U - 47 Copper
V - 48 Copper
1 - 10, 50 Aluminum
2 - 12, 52 Aluminum
3 - 13, 53 Aluminum
4 - 20, 60 Copper
5 - 23, 63 Copper
S - Special

25 ☐ COIL TUBE MATERIAL - FIRST IN CASING DIGIT DESCRIPTION
0 - None
A - Standard Copper
B - .035 Red Brass
C - 0.49 Red Brass
D - .024 Copper
S - Special

26 ☐ TURBULATORS - FIRST IN CASING DIGIT DESCRIPTION
0 - None
1 - Sigma Flo® Without Turbulator
2 - Sigma Flo With Turbulator
3 - Prima Flo Without Turbulator
4 - Prima Flo With Turbulator
S - Special

27 ☐ COIL ROWS - FIRST IN CASING DIGIT DESCRIPTION
0 - None
B - 1
C - 2
D - 3
E - 4
F - 5
G - 6
H - 8
S - Special

Figure 72: Trane CLCH-MN-2A Model Number Code - Primary Coils / Digits 22 - 33

28 ☐ COIL HEIGHT - SECOND IN CASING DIGIT DESCRIPTION
0 - None
1 - Full
2 - Modified
S - Special

29 ☐ COIL CIRCUITS - SECOND IN CASING DIGIT DESCRIPTION

0 - None							
B - 2 D - 4 H - 8		Digits 8 &9 Selection J (Type P Coil)					
	Digits 8 & 9	Coil Height 12	18	24	30	33	
A	A, B	8	12	16	20	22	Type F Coil
	C, D	8	12	16	20	22	
C	A, B	4	6	8	10	11	
	C, D	4	6	8	10	11	
E	A, B	2	3	4	5	7	
	C, D	2	—	4	—	7	
F	A, B	1	2	2	4	3	
	C, D	—	2	2	4	—	
G	A, B	—	1	—	2	—	
	C, D	—	—	—	2	—	
S - Special							

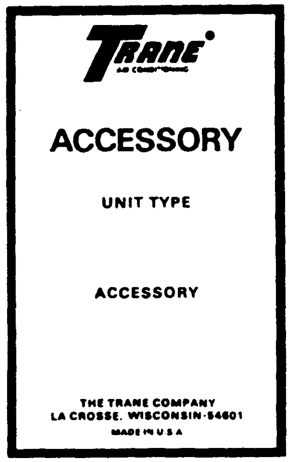
30 ☐ COIL FIN SERIES - SECOND IN CASING DIGIT DESCRIPTION
0 - None
A - 15, 55 Aluminum
B - 16, 56 Aluminum
C - 18, 58 Aluminum
D - 25, 65 Copper
E - 26, 66 Copper
F - 28, 68 Copper
G - 33 Aluminum
H - 34 Aluminum
J - 35 Aluminum
K - 36 Aluminum
L - 37 Aluminum
M - 38 Aluminum
N - 43 Copper
P - 44 Copper
R - 45 Copper
T - 46 Copper
U - 47 Copper
V - 48 Copper
1 - 10, 50 Aluminum
2 - 12, 52 Aluminum
3 - 13, 53 Aluminum
4 - 20, 60 Copper
5 - 23, 63 Copper
S - Special

31 ☐ COIL TUBE MATERIAL - SECOND IN CASING DIGIT DESCRIPTION
0 - None
A - Standard Copper
B - .035 Red Brass
C - .049 Red Brass
D - .024 Copper
S - Special

32 ☐ TURBULATORS - SECOND IN CASING DIGIT DESCRIPTION
0 - None
1 - Sigma Flo® Without Turbulator
2 - Sigma Flo With Turbulator
3 - Prima Flo Without Turbulator
4 - Prima Flo With Turbulator
S - Special

33 ☐ COIL ROWS - SECOND IN CASING DIGIT DESCRIPTION
0 - None
B - 1
C - 2
D - 3
E - 4
F - 5
G - 6
H - 8
S - Special

Figure 73: Trane CLCH-MN-2A Model Number Code - Primary Coils / Digits 22 - 33 (cont'd)



ACCESSORIES
DIGITS 34 THROUGH 49

34 ☐ DRIVE AND OVERLOAD FACTOR DIGIT DESCRIPTION
0 - None
1 - 1.2, Standard Drive
2 - 1.5, Standard Drive
S - Special

35 ☐ BELT GUARD DIGIT DESCRIPTION
0 - None
1 - Standard (Non UL)
2 - Totally Enclosed (UL)
S - Special

36 ☐ DAMPER SECTION DIGIT DESCRIPTION
0 - None
A - Internal Face & Bypass, Right Hand Drive
B - Internal Face & Bypass, Left Hand Drive
C - Internal Face & Bypass, Both Ends Drive (03 to 17)
D - External Face & Bypass, Right Hand Drive Without Duct
E - External Face & Bypass, Left Hand Drive Without Duct
F - External Face & Bypass, Both Ends Drive Without Duct (03 to 17)
G - External Face & Bypass, Right Hand Drive With Duct
H - External Face & Bypass, Left Hand Drive With Duct
J - External Face & Bypass, Both Ends Drive With Duct (03 to 17)
K - Face Damper, Right Hand Drive
L - Face Damper, Left Hand Drive
S - Special

37 ☐ ACCESS DOOR (FAN SECTION) DIGIT DESCRIPTION
0 - None
1 - Right Hand
2 - Left Hand
3 - Both Sides
S - Special

38 ☐ ACCESS DOOR (COIL SECTION) DIGIT DESCRIPTION
0 - None
4 - Right Hand
5 - Left Hand
6 - Both Sides
S - Special

Figure 74: Trane CLCH-MN-2A Model Number Code - Accessories / Digits 34 - 49

39 ☐ COMBINATION FILTER/MIXING BOX DIGIT DESCRIPTION
0 - None
A - 90 Degree Opening, No Filter
B - 90 Degree Opening, Throwaway Filter
C - 90 Degree Opening, Low Velocity Filter
D - 90 Degree Opening, High Velocity Filter
E - 180 Degree Opening, No Filter
F - 180 Degree Opening, Throwaway Filter
G - 180 Degree Opening, Low Velocity Filter
H - 180 Degree Opening, High Velocity Filter
J - 90 Degree Opening, No Filter (See Note 1) .
K - 90 Degree Opening, Throwaway Filter (See Note 1)
L - 90 Degree Opening, Low Velocity Filter (See Note 1)
M - 90 Degree Opening, High Velocity Filter (See Note 1)
N - 90 Degree Opening, No Filter (See Note 2)
P - 90 Degree Opening, Throwaway Filter (See Note 2)
R - 90 Degree Opening, Low Velocity Filter (See Note 2)
T - 90 Degree Opening, High Velocity Filter (See Note 2)
S - Special

NOTES:
1. Top and Back Right Hand, Bottom and Back Left Hand.
2. Top and Back Left Hand, Bottom and Back Right Hand.

40 ☐ FILTER BOX DIGIT DESCRIPTION
0 - None
A - Flat Filter Box, No Filter
B - Flat Filter Box, Throwaway Filter
C - Flat Filter Box, Low Velocity Filter
D - Flat Filter Box, High Velocity Filter
E - Medium Capacity, No Filter
F - Medium Capacity, Throwaway Filter
G - Medium Capacity, Low Velocity Filter
H - Medium Capacity, High Velocity Filter
J - High Capacity, No Filter
K - High Capacity, Throwaway Filter
L - High Capacity, Low Velocity Filter
M - High Capacity, High Velocity Filter
S - Special

41 ☐ HIGH EFFICIENCY PREFILTER BOX DIGIT DESCRIPTION
0 - None
A - 55% Efficiency ≤ 500 FPM RH
B - 85% Efficiency ≤ 500 FPM RH
C - 95% Efficiency ≤ 500 FPM RH
D - 55% Efficiency > 500 FPM RH
E - 85% Efficiency > 500 FPM RH
F - 95% Efficiency > 500 FPM RH
G - 55% Efficiency ≤ 500 FPM LH
H - 85% Efficiency ≤ 500 FPM LH
J - 95% Efficiency ≤ 500 FPM LH
K - 55% Efficiency > 500 FPM LH
L - 85% Efficiency > 500 FPM LH
M - 95% Efficiency > 500 FPM LH
N - 40% Efficiency ≤ 500 FPM BOTH
P - 40% Efficiency > 500 FPM BOTH
S - Special

42 ☐ HIGH EFFICIENCY FINAL FILTER BOX DIGIT DESCRIPTION
0 - None
A - 55% Efficiency ≤ 500 FPM RH
B - 85% Efficiency ≤ 500 FPM RH
C - 95% Efficiency ≤ 500 FPM RH
D - 55% Efficiency > 500 FPM RH
E - 85% Efficiency > 500 FPM RH
F - 95% Efficiency > 500 FPM RH
G - 55% Efficiency ≤ 500 FPM LH
H - 85% Efficiency ≤ 500 FPM LH
J - 95% Efficiency ≤ 500 FPM LH
K - 55% Efficiency > 500 FPM LH
L - 85% Efficiency > 500 FPM LH
M - 95% Efficiency > 500 FPM LH
S - Special

43 ☐ HUMIDIFIER DIGIT DESCRIPTION
0 - None
1 - Steam Grid, Horizontal, Right Hand
2 - Steam Grid, Horizontal, Left Hand
3 - Water Spray, Horizontal, Right Hand
4 - Water Spray, Horizontal, Left Hand
5 - Steam Grid, Vertical, Right Hand
6 - Steam Grid, Vertical, Left Hand
7 - Water Spray, Vertical, Right Hand
8 - Water Spray, Vertical, Left Hand
S - Special

44 ☐ MIXING BOX DIGIT DESCRIPTION
0 - None
1 - Top and Back Right Hand, Bottom and Back Left Hand
2 - Top and Back Left Hand, Bottom and Back Right Hand
3 - Top and Bottom
S - Special

45 ☐ ACCESS SECTION DIGIT DESCRIPTION
0 - None
1 - With (35 through 65 only)
2 - Special

Figure 75: Trane CLCH-MN-2A Model Number Code - Accessories / Digits 34 - 49 (cont'd)

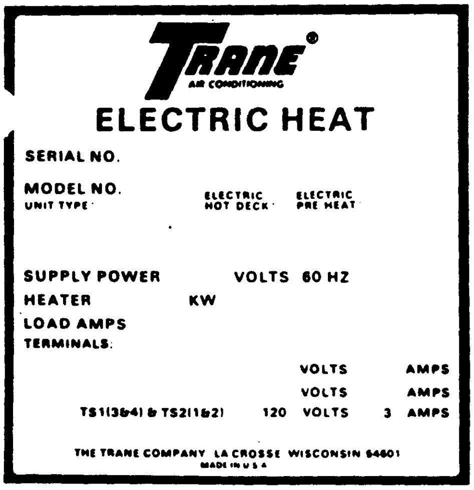
46 ☐ PREHEAT SECTION DIGIT DESCRIPTION
0 - None
A - NS Right Hand
B - NS Left Hand
C - N Left Hand
D - N Right Hand
E - A Left Hand
F - A Right Hand
G - AW Left Hand
H - AW Right Hand
J - WC Right Hand
K - WC Left Hand
L - W Right Hand
M - W Left Hand
N - Electric Right Hand
P - Electric Left Hand
S - Special

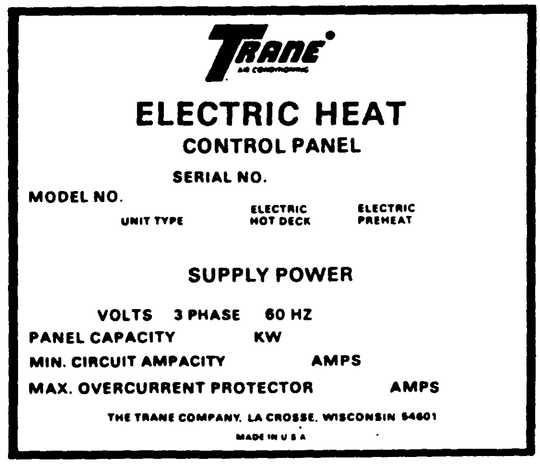
47 ☐ PREHEAT COIL FIN SERIES DIGIT DESCRIPTION
0 - None
A - 15, 55 Aluminum
B - 16, 56 Aluminum
C - 18, 58 Aluminum
D - 25, 65 Copper
E - 26, 66 Copper
F - 28, 68 Copper
G - 33 Aluminum
H - 34 Aluminum
J - 35 Aluminum
K - 36 Aluminum
L - 37 Aluminum
M - 38 Aluminum
N - 43 Copper
P - 44 Copper
R - 45 Copper
T - 46 Copper
U - 47 Copper
V - 48 Copper
1 - 10, 50 Aluminum
2 - 12, 52 Aluminum
3 - 13, 53 Aluminum
4 - 20, 60 Copper
5 - 23, 63 Copper
S - Special

48 ☐ PREHEAT COIL TUBE MATERIAL DIGIT DESCRIPTION
0 - None
A - Standard Copper
B - .035 Red Brass
C - .049 Red Brass
D - .024 Copper
S - Special

49 ☐ PREHEAT COIL TURBULATOR DIGIT DESCRIPTION
0 - None
1 - Sigma Flo • Without Turbulator
2 - Sigma Flo With Turbulator
3 - Prima Flo Without Turbulator
4 - Prima Flo With Turbulator
S - Special

Figure 76: Trane CLCH-MN-2A Model Number Code - Accessories / Digits 34 - 49 (cont'd)





ELECTRIC PREHEAT
DIGITS 50 THROUGH 55

50 ☐ ELECTRIC COIL VOLTAGE AND STEP CONTROLLER DIGIT DESCRIPTION

0 - None
A - 208V 3PH 60HZ 3 Step
B - 240V 3PH 60HZ 3 Step
C - 480V 3PH 60HZ 3 Step
D - 208V 3PH 60HZ 6 Step
E - 240V 3PH 60HZ 6 Step
F - 480V 3PH 60HZ 6 Step
G - 208V 3PH 60HZ 10 Step
H - 240V 3PH 60HZ 10 Step
J - 480V 3PH 60HZ 10 Step
K - 208V 3PH 60HZ 18 Step
L - 240V 3PH 60HZ 18 Step
M - 480V 3PH 60HZ 18 Step
S - Special

51 ☐ ELECTRIC CONTROL PANEL DIGIT DESCRIPTION

0 - None

TRANE SUPPLIED CONDUIT:

A - Remote Panel Wall Mounted W/Top Conn-Coil Conn. Top
B - Remote Panel Floor Mounted W/Top Conn-Coil Conn. Top
C - Remote Panel Wall Mounted W/Top Conn-Coil Conn. Bottom
D - Remote Panel Floor Mounted W/Top Conn-Coil Conn. Bottom
E - Remote Panel Wall Mounted W/Bottom Conn-Coil Conn. Top
F - Remote Panel Floor Mounted W/Bottom Conn-Coil Conn. Top
G - Remote Panel Wall Mounted W/Bottom Conn-Coil Conn. Bottom
H - Remote Panel Floor Mounted W/Bottom Conn-Coil Conn. Bottom

J - Remote Panel Wall - No Conduit
K - Remote Panel Floor - No Conduit
L - Integral
S - Special

52 ☐ CONTROL SYSTEM SUPPLIER DIGIT DESCRIPTION

0 - None
A - Honeywell With Thermostat
B - Honeywell Without Thermostat
C - Barber Colman With Thermostat
D - Barber Colman Without Thermostat
S - Special

Figure 77: Trane CLCH-MN-2A Model Number Code - Electric Preheat / Digits 50 - 55

53 ☐ ELECTRIC PREHEAT OPTION DIGIT DESCRIPTION
- 0 - None
- 1 - Manual Reset Without Flow Switch
- 2 - Manual Reset With Flow Switch
- 3 - Nonreset With Flow Switch
- S - Special

54 ☐ CONDUIT LENGTH DIGIT DESCRIPTION
- 0 - None
- A - 36"
- B - 42"
- C - 48"
- D - 54"
- E - 60"
- F - 66"
- G - 72"
- H - 78"
- J - 84"
- K - 90"
- L - 96"
- M - 108"
- N - 120"
- P - 132"
- Q - 144"
- R - 156"
- T - 168"
- U - 180"
- V - 192"
- W - 204"
- X - 216"
- Y - 228"
- Z - 240"
- S - Special

55 ☐ MISCELLANEOUS DIGIT DESCRIPTION
- A - One Extra Set of Throwaway Filters
- B - One Extra Set of Low Velocity Filters
- C - One Extra Set of High Velocity Filters
- D - Two Extra Sets of Throwaway Filters
- E - Two Extra Sets of Low Velocity Filters
- F - Two Extra Sets of High Velocity Filters
- G - Damper (Shutoff) Right Hand
- H - Damper (Shutoff) Left Hand
- P - ZRC Paint on Coil
- R - Curb Unit
- U - UL Listed

- 1 - Low Leak 1 Damper Back (90°) Bottom LH or Top RH (180°)
- 2 - Ultra Low Leak Damper 1 Damper Back (90°), Bottom LH or Top RH (180°)
- 3 - Low Leak Damper 2 Dampers Top and Bottom or Back
- 4 - Ultra Low Leak Damper 2 Dampers Top and Bottom or Back
- 5 - Low Leak Damper 1 Damper Top (90°) Bottom RH or Top LH (180°)
- 6 - Ultra Low Leak Damper 1 Damper Top (90°) Bottom RH or Top LH (180°)
- 7 - Low Leak Damper External and Internal Face and Bypass Dampers
- 8 - Ultra Low Leak Damper External and Internal Face and Bypass Dampers

Figure 78: Trane CLCH-MN-2A Model Number Code - Electric Preheat / Digits 50 - 55 (cont'd)

COOLING
HEATING
HORIZONTAL DRAW-THRU CLIMATE CHANGER®

REF: DS CLCH-1/JUNE 81
CENTRAL STATION AIR HANDLERS 600-65,000 CFM

FIGURE 45-1 — Horizontal Draw-Thru (Sizes 35-63)

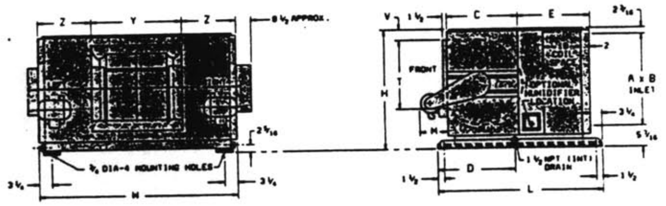


TABLE 45-1 — Casing Dimensions

SIZE	W	L			H	A	B	C			D	E			M
		ARR. 1, 2	ARR. 3	ARR. 4				ARR. 1, 2	ARR. 3	ARR. 4		ARR. 1, 2	ARR. 3	ARR. 4	
35	9' 7"	6' 8½"	7' 4½"	7' 11½"	5' 1/8"	4' 4½"	9' 3¼"	3' 8"	4' 4"	4' 9"	3' 4¼"	2' 6"	2' 6"	2' 8"	Refer to Table 77-1
41	9' 10"	7' 1½"	7' 10"	8' 4½"	5' 5 1/8"	4' 9½"	9' 6¼"	4' 2"	4' 10½"	5' 1"	3' 6¾"	2' 5"	2' 6"	2' 9"	
50	9' 10"	7' 7½"	8' 5"	9' 1"	6' 4 1/8"	5' 8½"	9' 6¼"	4' 8"	5' 5½"	5' 9"	3' 9¾"	2' 5"	2' 5"	2' 10"	
63	10' 6"	8' 2½"	9' 1"	9' 1"	8' 0 5/8"	7' 5"	9' 6¼"	4' 8"	5' 6½"	6' 3½"	4' 1¼"	3' 0"	3' 0"	3' 0"	

TABLE 45-2 — Duct Connection Size/Location

SIZE	T	Y	Z	V		R	
				ARRG 1	ARRG 3	ARRG 2	ARRG 4
35	40 1/8"	40¼"	37 3/8"	2½"	2½"	14¼"	15¼"
41	44½"	44¼"	36 7/8"	2½"	2½"	14 7/8"	14 7/8"
50	49 1/8"	48 7/8"	34¾"	2½"	2½"	21¼"	17¾"
63	54 3/8"	53 7/8"	36 1/8"	2½"	3½"	24½"	18½

FIGURE 45-2 — Horizontal Draw-Thru Discharge Arrangements (Sizes 35-63)

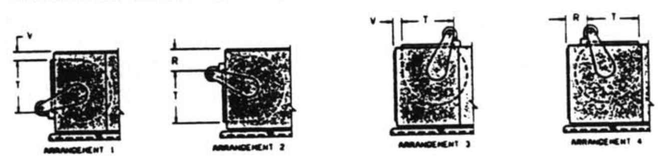


FIGURE 45-3 — Horizontal Draw-Thru (Sizes 73-86)

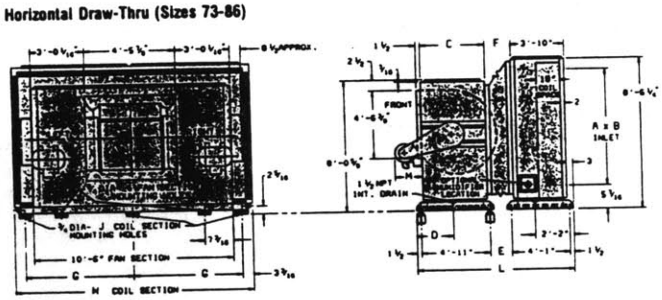


TABLE 45-3 — Casing Dimensions

SIZE	W		L			A	B	C			D		
	FAN SEC	COIL SEC	ARRG. 1, 2	ARRG. 3	ARRG. 4			ARRG. 1, 2.	ARRG. 3	ARRG. 4	ARRG. 1, 2	ARRG. 3	ARRG. 4
73	10' 6"	10' 6"	9' 9"	11' 4¾"	12' 2¼"	10' 2¼"	7' 11"	4' 8"	5' 7"	6' 4"	2' 7"	2' 7"	4' 1¾"
86	10' 6"	12' 4"	11' 0"	11' 4¾"	12' 2¼"	12' 0¼"	7' 11"	4' 8"	5' 7"	6' 4"	2' 7"	2' 7"	4' 1¾"

Table 45-3 (Cont.)

E			F	G	J	M
ARRG. 1, 2	ARRG. 3	ARRG. 4				
4' 11"	5' 9½"	6' 7"	6"	9' 11 5/8"	7¼"	Refer to Table 77-1
4' 11"	5' 9½"	6' 7"	1' 9"	11' 9 5/8"	1' 6¼"	

Figure 79: Trane CLCH Fan Box Dimensions (ref: Trane DS-CLCH-1/June 81, P. 45)

DIMENSIONAL DATA
FILTER BOXES

TABLE 64-1 — Flat Filter Box Dimensions

UNIT SIZE	W	L	H	A	B
3	2' 10"	6"	1' 9"	1' 5"	2' 6"
6	4' 7"	6"	1' 11"	1' 5"	4' 3"
7	5' 1"	6"	1' 9"	1' 5"	4' 9"
8	3' 10"	6"	2' 9"	2' 5¼"	3' 6"
9	7' 1"	6"	1' 11"	1' 5"	6' 9"
10	4' 7"	6"	2' 9"	2' 5¼"	4' 3"
12	5' 1"	6"	3' 1"	2' 9¼"	4' 9"
14	5' 10"	6"	3' 1"	2' 9¼"	5' 6"
17	7' 7"	6"	2' 9"	2' 5¼"	7' 3"
21	9' 1"	6"	2' 9"	2' 5¼"	8' 9"
25	9' 7"	6"	3' 1"	2' 9¼"	9' 3½"
31	9' 7"	6"	3' 11"	3' 6¼"	9' 3¼"
35	9' 7"	6"	4' 8"	3' 11¼"	9' 3½"
41	9' 10"	6"	5' 1"	4' 9½"	9' 6"
50	9' 10"	6"	6' 0"	5' 7½"	9' 6"
63	9' 10"	6"	7' 8½"	7' 4¾"	9' 6"
73	10' 6"	6"	8' 2½"	7' 8¾"	10' 2"
86	12' 4"	6"	8' 2½"	7' 8¾"	12' 0"

NOTE: For 2" deep filters.

FIGURE 64-1 — Flat Filter Box

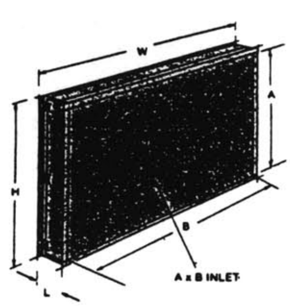
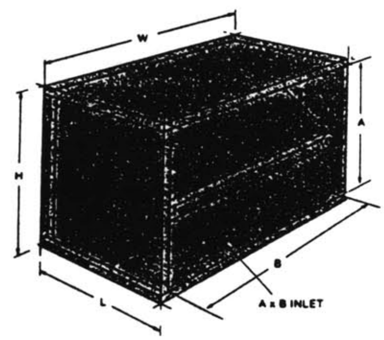


TABLE 64-2 — Medium Capacity Filter Box Dimensions

UNIT SIZE	W	L	H	A	B
3	2' 9"	1' 7¾"	1' 9"	1' 5"	2' 6"
6	4' 6"	1' 7³/₈"	1' 1"	' 7"	4' 3"
7	5' 0"	1' 7¾"	1' 9"	1' 5"	4' 9"
8	3' 9"	2' 3"	2' 9"	2' 5"	3' 6"
9	7' 0"	1' 7³/₈"	1' 11"	1' 7"	6' 9"
10	4' 6"	2' 3"	2' 9"	2' 5"	4' 3"
12	5' 0"	2' 1¾"	3' 1"	2' 9"	4' 9"
14	5' 9"	2' 1¾"	3' 1"	2' 9"	5' 6"
17	7' 6"	2' 3"	2' 9"	2' 5"	7' 3"
21	9' 0"	2' 3"	2' 9"	2' 5"	8' 9"
25	9' 6"	2' 1¾"	3' 1"	2' 9"	9' 3"
31	9' 6"	1' 6¾"	3' 11"	3' 7"	9' 3"
35	9' 7"	1' 10¾"	4' 8"	4' 4"	9' 3"
41	9' 10"	2' 3"	5' 1"	4' 9"	9' 6"
50	9' 10"	2' 2"	6' 0"	5' 8"	9' 6"
63	9' 10"	2' 3"	7' 8½"	7' 4½"	9' 6"
73	10' 6"	2' 2½"	8' 2½"	7' 10½"	10' 2"
86	12' 4"	2' 2½"	8' 2½"	7' 10½"	12' 0"

NOTE: For 2" deep filters.

FIGURE 64-2 — Medium Capacity Filter Box



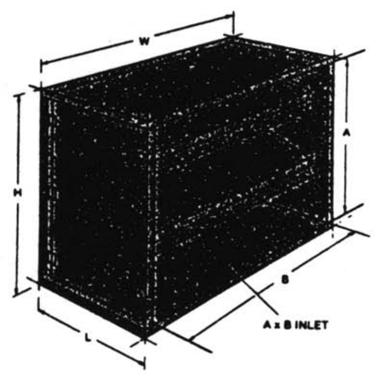
NOTE:
Size 3-31 large hinged filter access doors
Size 35-86 individual filter access doors

TABLE 64-3 — High Capacity Filter Box Dimensions

UNIT SIZE	W	L	H	A	B
3	2' 9"	1' 11¾"	1' 9"	1' 5"	2' 6"
6	4' 6"	1' 11½"	1' 11"	1' 7"	4' 3"
7	5' 0"	1' 11¾"	1' 9"	1' 5"	4' 9"
8	3' 9"	1' 11½"	2' 9"	2' 5"	3' 6"
9	7' 0"	1' 11½"	1' 11"	1' 7"	6' 9"
10	4' 6"	1' 11½"	2' 9"	2' 5"	4' 3"
12	5' 0"	1' 11"	3' 1"	2' 9"	4' 9"
14	5' 9"	1' 11"	3' 1"	2' 9"	5' 6"
17	7' 6"	1' 11½"	2' 9"	2' 5"	7' 3"
21	9' 0"	1' 11½"	2' 9"	2' 5"	8' 9"
25	9' 5"	1' 11"	3' 1"	2' 9"	9' 3"
31	9' 7"	1' 11¹/₈"	3' 11"	3' 7"	9' 3"
35	9' 7"	2' 3¼"	4' 8"	4' 4"	9' 3½"
41	9' 10"	2' 3½"	5' 1"	4' 9"	9' 6"
50	9' 10"	2' 3¾"	6' 0"	5' 8"	9' 6"
63	9' 10"	2' 4"	7' 8½"	7' 4½"	9' 6"
73	10' 6"	2' 3½"	8' 2½"	7' 10½"	10' 2"
86	12' 4"	2' 3½"	8' 2½"	7' 10½"	12' 0"

NOTE: For 2" deep filters.

FIGURE 64-3 — High Capacity Filter Box



NOTE:
Size 3-31 large hinged filter access doors
Size 35-86 individual filter access doors

All dimensions approximate

Figure 80: Trane CLCH Filter Box Dimensions (ref: Trane DS-CLCH-1/June 81, P. 64)

DIMENSIONAL DATA
MIXING BOXES

TABLE 66-1 — Mixing Box Dimensions

UNIT SIZE	W	90° OPENING L	90° OPENING H	180° OPENING L	180° OPENING H	A	B
3	2' 9"	1' 9¾"	2' 0¾"	1' 5"	2' 4½"	1' 0½"	2' 5¼"
6	4' 6"	1' 9¾"	2' 2¾"	1' 5"	2' 6½"	1' 0½"	4' 2¼"
7	5' 0"	1' 9¾"	2' 0¾"	1' 5"	2' 4½"	1' 0½"	4' 6 5/8"
8	3' 9"	2' 6¾"	3' 1¾"	2' 1"	3' 6½"	1' 8½"	3' 3 5/8"
9	7' 0"	1' 9¾"	2' 2¾"	1' 5"	2' 6½"	1' 0½"	6' 7 3/8"
10	4' 6"	2' 6¾"	3' 1¾"	2' 1"	3' 6½"	1' 8½"	4' 2¼"
12	5' 0"	2' 7¾"	3' 4¾"	2' 3"	3' 8½"	1' 10½"	4' 6 5/8"
14	5' 9"	2' 7¾"	3' 4¾"	2' 3"	3' 8½"	1' 10½"	5' 4 5/8"
17	7' 6"	2' 6¾"	3' 1¾"	2' 1"	3' 6½"	1' 8½"	7' 0 5/8"
21	9' 0"	2' 6¾"	3' 1¾"	2' 1"	3' 6½"	1' 8½"	8' 6¼"
25	9' 6"	2' 7¾"	3' 4¾"	2' 3"	3' 8½"	1' 10½"	9' 0¼"
31	9' 7"	3' 2¼"	4' 3¾"	2' 8½"	4' 8½"	2' 2½"	9' 0¼"
35	9' 7"	3' 4¾"	5' 1¾"	2' 11"	6' 7½"	2' 6½"	9' 0¼"
41	9' 10"	4' 1¾"	5' 7¾"	3' 6"	5' 2½"	2' 10½"	9' 3¼"
50	9' 10"	4' 7¾"	6' 6¾"	4' 0"	7' 1½"	3' 3½"	9' 3¼"
63	9' 10"	5' 3¾"	8' 3¼"	4' 8"	8' 10"	4' 2½"	9' 3¼"
73	10' 6"	5' 7¾"	8' 9¼"	6' 0"	9' 4"	4' 10½"	9' 11¼"
86	12' 4"	6' 7¾"	8' 9¼"	6' 0"	9' 4"	4' 10½"	11' 9¼"

FIGURE 66-1 — Mixing Boxes

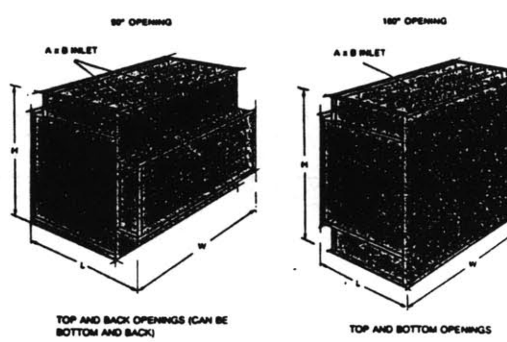


TABLE 66-2 — Deluxe Mixing Box Dimensions

UNIT SIZE	W	L	H	A	B
T3	2' 10"	1' 5"	1' 9"	10½"	2' 6"
T6	4' 7"	1' 4"	1' 11"	10½"	4' 3"
T7	5' 1"	1' 5"	1' 9"	10½"	4' 9"
T8	3' 10"	2' 0"	2' 9"	1' 6½"	3' 6"
T9	7' 1"	1' 4"	1' 1"	10¼"	6' 9"
T10	4' 7"	2' 0"	2' 9"	1' 6½"	4' 3"
T12	5' 1"	2' 2"	3' 1"	1' 8½"	4' 9"
T14	5' 10"	2' 2"	3' 1"	1' 8½"	5' 6"
T17	7' 7"	2' 0"	2' 9"	1' 6½"	7' 3"
T21	9' 1"	2' 0"	2' 9"	1' 6½"	8' 9"
T25	9' 7"	2' 2"	3' 1"	1' 8½"	7' 3"
T31	9' 7"	2' 6"	3' 11"	2' 0¼"	9' 3"
T35	9' 7"	2' 10"	4' 8"	2' 4½"	9' 3"

NOTE 1: Boxes able to support vertical floor tornvents.

FIGURE 66-2 — Deluxe Mixing Boxes

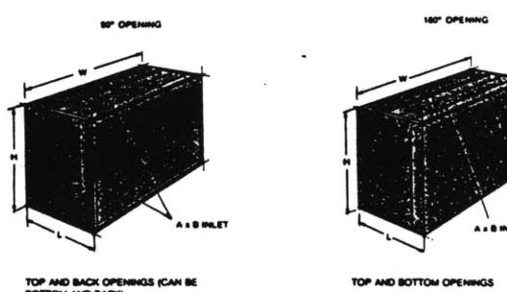
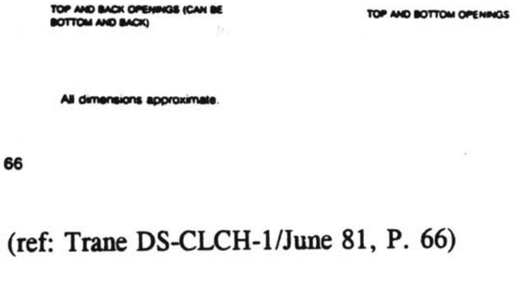


TABLE 66-3 — High Efficiency Mixing Box Dimensions

UNIT SIZE	W	90° OPENING L	90° OPENING H	180° OPENING L	180° OPENING H	A	B	C
3	2' 6½"	2' 0¾"	2' 2"	1' 7½"	2' 7"	11"	2' 4½"	5¾"
6	4' 1½"	2' 1¼"	2' 3"	1' 8"	2' 7"	11½"	3' 11¾"	5¾"
7	5' 0"	2' 1"	2' 2"	1' 7¾"	2' 7"	11¼"	4' 6"	5¾"
8	3' 4"	3' 3¼"	3' 1¼"	2' 8"	3' 5½"	1' 8¾"	3' 2"	5¾"
9	7' 0"	2' 0 5/8"	2' 3"	1' 7 3/8"	2' 7"	10 7/8"	6' 5"	5¾"
10	4' 11"	3' 3¼"	3' 1¼"	2' 8"	3' 5½"	1' 8¾"	3' 11"	5¾"
12	4' 6"	3' 7¾"	3' 5¾"	2' 11½"	3' 10½"	1' 10¾"	4' 4"	5¾"
14	5' 3"	3' 7¾"	3' 5¾"	2' 11½"	3' 10½"	1' 10¾"	5' 1"	5¾"
17	7' 6"	3' 0¾"	3' 1¼"	2' 5½"	3' 5½"	1' 6½"	7' 3"	5¾"
21	9' 0"	3' 0¾"	3' 1¼"	2' 5½"	3' 5½"	1' 6½"	8' 9"	5¾"
25	9' 11"	3' 6½"	3' 5¾"	2' 10¼"	3' 10½"	1' 9½"	8' 11"	5¾"
31	9' 7"	4' 6¼"	4' 8¾"	3' 6"	5' 6½"	2' 0¼"	9' 3½"	5¾"
35	9' 7"	4' 10¼"	5' 2¼"	3' 10"	5' 8½"	2' 4½"	9' 3½"	7¼"
41	9' 10"	5' 1¾"	5' 11¾"	4' 8½"	6' 10½"	2' 11½"	9' 6"	7¼"
50	9' 10"	7' 3¼"	6' 10¼"	5' 10"	8' 6½"	3' 10½"	9' 6"	7¼"
63	9' 10"	8' 9¾"	8' 11¾"	6' 10½"	10' 3"	4' 3"	9' 6"	7¼"
73	10' 6"	7' 3"	9' 5¾"	9' 2¼"	11' 1"	4' 7½"	10' 2"	7 ¼"
86	12' 4"	7' 3"	9' 5¾"	9' 2¼"	11' 1"	4' 7½"	12' 0"	7¼"

NOTE: Designed to minimize air stratification with efficient mixing by the use of staggered vertical blades not designed for complete shutoff

FIGURE 66-3 — High Efficiency Mixing Boxes



All dimensions approximate.

Figure 81: Trane CLCH Mixing Box Dimensions (ref: Trane DS-CLCH-1/June 81, P. 66)

COIL CONNECTION

TABLE 75-1 — Refrigerant Coil (Type F) Piping Sizes (Inches)

HEADER HEIGHT	NO. OF CIRCUITS	CONNECTION SIZE (INCHES) LIQUID	SUCTION
18	2	⅞	1⅜
	3	⅞	1⅝
	6	1⅛	2⅛
	12	1⅜	2⅛
24	2	⅞	1⅝
	4	⅞	1⅝
	8	1⅛	2⅛
	16	(2)1⅛	(2)2⅛
30	2	⅞	1⅜
	4	⅞	1⅝
	5	⅞	2⅛
	10	1⅜	2⅛
	20	(2)1⅜	(2)2⅛
33	3	⅞	1⅝
	7	1⅛	2⅛
	11	1⅜	2⅛
	22	(2)1⅜	(2)2⅛

NOTE Connections are piping OD

TABLE 75-2 — Water and Steam Coil Connection Size (Inches)

COIL TYPE	HEADER HEIGHT	CONNECTION SIZE (IN.) SUPPLY	RETURN	DRAIN & VENT
W	18, 24, 30, 33	2½	2½	½
D	18, 24, 30, 33	2½	2½	½
DD	18, 24, 30, 33	2½	2½	½
P2	18, 24, 30	¾	¾	½
P4	18, 24, 30	1	1	½
P8	18, 24, 30	1¼	1¼	½
K	18, 24, 30, 33	2½	2½	½
WC	18	1	1	½
WC	24	1¼	1¼	½
WC	30, 33	2½	1½	½
WA	18, 24, 30, 33	2½	2½	½
N, NS	18	2	1	NA
	24	2½	1¼	NA
	30, 33	3	1¼	NA
A, AA	18	2½	1	NA
	24, 30, 33	2½	1¼	NA
TT	18, 24, 30, 33	¾	¾	NA

NOTE Connections are N.P.T internal

CLIMATE CHANGER AND COIL MODULE CONNECTION LOCATION

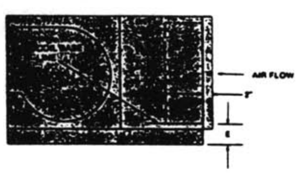


TABLE 75-3 — W-D-K Cooling Coil Connection Location (Inches)

HEADER HEIGHT	H	A	B	C	D 2 ROW	4 ROW	6 ROW	8 ROW
18"	19½	11¼	8¼	1⅞	4½	7½	10½	13½
24"	25½	14¼	11¼	1⅞				
30"	31½	17¼	14¼	1⅞				
33"	34½	18¾	15¾	1⅞				

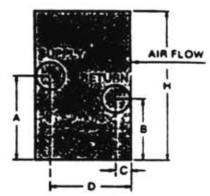


TABLE 75-4 — NS Heating Coil Connection Location (Inches)

HEADER HEIGHT	H	A	B	C	D
18"	19½	1⅞	8¼	1⅜	2½
24"	25½	1½	11¼	1¼	2½
30"	31½	1½	14¼	1¼	2½
33"	34½	1½	17¼	1¼	2½

B = Right hand conn.

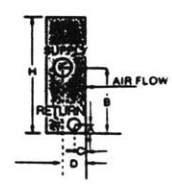


TABLE 75-5 — WC Heating Coil Connection Location (Inches)

HEADER HEIGHT	H	A	B	C
18	19½	1⅝	17⅞	2
24	25½	12	24⅛	2
30	31½	8¼	23¼	2
33	34½	8¼	24¾	2

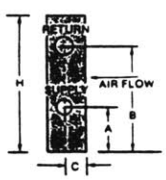


TABLE 75-6 — Coil Base Line

UNIT SIZE	E
3-31	3"
35-63	4¼
73-86	5¾

All dimensions approximate

Example: Determine piping connection location on No. 10 Horizontal Draw-Thru Climate Changer with a 4-row, type W coil.

Size 3-25: To determine coil connection location, add 2 inches to C and D dimensions above and 3 inches to dimensions A and B above.

Size 31 and Larger: Units with multiple coils can use above method to determine location of bottom coil. Then the additional coils can be added on top of bottom coil which is H plus E.

Supply Piping:
Centerline Height above floor = Table 75-6 "E" Dimension + Table 75-3 "A" Dimension
= 3" + 11¼" = 14¼"
Centerline from end of unit = 2" + Table 75-3 "D" Dimension
= 2" + 7½" = 9½"

Return Piping:
Centerline Height above floor = Table 75-6 "E" Dimension + Table 75-3 "B" Dimension
= 3" + 8¼" = 11¼"
Centerline from end of unit = 2" + Table 75-3 "C" Dimension
= 2" + 1⅞" = 3⅞"

TRANE AIR CONDITIONING

Figure 82: Trane CLCH Coil Connection Dimensions (ref: Trane DS-CLCH-1/June 81, P. 75)

41 TRANE AIR CONDITIONING

FIGURE 30-1 — No. 41J, K, L - 27" AF Fan

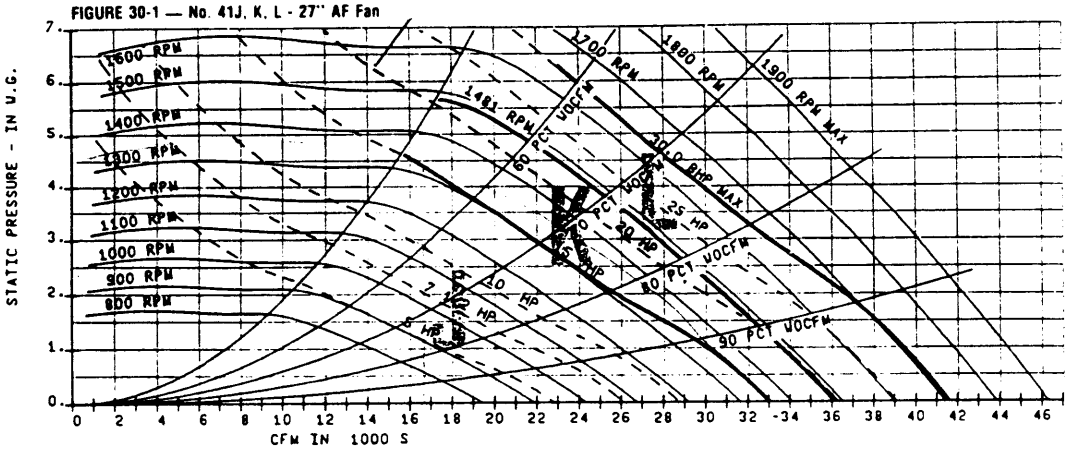


FIGURE 30-2 — No. 41M, N, P - 24.5" AF Fan

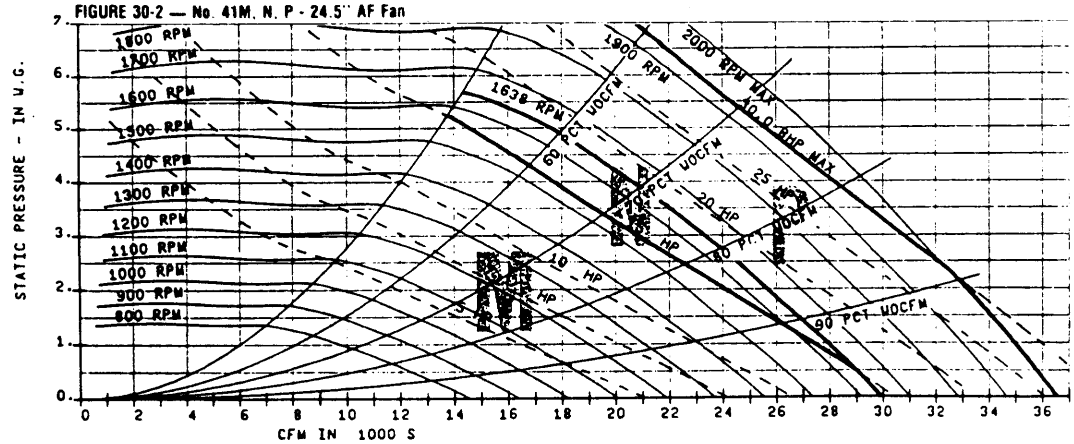


Figure 83: Trane CLCH Fan Curves - w/o Inlet Vanes (ref: Trane CS CLCH-2)

HORIZONTAL DRAW-THRU CLIMATE CHANGER

AND CABINET FANS

41

TABLE 31-1 — No. 41J, K, L - 27" AF Fan

COIL FACE VEL	CFM STD AIR	OUT-LET VEL	¼" RPM	¼" BHP	½" RPM	½" BHP	¾" RPM	¾" BHP	1" RPM	1" BHP	1¼" RPM	1¼" BHP	1½" RPM	1½" BHP	1¾" RPM	1¾" BHP	2" RPM	2" BHP	2¼" RPM	2¼" BHP	2½" RPM	2½" BHP	2¾" RPM	2¾" BHP	3" RPM	3" BHP	3¼" RPM	3¼" BHP
346	14000	1024	636	1.60	692	2.20	745	2.81	790	3.39	835	4.01	875	4.60	915	5.23	953	5.88	990	6.56	1024	7.22	1060	7.92	1095	8.64	1131	9.33
395	16000	1170	711	2.20	762	2.84	810	3.55	855	4.25	894	4.90	934	[illegible].60	972	6.31	1006	6.98	1041	7.70	1074	8.44	1107	9.21	1139	9.99	1168	10.72
444	18000	1316	787	2.97	834	3.63	877	4.42	920	5.21	960	6.00	994	[illegible]6.73	1030	7.51	1065	8.30	1098	9.10	1128	9.84	1159	10.64	1189	11.48	1218	12.31
494	20000	1463	864	3.92	907	4.61	948	5.42	986	6.33	1024	7.20	1060	[illegible]8.08	1091	8.88	1124	9.74	1156	10.61	1187	11.49	1217	12.38	1244	13.19	1271	14.07
543	22000	1609	942	5.07	982	5.80	1020	6.63	1055	7.60	1090	8.58	112[illegible]	[illegible]9.53	1158	10.50	1187	11.37	1216	12.31	1246	13.27	1275	14.22	1303	15.20	1331	16.18
593	24000	1755	1021	6.45	1057	7.20	1093	8.07	1127	9.03	1159	10.12	11[illegible]	[illegible]1.19	1223	12.22	1254	13.28	1283	14.32	1307	15.25	1335	16.28	1361	17.33	1388	18.37
642	26000	1901	1101	8.06	1134	8.86	1167	9.76	1199	10.75	1230	11.82	1259	13.01	1289	14.17	1319	15.29	13[illegible]	[illegible].44	1375	17.58	1398	18.58	1423	[illegible].68	1448	20.80
691	28000	2048	1180	9.94	1211	10.78	1242	11.70	1272	12.73	1302	13.83	1330	15.01	1357	16.30	1385	17.55	141[illegible]	[illegible]8.79	1440	19.99	1465	21.22	1490	[illegible].44	1511	23.49
741	30000	2194	1260	12.10	1289	12.98	1318	13.94	1347	15.00	1375	16.12	1402	17.32	1428	18.60	1453	20.00	147[illegible]	[illegible].34	1505	22.67	1530	23.95	1555	[illegible].28	1579	26.59

COIL FACE VEL	CFM STD AIR	OUT-LET VEL	3½" RPM	3½" BHP	3¾" RPM	3¾" BHP	4" RPM	4" BHP	4¼" RPM	4¼" BHP	4½" RPM	4½" BHP	4¾" RPM	4¾" BHP	5" RPM	5" BHP	5¼" RPM	5¼" BHP	5½" RPM	5½" BHP	5¾" RPM	5¾" BHP	6" RPM	6" BHP	6¼" RPM	6¼" BHP	6½" RPM	6½" BHP
346	14000	1024	1167	[illegible]10	1204	10.91																						
395	16000	1170	1200	[illegible]52	1231	12.33	1262	13.17	1293	13.95	1325	14.82	135[illegible]	[illegible].73														
444	18000	1316	124[illegible]	[illegible]18	1276	14.05	1304	14.93	1330	15.75	1367	16.65	13[illegible]	[illegible]7.57	1413	18.51	1440	19.36	1468	20.33	149[illegible]	[illegible]1.33	1525	22.35	1554	23.40		
494	20000	1463	129[illegible]	[illegible].98	1326	15.91	1352	16.83	1379	17.80	1405	18.77	14[illegible]	[illegible]9.75	1453	20.63	1478	21.61	1503	22.62	152[illegible]	[illegible]3.63	1553	24.67	1578	25.71	1602	26.64
543	22000	1609	1357	17.14	1380	18.01	1405	19.00	1430	20.00	1455	21.03	14[illegible]	[illegible].03	1503	23.06	1527	24.14	1551	25.22	157[illegible]	[illegible]6.29	1594	27.24	1616	28.32	1639	29.41
593	24000	1755	1414	19.43	1440	20.50	1464	21.56	1486	22.49	1509	23.54	153[illegible]	[illegible].62	1555	25.71	1578	26.82	1600	27.91	162[illegible]	[illegible].04						
642	26000	1901	1473	21.94	1498	23.05	1522	24.21	1546	25.36	1569	26.52	1591	27.67	1611	28.64	1632	29.79										
691	28000	2048	1534	24.68	1558	25.89	1581	27.11	1604	28.33	1627	29.54																
741	30000	2194	1602	27.89	1621	28.99																						

TABLE 31-2 — No. 41M, N, P - 24.5" AF Fan

COIL FACE VEL	CFM STD AIR	OUT-LET VEL	¼" RPM	¼" BHP	½" RPM	½" BHP	¾" RPM	¾" BHP	1" RPM	1" BHP	1¼" RPM	1¼" BHP	1½" RPM	1½" BHP	1¾" RPM	1¾" BHP	2" RPM	2" BHP	2¼" RPM	2¼" BHP	2½" RPM	2½" BHP	2¾" RPM	2¾" BHP	3" RPM	3" BHP	3¼" RPM	3¼" BHP
346	14000	1024	822	2.00	876	2.56	925	3.15	971	3.74	1015	4.35	1057	4.95	1099	5.56	1139	6.20	1176	6.81	1212	7.46	1248	8.12	1281	8.75	1316	9.43
395	16000	1170	925	2.79	973	3.42	1019	4.09	1060	4.75	1100	5.42	11[illegible]	[illegible]2	1177	6.79	1214	7.50	1251	8.20	1286	8.93	1321	9.66	1352	10.34	1384	11.06
444	18000	1316	1029	3.78	1071	4.50	1114	5.21	1154	5.97	1190	6.71	12[illegible]	[illegible]7	1262	8.25	1296	9.03	1329	9.78	1362	10.57	1394	11.38	1426	12.17	145[illegible]	[illegible]9
494	20000	1463	1134	5.01	1173	5.79	1210	6.61	1249	7.40	1284	8.24	13[illegible]	[illegible]06	1349	9.90	1381	10.75	1413	11.62	1444	12.49	1473	13.32	1503	14.20	153[illegible]	[illegible]09
543	22000	1609	1240	6.49	1275	7.34	1310	8.23	1346	9.08	1379	10.00	14[illegible]	[illegible]92	1441	11.82	1470	12.74	1500	13.67	1529	14.61	1557	15.57	1585	16.53	161[illegible]	[illegible]3
593	24000	1755	1347	8.25	1379	9.17	1411	10.12	1442	11.10	1476	12.02	1506	13.03	1535	14.03	1563	15.03	1590	16.01	1617	17.02	164[illegible]	18.04	1670	19.07	169[illegible]	[illegible]2
642	26000	1901	1454	10.31	1484	11.31	1513	12.33	1542	13.37	1572	14.44	1602	15.43	1631	16.51	1658	17.61	1684	18.69	1709	19.75	173[illegible]	[illegible].83	1758	21.93	178[illegible]	[illegible].03
691	28000	2048	1562	12.71	1589	13.77	1616	14.86	1644	15.98	1671	17.11	1700	18.15	1727	19.31	1753	20.48	1778	21.66	1803	22.84	182[illegible]	[illegible].00	1849	25.13	1872	26.30
741	30000	2194	1670	15.47	1695	16.60	1721	17.76	1746	18.94	1772	20.14	1797	21.36	1824	22.47	1849	23.71	1874	24.96	1898	26.22	192[illegible]	27.48	1943	28.74	1965	29.95

COIL FACE VEL	CFM STD AIR	OUT-LET VEL	3½" RPM	3½" BHP	3¾" RPM	3¾" BHP	4" RPM	4" BHP	4¼" RPM	4¼" BHP	4½" RPM	4½" BHP	4¾" RPM	4¾" BHP	5" RPM	5" BHP	5¼" RPM	5¼" BHP	5½" RPM	5½" BHP	5¾" RPM	5¾" BHP	6" RPM	6" BHP	6¼" RPM	6¼" BHP	6½" RPM	6½" BHP
346	14000	1024	1350	10.13	1[illegible]	[illegible].81	1418	11.53	1451	12.26	1484	13.01	1514	13.69	1546	14.45	1579	15.25										
395	16000	1170	1415	11.83	14[illegible]	[illegible].59	1474	[illegible]3.81	1504	14.09	1534	14.89	1564	15.69	1594	16.46	1623	17.29	1653	18.13	1682	18.98	1711	19.84	1735	20.59	1764	21.46
444	18000	1316	1488	13.82	1[illegible]	[illegible].57	154[illegible]	[illegible]0	1572	16.24	1600	17.09	1627	17.94	1652	18.74	1678	19.61	170[illegible]	[illegible]50	1732	21.40	1758	22.30	1784	23.15	1811	24.07
494	20000	1463	1561	15.96	1590	16.86	161[illegible]	[illegible]8	1646	18.69	1672	19.61	1696	20.43	1722	21.35	1747	22.28	177[illegible]	[illegible]22	1797	24.17	1818	25.04	1842	26.00	1867	26.97
543	22000	1609	1639	18.39	1666	19.36	169[illegible]	[illegible]5	1719	21.29	1745	22.29	1771	23.29	1796	24.30	1821	25.31	184[illegible]	[illegible]6.32	1866	27.20	1889	28.21	1912	29.23		
593	24000	1755	1722	21.17	1747	22.13	177[illegible]	[illegible]7	1796	24.23	1821	25.30	1846	26.37	1870	27.45	1894	28.48	191[illegible]	29.57								
642	26000	1901	1808	24.16	1832	25.29	1856	26.42	1879	27.55	1901	28.58	1924	29.72														
691	28000	2048	1895	27.48	1918	28.67	1941	29.88																				
741	30000	2194																										

Figure 84: Trane CLCH Fan Tables - w/o Inlet Vanes (ref: Trane CS CLCH-2)

CCDB41K

FIGURE 28-2 — No. 41J, K, L HDT - 27" AF Fan With Inlet Vanes

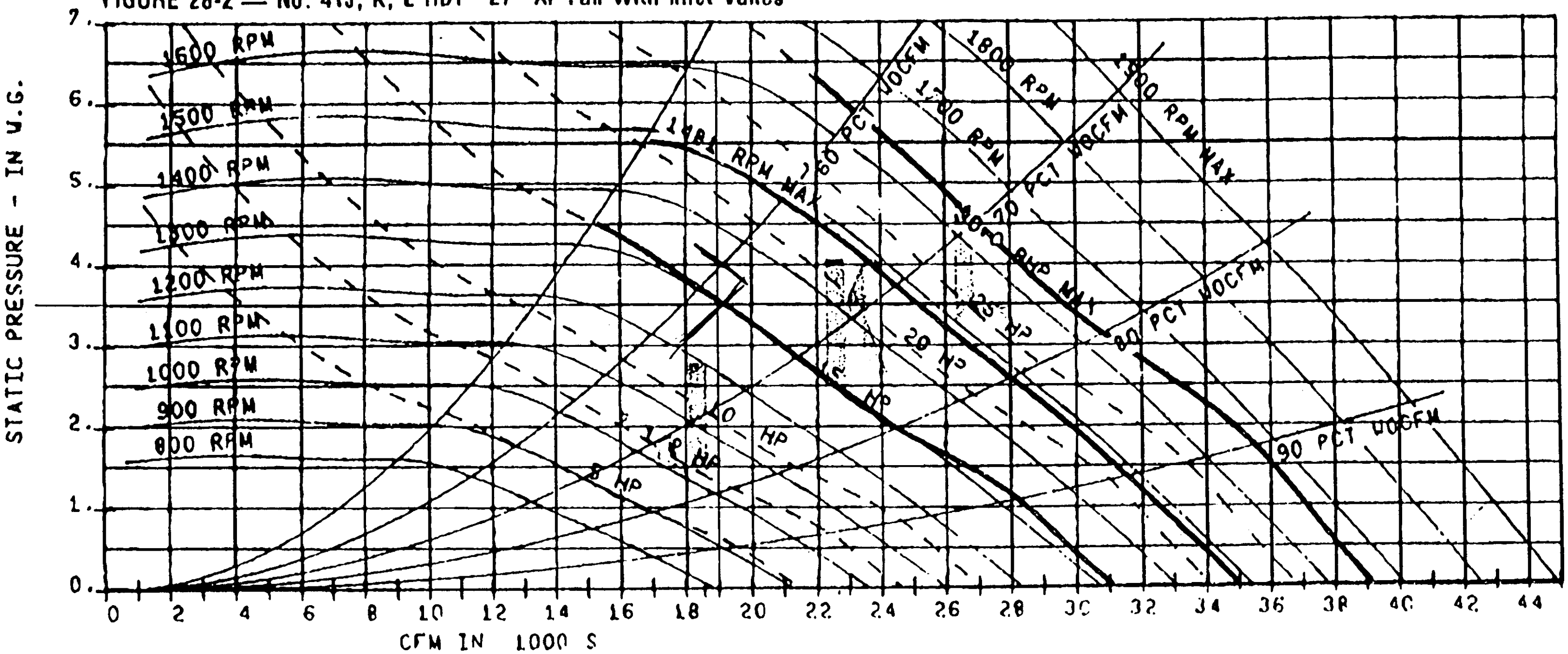


Figure 85: Trane CLCH Fan Curves - w/ Inlet Vanes (ref: Trane CS CLCH-3)

FIGURE 16-1 — Inlet Vane Performance

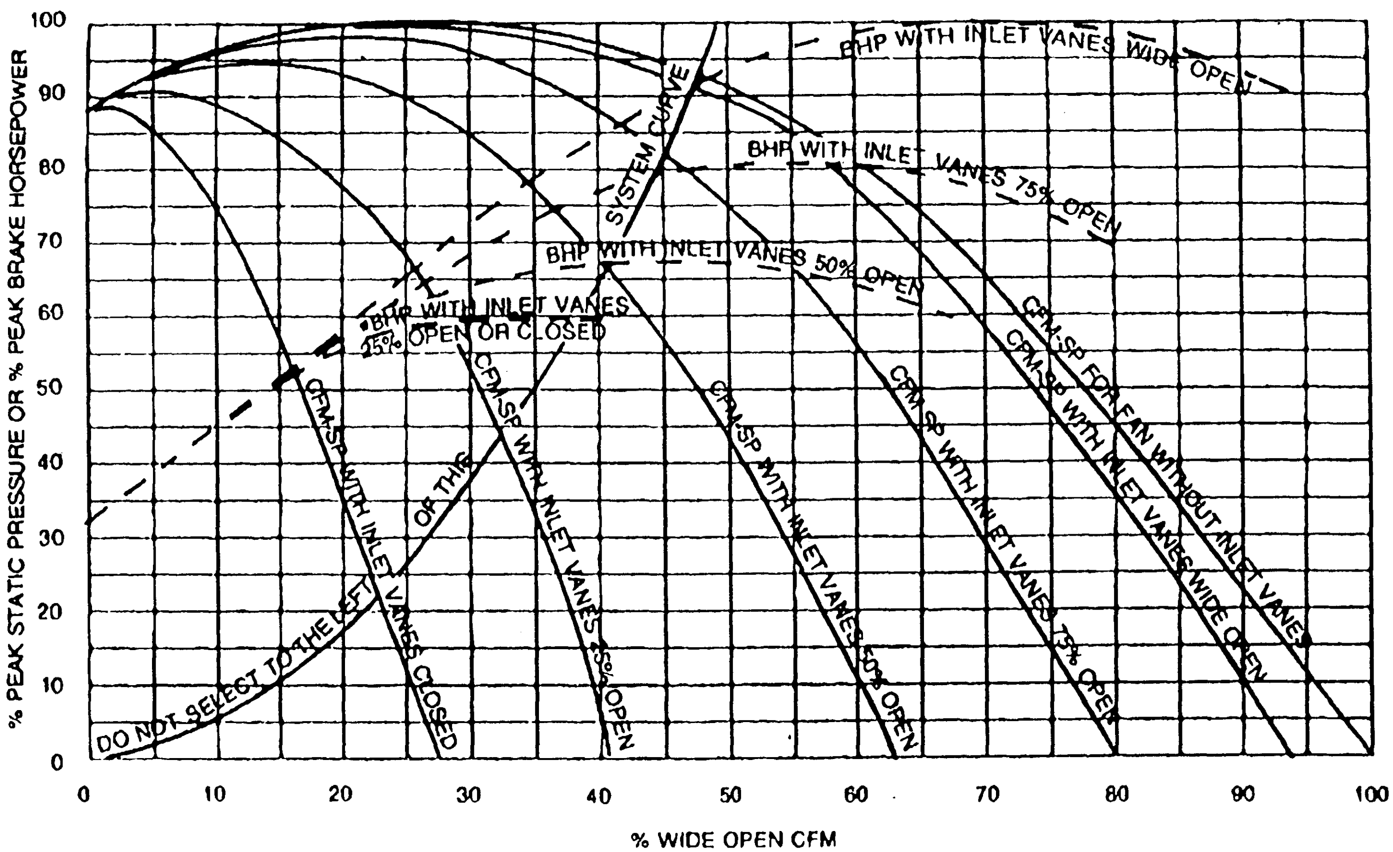


Figure 86: Trane CLCH Inlet Vane Performance Curves (ref: Trane CS CLCH-3)

DATA

TABLE 79-1 — Filter Area and Sizes

	UNIT SIZE	3	6	7	8	9	10	12	14	17	21	25	31	35	41	50	63	73	86
FLAT FILTER BOX	Area Sq Ft	3 46	6 94	7 70	8.91	11 10	11 10	13 40	15.90	18 80	23 30	26.60	34 90	38 90	46 70	54 30	69 30	79 30	92 40
	16×20	—	—	1	4	—	—	1	4	6	8	12	7	—	6	7	—	—	—
	16×25	—	—	—	—	—	4	2	—	—	2	—	7	14	—	14	10	—	—
	20×20	—	—	2	—	4	—	2	—	—	—	—	—	—	12	—	—	6	7
	20×25	1	2	—	—	—	—	—	2	—	—	—	—	—	—	—	12	18	21
MED CAP FILT-BOX COMB & DEL FILT-MIX BOXES	Area Sq Ft	5 56	11 12	11 12	13 88	17 76	16 88	19 44	22 24	27 76	34 70	37 50	48 80	55 80	69 60	77 84	104 10	124 60	145 30
	16×20	—	—	—	—	8	—	—	—	—	—	—	12	—	—	—	—	—	—
	16×25	2	4	4	—	—	6	2	8	—	—	6	8	—	—	28	—	—	—
	20×20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	20×25	—	—	—	4	—	—	4	—	8	10	6	—	16	20	—	30	36	42
HIGH CAPACITY FILTER BOX	Area Sq Ft	6 94	13 92	15 40	16 70	22 20	20 80	24 80	27 10	35 40	43 70	45 90	61 00	77 84	88 16	97 50	136 22	145 10	170 20
	16×20	—	—	2	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—
	16×25	—	—	—	—	—	—	—	—	—	—	—	—	28	32	35	49	—	—
	20×20	—	—	4	6	8	—	—	6	9	12	9	12	—	—	—	—	—	—
	20×25	2	4	—	—	—	6	3	3	3	3	6	8	—	—	—	—	42	49
ROLL FILTER	Area Sq Ft	3 17	6 22	6 22	7 87	10 00	9 64	12 35	14 36	16 70	20 23	24 43	32 02	38 84	43 80	46 91	64 04	77 81	92 97
HIGH EFFICIENCY FILTER BOX	Area Sq Ft	—	—	—	6 0	—	8 0	9 56	12 34	14 0	16 0	21 9	27 8	36 0	36 0	41 7	55 6	—	—
	24×12	—	—	—	1	—	—	2	2	1	—	4	—	2	2	—	—	—	—
	24×24	—	—	—	1	—	2	—	—	3	—	—	—	8	8	—	—	—	—
	20×20	—	—	—	—	—	—	2	3	—	—	5	10	—	—	15	20	—	—
	24×20	—	—	—	—	—	—	—	—	—	5	—	—	—	—	—	—	—	—

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TABLE 79-2 — Filter Air Pressure Drop (Inches wg)

FULL COIL FACE VELOCITY (FPM)		200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
FLAT FILTER BOX	TA	02	04	07	10	13	17	20	—	—	—	—	—	—	—	—	—	—
	Lo Vel Perm	01	02	03	04	05	06	08	—	—	—	—	—	—	—	—	—	—
	Hi Vel Perm	01	02	03	04	06	08	09	11	13	—	—	—	—	—	—	—	—
MED CAP FILT-BOX COMB & DEL FILT-MIX BOXES	TA	02	03	05	07	09	11	14	17	20	23	27	—	—	—	—	—	—
	Lo Vel Perm	01	01	01	02	03	04	05	06	07	09	10	12	—	—	—	—	—
	Hi Vel Perm	01	02	03	04	05	06	07	09	10	12	13	15	17	—	—	—	—
HIGH CAPACITY FILTER BOX	TA	01	02	03	05	07	09	11	14	17	20	24	28	32	37	—	—	—
	Lo Vel Perm	01	01	01	02	02	03	04	05	06	07	09	10	11	13	15	—	—
	Hi Vel Perm	01	01	02	03	04	05	06	07	09	10	12	13	15	17	19	21	24
ROLL FILTER	—	01	01	02	03	06	10	15	21	28	—	—	—	—	—	—	—	—

FILTER FACE VELOCITY (FPM)	200	250	300	350	400	450	500	550	600	650	700	750
BAG FILTER EFFICIENCY												
55	06	09	11	14	18	21	25	29	33	38	43	50
85	11	15	18	12	27	30	35	39	43	47	52	60
95	14	18	24	29	34	39	45	50	56	63	69	75
DISPOSABLE PANEL PREFILTER	08	09	12	14	18	22	25	28	33	39	45	50

Note: * Filter pressure drop based on clean filters. Add 0.2 to 0.5 in wg (depending on application) for loaded filter.
For high efficiency bag filters final resistance is 1.0 in wg
For diffuser section for final filters use 0.3 in wg

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TABLE 79-3 — Accessory Air Pressure Drop (Inches wg)

FULL COIL FACE VELOCITY (FPM)		200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
DAMPERS	Mixing Box	01	01	02	03	04	05	06	07	09	10	11	13	15	17	19	21	23
	Face & Bypass	01	02	03	04	05	06	07	08	10	12	14	16	18	20	22	24	27
	Multizone	04	06	08	10	13	16	19	23	27	31	37	43	—	—	—	—	—
PRESSURE EQUALIZING BAFFLES	#22	05	10	20	25	37	47	57	69	83	97	1 1	1 3	1.5	1 6	1 8	2 1	2 3
	#40	02	04	06	08	10	13	17	21	25	29	34	40	45	51	47	64	72
	#60	01	02	03	04	06	08	10	12	15	18	21	24	26	29	33	37	41
	#70	01	01	02	03	04	05	07	08	09	10	14	14	16	18	20	22	25
SINE WAVE ELIMINATORS		02	03	04	06	07	09	11	11	16	19	22	25	28	32	37	42	47
DISCHARGE PLENUM		01	01	01	02	03	05	06	07	09	10	12	14	17	19	22	25	28

NOTE: For mixing box dampers pressure drop low and ultra low leak is same as standard

TABLE 79-4 — Nozzle Air Pressure Drop (Inches wg)

	FAN OUTLET VELOCITY FPM																
NOZZLES	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2200	2400	2600	2800
#1	09	12	15	18	21	25	29	33	38	43	49	54	60	72	85	1 0	1 2
#3	06	08	10	12	15	17	20	22	25	28	32	36	40	48	58	68	79
#5	07	09	11	13	16	19	22	25	28	32	36	40	44	54	64	75	87
#6	01	01	02	02	03	03	04	04	05	05	06	07	08	10	12	14	16
#7	01	01	01	01	02	02	02	02	03	03	04	04	05	07	08	09	10
30° SWIVEL	04	05	06	07	09	11	13	14	16	18	20	22	25	30	37	43	53
90° SWIVEL	06	08	10	12	14	16	19	21	24	27	31	34	38	46	55	65	75

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Figure 87: AH1 High Capacity Filter Air Pressure Drop (ref: Trane DS CLCH-1/June 81)

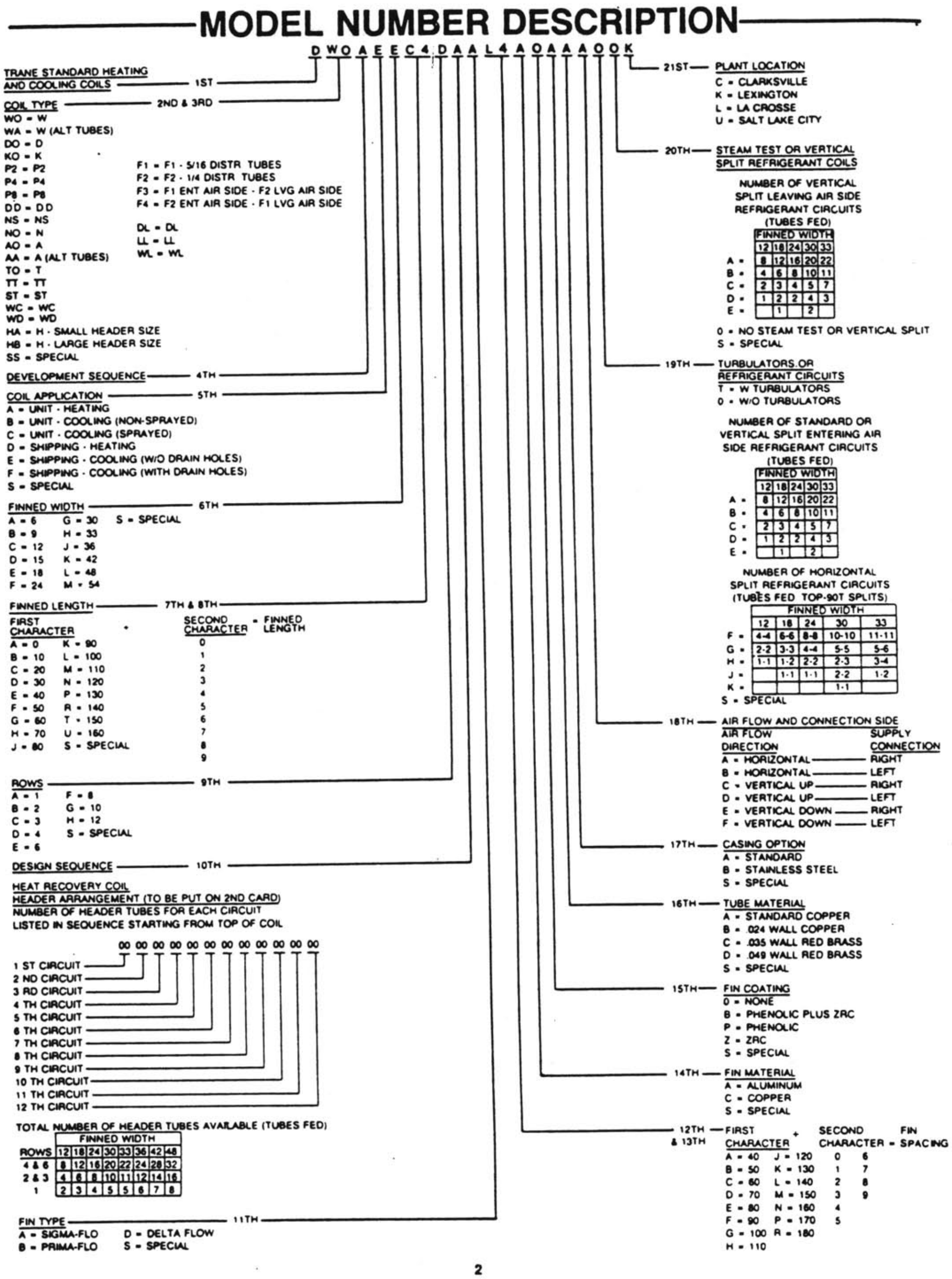

Figure 88: AH1 Cooling Coil Model Number Key Code (Trane: Coil-IM-3A/Jan 85)

GENERAL

Trane chilled water cooling coils are identified according to specific types (W, WD, D, DD, K, LL, WL, DL, P2, P4 and P8), fins per foot, widths and lengths.

Chilled water coils are shipped assembled and packaged. Inspect each coil for any in-transit damage. Claims for any shipping damage must be filed with the delivery carrier.

General data is given in Table 1 and Figures 1 to 7.

TABLE 1 - General Data

COIL TYPE	ROWS	END CONNECTION	FINNED WIDTH	FINNED LENGTH	FINS PER FOOT	TUBE MATERIAL	MAXIMUM STANDARD OPERATING PRESSURE (TUBE SIDE) PSI	TEMP (F)
W	2,3,4,6, 8,10,12	Same	12,18,24 30,33" 36,42,48"	12 Thru 144" 12 Thru 168"	Aluminum 80-168 Copper 80-144	$^5/_8$" OD Copper (Std) RED BRASS (0.035) Red Brass (0.049)	200	220
LL WL DL	4-6-8 2-4-6-8 2-4-6	Same	12,18,24 30,33,36, 42,48,54	12 Thru 168"	Aluminum 80-168	$^1/_2$" OD Copper	200	220
K	2,4,6, 8,10,12	Same	12, 18, 24, 30, 33"	12 Thru 144"	Aluminum- 80-168 Copper- 80-144	$^5/_8$" OD Copper(Std) Red Brass (0.035) Red Brass (0.049)	200	220
	3	Opposite						
P2	4,6	Same	12, 18, 24, 30"	12 Thru 120"	Aluminum- 80-168 Copper- 80-144	$^5/_8$" OD Copper(Std) Red Brass (0.035) Red Brass (0.049)	200	220
P4	2,4, 6,8	Same	12, 18, 24, 30"	12 Thru 120"	Aluminum- 80-168 Copper- 80-144	$^5/_8$" OD Copper(Std) Red Brass (0.035) Red Brass (0.049)	200	220
P8	4,8	Same	18, 24, 30"	12 Thru 120"	Aluminum- 80-168 Copper- 80-144	$^5/_8$" OD Copper(Std) Red Brass (0.035) Red Brass (0.049)	200	220
D	4,6,8, 10,12	Same	12, 18, 24, 30, 33"	12 Thru 144"	Aluminum- 80-168 Copper- 80-144	$^5/_8$" OD Copper (Std) Red Brass (0.035) Red Brass (0.049)	200	220
	3	Opposite						
DD	4,8,12	Same	18, 24, 30, 33"	12 Thru 144"	Aluminum- 80-168 Copper- 80-144	$^5/_8$" OD Copper(Std) Red Brass (0.035) Red Brass (0.049)	200	220
	6,10	Opposite						
WD	6,8, 10,12	Same	18, 24, 30, 33"	12 Thru 144"	Aluminum 80-168 Copper 80-144	$^5/_8$" OD Copper (Std) Red Brass (0.035) Red Brass (0.049)	200	220

Figure 89: AH1 Cooling Coil Tube Specification Material Data (Trane: COIL-IM-3A/Jan 85)

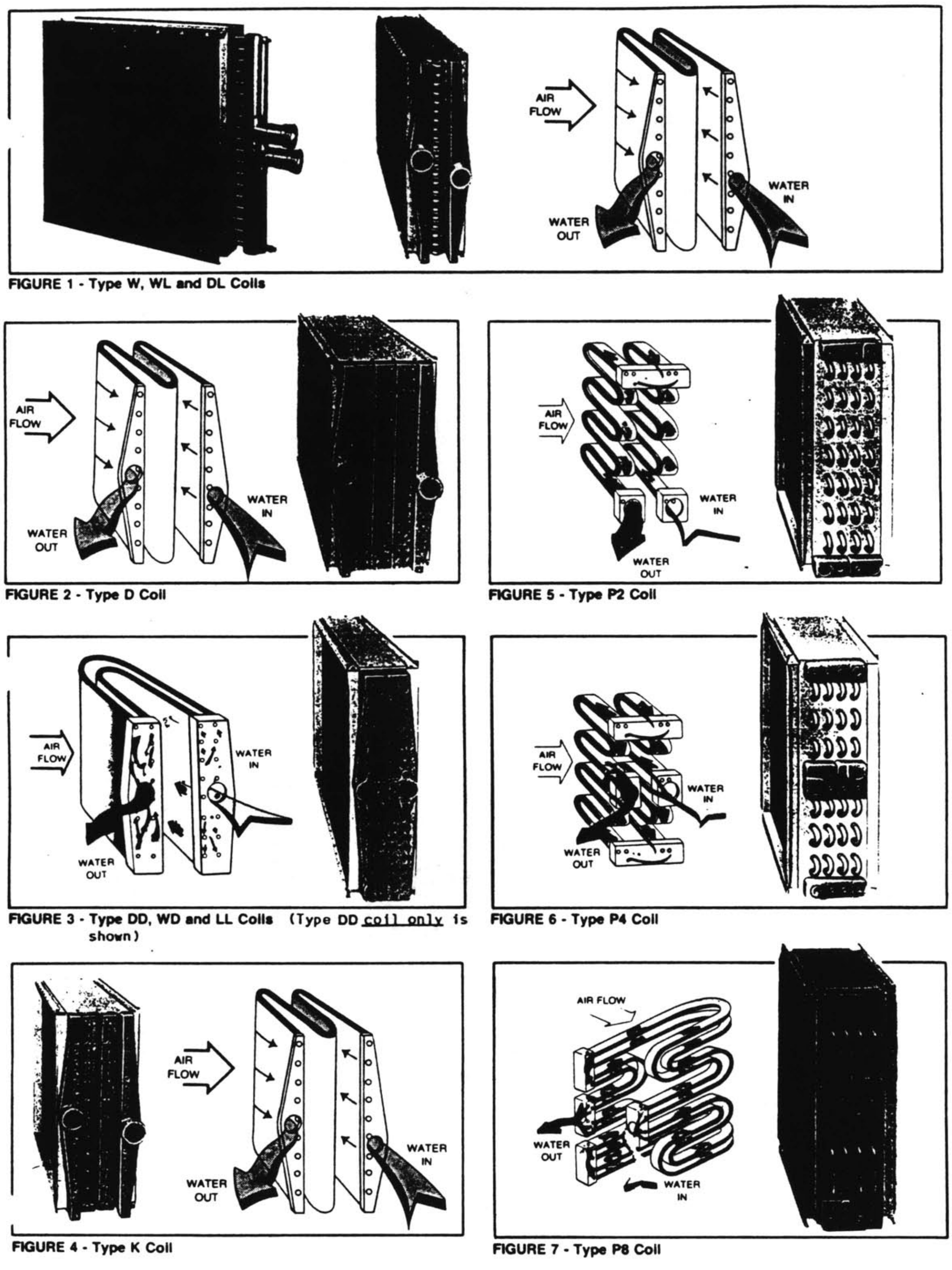

Figure 90: AH1 Cooling Coil Pictorial Representation (Trane: COIL-IM-3A/Jan 85)

TYPE D

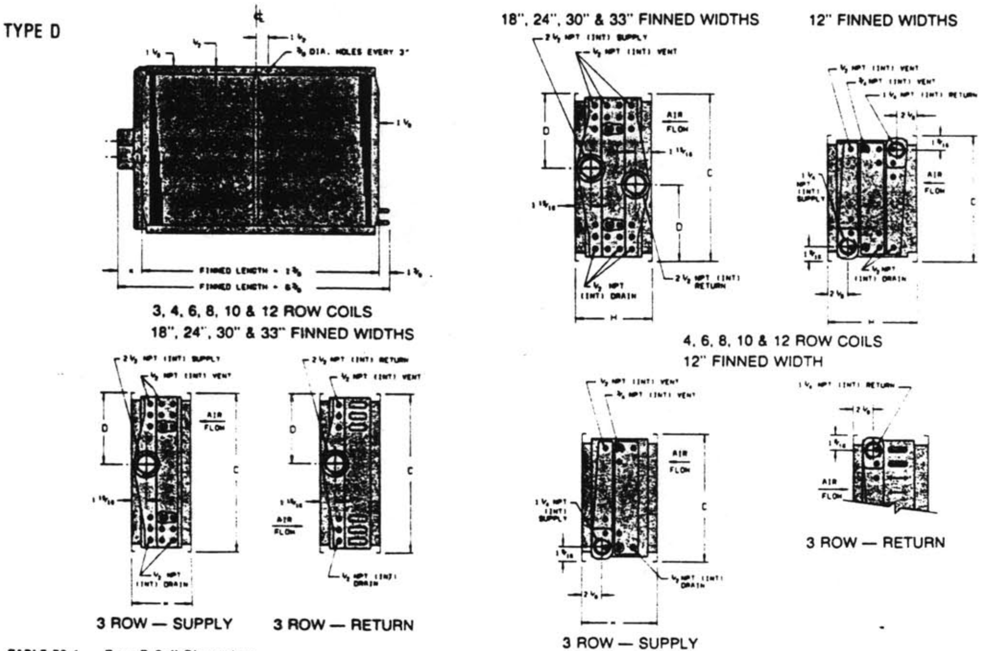

TABLE 59-1 — Type D Coil Dimensions

FINNED WIDTH	C	D	H: 3 ROW	H: 4 ROW	H: 6 ROW	H: 8 ROW	H: 10 ROW	H: 12 ROW	K
12	13½	—	8	9½	12½	15½	18½	21½	2
18	19½	8¼							3³⁄₈
24	25½	11¼							
30	31½	14¼							
33	34½	15¼							

NOTE All dimensions approximate Submittals on request

TYPE DD

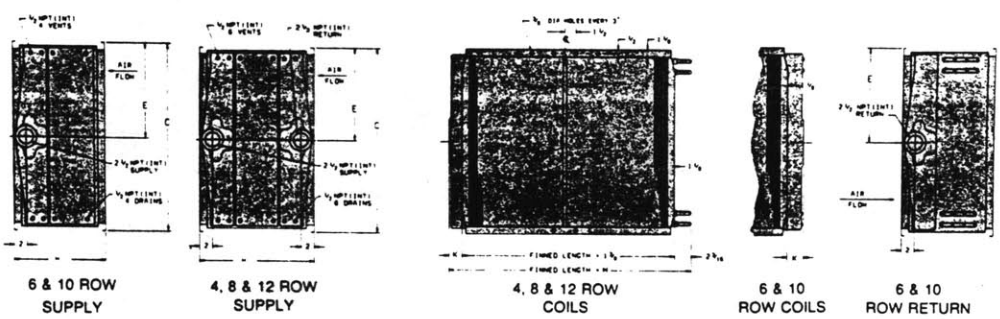

TABLE 59-2 — Type DD Coil Dimensions

FINNED WIDTH	C	E	H: 4 ROW	H: 6 ROW	H: 8 ROW	H: 10 ROW	H: 12 ROW	K	W: 4, 8 & 12 ROW	W: 6 & 10 ROW
18	19½	9¾	9½	12½	15½	18½	21½	2	5⁹⁄₁₆	5³⁄₈
24	25½	12¾								
30	31½	15¾						2¼	5¹³⁄₁₆	5⁷⁄₈
33	34½	17¼								

NOTE All dimensions approximate Submittals on request

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Figure 91: AH1 Cooling Coil Dimensions (Trane: COIL-DS-1/Jun 85)

THE C.D.S. CHILLED WATER COIL SELECTION PROGRAM

For exclusive use by: C.D.S. MARKETING

PROJECT: RESEARCH PROJECT - ASHRAE 825-RP — VERSION:12.12
LOCATION: E51 MECHANICAL ROOM — RUN DATE: 7/24/1995
OWNER: MIT
USER: MARK DESIMONE
COMMENTS: AH1 COIL PARAMETER VARIFICATION

INPUT DATA: ELEVATION: 0. — FOULING FACTOR: .00000

TAG	SCFM	AHU MAX FV	EDB	EWB	EWT	FLUID %	MAX APD	MAX WPD	MAX FPF	TURBS
	18590.	500.0	81.8	62.8	47.0	WATER				Y

STACK QTY	NOMINAL FINNED WIDTH LENGTH	UNIT TYPE	COIL TYPE	ROW	FPF	FIN TYPE	MBH	GPM	WTR	TWT
1 -	30.00 X 120.0	P74L	D		144	SF	·	74.0		.0240
2 -	24.00 X 120.0									
	78.00 X 120.0									

OUTPUT DATA: — DF/TF SF/PF

STANDARD FACE VELOCITY (FT/MIN): 286.0
ACTUAL FACE AREA (SQ.FT.): 65.0

SELECTION RUN:	1	2	3	4	5	6	7	8	9	10
DIAGNOSTIC:										
COIL TYPE:	D	D	D	D	D	D	D	D	D	D
ROWS:	3	3	4	4	6	6	8	8	10	10
FIN TYPE:	SF	SF	SF	SF	SF	SF	SF	SF	SF	SF
FPF:	144	144	144	144	144	144	144	144	144	144
TURBS:	N	Y	N	Y	N	Y	N	Y	N	Y
LDB:	58.2	55.9	55.3	53.3	51.8	50.5	50.3	49.6	49.7	49.2
LWB:	53.9	52.9	52.7	51.8	51.2	50.4	50.2	49.5	49.6	49.1
SENSIBLE MBH:	481.1	528.2	540.6	582.3	612.4	639.0	641.9	655.4	654.3	665.6
TOTAL MBH:	481.1	528.2	540.6	582.3	612.4	651.6	658.2	688.9	686.4	711.7
GPM:	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0
WTR:	13.0	14.3	14.6	15.7	16.6	17.6	17.8	18.6	18.6	19.2
VELOCITY(FT/SEC):	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
APD(IN H2O):	.17	.17	.23	.23	.35	.36	.48	.49	.61	.62
WPD(FT H2O):	1.2	3.3	1.5	4.2	2.2	6.0	2.9	7.8	3.5	9.6
WET WEIGHT-LBS:	-10782	-10767	-846	-826	19094	19123	-26502	-26463	-6562	-6513
VOLUME-GAL:	24.4	24.4	32.3	32.3	48.1	48.1	63.9	63.9	79.7	79.7

REFER TO DIAGNOSTIC PAGE THAT FOLLOWS FOR SELECTION COMMENTS

Figure 92: AH1 Cooling Coil Simulation Performance Report (ref: Trane CDS Marketing)

Bronze Body
Two Way Single Seat
Bronze Trim
3/4"-2" Sizes

- ☐ ideally suited to modulating and on-off service of liquids and gases below 50 psig
- ☐ meets ANSI Class IV shut-off standards (maximum leakage at closure is .01% of full flow)
- ☐ equal percentage flow characteristic provides excellent throttling over wide flow ranges

Specifications

Maximum Service	Steam Differential 50 PSI
	Liquid Differential 50 PSI
	Inlet Temperature 300°F
Body Material	Bronze
Connections	Screwed
Sizes	3/4"-2"
Rating	3/4"-1" ANSI Class 125
	1-1/4"-2" ANSI Class 250
Trim Material	Bronze
Flow Characteristic	Equal %
Rangeability	35:1
Shut Off Rating	ANSI Class IV

Flow Characteristic

Equal percentage is the characteristic most commonly used in process control. The change in flow per unit of valve stroke is directly proportional to the flow occurring just before the change is made. While the flow characteristic of the valve itself may be equal percentage, most control loops will produce an installed characteristic approaching linear when the overall system pressure drop is large relative to that across the valve.

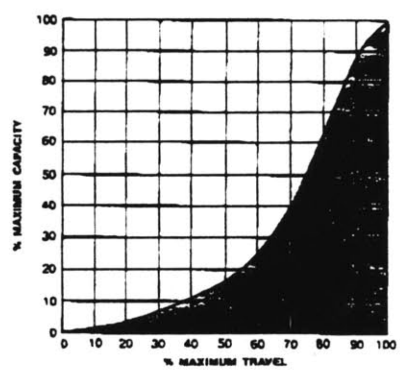


Figure 93: AH1 Cooling Coil Control Valve Specifications (Powers Process Controls)

MCC POWERS

FLOWRITE VF 591-SD

SINGLE SEAT TIGHT CLOSING VALVES
3/4"–2" SCREWED BRONZE VALVE BODIES

Technical Instruction
VF 591-0
January, 1981

FEATURES

MCC Powers Flowrite VF 591-SD Single Seat Valves are designed to provide modulating or 2-position control of steam, hot or chilled water, and other fluids. The design features a high lift stem and a characterized poppet for both high capacity and good modulating control. Teflon-coated asbestos packing facilitates quick response and reduced maintenance.

The unique valve trim design provides an alignment feature which allows close matching of the throttling plug and port for excellent rangeability. A replaceable disc is furnished to provide tight shutoff. The seating design provides controlled compression of the shutoff disc with the additional back-up of metal to metal seating.

Available in normally open (N.O.) or normally closed (N.C.) acting models the valve is furnished with an adjustable actuator, to facilitate sequencing of valve operation, and to obtain maximum close-off ratings. Available options include valve lubricator, and valve positioner.

APPLICATION

Flowrite VF 591-SD single seated valves are generally recommended for steam, hot water and chilled water applications. They are particularly recommended for installations requiring tight shutoff, quick response, and good rangeability. Steam and water convertors, duct heating coils, instantaneous heaters, chilled water control and humidifiers are typical examples of applications for these valves.

SPECIFICATIONS

Physical

Valve sizes	3/4" to 2" NPT
Body material	Bronze
Body rating	150 psi @ 350°F (3/4", 1" sizes) 300 psi @ 350°F (1-1/4", 1-1/2", 2" sizes)
Style	Single seat
Trim	Bronze
Close-off disc	EPT (Standard)
Action	Direct (N.O.) or Reverse (N.C.)
Stroke	3/4" (For 3/4", 1" valves) 1" (For 1-1/4", 1-1/2", 2" valves)
Temp. range	0 - 300°F (-18 to 167°C)(EPT disc)
Spring adj.	2-7 to 9-14 psi, (13.8-48.2; 62-96.5 kPa)
Act. diaphragm area	28 sq. in., (180 cm2)
Operation	Air or water operated
Max. press. at dia.	35 psi, (241 kPa) (air or water)

Operating

Max. inlet pressure.	Water 150 psi @ 350°F (3/4", 1" sizes) 300 psi @ 350°F (1-1/4", 1-1/2", 2" sizes) Steam 50 psig
Flow characteristic	Modified equal percentage
Rangeability	40:1
Hysteresis	0.6 psi, (4.1 kPa)
Rec. max. press. diff.	Water 35 psi, (241 kPa) Steam 50 psig

ACCESSORIES

Valve stem lubricator	No. 590-184A (Water or steam) No. 590-184E (Natural or mfg. gas)
Lub. for stem lubricator	No. 590-166 (water or steam) No. 590-150 (Natural or mfg. gas)
Valve positioner kit	No. 147-277
Positioning Relay	No. 147-2000
Stem pos. indicator	No. 672-137

OPERATION

The actuator spring provides the necessary force to hold the stem in the raised or normal position. [illegible] will start its downward stroke whenever [illegible] air pressure applied against the actuator diaph[illegible] exceeds the holding force of the spring. A further [illegible] in control air pressure will initiate a continued d[illegible] travel of the valve stem until the valve has comp[illegible] The air pressure change to initiate full stem [illegible] as

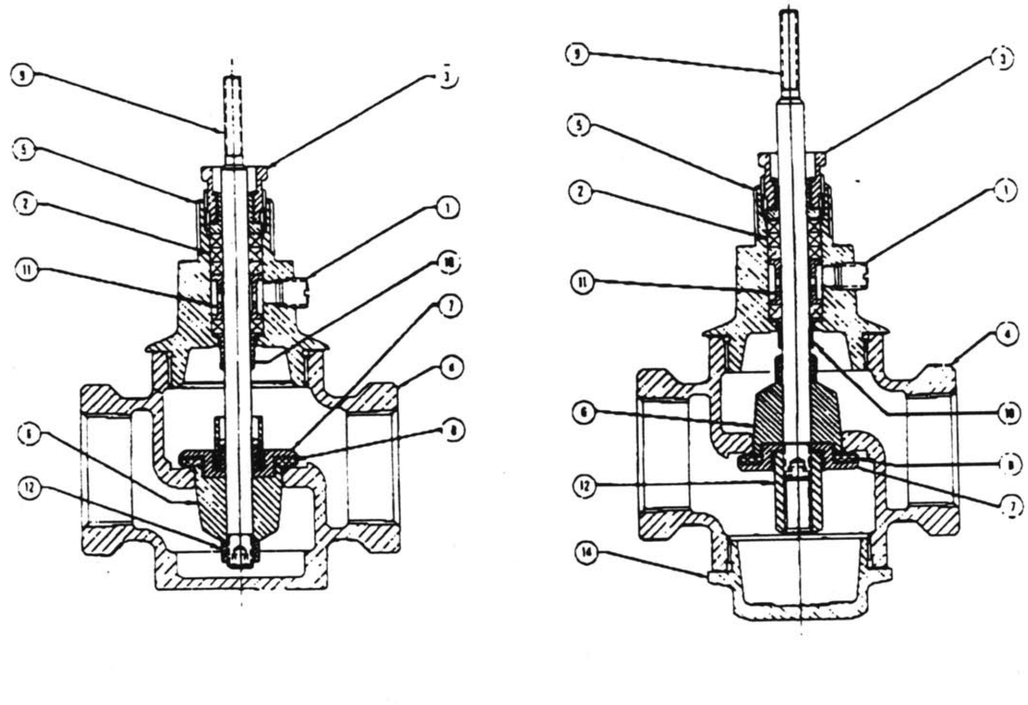
Figure 94: AH1 Cooling Coil Control Valve - Powers Flowrite VF 591-SD

ITEM NO.	DESCRIPTION	TYPE	3/4"	1"	1-1/4"	1-1/2"	2"	NO REQ'D.	MATERIAL
1	Pipe Plug, 1/8"	D.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	Brass
		R.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	Brass
2	Packing Ring	D.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	Teflon
		R.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	Asbestos
3	Packing Gland Assembly	D.A.	[illegible]	[illegible]	591-703	[illegible]	[illegible]	1	Brass
		R.A.	[illegible]	[illegible]	591-703	[illegible]	[illegible]	1	Brass
4	Valve Body	D.A.	591-730	591-731	591-732	591-733	591-734	1	Bronze
		R.A.	591-735	591-736	591-737	591-738	591-739	1	Bronze
5	Bonnet	D.A.	591-760	591-761	591-762	591-763	591-764	1	Bronze
		R.A.	591-760	591-761	591-762	591-763	591-764	1	Bronze
6	Throttling Plug	D.A.	591-765	[illegible]	591-767	[illegible]	[illegible]	1	Brass
		R.A.	591-765	[illegible]	591-767	[illegible]	[illegible]	1	Brass
7	Valve Disc Holder	D.A.	591-770	591-771	591-772	591-773	591-774	1	Brass
		R.A.	591-770	591-771	591-772	591-773	591-774	1	Brass

ITEM NO.	DESCRIPTION	TYPE	3/4"	1"	1-1/4"	1-1/2"	2"	NO. REQ'D.	MATERIAL
8	Valve Disc	D.A.	591-775	591-776	591-777	591-778	591-779	1	EPT
		R.A.	591-775	591-776	591-777	591-778	591-779	1	EPT
9	Valve Stem Assembly	D.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	St. Steel
		R.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	St. Steel
10	Stem Bearing	D.A.	[illegible]	[illegible]	591-797	591-797	591-797	1	Bronze
		R.A.	[illegible]	[illegible]	591-797	591-797	591-797	1	Bronze
11	Packing Spacer	D.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	Brass
		R.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	Brass
12	Nut	D.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	St. Steel
		R.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	St. Steel
13	Stop Sleeve	D.A.	-	-	-	[illegible]	[illegible]	1	Brass
14	Cap	R.A.	[illegible]	[illegible]	591-782	[illegible]	[illegible]	1	Brass

Table 1

See New Manuals for Correct #



DIRECT ACTING VALVE

REVERSE ACTING VALVE

FIGURE 20

3/4" – 2" BRONZE VALVE BODIES

VALVE BODY ASSEMBLIES	PART NUMBERS (By Valve Size)				
	3/4"	1"	1-1/4"	1-1/2"	2"
Direct Acting (N.O.)	591-731	591-732	591-733	591-734	591-735
Reverse Acting (N.C.)	591-741	591-742	591-743	591-744	591-745

Table 2

Figure 95: AH1 Cooling Coil Control Valve - Powers Flowrite VF 591-SD (continued)

SIZING and SELECTION

Application Engineering form AE-1 explains the procedure for proper valve sizing. Steam and water capacity tables and maximum differentials (for close-off) are shown below in Tables 1, 2, and 3.

MAXIMUM WATER CAPACITIES - U.S. GALLONS PER MINUTE

VALVE SIZE (Inches)	PRESSURE DIFFERENTIAL - PSI												
	<=1	2	3	4	5	6	8	10	15	20	25	30	40
3/4"	6	9	10	12	13	15	17	19	23	27	30	33	38
1"	10	14	17	20	22	25	28	32	39	45	50	54	63
1-1/4"	16	23	28	32	36	40	45	51	62	72	80	88	101
1-1/2"	20	29	35	40	45	49	57	63	77	89	100	110	126
2"	38	54	66	76	85	93	107	120	147	170	190	200	260

Table 3

STEAM CAPACITIES - POUNDS PER HOUR

VALVE SIZE (in.)	INLET PRESSURE - PSIG 2		5					10					15				30				60				VALVE SIZE (in.)
	PRESSURE DIFFERENTIAL - PSI 1	2	1	2	3	4	5	2	4	6	8	10	6	8	12	MAX. 15	5	10	15	MAX. 20	10	20	30	MAX 32.5	
3/4	77	100	70	100	130	150	166	123	170	202	220	250	275	294	[illegible]	324	249	332	302	433	430	480	[illegible]	700	3/4
1	119	160	130	163	210	250	775	304	303	330	382	417	376	447	501	540	600	563	663	722	720	883	1107	1177	1
1-1/4	181	288	228	251	351	400	441	371	453	542	611	667	501	719	591	[illegible]	640	[illegible]	1044	1100	1161	1572	1636	1604	1-1/4
1-1/2	230	333	260	303	436	500	601	600	609	678	784	834	763	804	1033	1081	810	1100	1306	1646	1461	1604	2160	2304	1-1/2
2	404	632	404	600	634	880	1047	717	1070	1288	1052	1404	1470	1700	1600	2004	1530	2102	2400	2746	2757	3753	4260	4479	2

Table 4

MAXIMUM PRESSURE DIFFERENTIAL* - PSI FOR CLOSE-OFF

VALVE SIZE (Inches)	NORMALLY OPEN				NORMALLY CLOSED	
	PRESSURE ON DIAPHRAGM					
	25 PSIG		18 PSIG		0 PSIG	
	3-8 Spring	10-15 Spring	3-8 Spring	10-15 Spring	3-8 Spring	10-15 Spring
3/4"	125	125	125	83	83	125
1"	125	125	125	51	51	125
1-1/4"	250	157	157	55	55	157
1-1/2"	207	113	113	25	25	113
2"	120	67	67	15	15	67

* Table values allow 1 psi for packing friction.

Table 5

GRAPH I - TYPICAL FLOW CURVE

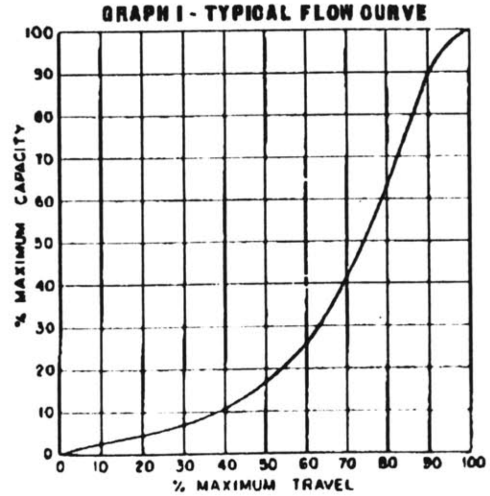


Figure 96: AHI Cooling Coil Control Valve - Powers Flowrite VF 591-SD (continued)

8" DIAMETER FLOWRITE ACTUATORS

ACTUATOR ASSEMBLIES	ACTUATOR ASSEMBLY PART NOS. (By Valve Size)				
	3/4"	1"	1-1/4"	1-1/2"	2"
Adjustable Actuator	672-285	672-285	672-286	672-286	672-286

Table 7

ADJUSTABLE ACTUATOR PARTS				
ITEM NO.	DESCRIPTION	PART NO.	NO. REQ'D.	MATERIAL
1	Drive Screw, No. 2 Type "U" (not shown)	030-939	4	Steel
3	Cap Screw, 3/16"-18x7/8" Lg.	035-129K	6	Steel
4	Hex Nut, 3/16"-18x9/16"	041-131K	6	Steel
6	Spring	672-284	1	Steel
		672-295*	1	Steel
7	Piston Plate & Stem Assembly	672-420	1	Alum.& St.
8	Std. Diaphragm	672-351	1	Syn. Rubber
	Heavy Duty Diaphragm	672-365	1	Syn. Rubber
10	Thrust Bearing Retainer	672-437	1	Steel
10A	Thrust Washer	672-438	2	Steel
11	Upper Housing	672-140	1	Aluminum
12	Lower Housing	672-141	1	Aluminum
13	Lower Housing Extension	672-142	1	Cast Iron
14	Adjustment Screw Assembly	672-145	1	Steel
16	Spring Seat	672-148	1	Steel
17	"Ferry" Cap Screw, 5/16"-18x3/4"	672-376	6	Steel
18NS	Set Screw, 3/16"-18x1"	035-316	1	Steel
19NS	Set Screw Plug	672-136	1	Copper
20	Nut, 1/4"-20x5/16"	041-125	2	Brass

*For 8" Powerstroke valve app, 1" stroke.
NS: Not Shown.

Table 8

PRODUCT NUMBERS (Valve Assembly)

VALVE ASSEMBLY	PRODUCT NUMBERS (By Pipe Size)									
	3/4"		1"		1-1/4"		1-1/2"		2"	
	DA	RA	DA	RA	DA	RA	DA	RA	DA	RA
Adjustable	591-7870	591-7875	591-7871	591-7876	591-7872	591-7877	591-7873	591-7878	591-7874	591-7879

Table 9

Control devices are combined to make a system. Each control device is mechanical in nature and all mechanical components must be regularly serviced to optimize their operation. All MCC Powers branch offices offer service contracts that will insure your continuous, trouble-free system performance.

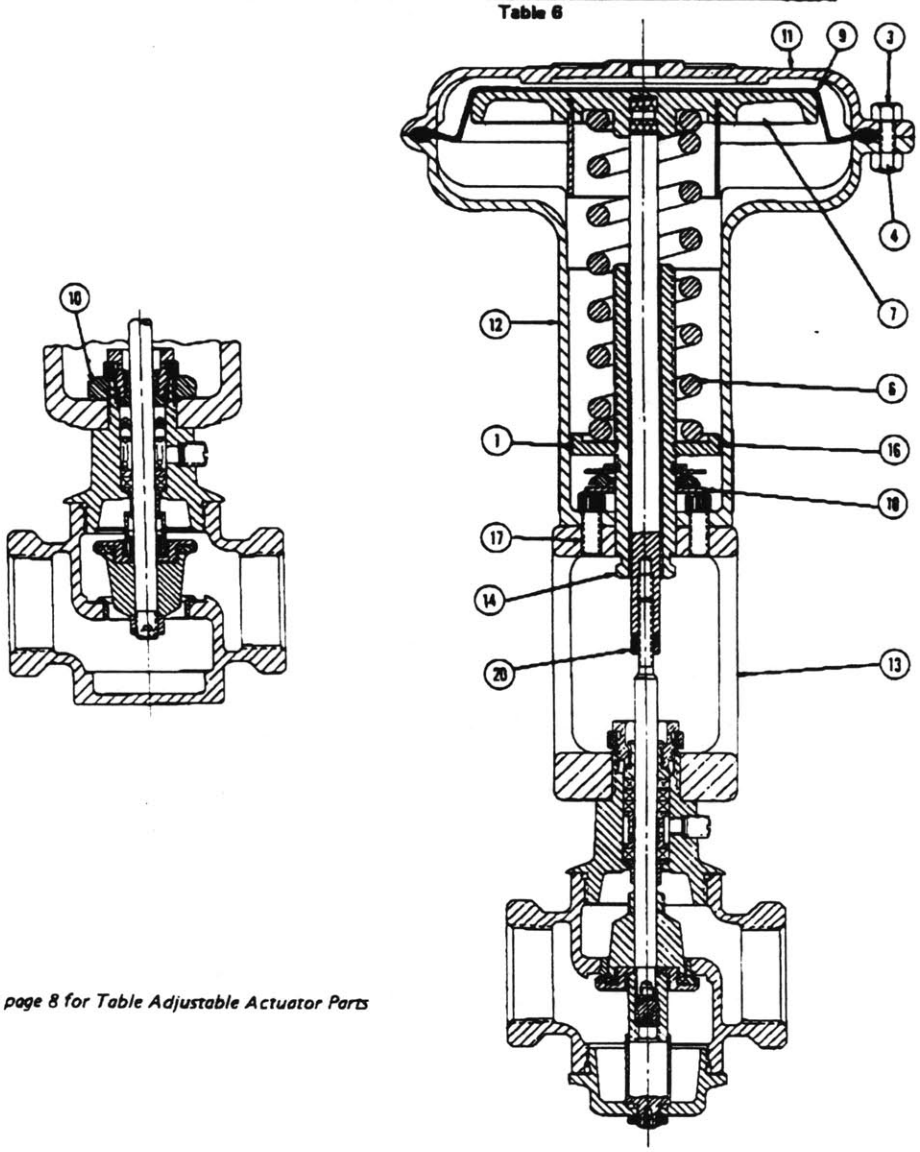
For Further Information Contact Your Nearest MCC Powers Representative

MCC POWERS
A UNIT OF MARK CONTROLS CORPORATION

Figure 97: AH1 Cooling Coil Control Valve - Powers 8" Pneumatic Actuator

VALVE SIZE NPT	DIMENSIONS (inches)					SHIPPING WEIGHT
	A	B	C	D		
				D.A.	R.A.	adj. act.
3/4	8-3/4	15	3-6/16	1-3/8	2	15
1"	8-3/4	15-1/8	3-13/16	1-7/16	2-1/16	18
1-1/4	8-3/4	14-15/16	4-11/16	1-11/16	2-7/16	20
1-1/2	8-3/4	15-11/16	5-1/16	2	2-3/4	21
2"	8-3/4	16	6-1/8	2-7/16	3-1/16	25

Table 6



See page 8 for Table Adjustable Actuator Parts

Figure 98: AH1 Cooling Coil Control Valve - Powers 8" Pneumatic Actuator (continued)

SPECIFICATIONS

Standard features include:

MODELS: 35 lb.-in. torque, SPDT Floating Series 60, Selectable 45°, 60°, and 90° stroke in both CW and CCW directions.

ML6161A—90 second, 7 minute timing models includes auxiliary potentiometer drive for use with field- addable feedback potentiometer. Includes minimum position adjustment set screws for CW or CCW operation. Includes 4074ENH bag assembly.

ML6161B—90 second, 7 minute timing models. Models available with minimum position adjustment set screws.

ELECTRICAL RATINGS:

INPUT VOLTAGE: 24 Vac + 20% - 30% 50/60 Hz.

POWER CURRENT CONSUMPTIONS (MAXIMUM):

ML6161A,B	WATTS	AMP	VA
90 sec / 7 minute	2.0	0.085	2.2

AUXILIARY SWITCH RATINGS: Selective N.O. or N.C. not simultaneous.

PILOT DUTY: 50 VA 24 Vac.

TEMPERATURE RATINGS: Ambient 32° F to 125° F [0° C to 52° C].

Shipping and Storage -20° F to 120° F [-29° C to 49° C].

HUMIDITY RATINGS: 5% to 95% RH Noncondensing.

TORQUE RATINGS:

	TORQUE
Running	35 lb.-in. (4.0 N-m)
Breakaway	35 lb.-in. (4.0 N-m)
Stall	45 lb.-in. (5.0 N-m) minimum
	60 lb.-in. (6.8 N-m) maximum

MOTOR TIMINGS AT 60 Hz (nominal):

90 Second Gear Train
- 90° - 90 sec.
- 60° - 60 sec.
- 45° - 45 sec.

7 Minute Gear Train
- 90° - 7 min.
- 60° - 276 sec.
- 45° - 210 sec.

DAMPER SHAFT MOUNTING:
- Suitable for mounting onto 3/8" to 1/2" square or round damper shafts secured by two 1/8" allen screws.
- Minimum damper shaft length 1 1/2" [35mm - 38mm].
- Motor may be mounted with motor shaft in any position.

APPROVALS: U.L., C. S. A. listing pending.

ACCESSORIES:
- 201052A One Auxiliary Switch.
- 201052B Two Auxiliary Switch.
- 201052C Three Auxiliary Switch.
- 200976A 0 to 500 OHM Auxiliary Potentiometer.
- 4074ENG Bag Assembly - Includes stop pin.
- 4074ENJ Bag Assembly - Includes stop pin, shaft adaptor and min. position screw.
- 4074ENH Bag Assembly - Includes stop pin and shaft adaptor.
- 4074ENF Bag Assembly - Includes shaft adaptor.
- 4074ENK Bag Assembly - Includes 1/4" minimum position screw.

(continued on page 3)

ORDERING INFORMATION

WHEN PURCHASING REPLACEMENT AND MODERNIZATION PRODUCTS FROM YOUR AUTHORIZED DISTRIBUTOR, REFER TO THE TRADELINE CATALOG OR PRICE SHEETS FOR COMPLETE ORDERING NUMBER.

IF YOU HAVE ADDITIONAL QUESTIONS, NEED FURTHER INFORMATION, OR WOULD LIKE TO COMMENT ON OUR PRODUCTS OR SERVICES, PLEASE WRITE OR PHONE:

1. YOUR LOCAL HONEYWELL BUILDING CONTROLS DIVISION SALES OFFICE (CHECK WHITE PAGES OF YOUR PHONE DIRECTORY).
2. BUILDING CONTROLS DIVISION CUSTOMER SERVICE
   HONEYWELL INC., 1985 DOUGLAS DRIVE NORTH
   MINNEAPOLIS, MINNESOTA 55422-4386 (612)542-7500

(IN CANADA—HONEYWELL LIMITED/HONEYWELL LIMITEE, 740 ELLESMERE ROAD, SCARBOROUGH, ONTARIO M1P 2V9) INTERNATIONAL SALES AND SERVICE OFFICES IN ALL PRINCIPAL CITIES OF THE WORLD.

Figure 99: AH1 Cooling Coil Control Valve - Honeywell Direct Coupled Actuator ML6161

Appendix K - RF1: Trane Centrifugal Fan FAN-IM-4

TRANE® AIR CONDITIONING

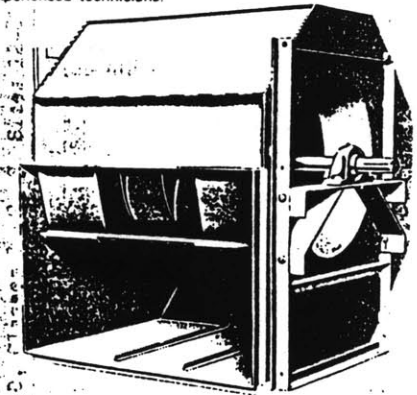
FILE:
TRANE AIR HANDLING PRODUCTS
FANS
Installation-Maintenance

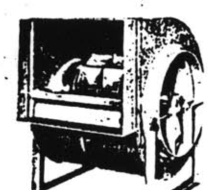
LITERATURE FILE NO.

FAN-IM-4

INST.-MAIN.

JUNE, 197
SUPERSEDES FAN-IM-
DATED OCTOBER, 197





CENTRIFUGAL FANS

SIZES 12-89

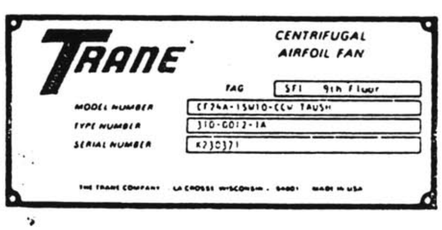
IMPORTANT

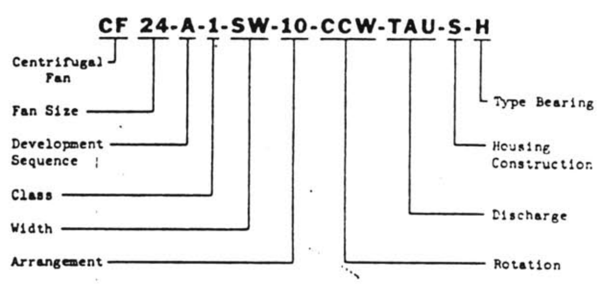
Trane Centrifugal Fans are dynamically balanced, inspected for proper alignment and lubricated before leaving the factory. These procedures, however, do not guarantee that the fan will be ready to operate upon receipt at the jobsite. Damage and misalignment, both obvious and hidden, can occur due to rough handling during shipment and installation. It is, therefore, important that the inspection and installation procedures outlined in this manual be followed carefully to assure a successful installation. Failure to do so may also void the unit warranty.

This manual should be retained with the fan because it contains the information necessary for proper maintenance procedures.

Before setting fans in place, check the tagging information for proper location of equipment. This data is given on the nameplate attached to each fan housing (see example given below). On

FAN NAMEPLATE AND MODEL NUMBER EXAMPLE



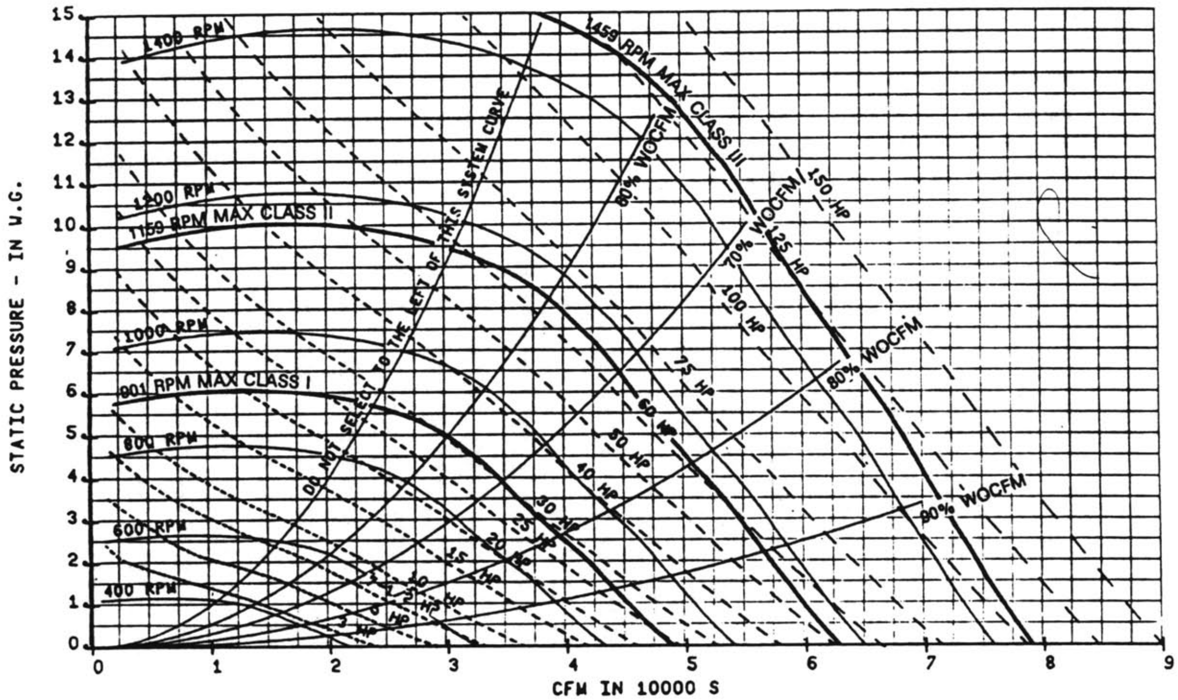


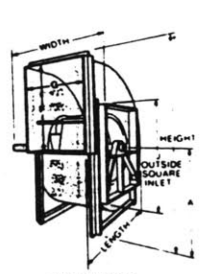
COMMERCIAL AIR CONDITIONING DIVISION
LACROSSE, WISCONSIN 54601
PRINTED IN U.S.A.

Figure 100: RF1 Trane Centrifugal Fan Nameplate Data Guide

Fan Curve
Roughing-in Dimensions

44 AFSW





ARRANGEMENT 3

ARRANGEMENT 9 LESS MOTOR AND DRIVE AND ARRANGEMENT 1

ARRANGEMENT 10

W												
CLASS I	ARR 1	ARR 3	ARR 9	ARR 10	CLASS II	ARR 1	ARR 3	ARR 9	ARR 10	CLASS III	ARR 3
	81⅜	54½	81⅜	86 3/16		82⅜	56½	82⅜	86 3/16		58 15/16

CLASS I & II (Arrangements 1, 9 & 10)

A								J	H								L								F		G	
TH	BH	UB	DB	TAU	TAD	BAU	BAD	ALL	TH	BH	UB	DB	TAU	TAD	BAU	BAD	TH	BH	UB	DB	TAU	TAD	BAU	BAD	ALL BUT TAU TAD BAU	TAU TAD BAU	ALL BUT DB BAD	DB BAD
37½	59¼	46¼	36	41½	33½	51½	29½	50	94⅜	95⅛	79¼	80 13/16	110⅝	83 1/16	83½	69 1/16	77 13/16	77 13/16	93	93	81 15/16	109 1/16	109 1/16	81 15/16	55 5/16	55½	35¾	35⅜

CLASS I & II (Arrangement 3)

A								J	H								L								F		G	
TH	BH	UB	DB	TAU	TAD	BAU	BAD	ALL	TH	BH	UB	DB	TAU	TAD	BAU	BAD	TH	BH	UB	DB	TAU	TAD	BAU	BAD	ALL BUT TAU TAD BAU	TAU TAD BAU	ALL BUT DB BAD	DB BAD
37½	59¼	46¼	36	41½	33½	51½	29½	50	94⅜	95⅛	79¼	80 13/16	110⅝	83 1/16	83½	69 1/16	77 13/16	77 13/16	93	93	81 15/16	109 1/16	109 1/16	81 15/16	55 5/16	55½	35¾	35⅜

[illegible]

A								J	H								L								F	G
TH	BH	UB	DB	TAU	TAD	BAU	BAD	ALL	TH	BH	UB	DB	TAU	TAD	BAU	BAD	TH	BH	UB	DB	TAU	TAD	BAU	BAD	ALL	ALL
37½	59¼	46¼	36	41½	36½	51½	29½	50	95⅝	95⅛	79¼	80 13/16	112⅝	86 5/16	83 1/16	69	77 13/16	77 13/16	94	94	82	110⅝	110⅝	82	55 1/16	35⅜

Due to Trane's policy of continuous product development, dimensions are subject to change
For complete dimension data, refer to the applicable submittal drawing

TRANE AIR CONDITIONING

Figure 101: Trane 44 AFSW Fan Curves - w/o Inlet Vanes (ref: Trane FAN-DS-6)

44 AFSW

Fan Performance Tables

Wheel diameter, 44½ inches
Outlet area, 13.48 square feet
Blast area, 11.15 square feet
Tip speed, FPM = 11.67 × RPM

Check motor starting torque for motors less than 3 HP. (see Page 14)

Pressure class limits:

Class	Maximum RPM
I	901
II	1159
III	1459

CFM STD. AIR	OUTLET VEL.	¼" RPM	¼" BHP	½" RPM	½" BHP	¾" RPM	¾" BHP	1" RPM	1" BHP	1¼" RPM	1¼" BHP	1½" RPM	1½" BHP	1¾" RPM	1¾" BHP	2" RPM	2" BHP	2¼" RPM	2¼" BHP	2½" RPM	2½" BHP	2¾" RPM	2¾" BHP	3" RPM	3" BHP
12000	890					357	1.9	391	2.4	428	3.0	465	3.7												
13500	1001					374	2.2	406	2.8	438	3.4	471	4.1	505	4.9										
15000	1112			360	2.0	392	2.5	424	3.2	451	3.8	481	4.5	513	5.3	542	6.1	571	7.0						
16500	1224			383	2.3	414	2.9	442	3.6	470	4.3	495	5.0	523	5.8	550	6.6	576	7.4	602	8.3	628	9.3		
18000	1335	368	1.9	404	2.7	435	3.4	463	4.1	488	4.8	514	5.7	537	6.4	562	7.2	585	8.0	611	9.0	634	9.9	659	10.9
19500	1446	393	2.3	427	3.1	458	3.9	484	4.7	509	5.4	532	6.3	556	7.1	576	7.9	599	8.8	621	9.7	644	10.7	667	11.7
21000	1557	420	2.8	451	3.6	479	4.4	505	5.3	530	6.1	552	7.0	573	7.8	595	8.7	614	9.6	635	10.5	656	11.5	677	12.5
22500	1669	447	3.3	475	4.1	502	5.0	529	6.0	551	6.9	574	7.7	593	8.6	613	9.5	634	10.5	651	11.5	671	12.5	691	13.5
24000	1780	474	3.9	503	4.8	526	5.7	551	6.7	573	7.7	596	8.6	616	9.5	633	10.5	652	11.5	671	12.5	690	13.6	706	14.6
25500	1891	500	4.5	529	5.5	551	6.5	574	7.5	599	8.6	619	9.5	638	10.5	656	11.5	672	12.5	690	13.6	708	14.7	726	15.8
27000	2002	527	5.1	554	6.2	575	7.3	597	8.3	621	9.4	641	10.5	661	11.6	679	12.7	695	13.7	711	14.8	727	15.9	744	17.0
28500	2114	553	5.8	579	7.0	600	8.1	621	9.2	643	10.4	665	11.6	682	12.7	701	13.9	718	15.0	734	16.1	748	17.2	763	18.4
30000	2225	580	6.7	604	8.0	627	9.2	645	10.3	665	11.5	686	12.7	707	14.0	722	15.1	740	16.4	757	17.6	771	18.6	785	19.8
31500	2336	607	7.7	630	9.0	652	10.3	670	11.4	688	12.6	708	13.9	728	15.2	748	16.6	762	17.7	779	19.0	794	20.3	808	21.4
33000	2448	634	8.7	655	10.0	677	11.4	694	12.6	713	13.9	730	15.2	750	16.5	769	17.9	784	19.2	800	20.6	816	21.9	831	23.2
34500	2559	660	9.8	681	11.2	702	12.6	722	14.1	737	15.2	754	16.6	772	18.0	791	19.4	809	20.9	822	22.2	838	23.6	853	25.0
36000	2670	687	11.0	707	12.5	727	14.0	746	15.5	761	16.7	778	18.1	794	19.5	812	21.0	830	22.5	847	24.0	859	25.3	874	26.8
37500	2781	714	12.3	734	13.8	753	15.4	771	17.0	789	18.5	803	19.7	818	21.2	835	22.7	852	24.2	868	25.8	885	27.4	896	28.7
39000	2893	741	13.8	760	15.3	778	16.9	796	18.5	814	20.2	827	21.4	843	23.0	856	24.4	874	26.0	890	27.7	906	29.3	922	31.0
40500	3004	768	15.3	787	16.9	804	18.5	822	20.2	839	21.9	852	23.3	867	24.8	881	26.4	896	28.0	912	29.6	928	31.3	943	33.1
42000	3115	795	16.9	813	18.6	830	20.3	847	22.0	864	23.8	880	25.5	891	26.8	906	28.5	919	30.1	935	31.8	949	33.5	964	35.2
43500	3227	822	18.7	840	20.4	856	22.1	873	23.9	889	25.8	904	27.6	916	29.0	930	30.6	944	32.3	956	33.9	972	35.8	986	37.6
45000	3338	849	20.5	867	22.3	882	24.1	898	26.0	914	27.8	929	29.7	944	31.6	954	32.9	968	34.7	981	36.4	993	38.1	1009	40.0
46500	3449	877	22.5	893	24.4	909	26.2	924	28.1	939	30.1	954	32.0	969	33.9	979	35.4	992	37.2	1005	39.0	1017	40.7	1030	42.6

CFM STD. AIR	OUTLET VEL.	3" RPM	3" BHP	3½" RPM	3½" BHP	4" RPM	4" BHP	4½" RPM	4½" BHP	5" RPM	5" BHP	5½" RPM	5½" BHP	6" RPM	6" BHP	6½" RPM	6½" BHP	7" RPM	7" BHP	7½" RPM	7½" BHP	8" RPM	8" BHP	8½" RPM	8½" BHP
20000	1483	670	12.0	714	14.0	758	16.3																		
21500	1594	681	12.8	723	15.0	764	17.2	805	19.6																
23000	1706	695	13.9	734	16.0	773	18.4	811	20.6	849	23.2	887	25.9												
24500	1817	712	15.0	748	17.2	784	19.5	821	22.0	856	24.4	892	27.1	928	29.9										
26000	1928	732	16.2	763	18.5	798	20.8	832	23.3	866	25.9	902	28.7	934	31.2	968	34.2	1001	37.2						
27500	2040	750	17.4	784	19.9	813	22.2	845	24.7	877	27.4	910	30.1	944	33.1	974	35.7	1006	38.7	1038	41.9				
29000	2151	770	18.8	801	21.3	833	23.9	860	26.4	891	29.0	922	31.8	952	34.6	984	37.7	1013	40.4	1043	43.5	1074	46.8	1105	50.2
30500	2262	793	20.3	820	22.9	851	25.5	880	28.2	906	30.8	935	33.6	964	36.5	993	39.4	1024	42.6	1054	45.9	1080	48.7	1109	52.0
32000	2373	815	22.0	842	24.5	869	27.1	898	30.0	926	32.8	950	35.5	978	38.4	1006	41.5	1033	44.6	1062	47.8	1091	51.2	1116	54.1
33500	2485	837	23.8	865	26.3	889	29.0	916	31.8	944	34.8	971	37.8	994	40.6	1020	43.6	1047	46.8	1073	50.0	1099	53.3	1127	56.9
35000	2596	860	25.6	887	28.4	912	31.0	936	33.9	962	36.8	989	39.9	1014	43.1	1035	46.0	1061	49.1	1086	52.4	1112	55.8	1137	59.2
36500	2707	881	27.5	909	30.4	935	33.2	958	36.1	981	39.1	1006	42.2	1032	45.4	1056	48.7	1076	51.7	1101	55.0	1125	58.4	1150	61.8
38000	2818	903	29.4	932	32.5	958	35.6	981	38.4	1002	41.4	1025	44.5	1050	47.8	1074	51.2	1098	54.6	1117	57.8	1140	61.2	[illegible]	[illegible]
39500	2930	929	31.7	953	34.7	980	38.0	1004	40.9	1025	44.0	1046	47.1	1068	50.4	1092	53.8	1116	57.4	1138	60.9	1156	64.1	[illegible]	[illegible]
41000	3041	950	33.8	975	37.0	1001	40.4	1025	43.6	1048	46.7	1068	49.9	1089	53.2	1111	56.6	1133	60.2	1156	63.8	[illegible]	[illegible]	[illegible]	[illegible]
42500	3152	972	36.0	1001	39.7	1022	42.8	1048	46.4	1071	49.8	1091	52.9	1111	56.2	1131	59.7	1152	63.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44000	3264	994	38.4	1022	42.1	1045	45.5	1070	49.1	1093	52.7	1114	56.1	1134	59.4	1153	62.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45500	3375	1016	40.9	1044	44.7	1071	48.6	1090	51.9	1115	55.7	1136	59.3	1157	62.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47000	3486	1038	43.5	1066	47.4	1092	51.3	1119	55.5	1136	58.8	1159	62.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
48500	3597	1062	46.3	1088	50.2	1114	54.3	1140	58.5	1157	62.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50000	3709	1086	49.3	1109	53.1	1136	57.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
51500	3820	1111	52.5	1132	56.2	1157	60.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

CFM STD. AIR	OUTLET VEL.	8½" RPM	8½" BHP	9" RPM	9" BHP	9½" RPM	9½" BHP	10" RPM	10" BHP	10½" RPM	10½" BHP	11" RPM	11" BHP	11½" RPM	11½" BHP	12" RPM	12" BHP	12½" RPM	12½" BHP	13" RPM	13" BHP	13½" RPM	13½" BHP	14" RPM	14" BHP
30000	2225	1107	51.4	1137	54.9																				
31500	2336	1114	53.4	1142	56.9																				
33000	2448	1125	56.1	1149	59.1																				
34500	2559	1133	58.3																						
36000	2670	1145	60.9																						
37500	2781	1159	63.7																						
39000	2893																								
40500	3004																								
42000	3115																								
43500	3227																								
45000	3338																								
46500	3449																								
48000	3560																								
49500	3672																								

Performance based on 0.075 lbs. per cubic foot density (Air at 70F and 29.92" Hg Bar.)

The test result on which these ratings are based were obtained from test of Arrangement 1 AFSW fans. Performance shown is for AFSW fans with outlet duct. BHP does not include drive losses.

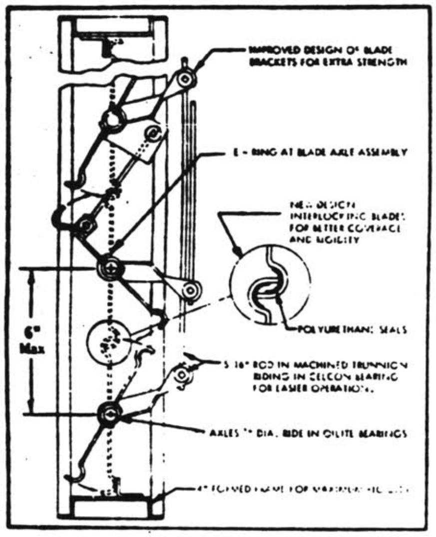
Figure 102: Trane 44 AFSW Fan RPM Tables - w/o Inlet Vanes (ref: Trane FAN-DS-6)

Appendix L - Mixing Box: Dampers and Actuators

ARROW STEEL CONTROL DAMPERS SERIES 1770

A More Efficient Damper at Lower Cost

PARALLEL OR OPPOSED BLADES WITH SEALS OR NO SEALS



1772-OB — OPPOSED BLADES

OPTIONAL FEATURES:

2 Blades on Dampers 10" h to 13 5/8" h. Opposed action only.

DRIVESHAFTS:
- A. Extendable to 8" beyond frame.
- B. More than 8", using exterior bearing support.
- C. Stainless steel.

FLANGE FRAMES

WIDER FRAMES: Frames wider than 4".

AXLES: Stainless Steel.

SEALS: Also available with Neoprene Side and Blade Seals; Stainless Steel Side Seals.

LINKAGE: Stainless steel.

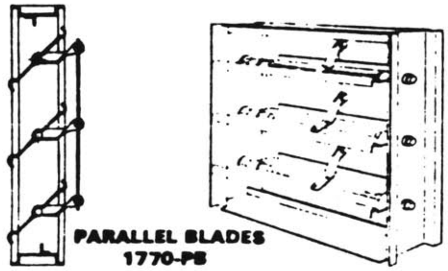
MOTOR MOUNTING BRACKETS: For all internally mounted pneumatic or electric operators. Specify type and N.O. or N.C.

BEARINGS: Oilite thrust, Nylon, Ball, etc.

MIXING/FACE & BYPASS Dampers.

JACKSHAFTING:

UNION MADE



PARALLEL BLADES 1770-PB

SPECIFICATIONS

FRAME: 4" wide, 16 ga. galv. Hat Shaped channel provides greater rigidity and strength.

BLADES: Maximum 6" spacing. 16 ga. galv. new design for more strength and overlap coverage. Max. length 48".

LINKAGE: Type GS - 92 formed brackets of 1/8" steel, Cadmium plated.

BEARINGS: Oilite Bronze.

AXLES: ½" Dia. C.R. Cad. plated steel.

DRIVE SHAFT: ½" Dia. cadmium plated; extendable 6" beyond frame.

SEALS: Blade and Jamb of polyurethane.

SIZES: Made to exact size as required.
Max. Panel: 48" w x 96" h.
Min. Panel: 6" w x 5" h.

Dampers less than 9" h made with ½" x 3" x ½" channel frame.

Dampers under 13 5/8" h will be made with one blade as standard. See "Options"

Note: Series 1770 dampers are rated for systems up to 2,000 fpm or up to 4" s.p. If being used for applications beyond this, please advise when ordering.

SHIPPING WEIGHT: 6½ lbs. per sq. ft.

SEE OTHER SIDE FOR SUBMITTAL SHEET AND DAMPER ORDER FORM

ARROW UNITED INDUSTRIES, Inc.
WYALUSING, PA 18853 (717) 746 1000
Contact Sales Offices Below

ARROW LOUVER AND DAMPER CORP.
707 CONCOURSE VILLAGE W., BRONX, N.Y 10451
(212) 993 3880

15900-2

#463-1-K

Leakage

HEIGHT	12"
12"	.5
18"	.5
24"	.4
30"	.4
36"	.4
42"	.4
48"	.4
54"	.4
60"	.4
66"	.4
72"	.4
76"	.4
80"	.4

HEIGHT	12
12"	.6
18"	.6
24"	.5
30"	.5
36"	.5
42"	.5
48"	.5
54"	.5
60"	.5
66"	.5
72"	.5
76"	.5
80"	.5

HEIGHT	12
12"	.7
18"	.7
24"	.6
30"	.6
36"	.6
42"	.6
48"	.6
54"	.6
60"	.6
66"	.6
72"	.6
76"	.6
80"	.6

Figure 103: Mixing Box Damper Blade Pictorial (Arrow Steel Dampers - Series 1770)

A

LEAKAGE - ARROW 1770 STEEL DAMPERS

1770 SERIES STEEL DAMPERS WITH SIDE & BLADE SEALS

TABLES SHOW PERCENTAGE AND CFM TOTAL LEAKAGE AT 2000 FPM

Leakage by Percentage | Leakage by CFM

1" w.g. static pressure

Leakage by Percentage

Height \ Width	12"	18"	24"	30"	36"	42"	48"
12"	.5	.5	.5	.4	.4	.4	.4
18"	.5	.4	.4	.4	.4	.4	.4
24"	.4	.4	.4	.4	.4	.4	.4
30"	.4	.4	.4	.4	.4	.4	.4
36"	.4	.4	.4	.4	.4	.4	.4
42"	.4	.4	.4	.4	.4	.4	.4
48"	.4	.4	.4	.4	.4	.4	.4
54"	.4	.4	.4	.4	.4	.4	.4
60"	.4	.4	.4	.4	.4	.4	.4
66"	.4	.4	.4	.4	.4	.4	.4
72"	.4	.4	.4	.4	.4	.4	.4
76"	.4	.4	.4	.4	.4	.4	.4
80"	.4	.4	.4	.5	.4	.4	.4

Leakage by CFM

Height \ Width	12"	18"	24"	30"	36"	42"	48"
12"	10	15	20	20	24	28	32
18"	15	18	24	30	36	42	48
24"	16	24	32	40	48	56	64
30"	20	30	40	50	60	70	80
36"	24	36	48	60	72	84	96
42"	28	42	56	70	84	98	112
48"	32	48	64	80	96	112	128
54"	36	54	72	90	108	126	144
60"	40	60	80	100	120	140	160
66"	44	66	88	110	132	154	176
72"	48	72	96	120	144	168	192
76"	52	78	104	130	156	184	208
80"	56	84	112	145	168	200	224

2" w.g. static pressure

Leakage by Percentage

Height \ Width	12"	18"	24"	30"	36"	42"	48"
12"	.6	.6	.6	.5	.5	.5	.5
18"	.6	.5	.5	.5	.5	.5	.5
24"	.5	.5	.5	.5	.5	.5	.5
30"	.5	.5	.5	.5	.5	.5	.5
36"	.5	.5	.5	.5	.5	.5	.5
42"	.5	.5	.5	.5	.5	.5	.5
48"	.5	.5	.5	.5	.5	.5	.5
54"	.5	.5	.5	.5	.5	.5	.5
60"	.5	.5	.5	.5	.5	.5	.5
66"	.5	.5	.5	.5	.5	.5	.5
72"	.5	.5	.5	.5	.5	.5	.5
76"	.5	.5	.5	.5	.5	.5	.5
80"	.5	.5	.5	.6	.5	.5	.5

Leakage by CFM

Height \ Width	12"	18"	24"	30"	36"	42"	48"
12"	12	18	24	25	30	35	40
18"	18	23	30	38	45	53	60
24"	20	30	48	50	60	70	80
30"	25	38	50	63	75	88	100
36"	30	45	60	75	90	105	120
42"	35	53	70	88	105	123	140
48"	40	60	80	100	120	140	160
54"	45	68	90	113	135	158	180
60"	50	75	100	125	150	175	200
66"	55	83	110	138	165	193	220
72"	60	90	120	150	180	210	240
76"	64	95	127	160	190	222	253
80"	66	100	134	200	200	233	267

4" w.g. static pressure

Leakage by Percentage

Height \ Width	12"	18"	24"	30"	36"	42"	48"
12"	.7	.7	.7	.6	.6	.6	.6
18"	.7	.6	.6	.6	.6	.6	.6
24"	.6	.6	.6	.6	.6	.6	.6
30"	.6	.6	.6	.6	.6	.6	.6
36"	.6	.6	.6	.6	.6	.6	.6
42"	.6	.6	.6	.6	.6	.6	.6
48"	.6	.6	.6	.6	.6	.6	.6
54"	.6	.6	.6	.6	.6	.6	.6
60"	.6	.6	.6	.6	.6	.6	.6
66"	.6	.6	.6	.6	.6	.6	.6
72"	.6	.6	.6	.6	.6	.6	.6
76"	.6	.6	.6	.6	.6	.6	.6
80"	.6	.6	.6	.6	.6	.6	.6

Leakage by CFM

Height \ Width	12"	18"	24"	30"	36"	42"	48"
12"	14	21	28	30	36	42	48
18"	21	27	36	45	54	63	72
24"	24	36	48	60	72	84	96
30"	30	45	60	75	90	105	120
36"	36	54	72	90	108	126	144
42"	42	63	84	105	126	147	168
48"	48	72	96	120	144	168	192
54"	54	81	108	135	162	189	216
60"	60	90	120	150	180	210	240
66"	66	99	132	165	198	231	264
72"	72	108	144	180	216	252	288
76"	78	117	156	195	234	273	312
80"	84	126	168	210	252	294	336

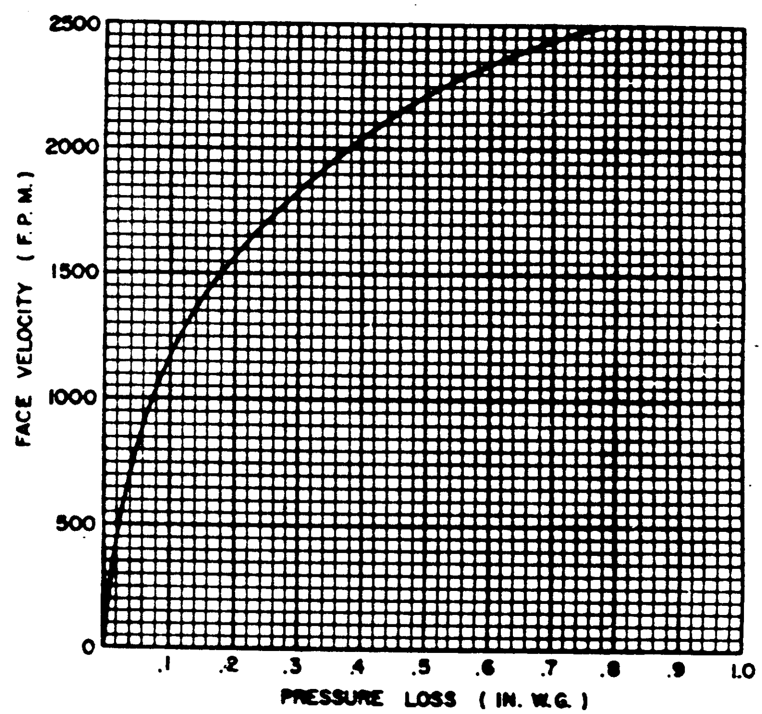
FACE VELOCITY (F.P.M.)

Figure 104: Mixing Box Damper Performance Data (Arrow Steel Damper Series 1770)

ARROW STEEL CONTROL DAMPERS – SERIES 1770

PERFORMANCE DATA

PRESSURE LOSS VS. FACE VELOCITY



PRESSURE DROP CHART

ARROW UNITED INDUSTRIES, Inc.
WYALUSING, PA 18853 (717) 746 1888

ARROW LOUVER AND DAMPER CORP.
787 CONCOURSE VILLAGE W., BRONX, N.Y. 10451

AGENT ____________________

#593

Figure 105: Mixing Box Damper Leakage Rates (Arrow Steel Dampers - Series 1770)

Appendix M - Intake & Exhaust Grills and Louvers

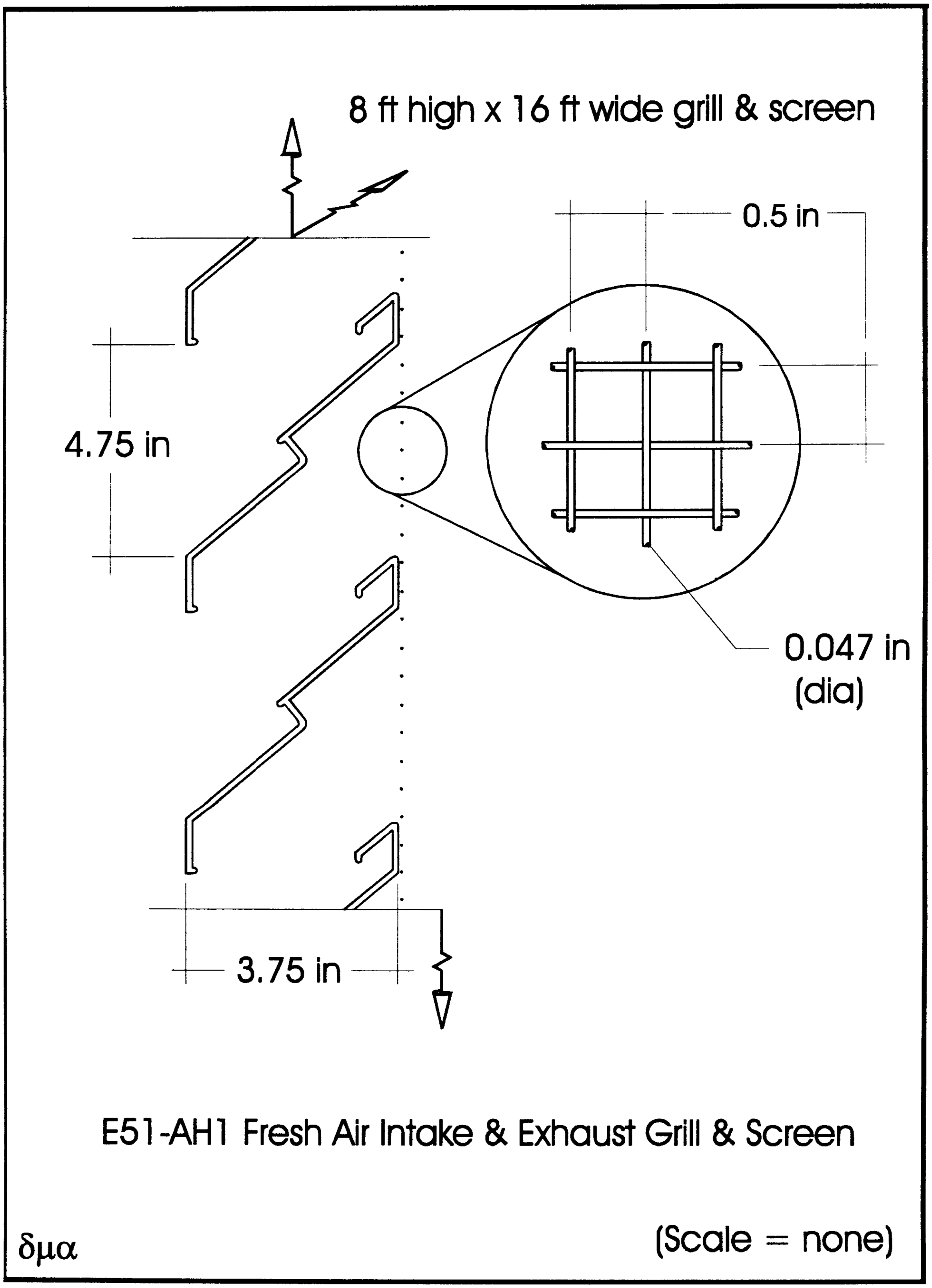


Figure 106: Louver - Fresh Air Intake and Spent Air Exhaust

638-C-100
(5" blade centers)

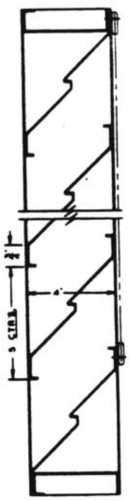
FREE AREA IN SQUARE FEET

WIDTH (INCHES)

HEIGHT (INCHES)	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72
20	.43	.62	.80	.99	1.18	1.37	1.56	1.75	1.94	2.13	2.32	2.51	2.70	2.89	3.07	3.26
28	.61	.88	1.15	1.42	1.69	1.96	2.23	2.50	2.77	3.04	3.31	3.58	3.85	4.12	4.39	4.66
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	.85	1.23	1.61	1.99	2.37	2.74	3.12	3.50	3.88	4.26	4.64	5.01	5.39	5.77	6.15	6.53
44	1.10	1.58	2.07	2.56	3.05	3.53	4.02	4.51	4.99	5.48	5.97	6.46	6.94	7.43	7.92	8.41
52	1.28	1.84	2.41	2.98	3.55	4.11	4.68	5.25	5.82	6.38	6.95	7.52	8.09	8.65	9.22	9.79
60	1.56	2.25	2.95	3.64	4.34	5.03	5.72	6.42	7.11	7.80	8.50	9.19	9.88	10.58	11.27	11.97
68	1.74	2.52	3.29	4.07	4.84	5.62	6.39	7.17	7.94	8.72	9.49	10.27	11.04	11.82	12.59	13.34
76	1.99	2.87	3.75	4.64	5.52	6.40	7.28	8.17	9.05	9.93	10.81	11.70	12.58	13.46	14.35	15.23
84	2.23	3.22	4.22	5.21	6.20	7.19	8.18	9.17	10.17	11.16	12.15	13.14	14.13	15.12	16.12	17.11
92	2.41	3.48	4.56	5.63	6.70	7.77	8.84	9.92	10.99	12.06	13.13	14.20	15.28	16.35	17.42	18.49
100	2.70	3.89	5.09	6.29	7.49	8.69	9.88	11.08	12.28	13.48	14.68	15.87	17.07	18.27	19.47	20.67
108	2.88	4.16	5.44	6.72	8.00	9.27	10.55	11.83	13.11	14.39	15.67	16.95	18.23	19.51	20.79	22.07
116	3.12	4.51	5.90	7.28	8.67	10.06	11.45	12.83	14.22	15.61	16.99	18.38	19.77	21.16	22.54	23.93

Chart 1

16 x 2



TYPE 638-C-100
(5" blade centers)
Stationary
4" Thick
45° Blade
16 Ga. Galv. Steel
or 14 Ga. Alum.

amca CERTIFIED RATINGS — WATER PENETRATION — AIR PERFORMANCE — AIR MOVEMENT AND CONTROL ASSOCIATION, INC.

Airolite certifies that the louver shown herein is licensed to bear the AMCA Seal. The ratings shown are based on tests made in accordance with AMCA Standard 500 and comply with the requirements of the AMCA Certified Ratings Program. The AMCA Certified Ratings Seal applies to air performance and water penetration ratings.

See Reverse Side for Water Penetration Chart

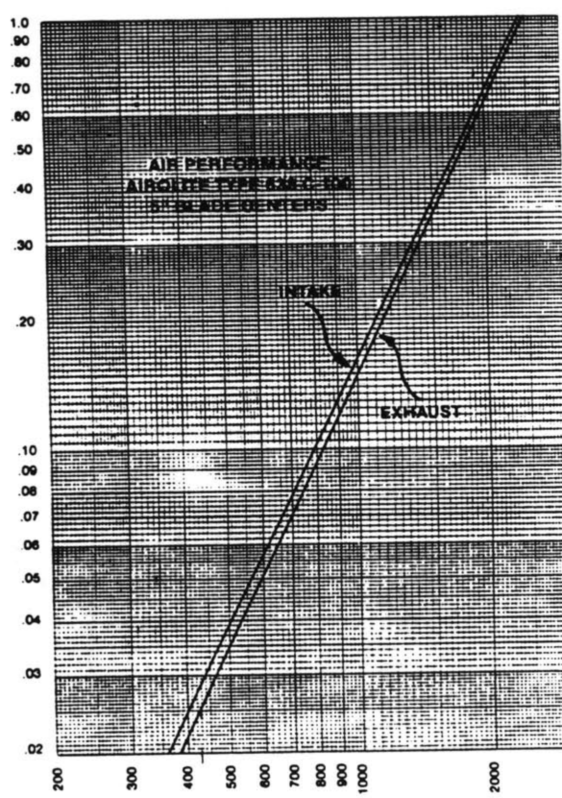


Chart 2

CAT. CRP-1-1975

Figure 107: Louver - Airolite Type 638-C-100 Pressure Drop & Free Area

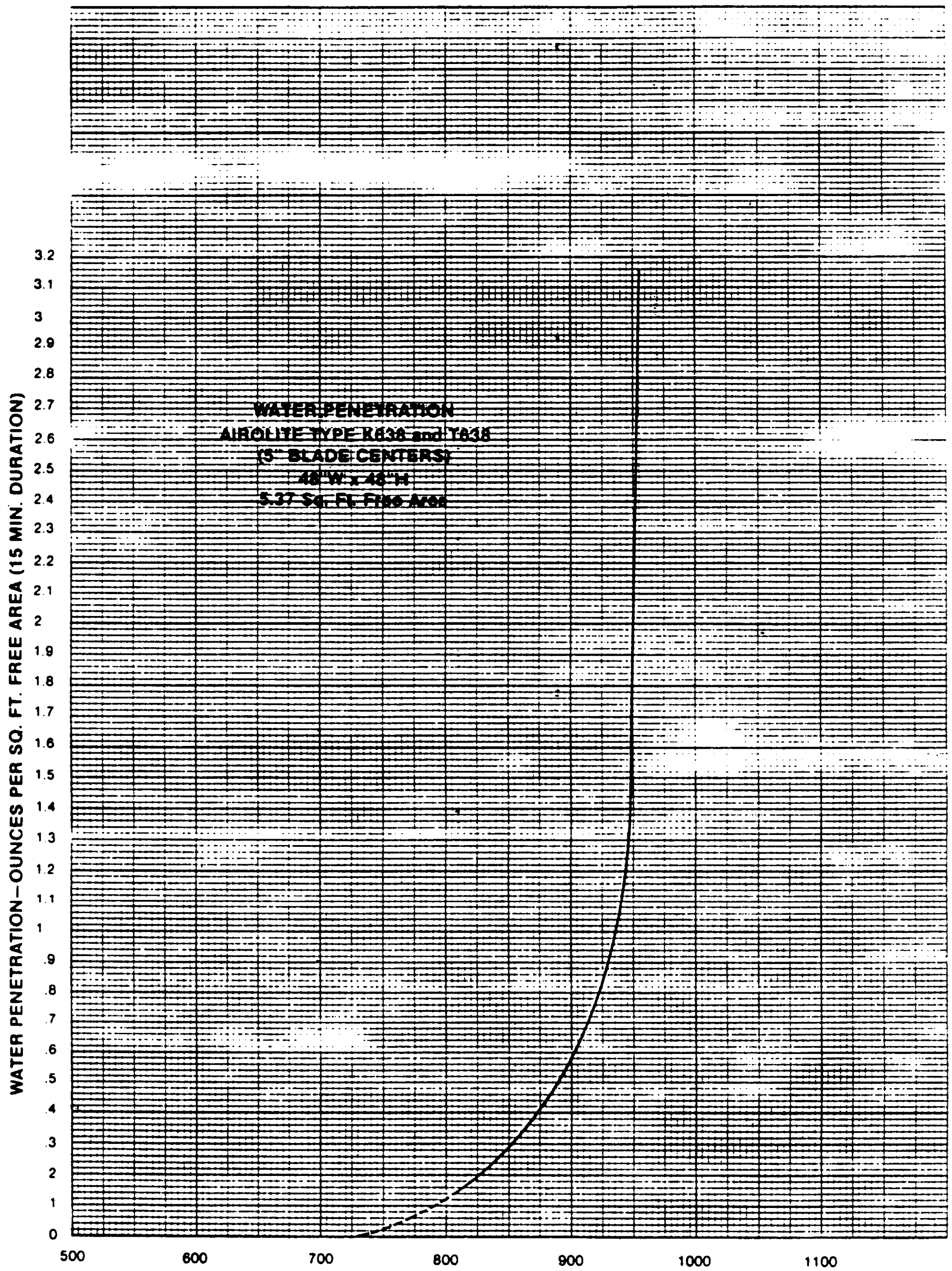


Chart 3

VELOCITY THROUGH FREE AREA (FPM)
STANDARD AIR—.075 LB. PER CU. FT.

Figure 108: Louver - Airolite Type 638-C-100 Water Penetration

Appendix N - Zone Components

Figure 109: VAV Flow Tally - 34 Zone Configuration - ref: Appendix D

a = zone designation

b = room designation

c = VAV terminal box designation (refer to spreadsheet file: dsgnspec.wq2 for VAV Box Schedule)

d = design supply air flow rate for each of 34 zones in the as built design [cfm]

Refer to Building E51 Supply & Return Duct Layout Drawing Files e510thsr.cdr, e511stsr.cdr, e512ndsr.cdr, & e513rdsr.cdr.

e = supply diffuser dimensions [in x in]

f = area of supply diffuser [in2]

g = diffuser face velocity [ft/min]

h = dimension of duct leading to diffuser [in x in]

i = supply duct cross sectional area [in2]

j = average velocity normal to supply duct cross section [ft/min]

k = design retrun air flow rate for each of 34 zones in the as built design [cfm]

l = return grill dimensions [in x in]

m = area of return grill [in2]

n = return grill face velocity [ft/min]

o = dimension of duct leading away from grill [in x in]

p = return duct cross sectional area [in2]

q = average velocity normal to return duct cross section [ft/min]

r = difference between design supply and return air flow rates [cfm]

Note: Refer to E51 Mechanical Drawings and Specifications for the data found in this table (Phil Green, MIT Physical Plant)

Figure 110: VAV Flow Tally - 34 Zone Configuration - ref: Appendix D (cont'd)

Flow Tally and VAV Box Coil Reheat Requirements

a	b	c	d	e1	e2	f	g	h1	h2	i	j	k	l1	l2	m	n	o1	o2	p	q	r
			Supply									Return									Delta
Zone	Room	VAV		Diffuser				Duct					Collector				Duct				Flow
		Box	[cfm]	Dimensions		[sqin]	[ft/min]	Dimensions		[sqin]	[ft/min]	[cfm]	Dimensions		[sqin]	[ft/min]	Dimensions		[sqin]	[ft/min]	Sup-Ret
I	003	B	280	9	12	108	373	10	6	60	672	266	9	12	108	355	10	6	60	638	
I	005	A	80	6	6	36	320	8	4	32	360	70	6	6	36	280	8	4	32	315	
I	000	Ca	210	9	9	81	373	10	6	60	504	200	9	9	81	356	10	6	60	480	
I	006	Cb	90	6	6	36	360	8	4	32	405	80	6	6	36	320	8	10	80	144	
I	006	Da	430	9	15	135	459	10	10	100	619	410	9	15	135	437	10	6	60	984	
I	008	Db	260	9	12	108	347	12	6	72	520	245	9	12	108	327	12	6	72	490	
I	012	Da	355	9	12	108	473	12	8	96	533	340	9	12	108	453	12	8	96	510	
I	012	Db	355	9	12	108	473	12	8	96	533	340	9	12	108	453	12	8	96	510	
			2,060	Sub-Tots		720	412	Sub-Tots		548	541	1,951	Sub-Tots		720	390	Sub-Tots		556	505	109
			Supply Exit Avg Speed [ft/min]				397				518	Rtn Entry Avg Speed [ft/min]				373				509	
II	007	Ba	90	6	6	36	360	8	4	32	405	80	6	6	36	320	8	4	32	360	
II	007	Bb	90	6	6	36	360	8	4	32	405	80	6	6	36	320	8	6	48	240	
II	007	Bc	160	9	9	81	284	10	5	50	461	150	6	6	36	600	8	6	48	450	
			340	Sub-Tots		153	320	Sub-Tots		114	429	310	Sub-Tots		108	413	Sub-Tots		128	349	30
			Supply Exit Avg Speed [ft/min]				335				424	Rtn Entry Avg Speed [ft/min]				413				350	
III	004	Fa	1,100	11	36	396	400	16	12	192	825	400	11	36	396	145	16	12	192	300	
III	004	Fb	1,100	11	36	396	400	16	12	192	825	400	11	36	396	145	16	12	192	300	
III	100	Ea	220	9	9	81	391	10	6	60	528	200	9	9	81	356	10	6	60	480	
III	106	Eb	225	9	9	81	400	10	6	60	540	240	9	9	81	427	10	6	60	576	
III	106	Ec	225	9	9	81	400	10	6	60	540	240	9	9	81	427	10	6	60	576	
III	110d	Ed	220	9	9	81	391	10	6	60	528	245	9	9	81	436	10	6	60	588	
III	110d	Ee	220	9	9	81	391	10	6	60	528	245	9	9	81	436	10	6	60	588	
III	110	Ef	180	9	9	81	320	10	6	60	432	220	9	9	81	391	10	6	60	528	
III	110	Eg	180	9	9	81	320	10	6	60	432	120	8	8	64	270	10	6	60	288	
III	110c	B	200	9	9	81	356	10	6	60	480	190	9	9	81	338	10	6	60	456	
III	201b	Ca	300	9	12	108	400	10	6	60	720	285	9	12	108	380	10	8	80	513	
III	201a	Cb	300	9	12	108	400	10	8	80	540	285	9	12	108	380	10	8	80	513	
III	206	Ea	300	9	12	108	400	10	8	80	540	285	9	12	108	380	10	8	80	513	

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Figure 111: VAV Flow Tally - 34 Zone Configuration - ref: Appendix D (cont'd)

III	208	Eb	280	9	12	108	373	10	8	80	504	285	9	12	108	380	10	8	80	513	
III	210a	Ec	280	9	12	108	373	10	8	80	504	265	9	12	108	353	10	8	80	477	
III												175	9	9	81	311	10	6	60	420	
III	210	Ed	370	12	12	144	370	10	8	80	666	175	9	9	81	311	8	6	48	525	
III	210b	A	100	6	6	36	400	6	6	36	400	95	6	6	36	380	8	6	48	285	
III	216	C	570	12	15	180	456	12	10	120	684	540	12	15	180	432	12	10	120	648	
III	200	C	340	9	12	108	453	10	8	80	612	150	6	9	54	400	10	6	60	360	
III	302	Fa	397	9	12	108	529	12	8	96	596	565	9	12	108	753	16	10	160	509	
III	302	Fb	397	9	12	108	529	12	8	96	596	565	9	12	108	753	16	10	160	509	
III	302	Fc	397	9	12	108	529	12	8	96	596	565	9	12	108	753	16	10	160	509	
III	302	Fd	397	9	12	108	529	12	8	96	596	565	9	12	108	753	16	10	160	509	
III	302	Fe	397	9	12	108	529	12	8	96	596	-----	-----	-----	-----				-----		
III	302	Ff	397	9	12	108	529	12	8	96	596	-----	-----	-----	-----				-----		
III	306	Da	435	12	12	144	435	12	8	96	653	405	12	12	144	405	12	8	96	608	
III	306	Db	435	12	12	144	435	12	8	96	653	405	12	12	144	405	12	8	96	608	
III	310	Da	405	12	12	144	405	12	8	96	608	385	12	12	144	385	16	8	128	433	
III	310	Db	405	12	12	144	405	12	8	96	608	385	12	12	144	385	16	8	128	433	
			10,772	Sub-Tots		3,672	422	Sub-Tots		2,520	616	8,880	Sub-Tots		3,403	376	Sub-Tots		2,688	476	1,892
			Supply Exit Avg Speed [ft/min]				422				583	Rtn Entry Avg Speed [ft/min]				417				484	
IV	101	B	120	6	6	36	480	10	6	60	288	115	6	6	36	460	10	6	60	276	
IV	101a	B	140	9	6	54	373	8	6	48	420	-----	-----	-----	-----				-----		
IV	101b	C	500	9	18	162	444	10	10	100	720	475	9	18	162	422	10	10	100	684	
IV	101c	B	180	9	9	81	320	10	6	60	432	120	6	6	36	480	10	6	60	288	
IV	201	B	260	9	12	108	347	10	6	60	624	250	9	12	108	333	10	6	60	600	
IV	201d	C	500	12	15	180	400	8	14	112	643	475	12	12	144	475	10	10	100	684	
IV	201f	Ba	130	6	9	54	347	6	6	36	520	125	6	6	36	500	8	6	48	375	
IV	201g	Bb	160	6	9	54	427	8	6	48	480	150	6	9	54	400	8	6	48	450	
			1,990	Sub-Tots		729	393	Sub-Tots		524	547	1,710	Sub-Tots		576	428	Sub-Tots		476	517	280
			Supply Exit Avg Speed [ft/min]				392				516	Rtn Entry Avg Speed [ft/min]				439				480	
V	105	Ca	180	9	9	81	320	10	6	60	432	170	9	9	81	302	10	6	60	408	
V	107	Cb	130	9	9	81	231	10	6	60	312	125	9	9	81	222	10	6	60	300	
V	109	Ba	70	6	6	36	280	8	4	32	315	70	6	6	36	280	8	4	32	315	
V	111	Bb	280	9	12	108	373	10	8	80	504	265	9	12	108	353	10	6	60	636	

Figure 112: VAV Flow Tally - 34 Zone Configuration - ref: Appendix D (cont'd)

Flow Tally and VAV Box Coil Reheat Requirements

V	113	B	180	9	9	81	320	10	6	60	432	170	9	9	81	302	8	6	48	510	
V	115	B	100	6	6	36	400	8	4	32	450	95	6	6	36	380	8	4	32	428	
V	207	Ca	210	9	9	81	373	8	8	64	473	205	9	9	81	364	10	6	60	492	
V	209	Cb	150	6	9	54	400	8	6	48	450	140	6	9	54	373	10	4	40	504	
V												85	6	6	36	340	6	6	36	340	
V	211	B	180	6	12	72	360	12	8	96	270	85	6	6	36	340	6	6	36	340	
V	211b	B	260	9	12	108	347	12	6	72	520	245	9	12	108	327	10	6	60	588	
V	215	B	300	9	12	108	400	12	6	72	600	285	9	12	108	380	12	6	72	570	
V	307	Da	420	12	12	144	420	14	6	84	720	400	12	12	144	400	12	8	96	600	
V	307	Db	420	12	12	144	420	14	6	84	720	400	12	12	144	400	12	8	96	600	
V	311	Ea	400	12	12	144	400	14	7	98	588	760	15	15	225	486	18	8	144	760	
V	311	Eb	400	12	12	144	400	14	7	98	588	760	15	15	225	486	18	8	144	760	
V	311	Ec	400	12	12	144	400	14	7	98	588	-----	-----	-----	-----				-----		
V	311	Ed	400	12	12	144	400	14	7	98	588	-----	-----	-----	-----				-----		
V	317	Ea	470	12	12	144	470	14	8	112	604	665	18	12	216	443	14	10	140	684	
V	317	Eb	470	12	12	144	470	14	8	112	604	665	18	12	216	443	14	10	140	684	
V	317	Ec	470	12	12	144	470	14	8	112	604	-----	-----	-----	-----				-----		
			5,890	Sub-Tots		2,142	396	Sub-Tots		1,572	540	5,590	Sub-Tots		2,016	399	Sub-Tots		1,356	594	300
			Supply Exit Avg Speed [ft/min]				383				518	Rtn Entry Avg Speed [ft/min]				368				529	
VI	201c	Da	380	9	12	108	507	10	8	80	684	720	15	15	225	461	14	10	140	741	
VI	201c	Db	380	9	12	108	507	10	8	80	684	-----	-----	-----	-----				-----		
			760	Sub-Tots		216	507	Sub-Tots		160	684	720	Sub-Tots		225	461	Sub-Tots		140	741	40
			Supply Exit Avg Speed [ft/min]				507				684	Rtn Entry Avg Speed [ft/min]				461				741	
Totals			21,812			7,632	412			5,438	578	19,161			7,048	391			5,344	516	2,651
			Supply Exit Avg Speed [ft/min]				403				546	Rtn Entry Avg Speed [ft/min]				401				497	2,651

Figure 113: VAV Reheat Coil Output - 34 Zone Configuration - ref: Appendix H

a = zone designation

b = room designation

c = VAV terminal box designation (refer to spreadsheet file: dsgnspec.wq2 for VAV Box Schedule)

d = design output for VAV reheat coil [1000's of Btuh]

e = waterside design flow for VAV reheat coil [gpm]

f = design supply air flow rate for zones on the ground level in the as built design [cfm]

g = design return air flow rate for zones on the ground level in the as built design [cfm]

h = design supply air flow rate for zones on the first level in the as built design [cfm]

i = design return air flow rate for zones on the first level in the as built design [cfm]

j = design supply air flow rate for zones on the second level in the as built design [cfm]

k = design return air flow rate for zones on the second level in the as built design [cfm]

l = design supply air flow rate for zones on the third level in the as built design [cfm]

m = design return air flow rate for zones on the third level in the as built design [cfm]

n = design VAV reheat coil output for zones on the ground level in the as built design [cfm]

o = design waterside flow rate for reheat coil for zones on the ground level in the as built design [cfm]

p = design VAV reheat coil output for zones on the first level in the as built design [cfm]

q = design waterside flow rate for reheat coil for zones on the first level in the as built design [cfm]

r = design VAV reheat coil output for zones on the second level in the as built design [cfm]

s = design waterside flow rate for reheat coil for zones on the second level in the as built design [cfm]

t = design VAV reheat coil output for zones on the third level in the as built design [cfm]

u = design waterside flow rate for reheat coil for zones on the third level in the as built design [cfm]

Note: Refer to E51 Mechanical Drawings and Specifications for the data found in this table (Phil Green, MIT Physical Plant)

Flow Tally and VAV Box Coil Reheat Requirements

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u
			Reheat Output		Flow per Floor								Reheat per Floor							
Zone	Room	VAV Box	MBH	GPM	0th [cfm]		1st [cfm]		2nd [cfm]		3rd [cfm]		0th		1st		2nd		3rd	
					Supply	Return	Supply	Return	Supply	Return	Supply	Return	MBH	GPM	MBH	GPM	MBH	GPM	MBH	GPM
I	003	B	1.7	0.2	280	266							1.7	0.2						
I	005	A	0.6	0.1	80	70							0.6	0.1						
I	000	Ca	3.6	0.4	210	200							3.6	0.4						
I	006	Cb			90	80														
I	006	Da	6.6	0.7	430	410							6.6	0.7						
I	008	Db			260	245														
I	012	Da	6.6	0.7	355	340							6.6	0.7						
I	012	Db			355	340														
			19.1	2.1																
II	007	Ba	1.7	0.2	90	80							1.7	0.2						
II	007	Bb			90	80														
II	007	Bc			160	150														
			1.7	0.2																
III	004	Fa	13.3	1.4	1,100	400							13.3	1.4						
III	004	Fb			1,100	400														
III	100	Ea	8.9	0.9			220	200							8.9	0.9				
III	106	Eb					225	240												
III	106	Ec					225	240												
III	110d	Ed					220	245												
III	110d	Ee					220	245												
III	110	Ef					180	220												
III	110	Eg					180	120												
III	110c	B	1.7	0.2			200	190							1.7	0.2				
III	201b	Ca	3.6	0.4					300	285							3.6	0.4		
III	201a	Cb							300	285										
III	206	Ea	8.9	0.9					300	285							8.9	0.9		

file: flwtally.wq2

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Figure 114: VAV Reheat Coil Output - 34 Zone Configuration - ref: Appendix H (cont'd)

Figure 115: VAV Reheat Coil Output - 34 Zone Configuration - ref: Appendix H (cont'd)

Flow Tally and VAV Box Coil Reheat Requirements

III	208	Eb							280	285										
III	210a	Ec							280	265										
III										175										
III	210	Ed							370	175										
III	210b	A	0.6	0.1					100	95							0.6	0.1		
III	216	C	3.6	0.4					570	540							3.6	0.4		
III	200	C	3.6	0.4					340	150							3.6	0.4		
III	302	Fa	13.3	1.4							397	565							13.3	1.4
III	302	Fb									397	565								
III	302	Fc									397	565								
III	302	Fd									397	565								
III	302	Fe									397	-----								
III	302	Ff									397	-----								
III	306	Da	6.6	0.7							435	405							6.6	0.7
III	306	Db									435	405								
III	310	Da									405	385								
III	310	Db									405	385								
			64.1	6.8																
IV	101	B	1.7	0.2			120	115							1.7	0.2				
IV	101a	B	1.7	0.2			140	-----							1.7	0.2				
IV	101b	C	3.6	0.4			500	475							3.6	0.4				
IV	101c	B	1.7	0.2			180	120							1.7	0.2				
IV	201	B	1.7	0.2					260	250							1.7	0.2		
IV	201d	C	3.6	0.4					500	475							3.6	0.4		
IV	201f	Ba	1.7	0.2					130	125							1.7	0.2		
IV	201g	Bb							160	150										
			15.7	1.8																
V	105	Ca	3.6	0.4			180	170							3.6	0.4				
V	107	Cb					130	125												
V	109	Ba	1.7	0.2			70	70							1.7	0.2				
V	111	Bb					280	265												

Flow Tally and VAV Box Coil Reheat Requirements

V	113	B	1.7	0.2			180	170							1.7	0.2				
V	115	B	1.7	0.2			100	95							1.7	0.2				
V	207	Ca	3.6	0.4					210	205							3.6	0.4		
V	209	Cb							150	140										
V									0	85										
V	211	B	1.7	0.2					180	85							1.7	0.2		
V	211b	B	1.7	0.2					260	245							1.7	0.2		
V	215	B	1.7	0.2					300	285							1.7	0.2		
V	307	Da	6.6	0.7							420	400							6.6	0.7
V	307	Db									420	400								
V	311	Ea	8.9	0.9							400	760							8.9	0.9
V	311	Eb									400	760								
V	311	Ec									400	-----								
V	311	Ed									400	-----								
V	317	Ea									470	665								
V	317	Eb									470	665								
V	317	Ec									470	-----								
			32.9	3.6																
VI	201c	Da	6.6	0.7					380	720							6.6	0.7		
VI	201c	Db							380	-----										
			6.6	0.7																
Totals																				
	Flows per Floor		140.1	15.2	4,600	3,061	3,550	3,305	5,750	5,305	7,912	7,490	34.1	3.7	28.0	3.1	42.6	4.7	35.4	3.7
	Delta Flow [cf		34	34		1,539		245		445		422							140.1	15.2
	Flows thru Main Ducts [cfm]				4,600	3,061	8,150	6,366	13,900	11,671	21,812	19,161								
					Chk Sum Delta Flow			2,651	Chk Sum		21,812	19,161					Chk Sum		140.1	15.2

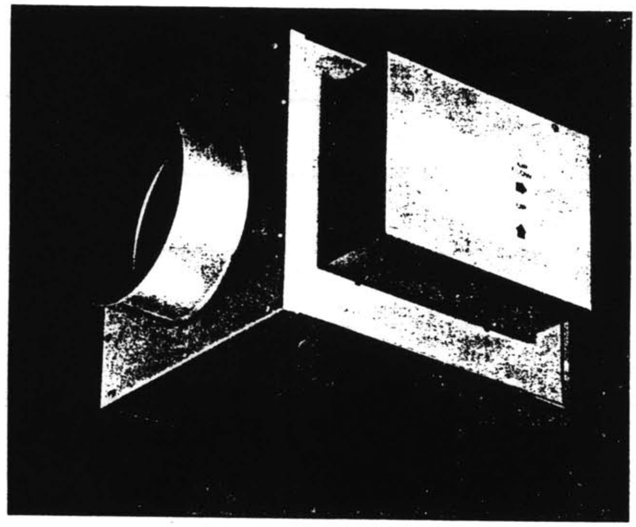
Figure 116: VAV Reheat Coil Output - 34 Zone Configuration - ref: Appendix H (cont'd)

TITUS® Single/Dual Duct Terminals ▶ Performance Data

Recommended CFM Ranges

Single Duct VAV Terminal Units

Models:
- PESV ▪ Pneumatic
- AESV ▪ Electronic
- DESV ▪ Digital
- EESV ▪ Electric



Inlet Size	Total CFM Range	CFM Ranges of Minimum and Maximum Settings							
		PESV Pneumatic TITUS II Controller		PESV Pneumatic TITUS I Controller		AESV Analog Electronic Controller		DESV Digital TD1 Controller	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
4	0-225	45*-170	80-225	55*-170	80-225	30*-225	30-225	45*-225	45-225
5	0-350	65*-270	120-350	85*-270	120-350	50*-350	50-350	65*-350	65-350
6	0-500	80*-330	150-500	105*-330	150-500	60*-500	60-500	80*-500	80-500
7	0-650	105*-425	190-650	135*-425	190-650	75*-650	75-650	105*-650	105-650
8	0-900	145*-590	265-900	190*-590	265-900	105*-900	105-900	145*-900	145-900
9	0-1050	175*-700	315-1050	225*-700	315-1050	125*-1050	125-1050	175*-1050	175-1050
10	0-1400	230*-925	415-1400	300*-925	415-1400	165*-1400	165-1400	230*-1400	230-1400
12	0-2000	325*-1330	600-2000	425*-1330	600-2000	235*-2000	235-2000	325*-2000	325-2000
14	0-3000	450*-1800	810-3000	575*-1800	810-3000	320*-3000	320-3000	450*-3000	450-3000
16	0-4000	580*-2350	1100-4000	750*-2350	1100-4000	420*-4000	420-4000	580*-4000	580-4000
24x16	0-8000	1400*-5200	2600-8000*	1800*-5200	2600-8000	1000*-7500	1000-7500*	1400*-7500	1400-7500

* Factory cfm settings (except zero) will not be made below this range because control accuracy is reduced.
On pressure dependent units, minimum cfm is always zero, and there is no maximum.

Figure 117: VAV Terminal Box Performance Data (Titus Single Duct Pressure Independent)

TITUS® Variable Volume Terminal Units • Design Features

The Basic Terminal Unit

Low-Leakage Casing

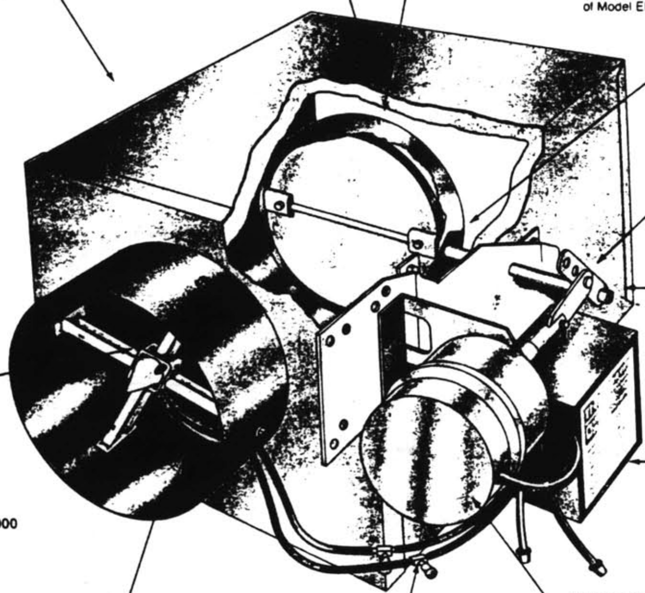
Inlet Size	Leakage, CFM 0.5"ΔP_s	1.5"ΔP_s
4, 5, 6	1.5	3
7, 8	1.5	3
9, 10	2	4
12	3	5
14	4	6
16	5	7

Values for single duct unit or one side of Model EDV-3000 dual duct unit

Tight Close-Off Damper

Inlet Size	Leakage, CFM 1.5"ΔP_s	3.0"ΔP_s	6.0"ΔP_s
4, 5, 6	4	5	7
7, 8	4	5	7
9, 10	4	5	7
12	4	5	7
14	4	6	8
16	5	7	9

Values for single duct unit or one side of Model EDV-3000 dual duct unit



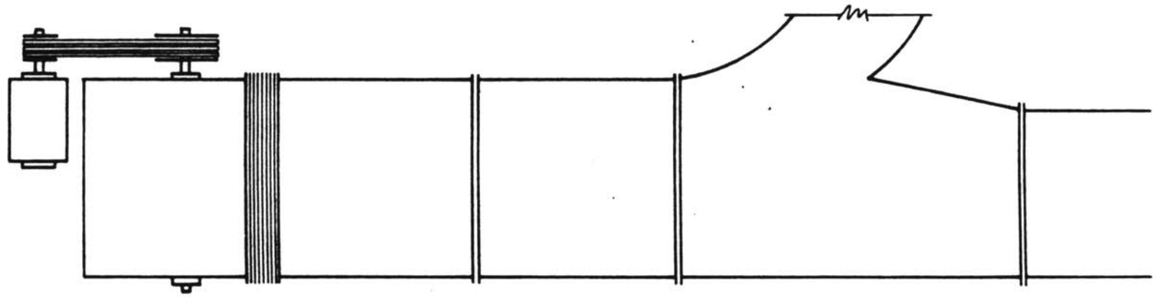


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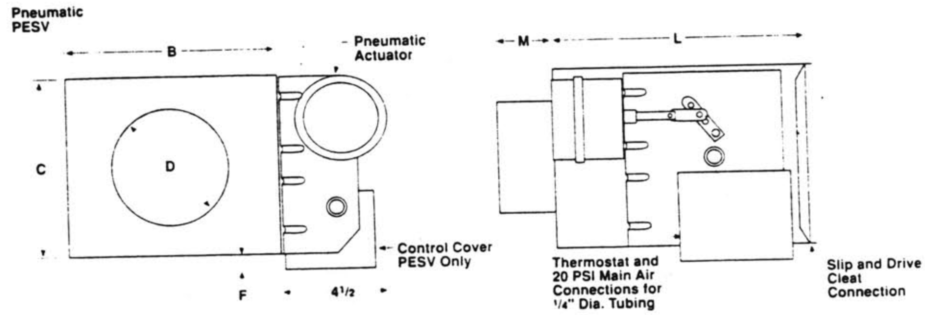
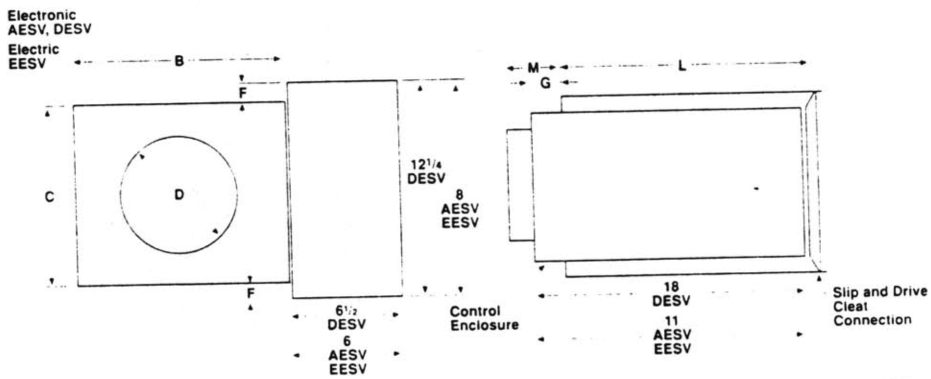
Figure 118: VAV Terminal Box Design Features (Titus Single Duct Pressure Independent)

TITUS® Single/Dual Duct Terminals ▶ Dimensions

Single Duct Units ■ Dimensional Data





Inlet Size	CFM Range	D	L	B	C	G DESV	G AESV EESV	F PESV	F DESV	M PESV DESV EESV	M AESV
4	0 - 225	3 7/8	15 1/2	12	8	7 7/16	3/8	3 9/16	2 7/8	5 3/8	8
5	0 - 350	4 7/8	15 1/2	12	8	7 7/16	3/8	3 9/16	2 7/8	5 3/8	8
6	0 - 500	5 7/8	15 1/2	12	8	7 7/16	3/8	3 9/16	2 7/8	3 3/8	6
7	0 - 650	6 7/8	15 1/2	12	10	5 7/16	—	2 9/16	1 7/8	3 3/8	6
8	0 - 900	7 7/8	15 1/2	12	10	5 7/16	—	2 9/16	1 7/8	3 3/8	6
9	0 - 1050	8 7/8	15 1/2	14	12 1/2	5 7/16	—	9/16	—	3 3/8	6
10	0 - 1400	9 7/8	15 1/2	14	12 1/2	5 7/16	—	9/16	—	3 3/8	6
12	0 - 2000	11 7/8	15 1/2	16	15	5 7/16	—	—	—	3 3/8	6
14	0 - 3000	9 7/8	15 1/2	20	17 1/2	3 7/16	—	—	—	3 3/8	6
16	0 - 4000	11 7/8	15 1/2	24	18	3 7/16	—	—	—	3 3/8	6
24 x 16	0 - 8000	23 7/8 x 15 7/8	16 5/8	28	18	5 1/2	—	2 9/16	1 7/8	3 11/16	—

▶ For optimum control, the inlet duct must be the same size as the unit inlet.
▶ Right hand control location, as shown above, is standard. Left hand is optional.
▶ All dimensions are in inches.

Figure 119: VAV Terminal Box Dimensions (Titus Single Duct Pressure Independent)

Models: PESV, AESV, DESV ■ Sound Application Data ■ NC Values

Sound Noise Criteria (NC)									
Inlet Size	CFM	Discharge ΔPs				Radiated ΔPs			
		0.5"	1.0"	2.0"	3.0"	0.5"	1.0"	2.0"	3.0"
4	75	-	-	-	-	-	-	-	21
	125	-	-	20	23	-	-	25	28
	175	-	20	25	28	-	23	29	33
	250	21	26	30	33	22	28	34	38
5	125	-	-	-	-	-	-	-	-
	175	-	-	-	23	-	-	-	-
	250	-	-	25	28	-	-	23	26
	300	-	21	27	31	-	22	27	30
	350	-	24	30	33	21	26	31	34
6	175	-	-	-	-	-	-	20	22
	225	-	-	-	22	-	-	23	26
	300	-	-	23	26	-	23	27	30
	350	-	20	26	28	20	25	29	32
	400	-	23	28	31	22	27	31	34
	450	-	24	29	32	24	29	33	36
	500	21	26	31	34	26	30	35	37
7	250	-	-	-	-	-	-	20	23
	300	-	-	-	21	-	-	22	26
	350	-	-	20	24	-	-	24	27
	400	-	-	23	26	-	21	26	29
	500	-	20	27	30	-	23	28	31
	600	-	23	30	34	20	25	30	34
	650	-	25	31	35	21	26	31	34
8	350	-	-	-	-	-	-	-	21
	400	-	-	-	-	-	-	20	23
	450	-	-	-	20	-	-	22	24
	500	-	-	-	22	-	20	24	26
	600	-	-	21	24	-	23	26	29
	700	-	-	23	27	21	25	29	31
	800	-	20	26	29	23	27	31	33
9	450	-	-	-	22	-	-	22	26
	500	-	-	-	23	-	-	23	27
	600	-	-	21	25	-	22	25	28
	700	-	-	22	26	22	25	28	29
	800	-	-	23	27	24	27	30	31
	900	-	-	24	28	26	29	32	33
	1000	-	20	26	29	27	30	33	36
10	550	-	-	-	-	-	20	24	28
	600	-	-	-	-	-	21	24	29
	700	-	-	-	-	22	24	26	29
	800	-	-	-	20	25	27	29	30
	1000	-	-	21	25	29	31	33	34
	1200	-	-	25	29	32	34	36	37
	1400	-	22	28	32	35	37	39	40
12	800	-	-	-	20	-	-	25	29
	900	-	-	-	21	-	20	26	30
	1000	-	-	-	22	-	22	27	30
	1200	-	-	-	23	21	25	29	32
	1500	-	-	21	25	25	29	33	36
	1800	-	-	22	26	28	32	37	39
	2100	-	-	23	28	31	35	39	42
14	1000	-	-	-	-	-	-	24	29
	1200	-	-	-	-	22	24	27	30
	1500	-	-	-	20	27	30	32	34
	1800	-	-	-	22	32	35	37	39
	2100	-	-	-	23	36	39	41	42
	2400	-	-	21	25	40	42	44	46
	3000	-	-	23	27	45	48	50	52
16	1400	-	-	-	15	-	-	23	27
	1600	-	-	-	16	-	20	25	28
	2000	-	-	-	19	-	23	28	31
	2400	-	-	-	21	20	26	31	34
	2800	-	-	-	22	23	28	34	37
	3200	-	-	21	24	25	30	36	39
	4000	-	-	25	28	28	-34	39	42
24 X 16	3000	21	25	29	32	24	29	33	36
	3500	23	27	31	34	27	32	36	39
	4000	25	29	33	36	30	35	39	42
	5000	28	32	35	38	34	39	44	47
	6000	31	35	39	42	38	[illegible]	48	51
	7000	33	37	41	44	42	46	51	54
	8000	35	39	43	46	44	49	54	57

- ΔP_s is the difference in static pressure from inlet to discharge.
- Dash (-) in space denotes NC value less than 20.
- All Sound Data are based upon tests conducted in accordance with ARI 880-94 in the Laboratory at TITUS, Richardson Texas.

Octave Band Sound Attenuation Factors:

Radiated Sound	Octave Band					
	2	3	4	5	6	7
Environmental Effect	3	2	1	1	1	1
Ceiling Effect	9	10	12	14	15	15
Room Effect	9	10	11	12	13	14
Total dB Reduction	21	22	24	27	29	30

Per ARI 885-90
Mineral Fiber Tile, 5/8"-35#/ Cu. Ft.
3000 Cu. Ft. Space, 10 Ft. from Source

Discharge Sound	Octave Band					
	2	3	4	5	6	7
Environmental Effect	3	2	1	1	1	1
Duct Lining	1	3	8	21	20	12
End Reflection	11	6	2	0	0	0
5 Ft., 8" Flex Duct	6	10	17	19	19	12
Room Effect	9	10	11	12	13	14
Total dB Reduction	30	31	39	53	53	39

Per ARI 885-90
5 Ft., 1" Fiberglass Duct Lining
8" Termination to Diffuser
Vinyl Core Flex
3000 Cu. Ft. Space, 10 Ft. from Source

Additional dB reduction in sound resulting from 300 cfm flow division:

Inlet Size	(dB)
7,8	3
9	5
10	7
12	8
14	10
16	11
24 X 16	14

Adjustments for Optional Attenuators

	Octave Band					
Inlet Size	2	3	4	5	6	7
4,5,6	2	2	5	13	12	8
7,8	2	2	5	12	11	8
9,10	1	2	4	10	9	7
12	1	2	4	9	7	6
14	1	2	3	8	6	5
16	1	1	3	8	6	5
24 X 16	1	1	3	8	6	5

- Select the appropriate unit size, and subtract the value shown under each octave band heading from the Discharge Sound Power Data shown on the following pages. Use the resultant values to calculate discharge NC.
- Data are based upon calculation procedures provided by the ASHRAE 1991 HVAC Applications Handbook, Chapter 42.

Figure 120: VAV Terminal Box NC Values (Titus Single Duct Pressure Independent)

Models: PESV, AESV, DESV ■ Discharge Sound Power

Inlet Size	CFM	Min. ΔP_s	Sound Power Octave Bands																							
			0.5" ΔP_s						1.0" ΔP_s						2.0" ΔP_s						3.0" ΔP_s					
			2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7
10	550	0.038	58	52	48	43	39	33	63	56	52	46	44	39	68	61	55	50	49	44	71	64	58	52	51	47
	600	0.045	59	53	50	44	40	35	65	58	53	48	45	40	70	62	57	52	50	45	72	65	59	54	53	49
	700	0.061	62	55	52	47	43	37	67	60	56	51	47	42	72	65	59	54	52	48	75	67	62	56	55	51
	800	0.080	64	57	54	49	45	39	69	62	58	53	49	45	74	67	62	57	54	50	77	69	64	59	57	53
	1000	0.124	68	61	58	53	48	43	73	65	62	57	53	48	78	70	65	61	58	53	81	73	67	63	61	57
	1200	0.179	71	64	61	56	51	45	76	68	65	60	56	51	81	73	68	64	61	56	84	76	70	66	63	59
	1400	0.244	74	66	63	59	53	48	79	71	67	63	58	53	84	75	71	67	63	59	87	78	73	69	66	62
12	800	0.042	61	57	53	47	45	40	64	63	58	54	52	47	68	69	63	61	58	55	70	73	66	66	62	59
	900	0.053	62	58	54	47	46	40	66	64	59	55	52	48	69	70	64	62	59	55	71	73	67	66	63	60
	1000	0.065	64	58	55	48	46	41	67	64	60	55	53	48	71	71	65	62	59	56	73	74	68	67	63	60
	1200	0.094	66	59	57	49	47	42	70	66	62	56	54	49	73	72	67	63	60	56	75	75	70	68	64	61
	1500	0.146	69	61	59	50	48	43	73	67	64	57	55	50	76	73	69	65	61	57	78	77	72	69	65	62
	1800	0.211	71	62	61	51	49	44	75	68	66	58	56	51	79	74	71	65	62	58	81	78	73	70	66	63
	2100	0.287	73	63	62	52	50	44	77	69	67	59	56	52	81	75	72	66	63	59	83	79	75	71	67	63
14	1000	0.036	61	54	54	50	46	41	65	60	60	57	53	49	68	66	65	64	60	57	70	70	68	68	64	62
	1200	0.051	63	56	56	51	46	42	67	62	61	58	53	51	71	68	66	65	61	59	73	71	69	69	65	63
	1500	0.080	66	58	57	52	47	44	70	64	62	59	54	52	74	70	68	66	61	60	76	74	71	70	65	65
	1800	0.116	69	60	58	53	47	45	72	66	64	60	55	53	76	72	69	66	62	61	78	75	72	70	66	66
	2100	0.158	71	61	59	53	48	46	74	67	65	60	55	54	78	73	70	67	62	62	80	77	73	71	66	67
	2400	0.206	72	62	60	54	48	47	76	68	66	61	55	55	80	74	71	68	63	63	82	78	74	72	67	67
	3000	0.321	75	64	62	55	49	48	79	71	67	62	56	56	83	77	72	69	63	64	85	80	75	73	67	69
16	1400	0.039	62	57	55	50	46	40	66	62	60	57	53	48	71	68	65	64	61	55	73	71	68	68	65	60
	1600	0.050	64	59	56	51	47	41	68	64	61	58	54	49	72	69	66	65	61	56	75	72	69	69	66	61
	2000	0.079	67	61	59	52	49	43	71	66	64	59	56	50	76	71	69	66	63	58	78	74	72	71	67	62
	2400	0.113	69	62	60	54	50	44	74	67	65	61	57	51	78	73	70	68	64	59	81	76	73	72	68	63
	2800	0.154	71	64	62	55	51	45	76	69	67	62	58	52	80	74	72	69	65	60	83	77	75	73	69	64
	3200	0.202	73	65	63	56	52	46	78	70	68	63	59	53	82	75	73	70	66	61	85	78	76	74	70	65
	4000	0.315	76	67	65	58	53	47	81	72	70	65	60	55	85	77	76	72	67	62	88	80	78	76	72	67
24 X 16	3000	0.020	74	71	69	66	63	59	77	74	74	71	68	63	81	78	78	76	73	68	83	80	80	79	76	71
	3500	0.027	76	72	71	67	64	60	79	76	75	72	69	64	83	79	79	77	74	69	84	81	81	80	77	72
	4000	0.036	77	73	71	67	65	61	81	77	76	72	70	65	84	80	80	77	75	70	86	82	82	80	78	73
	5000	0.056	80	75	73	69	66	63	83	78	77	74	71	67	86	82	81	79	76	72	88	84	84	82	79	75
	6000	0.080	82	76	74	70	68	64	85	80	78	75	73	69	88	84	82	80	78	73	90	86	85	83	81	76
	7000	0.109	84	78	75	71	69	65	87	81	79	76	74	70	90	85	84	81	79	74	92	87	86	84	82	77
	8000	0.143	85	79	76	71	70	66	88	82	80	76	75	71	92	86	84	81	80	76	94	88	87	84	83	78

- ΔP_s is the difference in static pressure from inlet to discharge.
- Sound power levels are in decibels, re 10^{-12} watts.
- End discharge sound power is the noise emitted from the unit discharge into the downstream duct.
- All Sound Data are based upon tests conducted in accordance with ARI 880-94 in the Laboratory at TITUS, Richardson Texas.

Figure 121: VAV Terminal Box Discharge Sound Pwr (Titus Single Duct Pressure Independent)

Models: PESV, AESV, DESV ■ Discharge Sound Power

Inlet Size	CFM	Min. ΔP_s	Sound Power Octave Bands																							
			0.5" ΔP_s						1.0" ΔP_s						2.0" ΔP_s						3.0" ΔP_s					
			2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7
4	75	0.004	57	49	43	38	36	28	61	53	48	44	42	35	65	57	53	49	48	42	67	60	56	52	52	46
	125	0.010	62	56	48	44	41	34	66	60	54	49	47	41	70	64	59	55	53	47	72	66	62	58	57	51
	175	0.019	65	60	52	47	44	38	69	64	57	53	50	45	73	68	62	58	57	51	75	71	65	61	60	55
	250	0.039	69	64	56	51	47	42	73	69	61	56	54	49	77	73	66	62	60	55	79	75	69	65	64	59
5	125	0.015	56	49	43	38	35	30	60	54	48	43	41	37	64	59	54	48	47	45	67	62	57	51	51	49
	175	0.030	60	53	47	42	39	34	64	58	52	47	45	41	68	63	58	52	51	48	70	66	61	55	55	52
	250	0.061	63	58	52	47	43	37	67	63	57	52	49	45	71	68	62	57	55	52	74	71	65	59	59	56
	300	0.088	65	60	54	49	45	39	69	65	59	54	51	47	73	70	64	59	57	54	76	73	67	62	61	58
	350	0.119	67	62	56	51	47	41	71	67	61	56	53	48	75	72	66	61	59	55	77	75	69	64	62	60
6	175	0.034	58	51	41	37	35	29	61	55	47	42	40	36	64	59	52	47	46	43	66	62	55	50	50	47
	225	0.056	61	54	45	40	37	31	64	59	50	45	43	38	67	63	56	50	49	45	69	65	59	53	52	49
	300	0.099	64	58	49	44	39	33	67	62	54	49	45	40	71	67	60	54	51	47	73	69	63	57	55	51
	350	0.135	66	60	51	46	41	35	69	64	56	51	47	42	73	69	62	56	53	49	75	71	65	59	56	53
	400	0.177	67	62	53	47	42	36	71	66	58	52	48	43	74	70	64	57	54	50	76	73	67	60	57	54
	450	0.223	69	63	54	49	43	37	72	68	60	54	49	44	75	72	65	59	55	51	77	74	69	62	58	55
	500	0.276	70	65	56	50	44	38	73	69	61	55	50	45	77	73	67	60	56	52	79	76	70	63	59	56
7	250	0.035	59	51	46	41	38	33	64	57	51	44	44	40	68	62	56	47	49	47	71	65	58	49	53	51
	300	0.050	60	54	49	44	40	35	65	59	53	47	46	42	69	65	58	51	51	48	72	68	61	52	54	53
	350	0.068	61	56	51	47	42	36	66	62	56	50	47	43	70	67	61	53	53	50	73	70	63	55	56	54
	400	0.089	62	58	53	49	43	38	66	64	58	53	49	45	71	69	63	56	54	51	73	72	65	58	58	56
	500	0.139	63	62	56	53	46	40	68	67	61	57	51	47	72	73	66	60	57	54	75	76	69	62	60	58
	600	0.201	64	65	59	57	48	42	69	70	64	60	53	49	73	75	69	63	59	56	76	78	71	65	62	60
	650	0.236	65	66	60	58	49	43	69	71	65	61	54	50	74	77	70	64	60	57	76	80	73	66	63	61
8	350	0.039	59	51	48	46	38	32	64	56	53	51	44	39	68	61	57	56	50	45	71	63	60	59	53	49
	400	0.051	60	53	50	48	40	34	64	58	54	53	45	40	69	62	59	58	51	47	72	65	62	60	55	51
	450	0.064	60	54	51	49	41	35	65	59	56	54	47	41	69	64	61	59	52	48	72	67	63	62	56	52
	500	0.079	61	56	53	50	42	36	65	61	57	55	48	43	70	65	62	60	54	49	73	68	65	63	57	53
	600	0.114	62	58	55	52	44	38	66	63	60	57	50	45	71	68	64	62	55	51	74	71	67	65	59	55
	700	0.155	62	60	57	54	46	40	67	65	62	58	51	46	72	70	66	63	57	53	74	73	69	66	60	57
	800	0.203	63	62	59	55	47	41	68	67	63	60	53	48	72	72	68	65	59	55	75	75	71	68	62	59
9	450	0.045	61	55	51	48	45	40	64	61	57	54	51	47	68	67	63	60	58	54	70	71	67	64	61	58
	500	0.056	62	56	52	48	45	41	66	62	58	55	52	48	69	68	64	61	58	54	71	71	68	65	62	58
	600	0.080	65	57	53	49	46	42	68	63	59	56	53	48	72	69	65	62	59	55	74	73	69	66	63	59
	700	0.109	67	58	54	50	47	42	70	64	60	57	53	49	74	70	66	63	60	56	76	74	70	67	64	60
	800	0.142	69	59	55	51	48	43	72	65	61	58	54	50	76	71	67	64	61	57	78	75	71	68	64	61
	900	0.180	70	60	56	52	48	44	74	66	62	58	55	51	77	72	68	65	61	57	79	76	72	68	65	61
	1000	0.222	72	61	57	53	49	44	75	67	63	59	55	51	79	73	69	65	62	58	81	76	73	69	65	62

ARI Certification Rating Points

Inlet Size	Rated CFM	Min. ΔP_s	Sound Power @ 1.5" ΔP_s					
			2	3	4	5	6	7
4	150	0.040	70	65	59	54	52	47
5	250	0.120	70	66	60	55	53	49
6	400	0.220	73	69	61	55	51	47
7	550	0.200	71	72	65	60	56	52
8	700	0.200	70	68	64	61	55	50
9	900	0.220	76	69	66	62	59	55
10	1100	0.180	78	70	65	61	57	53
12	1600	0.210	76	71	67	62	59	55
14	2100	0.210	77	71	68	64	59	59
16	2800	0.200	78	72	70	66	62	57
24 X 16	5300	0.063	86	81	80	77	75	70

Figure 122: VAV Terminal Box Discharge Sound Pwr - continued (Titus Single Duct PI)

Models: PESV, AESV, DESV ■ Radiated Sound Power

Inlet Size	CFM	Min. ΔP_s	Sound Power Octave Bands																							
			0.5" ΔP_s						1.0" ΔP_s						2.0" ΔP_s						3.0" ΔP_s					
			2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7
	75	0.004	50	39	30	25	22	18	55	43	33	28	26	25	60	47	36	30	30	31	62	49	38	31	32	35
	125	0.010	56	45	36	33	31	26	60	49	39	35	35	33	65	53	43	38	39	39	68	55	45	39	42	43
4	175	0.019	59	50	40	38	37	31	64	54	44	41	41	38	69	58	47	43	45	44	71	60	49	44	48	48
	250	0.039	63	54	45	44	44	36	68	58	48	46	48	43	72	62	51	48	52	50	75	64	53	50	54	54
	125	0.015	42	27	18	16	16	15	46	30	22	20	22	22	50	33	27	24	28	30	52	35	29	27	31	34
	175	0.030	49	36	27	23	23	20	53	39	31	27	28	28	56	42	35	31	34	35	59	44	38	34	37	39
5	250	0.061	56	46	36	30	29	26	60	49	40	34	35	33	63	52	44	39	41	41	66	54	47	41	44	45
	300	0.088	59	51	40	34	33	29	63	54	45	38	38	36	67	57	49	42	44	44	69	59	52	45	47	48
	350	0.119	62	55	44	37	36	31	66	58	49	41	41	39	70	61	53	46	47	46	72	63	55	48	50	51
	175	0.034	54	46	32	23	20	14	57	50	37	29	25	19	61	54	42	34	29	24	63	56	46	37	32	26
	225	0.056	56	50	35	27	24	18	59	53	41	32	29	23	63	57	46	37	33	28	65	60	49	40	36	31
	300	0.099	58	53	39	30	28	23	61	57	45	35	33	28	65	61	50	41	37	33	67	63	53	44	40	36
6	350	0.135	59	55	41	32	30	26	62	59	47	37	35	31	66	63	52	42	40	36	68	65	55	45	42	39
	400	0.177	60	57	43	33	32	28	63	61	49	39	37	33	67	65	54	44	42	38	69	67	57	47	44	41
	450	0.223	61	58	45	35	34	30	64	62	50	40	39	35	68	66	55	45	43	40	70	68	59	48	46	43
	500	0.276	61	60	46	36	36	32	65	64	52	41	40	37	69	67	57	47	45	42	71	70	60	50	48	45
	250	0.035	53	39	34	28	25	22	58	43	38	31	29	29	62	48	42	34	33	35	64	50	44	35	36	38
	300	0.050	55	42	36	31	28	25	59	46	40	34	32	31	63	51	44	37	37	37	66	53	46	38	39	41
	350	0.068	56	44	38	34	31	27	61	49	42	37	35	33	65	53	46	39	39	39	67	56	48	41	42	43
7	400	0.089	58	46	40	36	33	29	62	51	44	39	37	35	66	55	48	42	42	41	68	58	50	43	44	44
	500	0.139	60	50	43	40	37	32	64	54	47	43	41	38	68	59	51	45	46	44	70	61	53	47	48	47
	600	0.201	61	53	45	43	40	34	65	57	49	46	44	40	69	62	53	49	49	46	72	64	55	50	51	50
	650	0.236	62	54	47	45	42	35	66	59	50	47	46	41	70	63	54	50	50	47	73	66	56	52	53	51
	350	0.039	54	40	35	30	27	23	57	45	39	33	31	29	60	49	43	36	35	35	62	52	46	38	37	39
	400	0.051	56	42	37	32	29	25	59	47	41	35	33	31	62	51	45	38	37	37	63	54	48	40	39	41
	450	0.064	57	44	38	34	31	27	60	48	42	37	35	33	63	53	47	40	39	39	65	56	49	42	41	43
8	500	0.079	58	45	39	36	33	29	61	50	44	39	37	35	64	54	48	42	41	41	66	57	51	43	43	45
	600	0.114	60	48	42	39	36	31	63	52	46	42	40	38	66	57	51	45	44	44	68	60	53	46	46	47
	700	0.155	62	50	44	41	39	34	65	55	48	44	43	40	68	59	53	47	46	46	70	62	55	49	49	50
	800	0.203	64	52	46	43	41	36	67	57	50	46	45	42	70	61	54	49	49	48	71	64	57	51	51	52
	450	0.045	57	46	38	31	29	26	59	51	45	38	35	33	62	56	52	44	41	39	63	59	56	48	45	43
	500	0.056	58	47	38	32	30	27	61	52	45	38	36	33	63	57	52	45	42	40	64	60	56	49	46	44
	600	0.080	61	48	39	33	31	28	63	53	46	40	37	35	65	59	53	47	43	41	67	62	57	50	47	45
9	700	0.109	63	49	40	34	32	29	65	55	47	41	39	35	67	60	54	48	45	42	69	63	58	52	48	46
	800	0.142	64	50	41	36	34	30	67	56	48	42	40	36	69	61	55	49	46	43	70	64	59	53	49	47
	900	0.180	66	51	41	36	34	30	68	57	48	43	40	37	70	62	55	50	47	44	72	65	59	54	50	47
	1000	0.222	67	52	42	37	35	31	69	57	49	44	41	38	72	63	56	51	47	44	73	66	60	55	51	48

ARI Certification Rating Points

Inlet Size	Rated CFM	Min. ΔP_s	Sound Power @ 1.5" ΔP_s					
			2	3	4	5	6	7
4	175	0.019	67	56	46	42	44	42
5	275	0.074	64	53	45	39	40	39
6	400	0.220	66	63	52	42	40	36
7	550	0.200	67	59	51	46	46	43
8	700	0.200	67	57	51	46	45	44
9	900	0.220	70	60	53	47	44	41
10	1100	0.180	72	59	53	48	45	43
12	1600	0.210	71	62	57	51	47	43
14	2100	0.210	77	61	55	50	51	48
16	2800	0.200	70	62	57	53	51	50
24X16	5300	0.063	76	71	70	65	60	54

Figure 123: VAV Terminal Box Radiated Sound Power (Titus Single Duct Pressure Independent)

Models: PESV, AESV, DESV ■ Radiated Sound Power

Inlet Size	CFM	Min. ΔP_s	Sound Power Octave Bands																							
			0.5" ΔP_s						1.0" ΔP_s						2.0" ΔP_s						3.0" ΔP_s					
			2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7
	550	0.038	60	46	39	33	31	29	61	52	46	40	37	35	62	58	54	48	42	41	63	61	58	50	45	44
	600	0.045	61	47	39	34	32	29	62	52	47	40	37	35	64	58	54	47	43	41	65	61	58	51	46	45
	700	0.061	63	48	40	35	33	30	65	53	47	41	38	36	66	59	55	48	44	42	67	62	59	52	47	46
10	800	0.080	65	48	40	35	34	31	67	54	48	42	40	37	68	60	55	49	45	43	69	63	59	52	48	47
	1000	0.124	68	50	41	37	36	33	70	55	49	43	41	39	71	61	56	50	47	45	72	64	60	54	50	48
	1200	0.179	71	50	42	38	37	34	72	56	49	44	43	40	74	62	57	51	48	46	75	65	61	55	51	49
	1400	0.244	73	51	43	39	39	35	75	57	50	45	44	41	76	62	57	52	49	47	77	66	61	56	53	50
	800	0.042	56	49	43	36	33	29	60	54	49	42	39	36	63	59	55	48	45	43	65	62	58	52	48	47
	900	0.053	58	50	44	37	34	29	61	55	49	43	40	36	65	60	55	49	45	43	67	62	59	53	49	48
	1000	0.065	60	50	44	38	35	30	63	55	50	44	40	37	66	60	56	50	46	44	68	63	60	54	49	48
12	1200	0.094	62	52	46	39	36	31	65	57	52	45	41	38	69	62	57	51	47	45	71	65	61	55	50	49
	1500	0.146	65	53	47	41	37	32	69	58	53	47	43	39	72	63	59	53	48	46	74	66	63	56	52	50
	1800	0.211	68	55	49	42	38	33	71	59	54	48	44	40	74	64	60	54	50	47	76	67	64	58	53	51
	2100	0.287	70	56	50	43	39	33	73	61	56	49	45	40	76	66	62	55	51	47	78	69	65	59	54	51
	1000	0.036	59	47	39	34	33	31	61	52	46	40	39	38	63	58	54	47	45	46	64	61	58	51	49	50
	1200	0.051	63	48	40	35	35	32	65	54	47	42	41	40	66	59	55	49	47	47	68	62	59	52	51	51
	1500	0.080	67	50	41	37	37	34	69	55	49	43	43	41	71	61	56	50	50	49	72	64	61	54	53	53
14	1800	0.116	71	51	42	38	39	35	73	57	50	45	45	43	75	62	57	52	51	50	76	66	62	56	55	54
	2100	0.158	74	53	43	39	40	37	76	58	51	46	47	44	78	64	58	53	53	51	79	67	63	57	57	55
	2400	0.206	77	54	44	40	42	38	79	59	52	47	48	45	80	65	59	54	54	52	82	68	63	58	58	56
	3000	0.321	81	55	45	42	44	39	83	61	53	49	50	46	85	66	60	55	57	54	86	70	65	59	60	58
	1400	0.039	55	48	44	38	39	32	59	53	49	43	43	38	63	58	53	48	47	44	66	61	56	51	50	48
	1600	0.050	57	49	45	39	40	33	61	54	50	44	44	40	65	59	54	49	49	46	68	62	57	52	51	49
	2000	0.079	59	51	47	41	42	36	63	56	52	46	46	42	68	61	56	52	50	48	70	64	59	65	53	52
16	2400	0.113	61	52	49	43	44	38	66	58	53	48	48	44	70	63	58	53	52	50	73	66	61	56	54	54
	2800	0.154	63	54	50	45	45	40	68	59	55	50	49	46	72	64	59	55	53	52	74	67	62	58	56	56
	3200	0.202	65	55	51	46	46	41	69	60	56	51	50	47	73	65	60	56	54	54	76	68	63	59	57	57
	4000	0.315	68	57	53	48	48	44	72	62	58	53	52	50	76	67	62	58	56	56	79	70	65	61	59	60
	3000	0.020	61	57	56	51	46	42	65	61	61	56	50	45	69	65	65	61	54	48	71	67	68	64	56	50
	3500	0.027	64	59	58	52	48	44	67	63	62	57	52	47	71	67	67	63	56	50	73	69	70	66	58	52
	4000	0.036	66	61	60	54	50	45	70	65	64	59	54	49	73	69	69	64	58	52	76	71	71	67	60	54
24X18	5000	0.056	70	64	62	56	53	48	73	68	67	61	57	52	77	72	71	67	61	55	79	74	74	70	63	57
	6000	0.080	73	67	64	58	56	51	76	71	69	63	60	54	80	74	73	69	63	57	82	77	76	72	66	59
	7000	0.109	75	69	66	60	58	53	79	73	71	65	62	56	83	77	75	70	65	59	85	79	78	73	68	61
	8000	0.143	77	71	68	62	60	55	81	75	72	67	63	58	85	78	77	72	67	61	87	81	80	75	69	63

- ΔP_s is the difference in static pressure from inlet to discharge.
- Sound power levels are in decibels, re 10^{-12} watts.
- Radiated sound power is the noise transmitted through the casing walls.
- All Sound Data are based upon tests conducted in accordance with ARI 880-94 in the Laboratory at TITUS, Richardson Texas.

Figure 124: VAV Terminal Box Radiated Sound Power (Titus Single Duct Pressure Independent)

TITUS® Square and Rectangular Diffusers • Performance

Model TDC

Neck Size	Pattern	Neck Vel. / Total Press.	300 / 0.042		400 / 0.075		500 / 0.117		600 / 0.168		700 / 0.229		800 / 0.299		900 / 0.379	
6 x 6		Total CFM	75		100		125		150		175		200		225	
		NC	5		13		19		23		27		31		34	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	S1	CFM/Side	75	0	100	0	125	0	150	0	175	0	200	0	225	0
		Throw, Feet	7-9-13	—	9-11-16	—	10-12-18	—	11-13-19	—	12-15-21	—	13-16-22	—	13-17-24	—
	S2	CFM/Side	38	38	50	50	63	63	75	75	88	88	100	100	113	113
		Throw, Feet	3-5-10	3-5-10	5-7-12	5-7-12	6-9-13	6-9-13	7-10-14	7-10-14	8-11-15	8-11-15	9-12-17	9-12-17	10-12-18	10-12-18
	G2	CFM/Side	38	38	50	50	63	63	75	75	88	88	100	100	113	113
		Throw, Feet	3-5-10	3-5-10	5-7-12	5-7-12	6-9-13	6-9-13	7-10-14	7-10-14	8-11-15	8-11-15	9-12-17	9-12-17	10-12-18	10-12-18
0.25 Sq. Ft.	A3	CFM/Side	19	28	25	38	31	47	38	56	44	66	50	75	56	84
		Throw, Feet	3-4-8	3-5-9	4-6-9	4-7-10	5-7-10	6-8-11	6-8-11	7-9-13	7-8-12	8-9-14	7-9-13	8-10-15	8-9-13	9-11-16
	A4	CFM/Side	19	19	25	25	31	31	38	38	44	44	50	50	56	56
		Throw, Feet	3-4-8	3-4-8	4-6-9	4-6-9	5-7-10	5-7-10	6-8-11	6-8-11	7-8-12	7-8-12	7-9-13	7-9-13	8-9-13	8-9-13
9 x 9		Total CFM	169		225		281		338		394		450		506	
		NC	8		15		21		26		30		34		37	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	S1	CFM/Side	169	0	225	0	281	0	338	0	394	0	450	0	506	0
		Throw, Feet	11-14-20	—	13-17-24	—	15-19-27	—	17-20-29	—	18-22-31	—	19-24-34	—	20-25-36	—
	S2	CFM/Side	84	84	113	113	141	141	169	169	197	197	225	225	253	253
		Throw, Feet	5-8-15	5-8-15	7-11-18	7-11-18	9-14-20	9-14-20	11-15-22	11-15-22	13-16-23	13-16-23	14-18-25	14-18-25	15-19-27	15-19-27
	G2	CFM/Side	84	84	113	113	141	141	169	169	197	197	225	225	253	253
		Throw, Feet	5-8-15	5-8-15	7-11-18	7-11-18	9-14-20	9-14-20	11-15-22	11-15-22	13-16-23	13-16-23	14-18-25	14-18-25	15-19-27	15-19-27
0.5625 Sq. Ft.	A3	CFM/Side	42	63	56	84	70	105	84	127	98	148	113	169	127	190
		Throw, Feet	4-7-12	5-8-13	6-9-13	7-11-16	8-11-15	9-12-17	9-12-17	11-13-19	10-13-18	12-14-21	11-13-19	13-16-22	14-14-20	13-16-24
	A4	CFM/Side	42	42	56	56	70	70	84	84	98	98	113	113	127	127
		Throw, Feet	4-7-12	4-7-12	6-9-13	6-9-13	8-11-15	8-11-15	9-12-17	9-12-17	10-13-18	10-13-18	11-13-19	11-13-19	14-14-20	14-14-20
12 x 12		Total CFM	300		400		500		600		700		800		900	
		NC	10		17		23		28		32		35		38	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	S1	CFM/Side	300	0	400	0	500	0	600	0	700	0	800	0	900	0
		Throw, Feet	15-19-27	—	18-22-32	—	20-25-36	—	22-27-39	—	24-30-42	—	26-32-45	—	27-34-48	—
	S2	CFM/Side	150	150	200	200	250	250	300	300	350	350	400	400	450	450
		Throw, Feet	7-11-20	7-11-20	10-15-24	10-15-24	12-19-27	12-19-27	15-20-29	15-20-29	17-22-31	17-22-31	19-24-34	19-24-34	20-25-36	20-25-36
	G2	CFM/Side	150	150	200	200	250	250	300	300	350	350	400	400	450	450
		Throw, Feet	7-11-20	7-11-20	10-15-24	10-15-24	12-19-27	12-19-27	15-20-29	15-20-29	17-22-31	17-22-31	19-24-34	19-24-34	20-25-36	20-25-36
1.0 Sq. Ft.	A3	CFM/Side	75	113	100	150	125	188	150	225	175	263	200	300	225	338
		Throw, Feet	6-9-16	7-11-18	8-13-18	9-14-21	11-14-20	12-16-23	13-16-22	14-18-26	14-17-24	16-19-28	15-18-26	17-21-30	16-19-27	18-22-32
	A4	CFM/Side	75	75	100	100	125	125	150	150	175	175	200	200	225	225
		Throw, Feet	6-9-16	6-9-16	8-13-18	8-13-18	11-14-20	11-14-20	13-16-22	13-16-22	14-17-24	14-17-24	15-18-26	15-18-26	16-19-27	16-19-27
15 x 15		Total CFM	469		625		781		938		1094		1250		1406	
		NC	11		19		25		29		33		37		40	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	S1	CFM/Side	469	0	625	0	781	0	938	0	1094	0	1250	0	1406	0
		Throw, Feet	19-24-34	—	23-28-40	—	26-31-45	—	28-34-49	—	30-37-53	—	32-40-57	—	34-42-60	—
	S2	CFM/Side	234	234	313	313	391	391	469	469	547	547	625	625	703	703
		Throw, Feet	9-14-26	9-14-26	12-19-30	12-19-30	15-23-33	15-23-33	19-26-36	19-26-36	22-28-39	22-28-39	24-30-42	24-30-42	26-32-45	26-32-45
	G2	CFM/Side	234	234	313	313	391	391	469	469	547	547	625	625	703	703
		Throw, Feet	9-14-26	9-14-26	12-19-30	12-19-30	15-23-33	15-23-33	19-26-36	19-26-36	22-28-39	22-28-39	24-30-42	24-30-42	26-32-45	26-32-45
1.5625 Sq. Ft.	A3	CFM/Side	117	176	156	234	195	293	234	352	273	410	313	469	352	527
		Throw, Feet	8-12-20	9-13-23	11-16-23	12-18-26	13-18-25	15-21-29	16-20-28	18-23-32	17-21-30	20-24-35	18-23-32	21-26-37	20-24-34	23-28-40
	A4	CFM/Side	117	117	156	156	195	195	234	234	273	273	313	313	352	352
		Throw, Feet	8-12-20	8-12-20	11-16-23	11-16-23	13-18-25	13-18-25	16-20-28	16-20-28	17-21-30	17-21-30	18-23-32	18-23-32	20-24-34	20-24-34
18 x 18		Total CFM	675		900		1125		1350		1575		1800		2025	
		NC	12		20		26		31		35		38		41	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	S1	CFM/Side	675	0	900	0	1125	0	1350	0	1575	0	1800	0	2025	0
		Throw, Feet	22-29-41	—	27-34-48	—	31-38-54	—	34-41-59	—	36-45-63	—	39-48-68	—	41-51-72	—
	S2	CFM/Side	338	338	450	450	563	563	675	675	788	788	900	900	1013	1013
		Throw, Feet	11-17-31	11-17-31	15-22-36	15-22-36	19-28-40	19-28-40	22-31-44	22-31-44	26-33-47	26-33-47	29-36-51	29-36-51	31-38-54	31-38-54
	G2	CFM/Side	338	338	450	450	563	563	675	675	788	788	900	900	1013	1013
		Throw, Feet	11-17-31	11-17-31	15-22-36	15-22-36	19-28-40	19-28-40	22-31-44	22-31-44	26-33-47	26-33-47	29-36-51	29-36-51	31-38-54	31-38-54
2.25 Sq. Ft.	A3	CFM/Side	169	253	225	338	281	422	338	506	394	591	450	675	506	759
		Throw, Feet	9-14-24	11-16-27	13-19-27	14-22-32	16-22-31	18-25-35	19-24-34	22-27-39	21-26-36	24-29-42	22-27-39	26-32-45	24-29-41	27-33-48
	A4	CFM/Side	169	169	225	225	281	281	338	338	394	394	450	450	506	506
		Throw, Feet	9-14-24	9-14-24	13-19-27	13-19-27	16-22-31	16-22-31	19-24-34	19-24-34	21-26-36	21-26-36	22-27-39	22-27-39	24-29-41	24-29-41

See Page B96 for explanation of Side A and Side B in relation to diffuser configuration and discharge pattern.

B98

Figure 125: VAV Megazone Supply Air Diffuser Performance Data - Titus Catalog T91

TITUS® Square and Rectangular Diffusers • Performance

Model TDC

Neck Size	Pattern	Neck Velocity Total Pressure	300 0.042		400 0.075		500 0.117		600 0.168		700 0.229		800 0.299		900 0.379	
9 x 30 1.875 Sq. Ft.		Total CFM	563		750		938		1125		1313		1500		1688	
		NC	12		19		25		30		34		37		41	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	A1 B1	CFM/Side	563	0	750	0	938	0	1125	0	1313	0	1500	0	1688	0
		Throw, Feet	23-28-40	—	27-33-47	—	30-37-52	—	33-40-57	—	35-44-62	—	38-47-66	—	40-49-70	—
	A2 B2	CFM/Side	281	281	375	375	469	469	563	563	656	656	750	750	844	844
		Throw, Feet	12-19-33	12-19-33	17-25-38	17-25-38	21-30-43	21-30-43	25-33-47	25-33-47	29-36-51	29-36-51	31-38-54	31-38-54	33-41-58	33-41-58
	E2 F2	CFM/Side	84	478	113	638	141	797	169	956	197	1116	225	1275	253	1434
		Throw, Feet	9-14-26	16-22-31	13-19-30	21-25-36	16-23-33	23-29-41	19-26-37	25-31-45	23-28-40	28-34-48	24-30-42	30-36-51	26-32-45	31-38-55
	A3	CFM/Side	42	260	56	347	70	434	84	520	98	607	113	694	127	780
		Throw, Feet	9-14-23	14-21-30	13-19-27	19-24-35	16-21-30	22-27-39	19-23-33	24-30-42	20-25-35	26-32-46	22-27-38	28-35-49	23-28-40	30-37-52
	A3-2	CFM/Side	394	84	525	113	656	141	788	169	919	197	1050	225	1181	253
		Throw, Feet	20-25-36	9-14-26	24-29-42	13-19-30	27-33-46	16-22-33	29-36-51	19-26-37	32-39-55	23-28-40	34-42-59	24-30-42	36-44-63	26-32-45
	B4	CFM/Side	42	239	56	319	70	398	84	478	98	558	113	638	127	717
		Throw, Feet	9-14-23	14-21-30	13-19-27	19-24-35	16-21-30	22-27-39	19-23-33	24-30-42	20-25-35	26-32-46	22-27-38	28-35-49	23-28-40	30-37-52

Neck Size	Pattern															
9 x 36 2.250 Sq. Ft.		Total CFM	675		900		1125		1350		1575		1800		2025	
		NC	12		20		26		31		35		38		41	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	A1 B1	CFM/Side	675	0	900	0	1125	0	1350	0	1575	0	1800	0	2025	0
		Throw, Feet	25-31-44	—	29-36-51	—	33-40-57	—	36-44-63	—	39-48-68	—	42-51-72	—	44-54-77	—
	A2 B2	CFM/Side	338	338	450	450	563	563	675	675	788	788	900	900	1013	1013
		Throw, Feet	14-21-36	14-21-36	18-28-42	18-28-42	23-33-47	23-33-47	28-36-52	28-36-52	32-39-56	32-39-56	34-42-60	34-42-60	36-45-63	36-45-63
	E2 F2	CFM/Side	84	591	113	788	141	984	169	1181	197	1378	225	1575	253	1772
		Throw, Feet	10-16-28	18-24-34	14-21-33	23-28-40	18-26-37	25-31-45	21-28-40	28-34-49	25-31-43	30-37-53	27-33-46	32-40-56	28-35-49	34-42-60
	A3	CFM/Side	42	316	56	422	70	527	84	633	98	738	113	844	127	949
		Throw, Feet	10-16-25	15-23-33	14-21-29	21-27-38	17-23-33	24-30-42	21-25-36	27-33-46	22-27-39	29-35-50	24-29-42	31-38-54	25-31-44	33-40-57
	E3	CFM/Side	506	84	675	113	844	141	1013	169	1181	197	1350	225	1519	253
		Throw, Feet	22-28-39	10-16-28	26-32-46	14-21-33	29-36-51	18-26-37	32-39-56	21-28-40	35-43-60	25-31-43	37-46-65	27-33-46	39-48-69	28-3549
	B4	CFM/Side	42	295	56	394	70	492	84	591	98	689	113	788	127	886
		Throw, Feet	10-16-25	15-23-33	14-21-29	21-27-38	17-23-33	24-30-42	21-25-36	27-33-46	22-27-39	29-35-50	24-29-42	31-38-54	25-31-44	33-40-57

Neck Size	Pattern															
12 x 15 1.25 Sq. Ft.		Total CFM	375		500		625		750		875		1000		1125	
		NC	10		18		24		29		33		36		39	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	A1 B1	CFM/Side	375	0	500	0	625	0	750	0	875	0	1000	0	1125	0
		Throw, Feet	19-23-33	—	22-27-38	—	24-30-42	—	27-33-47	—	29-35-50	—	31-38-54	—	33-40-57	—
	A2 B2	CFM/Side	188	188	250	250	313	313	375	375	438	438	500	500	563	563
		Throw, Feet	10-15-27	10-15-27	14-21-31	14-21-31	17-25-35	17-25-35	21-27-38	21-27-38	24-29-41	24-29-41	25-31-44	25-31-44	27-33-47	27-33-47
	E2 F2	CFM/Side	150	225	200	300	250	375	300	450	350	525	400	600	450	675
		Throw, Feet	8-12-21	13-18-25	10-18-24	17-21-30	13-19-27	19-23-33	16-21-30	21-25-36	18-23-32	22-28-39	20-24-35	24-30-42	21-26-37	25-31-45
	A3	CFM/Side	75	150	100	200	125	250	150	300	175	350	200	400	225	450
		Throw, Feet	8-12-19	11-17-24	10-15-22	15-20-28	13-17-24	18-22-31	15-19-27	20-24-35	16-20-29	21-26-37	18-22-31	23-28-40	19-23-33	24-30-42
	E3	CFM/Side	117	129	156	172	195	215	234	258	273	301	313	344	352	387
		Throw, Feet	11-17-27	8-12-21	15-22-31	10-16-24	18-24-35	13-19-27	22-27-38	16-21-30	24-29-41	18-23-32	25-31-44	20-24-35	27-33-47	21-26-37
	B4	CFM/Side	75	113	100	150	125	188	150	225	175	263	200	300	225	338
		Throw, Feet	8-12-19	11-17-24	10-15-22	15-20-28	13-17-24	18-22-31	15-19-27	20-24-35	16-20-29	21-26-37	18-22-31	23-28-40	19-23-33	24-30-42

Neck Size	Pattern															
12 x 18 1.50 Sq. Ft.		Total CFM	450		600		750		900		1050		1200		1350	
		NC	11		19		24		29		33		37		40	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	A1 B1	CFM/Side	450	0	600	0	750	0	900	0	1050	0	1200	0	1350	0
		Throw, Feet	21-25-36	—	24-29-42	—	27-33-47	—	29-36-51	—	32-39-55	—	34-42-59	—	36-44-63	—
	A2 B2	CFM/Side	225	225	300	300	375	375	450	450	525	525	600	600	675	675
		Throw, Feet	11-17-30	11-17-30	15-23-34	15-23-34	19-27-38	19-27-38	23-30-42	23-30-42	26-32-45	26-32-45	28-34-49	28-34-49	30-36-52	30-36-52
	E2 F2	CFM/Side	150	300	200	400	250	500	300	600	350	700	400	800	450	900
		Throw, Feet	8-13-23	14-20-28	11-17-27	18-23-32	14-21-30	21-25-36	17-23-33	23-28-40	20-25-35	25-30-43	22-27-38	26-32-46	23-28-40	28-34-49
	A3	CFM/Side	75	188	100	250	125	313	150	375	175	438	200	500	225	563
		Throw, Feet	8-13-21	12-19-27	11-17-24	17-22-31	14-19-27	20-24-35	17-21-29	22-27-38	18-22-32	23-29-41	19-24-34	25-31-44	21-25-36	27-33-46
	A3-2	CFM/Side	169	141	225	188	281	234	338	281	394	328	450	375	506	422
		Throw, Feet	12-18-29	8-13-23	16-24-34	11-17-27	20-27-38	14-21-30	24-29-42	17-23-33	26-32-45	20-25-35	28-34-48	22-27-38	29-36-51	23-28-40
	B4	CFM/Side	75	150	100	200	125	250	150	300	175	350	200	400	225	450
		Throw, Feet	8-13-21	12-19-27	11-17-24	17-22-31	14-19-27	20-24-35	17-21-29	22-27-38	18-22-32	23-29-41	19-24-34	25-31-44	21-25-36	27-33-46

See Page B96 for explanation of Side A and Side B in relation to diffuser configuration and discharge pattern.

Figure 126: VAV Megazone Supply Air Diffuser Performance Data - Titus Catalog T91 (cont'd)

TITUS® Square and Rectangular Diffusers • Performance

Model TDC

Neck Size	Pattern	Neck Velocity Total Pressure	300 0.042		400 0.075		500 0.117		600 0.168		700 0.229		800 0.299		900 0.379	
		Total CFM	1050		1400		1750		2100		2450		2800		3150	
		NC	14		21		27		32		36		40		43	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
21 x 24 3.5 Sq. Ft.	A1 B1	CFM/Side	1050	0	1400	0	1750	0	2100	0	2450	0	2800	0	3150	0
		Throw, Feet	32-39-55	—	37-45-64	—	41-50-71	—	45-55-78	—	49-60-85	—	52-64-90	—	55-68-96	—
	A2 B2	CFM/Side	525	525	700	700	875	875	1050	1050	1225	1225	1400	1400	1575	1575
		Throw, Feet	17-26-45	17-26-45	23-35-53	23-35-53	29-41-59	29-41-59	35-45-64	35-45-64	40-49-70	40-49-70	43-53-74	43-53-74	45-56-79	45-56-79
	E2 F2	CFM/Side	459	591	613	788	766	984	919	1181	1072	1378	1225	1575	1378	1772
		Throw, Feet	13-20-35	22-30-43	18-27-41	28-35-50	22-32-46	32-39-56	27-35-50	35-43-61	31-38-54	38-46-66	33-41-58	41-50-71	35-43-62	43-53-75
	A3	CFM/Side	230	411	307	547	383	684	460	821	537	958	613	1095	690	1232
		Throw, Feet	13-20-32	19-29-41	17-26-37	26-33-47	22-29-41	30-37-53	26-32-45	33-41-58	28-34-49	36-44-63	30-37-52	39-47-67	32-39-55	41-50-71
	A3-2	CFM/Side	300	375	400	500	501	625	601	750	701	875	801	1000	901	1125
		Throw, Feet	18-28-45	13-20-35	25-37-52	18-27-41	31-41-58	22-32-46	37-45-64	27-35-50	40-49-69	31-38-54	42-52-74	33-41-58	45-55-78	35-43-62
	B4	CFM/Side	230	295	307	393	383	492	460	590	537	688	613	787	690	885
		Throw, Feet	13-20-32	19-29-41	17-26-37	26-33-47	22-29-41	30-37-53	26-32-45	33-41-58	28-34-49	36-44-63	30-37-52	39-47-67	32-39-55	41-50-71
		Total CFM	1313		1750		2188		2625		3063		3500		3938	
		NC	15		22		28		33		37		40		43	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
21 x 30 4.375 Sq. Ft.	A1 B1	CFM/Side	1313	0	1750	0	2188	0	2625	0	3063	0	3500	0	3938	0
		Throw, Feet	35-44-62	—	41-50-71	—	46-56-80	—	50-62-88	—	54-67-95	—	58-71-101	—	62-76-107	—
	A2 B2	CFM/Side	656	656	875	875	1094	1094	1313	1313	1531	1531	1750	1750	1969	1969
		Throw, Feet	19-29-51	19-29-51	26-39-59	26-39-59	32-46-66	32-46-66	39-51-72	39-51-72	45-55-78	45-55-78	48-59-83	48-59-83	51-62-88	51-62-88
	E2 F2	CFM/Side	459	853	613	1138	766	1422	919	1706	1072	1991	1225	2275	1376	2559
		Throw, Feet	15-22-40	25-34-48	20-30-46	32-38-56	25-36-51	36-44-62	30-40-56	39-48-68	35-43-61	42-52-74	37-46-65	45-56-79	40-49-69	48-59-84
	A3	CFM/Side	230	542	306	723	383	903	459	1084	536	1265	613	1446	689	1626
		Throw, Feet	14-22-35	22-32-46	19-29-41	29-37-53	24-32-46	34-42-59	29-35-50	37-46-65	31-38-54	40-50-70	33-41-58	43-53-75	35-43-62	46-56-80
	A3-2	CFM/Side	469	421	625	562	781	702	937	843	1093	983	1250	1124	1406	1264
		Throw, Feet	21-31-50	15-22-40	28-41-58	20-30-46	35-46-65	25-36-51	41-50-72	30-40-56	44-55-77	35-43-61	48-58-83	37-46-65	50-62-88	40-49-69
	B4	CFM/Side	230	427	306	569	383	711	459	853	536	995	613	1138	689	1280
		Throw, Feet	14-22-35	22-32-46	19-29-41	29-37-53	24-32-46	34-42-59	29-35-50	37-46-65	31-38-54	40-50-70	33-41-58	43-53-75	35-43-62	46-56-80
		Total CFM	1575		2100		2625		3150		3675		4200		4725	
		NC	15		23		29		33		37		41		44	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
21 x 36 5.25 Sq. Ft.	A1 B1	CFM/Side	1575	0	2100	0	2625	0	3150	0	3675	0	4200	0	4725	0
		Throw, Feet	39-48-68	—	45-55-78	—	50-62-88	—	55-68-96	—	60-73-104	—	64-78-111	—	68-83-118	—
	A2 B2	CFM/Side	788	788	1050	1050	1313	1313	1575	1575	1838	1838	2100	2100	2363	2363
		Throw, Feet	21-32-56	21-32-56	28-43-64	28-43-64	35-51-72	35-51-72	43-56-79	43-56-79	49-60-85	49-60-85	53-64-91	53-64-91	56-68-97	56-68-97
	E2 F2	CFM/Side	459	1116	613	1487	766	1859	919	2231	1072	2603	1225	2975	1378	3347
		Throw, Feet	16-24-43	27-37-53	22-33-50	35-43-61	27-40-56	39-48-68	33-43-62	43-53-75	38-47-67	46-57-81	41-50-71	50-61-86	43-53-76	53-65-92
	A3	CFM/Side	230	673	307	897	383	1121	460	1345	537	1569	613	1793	690	2018
		Throw, Feet	16-24-39	24-35-50	21-32-45	32-41-58	27-35-50	37-46-65	32-39-55	41-50-71	34-42-60	44-54-77	37-45-64	47-58-82	39-48-68	50-62-87
	E3	CFM/Side	676	450	901	601	1126	751	1351	901	1577	1051	1802	1201	2027	1351
		Throw, Feet	23-34-55	16-24-43	30-45-64	22-33-50	38-50-72	27-40-56	45-55-78	33-43-62	49-60-85	38-47-67	52-64-91	41-50-71	55-68-96	43-53-76
	B4	CFM/Side	230	558	307	743	383	929	460	1115	537	1301	613	1487	690	1673
		Throw, Feet	16-24-39	24-35-50	21-32-45	32-41-58	27-35-50	37-46-65	32-39-55	41-50-71	34-42-60	44-54-77	37-45-64	47-58-82	39-48-68	50-62-87
		Total CFM	2100		2800		3500		4200		4900		5600		6300	
		NC	16		24		30		34		38		42		45	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
21 x 48 7.0 Sq. Ft.	A1 B1	CFM/Side	2100	0	2800	0	3500	0	4200	0	4900	0	5600	0	6300	0
		Throw, Feet	45-55-78	—	52-64-90	—	58-71-101	—	64-78-111	—	69-85-120	—	74-90-128	—	78-96-136	—
	A2 B2	CFM/Side	1050	1050	1400	1400	1750	1750	2100	2100	2450	2450	2800	2800	3150	3150
		Throw, Feet	24-37-64	24-37-64	33-49-74	33-49-74	41-59-83	41-59-83	49-64-91	49-64-91	57-70-99	57-70-99	61-74-106	61-74-106	64-79-112	64-79-112
	E2 F2	CFM/Side	459	1641	613	2188	766	2735	919	3281	1072	3828	1225	4375	1378	4922
		Throw, Feet	19-28-50	31-43-61	25-38-58	41-50-71	32-46-65	42-51-73	38-50-71	50-61-86	44-54-77	54-66-93	47-58-82	57-71-100	50-62-87	61-75-106
	A3	CFM/Side	230	935	306	1247	383	1559	459	1870	563	2182	613	2494	689	2805
		Throw, Feet	18-28-45	27-41-58	25-37-52	37-47-67	31-41-58	43-53-75	37-45-64	47-58-82	40-49-69	51-63-89	42-52-74	55-67-95	45-55-78	58-71-101
	B3	CFM/Side	1181	459	1575	613	1969	766	2363	919	2756	1072	3150	1225	3544	1378
		Throw, Feet	40-49-70	19-28-50	46-57-81	25-38-58	52-64-90	32-46-65	57-70-99	38-58-71	62-75-107	44-54-77	68-81-114	47-58-82	70-88-121	50-62-87
	B4	CFM/Side	230	820	306	1094	383	1367	459	1641	536	1914	613	2187	689	2461
		Throw, Feet	18-28-45	27-41-58	25-37-52	37-47-67	31-41-58	43-53-75	37-45-64	47-58-82	40-49-69	51-63-89	42-52-74	55-67-95	45-55-78	58-71-101

See Page B96 for explanation of Side A and Side B in relation to diffuser configuration and discharge pattern.

Figure 127: VAV Megazone Supply Air Diffuser Performance Data - Titus Catalog T91 (cont'd)

TITUS® Square and Rectangular Diffusers • Performance

Model TDC

Neck Size	Pattern	Neck Velocity Total Pressure	300 0.042		400 0.075		500 0.117		600 0.168		700 0.229		800 0.299		900 0.379	
		Total CFM	3000		4000		5000		6000		7000		8000		9000	
		NC	17		25		31		35		39		43		46	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
30 x 48 10.0 Sq. Ft.	A1 B1	CFM/Side	3000	0	4000	0	5000	0	6000	0	8000	0	8000	0	9000	0
		Throw, Feet	54-66-94	—	62-76-108	—	70-85-121	—	76-94-133	—	83-101-143	—	88-108-153	—	94-115-163	—
	A2 B2	CFM/Side	1500	1500	2000	2000	2500	2500	3000	3000	3500	3500	4000	4000	4500	4500
		Throw, Feet	29-44-77	29-44-77	39-59-89	39-59-89	49-70-100	49-70-100	59-77-109	59-77-109	68-83-118	68-83-118	73-89-126	73-89-126	77-95-134	77-95-134
	E2 F2	CFM/Side	468	2532	624	3376	780	4220	936	5064	1092	5908	1248	6752	1404	7596
		Throw, Feet	22-34-60	37-51-73	30-45-70	49-60-84	38-55-78	54-67-94	45-60-85	60-73-103	53-65-92	64-79-112	57-70-99	69-84-120	60-74-105	73-90-127
	A3	CFM/Side	468	1266	624	1688	780	2110	936	2532	1092	2954	1248	3376	1404	3798
		Throw, Feet	22-33-54	33-49-70	30-44-62	44-57-80	37-49-70	52-63-90	44-54-76	57-70-99	47-58-82	61-75-106	51-62-88	66-80-114	54-66-94	70-85-121
	A3-2	CFM/Side	1200	900	1600	1200	2000	1500	2400	1800	2800	2100	3200	2400	3600	2700
		Throw, Feet	32-48-76	22-34-60	42-62-88	30-45-70	53-70-99	38-55-78	62-76-108	45-60-85	67-83-117	53-65-92	72-88-125	57-70-99	76-94-133	60-74-105
	B4	CFM/Side	468	1032	624	1376	780	1720	936	2064	1092	2408	1248	2752	1404	3096
		Throw, Feet	22-33-54	33-49-70	30-44-62	44-57-80	37-49-70	52-63-90	44-54-76	57-70-99	47-58-82	61-75-106	51-62-88	66-80-114	54-66-94	70-85-121

		Total CFM	3600		4800		6000		7200		8400		9600		10800	
		NC	18		25		31		36		40		44		47	
		Side	A	B	A	B	A	B	A	B	A	B	A	B	A	B
36 x 48 12.0 Sq. Ft.	A1 B1	CFM/Side	3600	0	4800	0	6000	0	7200	0	8400	0	9600	0	10800	0
		Throw, Feet	59-72-103	—	68-84-119	—	76-94-133	—	84-103-145	—	90-111-157	—	97-119-168	—	103-126-178	—
	A2 B2	CFM/Side	1800	1800	2400	2400	3000	3000	3600	3600	4200	4200	4800	4800	5400	5400
		Throw, Feet	38-48-85	38-48-85	43-65-98	43-65-98	54-77-109	54-77-109	65-85-120	65-85-120	74-91-129	74-91-129	80-98-138	80-98-138	85-104-147	85-104-147
	E2 F2	CFM/Side	677	2927	902	3902	1128	4878	1354	5854	1579	6829	1805	7805	2030	8780
		Throw, Feet	25-37-66	41-56-80	33-50-76	53-65-92	41-60-85	60-73-103	50-66-93	65-80-113	58-71-101	71-86-123	62-76-108	75-92-131	66-81-115	80-98-139
	A3	CFM/Side	677	1462	902	1949	1128	2436	1354	2923	1579	3410	1805	3898	2030	4385
		Throw, Feet	24-37-59	36-54-76	33-48-68	48-62-88	41-54-76	57-70-99	48-59-84	62-76-108	52-64-90	67-82-117	56-68-97	72-88-125	59-72-103	76-93-132
	B3	CFM/Side	1199	1199	1598	1598	1198	1198	2398	2398	2797	2797	3197	3197	3596	3596
		Throw, Feet	35-52-84	25-37-66	46-68-97	33-50-76	58-76-108	41-60-85	68-84-119	50-66-93	74-91-128	58-71-101	79-97-137	62-76-108	84-103-146	66-81-115
	B4	CFM/Side	677	1127	902	1502	1128	1878	1354	2254	1579	2629	1805	3005	2030	3380
		Throw, Feet	24-37-59	36-54-76	33-48-68	48-62-88	41-54-76	57-70-90	48-59-84	62-76-108	52-64-90	67-82-117	56-68-97	44-54-76	76-93-132	76-93-132

See Page B96 for explanation of Side A and Side B in relation to diffuser configuration and discharge pattern.

Figure 128: VAV Megazone Supply Air Diffuser Performance Data - Titus Catalog T91 (cont'd)

TITUS® 300/350 Series Grilles & Registers

Models 350ZR, 350ZF • Return • ¾" Spacing • 0° Deflection

NC-20

Core Area, Sq. Ft.	Nominal Duct Size, Inches			Core Vel. Vel. Press. Neg. SP	400 .010 .029	500 .016 .046	600 .022 .064	700 .031 .089	800 .040 .116	900 .050 .145	1000 .062 .180	1100 .075 .218	1200 .090 .261	1300 .105 .354
.12	6 × 4			CFM	48	60	72	84	95	108	120	130	143	168
				NC	—	—	—	—	12	17	20	22	25	30
.18	8 × 4	7 × 5	6 × 6	CFM	72	90	108	126	144	162	180	198	216	252
				NC	—	—	—	10	15	19	23	27	31	37
.22	10 × 4	7 × 6		CFM	88	110	132	154	176	198	220	242	264	308
				NC	—	—	—	11	16	21	25	29	32	38
.26	12 × 4	6 × 6		CFM	104	130	156	182	208	234	260	286	312	364
				NC	—	—	—	12	17	22	26	30	33	39
.30	14 × 4			CFM	120	150	180	210	240	270	300	330	360	420
				NC	—	—	—	13	18	23	27	31	34	40
.34	16 × 4	10 × 6		CFM	136	170	204	238	272	306	340	374	408	476
				NC	—	—	—	14	19	24	28	32	35	41
.46	20 × 4	14 × 6	10 × 8	CFM	184	230	276	322	368	414	460	506	552	644
				NC	—	—	10	16	22	26	30	34	37	43
.52	24 × 4	16 × 6		CFM	208	260	312	364	416	468	520	572	624	728
				NC	—	—	11	17	22	27	31	35	38	44
.69	30 × 4	14 × 8		CFM	276	345	414	483	552	621	690	759	828	966
	20 × 6	12 × 10		NC	—	—	13	19	25	29	33	37	40	46
.81	36 × 4	16 × 8		CFM	324	405	486	567	648	729	810	891	972	1134
	22 × 6	14 × 10		NC	—	—	14	21	26	30	34	38	42	48
.90	40 × 4	18 × 8	12 × 12	CFM	360	450	540	630	720	810	900	990	1080	1260
	26 × 6	16 × 10		NC	—	—	15	21	27	31	35	39	42	48
1.07	48 × 4	18 × 10		CFM	428	535	642	749	856	963	1070	1177	1284	1498
	30 × 6	14 × 12		NC	—	—	17	23	28	32	36	40	44	50
1.18	34 × 6	20 × 10	14 × 14	CFM	472	590	708	826	944	1062	1180	1298	1416	1652
	24 × 8	16 × 12		NC	—	10	17	23	28	33	37	41	44	50
1.34	36 × 6	18 × 12	16 × 14	CFM	536	670	804	938	1072	1206	1340	1474	1608	1876
				NC	—	11	18	24	29	34	38	42	45	51
1.60	30 × 8	22 × 12	16 × 16	CFM	640	800	960	1120	1280	1440	1600	1760	1920	2240
	24 × 10	18 × 14		NC	—	12	19	25	31	35	39	43	47	53
1.80	48 × 6	30 × 10	18 × 16	CFM	720	900	1080	1260	1440	1620	1800	1980	2160	2520
	36 × 8	24 × 12		NC	—	13	20	26	32	36	40	44	47	53
2.08	40 × 8	30 × 12	20 × 16	CFM	832	1040	1248	1456	1664	1872	2080	2288	2496	2912
	36 × 10	30 × 12	20 × 16	NC	—	14	21	27	33	37	41	45	48	54
2.78	36 × 12	26 × 16	22 × 20	CFM	1112	1390	1668	1946	2224	2502	2780	3058	3336	3892
	30 × 14	24 × 18		NC	—	16	23	29	35	39	43	47	51	57
3.11	48 × 10	36 × 14	26 × 18	CFM	1244	1555	1866	2177	2488	2799	3110	3421	3732	4354
	40 × 12	36 × 14	26 × 18	NC	—	17	24	30	36	40	44	48	51	57
3.61	48 × 12	30 × 18		CFM	1444	1805	2166	2527	2888	3249	3610	3971	4332	5054
	36 × 16	24 × 24		NC	10	18	25	31	37	41	45	49	52	58
4.65	48 × 16	36 × 20	30 × 24	CFM	1860	2325	2790	3255	3720	4185	4650	5115	5580	6510
				NC	11	20	27	33	38	43	47	51	54	60
5.58	48 × 18	36 × 24		CFM	2232	2790	3348	3906	4464	5022	5580	6138	6696	7812
				NC	13	21	29	35	40	44	49	52	56	62
6.25	48 × 20	30 × 30		CFM	2500	3125	3750	4375	5000	5625	6250	6875	7500	8750
				NC	14	22	29	35	41	45	49	53	56	62

NC-30
NC-40
NC-50
NC-60

- Core velocities are in feet per minute.
- All pressures are in inches of water.
- Neg. SP is negative static pressure.
- NC values are based on a room absorption of 10 dB, re 10^{-12} watts.

- Shaded dividing lines denote ranges of NC values.
- Dash (—) in space indicates NC value less than 10.

- Data were obtained from tests conducted in accordance with ISO Standard 5219, ISO Standard 3741 and ADC Test Code 1062 GRD84.

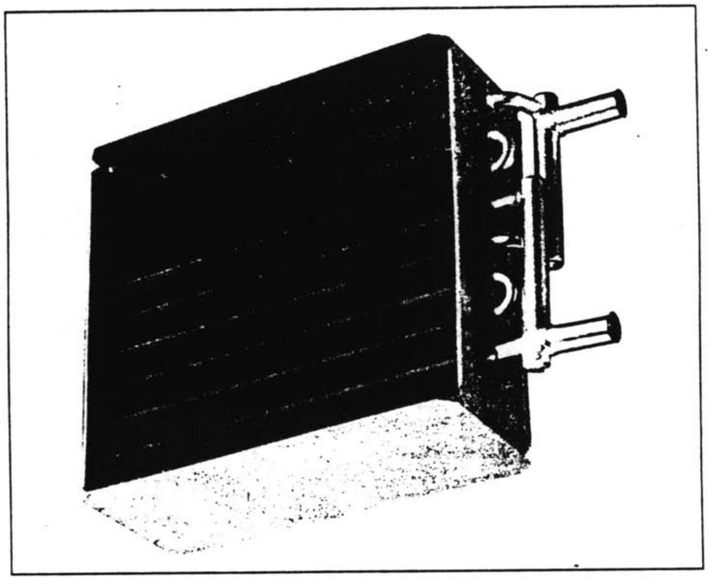
Figure 129: VAV Megazone Return Air Grill Performance Data - Titus Catalog T91 (cont'd)

Hot Water and Electric Coils for Single Duct Units

Hot Water Coil

The hot water coil is enclosed in a galvanized steel casing module to match the basic terminal unit. It is factory installed on the terminal discharge as shown on page G6.

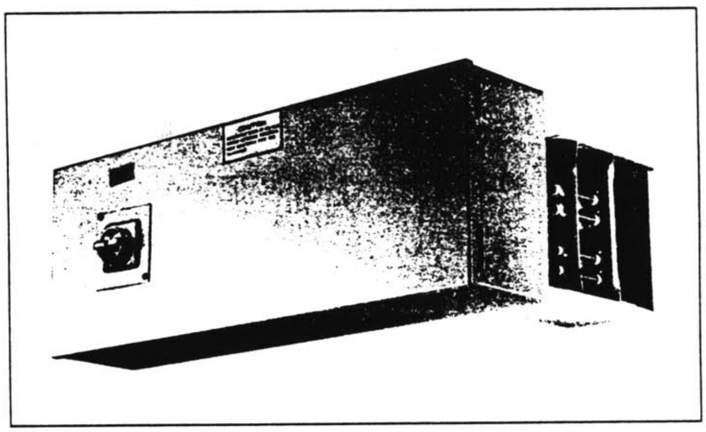
- ▶ Optional on all models of TITUS single duct terminals.
- ▶ Tubes are 1/2" OD copper.
- ▶ Connections: Single circuit is 1/2" OD male solder. Multiple circuit is 7/8" OD male solder.
- ▶ Fins are aluminum, rippled, ten per inch.
- ▶ Casing is galvanized steel.
- ▶ Downstream duct connection is slip and drive cleat.
- ▶ For capacities, see pages G33-G36.
- ▶ For dimensions, see page G24.
- ▶ Water coil valves—pneumatic and electronic are available from TITUS.



Electric Coil

TITUS electric heating coils are designed specifically for use with variable air volume terminals. They are furnished factory mounted in an integral sound attenuator.

- ▶ Furnished with TITUS Model PESV, AESV, and DESV pressure independent units. Not furnished with pressure dependent units.
- ▶ Elements are high grade nickel chrome.
- ▶ 1, 2, or 3 steps of control.
- ▶ Current characteristics available: 208/240/277 volt, 1 phase, 60 Hertz and 208 or 480 volt, 3 phase, 60 Hertz.
- ▶ Ratings, dimensions, and additional features, see page G37.



The control panel is an integral part of the coil. The panel mounts on the side of the duct and contains:

- ▶ Automatic reset thermal cut out.
- ▶ Secondary protection with replaceable heat limiter.
- ▶ Positive pressure air flow switch.
- ▶ PE switch for each step of control (pneumatic units).
- ▶ Magnetic contactor for each step of control (electronic units).
- ▶ Fuses per NEC (coils over 48 amps).
- ▶ Optional features, see page G37.

Figure 130: VAV Terminal Box Reheat Coil Physical Properties

Models: PESV, AESV, DESV ■ Hot Water Coil Data ■ 1 and 2 Row

Sizes 4-5-6

Rows/ Circuits	G.P.M.	Head Loss	Air Flow, CFM 50	100	150	200	250	300	350	400	450
	0.5	0.16	4.0	5.4	6.3	6.8	7.5	8.1	8.5	8.9	9.3
One Row	1.0	0.59	4.2	5.9	7.0	7.7	8.6	9.4	10.1	10.6	11.2
Single	2.0	1.95	4.4	6.3	7.5	8.3	9.4	10.3	11.1	11.8	12.5
Circuit	4.0	6.67	4.4	6.5	7.8	8.7	9.8	10.9	11.8	12.6	13.4
	Airside ΔP_s		0.01	0.01	0.02	0.03	0.05	0.07	0.09	0.12	0.14
	1.0	0.17	5.3	8.6	11.0	12.9	14.4	15.6	16.7	17.6	18.4
Two Rows	2.0	0.59	5.5	9.2	12.1	14.4	16.3	18.0	19.5	20.8	22.0
Multi-	4.0	1.95	5.6	9.5	12.7	15.3	17.6	19.6	21.4	23.0	24.4
Circuit	5.0	2.89	5.6	9.6	12.8	15.5	17.9	19.9	21.8	23.5	25.0
	Airside ΔP_s		0.01	0.02	0.04	0.07	0.10	0.13	0.18	0.22	0.27

Sizes 7-8

Rows/ Circuits	G.P.M.	Head Loss	Air Flow, CFM 100	200	300	400	500	600	700	800	900
	1.0	0.80	6.9	9.2	10.7	12.2	13.4	14.5	15.3	16.1	16.8
One Row	2.0	2.71	7.2	9.9	11.7	13.6	15.1	16.4	17.6	18.6	19.5
Single	4.0	9.23	7.4	10.3	12.3	14.4	16.1	17.7	19.0	20.2	21.3
Circuit	6.0	19.00	7.5	10.5	12.5	14.7	16.5	18.1	19.6	20.9	22.0
	Airside ΔP_s		0.01	0.02	0.04	0.07	0.10	0.14	0.19	0.24	0.30
	1.0	0.23	9.4	14.3	17.6	20.1	21.9	23.4	24.7	25.7	26.6
Two Rows	3.0	1.64	10.1	16.5	21.2	25.0	28.1	30.8	33.1	35.1	37.0
Multi-	5.0	4.01	10.3	17.0	22.2	26.3	29.9	32.9	35.6	38.0	40.2
Circuit	7.0	7.28	10.3	17.2	22.6	27.0	30.7	34.0	36.9	39.5	41.8
	Airside ΔP_s		0.01	0.04	0.08	0.13	0.20	0.27	0.36	0.46	0.56

Sizes 9-10

Rows/ Circuits	G.P.M.	Head Loss	Air Flow, CFM 200	300	400	500	600	700	800	900	1000
	1.0	0.14	10.7	12.3	13.5	14.8	15.9	16.8	17.6	18.3	19.0
One Row	2.0	0.50	11.7	13.8	15.3	17.0	18.5	19.8	21.0	22.0	23.0
Multi-	4.0	1.67	12.4	14.7	16.5	18.5	20.3	21.9	23.4	24.7	25.9
Circuit	6.0	3.42	12.6	15.1	16.9	19.1	21.1	22.8	24.3	25.8	27.1
	Airside ΔP_s		0.01	0.02	0.04	0.05	0.07	0.10	0.12	0.15	0.18
	1.0	0.08	15.7	19.4	22.1	24.2	25.9	27.3	28.5	29.5	30.3
Two Rows	3.0	0.70	18.1	23.6	28.0	31.7	34.9	37.7	40.1	42.2	44.2
Multi-	5.0	1.69	18.7	24.7	29.7	33.9	37.6	40.8	43.7	46.4	48.8
Circuit	7.0	3.05	19.0	25.2	30.4	34.9	38.9	42.4	45.6	48.5	51.1
	Airside ΔP_s		0.02	0.04	0.07	0.10	0.14	0.18	0.23	0.29	0.35

Size 12

Rows/ Circuits	G.P.M.	Head Loss	Air Flow, CFM 200	400	600	800	1000	1200	1400	1600	1800
	1.0	0.18	12.5	16.2	18.4	20.6	22.2	23.6	24.7	25.6	26.4
One Row	2.0	0.66	13.7	18.4	21.4	24.5	26.9	28.9	30.7	32.2	33.6
Multi-	4.0	2.18	14.4	19.8	23.4	27.1	30.2	32.8	35.1	37.2	39.0
Circuit	6.0	4.45	14.7	20.3	24.2	28.2	31.5	34.4	37.0	39.3	41.3
	Airside ΔP_s		0.01	0.02	0.04	0.07	0.10	0.14	0.19	0.24	0.30
	1.0	0.11	17.3	25.0	29.5	32.5	34.7	36.4	37.8	38.9	39.8
Two Rows	3.0	0.91	19.6	31.3	39.5	45.8	50.9	55.1	58.6	61.7	64.4
Multi-	5.0	2.19	20.2	32.9	42.3	49.8	56.0	61.2	65.8	69.8	73.3
Circuit	7.0	3.94	20.4	33.7	43.7	51.8	58.6	64.4	69.5	74.0	78.0
	Airside ΔP_s		0.01	0.04	0.08	0.13	0.20	0.27	0.36	0.46	0.56

Figure 131: VAV Terminal Box Reheat Coil Performance Data

Models: PESV, AESV, DESV ■ Hot Water Coil Data ■ 1 and 2 Row

Size 14

Rows/ Circuits	G.P.M.	Head Loss	Air Flow, CFM 400	700	1000	1300	1600	1900	2200	2500	2800
One Row Single Circuit	1.0	0.06	18.9	22.3	24.9	27.0	28.6	29.9	31.0	31.9	32.7
	2.0	0.27	21.9	26.8	30.7	34.2	36.9	39.2	41.1	42.8	44.3
	4.0	0.89	23.8	29.9	35.0	39.5	43.4	46.6	49.4	51.9	54.1
	6.0	1.80	24.6	31.1	36.7	41.8	46.1	49.8	53.1	56.0	58.6
	Airside Δ P_s		0.01	0.03	0.05	0.08	0.12	0.17	0.21	0.27	0.33
Two Rows Multi-Circuit	1.0	0.04	27.5	34.4	38.3	40.9	42.8	44.2	45.3	46.1	46.9
	3.0	0.53	34.5	48.1	57.6	64.8	70.5	75.1	79.0	82.3	85.2
	5.0	1.27	36.3	52.1	63.8	72.9	80.5	86.8	92.2	97.0	101.2
	7.0	2.27	37.1	54.0	66.8	77.1	85.7	93.0	99.4	105.0	110.0
	Airside Δ P_s		0.02	0.05	0.10	0.16	0.23	0.31	0.41	0.51	0.63

Size 16

Rows/ Circuits	G.P.M.	Head Loss	Air Flow, CFM 600	1000	1400	1800	2200	2600	3000	3400	3800
One Row Single Circuit	1.0	0.07	23.6	26.9	29.9	32.0	33.6	34.9	36.0	36.9	37.6
	2.0	0.29	28.1	33.3	38.2	41.9	44.9	47.4	49.4	51.2	52.8
	4.0	0.98	31.1	37.8	44.5	49.7	54.0	57.7	60.9	63.7	66.2
	6.0	1.98	32.3	39.7	47.1	53.1	58.1	62.4	66.2	69.5	72.5
	Airside Δ P_s		0.02	0.04	0.07	0.11	0.16	0.21	0.27	0.34	0.41
Two Rows Multi-Circuit	1.0	0.01	32.7	38.3	41.5	43.5	44.9	46.0	46.8	47.5	48.0
	3.0	0.17	45.4	59.2	68.5	75.3	80.7	85.0	88.5	91.5	94.1
	5.0	0.44	49.1	66.1	78.4	87.9	95.5	101.9	107.2	111.9	115.9
	7.0	0.78	50.8	69.6	83.6	94.6	103.7	111.4	118.0	123.7	128.8
	Airside Δ P_s		0.03	0.07	0.13	0.21	0.30	0.40	0.51	0.64	0.78

Size 24 X 16

Rows/ Circuits	G.P.M.	Head Loss	Air Flow, CFM 600	1200	1800	2400	3000	3600	4200	4800	5400
One Row Multi-Circuit	1.0	0.09	29.4	35.1	38.4	41.2	43.1	44.6	45.7	46.6	47.4
	2.0	0.39	35.5	45.0	51.2	56.7	60.8	64.1	66.8	69.1	71.1
	4.0	1.29	39.4	52.1	61.0	69.3	75.8	81.3	86.0	90.0	93.5
	6.0	2.59	40.9	55.0	65.2	74.8	82.6	89.2	94.9	99.9	104.4
	Airside Δ P_s		0.01	0.02	0.05	0.08	0.12	0.17	0.22	0.27	0.34
Two Rows Multi-Circuit	1.0	0.01	38.0	46.6	50.3	52.3	53.6	54.5	55.2	55.7	56.2
	3.0	0.23	52.2	76.1	90.4	100.1	107.2	112.7	117.0	120.6	123.6
	5.0	0.57	55.9	85.8	105.6	120.0	131.2	140.1	147.5	153.7	159.0
	7.0	1.02	57.6	90.6	113.5	130.8	144.6	155.9	165.4	173.5	180.6
	Airside Δ P_s		0.01	0.04	0.09	0.15	0.23	0.31	0.41	0.52	0.64

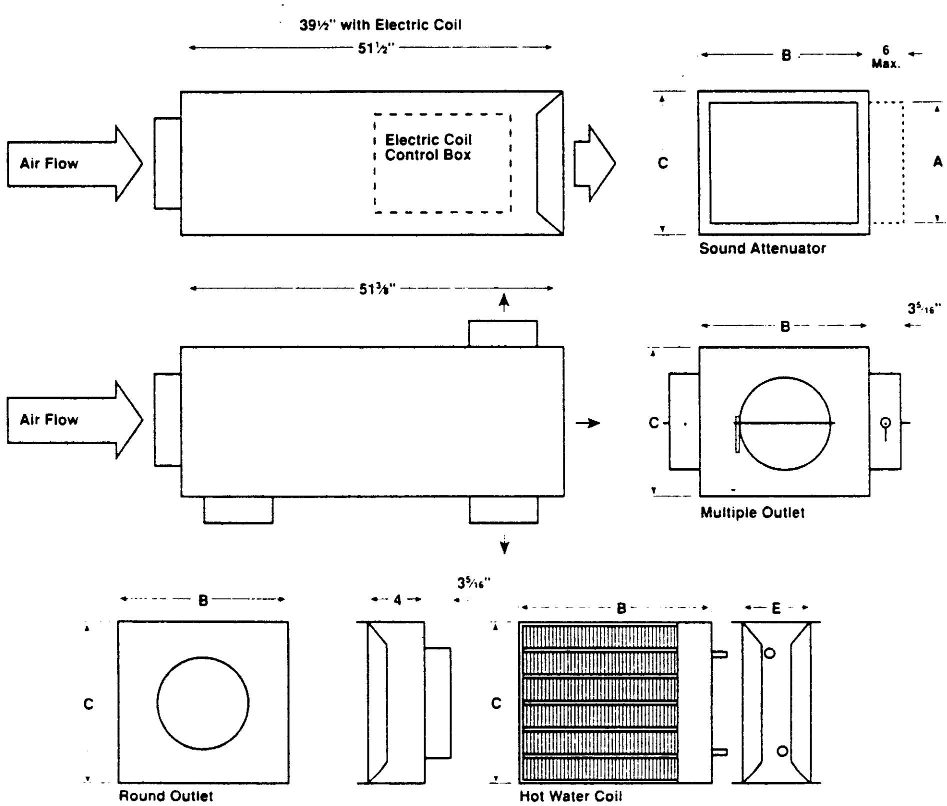
- Hot water capacities are in MBH.
- Data are based upon 180°F entering water and 65°F entering air.
- HD (head) loss is in feet of water.
- Tables are based upon a temperature difference of 115°F between entering air and entering water. For other temperature differences, multiply MBH values by factors below.
- Air temperature rise = 927 x MBH / CFM.
- Water temperature drop = 2.04 x MBH / G.P.M.
- Connections: All coils are 5/8" O.D. male solder
- Coils are not for steam application. Contact your TITUS representative for steam coil data.

Correction Factors For Other Entering Conditions:

Δ T	50	60	70	80	90	100	115	125	140	150
Factor	0.44	0.52	0.61	0.70	0.79	0.88	1.00	1.07	1.20	1.30

Figure 132: VAV Terminal Box Reheat Coil Performance Data (continued)

Single Duct Units ▪ Accessory Modules



Inlet Size	B	C	E	Rnd. Outlet Size	Multiple Outlets
4, 5, 6	12	8	5	4, 5, 6	2@6"
7, 8	12	10	5	7, 8	3@8"
9, 10	14	12½	5	9, 10	3@8"
12	16	15	5	12	4@8"
14	20	17½	7½	14	NA
16	24	18	7½	16	NA
24 x 16	28	18	5	NA	NA

- ▶ Symbol NA means accessory module is not available in that size.
- ▶ Multiple outlets have manual dampers with locking quadrants.
- ▶ Outlet collar diameters are 1/8" less than the nominal sizes shown.
- ▶ Water coil connections: Single circuit is ½" OD male solder. Multiple circuit is ⅞" OD male solder.
- ▶ Electric heating coils are not available on pressure dependent terminals.
- ▶ Dimensions are in inches.

Figure 133: VAV Terminal Box Reheat Coil Dimensions

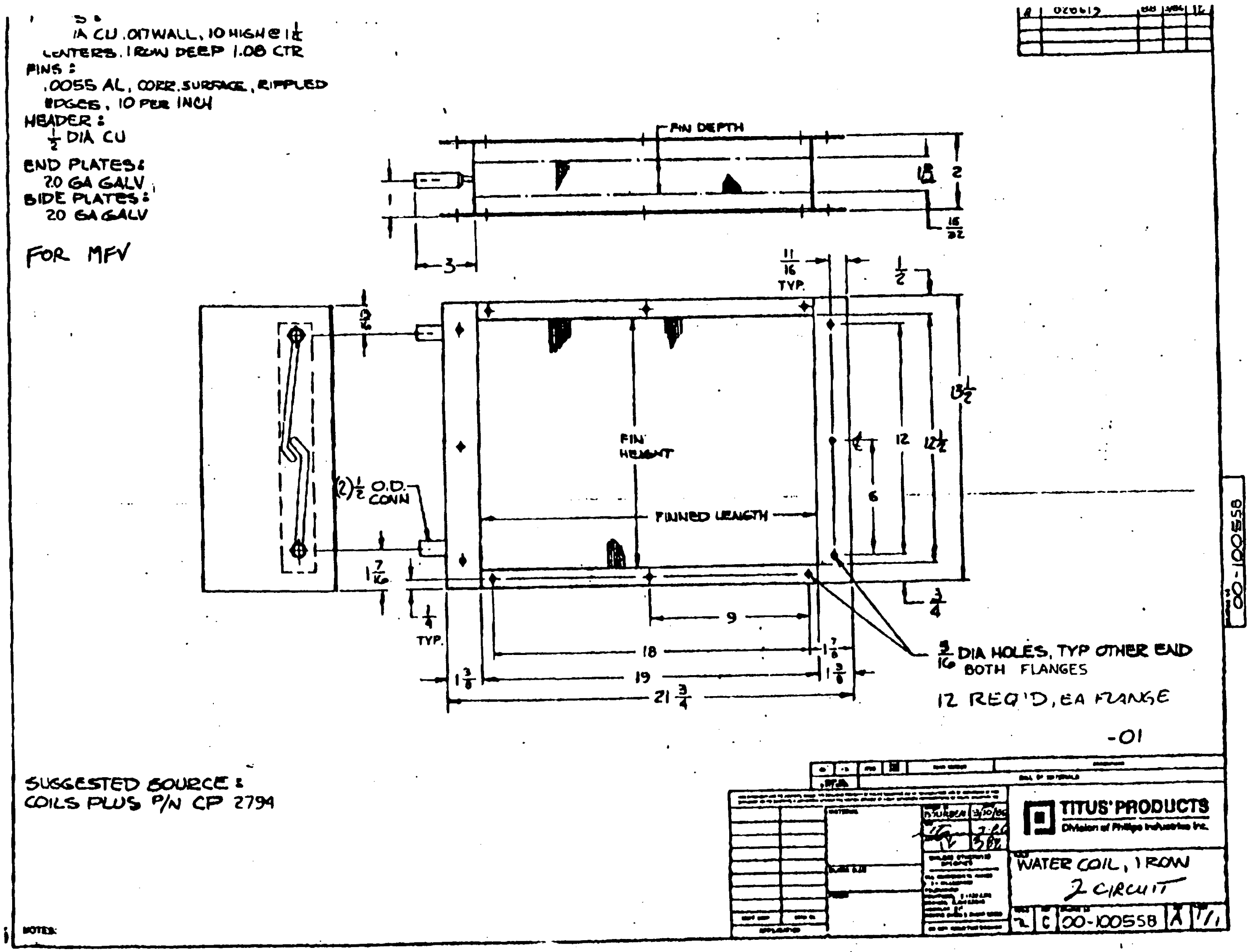


Figure 134: VAV Terminal Box Reheat Coil - Titus Shop Drawing 1

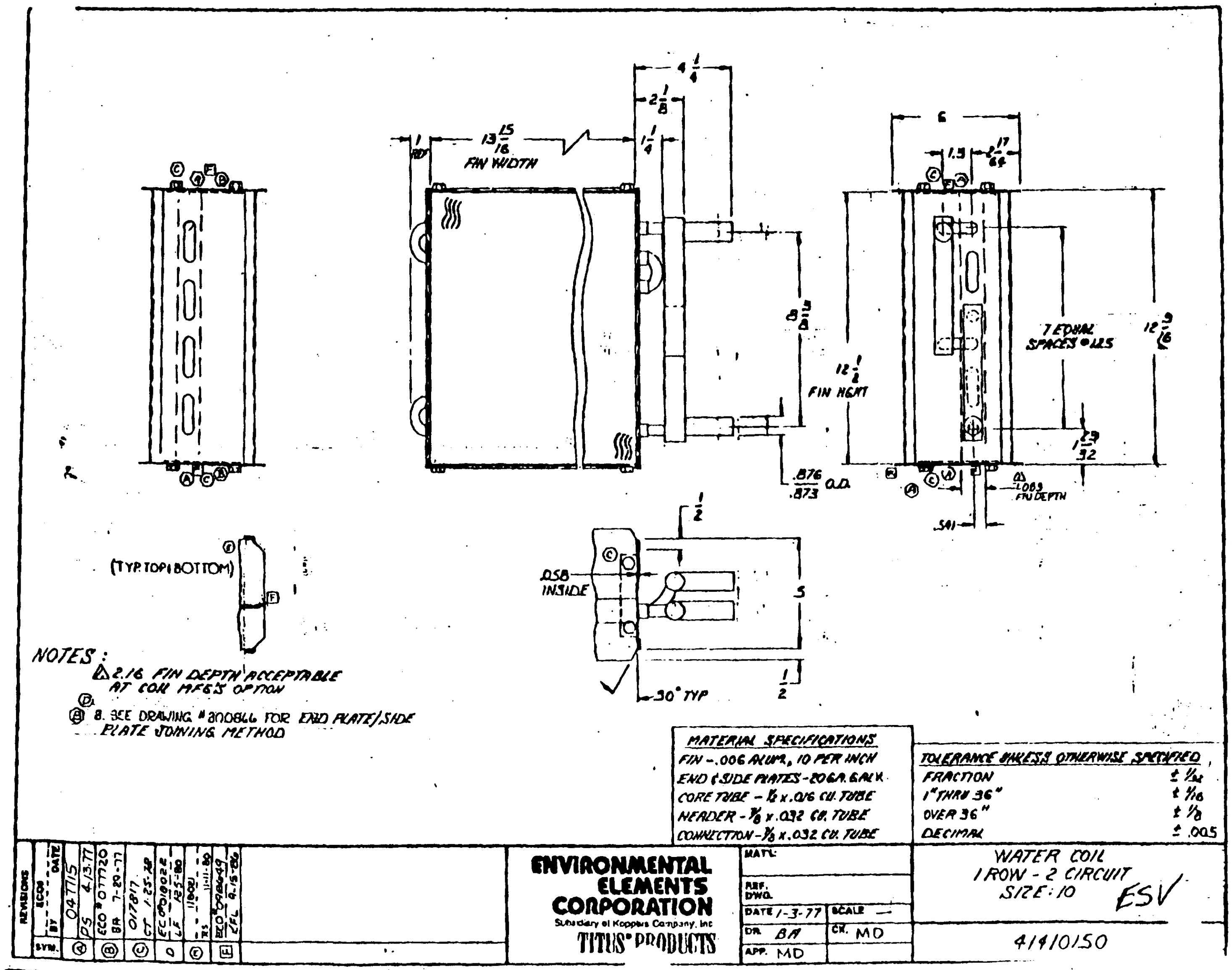


Figure 135: VAV Terminal Box Reheat Coil - Titus Shop Drawing 2

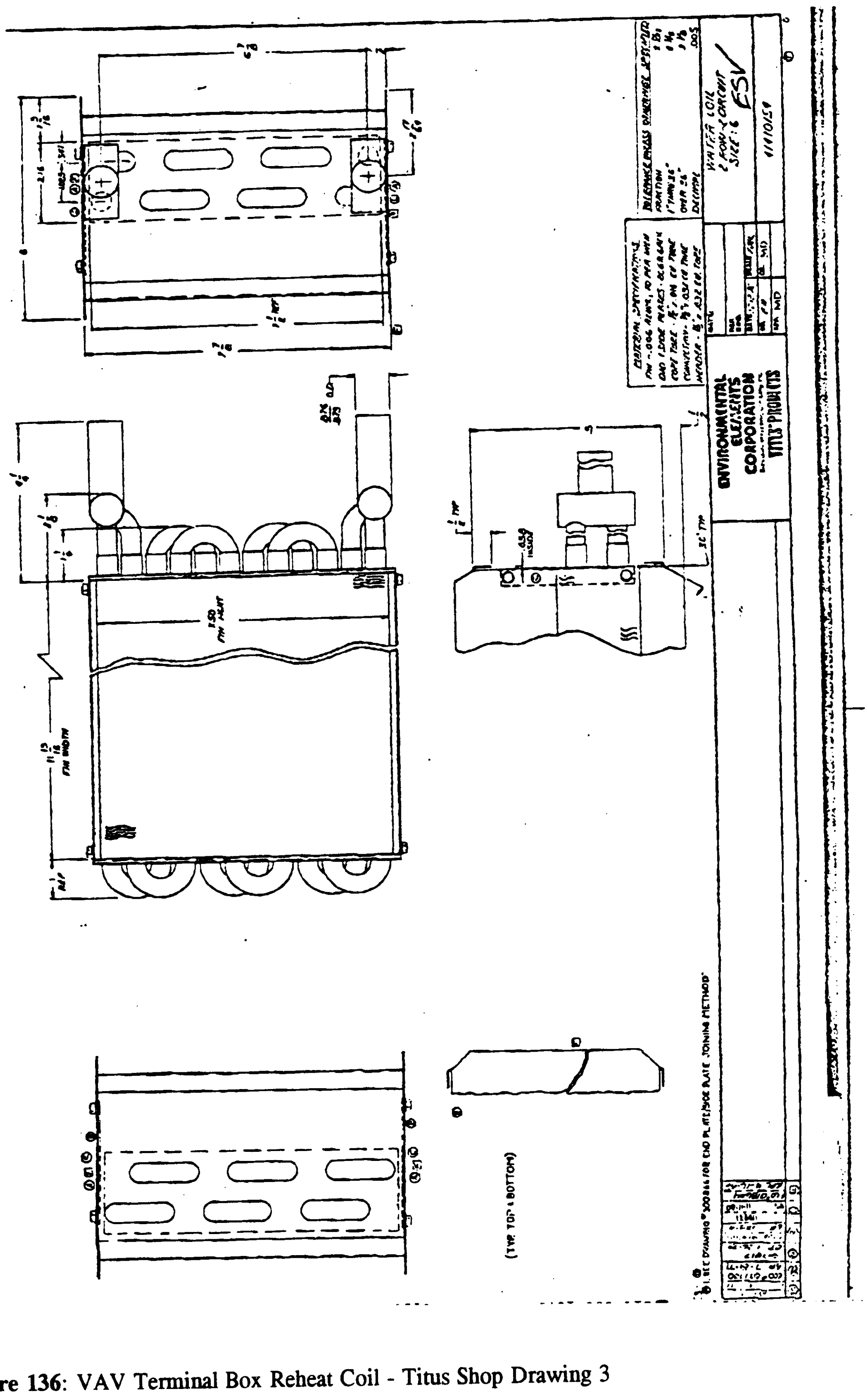
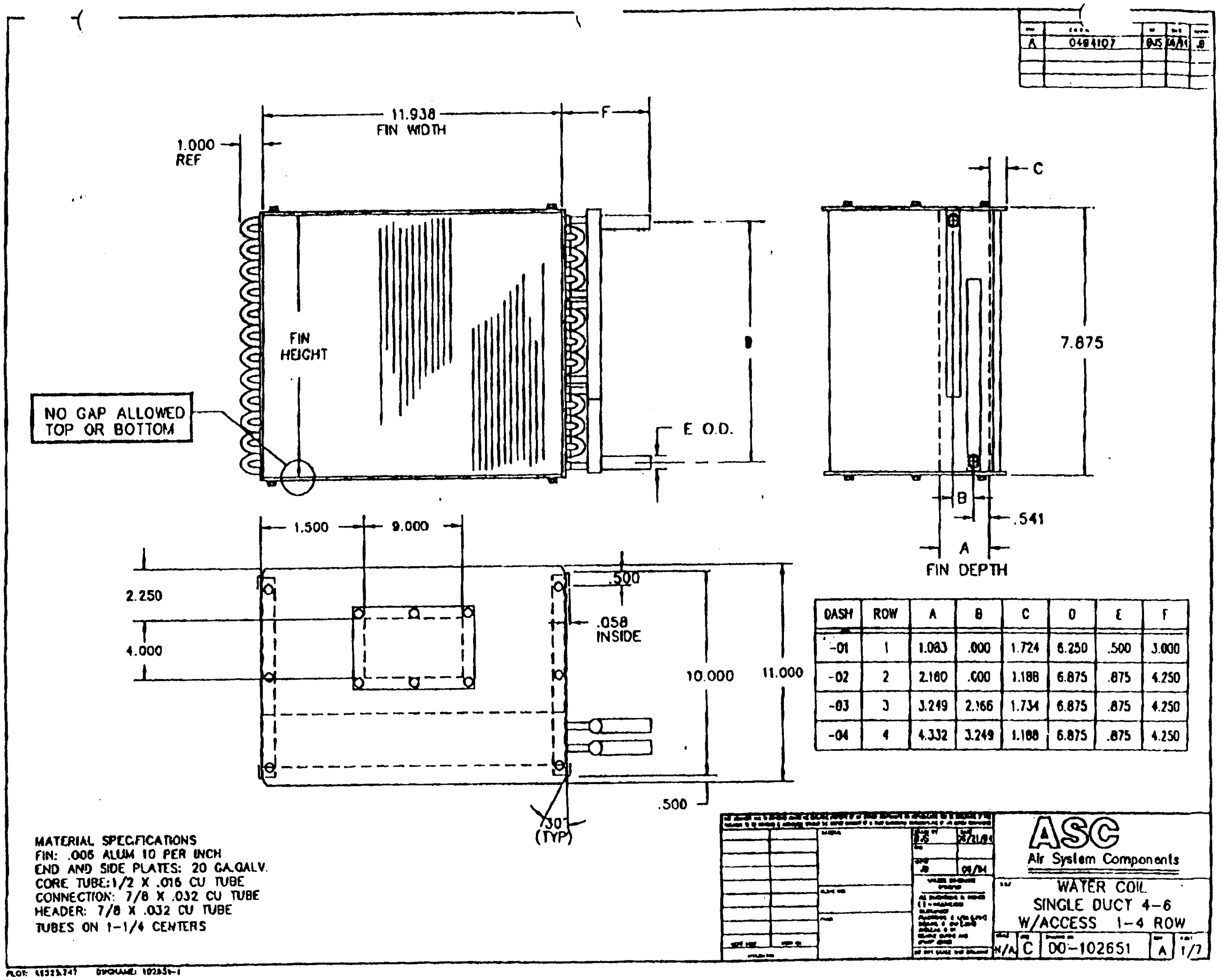


Figure 136: VAV Terminal Box Reheat Coil - Titus Shop Drawing 3



DASH	ROW	A	B	C	D	E	F
-01	1	1.083	.000	1.724	6.250	.500	3.000
-02	2	2.160	.000	1.188	6.875	.875	4.250
-03	3	3.249	2.166	1.734	6.875	.875	4.250
-04	4	4.332	3.249	1.188	6.875	.875	4.250

Figure 137: VAV Terminal Box Reheat Coil - Titus Shop Drawing 4

Models: PESV, AESV, DESV ■ Application Data ■ Minimum Pressures

Inlet Size	CFM	Velocity Press. ΔV_{ps}	Basic Unit ΔP_s	Basic + Atten. ΔP_s	Basic + Mult.-Out ΔP_s	Basic + Rd. Outlet ΔP_s	Basic + 1 R - Coil ΔP_s	Basic + 2 R - Coil ΔP_s	Basic + 3 R - Coil ΔP_s	Basic + 4 R - Coil ΔP_s	Electric Heater ΔP_s
4	100	0.080	0.006	0.007	0.007	0.011	0.013	0.020	0.026	0.032	0.015
	150	0.181	0.014	0.016	0.017	0.025	0.030	0.044	0.059	0.073	0.033
	200	0.322	0.025	0.028	0.030	0.044	0.053	0.078	0.104	0.130	0.058
	250	0.503	0.039	0.043	0.047	0.069	0.083	0.123	0.163	0.203	0.091
5	150	0.072	0.022	0.024	0.028	0.033	0.044	0.052	0.066	0.081	0.033
	200	0.129	0.039	0.043	0.049	0.058	0.078	0.092	0.118	0.144	0.058
	300	0.289	0.088	0.096	0.111	0.131	0.175	0.208	0.265	0.323	0.131
	350	0.394	0.119	0.130	0.151	0.178	0.238	0.282	0.361	0.440	0.178
6	200	0.059	0.044	0.049	0.055	0.071	0.088	0.097	0.123	0.149	0.058
	300	0.133	0.099	0.109	0.125	0.160	0.199	0.219	0.277	0.335	0.131
	400	0.236	0.177	0.194	0.221	0.284	0.353	0.390	0.493	0.595	0.233
	450	0.299	0.223	0.246	0.280	0.360	0.447	0.493	0.623	0.753	0.295
7	300	0.070	0.050	0.056	0.064	0.074	0.097	0.112	0.142	0.172	0.071
	400	0.125	0.089	0.099	0.113	0.132	0.173	0.200	0.253	0.307	0.126
	600	0.282	0.201	0.222	0.254	0.298	0.388	0.450	0.570	0.690	0.284
	650	0.331	0.236	0.261	0.298	0.349	0.456	0.528	0.669	0.810	0.334
8	350	0.052	0.039	0.043	0.048	0.065	0.103	0.123	0.164	0.205	0.097
	500	0.105	0.079	0.088	0.099	0.133	0.209	0.252	0.335	0.419	0.197
	700	0.207	0.155	0.172	0.193	0.260	0.410	0.494	0.657	0.821	0.387
	900	0.342	0.257	0.284	0.319	0.430	0.678	0.817	1.087	1.357	0.640
9	500	0.069	0.056	0.061	0.071	0.085	0.111	0.143	0.183	0.226	0.089
	650	0.117	0.094	0.103	0.119	0.144	0.188	0.242	0.309	0.381	0.151
	800	0.177	0.142	0.156	0.181	0.218	0.284	0.366	0.469	0.577	0.228
	1050	0.306	0.245	0.269	0.311	0.375	0.490	0.631	0.807	0.995	0.393
10	600	0.060	0.045	0.051	0.057	0.075	0.125	0.171	0.229	0.290	0.128
	800	0.107	0.080	0.090	0.101	0.133	0.222	0.304	0.406	0.515	0.228
	1100	0.203	0.151	0.171	0.190	0.251	0.420	0.575	0.768	0.974	0.432
	1400	0.328	0.245	0.277	0.308	0.407	0.680	0.931	1.245	1.578	0.699
12	900	0.064	0.053	0.058	N/A	0.085	0.128	0.193	0.260	0.325	0.118
	1200	0.113	0.094	0.103	N/A	0.151	0.227	0.343	0.463	0.578	0.209
	1500	0.177	0.146	0.161	N/A	0.236	0.355	0.535	0.723	0.903	0.327
	2100	0.347	0.287	0.315	N/A	0.462	0.695	1.049	1.416	1.770	0.641
14	1200	0.063	0.051	0.057	N/A	0.085	0.112	0.129	0.220	0.276	0.089
	1600	0.113	0.091	0.101	N/A	0.151	0.199	0.230	0.392	0.490	0.159
	2000	0.176	0.143	0.157	N/A	0.236	0.311	0.359	0.612	0.765	0.248
	3000	0.396	0.321	0.354	N/A	0.530	0.700	0.808	1.378	1.722	0.559
16	1500	0.056	0.044	0.050	N/A	0.075	0.108	0.166	0.224	0.281	0.079
	2000	0.100	0.079	0.088	N/A	0.133	0.192	0.295	0.397	0.500	0.140
	3000	0.225	0.177	0.199	N/A	0.300	0.433	0.663	0.894	1.125	0.316
	4000	0.401	0.315	0.354	N/A	0.533	0.769	1.179	1.589	1.999	0.562
24X16	2500	0.038	0.014	0.015	N/A	N/A	0.087	0.151	0.218	0.282	0.079
	4000	0.096	0.036	0.038	N/A	N/A	0.222	0.387	0.557	0.722	0.203
	6000	0.216	0.080	0.086	N/A	N/A	0.500	0.870	1.253	1.623	0.458
	8000	0.384	0.143	0.152	N/A	N/A	0.889	1.547	2.228	2.886	0.814

- Minimum ΔP_s is the lowest static pressure difference (damper wide open).
- ΔP_s is the difference in static pressure across the assembly.
- To obtain Total Pressure, add the Velocity Pressure for a given CFM to the Static Pressure drop (ΔP_s) of the desired ESV configuration.

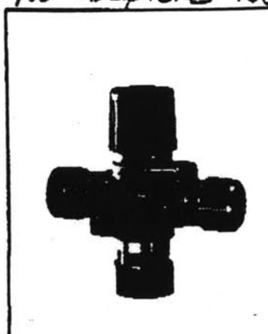
Figure 138: VAV Terminal Box Minimum Pressures (Titus Single Duct Pressure Independent)

V⌐'VMP Electronic Two-Way and Three-Way Valves

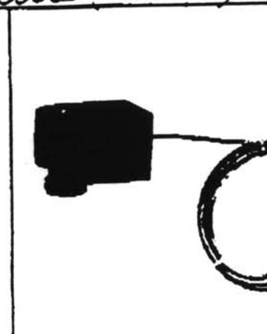
LANDIS & GYR

Landis & Gyr Powers, Inc.

\# No Adaptors Needed (old style)



VMP42.13(2)



SOS81/1008

Description

The Powers VE VMP electronic valves are designed to control the flow of water and glycol solutions. The electric actuator receives a 24 Vac floating control signal to control the valve. By removing the cap from the bottom by-pass port (III), this valve assembly is converted to a three-way valve.

Design features include:

- Maintenance-free actuator with reversible synchronous motor
- Magnetic hysteresis coupling protects against overload
- Manual adjustment on actuator
- Stainless steel stem and plug
- No tools required to assemble actuator to the valve
- Actuator easily removed for service

Application

The VMP is used in HVAC installations for the control of the water side of terminal units such as induction units, fan coil units and small reheat coils. It is suitable for use ir ___ pipe or three-pipe systems.

Specifications

Actuator

Operating Voltage	
60 Hz	24 Vac – 15% to + 5%
50 Hz	24 Vac – 20% to + 10%
Power Consumption	1.3 VA
Running Time	
at 60 Hz	125 s
at 50 Hz	150 s
Nominal Stroke	7/32 in. (5.5 mm)
Ambient Temperature	
Operation	32° to 122°F (0° to 50°C)
Transport and Storage	-13° to 149°F (-25° to 65°C)
Dimensions and Weight	Refer to Fig. 1 and Table 3.

Valve Body

Body Style	Globe Screwed
Line Size/Capacity	Refer to Tables 1 and 2.
Medium	Water, Glycol to 50%
Body	Bronze
Trim	Stainless Steel
Packing	Double O-Ring
Rangeability	
1/2" Valves	50:1
3/4" Valves	100:1
Flow Characteristics	Equal Percentage (II to I) Linear (III to I)
Leakage Rate	0.02% of C_v
Max. Medium Temp.	41°–230°F (5°–110°C)
Max. Operating Pressure	232 psi (1600 kPa)
Max. Pressure Differential for Modulating Service	58 psi (400 kPa)
Close-off Pressure	Refer to Table 1.
Dimensions and Weight	Refer to Fig. 2 & Table 3.

Product Numbers

VALVE SIZE	C_v (K_{vs})	Order Number VALVE	Order Number ACTUATOR
1/2"	0.29 (0.25)	VMP42.09(2)	SQS81/1008
1/2"	0.47 (0.4)	VMP42.10(2)	SQS81/1008
1/2"	0.74 (0.63)	VMP42.11(2)	SQS81/1008
1/2"	1.17 (1)	VMP42.12(2)	SQS81/1008
3/4"	1.87 (1.6)	VMP42.13(2)	SQS81/1008
3/4"	2.92 (2.5)	VMP42.14(2)	SQS81/1008

Table 1. Product Information.

'ALVE	C_v (K_{vs})		Close-Off psig	(kPa)	Max. ΔP psig	(kPa)	External Thread on Valve Body
VMP42.09(2)	0.29	(0.25)	58	(400)	58	(400)	1/2" – 14NPT
VMP42.10(2)	0.47	(0.4)	58	(400)	58	(400)	1/2" – 14NPT
VMP42.11(2)	0.74	(0.63)	58	(400)	58	(400)	1/2" – 14NPT
VMP42.12(2)	1.17	(1)	58	(400)	58	(400)	1/2" – 14NPT
VMP42.13(2)	1.87	(1.6)	58	(400)	58	(400)	3/4" – 14NPT

Figure 139: VAV Box Reheat Coil Control Valve Description - Landis & Gyr VE-VMP

Table 2. Maximum Water Capacities – U.S. Gallons per Minute.

VALVE	PRESSURE DIFFERENTIAL psi											
	C_v1	2	4	6	8	10	15	20	25	30	40	50
VMP42.09(2)	0.29	0.41	0.58	0.71	0.82	0.92	1.12	1.30	1.45	1.59	1.83	2.05
VMP42.10(2)	0.47	0.66	0.94	1.15	1.33	1.49	1.82	2.10	2.35	2.57	2.97	3.32
VMP42.11(2)	0.74	1.05	1.48	1.81	2.09	2.34	2.87	3.31	3.70	4.05	4.68	5.23
VMP42.12(2)	1.17	1.65	2.34	2.87	3.31	3.70	4.53	5.23	5.85	6.41	7.40	8.27
VMP42.13(2)	1.87	2.64	3.74	4.58	5.29	5.91	7.24	8.36	9.35	10.24	11.83	13.22
VMP42.14(2)	2.93	4.14	5.86	7.18	8.29	9.27	11.35	13.10	14.65	16.05	18.53	20.72

Figure 1. Actuator Dimensions.

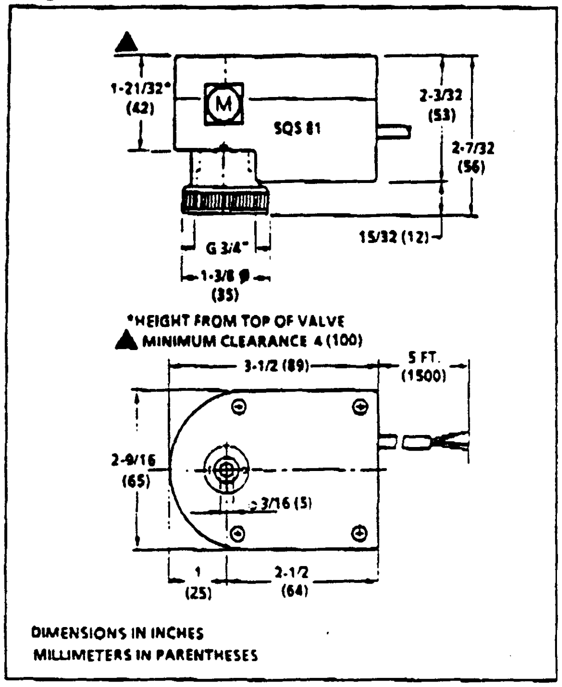
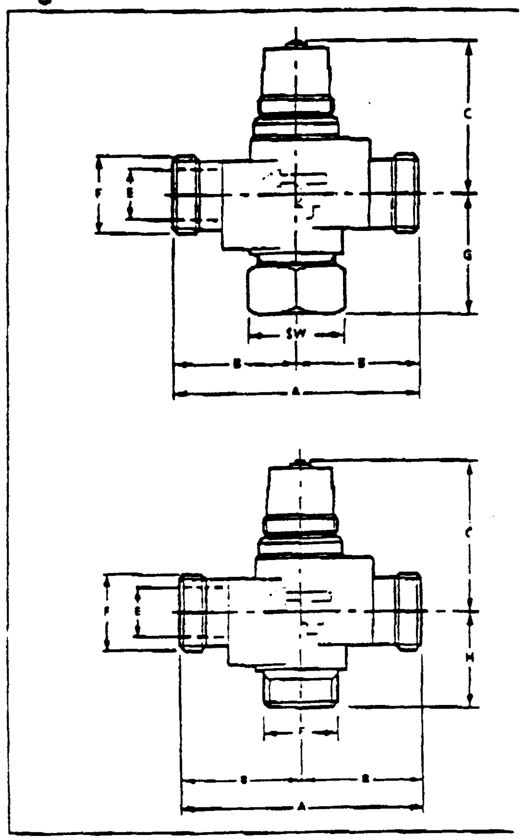


Figure 2. Valve Dimensions.



Valve Assembly Height

VALVE SIZE in. (mm)	2-WAY in. (mm)	3-WAY in. (mm)
1/2 (15)	5-3/16 (131)	4-15/16 (124)
3/4 (20)	5-9/16 (141)	5-5/16 (134)

Table 3. Dimensions.

Assembly	C_v	A	B	C	E	F	G	SW	H	Weight of Assembly
VMP42.09(2)	0.29	3-5/16 (84)	1-11/16 (42)	1-7/8 (47)	7/16 (11.5)	1/2 - 14 NPT	1-11/16(42)	15/16 (24)	1-3/8 (35)	1.4 lb (0.64 k
VMP42.10(2)	0.47	3-5/16 (84)	1-11/16 (42)	1-7/8 (47)	7/16 (11.5)	1/2 - 14 NPT	1-11/16(42)	15/16 (24)	1-3/8 (35)	1.4 lb (0.64 k
VMP42.11(2)	0.74	3-5/16 (84)	1-11/16 (42)	1-7/8 (47)	7/16 (11.5)	1/2 - 14 NPT	1-11/16(42)	15/16 (24)	1-3/8 (35)	1.4 lb (0.64 k
VMP42.12(2)	1.17	3-5/16 (84)	1-11/16 (42)	1-7/8 (47)	7/16 (11.5)	1/2 - 14 NPT	1-11/16(42)	15/16 (24)	1-3/8 (35)	1.4 lb (0.64 k
VMP42.13(2)	1.87	4 (101)	2 (50.5)	2(51)	11/16 (17)	3/4 - 14 NPT	1-7/8 (48)	1-3/16 (30)	1-5/8 (41)	2.55 lb (1.16
VMP42.14(2)	2.92	4 (101)	2 (50.5)	2(51)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 140: VAV Box Reheat Coil Control Valve Capacity - Landis & Gyr VE-VMP

Perimeter Heat Tally - Zone by Zone and Floor by Floor

Zone	Room	Unit ID	Perimeter Heat: Length FT	Perimeter Heat: Cap MBH/FT	Perimeter Heat: Output MBH	Perimeter Heat per Floor: 0th MBH/FT	0th FT	0th MBH	1st MBH/FT	1st FT	1st MBH	2nd MBH/FT	2nd FT	2nd MBH	3rd MBH/FT	3rd FT	3rd MBH
															Chk Sum =		212.4
I	003	C-6	6.0	0.800	4.800	0.800	6.0	4.800									
I	005	C-2	2.0	0.800	1.600	0.800	2.0	1.600									
I	000	-	-	-	-	-	-	-									
I	006	C-6	6.0	0.800	4.800	0.800	6.0	4.800									
I	008	C-4	4.0	0.800	3.200	0.800	4.0	3.200									
I	012	C-3	3.0	0.800	2.400	0.800	3.0	2.400									
I	012	C-3	3.0	0.800	2.400	0.800	3.0	2.400									
					19.200												
II	007	C-2	2.0	0.800	1.600	0.800	2.0	1.600									
II	007	C-2	2.0	0.800	1.600	0.800	2.0	1.600									
II	007	C-2	2.0	0.800	1.600	0.800	2.0	1.600									
					4.800												
III	004	E-24	24.0	1.200	28.800	1.200	24.0	28.800									
III	100	-	-	-	-												
III	106	C-8			3.200						3.200						
III	110d	C-8			3.200						3.200						
III	110	C-7			2.400						2.400						
III	110c	C-7			2.400						2.400						
III	201b	C-7			2.400									2.400			
III	201a	C-7			2.400									2.400			
III	206	C-7			2.400									2.400			
III	208	C-7			2.400									2.400			
III	210a	C-7			2.400									2.400			
III	210	C-7			2.400									2.400			
III	210b	C-2	2.0	0.800	1.600							0.800	2.0	1.600			
III	216	B-5	5.0	0.700	3.500							0.700	5.0	3.500			
III	200	-	-	-	-												
III	302	C-10			6.400												6.400
III	302	C-10			6.400												6.400
III	302	C-13			5.600												5.600
III	302	C-13			5.600												5.600
III	306	C-11			8.000												8.000
III	310	C-10			6.400												6.400

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Figure 141: Building E51 Perimeter Heat Requirement Tally (ref: Appendix D)

Perimeter Heat Tally - Zone by Zone and Floor by Floor

					97.900												
IV	101	-	-	-	-												
IV	101a	C-6			1.600						1.600						
IV	101b	C-9			5.600						5.600						
IV	101c	C-8			4.400						4.400						
IV	201	C-6			1.600									1.600			
IV	201d	C-9			5.600									5.600			
IV	201f	C-7			2.400									2.400			
IV	201g	C-7			2.400									2.400			
					23.600												
V	105	C-7			2.400						2.400						
V	107	C-7			2.400						2.400						
V	109	B-3	3.0	0.700	2.100				0.700	3.0	2.100						
V	111	C-8			4.400						4.400						
V	113	C-8			4.400						4.400						
V	115	C-6			1.600						1.600						
V	207	C-7			2.400									2.400			
V	209	C-7			2.400									2.400			
V	211	C-7			2.400									2.400			
V	211b	C-8			4.400									4.400			
V	215	C-8			4.400									4.400			
V	307	C-8			4.400												4.400
V	311	C-12			9.600												9.600
V	317	C-12			9.600												9.600
					56.900												
VI	201c	C-9			5.600									5.600			
VI	201c	C-8			4.400									4.400			
					10.000												
Totals					212.4												
	Total Heat Output per Floor [MBH]							52.8			40.1			57.5			62

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Figure 142: Building E51 Perimeter Heat Requirement Tally - Continued (ref: Appendix D)

Choice of two Basic Control Series

Pressure Independent

The TITUS terminal maintains the flow rate required to meet the load conditions regardless of system pressure fluctuations anywhere within its operating range. It is the best choice where system pressure will vary extensively and where precise control is essential.

A key component is the controller, which compensates for system pressure changes, processes signals from the thermostat, controls the damper actuator and regulates minimum and maximum air flow. Both minimum and maximum are factory preset, but are easily adjustable at the job site.

In the curves at right, the vertical, constant cfm (pressure independent) lines represent various cfm settings called for by the thermostat. Line B-C is the maximum cfm setting, while A-B is the pressure dependent characteristic that occurs only below the minimum operating pressure.

Controls are available in pneumatic, analog electronic, and digital electronic models.

Pressure Dependent

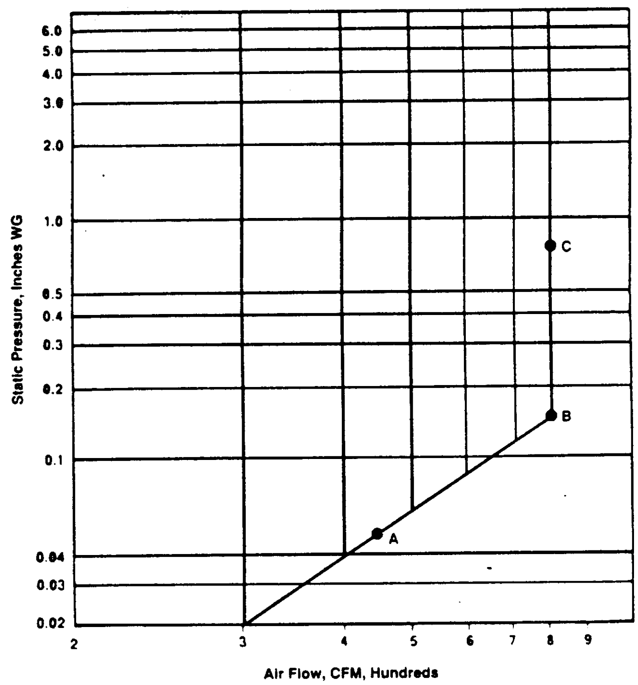
This TITUS terminal is designed for those applications where there is no need for either pressure independence or limit control.

The damper, actuator, and all casing parts are the same as pressure independent terminals and all casing dimensions match those of the other series, size for size. However, the controller and the amplifying sensor are omitted.

The curves at right show typical performance characteristics. Each curve represents a different damper setting, with the flow rate varying with static pressure drop through the assembly. In other words, for a given damper setting, the flow rate varies with the inlet pressure. This, of course, is typical of any damper or fixed orifice.

Pressure dependent terminals are available with pneumatic and electric controls only.

Typical Pressure Independent Performance Curves, Static Pressure vs. Air Flow



Typical Pressure Dependent Performance Curves, Static Pressure vs. Air Flow

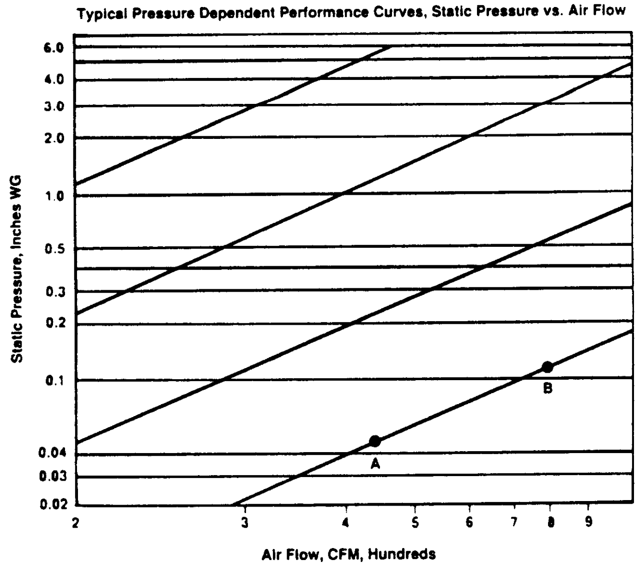


Figure 143: Zone Temperature Control System - Titus Pressure Independent Series

Appendix O - Supply Air Duct System

Figure 144: Megazone Supply Air Duct System Design Decision Table

Megazone Supply Duct Design Decision Table

a	b	c	d	e	f	g	h	i	j	k	l	m
Zone & Shape	Velocity Press [in w.g.]	Total Press [in wg]	Pmr(*) =	0.129	Implied Length L [ft]	Req'd Length L [ft]	Resulting Head Loss [in wg]	delta pressure [in wg]	equivalent loss coefficient	ftgs req'd		
			a' [in wg/ft]	b' [in w.g.]						ASHRAE 1989 Fund	loss coefficient	net quantity
III sq	0.185	1.398	0.00150	0.810	392	128	1.00	0.40	2.14	3-5 90 deg	0.550	3.9
V sq	0.221	1.398	0.00200	0.915	242	140	1.19	0.20	0.92	3-5 90 deg	0.450	2.0
I rd	0.101	1.398	0.00140	0.594	574	51	0.67	0.73	7.25	3-3 90 deg	1.230	5.9
IV rd	0.092	1.398	0.00130	0.594	618	124	0.76	0.64	6.99	3-3 90 deg	1.150	6.1
VI rd	0.086	1.398	0.00205	0.663	359	102	0.87	0.53	6.13	3-3 90 deg	1.230	5.0
II rd	0.069	1.398	0.00255	0.511	348	41	0.61	0.78	11.35	6-8 Perf	7.700	1.0
										3-3 90 deg	1.250	2.9

a = zone number identification and duct shape
b = velocity pressure for duct size and design flow rate
c = total pressure at system sensor control point = Static + Velocity (ref: MIT Drwg EA51 M07.002 for Static Set Point)
P(static) = 1.250" wg & P(velocity) for Design Flow Rate @ 18,590 cfm or 1,542 fpm = 0.148" wg
d = pressure loss gradient for duct size and flow rate (reference SMANCA HVAC Duct Design Calculator)
e = pressure losses in megazone supply duct design; includes losses from static pressure sensor to MR exit (refer to file pd_sup.wq2)
f = length based on c, d & e [(c-e)/d]
g = length based on equivalent surface area calculation (see file: area_tal.wq2)
h = pressure loss based on req'd duct length [d*g+e]
i = difference between loss resulting from implied and required duct lengths [c-h]
j = loss coefficient required to make up difference between required and resulting head loss [i/b]
k = specification of fitting or bend as defined in the ASHRAE 1989 Fundamentals (English Units)
l = loss coefficient valeu for fitting or bend selected
m = quantity of proposed fittings or bends based on equivalent loss coefficient [j/l]

Figure 145: Mechanical Room Supply Air Duct Pressure Drop Tally

Mechanical Room Supply Duct Pressure Drop Tally

Reference: drawings supduct.dwg & climchgr.dwg & damper.dwg

a	b	c	d	e	f	g	h	i	j	k	l	m
	Description	ASHRAE F1989 or Reference	Air Flow Velocity [fpm]	Velocity Pressure [in wg]	Friction Loss [in wg/ft]	Loss Coefficient n/a	Section Length [ft]	Pressure Drop [in wg]	Sub-Tot MR Press Loss Tally	Sub-Tot MR Press Loss Tally	Sub-Tot MR Press Loss Tally	Total MR Press Loss Tally
1	intake grill	cat cut sheet	350	----	----	----	----	0.0200		x	x	
----	bird screen	cat cut sheet	350	0.008	----	0.08	----	0.0006		x	x	
----	transition	4-3 F32.35	350	0.008	----	4.55	----	0.0347		x	x	
2	90 deg bend	3-10 F32.33	1,859	0.215	----	0.50	----	0.1077		x	x	
3	fresh air damper	damper.wq2	1,050	----	----	----	----	0.0800		x	x	
----	transition	4-4 F32.35	1,050	0.069	----	0.38	----	0.0261		x	x	
4	hi-cap filter box	Trane DS-CLCH	450	----	----	----	----	0.0500		x	x	
5	cooling coils	Trane CDS Sim	570	----	----	----	----	0.2300	0.549	x	x	
6	90 deg bend	3-5 F32.31	1,352	0.114	----	0.90	----	0.1025	x		x	
----	& offset	combined	----	----	----	----	----	----	x		x	
----	12 ft str duct	SMANCA	1,542	0.148	0.00075	----	12.00	0.0090	x	0.112	x	
----	air measure	F32.20	----	----	----	----	----	0.0600	x	x		
7	8 ft str duct	SMANCA	1,542	0.148	0.00075	----	8.00	0.0060	x	x		
8	90 deg bend	3-5 F32.31	1,542	0.148	----	0.25	----	0.0370	x	x		
9	6.9 ft str duct	SMANCA	1,542	0.148	0.00075	----	6.90	0.0052	x	x		
10	90 deg bend	3-5 F32.31	1,542	0.148	----	0.14	----	0.0207	x	x		
11	re-orientation	----	1,542	0.148	----	0.00	----	0.0000	x	x	0.129	0.790

a = section label
b = section description
c = section description per ASHRAE 1989 Fundementals F32 or Reference
d = supply air flow velocity based on 18,590 cfm and the geometry of the related section
e = velocity pressure based on flow speed through corresponding section Pv = 0.075 [(V * V)/(1097 * 1097)]
f = friction loss based on cross section and flow speed per SMACNA HVAC Duct Fitting Loss Calculator
g = duct design fitting pressure loss coefficient (ref: ASHRAE 1989 Fundamentals F32)
h = section length
i = pressure drop through section (delP for certain elements from manufacturer's data sheets or other)
j = pressure drop through mechanical room duct from fresh air intake through cooling coil
k = pressure drop through mechanical room duct AH exit through and not including static air pressure sensor
l = pressure drop through mechanical room duct from a point just before the static pressure sensor to MR exit
m = pressure drop through mechanical room duct from FA intake to MR exit

file: mr_rtn.wq2 12/27/95 Page 1

Supply & Return Duct Area Contact Tally (reference file: area_sup.wq2 & area_rtn.wq2)

An entry in the table => a part of the duct serving a register in a given zone has thermal contact with another zone on the level indicated

a	b	c1	c2	c3	c4	d	e1	e2	e3	e4	f	g1	g2	g3	g4	h
	Zone	I					II					III				
	Level	0	1	2	3	Total	0	1	2	3	Total	0	1	2	3	Total
Zone	Area	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2
I	Supply	148				148	63				63	4				4
	Return	121				121	48				48					
II	Supply	11				11	64				64					
	Return						18				18					
III	Supply	215				215	103				103	77	160	186	112	535
	Return	180				180	19				19	39	171	154	62	426
IV	Supply												104	70		173
	Return												216	134		350
V	Supply												73	39	220	331
	Return												64			64
VI	Supply													58		58
	Return													147		147

a	b	i1	i2	i3	i4	j	k1	k2	k3	k4	l	m1	m2	m3	m4	n	o	p	q
	Zone	IV					V					VI					Grand	Megazone	
	Level	0	1	2	3	Total	0	1	2	3	Total	0	1	2	3	Total	Totals	Req'd Duct Length	
Zone	Area	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2	ft2/ft	ft
I	Supply																215	4.19	51
	Return																168	4.19	40
II	Supply																75	1.83	41
	Return																18	2.09	8
III	Supply			8		8		45	149	314	508						1,369	10.67	128
	Return							31	58	280	369						993	9.33	106
IV	Supply		130	132		262		24	60		83						519	4.19	124
	Return		58	73		131		13	22		34						515	4.19	123
V	Supply							75	113	412	600						931	6.67	140
	Return							28	90	269	386						450	7.67	59
VI	Supply			120		120			43		43			46		46	266	2.62	102
	Return								16		16			36		36	199	2.88	69

file: area_tal.wq2 12/27/95 Page 1

Figure 146: Megazone Supply & Return Duct Surface Area Tally

a = zone number
b = designates either supply duct or return duct calculation
c = actual area of duct serving Zone Y in contact with Zone I at levels 0, 1, 2, & 3
d = total area of duct serving Zone Y in contact with Zone I for all levels [@sum(c)]
e = actual area of duct serving Zone Y in contact with Zone II at levels 0, 1, 2, & 3
f = total area of duct serving Zone Y in contact with Zone II for all levels [@sum(e)]
g = actual area of duct serving Zone Y in contact with Zone III at levels 0, 1, 2, & 3
h = total area of duct serving Zone Y in contact with Zone III for all levels [@sum(g)]
i = actual area of duct serving Zone Y in contact with Zone IV at levels 0, 1, 2, & 3
j = total area of duct serving Zone Y in contact with Zone IV for all levels [@sum(i)]
k = actual area of duct serving Zone Y in contact with Zone V at levels 0, 1, 2, & 3
l = total area of duct serving Zone Y in contact with Zone V for all levels [@sum(k)]
m = actual area of duct serving Zone Y in contact with Zone VI at levels 0, 1, 2, & 3
n = total area of duct serving Zone Y in contact with Zone VI for all levels [@sum(m)]
o = grand total of duct area attributed to Zone Y [@sum(d,f,h,j,l,n)]
p = surface area per foot of duct length in equivalent megazone system for Zone Y
q = length of duct in megazone system for Zone Y to duplicate total calculated in column "o" [o/p]

Figure 147: Megazone Supply & Return Duct Surface Area Tally (continued)

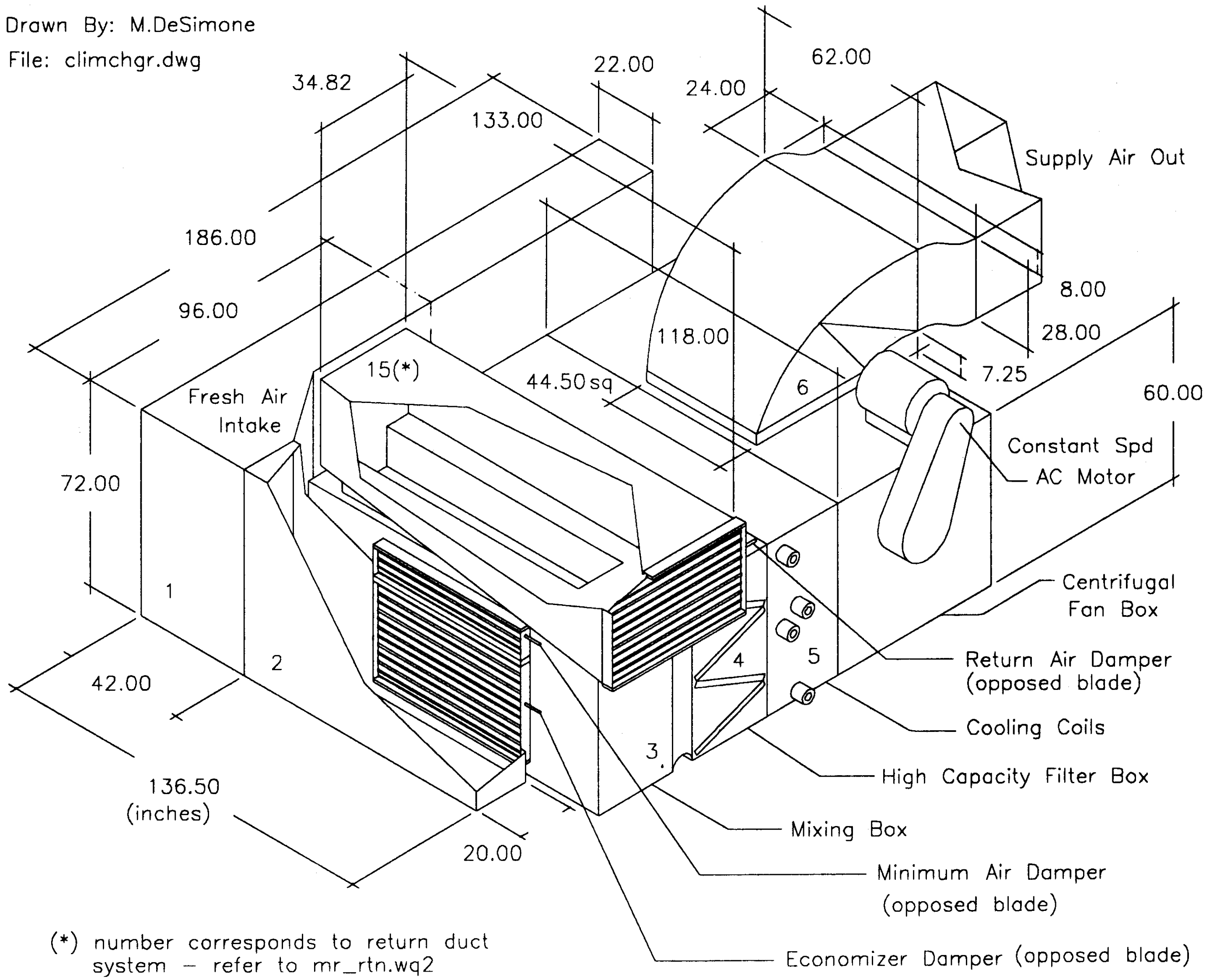


Figure 148: Supply Air Duct Design / Conditioning Equipment (file: climchgr.dwg)

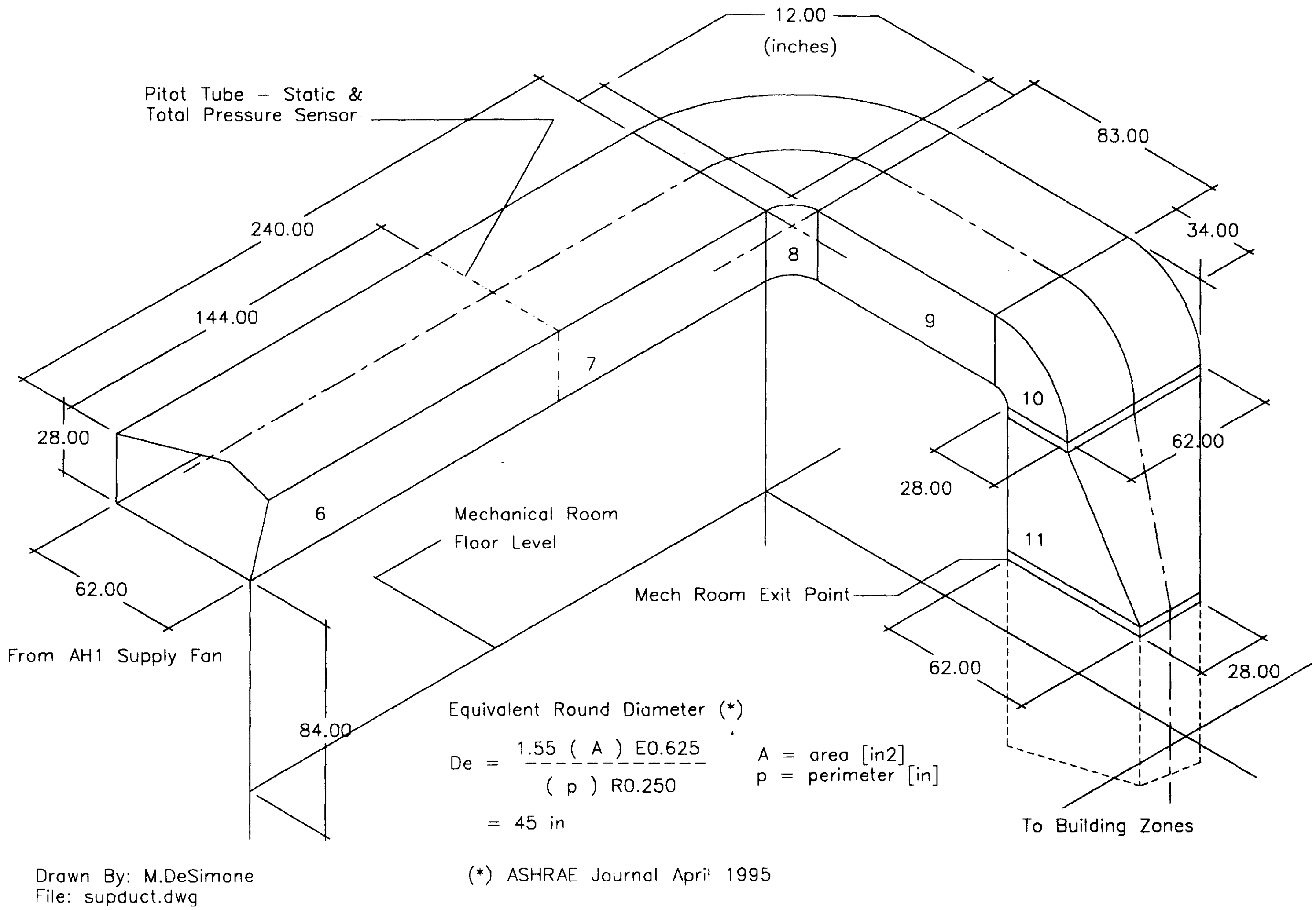


Figure 149: Megazone Supply Air Duct System - Mechanical Room (file: supduct.dwg)

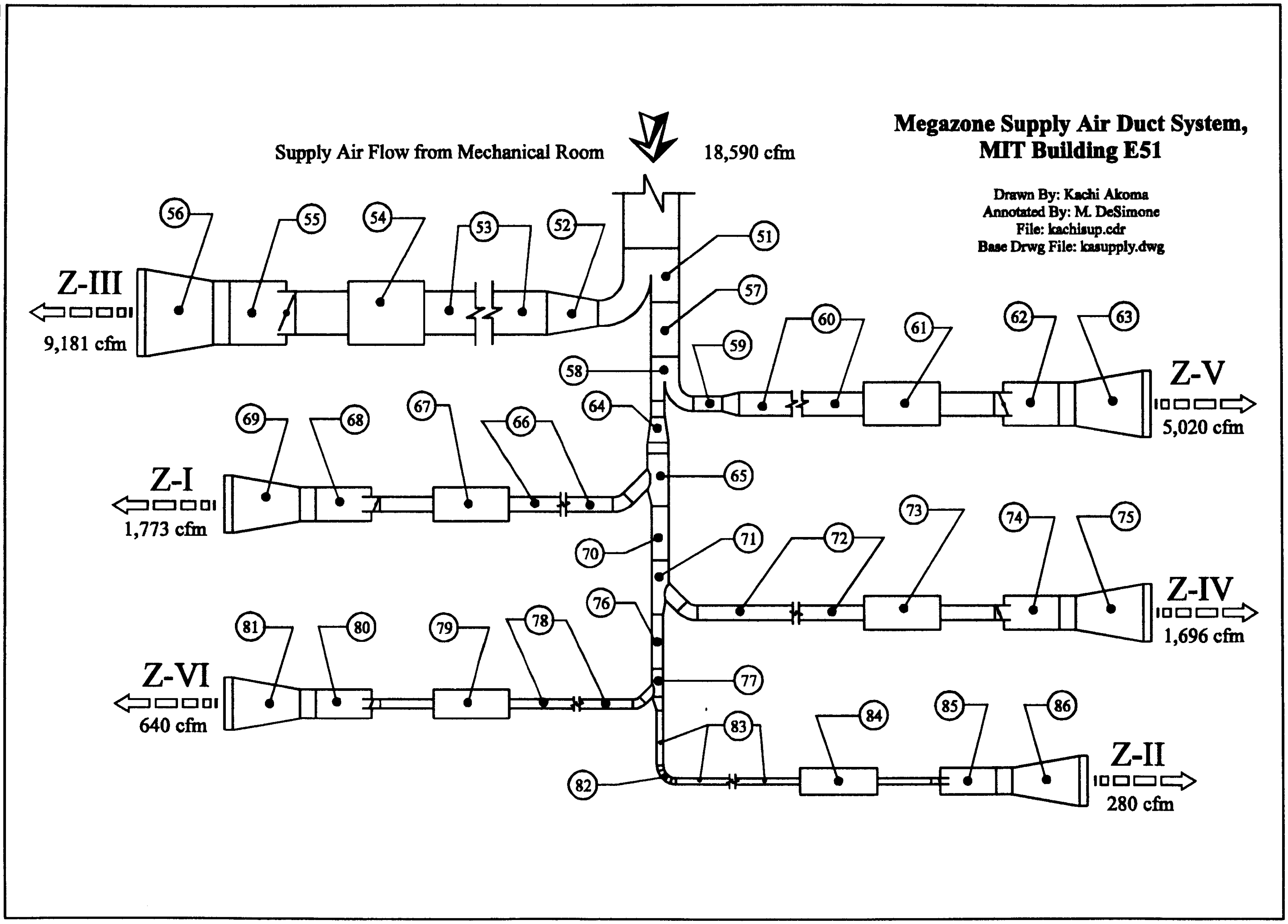


Figure 150: Megazone Supply Air Duct System (file: kachisup.cdr)

Figure 151: Megazone Supply Air Duct Pressure Drop Tally

Megazone Supply Duct Pressure Drop Tally
Reference: drawing - kachisup.cdr

a	b	c	d	e	f	g	h	i		j		k		l		m		n		o
Section Number see drwg	ASHRAE 1989 Fundamentals Designation	Section Description	Air Flow Velocity	Velocity Pressure	Friction Loss	Loss Coeff	Section Length	Pressure Loss	Total Pressure Loss In Supply Duct System For Each Path From Static Pressure Sensor to Mechanical Room Exit											
									Zone I		Zone II		Zone III		Zone IV		Zone V		Zone VI	
			[fpm]	[in wg]	[in wg/ft]	n/a	[ft]	[in wg]		[in wg]		[in wg]		[in wg]		[in wg]		[in wg]		[in wg]
III:51a	5-22 F32.42	28" x 28" branch	1,686	0.177	-----	0.520	-----	0.092					x	0.0921						
III:52	4-4 F32.35	transition	1,686	0.177	-----	0.000	-----	0.000					x	0.0000						
III:53	16" x 48"	square duct	1,721	-----	0.00150	-----	128.0	0.192					o	0.1920						
III:54	3-6 F32.32	4 ea 90 deg L	1,721	0.185	-----	2.200	-----	0.406					o	0.4061						
III:55	16x48 VAV Box	damper/box/coil	-----	-----	-----	-----	-----	0.435					x	0.4354						
III:56	4-4 F32.35	divergence	1,721	0.185	-----	0.200	-----	0.037					x	0.0369						
---	Titus B4 Pattern	30" x 96" diffuser	500	-----	-----	-----	-----	0.117					x	0.1170						
TR:51b	5-22 F32.42	28" x 31" main	1,542	0.148	-----	0.050	-----	0.007	x	0.0074	x	0.0074			x	0.0074	x	0.0074	x	0.0074
TR:57	28" x 31"	square duct	1,542	-----	0.00110	-----	5.0	0.006	x	0.0055	x	0.0055			x	0.0055	x	0.0055	x	0.0055
V:58a	5-22 F32.42	28" x 16" branch	1,614	0.162	-----	0.520	-----	0.084									x	0.0844		
V:59	4-4 F32.35	transition	1,614	0.162	-----	0.040	-----	0.006									x	0.0065		
V:60	24" x 16"	square duct	1,883	-----	0.00200	-----	140.0	0.280									o	0.2800		
V:61	3-5 F32.31	2 ea 90 deg L	1,883	0.221	-----	0.900	-----	0.199									o	0.1989		
V:62	16x24 VAV Box	damper/box/coil	-----	-----	-----	-----	-----	0.521									x	0.5210		
V:63	4-4 F32.35	divergence	1,883	0.221	-----	0.200	-----	0.044									x	0.0442		
---	B109 Diffuser	30" x 48" diffuser	500	-----	-----	-----	-----	0.117									x	0.1170		
TR:58b	5-22 F32.42	28" x 15" main	1,504	0.141	-----	0.050	-----	0.007	x	0.0070	x	0.0070			x	0.0070			x	0.0070
TR:64	28" x 15"	square duct	1,504	-----	0.00160	-----	1.5	0.002	x	0.0024	x	0.0024			x	0.0024			x	0.0024
---	4-6 F32.36	transition	1,504	0.141	-----	0.170	-----	0.024	x	0.0240	x	0.0240			x	0.0240			x	0.0240
---	24 " dia	round duct	1,397	-----	0.00110	-----	1.5	0.002	x	0.0017	x	0.0017			x	0.0017			x	0.0017
I:65a	5-17 F32.41	16" dia branch	1,270	0.101	-----	0.520	-----	0.052	x	0.0523										
I:66	16" dia	round duct	1,270	-----	0.00140	-----	51.0	0.071	o	0.0714										
I:67	3-3 F32.31	6 ea 90 deg L	1,270	0.101	-----	7.380	-----	0.742	o	0.7418										
I:68	Titus #16 VAV	damper/box/coil	-----	-----	-----	-----	-----	0.234	x	0.2339										
I:69	4-4 F32.35	divergence	1,270	0.101	-----	0.140	-----	0.014	x	0.0141										
---	B109 Diffuser	21" x 24" diffuser	500	-----	-----	-----	-----	0.117	x	0.1170										
TR:65b	5-17 F32.41	19" dia main	1,329	0.110	-----	0.180	-----	0.020			x	0.0198			x	0.0198			x	0.0198
TR:70	19 " dia	round duct	1,329	-----	0.00110	-----	5.0	,0.006			x	0.0055			x	0.0055			x	0.0055
IV:71a	5-17 F32.41	16" dia branch	1,215	0.092	-----	0.520	-----	0.048							x	0.0478				
IV:72	16" dia	round duct	1,215	-----	0.00130	-----	124.0	0.161							o	0.1612				
IV:73	3-3 F32.31	6 ea 90 deg L	1,215	0.092	-----	6.900	-----	0.635							o	0.6348				
IV:74	Titus #16 VAV	damper/box/coil	-----	-----	-----	-----	-----	0.214							x	0.2142				
IV:75	4-4 F32.35	divergence	1,215	0.092	-----	0.140	-----	0.013							x	0.0129				
---	B109 Diffuser	21" x 24" diffuser	500	-----	-----	-----	-----	0.117							x	0.1170				
TR:71b	5-17 F32.41	12" dia main	1,171	0.085	-----	0.120	-----	0.010			x	0.0103							x	0.0103

Figure 152: Megazone Supply Air Duct Pressure Drop Tally (continued)

Megazone Supply Duct Pressure Drop Tally

Reference: drawing - kachisup.cdr

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
Section Number see drwg	ASHRAE 1989 Fundamentals Designation	Section Description	Air Flow Velocity [fpm]	Velocity Pressure [in wg]	Friction Loss [in wg/ft]	Loss Coeff n/a	Section Length [ft]	Pressure Loss [in wg]	Total Pressure Loss In Supply Duct System For Each Path From Static Pressure Sensor to Mechanical Room Exit					
									Zone I [in wg]	Zone II [in wg]	Zone III [in wg]	Zone IV [in wg]	Zone V [in wg]	Zone VI [in wg]
TR:76	12 " dia	round duct	1,171	-----	0.00165	-----	5.0	0.008		x 0.0083				x 0.0083
VI:77a	5-17 F32.41	10" dia branch	1,173	0.086	-----	0.560	-----	0.048						x 0.0480
VI:78	10" dia	round duct	1,173	-----	0.00205	-----	102.0	0.209						o 0.2091
VI:79	3-3 F32.31	5 ea 90 deg L	1,173	0.086	-----	6.150	-----	0.527						o 0.5274
VI:80	Titus #10 VAV	damper/box/coil	-----	-----	-----	-----	-----	0.214						x 0.2138
VI:81	4-4 F32.35	divergence	1,173	0.086	-----	0.140	-----	0.012						x 0.0120
---	B109 Diffuser	12" x 15" diffuser	500	-----	-----	-----	-----	0.168						x 0.1680
TR:77b	5-17 F32.41	7" dia main	1,050	0.069	-----	0.140	-----	0.010		x 0.0096				
II:82	3-2 F32.31	5 pc 90 deg L	1,050	0.069	-----	0.190	-----	0.013		x 0.0131				
II:83	7 " dia	round duct	1,050	-----	0.00255	-----	41.0	0.105		o 0.1046				
II:84	3-3 F32.31	3 ea 90 deg L	1,050	0.069	-----	3.750	-----	0.258		o 0.2577				
---	6-8 F32.48	perf plate	1,050	0.069	-----	7.700	-----	0.529		o 0.5291				
II:85	Titus #7 VAV	damper/box/coil	-----	-----	-----	-----	-----	0.141		x 0.1408				
II:86	4-4 F32.35	divergence	1,050	0.069	-----	0.140	-----	0.010		x 0.0096				
---	B109 Diffuser	9" x 9" diffuser	500	-----	-----	-----	-----	0.117		x 0.1170				

			Zone I	Zone II	Zone III	Zone IV	Zone V	Zone VI
p	Total Pressure Loss In Supply Duct System For Each Path (MR Exit to Louvre)		1.2784	1.2732	1.2796	1.2612	1.2649	1.2701
q	Pressure Loss for Straight Duct Length & 90 deg L's		0.8132	0.8913	0.5981	0.7960	0.4789	0.7365
r	Pressure Loss for Zone XX From MR Exit to Louvre less Straight Duct & 90 deg L's	p - q	0.4652	0.3819	0.6815	0.4652	0.7860	0.5336
s	Pressure Loss for Supply Air Path in MR (from just in front of Static Pressure Sensor to M		0.1290	0.1290	0.1290	0.1290	0.1290	0.1290
t	Press Loss for Zone XX (from SP Sensor to MR Exit and out to Grill)	r + s	0.5942	0.5109	0.8104	0.5942	0.9150	0.6626

Figure 153: Megazone Supply Air System Total Pressure Grade Line Data Table

Data	Zone I			Zone II			Zone III			Zone IV			Zone V			Zone VI		
Pt		[in wg]	Total Pres		[in wg]	Total Pres		[in wg]	Total Pres		[in wg]	Total Pres		[in wg]	Total Pres		[in wg]	Total Pres
0			0.0000			0.0000			0.0000			0.0000			0.0000			0.0000
1	1	0.0200	(0.0200)	1	0.0200	(0.0200)	1	0.0200	(0.0200)	1	0.0200	(0.0200)	1	0.0200	(0.0200)	1	0.0200	(0.0200)
2	----	0.0006	(0.0206)	----	0.0006	(0.0206)	----	0.0006	(0.0206)	----	0.0006	(0.0206)	----	0.0006	(0.0206)	----	0.0006	(0.0206)
3	----	0.0347	(0.0553)	----	0.0347	(0.0553)	----	0.0347	(0.0553)	----	0.0347	(0.0553)	----	0.0347	(0.0553)	----	0.0347	(0.0553)
4	2	0.1077	(0.1630)	2	0.1077	(0.1630)	2	0.1077	(0.1630)	2	0.1077	(0.1630)	2	0.1077	(0.1630)	2	0.1077	(0.1630)
5	3	0.0800	(0.2430)	3	0.0800	(0.2430)	3	0.0800	(0.2430)	3	0.0800	(0.2430)	3	0.0800	(0.2430)	3	0.0800	(0.2430)
6	----	0.0261	(0.2691)	----	0.0261	(0.2691)	----	0.0261	(0.2691)	----	0.0261	(0.2691)	----	0.0261	(0.2691)	----	0.0261	(0.2691)
7	4	0.0500	(0.3191)	4	0.0500	(0.3191)	4	0.0500	(0.3191)	4	0.0500	(0.3191)	4	0.0500	(0.3191)	4	0.0500	(0.3191)
8	5	0.2300	(0.5491)	5	0.2300	(0.5491)	5	0.2300	(0.5491)	5	0.2300	(0.5491)	5	0.2300	(0.5491)	5	0.2300	(0.5491)
9	5a	1.5644	(2.1135)	5a	1.5644	(2.1135)	5a	1.5644	(2.1135)	5a	1.5644	(2.1135)	5a	1.5644	(2.1135)	5a	1.5644	(2.1135)
10	Fan	3.6230	1.5095	Fan	3.6230	1.5095	Fan	3.6230	1.5095	Fan	3.6230	1.5095	Fan	3.6230	1.5095	Fan	3.6230	1.5095
11	6	0.1025	1.4070	6	0.1025	1.4070	6	0.1025	1.4070	6	0.1025	1.4070	6	0.1025	1.4070	6	0.1025	1.4070
12	----	0.0090	1.3980	----	0.0090	1.3980	----	0.0090	1.3980	----	0.0090	1.3980	----	0.0090	1.3980	----	0.0090	1.3980
13	----	0.0600	1.3380	----	0.0600	1.3380	----	0.0600	1.3380	----	0.0600	1.3380	----	0.0600	1.3380	----	0.0600	1.3380
14	7	0.0060	1.3320	7	0.0060	1.3320	7	0.0060	1.3320	7	0.0060	1.3320	7	0.0060	1.3320	7	0.0060	1.3320
15	8	0.0370	1.2949	8	0.0370	1.2949	8	0.0370	1.2949	8	0.0370	1.2949	8	0.0370	1.2949	8	0.0370	1.2949
16	9	0.0052	1.2897	9	0.0052	1.2897	9	0.0052	1.2897	9	0.0052	1.2897	9	0.0052	1.2897	9	0.0052	1.2897
17	10	0.0207	1.2690	10	0.0207	1.2690	10	0.0207	1.2690	10	0.0207	1.2690	10	0.0207	1.2690	10	0.0207	1.2690
18	11	0.0000	1.2690	11	0.0000	1.2690	11	0.0000	1.2690	11	0.0000	1.2690	11	0.0000	1.2690	11	0.0000	1.2690
19	x	0.0074	1.2616	x	0.0074	1.2616	x	0.0921	1.1769	x	0.0074	1.2616	x	0.0074	1.2616	x	0.0074	1.2616
20	x	0.0055	1.2561	x	0.0055	1.2561	x	0.0000	1.1769	x	0.0055	1.2561	x	0.0055	1.2561	x	0.0055	1.2561
21	x	0.0070	1.2490	x	0.0070	1.2490	o	0.1920	0.9849	x	0.0070	1.2490	x	0.0844	1.1717	x	0.0070	1.2490
22	x	0.0024	1.2466	x	0.0024	1.2466	o	0.4061	0.5788	x	0.0024	1.2466	x	0.0065	1.1652	x	0.0024	1.2466
23	x	0.0240	1.2226	x	0.0240	1.2226	x	0.4354	0.1434	x	0.0240	1.2226	o	0.2800	0.8852	x	0.0240	1.2226
24	x	0.0017	1.2210	x	0.0017	1.2209	x	0.0369	0.1064	x	0.0017	1.2209	o	0.1990	0.6862	x	0.0017	1.2209
25	x	0.0523	1.1687	x	0.0198	1.2011	x	0.1170	(0.0106)	x	0.0198	1.2011	x	0.5210	0.1652	x	0.0198	1.2011
26	o	0.0714	1.0973	x	0.0055	1.1956				x	0.0055	1.1956	x	0.0442	0.1210	x	0.0055	1.1956
27	o	0.7418	0.3555	x	0.0103	1.1854				x	0.0478	1.1478	x	0.1170	0.0040	x	0.0103	1.1854
28	x	0.2339	0.1216	x	0.0083	1.1771				o	0.1612	0.9866				x	0.0083	1.1771
29	x	0.0141	0.1075	x	0.0096	1.1675				o	0.6348	0.3518				x	0.0480	1.1291
30	x	0.1170	(0.0095)	x	0.0131	1.1544				x	0.2142	0.1376				o	0.2091	0.9200
31				o	0.1046	1.0499				x	0.0129	0.1247				o	0.5274	0.3926
32				o	0.2577	0.7922				x	0.1170	0.0077				x	0.2138	0.1788
33				o	0.5291	0.2631										x	0.0120	0.1668
34				x	0.1408	0.1223										x	0.1680	(0.0012)
35				x	0.0096	0.1127												
36				x	0.1170	0.0053												

15250/SCH
BuyLine 5737

800 Series Spin-Glas® Fiber Glass Duct and Equipment Insulation

Temperature Limit: 450°F (232°C)

Description

800 Series Spin-Glas board insulations are manufactured from glass fibers bonded by a thermosetting resin.

Applications

800 Series Spin-Glas insulation can be used for heating ducts and equipment. It is ideal for commercial and industrial heating, air conditioning, and power and process equipment.

Available Forms

It is available in a variety of densities and with a choice of vapor retarder facings for a wide range of service requirements.

Advantages

- High insulating efficiency
- Fire safety. Meets the requirements of NFPA 90A and 90B
- Strong and durable. Resists settling, breakdown or sagging from vibration
- Easy to handle and apply
- ISO 9000 certified manufacturing location

Physical Properties

Temperature limit (max.)	
Unfaced	450°F
Faced	
— unfaced side	450°F
— faced side	150°F
Moisture sorption	Less than 1.0% by volume
Alkalinity	Less than 0.6% (Na_2O)
Resistance to microbial growth	Does not breed or promote fungi or bacterial growth
Surface burning characteristics (Composite)	FHC 25/50 per ASTM E 84, NFPA 255, UL 723, CAN/ULC S102-M88

Available Densities and Thicknesses

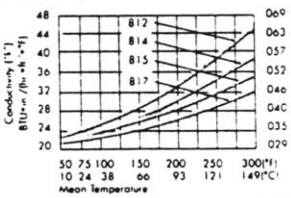
Type	Density (pcf)	Thickness (in.)
812	1.50	1½ - 4
814	3.00	1 - 4
815	4.25	1 - 2½
817	6.00	1 - 2

Standard sheet size 24" x 48"

Specification Property Compliance

ASTM C 612
ASTM C 795
NRC 1.36
MIL-I-24244
CGSB 51-GP-10M

Thermal Conductivity (ASTM C 177 and C 518)



Facing Information (ASTM C 1136)

FSK (Foil-Scrim-Kraft). Reinforced foil and paper

AP (All Purpose). White kraft bonded to aluminum foil, reinforced with fiber glass yarn

Water Vapor Transmission (faced)
0.02 perms

For additional product information, please refer to CI-9 data page.

Zeston® 2000 PVC Insulated Fitting Covers and Jacketing

Temperature Limits:
PVC: 0°F to 150°F (-18°C to +66°C)
Insert: 0°F to 450°F (-18°C to +232°C)

Description

Zeston 2000 PVC fitting covers come in many shapes and sizes with a Hi-Lo Temp® fiber glass insulation insert, all of which fit snugly over a variety of fittings.

Zeston 2000 PVC jacketing is a high-impact, UV-resistant, polyvinyl chloride covering designed for insulated pipe or bare metal.

Applications

For insulating chilled water, hot water, steam and other piping systems in commercial, institutional, industrial construction on indoor or outdoor piping systems.

Available Shapes and Sizes

Fitting Covers. Shapes available for 45° and 90° short and long radius elbows, tees and valves plus a wide variety of other fittings, flanges, reducers, end caps, soil pipe hubs, traps and mechanical line fittings.

Rolls. Zeston 2000 PVC jacketing is available in standard thicknesses of 10, 15, 20 and 30 mil.

Cut & Curled™. System 2000™ PVC Cut & Curled jacketing in thicknesses of 20 mil or 30 mil is available in factory-cut sizes to fit 3/8" to 20" iron pipe with 1/2" to 4" thick insulation, and 1/2" to 6 1/8" copper tubing with 1/2" to 4" thick insulation.

Advantages

- Code compliance. Meets flame spread rating of 25 or less and a smoke developed rating of 50 or less (up to 25 mil), according to ASTM E 84
- Weatherability
- Ease of maintenance
- Simple, fast installation
- Neat appearance, paintable
- Exceptional durability
- Corrosion resistance

Specification Property Compliance

USDA
New York City MEA #7-87
ICBO
SBCCI
BOCA
ASTM D 1784, Class 14253-C
L-P-535E*, Composition A, Type II, Grade GU
L-P-1035A*, Composition A, Type II, Grade GU
Canada CGSB 51-GP-53M

* Impact strength determined by Gardner-SPI test method rather than Izod, since Gardner is more appropriate for PVC sheeting materials

Thermal Conductivity of Hi-Lo Temp Fiber Glass Insulation Insert

Mean Temp °F	Mean Temp °C	"k" BTU•in/(hr•ft²•°F)	"k" W/m•°C
75	24	28	040
150	66	34	049
300	149	45	065

For additional product information, please refer to CI-55 data page.

3

Figure 154: Fiber Glass Duct Insulation Specifications (Schuller 800 Series Spin-Glas)

Appendix P - Return Air Duct System

Figure 155: Megazone Return Air Duct System Design Decision Table

Megazone Return Duct Design Decision Table

a	b	c	d	e	f	g	h	i	j	k	l	m
Zone & Shape	Velocity Press [in w.g.]	Total Press [in wg]	Pmr(*) = a' [in wg/ft]	0.523 b' [in w.g.]	Implied Length L [ft]	Req'd Length L [ft]	Resulting Head Loss [in wg]	delta pressure [in wg]	equivalent loss coefficient	ftgs req'd ASHRAE 1989 Fund	loss coefficient	net quantity
III sq	0.122	0.82	0.00075	0.572	331	106	0.65	0.17	1.38	3-7 90 deg	0.260	5.3
V sq	0.108	0.82	0.00095	0.588	244	59	0.64	0.18	1.63	3-7 90 deg	0.362	4.5
I rd	0.088	0.82	0.00120	0.621	166	40	0.67	0.15	1.72	3-2 90 deg	0.540	3.2
VI rd	0.054	0.82	0.00120	0.594	188	69	0.68	0.14	2.65	3-2 90 deg	0.420	6.3
II rd	0.036	0.82	0.00120	0.593	189	8	0.60	0.22	6.01	6-8 Perf	3.000	1.0
										3-2 90 deg	0.540	5.6
IV rd	0.068	0.82	0.00095	0.620	211	123	0.74	0.08	1.22	3-1 90 deg	0.120	10.2

a = zone number identification and duct shape
b = velocity pressure for duct size and design flow rate
c = total pressure rise across return fan = P(static) + P(velocity) ref: MIT Drwg EA51 M07.002 for Static Pressure
P(static) = 0.75" wg & P(velocity) for Design Flow Rate @ 16,331 cfm or 1,061 fpm = 0.07" wg
d = pressure loss gradient for duct size and flow rate (reference SMACNA HVAC Duct Design Calculator)
e = sum of zone pressure losses in megazone duct design; includes losses from grill to MR entry point (refer to file: pd_rtn.wq1)
f = length based on c, d & e [(c-e)/d]
g = length based on equivalent surface area calculation (see file: area_tal.wq2)
h = pressure loss based on req'd duct length [d*g+e]
i = difference between loss resulting from implied and required duct lengths [c-h]
j = loss coefficient required to make up difference between required and resulting head loss [i/b]
k = specification of fitting or bend as defined in the ASHRAE 1989 Fundamentals (English Units)
l = loss coefficient value for fitting or bend selected
m = quantity of proposed fittings or bends based on equivalent loss coefficient [j/l]

Pmr(*) = pressure loss due to duct and fittings in mechanical room; of two possible paths the one
with the highest loss is considered critical and that value is used (refer to file: mr_rtn.wq2)
Note: the path which results in the highest total pressure difference is to the outside;
the total pressure in mixing box is approx/ -0.24 [inwg]

Mechanical Room Return Duct Pressure Drop Tally
Reference: drawings rtnduct.dwg & damper.dwg

a	b Description	c ASHRAE F1989 Designation	d Air Flow Velocity [fpm]	e Velocity Pressure [in wg]	f Friction Loss [in wg/ft]	g Loss Coefficient n/a	h Section Length [ft]	i Pressure Drop [in wg]	j Loss via Path to Outside [in wg]	k Loss via Path to Mixing Box [in wg]
1	duct	---	1,507	---	0.00055	---	4.00	0.0022		
2	90 deg bend	3-5 F32.31	1,507	0.142	---	0.18	---	0.0256		
3	45 deg bend	3-5 F32.31	1,507	0.142	---	0.11	---	0.0156		
4	duct	---	1,507	---	0.00055	---	4.75	0.0026		
5	45 deg bend	3-5 F32.31	1,507	0.142	---	0.11	---	0.0156		
6	duct	---	1,507	---	0.00055	---	6.50	0.0036		
---	air measuring	F32.20	1,507	---	---	---	---	0.0600		
7	90 deg corner	3-10 F32.33	1,507	0.142	---	0.75	---	0.1065		
8	90 deg corner	3-10 F32.33	1,507	0.142	---	0.75	---	0.1065		
9	45 deg bend	3-5 F32.31	1,375	0.118	---	0.29	---	0.0342		
10	duct	---	1,452	---	0.00055	---	2.50	0.0014		
11a (*)	duct	---	1,452	---	0.00055	---	9.50	0.0052	X	
12	---	---	---	---	---	---	---	---	X	
13	45 deg corner	3-6 F32.32	1,452	0.131	---	0.36	---	0.0472	X	
14	opposed blade	6-6 F32.47	1,452	0.131	---	0.52	---	0.0681	X	
15	90 deg mitered	3-10 F32.33	1,452	0.131	---	0.75	---	0.0983	X	0.593
16	---	---	---	---	---	---	---	---		X
11b (*)	duct	---	1,452	---	0.00055	---	14.80	0.0081		X
17	opposed blade	6-6 F32.47	1,452	0.131	---	0.52	---	0.0681		X
18	27 deg bend	3-6 F32.32	1,452	0.131	---	0.14	---	0.0183		X
19	transition	4-3 F32.35	1,452	0.131	---	0.24	---	0.0314		X
20	screen	6-7 F32.47	762	0.036	---	0.08	---	0.0029		X
	grill	---	762	---	---	---	---	0.0200	0.523	X

a = section label
b = section description
c = section description per ASHRAE 1989 Fundementals F32
d = return air flow velocity based on 16,331 cfm and the geometry of the related section (assume 2" thick insulation sections 1 to 8 only)
e = velocity pressure based on flow speed through corresponding section Pv = 0.075 [(V * V)/(1097 * 1097)]
f = friction loss based on cross section and flow speed per SMACNA HVAC Duct Fitting Loss Calculator
g = duct design fitting pressure loss coefficient (ref: ASHRAE 1989 Fundamentals F32)
h = section length
i = pressure drop through section
j = pressure drop through mechanical room return duct to outside based on design flow equal to 16,331 cfm
k = pressure drop through mechanical room return duct to mixing box based on design flow equal to 16,331 cfm

(*) = the duct length, section 11, varies depending on the path taken either to the mixing box or to the outside

The design return duct static pressure includes the entire return duct system including the path to the outside or the path returning to the mixing box, whichever is greater.

X = components excluded from total pressure loss for path

file: mr_rtn.wq2 01/28/96 Page 1

Figure 156: Megazone Return Air Duct System - Mechanical Room Pressure Drop Tally

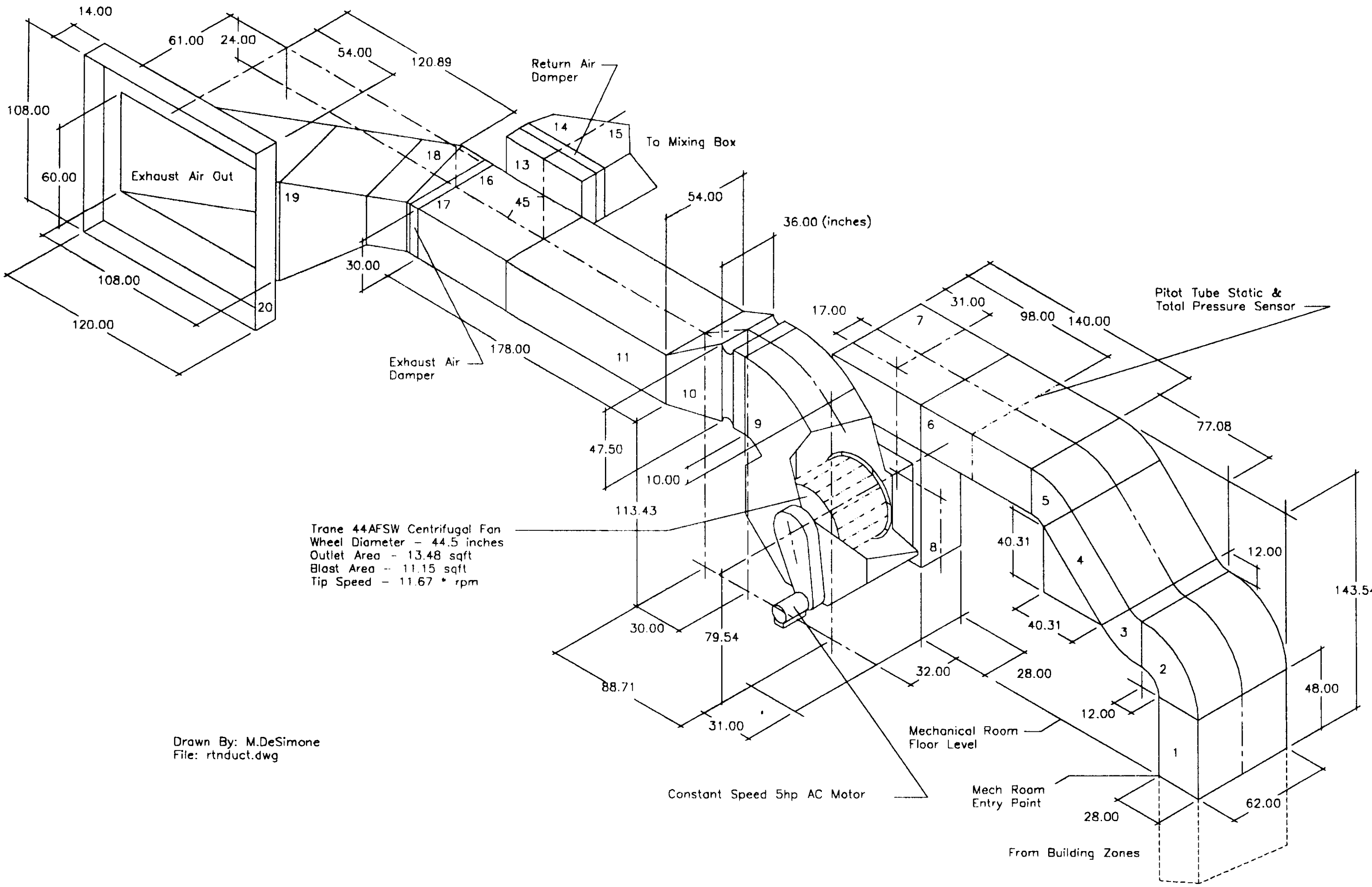


Figure 157: Megazone Return Air Duct System - Mechanical Room (file: rtnduct.dwg)

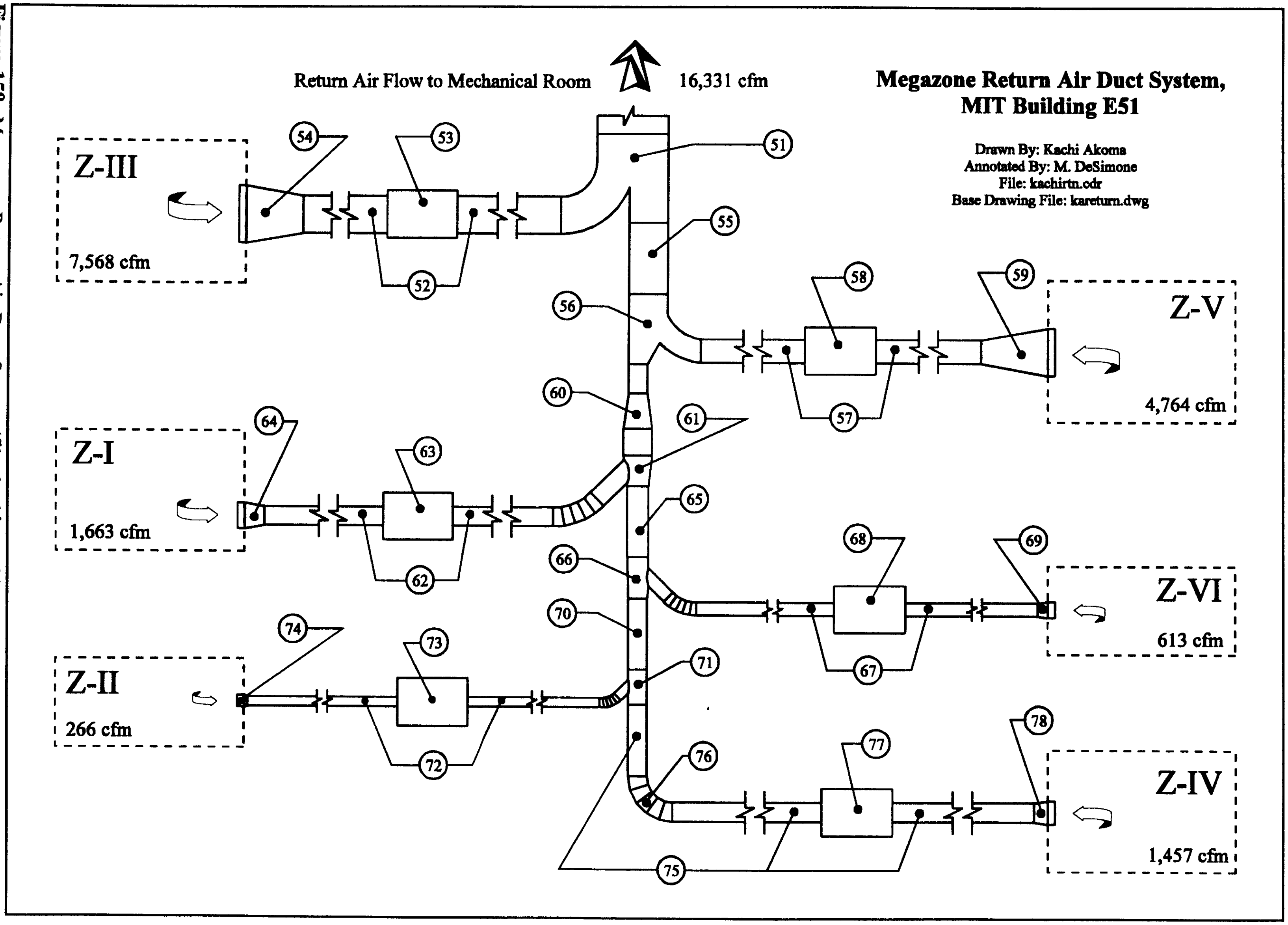


Figure 158: Megazone Return Air Duct System (file: kachirtn.cdr)

Figure 159: Megazone Return Air Duct Pressure Drop Tally

Megazone Return Duct Pressure Drop Tally
Reference: drawing - kachirtn.cdr

a	b	c	d	e	f	g	h	i	j		k		l		m		n		o	
Zone & Section Number	ASHRAE 1989 Fundamentals Designation	Section Description	Air Flow Velocity	Velocity Pressure	Friction Loss	Loss Coeff	Section Length	Pressure Loss	Total Pressure Loss In Return Duct System For Each Path From Grill to Entry to Mechanical Room											
									Zone I		Zone II		Zone III		Zone IV		Zone V		Zone VI	
			[fpm]	[in wg]	[in wg/ft]	n/a	[ft]	[in wg]		[in wg]		[in wg]		[in wg]		[in wg]		[in wg]		[in wg]
III:51a	5-6 F32.39	26" x 30" branch	1,397	0.122	-----	0.000	-----	0.000					x	0.000						
III:52	26 x 30	square duct	1,397	-----	0.00075	-----	106.00	0.080					o	0.080						
III:53	3-7 F32.32	5 ea 90 deg L's	1,397	0.122	-----	1.300	-----	0.158					o	0.158						
III:54	4-1 F32.35	10 deg converge	500	0.016	-----	0.200	-----	0.003					x	0.003						
----	Titus 300/350	48" x 48" grill	500	0.016	-----	-----	-----	0.046					x	0.046						
TR:51b	5-6 F32.39	26" x 33" main	1,471	0.135	-----	(0.040)	-----	(0.005)	x	(0.005)	x	(0.005)			x	(0.005)	x	(0.005)	x	(0.005)
TR:55	26" x 33"	square duct	1,471	-----	0.00090	-----	5.0	0.005	x	0.005	x	0.005			x	0.005	x	0.005	x	0.005
V:56a	5-6 F32.39	26" x 20" branch	1,319	0.108	-----	0.160	-----	0.017									x	0.017		
V:57	26" x 20"	square duct	1,319	-----	0.00095	-----	59.0	0.056									o	0.056		
V:58	3-7 F32.32	5 ea 90 deg L's	1,319	0.108	-----	1.810	-----	0.196									o	0.196		
V:59	4-1 F32.35	10 deg converge	500	0.016	-----	0.200	-----	0.003									x	0.003		
----	Titus 300/350	40" x 40" grill	500	0.016	-----	-----	-----	0.046									x	0.046		
TR:56b	5-6 F32.39	26" x 16" main	1,384	0.119	-----	(0.080)	-----	(0.010)	x	(0.010)	x	(0.010)			x	(0.010)			x	(0.010)
TR:60	26" x 16"	square duct	1,384	-----	0.00130	-----	1.5	0.002	x	0.002	x	0.002			x	0.002			x	0.002
----	4-5 F32.36	10 deg transition	1,273	0.101	-----	0.150	-----	0.015	x	0.015	x	0.015			x	0.015			x	0.015
----	24" dia	round duct	1,273	-----	0.00085	-----	1.5	0.001	x	0.001	x	0.001			x	0.001			x	0.001
I:61a	5-5 F32.38	16" dia branch	1,191	0.088	-----	0.350	-----	0.031	x	0.031										
----	3-2 F32.31	5 pc 45 deg L	1,191	0.088	-----	0.114	-----	0.010	x	0.010										
I:62	16" dia	round duct	1,191	-----	0.00120	-----	40.0	0.048	x	0.048										
I:63	3-2 F32.31	3 ea 90 deg L's	1,191	0.088	-----	1.620	-----	0.143	x	0.143										
I:64	4-1 F32.35	10 deg converge	500	0.016	-----	0.200	-----	0.003	x	0.003										
----	Titus 300/350	22" x 22" grill	500	0.016	-----	-----	-----	0.046	x	0.046										
TR:61b	5-5 F32.38	19" dia main	1,186	0.088	-----	0.080	-----	0.007			x	0.007			x	0.007			x	0.007
TR:65	19" dia	round duct	1,186	-----	0.00100	-----	5.0	0.005			x	0.005			x	0.005			x	0.005
VI:66a	5-5 F32.38	11" dia branch	928	0.054	-----	(0.070)	-----	(0.004)											x	(0.004)
----	3-2 F32.31	5 pc 45 deg L	928	0.054	-----	0.114	-----	0.006											x	0.006
VI:67	11" dia	round duct	928	-----	0.00120	-----	69.0	0.083											o	0.083
VI:68	3-2 F32.31	6 ea 90 deg L's	928	0.054	-----	2.520	-----	0.135											o	0.135
VI:69	4-1 F32.35	10 deg converge	500	0.016	-----	0.200	-----	0.003											x	0.003

file: pd_rtn.wq2

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Megazone Return Duct Pressure Drop Tally
Reference: drawing - kachirtn.cdr

a Zone & Section Number	b ASHRAE 1989 Fundamentals Designation	c Section Description	d Air Flow Velocity [fpm]	e Velocity Pressure [in wg]	f Friction Loss [in wg/ft]	g Loss Coeff n/a	h Section Length [ft]	i Pressure Loss [in wg]	j Zone I [in wg]	k Zone II [in wg]	l Zone III [in wg]	m Zone IV [in wg]	n Zone V [in wg]	o Zone VI [in wg]
----	Titus 300/350	14" x 14" grill	500	0.016	-----	-----	-----	0.046						x 0.046
TR:66b	5-5 F32.38	17" dia main	1,093	0.074	-----	0.020	-----	0.001		x 0.001		x 0.001		
TR:70	17" dia	round duct	1,093	-----	0.00100	-----	5,0	0.005		x 0.005		x 0.005		
II:71a	5-5 F32.38	8" dia branch	762	0.036	-----	(0.250)	-----	(0.009)		x (0.009)				
----	3-2 F32.31	5 pc 45 deg L	762	0.036	-----	0.114	-----	0.004		x 0.004				
II:72	8" dia	round duct	762	-----	0.00120	-----	8.0	0.010		o 0.010				
II:73	3-2 F32.31	6 ea 90 deg L's	762	0.036	-----	3.240	-----	0.117		o 0.117				
----	6-8 F32.48	1 ea perf plate	762	0.036	-----	3.000	-----	0.109		o 0.109				
II:74	4-1 F32.35	10 deg converge	500	0.016	-----	0.200	-----	0.003		x 0.003				
----	Titus 300/350	14" x 14" grill	500	0.016	-----	-----	-----	0.046		x 0.046				
TR:71b	5-5 F32.38	16" dia main	1,043	0.068	-----	0.200	-----	0.014				x 0.014		
IV:75	16" dia	round duct	1,043	-----	0.00095	-----	123.0	0.117				o 0.117		
IV:76	3-2 F32.31	smooth 90 deg L	1,043	0.068	-----	0.120	-----	0.008				x 0.008		
IV:77	3-2 F32.31	10 ea 90 deg L's	1,043	0.068	-----	1.200	-----	0.081				o 0.081		
IV:78	4-1 F32.35	10 deg converge	500	0.016	-----	0.200	-----	0.003				x 0.003		
----	Titus 300/350	14" x 14" grill	500	0.016	-----	-----	-----	0.046				x 0.046		

Columns j–o: Total Pressure Loss In Return Duct System For Each Path From Grill to Entry to Mechanical Room

			Zone I	Zone II	Zone III	Zone IV	Zone V	Zone VI
a	Total Pressure Loss In Return Duct System For Each Path (Grill to MR Entry)		0.289	0.306	0.287	0.295	0.318	0.289
b	Pressure Loss for Straight Duct Length & 90 deg L's		0.191	0.235	0.238	0.198	0.252	0.218
c	Pressure Loss for Zone XX From Grill to MR Entry less Straight Duct & 90 deg L's	a - b	0.098	0.071	0.049	0.097	0.066	0.071
d	Pressure Loss for Critical Path Thru MR (MR entry to Mixing Box)		0.523	0.523	0.523	0.523	0.523	0.523
e	Pressure Loss for Zone XX (Critical Path Thru MR + Zone - Str Duct & L's)	c + d	0.621	0.593	0.572	0.620	0.588	0.594

file: pd_rtn.wq2 01/28/96 Page 2

Figure 160: Megazone Return Air Duct Pressure Drop Tally (continued)

Figure 161: Megazone Return Air System Total Pressure Grade Line Data Table

Data	Zone I			Zone II			Zone III			Zone IV			Zone V			Zone VI		
Pt		[in wg]	Total Pres		[in wg]	Total Pres		[in wg]	Total Pres		[in wg]	Total Pres		[in wg]	Total Pres		[in wg]	Total Pres
0						0.000												
1				x	0.0460	(0.0460)						0.0000						
2				x	0.0031	(0.0491)				x	0.0460	(0.0460)						
3				o	0.1086	(0.1577)				x	0.0031	(0.0491)						0.0000
4				o	0.1172	(0.2749)				o	0.0814	(0.1305)				x	0.0460	(0.0460)
5			0.0000	o	0.0096	(0.2845)				x	0.0081	(0.1386)				x	0.0031	(0.0491)
6	x	0.0460	(0.0460)	x	0.0041	(0.2887)				o	0.1169	(0.2555)				o	0.1353	(0.1844)
7	x	0.0031	(0.0491)	x	(0.0090)	(0.2796)				x	0.0136	(0.2690)				o	0.0828	(0.2672)
8	x	0.1432	(0.1923)	x	0.0050	(0.2846)				x	0.0050	(0.2740)				x	0.0061	(0.2733)
9	x	0.0480	(0.2403)	x	0.0015	(0.2861)				x	0.0015	(0.2755)				x	(0.0038)	(0.2695)
10	x	0.0101	(0.2504)	x	0.0050	(0.2911)				x	0.0050	(0.2805)			0.0000	x	0.0050	(0.2745)
11	x	0.0309	(0.2813)	x	0.0070	(0.2981)				x	0.0070	(0.2875)	x	0.0460	(0.0460)	x	0.0070	(0.2815)
12	x	0.0013	(0.2826)	x	0.0013	(0.2994)			0.0000	x	0.0013	(0.2888)	x	0.0031	(0.0491)	x	0.0013	(0.2828)
13	x	0.0151	(0.2978)	x	0.0151	(0.3145)	x	0.0460	(0.0460)	x	0.0151	(0.3039)	o	0.1963	(0.2454)	x	0.0151	(0.2980)
14	x	0.0020	(0.2997)	x	0.0020	(0.3165)	x	0.0031	(0.0491)	x	0.0020	(0.3059)	o	0.0561	(0.3014)	x	0.0020	(0.2999)
15	x	(0.0096)	(0.2902)	x	(0.0096)	(0.3069)	o	0.1581	(0.2072)	x	(0.0096)	(0.2963)	x	0.0173	(0.3188)	x	(0.0096)	(0.2904)
16	x	0.0045	(0.2947)	x	0.0045	(0.3114)	o	0.0795	(0.2867)	x	0.0045	(0.3008)	x	0.0045	(0.3233)	x	0.0045	(0.2949)
17	x	(0.0054)	(0.2893)	x	(0.0054)	(0.3060)	x	0.0000	(0.2867)	x	(0.0054)	(0.2955)	x	(0.0054)	(0.3179)	x	(0.0054)	(0.2895)
18	1	0.0022	(0.2915)	1	0.0022	(0.3082)	1	0.0022	(0.2889)	1	0.0022	(0.2977)	1	0.0022	(0.3201)	1	0.0022	(0.2917)
19	2	0.0256	(0.3170)	2	0.0256	(0.3338)	2	0.0256	(0.3145)	2	0.0256	(0.3232)	2	0.0256	(0.3456)	2	0.0256	(0.3172)
20	3	0.0156	(0.3327)	3	0.0156	(0.3494)	3	0.0156	(0.3301)	3	0.0156	(0.3388)	3	0.0156	(0.3613)	3	0.0156	(0.3329)
21	4	0.0026	(0.3353)	4	0.0026	(0.3520)	4	0.0026	(0.3327)	4	0.0026	(0.3414)	4	0.0026	(0.3639)	4	0.0026	(0.3355)
22	5	0.0156	(0.3509)	5	0.0156	(0.3676)	5	0.0156	(0.3483)	5	0.0156	(0.3571)	5	0.0156	(0.3795)	5	0.0156	(0.3511)
23	6	0.0036	(0.3545)	6	0.0036	(0.3712)	6	0.0036	(0.3519)	6	0.0036	(0.3606)	6	0.0036	(0.3831)	6	0.0036	(0.3547)
24	---	0.0600	(0.4145)	---	0.0600	(0.4312)	---	0.0600	(0.4119)	---	0.0600	(0.4206)	---	0.0600	(0.4431)	---	0.0600	(0.4147)
25	7	0.1065	(0.5210)	7	0.1065	(0.5377)	7	0.1065	(0.5184)	7	0.1065	(0.5271)	7	0.1065	(0.5496)	7	0.1065	(0.5212)
26	8	0.1065	(0.6275)	8	0.1065	(0.6442)	8	0.1065	(0.6249)	8	0.1065	(0.6336)	8	0.1065	(0.6561)	8	0.1065	(0.6277)
27	Rtn	0.8200	0.1925	Rtn	0.8200	0.1758	Rtn	0.8200	0.1951	Rtn	0.8200	0.1864	Rtn	0.8200	0.1639	Rtn	0.8200	0.1923
28	9	0.0342	0.1583	9	0.0342	0.1416	9	0.0342	0.1609	9	0.0342	0.1521	9	0.0342	0.1297	9	0.0342	0.1581
29	10	0.0014	0.1569	10	0.0014	0.1402	10	0.0014	0.1595	10	0.0014	0.1508	10	0.0014	0.1283	10	0.0014	0.1567
30	11b	0.0081	0.1488	11b	0.0081	0.1320	11b	0.0081	0.1513	11b	0.0081	0.1426	11b	0.0081	0.1202	11b	0.0081	0.1486
31	17	0.0681	0.0807	17	0.0681	0.0639	17	0.0681	0.0832	17	0.0681	0.0745	17	0.0681	0.0521	17	0.0681	0.0805
32	18	0.0183	0.0623	18	0.0183	0.0456	18	0.0183	0.0649	18	0.0183	0.0562	18	0.0183	0.0337	18	0.0183	0.0621
33	19	0.0314	0.0309	19	0.0314	0.0141	19	0.0314	0.0334	19	0.0314	0.0247	19	0.0314	0.0023	19	0.0314	0.0307
34	20	0.0229	0.0080	20	0.0229	(0.0088)	20	0.0229	0.0105	20	0.0229	0.0018	20	0.0229	(0.0206)	20	0.0229	0.0078

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Appendix Q - Air Handler Control System

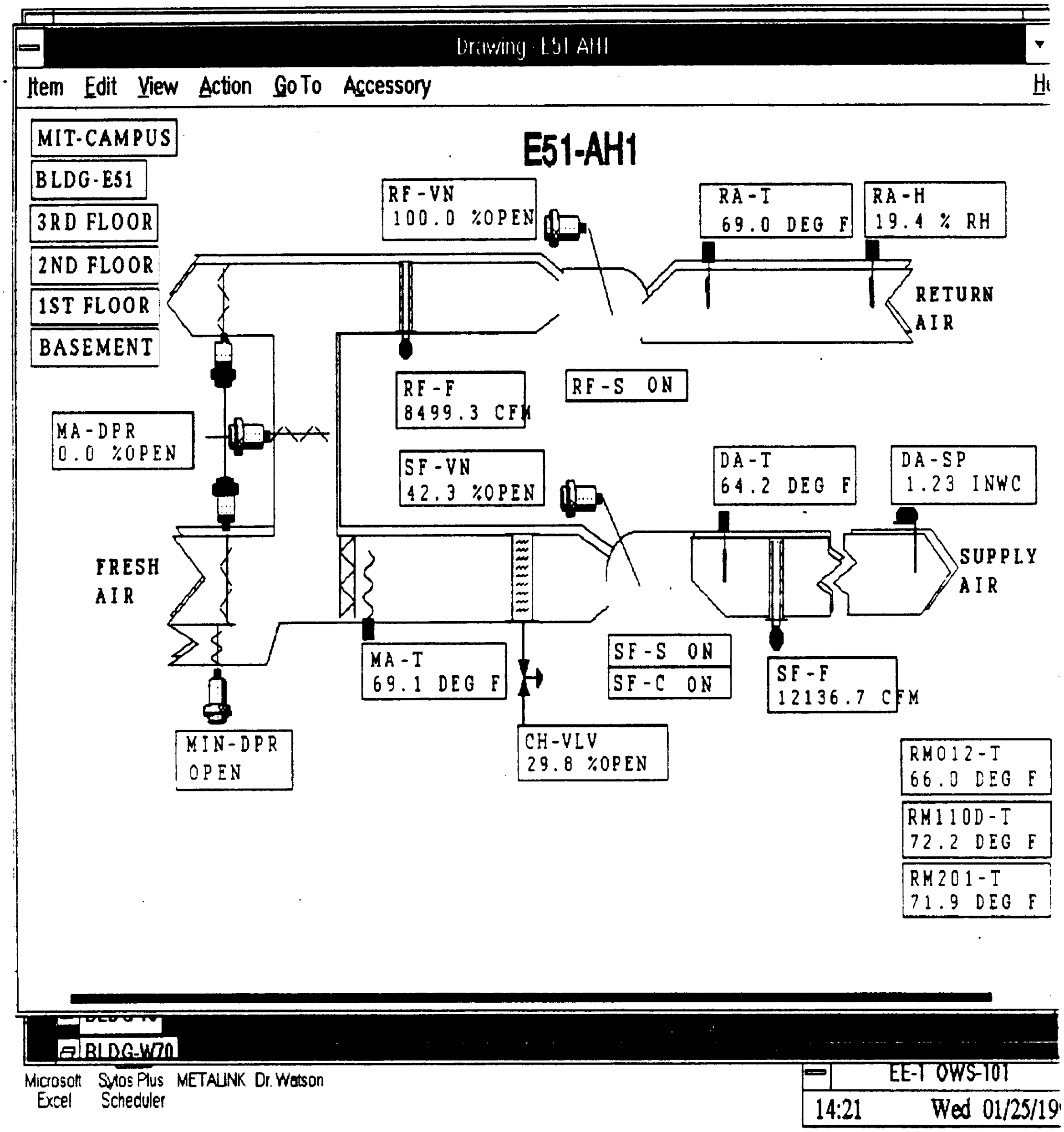

Figure 162: Johnson Metasys Control System - System Drawing

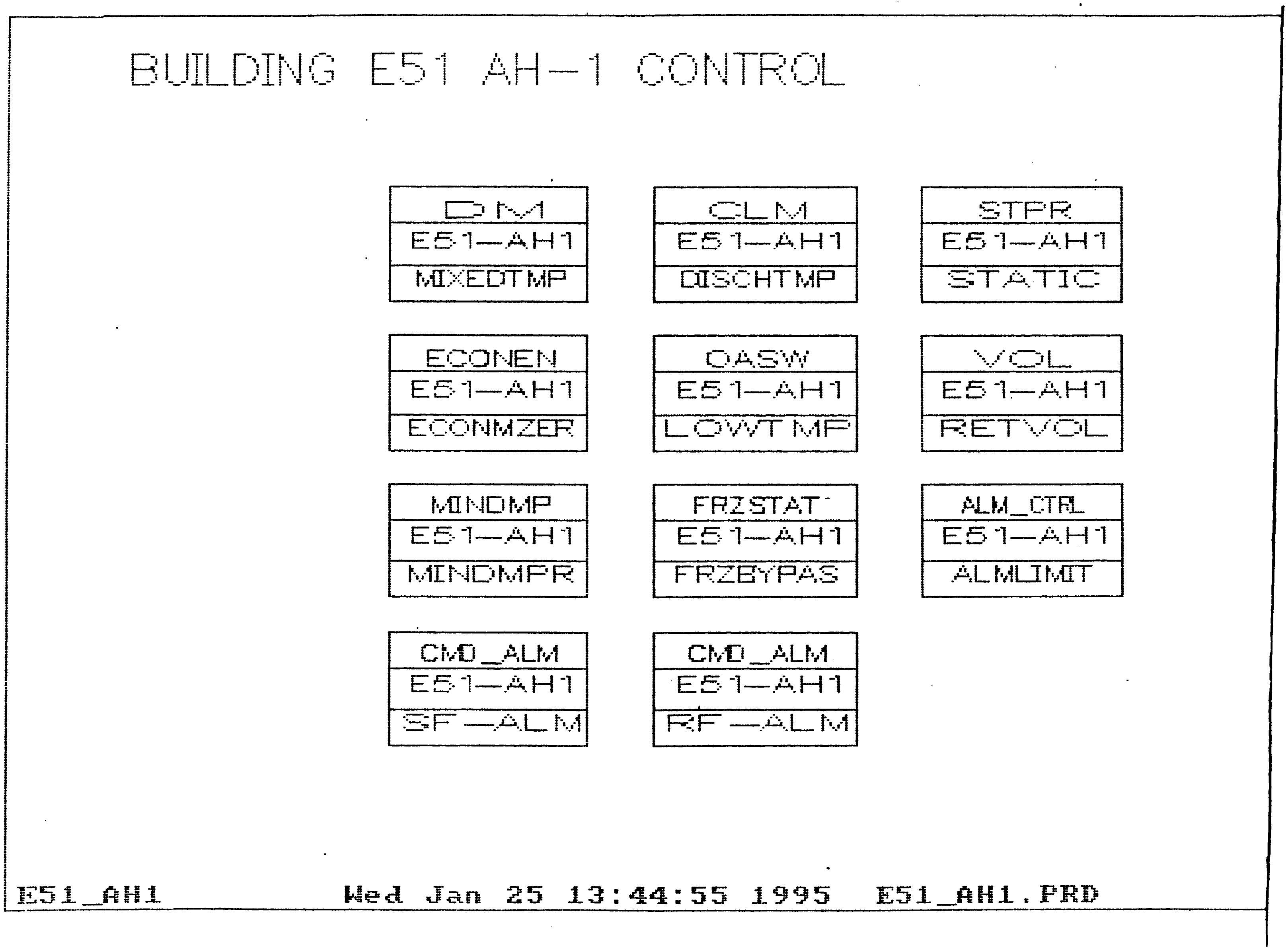

Figure 163: Johnson Metasys Control System - Compound Diagram

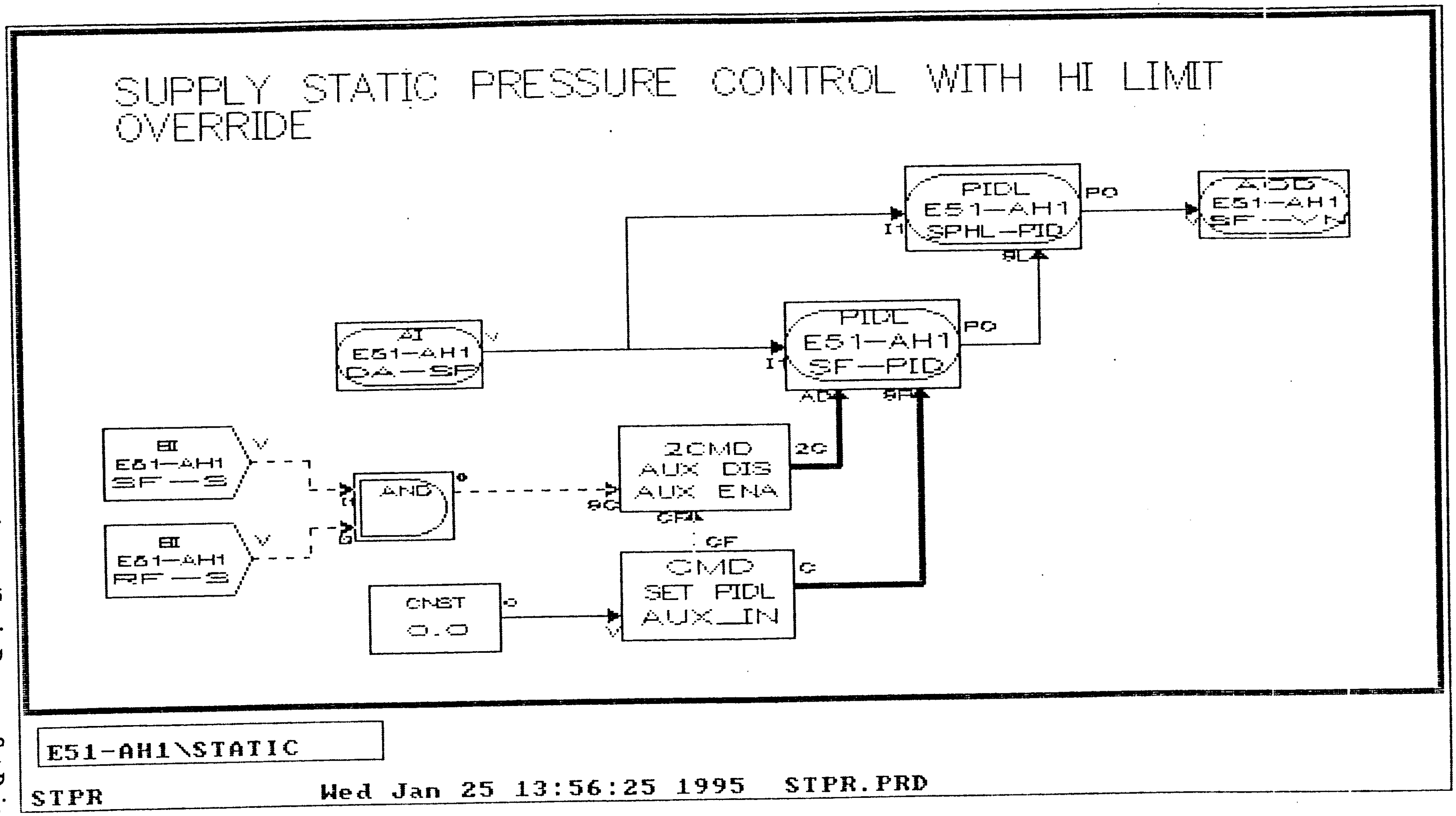

Figure 164: Johnson Metasys Control System - Function Diagram/Static Pressure Set Point

Appendix R - Building Zone Modeling: 2C 3R Component Model Structure

Figure 165: Global Parameters Annex 10 2C3R Zone Model

Global Parameters

Annex 10 Terms		1/R(wi)									
Mega-Zone Num-ber	External Surface Compass Heading	K(lite,ext)		K(lite,internal) Vertical				K(lite,internal) Horizontal			
				Vertical Room		Vertical Plenum		Horizontal Room		Horizontal Plenum	
		Sub-Total [W/K]	Total [W/K]	Ka [W/K]	Kb [W/K]	Ka [W/K]	Kb [W/K]	Ka [W/K]	Kb [W/K]	Ka [W/K]	Kb [W/K]
I	South	23.23									
I	West	4.20									
I	North	3.11	30.54	1,636	1,636	351	351	561	561	677	677
II	North	7.31	7.31	334	334	93	93	193	193	233	233
III	South	201.76									
III	West										
III	North	13.64									
III	Roof		215.40	4,398	4,398	977	977	1,610	1,610	1,942	1,942
IV	West	28.58									
IV	North	27.28	55.87	1,275	1,275	354	354	480	480	579	579
V	North	146.54									
V	Roof		146.54	3,026	3,026	757	757	1,372	1,372	1,655	1,655
VI	South	5.72									
VI	West	14.29	20.01	113	113	32	32	60	60	72	72

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Global Parameters

Annex 10 Terms										1/R(i)	
Mega-Zone Number	External Surface Compass Heading	K(hvy,ext,inner) External Shell				K(hvy,internal) Horizontal				K(hvy,inner) Total Sum	
		Room		Plenum		Horizontal Room		Horizontal Plenum			
		Sub-Tot [W/K]	Total [W/K]	Sub-Tot [W/K]	Total [W/K]	Ka [W/K]	Kb [W/K]	Ka [W/K]	Kb [W/K]	Room [W/K]	Plenum [W/K]
I	South	38.68		16.10							
I	West	10.98		4.02							
I	North	23.05	72.71	7.12	27.24	2,081	2,081	757	757	4,234	1,542
II	North	21.45	21.45	7.64	7.64	429	429	521	261	880	790
III	South	368.43		148.89							
III	West	177.45		49.29							
III	North	39.71		14.18							
III	Roof		585.59	286.88	499.24	4,737	4,737	1,234	1,234	10,059	2,968
IV	West	87.03		30.77							
IV	North	79.41	166.45	28.35	59.13	843	843	648	648	1,853	1,356
V	North	277.88		111.00							
V	Roof		277.88	46.44	157.43	2,606	2,606	1,852	1,852	5,490	3,861
VI	South	17.12		6.08							
VI	West	29.64	46.77	11.53	17.61	105	105	81	81	257	179

Global Parameters

Annex 10 Terms		K(ext)				theta(i)								
Mega-Zone Number	External Surface Compass Heading	Room		Plenum		Accessibility - theta(i)		Global Resistances						
		K(window) + K(wall)		K(wall)		K(hvy,ext)/K(hvy,inner)		R01	R21	R02	R22	R03	R23	R11
		Sub-Tot	Total	Sub-Tot	Total	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Plenum
		[W/K]	[W/K]	[W/K]	[W/K]	-----	-----	[K/kW]	[K/kW]	[K/kW]	[K/kW]	[K/kW]	[K/kW]	[K/kW]
I	South	48.37		10.47		47	18							
I	West	11.33		2.61		4,234	1,542							
I	North	18.10	77.80	4.63	17.71	0.01116	0.01149	3.27E+01	0	2.64E-03	7.45E-03	2.34E-01	6.41E-01	3.26E+00
II	North	21.25	21.25	4.97	4.97	0.01585	0.00629	1.37E+02	0	1.80E-02	7.97E-03	1.12E+00	1.26E+00	9.47E+00
III	South	441.24		96.78										
III	West	115.34		32.04		381	224							
III	North	39.45		9.22		10,059	2,968							
III	Roof		596.03	86.06	224.10	0.03784	0.07551	4.64E+00	0	3.76E-03	2.54E-02	9.56E-02	3.12E-01	1.14E+00
						108	38							
IV	West	85.16		20.00		1,853	1,356							
IV	North	78.90	164.06	18.43	38.43	0.05838	0.02834	1.79E+01	0	3.15E-02	2.09E-02	5.08E-01	7.17E-01	3.81E+00
						181	86							
V	North	327.16		72.15		5,490	3,861							
V	Roof		327.16	13.93	86.08	0.03290	0.02229	6.82E+00	0	5.99E-03	5.77E-03	1.76E-01	2.53E-01	1.33E+00
						30	11							
VI	South	16.85		3.95		257	179							
VI	West	33.56	50.41	7.50	11.44	0.11839	0.06390	5.00E+01	0	4.61E-01	3.57E-01	3.43E+00	5.23E+00	3.06E+01

Global Parameters

Annex 10 Terms		K(i)				xi(i)		1/Req(i)					
Mega-Zone Number	External Surface Compass Heading	K(i)		K(i)*xi(i) = Cdot(i,out)+K(lite,ext)		xi(i)		Keq(i)		aq(i)		at(i)	
		Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum
		[W/K]	[W/K]	[W/K]	[W/K]	-----	-----	[W/K]	[W/K]	-----	-----	-----	-----
I	South												
I	West												
I	North	1218.95	188.88	1171.69	171.17	0.96	0.91	5,406	1,713	0.22549	0.11028	0.21675	0.09994
II	North	209.60	33.22	195.65	28.25	0.93	0.85	1,075	818	0.19494	0.04061	0.18197	0.03454
III	South												
III	West												
III	North												
III	Roof	6563.27	1119.18	6182.63	895.09	0.94	0.80	16,242	3,863	0.40409	0.28973	0.38066	0.23171
IV	West												
IV	North	1266.44	203.79	1158.24	165.36	0.91	0.81	3,011	1,521	0.42055	0.13394	0.38462	0.10868
V	North												
V	Roof	3589.98	575.50	3409.35	489.42	0.95	0.85	8,899	4,351	0.40340	0.13228	0.38311	0.11250
VI	South												
VI	West	471.42	74.60	441.02	63.15	0.94	0.85	698	242	0.67559	0.30795	0.63203	0.26070

Global Parameters

Annex 10 Terms													
Mega-Zone Number	External Surface Compass Heading	Accessibility - theta(i) Annex 10		theta(my way)/ theta(annex10)		C(hvy,ext,inner) External Shell				C(hvy,internal) Horizontal			
						Room		Plenum		Horizontal Room		Horizontal Plenum	
		Room	Plenum	Room	Plenum	Sub-Tot	Total	Sub-Tot	Total	Ca	Cb	Ca	Cb
		-----	-----	-----	-----	[J/K]	[J/K]	[J/K]	[J/K]	[J/K]	[J/K]	[J/K]	[J/K]
I	South					4.64E+06	21,324	1.93E+06	7,990	68,447	68,447	61,583	61,583
I	West					1.32E+06	9,693	4.82E+05	3,632	31,112	31,112	27,992	27,992
I	North	0.01116	0.01149	1.00E+00	1.00E+00	2.77E+06	8.72E+06	8.54E+05	3.27E+06	2.49E+07	2.49E+07	2.24E+07	2.24E+07
							6,290		2,242	11,143	11,143	21,203	21,203
II	North	0.01585	0.00629	1.00E+00	1.00E+00	2.57E+06	2.57E+06	9.17E+05	9.17E+05	4.05E+06	4.05E+06	7.71E+06	7.71E+06
III	South					4.42E+07		1.79E+07					
III	West					2.13E+07	171,736	5.91E+06	127,566	286,433	286,433	100,391	100,391
III	North					4.76E+06	78,062	1.70E+06	57,984	130,197	130,197	45,632	45,632
III	Roof	0.03784	0.07551	1.00E+00	1.00E+00		7.03E+07	2.67E+07	5.22E+07	1.04E+08	1.04E+08	3.65E+07	3.65E+07
							92,066		32,782	52,746	52,746	52,746	52,746
IV	West					1.04E+07	41,848	3.69E+06	14,901	23,975	23,975	23,975	23,975
IV	North	0.05838	0.02834	1.00E+00	1.00E+00	2.72E+07	3.77E+07	9.72E+06	1.34E+07	1.92E+07	1.92E+07	1.92E+07	1.92E+07
							232,838		103,574	162,987	162,987	150,622	150,622
V	North					9.53E+07	105,836	3.80E+07	47,079	74,085	74,085	68,464	68,464
V	Roof	0.03290	0.02229	1.00E+00	1.00E+00		9.53E+07	4.32E+06	4.24E+07	5.93E+07	5.93E+07	5.48E+07	5.48E+07
							39,185		14,753	6,567	6,567	6,567	6,567
VI	South					5.87E+06	17,811	2.08E+06	6,706	2,985	2,985	2,985	2,985
VI	West	0.11839	0.06390	1.00E+00	1.00E+00	1.02E+07	1.60E+07	3.95E+06	6.04E+06	2.39E+06	2.39E+06	2.39E+06	2.39E+06

Annex 10 Terms		C(si)		tau(i)										
Mega-Zone Num-ber	External Surface Compass Heading	C(hvy,oa)		Tau(hvy,oa) Total Sum		Volume(air,i) w/ rho(air) = 1.22 [kg/m3] Cp(air) = 962 [J/kg-K]			C(lite,air)		C(lite,internal) Vertical			
		C03	C23								Vertical Room		Vertical Plenum	
		Room [J/K]	Plenum [J/K]	Room [s}	Plenum [s}	Room [m3]	Plenum [m3]	Total [m3]	Room [J/K]	Plenum [J/K]	Ca [J/K]	Cb [J/K]	Ca [J/K]	Cb [J/K]
I	South	160,883	132,154						1,736	335	8,899	8,899	1,908	1,908
I	West	73,129	60,070	13	71				789	152	4,045	4,045	867	867
I	North	5.85E+07	4.81E+07	4.80E+04	2.54E+05	647	125	772	7.59E+05	1.46E+05	4.04E+06	4.04E+06	8.67E+05	8.67E+05
								772						
		29,362	44,928	14	137				415	115	1,815	1,815	504	504
II	North	1.07E+07	1.63E+07	5.09E+04	4.92E+05	155	43	198	1.82E+05	5.04E+04	8.25E+05	8.25E+05	2.29E+05	2.29E+05
								198						
III	South													
III	West	766,068	344,294						5,576	962	23,916	23,916	5,313	5,313
III	North	348,213	156,497	12	31				2,535	437	10,871	10,871	2,415	2,415
III	Roof	2.79E+08	1.25E+08	4.24E+04	1.12E+05	2,077	358	2,436	2.44E+06	4.21E+05	1.09E+07	1.09E+07	2.41E+06	2.41E+06
								2,436						
		209,066	142,371						1,033	287	6,934	6,934	1,926	1,926
IV	West	95,030	64,714	17	71				470	130	3,152	3,152	875	875
IV	North	7.60E+07	5.18E+07	6.00E+04	2.54E+05	385	107	492	4.52E+05	1.25E+05	3.15E+06	3.15E+06	8.75E+05	8.75E+05
								492						
		587,918	417,764						3,259	819	16,455	16,455	4,118	4,118
V	North	267,235	189,893	17	73				1,482	372	7,480	7,480	1,872	1,872
V	Roof	2.14E+08	1.52E+08	5.96E+04	2.64E+05	1,214	305	1,520	1.43E+06	3.58E+05	7.48E+06	7.48E+06	1.87E+06	1.87E+06
								1,520						
		57,217	29,731						129	36	617	617	172	172
VI	South	26,008	13,514	12	40				58	16	280	280	78	78
VI	West	2.08E+07	1.08E+07	4.41E+04	1.45E+05	48	13	61	5.62E+04	1.56E+04	2.80E+05	2.80E+05	7.82E+04	7.82E+04
								61						

822,961	505,110		Sub Total Estimated Mass [kg]
		1,328,071	Total [kg]
	82,474		Avg Est'd Mass From Internal Wall
	851,920		Avg Est'd Mass From Horizontal Surfaces
	397,544		Avg Est'd Mass From External Walls x theta
		1,331,937	Total [kg]
		1.00	Ratio

Annex 10 Terms						C(i)	
Mega-Zone Number	External Surface Compass Heading	C(lite,internal) Horitzontal				C(lite,oa)	
		Vertical Room		Vertical Plenum		C02	C22
		Ca [J/K]	Cb [J/K]	Ca [J/K]	Cb [J/K]	Room [J/K]	Plenum [J/K]
I	South	1,055	1,055	1,055	1,055	23,671	6,151
I	West	479	479	479	479	10,759	2,796
I	North	2.83E+05	2.83E+05	2.83E+05	2.83E+05	9.41E+06	2.45E+06
		363	363	363	363	5,096	1,769
II	North	9.74E+04	9.74E+04	9.74E+04	9.74E+04	2.03E+06	7.03E+05
III	South						
III	West	3,028	3,028	3,028	3,028	64,878	17,285
III	North	1,376	1,376	1,376	1,376	29,490	7,857
III	Roof	8.12E+05	8.12E+05	8.12E+05	8.12E+05	2.58E+07	6.87E+06
		904	904	904	904	18,203	5,936
IV	West	411	411	411	411	8,274	2,698
IV	North	2.42E+05	2.42E+05	2.42E+05	2.42E+05	7.24E+06	2.36E+06
		2,580	2,580	2,580	2,580	44,675	13,794
V	North	1,173	1,173	1,173	1,173	20,307	6,270
V	Roof	6.92E+05	6.92E+05	6.92E+05	6.92E+05	1.78E+07	5.49E+06
		112	112	112	112	1,703	584
VI	South	51	51	51	51	774	266
VI	West	3.02E+04	3.02E+04	3:02E+04	3.02E+04	6.77E+05	2.32E+05

Internal & Adiabatic Wall Resistance & Capacitance Calculation

Level	Type	Thkness	**	ZONE (areas from file: intvert.wq2)					
				I	II	III	IV	V	VI
				[ft2]	[ft2]	[ft2]	[ft2]	[ft2]	[ft2]
All	Internal	t	P	323	69	1007	305	587	0
All	Gyp & SS		R	1163	249	3626	1099	2093	0
All	Adiabatic	1/2 t	P	285	108	579	330	836	84
All	Gyp & SS		R	2017	388	4420	1186	3845	301

** implies values for plenum P or room R

Calculation for Resistance per area Rbar(m) of Internal Gypsum and Steel Stud Walls
(refer to document text [Section 3] for calculation of R value)

R = L/kA	previous calculation	Rbar(int wall) =	2.636	[degF-hr-ft2 / Btu]
&	or	Kbar(int wall) =	0.379	[btu / degF-hr-ft2]
K = 1/R	or in SI units with	5.678 [(W / ft2 degK) / (Btu / degF-hr-ft2)]		
	the conductance is	Kbar(int wall) =	2.152	[W / m2-degK]
	or	Rbar(int wall) =	0.465	[m2-degK / W]

For the intenal wall the structure is symmetrical, therefore:	theta(m) =	0.5
from work prepared by reserach assistant P.Balun	theta(am) =	0.35
	theta(bm) =	0.35

Resistance due to Conduction

Rbar(am) = (1 - theta(m)) * Rbar(m)	or Rbar(am) =	0.232	[m2-degK / W] or [m2-degK-s / J]
Rbar(bm) = theta(m) * Rbar(m)	or R(bar)bm =	0.232	[m2-degK / W] or [m2-degK-s / J]

film resistance for vertical surface w/still air [F22.1 ASHRAE (SI)]

film resistance for vert surface * = 0.12 [m2-degK-s/J]

Figure 166: Physical Properties for Resistance - Internal & Adiabatic Vertical Walls

Figure 167: Resistances - Internal & Adiabatic Vertical Walls

Internal & Adiabatic Wall Resistance & Capacitance Calculation

Level	Type	Thkness *	**	Resistance theta(am)*Ram [film + conduction] for Int'l & Adiabatic					
				I	II	III	IV	V	VI
				[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]
All	Internal	t	P	4.11E-03	1.92E-02	1.32E-03	4.35E-03	2.26E-03	-----
All	Gyp & SS		R	1.14E-03	5.33E-03	3.66E-04	1.21E-03	6.34E-04	-----
All	Adiabatic	1/2 t	P	9.31E-03	2.46E-02	4.58E-03	8.04E-03	3.17E-03	3.16E-02
All	Gyp & SS		R	1.32E-03	6.84E-03	6.00E-04	2.24E-03	6.90E-04	8.82E-03

Level	Type	Thkness *	**	Resistance theta(bm)*Rbm [film + conduction] for Int'l & Adiabatic					
				I	II	III	IV	V	VI
				[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]
All	Internal	t	P	4.11E-03	1.92E-02	1.32E-03	4.35E-03	2.26E-03	-----
All	Gyp & SS		R	1.14E-03	5.33E-03	3.66E-04	1.21E-03	6.34E-04	-----
All	Adiabatic	1/2 t	P	9.31E-03	2.46E-02	4.58E-03	8.04E-03	3.17E-03	3.16E-02
All	Gyp & SS		R	1.32E-03	6.84E-03	6.00E-04	2.24E-03	6.90E-04	8.82E-03

* For adiabatic walls the thickness is 1/2 t. Resistances and capacitances are calculated as for internal walls, but the wall is folded in half (making the effective face area equal to 1/2 of the actual area transverse to the direction of heat flow). The effective area is used to calculate Ram(adiabatic) & Rbm(adiabatic)

** implies values for plenum P or room R

Figure 168: Physical Properties for Capacitance - Internal & Adiabatic Vertical Walls

Internal & Adiabatic Wall Resistance & Capacitance Calculation

35.31	[ft3/m3]
Cam = Cbm = 0.5 Cm	

Calculation for Capacitance of Internal Gypsum and Steel Stud Walls
a 1 ft2 piece of the wall has the following capacitive properties

the density of gypsum is [F22.6 ASHRAE (SI)]:	801	[kg/m3]
the density of steel is [F36.4 ASHRAE (SI)]:	7,833	[kg/m3]
the density of fiberglass is [F22.6 ASHRAE (SI)]:	104	[kg/m3]
the specific heat of gypsum is [F22.6 ASHRAE (SI)]:	1,088	[J/kg-degK]
the specific heat of steel is [F36.4 ASHRAE (SI)]:	502	[J/kg-degK]
the specific heat of fiberglass is [F22.6 ASHRAE (SI)]:	962	[J/kg-degK]
the fractional area of steel transverse to the direction of heat flow is:	0.01	[m2/m2]
the fractional area of fiber glass transverse to the direction of heat flow is:	0.99	[m2/m2]
the volume of 2 ply thkness of 5/8" thk gypsum in 1 ft2 of wall is:	0.00295	[m3/ft2]
the volume of steel in 1 ft2 of wall with 3 5/8" steel studs is:	0.00009	[m3/ft2]
the volume of fiberglass in 1 ft2 of wall with 3 5/8" steel studs is:	0.00818	[m3/ft2]
the mass M(gypsum) in 1 ft2 of wall is:	2.36	[kg/ft2]
the mass M(steel) in 1 ft2 of wall is:	0.67	[kg/ft2]
the mass M(fibergalss) in 1 ft2 of wall is:	0.85	[kg/ft2]

Cbar(gypsum) =	Cp(gypsum)* M(gypsum)/ft2 =	2,570	[(J/degK)/ft2]
Cbar(steel) =	Cp(steel)* M(steel)/ft2 =	336	[(J/degK)/ft2]
Cbar(fiber glass) =	Cp(f-glass)* M(f-glass)/ft2 =	819	[(J/degK)/ft2]
Cbar(total) = sum of individual capacitances		3,725	[(J/degK)/ft2]

Figure 169: Capacitances - Internal & Adiabatic Vertical Walls

Internal & Adiabatic Wall Resistance & Capacitance Calculation

Level	Type	Thkness *	**	Individual zone capacitances Cam					
				I	II	III	IV	V	VI
				[(J/degK]	[(J/degK]	[(J/degK]	[(J/degK]	[(J/degK]	[(J/degK]
All	Internal	t	P	6.02E+05	1.29E+05	1.88E+06	5.68E+05	1.09E+06	-----
All	Gyp & SS		R	2.17E+06	4.64E+05	6.75E+06	2.05E+06	3.90E+06	-----
All	Adiabatic	1/2 t	P	2.65E+05	1.01E+05	5.39E+05	3.07E+05	7.79E+05	7.82E+04
All	Gyp & SS		R	1.88E+06	3.61E+05	4.12E+06	1.10E+06	3.58E+06	2.80E+05

Level	Type	Thkness *	**	Individual zone capacitances Cbm					
				I	II	III	IV	V	VI
				[(J/degK]	[(J/degK]	[(J/degK]	[(J/degK]	[(J/degK]	[(J/degK]
All	Internal	t	P	6.02E+05	1.29E+05	1.88E+06	5.68E+05	1.09E+06	-----
All	Gyp & SS		R	2.17E+06	4.64E+05	6.75E+06	2.05E+06	3.90E+06	-----
All	Adiabatic	1/2 t	P	2.65E+05	1.01E+05	5.39E+05	3.07E+05	7.79E+05	7.82E+04
All	Gyp & SS		R	1.88E+06	3.61E+05	4.12E+06	1.10E+06	3.58E+06	2.80E+05

* For adiabatic walls the thickness is 1/2 t. Resistances and capacitances are calculated as for internal walls, but the wall is folded in half (making the effective face area equal to 1/2 of the actual area transverse to the direction of heat flow). The effective area is used to calculate Cam(adiabatic) & Cbm(adiabatic)

** implies values for plenum P or room R

Figure 170: Time Constants for Internal & Adiabatic Vertical Walls

Internal & Adiabatic Wall Resistance & Capacitance Calculation

Calculate time constants theta(am) and theat(bm) tau(approx. time constant [s]) = 0.92

Level	Type	Thkness *	**	Time constant tau(am)					
				I	II	III	IV	V	VI
				[s]	[s]	[s]	[s]	[s]	[s]
All	Internal	t	P	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03	-----
All	Gyp & SS		R	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03	-----
All	Adiabatic	1/2 t	P	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03
All	Gyp & SS		R	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03

Level	Type	Thkness *	**	Time constant tau(bm)					
				I	II	III	IV	V	VI
				[s]	[s]	[s]	[s]	[s]	[s]
All	Internal	t	P	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03	-----
All	Gyp & SS		R	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03	-----
All	Adiabatic	1/2 t	P	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03
All	Gyp & SS		R	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03	2.47E+03

* see notes for resistance and capacitance calculation

** implies values for plenum P or room R

	Internal	Adiabatic
Time Constant For Internal Wall [hr]	0.69	0.69
Total Heat Capacity for Internal Walls [J/K]		6.60E+07
Estimated Average Mass [kg]		82,474
Total Internal Wall Surface Area [ft2]		24,900
Estimated Average Mass per Unit Area [kg/ft2]		3.3

Vertical Surface Areas - Internal Only

Level	Type	Thknes **	*	ZONE *** I [ft2]	II [ft2]	III [ft2]	IV [ft2]	V [ft2]	VI [ft2]
0	Internal	t	P	323	69	77			
0	Gyp & SS		R	1,163	249	277			
0	Adiabatic	1/2 t	P	285	108	79			
0	Gyp & SS		R	2,017	388	727			
1	Internal	t	P			317	138	174	
1	Gyp & SS		R			1,142	497	624	
1	Adiabatic	1/2 t	P			57	159	280	
1	Gyp & SS		R			1,211	570	1,008	
2	Internal	t	P			524	167	178	
2	Gyp & SS		R			1,887	602	624	
2	Adiabatic	1/2 t	P			176	171	264	84
2	Gyp & SS		R			1,520	616	950	301
3	Internal	t	P			89		235	
3	Gyp & SS		R			320		845	
3	Adiabatic	1/2 t	P			267		292	
3	Gyp & SS		R			962		1,887	
All	Internal	t	P	323	69	1007	305	587	
All	Gyp & SS		R	1163	249	3626	1099	2093	
All	Adiabatic	1/2 t	P	285	108	579	330	836	84
All	Gyp & SS		R	2017	388	4420	1186	3845	301

* P = plenum R = room

** t = thickness of internal wall & 1/2 t = 1/2 thickness of internal wall

*** linear wall dimensions taken from drawings: e510thrs.cdr e512ndrs.cdr e511stsr.cdr e513rdrs.cdr

using linear measures, areas were calculated w/ 9 ft ceiling & 2.5 ft plenum

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Figure 171: Internal Vertical Surface Identification & Area Tally

Figure 172: Physical Properties and Summary Area Tally, Horizontal Surfaces

Resistances & Capacitances for Internal & External Horizontal Surfaces

Surface	Orientation	Location	Mat'l	Thickness	Type		ZONE Areas					
					Code	Int/Ext	I	II	III	IV	V	VI
				[in]			[ft2]	[ft2]	[ft2]	[ft2]	[ft2]	[ft2]
* All	up	Rm	conc	3.00	A	Int	2,707	638	970	0	0	0
All	dn	Rm	ceil	0.63	B	Int	1,763	607	5,061	1,510	4,312	188
All	up	Pl	ceil	0.63	B	Int	1,763	607	5,061	1,510	4,312	188
All	dn	Pl	conc	6.00	C	Int	1,763	607	2,874	1,510	4,312	188
All	dn	Rm	conc	6.00	C	Int	606	0	1,738	0	0	0
All	up	Rm	conc	6.00	C	Int	0	0	5,977	1,510	4,666	188
** All	dn	Rm	roof	4.75	D	Ext	0	0	0	0	354	0
All	up	Out	roof	4.75	D	Ext	0	0	0	0	354	0
All	dn	Pl	roof	4.75	D	Ext	0	0	2,187	0	0	0
All	up	out	roof	4.75	D	Ext	0	0	2,187	0	0	0
				Check Sums		62,218	8602	2459	26055	6040	18310	752

* concrete foundation slab actual thickness is assumed to be 12" - 1/4 thickness is taken to reflect actaul thermal behavior

** thickness for roof includes 2.5" concrete + 2" insulation + 0.25" built-up roofing surface

Surface	Orientation	Location	Mat'l	Thickness [in]	k [W/m-K]	C [W/m2-K]	Rbar(m) [m2-K/W]	Film Coeff [m2-K/W]	Density [kg/m3]	Density [kg-m/m3]	Cp [J/kg-K]	Cbar(m) [J/m2-K]
All	up	Rm	conc	3.00	1.350	17.730	0.056	0.110	2,250	171	800	1.37E+05
All	dn	Rm	ceil	0.63	0.060	3.782	0.264	0.160	370	6	590	3.46E+03
All	up	Pl	ceil	0.63	0.060	3.782	0.264	0.110	370	6	590	3.46E+03
All	dn	Pl	conc	6.00	1.350	8.865	0.113	0.160	2,250	343	800	2.74E+05
All	dn	Rm	conc	6.00	1.350	8.865	0.113	0.160	2,250	343	800	2.74E+05
All	up	Rm	conc	6.00	1.350	8.865	0.113	0.110	2,250	343	800	2.74E+05
All	dn	Rm	roof	4.75		0.462	2.163	0.160	1,354	163	1,150	1.88E+05
All	up	Out	roof	4.75		0.462	2.163	0.039	1,354	163	1,150	1.88E+05
All	dn	Pl	roof	4.75		0.462	2.163	0.160	1,354	163	1,150	1.88E+05
All	up	out	roof	4.75		0.462	2.163	0.039	1,354	163	1,150	1.88E+05
							Average Mass per ft2 [kg/ft2] =			17		

Figure 173: Resistances - Internal Horizontal Surfaces

Resistances & Capacitances for Internal & External Horizontal Surfaces

Sur-face	Orien-ation	Loca-tion	Mat'l	Thick-ness	theta(m)	0.5	Resistance theta(am)* Ram [film + conduction] for Int Horz Surf					
					theta(am)	0.5	I	II	III	IV	V	VI
				[in]	(m)	(am)	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]
All	up	Rm	conc	3.00	0.5	0.5	5.49E-04	2.33E-03	1.53E-03	-----	-----	-----
All	dn	Rm	ceil	0.63	0.5	0.5	1.78E-03	5.18E-03	6.21E-04	2.08E-03	7.29E-04	1.67E-02
All	up	Pl	ceil	0.63	0.5	0.5	1.48E-03	4.29E-03	5.15E-04	1.73E-03	6.04E-04	1.39E-02
All	dn	Pl	conc	6.00	0.5	0.5	1.32E-03	3.84E-03	8.10E-04	1.54E-03	5.40E-04	1.24E-02
All	dn	Rm	conc	6.00	0.5	0.5	3.84E-03	-----	1.34E-03	-----	-----	-----
All	up	Rm	conc	6.00	0.5	0.5	-----	-----	3.00E-04	1.19E-03	3.84E-04	9.52E-03

Sur-face	Orien-ation	Loca-tion	Mat'l	Thick-ness	theta(m)	0.5	Resistance theta(bm)* Rbm [film + conduction] for Int Horz Surf					
					theta(bm)	0.5	I	II	III	IV	V	VI
				[in]	(m)	(bm)	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]
All	up	Rm	conc	3.00	0.5	0.5	5.49E-04	2.33E-03	1.53E-03	-----	-----	-----
All	dn	Rm	ceil	0.63	0.5	0.5	1.78E-03	5.18E-03	6.21E-04	2.08E-03	7.29E-04	1.67E-02
All	up	Pl	ceil	0.63	0.5	0.5	1.48E-03	4.29E-03	5.15E-04	1.73E-03	6.04E-04	1.39E-02
All	dn	Pl	conc	6.00	0.5	0.5	1.32E-03	3.84E-03	8.10E-04	1.54E-03	5.40E-04	1.24E-02
All	dn	Rm	conc	6.00	0.5	0.5	3.84E-03	-----	1.34E-03	-----	-----	-----
All	up	Rm	conc	6.00	0.5	0.5	-----	-----	3.00E-04	1.19E-03	3.84E-04	9.52E-03

Figure 174: Capacitances & Time Constants - Internal Horizontal Surfaces

Resistances & Capacitances for Internal & External Horizontal Surfaces

Sur- face	Orien- ation	Loca- tion	Mat'l	Thick- ness	theta(m) / theta(am)	0.5 / 0.5	Net Capacitance Cam for Internal Horizontal Surfaces					
							I	II	III	IV	V	VI
				[in]	(m)	(am)	[J/K]	[J/K]	[J/K]	[J/K]	[J/K]	[J/K]
All	up	Rm	conc	3.00	0.5	0.5	1.72E+07	4.05E+06	6.16E+06	-----	-----	-----
All	dn	Rm	ceil	0.63	0.5	0.5	2.83E+05	9.74E+04	8.12E+05	2.42E+05	6.92E+05	3.02E+04
All	up	Pl	ceil	0.63	0.5	0.5	2.83E+05	9.74E+04	8.12E+05	2.42E+05	6.92E+05	3.02E+04
All	dn	Pl	conc	6.00	0.5	0.5	2.24E+07	7.71E+06	3.65E+07	1.92E+07	5.48E+07	2.39E+06
All	dn	Rm	conc	6.00	0.5	0.5	7.70E+06	-----	2.21E+07	-----	-----	-----
All	up	Rm	conc	6.00	0.5	0.5	-----	-----	7.59E+07	1.92E+07	5.93E+07	2.39E+06

Sur- face	Orien- ation	Loca- tion	Mat'l	Thick- ness	theta(m) / theta(bm)	0.5 / 0.5	Net Capacitance Cbm for Internal Horizontal Surfaces					
							I	II	III	IV	V	VI
				[in]	(m)	(bm)	[J/K]	[J/K]	[J/K]	[J/K]	[J/K]	[J/K]
All	up	Rm	conc	3.00	0.5	0.5	1.72E+07	4.05E+06	6.16E+06	-----	-----	-----
All	dn	Rm	ceil	0.63	0.5	0.5	2.83E+05	9.74E+04	8.12E+05	2.42E+05	6.92E+05	3.02E+04
All	up	Pl	ceil	0.63	0.5	0.5	2.83E+05	9.74E+04	8.12E+05	2.42E+05	6.92E+05	3.02E+04
All	dn	Pl	conc	6.00	0.5	0.5	2.24E+07	7.71E+06	3.65E+07	1.92E+07	5.48E+07	2.39E+06
All	dn	Rm	conc	6.00	0.5	0.5	7.70E+06	-----	2.21E+07	-----	-----	-----
All	up	Rm	conc	6.00	0.5	0.5	-----	-----	7.59E+07	1.92E+07	5.93E+07	2.39E+06

Sur- face	Orien- ation	Loca- tion	Mat'l	Thick- ness			Time Constants tau(am) & tau(bm) Internal Horizontal Walls					
							I	II	III	IV	V	VI
				[in]			[s]	[s]	[s]	[s]	[s]	[s]
All	up	Rm	conc	3.00			9.44E+03	9.44E+03	9.44E+03	-----	-----	-----
All	dn	Rm	ceil	0.63			5.05E+02	5.05E+02	5.05E+02	5.05E+02	5.05E+02	5.05E+02
All	up	Pl	ceil	0.63			4.18E+02	4.18E+02	4.18E+02	4.18E+02	4.18E+02	4.18E+02
All	dn	Pl	conc	6.00			2.96E+04	2.96E+04	2.96E+04	2.96E+04	2.96E+04	2.96E+04
All	dn	Rm	conc	6.00			2.96E+04	-----	2.96E+04	-----	-----	-----
All	up	Rm	conc	6.00			-----	-----	2.27E+04	2.27E+04	2.27E+04	2.27E+04

Minimum Time Constant

Figure 175: Resistances & Capacitances - External Horizontal Surfaces

Resistances & Capacitances for Internal & External Horizontal Surfaces

Sur-face	Orien-ation	Loca-tion	Mat'l	Thick-ness	theta(m)	0.3	Net Resistance Rm (film + conduction) for External Horz Walls					
							I	II	III	IV	V	VI
				[in]	(m)		[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]
All	dn	Rm	roof	4.75	0.3		-----	-----	-----	-----	7.18E-02	-----
All	up	Out	roof	4.75	0.3		-----	-----	-----	-----	-----	-----
All	dn	Pl	roof	4.75	0.3		-----	-----	1.16E-02	-----	-----	-----
All	up	out	roof	4.75	0.3		-----	-----	-----	-----	-----	-----

Sur-face	Orien-ation	Loca-tion	Mat'l	Thick-ness	theta(m)	0.3	Net Capacitance Cm for External Horz Walls					
							I	II	III	IV	V	VI
				[in]	(m)		[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]	[s-degK/J]
All	dn	Rm	roof	4.75	0.3		-----	-----	-----	-----	6.18E+06	-----
All	up	Out	roof	4.75	0.3		-----	-----	-----	-----	-----	-----
All	dn	Pl	roof	4.75	0.3		-----	-----	3.82E+07	-----	-----	-----
All	up	out	roof	4.75	0.3		-----	-----	-----	-----	-----	-----

Sur-face	Orien-ation	Loca-tion	Mat'l	Thick-ness	theta(m)	0.3	Time Constants tau(m) External Horizontal Walls (ie. roof)					
							I	II	III	IV	V	VI
				[in]	(m)		[s]	[s]	[s]	[s]	[s]	[s]
All	dn	Rm	roof	6.00	0.3		-----	-----	-----	-----	4.12E+04	-----
All	dn	Pl	roof	4.75	0.3		-----	-----	4.12E+04	-----	-----	-----

	I	II	III	IV	V	VI
Total Heat Capacity for all Horizontal Surfaces [J/K]	9.57E+07	2.39E+07	3.23E+08	7.77E+07	2.37E+08	9.67E+06
Average Specific Heat over all Materials [J/kg-k] *	900	900	900	900	900	900
Estimated Mass of Horizontal Surfaces [kg]	106,332	26,571	358,589	86,322	263,359	10,747
Estinated, Averaged Mass per Unit Area [kg/ft2]	12.4	10.8	13.8	14.3	14.4	14.3
	Total Estimated Mass for Horizontal Surfaces [kg]					851,920

* based on a proportional mix of materials for all horizontal surfaces

Time Constant 3" (12") Slab [hr]	2.6
Time Constant Roof [hr]	11.4
Time Constant 6" Floor [hr]	8.2
Time Constant 3/4" Ceiling Tile [hr]	0.1

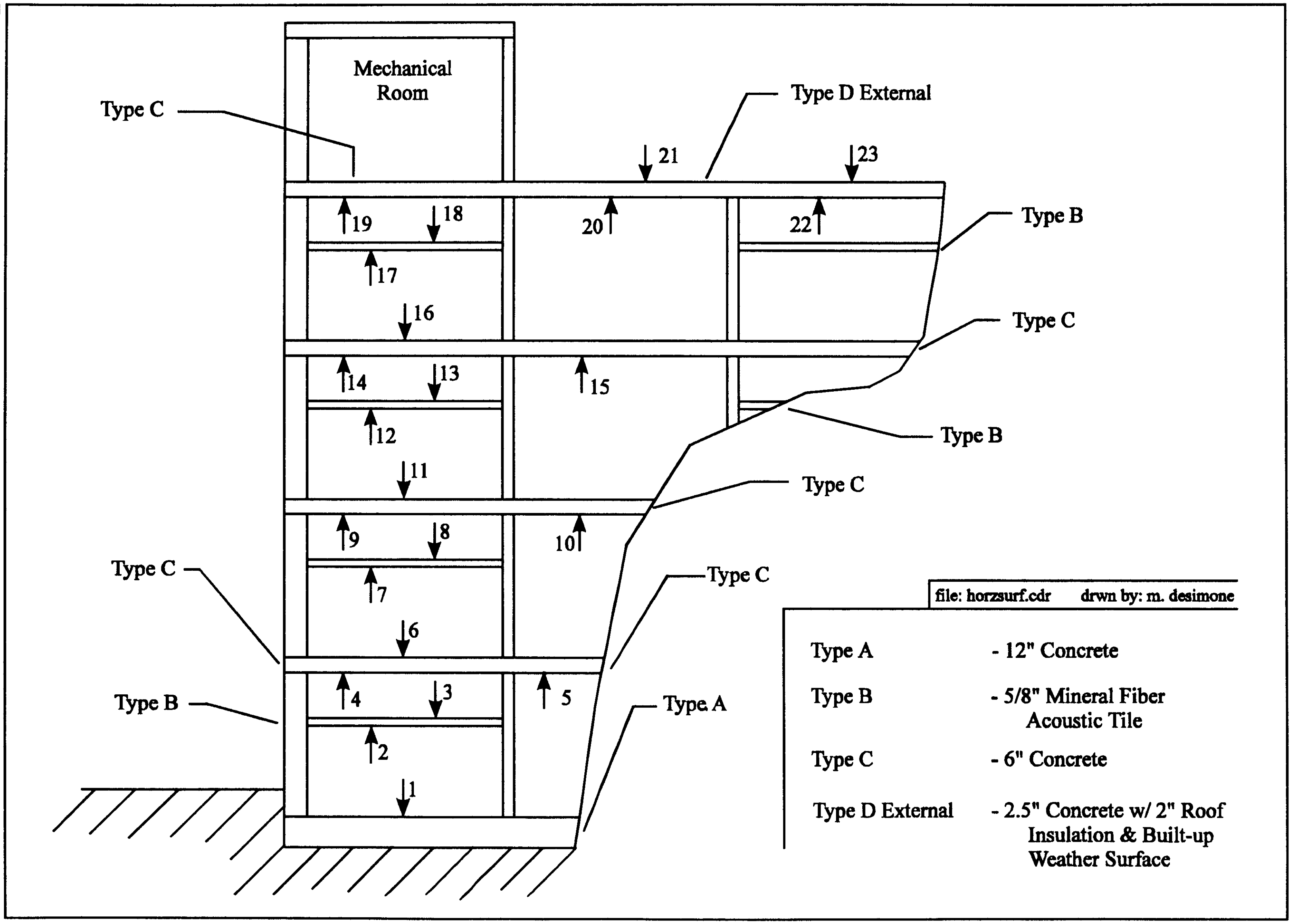

Figure 176: Horizontal Surface Identification, Building E51

Horizontal Surface Areas - Both Internal & External

Sur-face (1)	Orien-ation (2)	Loca-tion (3)	Mat'l (4)	Thick-ness [in]	Type Code (5)	Type Int/Ext (6)	ZONE (7) I [ft2]	II [ft2]	III [ft2]	IV [ft2]	V [ft2]	VI [ft2]
1	up	Rm	conc	3.00	A	Int	2,707	638	970			
2	dn	Rm	ceil	0.63	B	Int	1,763	607	142			
3	up	Pl	ceil	0.63	B	Int	1,763	607	142			
4	dn	Pl	conc	6.00	C	Int	1,763	607	142			
5	dn	Rm	conc	6.00	C	Int	606					
6	up	Rm	conc	6.00	C	Int			1,660	720	949	
7	dn	Rm	ceil	0.63	B	Int			1,121	720	949	
8	up	Pl	ceil	0.63	B	Int			1,121	720	949	
9	dn	Pl	conc	6.00	C	Int			1,121	720	949	
10	dn	Rm	conc	6.00	C	Int			1,219			
11	up	Rm	conc	6.00	C	Int			2,130	790	1,123	188
12	dn	Rm	ceil	0.63	B	Int			1,611	790	1,123	188
13	up	Pl	ceil	0.63	B	Int			1,611	790	1,123	188
14	dn	Pl	conc	6.00	C	Int			1,611	790	1,123	188
15	dn	Rm	conc	6.00	C	Int			519			
16	up	Rm	conc	6.00	C	Int			2,187		2,594	
17	dn	Rm	ceil	0.63	B	Int			2,187		2,240	
18	up	Pl	ceil	0.63	B	Int			2,187		2,240	
19	dn	Pl	conc	6.00	C	Int					2,240	
20	dn	Rm	roof	4.75	D	Ext					354	
21	up	Out	roof	4.75	D	Ext					354	
22	dn	Pl	roof	4.75	D	Ext			2,187			
23	up	Out	roof	4.75	D	Ext			2,187			
				Check Sums		62,218	8,602	2,459	26,055	6,040	18,310	752
All	up	Rm	conc	3.00	A	Int	2,707	638	970	0	0	0
All	dn	Rm	ceil	0.63	B	Int	1,763	607	5,061	1,510	4,312	188
All	up	Pl	ceil	0.63	B	Int	1,763	607	5,061	1,510	4,312	188
All	dn	Pl	conc	6.00	C	Int	1,763	607	2,874	1,510	4,312	188
All	dn	Rm	conc	6.00	C	Int	606	0	1,738	0	0	0
All	up	Rm	conc	6.00	C	Int	0	0	5,977	1,510	4,666	188
All	dn	Rm	roof	4.75	D	Ext	0	0	0	0	354	0
All	up	Out	roof	4.75	D	Ext	0	0	0	0	354	0
All	dn	Pl	roof	4.75	D	Ext	0	0	2,187	0	0	0
All	up	out	roof	4.75	D	Ext	0	0	2,187	0	0	0
				Check Sums		62,218	8,602	2,459	26,055	6,040	18,310	752

(1) surface number corresponding to diagram
(2) surface orientation for correct assignation of surface film coefficient
(3) surface location per diagram
(4) surface material and thickness
(5) surface type code for clarification purposes cross referenced to diagram
(6) declaration for internal or external surface
(7) take off quantity based on drawings in appendix

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Figure 177: Horizontal Surface Identification & Area Tally

Building Envelope Wall Resistance & Capacitance Calculation

Calculation for Resistance per area Rbar(m) of External Vertical Envelope Walls

R = L/kA	previous calculation	Rbar(ext wall) =	4.500	[degF-hr-ft2 / Btu]
&	or	Kbar(ext wall) =	0.222	[btu / degF-hr-ft2]
K = 1/R	or in SI units with	5.678 [(W/ft2-degK) / (Btu/degF-hr-ft2)]		
	the conductance is	Kbar(ext wall) =	1.262	[W / m2-degK]
	or	Rbar(ext wall) =	0.793	[m2-degK / W]

From Calculations for External Shell Wall one by Research Assistant P.Balun theta(m) = 0.65

Calculation for Resistance per area Rbar(m) of External Windows (ref: 1993 ASHRAE, F27.19, Ex.8)

previous calculation	Rbar(window) =	2.014	[degF-hr-ft2 / Btu]
or	Kbar(window) =	0.497	[btu / degF-hr-ft2]
or in SI units with	5.678 [(W / ft2 degK) / (Btu / degF-hr-ft2)]		
the conductance is	Kbar(window) =	2.819	[W / m2-degK]
or	Rbar(window) =	0.355	[m2-degK / W]

film resistance for vertical surface w/still air [F22.1 1993 ASHRAE (SI)]

film resistance for external vertical surface =	0.039 [m2-degK/W]				
film resistance for internal vertical surface =	0.120 [m2-degK/W]				
	[m2-degK/W]		[W/m2-degK]		
** Rbar,tot,wall(m) = Rbar(int wall) + R(film out) + R(film in) =	0.952	or	1.05	= U-Factor	
** Rbar,tot,window(m) = Rbar(window) + R(film out) + R(film in) =	0.514	or	1.95	= U-Factor	

** Overall resistance for external vertical walls is the series sum of film resistance + conductive resistance

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Figure 178: Thermal Resistivity, External Vertical Walls & Double Glazed Windows

Calculation for Capacitance of Double Glazed Windows

35.31	[ft3/m3]

A 1 ft2 piece of window has the following capacitive properties

Layer	Description	Reference	Density [kg/m3]	Specific Heat [J/kg-degK]
1	glass (3/16" thick)	[Mills, p. 815]:	2,220	745
2	air & 1/2" alum insulated spacer			
	2a 1/2" alum spacer	[F36.4 ASHRAE (SI)]:	2,740	896
	2b 1/2" air space	[F22.6 ASHRAE (SI)]:	1.20	962
3	glass (3/16" thick)	[F22.6 ASHRAE (SI)]:	2,220	745

the fractional area of aluminum transverse to the direction of heat flow is: 0.0100 [m2/m2]

the fractional area of air transverse to the direction of heat flow is: 0.9900 [m2/m2]

Layer	Description	Volume in 1 ft2 wall [m3/ft2]	Mass in 1 ft2 wall [kg/ft2]	Heat Cap 1 ft2 wall [(J/K)/ft2]	Total Heat Cap 1 ft2 wall [(J/K)/ft2]
1	glass (3/16" thick)	4.44E-04	9.85E-01	7.34E+02	
2	air & 1/2" alum insulated spacer				
	2a 1/2" alum spacer	1.18E-05	3.23E-02	2.90E+01	
	2b 1/2" air space	1.17E-03	1.40E-03	1.35E+00	
3	glass (3/16" thick)	4.44E-04	9.85E-01	7.34E+02	1.50E+03
	Mass of 1 ft2 of Dbl Glazed Window	=	2.00	[kg/ft2]	

Figure 179: Heat Capacity, Double Glazed Windows

Figure 180: Physical Properties - Heat Capacity, External Vertical Walls

Calculation for Capacitance of External Shell Walls

35.31	[ft3/m3]

A 1 ft2 piece of the curtain wall has the following capacitive properties

Layer	Description		Reference	Density [kg/m3]	Specific Heat [J/kg-degK]
1	gypsum		[F22.6 ASHRAE (SI)]:	801	1,088
2	fiberglass and steel stud				
	2a	steel stud	[F36.4 ASHRAE (SI)]:	7,833	502
	2b	fiberglass	[F22.6 ASHRAE (SI)]:	104	962
3	furring strip and air				
	3a	furring strip	[F22.9 ASHRAE (SI)]:	600	1,633
	3b	air	[CRC Handbook]:	1.20	1,000
4	concrete block		[F22.8 ASHRAE (SI)]:	2,082	920
5	mopped felp vapor barrier		[F22.6 ASHRAE (SI)]:	230	1,460
5	steel clips and air				
	6a	steel clip	[F36.4 ASHRAE (SI)]:	7,832	502
	6b	air	[CRC Handbook]:	1.20	1,000
7	brick		[F22.7 ASHRAE (SI)]:	1,922	790

the fractional area of steel transverse to the direction of heat flow is:	0.0100	[m2/m2]
the fractional area of fiber glass transverse to the direction of heat flow is:	0.9900	[m2/m2]
the fractional area of furring strip to the direction of heat flow is:	0.1458	[m2/m2]
the fractional area of air transverse to the direction of heat flow is:	0.8542	[m2/m2]
the fractional area of steel clip transverse to the direction of heat flow is:	0.0005	[m2/m2]
the fractional area of air transverse to the direction of heat flow is:	0.9995	[m2/m2]

Figure 181: Heat Capacity, External Vertical Walls

Building Envelope Wall Resistance & Capacitance Calculation

Layer	Description	Volume in 1 ft2 wall [m3/ft2]	Mass in 1 ft2 wall [kg/ft2]	Heat Cap 1 ft2 wall [(J/K)/ft2]	Total Heat Cap 1 ft2 wall [(J/K)/ft2]
1	gypsum	1.47E-03	1.18E+00	1.28E+03	
2	fiberglass and steel stud				
	2a steel stud	8.55E-05	6.70E-01	3.36E+02	
	2b fiberglass	8.18E-03	8.51E-01	8.19E+02	
3	furring strip and air				
	3a furring strip	2.58E-04	1.55E-01	2.53E+02	
	3b air	1.51E-03	1.81E-03	1.81E+00	
4	concrete block	1.89E-02	3.93E+01	3.62E+04	
5	mopped felp vapor barrier	2.95E-04	6.78E-02	9.91E+01	
5	steel clips and air				
	6a steel clip	1.77E-06	1.39E-02	6.96E+00	
	6b air	3.54E-03	4.25E-03	4.25E+00	
7	brick	8.26E-03	1.59E+01	1.25E+04	5.15E+04

Mass of 1 ft2 of Curtain Wall = 58 [kg/ft2]

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Building Envelope Wall Resistance & Capacitance Calculation

Zone Number	External Surface Compass Heading	Resistances - External/Vertical			Capacitances - External/Vertical			Tau [s] w/ thete(m) =		0.65
		Hdg Window Area [s-degK/J]	Heading Room [s-degK/J]	Heading Plenum [s-degK/J]	Hdg Window Area [J/K]	Heading Room [J/K]	Heading Plenum [J/K]	Hdg Window Area [J/K]	Heading Room [J/K]	Heading Plenum [J/K]
I	South	4.30E-02	3.98E-02	9.55E-02	1.92E+05	1.33E+07	5.52E+06	1.88E+03	1.20E+05	1.20E+05
I	West	2.38E-01	1.40E-01	3.83E-01	3.47E+04	3.76E+06	1.38E+06	1.88E+03	1.20E+05	1.20E+05
I	North	3.21E-01	6.67E-02	2.16E-01	2.58E+04	7.90E+06	2.44E+06	1.88E+03	1.20E+05	1.20E+05
II	North	1.37E-01	7.17E-02	2.01E-01	6.05E+04	7.35E+06	2.62E+06	1.88E+03	1.20E+05	1.20E+05
III	South	4.96E-03	4.18E-03	1.03E-02	1.67E+06	1.26E+08	5.10E+07	1.88E+03	1.20E+05	1.20E+05
III	West		8.67E-03	3.12E-02		6.08E+07	1.69E+07		1.20E+05	1.20E+05
III	North	7.33E-02	3.87E-02	1.09E-01	1.13E+05	1.36E+07	4.86E+06	1.88E+03	1.20E+05	1.20E+05

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Figure 182: Thermal Resistance & Capacitance, External Walls & Double Glazed Windows

Figure 183: Thermal Resistance & Capacitance, External Walls & Windows (cont'd)

Building Envelope Wall Resistance & Capacitance Calculation

Zone Number	External Surface Compass Heading	Resistances - External/Vertical			Capacitances - External/Vertical			Tau [s] w/ theta(m) =		0.65
		Hdg Window Area [s-degK/J]	Heading Room [s-degK/J]	Heading Plenum [s-degK/J]	Hdg Window Area [J/K]	Heading Room [J/K]	Heading Plenum [J/K]	Hdg Window Area [J/K]	Heading Room [J/K]	Heading Plenum [J/K]
IV	West	3.50E-02	1.77E-02	5.00E-02	2.37E+05	2.98E+07	1.05E+07	1.88E+03	1.20E+05	1.20E+05
IV	North	3.67E-02	1.94E-02	5.43E-02	2.26E+05	2.72E+07	9.72E+06	1.88E+03	1.20E+05	1.20E+05
V	North	6.82E-03	5.54E-03	1.39E-02	1.21E+06	9.53E+07	3.80E+07	1.88E+03	1.20E+05	1.20E+05
VI	South	1.75E-01	8.98E-02	2.53E-01	4.73E+04	5.87E+06	2.08E+06	1.88E+03	1.20E+05	1.20E+05
VI	West	7.00E-02	5.19E-02	1.33E-01	1.18E+05	1.02E+07	3.95E+06	1.88E+03	1.20E+05	1.20E+05
Total Heat Capacities for Each Surface Type [J/K]					3.94E+06	4.01E+08	1.49E+08			
Implied Total Mass w/ Cp(avg) [kg]					4,923	445,937	165,668	Time Constants [hr]		
Total Area of Each Surface Type [ft2]					2,629	7,792	2,895	0.5	33.3	33.3
Approximate Mass per ft2 [kg/ft2]					2	57	57			
Actual Mass per ft2 calculated above [kg/ft2]					2	58	58			
Total Implied Mass of External Shell							616,528			

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Figure 184: External Vertical Surface Identification & Area Tally

Zone Number	External Surface Compass Heading	Total Hdg Room & Plenum & Window	AREAS *				
			Heading Win & Room [ft2]	Hdg Window Area [ft2]	Heading Room [ft2]	Heading Plenum [ft2]	Check Sum [ft2]
I	South	493	386	128	257	107	493
I	West	123	96	23	73	27	123
I	North	218	171	17	153	47	218
II	North	234	183	40	143	51	234
III	South	4,558	3,567	1,115	2,452	991	4,558
III	West	1,509	1,181	0	1,181	328	1,509
III	North	434	340	75	264	94	434
IV	West	942	737	158	579	205	942
IV	North	868	679	151	529	189	868
V	North	3,398	2,659	810	1,849	739	3,398
VI	South	186	146	32	114	40	186
VI	West	353	276	79	197	77	353
Chk Sums		13,316 13,316	10,421	2,629	7,792 10,421	2,895 2,895	13,316 13,316

* taken from file: extwall.wq2

Capacitive Flow of Air Flow Through Zone

Zone Number	supply flow from flwtally.wq2 [cfm]	[m3/s]	mass flow [kg/s]	capacitive flow of air thru zone [J/s-K]	[J/s-K]
I	2,060	0.97	1.19	1,141	171
II	340	0.16	0.20	188	28
III	10,772	5.08	6.20	5,967	895
IV	1,990	0.94	1.15	1,102	165
V	5,890	2.78	3.39	3,263	489
VI	760	0.36	0.44	421	63
C(p)air =	962	[J/kg-K]	rho(air) =	1.22	[kg/m3]
convert	0.0283	[m3/ft3]	convert	60	[s/m]

file: infltrn.wq2 01/27/96 Page 1

Figure 185: Capacitive Flow of Infiltration

Appendix S - Thermal and Airflow Schematics

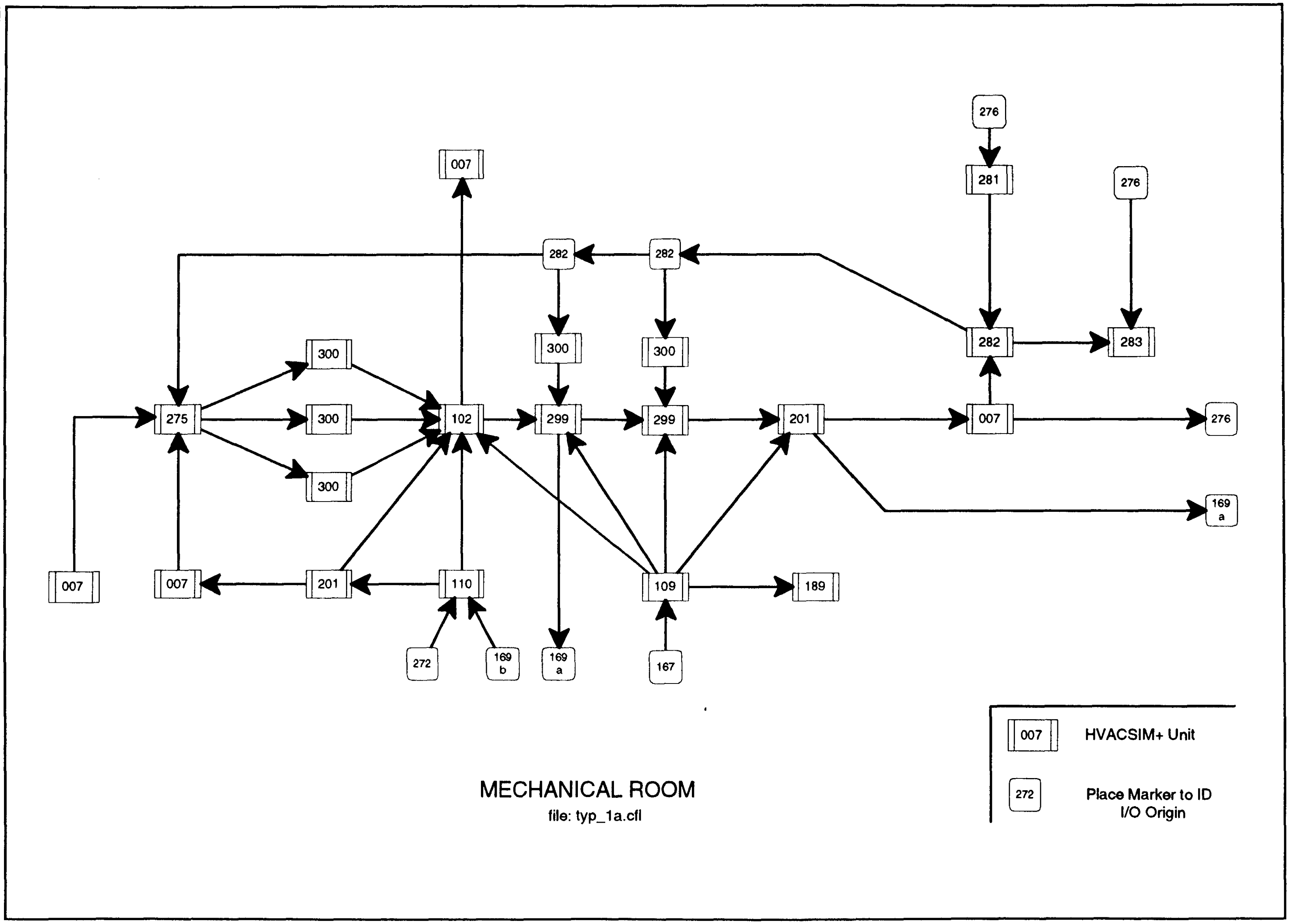

Figure 186: Sample Arrangement HVACSIM+ Implicit Flow Simulation - Mechanical Room

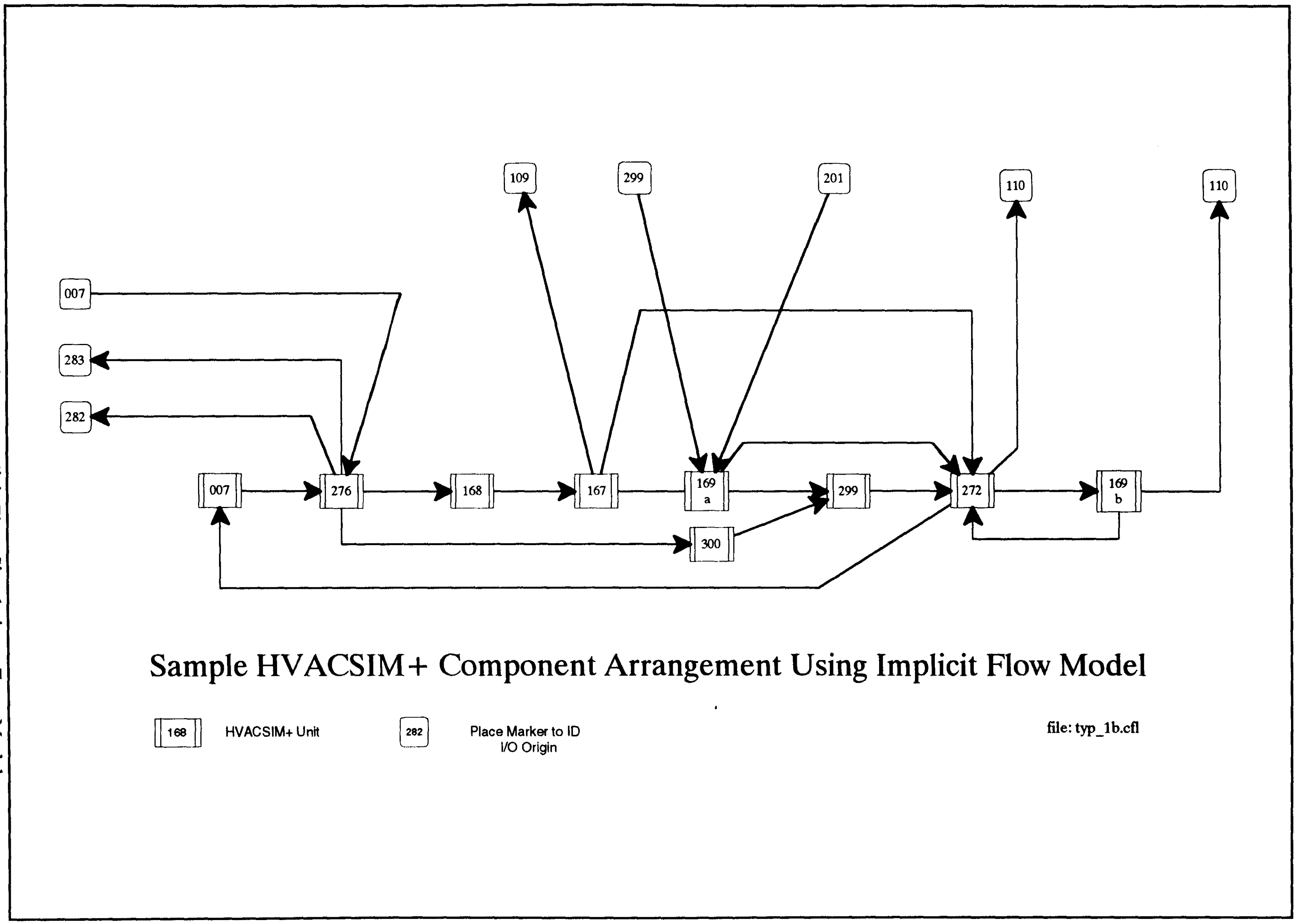

Figure 187: Sample Arrangement HVACSIM+ Implicit Flow Simulation - Zone Model

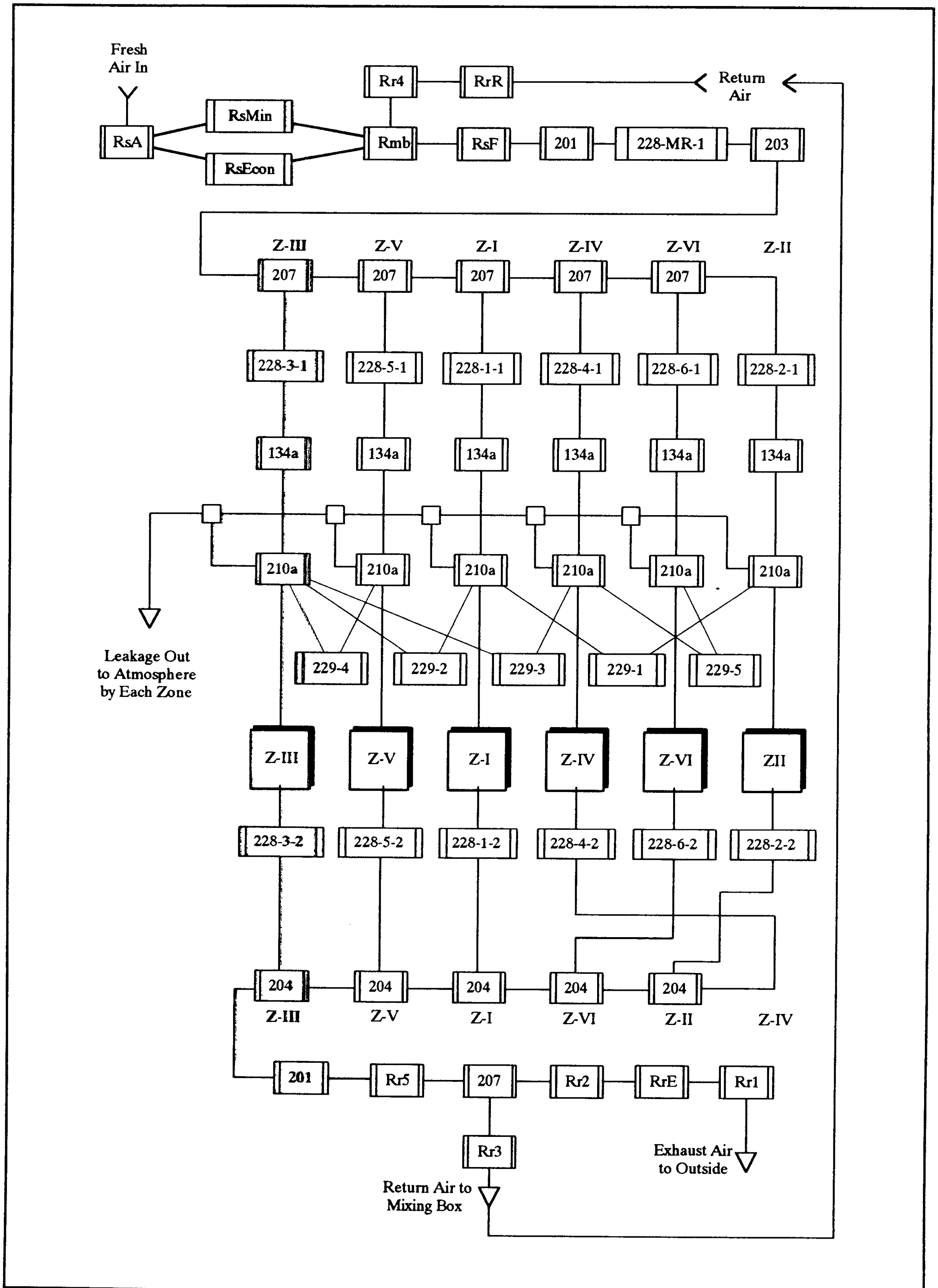

Figure 188: Airflow Component Network Diagram

Appendix T - E51 Simulation: Controllers [148]

148 Controllers modeled by LUT Team.

Appendix U - E51 Simulation: Actuators

Type 300: Actuator w/ Faults, Deadband and Hysteresis (revised)

a	b	c	d	e	f	g	h	i	j
	Parameter Description	Mecahnical Room							
		MB Fresh Air Dampers		MB Return Air Damper		MB Exhaust Air Damper		Cooling Coil Valve	
		English	SI	English	SI	English	SI	English	SI
1	direction: 1 = forward, -1 = stuck, 0 = reverse	1	1	1	1	1	1	1	1
2	starting position (0-1)	0	0	0	0	0	0	0	0
3	actuator travel time [secs] (limit to limit)	5	5	5	5	5	5	9	9
4	min change in demanded position for movement (-)	0	0	0	0	0	0	0	0
5	hsyteresis (-)	0	0	0	0	0	0	0	0
6	crank travel angle [deg] (0 for linear movement)	90	90	90	90	90	90	0	0
7	A: coefficient in range transformation CC = A*C + B	1	1	1	1	1	1	1	1
8	B: coefficient in range transformation CC = A*C + B	0	0	0	0	0	0	0	0

a	b	k	l	m	n	o	p	q	r
	Parameter Description	Zone I VAV Damper		Zone I Reheat Coil		Zone II VAV Damper		Zone II Reheat Coil	
		English	SI	English	SI	English	SI	English	SI
1	direction: 1 = forward, -1 = stuck, 0 = reverse	1	1	1	1	1	1	1	1
2	starting position (0-1)	0	0	0	0	0	0	0	0
3	actuator travel time [secs] (limit to limit)	125	125	125	125	125	125	125	125
4	min change in demanded position for movement (-)	0	0	0	0	0	0	0	0
5	hsyteresis (-)	0	0	0	0	0	0	0	0
6	crank travel angle [deg] (0 for linear movement)	0	0	0	0	0	0	0	0
7	A: coefficient in range transformation CC = A*C + B	1	1	1	1	1	1	1	1
8	B: coefficient in range transformation CC = A*C + B	0	0	0	0	0	0	0	0

a	b	s	t	u	v	w	x	y	z
	Parameter Description	Zone III VAV Damper		Zone III Reheat Coil		Zone IV VAV Damper		Zone IV Reheat Coil	
		English	SI	English	SI	English	SI	English	SI
1	direction: 1 = forward, -1 = stuck, 0 = reverse	1	1	1	1	1	1	1	1
2	starting position (0-1)	0	0	0	0	0	0	0	0
3	actuator travel time [secs] (limit to limit)	125	125	125	125	125	125	125	125
4	min change in demanded position for movement (-)	0	0	0	0	0	0	0	0
5	hsyteresis (-)	0	0	0	0	0	0	0	0
6	crank travel angle [deg] (0 for linear movement)	0	0	0	0	0	0	0	0
7	A: coefficient in range transformation CC = A*C + B	1	1	1	1	1	1	1	1
8	B: coefficient in range transformation CC = A*C + B	0	0	0	0	0	0	0	0

a	b	a1	b1	c1	d1	e1	f1	g1	h1
	Parameter Description	Zone V VAV Damper		Zone V Reheat Coil		Zone VI VAV Damper		Zone VI Reheat Coil	
		English	SI	English	SI	English	SI	English	SI
1	direction: 1 = forward, -1 = stuck, 0 = reverse	1	1	1	1	1	1	1	1
2	starting position (0-1)	0	0	0	0	0	0	0	0
3	actuator travel time [secs] (limit to limit)	125	125	125	125	125	125	125	125
4	min change in demanded position for movement (-)	0	0	0	0	0	0	0	0
5	hsyteresis (-)	0	0	0	0	0	0	0	0
6	crank travel angle [deg] (0 for linear movement)	0	0	0	0	0	0	0	0
7	A: coefficient in range transformation CC = A*C + B	1	1	1	1	1	1	1	1
8	B: coefficient in range transformation CC = A*C + B	0	0	0	0	0	0	0	0

file: type_300.wq2 12/27/95 Page 1

Figure 189: E51 Parameters - Type 300 (Actuators)

Appendix V - E51 Simulation: Airflow Components

Figure 190: E51 Parameters - Type xxx (Mixing Box)

Type xxx: Mixing Box: Parallel and/or Opposed Blade Dampers - Calculates Supply Flow

a	b	c	d	e	f
Para-Meter	Description	Reference		Proposed Value	Units
		Document	Designation		
1	Auxillary Psychometric Outputs (0 = no & 1 = yes)	establish baseline	----	0	[-]
2	0 = no faults; 1 = 100% oversized; 2 = 20% leakage, 3 = both	establish baseline	----	0	[-]
3	Fresh Air Damper: Opposed = (0) & Parallel = (1)	inspection	----	0	[-]
4	Return Air Damper: Opposed = (0) & Parallel = (1)	inspection	----	0	[-]
5	Exhaust Air Damper: Opposed = (0) & Parallel = (1)	inspection	----	0	[-]
6	Open Resistance Rr1 [1/(kg-m)] ref: Mixing Box Airflow Network	res_trn.wq2	Rr1	1.64E-01	[1/(kg-m)]
7	Open Resistance Rr2 [1/(kg-m)] ref: Mixing Box Airflow Network	res_trn.wq2	Rr2	0.00E+00	[1/(kg-m)]
8	Open Resistance Rr3 [1/(kg-m)] ref: Mixing Box Airflow Network	res_trn.wq2	Rr3	3.80E-01	[1/(kg-m)]
9	Open Resistance Rr4 [1/(kg-m)] ref: Mixing Box Airflow Network	res_trn.wq2	Rr4	2.85E-01	[1/(kg-m)]
10	Open Resistance Rr5 [1/(kg-m)] ref: Mixing Box Airflow Network	res_trn.wq2	Rr5	1.18E-01	[1/(kg-m)]
11	Open Resistance RrE [1/(kg-m)] ref: Mixing Box Airflow Network	damper.wq2	RrE	4.78E-01	[1/(kg-m)]
12	Open Resistance RrR [1/(kg-m)] ref: Mixing Box Airflow Network	damper.wq2	RrR	4.78E-01	[1/(kg-m)]
13	Open Resistance RsA [1/(kg-m)] ref: Mixing Box Airflow Network	res_sup.wq2	RsA	4.67E-01	[1/(kg-m)]
14	Open Resistance RsEcon [1/(kg-m)] ref: Mixing Box Airflow Network	damper.wq2	RsEcon	2.75E-01	[1/(kg-m)]
15	Open Resistance RsMin [1/(kg-m)] ref: Mixing Box Airflow Network	damper.wq2	RsMin	3.55E-01	[1/(kg-m)]
16	Open Resistance Rmb [1/(kg-m)] ref: Mixing Box Airflow Network	res_sup.wq2	Rmb	1.01E-02	[1/(kg-m)]
17	Open Resistance RsF [1/(kg-m)] ref: Mixing Box Airflow Network	res_sup.wq2	RsF	5.36E-01	[1/(kg-m)]
18	Leakage for Exhaust Air Damper, RrE (fraction of full flow)	Arrow 1770	RrE	4.00E-03	[%]
19	Leakage for Fresh Air Damper, RsEcon (fraction of full flow)	Arrow 1770	RsEcon	4.00E-03	[%]
20	Leakage for Fresh Air Damper, RsMin (fraction of full flow)	Arrow 1770	RsMin	4.00E-03	[%]
21	Leakage for Return Air Damper, RsR (fraction of full flow)	Arrow 1770	RsR	4.00E-03	[%]
22	0 = invert return air damper; 1 = not inverted	inspection	----	0	[-]

a = parameter number
b = parameter description
c = document or spreadsheet from which value was taken
d = designation of value in reference document
e = proposed parameter value
f = units on which parameter is based

Type xxx: Mixing Box Damper Resistances

area	10.76 [ft2/m2]	length	3.2808 [ft/m]	volume	35.31 [ft3/m3]	pressure	248.8 [Pa/in wg]
Rho =	1.22 [kg/m3]	time	60 [sec/min]	R = delP/(rho*rho*v*v*A*A) .			

a	b	c	d	e	f	g	h	i	j	k	l	m
Damper	Damper Dim's		Damper Area		Pressure Drop		Velocity		Flow Rate		Resistance	
Designation	Width	Height	(A)		(delP)		(v)		(Q)		Individual	Average
	[in]	[in]	[ft2]	[m2]	[in wg]	[Pa]	[fpm]	[m/s]	[cfm]	[m3/s]	[1/(kg-m)]	[1/(kg-m)]
return	54	30	11.3	1.05	0.02	4.976	450	2.29	5,063	2.39	5.85E-01	
&	54	30	11.3	1.05	0.04	9.952	700	3.56	7,875	3.72	4.84E-01	
exhaust	54	30	11.3	1.05	0.06	14.928	900	4.57	10,125	4.78	4.39E-01	
	54	30	11.3	1.05	0.08	19.904	1,040	5.28	11,700	5.52	4.38E-01	
	54	30	11.3	1.05	0.10	24.88	1,175	5.97	13,219	6.24	4.29E-01	
(RrR & RrE)	54	30	11.3	1.05	0.20	49.76	1,575	8.00	17,719	8.36	4.78E-01	
	54	30	11.3	1.05	0.30	74.64	1,840	9.35	20,700	9.77	5.25E-01	
	54	30	11.3	1.05	0.40	99.52	2,040	10.36	22,950	10.83	5.70E-01	
	54	30	11.3	1.05	0.50	124.4	2,220	11.28	24,975	11.79	6.01E-01	
	54	30	11.3	1.05	0.60	149.28	2,340	11.89	26,325	12.43	6.49E-01	5.20E-01
minimum	60	10	4.1	0.38	0.02	4.976	450	2.29	1,856	0.88	4.35E+00	
air intake	60	10	4.1	0.38	0.04	9.952	700	3.56	2,888	1.36	3.60E+00	
	60	10	4.1	0.38	0.06	14.928	900	4.57	3,713	1.75	3.26E+00	
(RsMin)	60	10	4.1	0.38	0.08	19.904	1,040	5.28	4,290	2.02	3.26E+00	
	60	10	4.1	0.38	0.10	24.88	1,175	5.97	4,847	2.29	3.19E+00	
	60	10	4.1	0.38	0.20	49.76	1,575	8.00	6,497	3.07	3.55E+00	
	60	10	4.1	0.38	0.30	74.64	1,840	9.35	7,590	3.58	3.91E+00	
	60	10	4.1	0.38	0.40	99.52	2,040	10.36	8,415	3.97	4.24E+00	
	60	10	4.1	0.38	0.50	124.4	2,220	11.28	9,158	4.32	4.47E+00	
	60	10	4.1	0.38	0.60	149.28	2,340	11.89	9,653	4.56	4.83E+00	3.87E+00
economizer	60	34	14.2	1.32	0.02	4.976	450	2.29	6,392	3.02	3.67E-01	
air intake	60	34	14.2	1.32	0.04	9.952	700	3.56	9,943	4.69	3.03E-01	
	60	34	14.2	1.32	0.06	14.928	900	4.57	12,784	6.03	2.75E-01	
(RsEcon)	60	34	14.2	1.32	0.08	19.904	1,040	5.28	14,772	6.97	2.75E-01	
	60	34	14.2	1.32	0.10	24.88	1,175	5.97	16,690	7.88	2.69E-01	
	60	34	14.2	1.32	0.20	49.76	1,575	8.00	22,372	10.56	3.00E-01	
	60	34	14.2	1.32	0.30	74.64	1,840	9.35	26,136	12.34	3.29E-01	
	60	34	14.2	1.32	0.40	99.52	2,040	10.36	28,977	13.68	3.57E-01	
	60	34	14.2	1.32	0.50	124.4	2,220	11.28	31,533	14.88	3.77E-01	
	60	34	14.2	1.32	0.60	149.28	2,340	11.89	33,238	15.69	4.07E-01	3.26E-01

a = damper in mixing box system for resistance calculation (ref: Mixing Box Airflow Resistance Network)
b = damper width (ref: damper.dwg)
c = damper height (ref: damper.dwg)
d = damper area A [b*c]
e = damper area A [d/10.76]
f = presure drop across damper (ref: Arrow United Industries, Inc. Series 1770 Damper performance Data)
g = presure drop across damper [f*248.8]
h = flow stream velocity v for pressure in f (Series 1770 Damper Performance Data)
i = flow stream velocity v [h/3.2808/60]
j = stream flow rate Q [d*h]
k = stream flow rate Q [j/35.31/60]]
l = effective resistance R for given pressure, velocity & face area [delP/(rho2*v2*A2)]
m = average resistance Ravg over performance data provided by Arrow [@avg(l)]

Note: The single underlined resistance values, for each damper type, are for flow rates very close to design conditions.

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Figure 191: Mixing Box Damper Resistances (Arrow Series 1770 Steel Dampers)

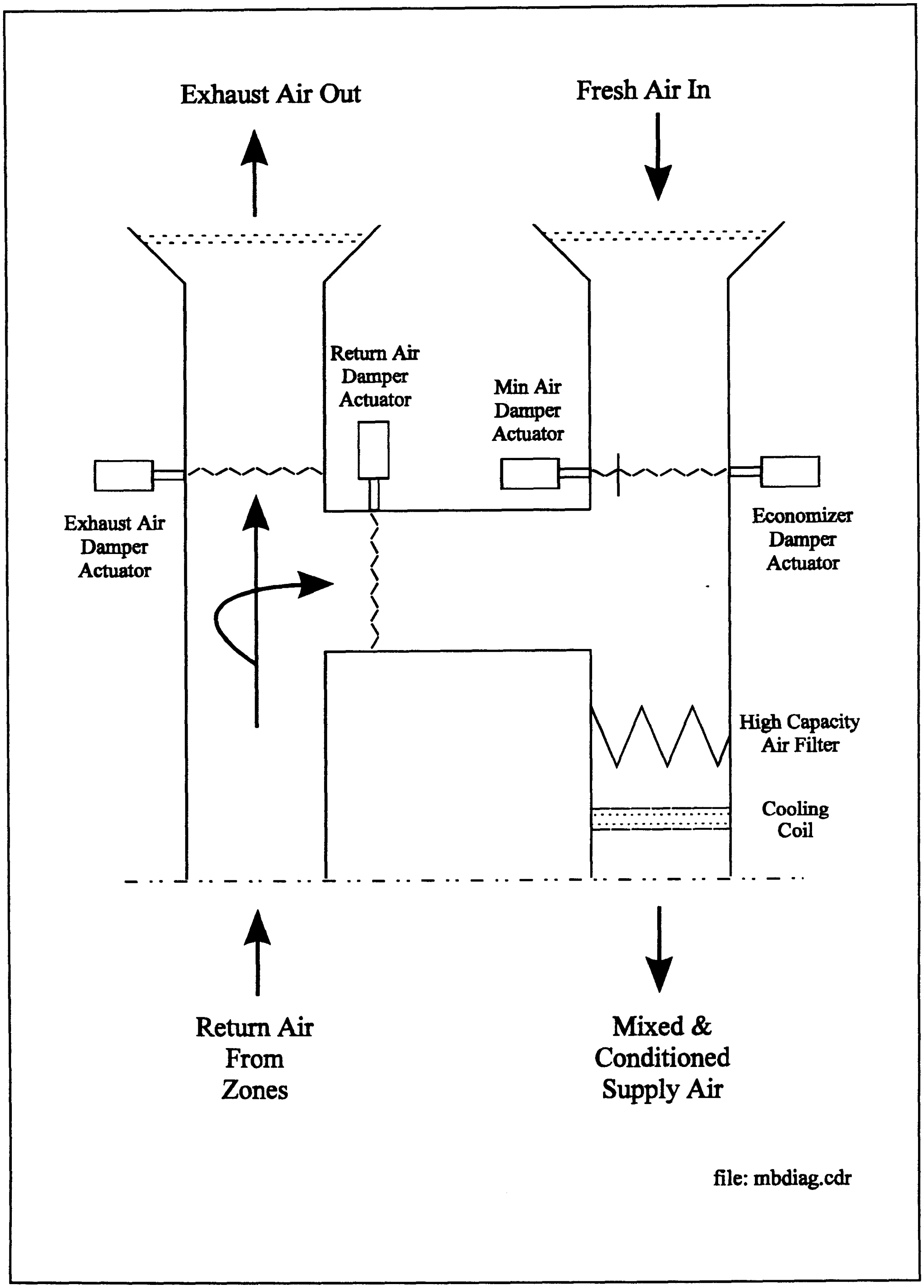

Figure 192: Mixing Box Diagram

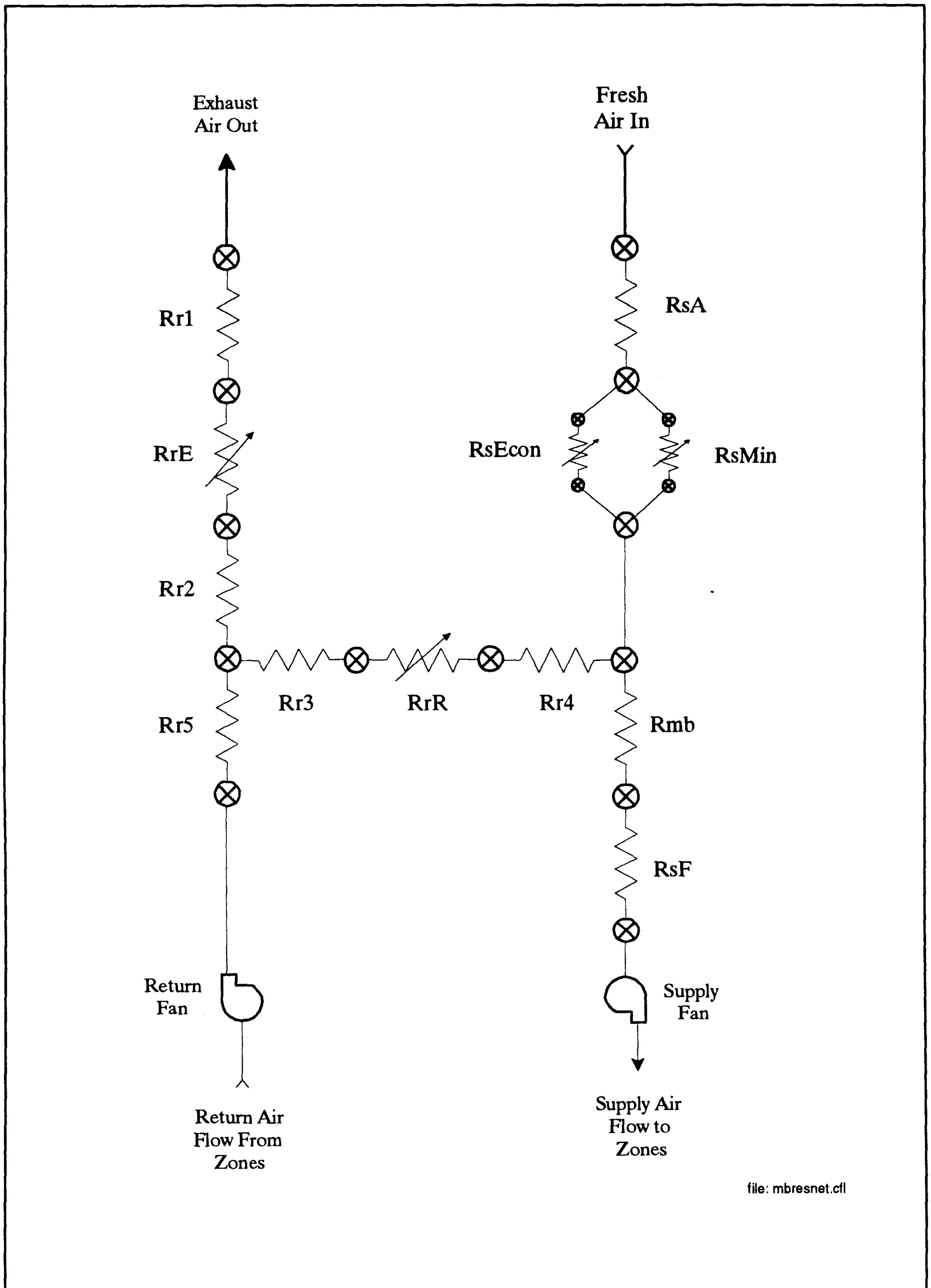

Figure 193: Mixing Box Airflow Resistance Network

Figure 194: E51 Parameters - Type 134 (VAV Terminal Box)

Type 134: Pressure Independent VAV Box

a	b	c1	c2	d	e1	e2	f1	f2	g1	g2	h	i	j1	j2
Zone	VAV Box Size	Nominal Volumetric Air Flow Rate		Reheat Coil							VAV Box Damper			
				Output	H2O Flow Rate		Head Loss		Hydraulic Resistance		Dimensions		Damper Face Area	
											h	w		
	[in x in]	[cfm]	[m3/s]	[MBH]	[gpm]	[m3/s]	[lbf/in2]	[kPa]	[1/(lbm-ft)]	[.001/ (kg-m)]	[in]	[in]	[ft2]	[m2]
MR	----	18,590	8.774	518	74	4.67E-03	1.82	1.25E+01	7.97E-02	5.75E-01	----	----	----	----
Parameter Number			P1											P2
I	16	1,773	0.837	19	1	6.31E-05	0.07	4.83E-01	1.68E+01	1.21E+02	15.875		1.37	1.28E-01
II	7	280	0.132	2	1	6.31E-05	0.80	5.52E+00	1.92E+02	1.39E+03	6.875		0.26	2.40E-02
III	48 x 16	9,180	4.333	64	1	6.31E-05	0.05	3.45E-01	1.20E+01	8.66E+01	47.875	15.875	5.28	4.90E-01
IV	16	1,696	0.801	16	1	6.31E-05	0.07	4.83E-01	1.68E+01	1.21E+02	15.875		1.37	1.28E-01
V	24 x 16	5,020	2.369	33	1	6.31E-05	0.09	6.21E-01	2.16E+01	1.56E+02	23.875	15.875	2.63	2.45E-01
VI	10	640	0.302	7	1	6.31E-05	0.14	9.65E-01	3.36E+01	2.43E+02	9.875		0.53	4.94E-02

a	b	c1	c2	k	l1	l2	m	n	o	p	q1	q2	r1	r2
Zone	VAV Box Size	Air Flow rate		Average Flow Speed	Air Flow Pressure Drop (box, coil & damper)		Actuator Travel Time	Minimum Frac Motor Speed	Hysteresis	Controller Gain	Air Flow Pressure Drop (coil only)		Cooling Coil Airflow Resistance	
	[in x in]	[cfm]	[m3/s]	[ft/min]	[in wg]	[Pa]	[sec]				[in wg]	[Pa]	[1/(lbm-ft)]	[1/(kg-m)]
MR	----	18,590	8.774	----	0.230	57	----	----	----	----	0.230	57	6.92E-02	4.99E-01
Parameter Number						P3	P4	P5	P6	P7				
I	16	1,773	0.837	1270	0.154	38	30	1	----	10	0.083	21	2.74E+00	1.98E+01
II	7	280	0.132	1048	0.082	20	30	1	----	10	0.034	8	4.51E+01	3.25E+02
III	48 x 16	9,180	4.333	1721	0.304	76	30	1	----	10	0.282	70	3.48E-01	2.51E+00
IV	16	1,696	0.801	1215	0.141	35	30	1	----	10	0.076	19	2.75E+00	1.98E+01
V	24 x 16	5,020	2.369	1883	0.364	91	30	1	----	10	0.337	84	1.39E+00	1.00E+01
VI	10	640	0.302	1173	0.144	36	30	1	----	10	0.086	21	2.18E+01	1.58E+02

Figure 195: E51 Parameters - Type 134 continued (VAV Terminal Box)

a = zone designation
b = VAV Box Size (for round boxes the diameter is provided)
c = nominal design flow rate for zone [cfm] or [m3/s] type_134:P1
d = reheat coil output (reference file: flwtally.wq2)
e = flow rate (Q) for reheat coil design condition (refer Titus Catalog)
f = head loss (delP) for reheat coil design condition (ref: Titus Catalog)
g = hydraulic resistance (R) based on design flow rate and head loss
R = {f2/[rho(h2o)*rho(h2o)*e2*e2]}
h = damper dimensions [in] (reference Titus Catalog)
i = damper dimensions [in] (reference Titus Catalog)
j = damper area calculated from columns d & e type_134: P2
k = average flow speed based on VAV box size (b) & nominal flow rate (c1)
l = air pressure drop for VAV box at design flow rate (reference file: sup_vav.wq2)
& (ref: CDS Output for Trane Cooling Coil delP) type_134: P3
m = actuator travel time based on conversation with Titus representative type_134: P4
n = min fractional motor speed (motor runs at constant speed when operating) type_134: P5
o = hysteresis when reversing motor turning direction type_134: P6
p = controller gain (adjust as req'd to reflect actual controller performance) type_134: P7
q = cooling coil airflow pressure drop at nominal flow (ref: Titus Catalog Terminal Box
Reheat Coil Performance Data - file: sup_vav.wq2)
r = airflow resistance R, based on design flow rate R = {q2/[rho(air)*rho(air)*c2*c2]}

R = delP/(rho*rho*Q*Q)		[1/(kg-m)]	length	3.2808	[ft/m]	volume	7.48	gal/ft3
rho(H2O) =	62.34	[lbm/ft3]	mass	2.2	[lbm/kg]	pressure	6895	[Pa/psi]
rho(H2O) =	1000	[kg/m3]	mass	32.2	[lbm/slug]	pressure	248.8	[Pa/in wg]
rho(air) =	0.075	[lbm/ft3]	force	1	[(slug-ft/s2)/lbf]			
rho(air) =	1.22	[kg/m3]						

Minimum Static Pressure & total Drop Across Titus DESV VAV Boxes (includes coil, damper and box geometry)
(interpolated static & total pressure drops based on Titus catalog data sheets)

a	b	c	d	e1	e2	f1	f2	g	h	i	j1	j2
Zone	VAV Box Size	Flow Rate	Configuration	Titus Single Duct Pressure Independent VAV Terminal Box Table Values								
				y1 Pressure		y2 Pressure		x1	x2	x3	y3 Pressure	
				Static	Total	Static	Total				Static	Total
	[in]	[cfm]		[in wg]	[in wg]	[in wg]	[in wg]	[cfm]	[cfm]	[cfm]	[in wg]	[in wg]
I	16	1773	basic + attenuator	0.050	0.106	0.088	0.188	1500	2000	1773	0.071	0.151
			1 row coil								0.083	0.083
			complete unit	0.108	0.164	0.192	0.292	1500	2000	1773	0.154	0.234
II	7	280	basic + attenuator	0.056	0.126	0.099	0.224	300	400	280	0.047	0.106
			1 row coil								0.034	0.034
			complete unit	0.097	0.167	0.173	0.298	300	400	280	0.082	0.141
III**	24 x 16	4590	basic + attenuator	0.015	0.111	0.038	0.254	4000	6000	4590	0.022	0.153
	24 x 16	4590	1 row coil								0.282	0.282
			complete unit	0.222	0.318	0.500	0.716	4000	6000	4590	0.304	0.435
IV	16	1696	basic + attenuator	0.050	0.106	0.088	0.188	1500	2000	1696	0.065	0.138
			1 row coil								0.076	0.076
			complete unit	0.108	0.164	0.192	0.292	1500	2000	1696	0.141	0.214
V	24 x 16	5020	basic + attenuator	0.015	0.111	0.038	0.254	4000	6000	5020	0.027	0.184
			1 row coil								0.337	0.337
			complete unit	0.222	0.318	0.500	0.716	4000	6000	5020	0.364	0.521
VI	10	640	basic + attenuator	0.051	0.111	0.090	0.197	600	800	640	0.059	0.128
			1 row coil								0.086	0.086
			complete unit	0.125	0.185	0.222	0.329	600	800	640	0.144	0.214

Equation for linear interpolation: $y3 = [(y2-y1)/(x2-x1)*(x3-x1)] + y1$
Note: used to interpolate between points in Titus specs which are closest to flow rate for each megazone

** The flow in Zone III exceeds the maximum specification for Titus equipment. As a result the flow stream was divided into two equal portions allowing the pressure drop to be calculated for two boxes sitting side by side in a 16 x 48 duct.

a = zone designation
b = VAV box size
c = design flow rate less 15% for diversity
d = configuration of equipment for which stated pressure difference applies
e1 = lower static pressure drop value for linear interpolaton
e2 = lower total pressure drop value for linear interpolaton
f1 = upper static pressure drop value for linear interpolaton
f2 = upper total pressure drop value for linear interpolaton
g = lower flow rate value for linear interpolaton
h = upper flow rate value for linear interpolaton
i = zone flow rate value
j1a = interpolated static pressure drop value for box, wide open damper, and flow attenuator
j1b = interpolated static pressure drop value coil
j1c = interpolated static pressure drop value for box, wide open damper, flow attenuator, and coil
j2a = interpolated total pressure drop value for box, wide open damper, and flow attenuator
j2b = interpolated total pressure drop value coil
j2c = interpolated total pressure drop value for box, wide open damper, flow attenuator, and coil

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Figure 196: Minimum Static Pressure Drop Across Titus DESV Boxes

Figure 197: E51 Parameters - Type 201 (Supply & Return Fans)

Type 201: Fan or Pump - Temperature Rise Corrected for Work Done

a	b		c	d	e	f
Parameter Number	Description & Coefficient Designation		Unit			
			Supply Fan		Return Fan	
			[English]	[SI]	[English]	[SI]
1	1st Pressure Coefficient	a4	8.534E-01	8.534E-01	9.816E+00	9.816E+00
2	2nd Pressure Coefficient	a3	-3.929E+00	-3.929E+00	-2.396E+01	-2.396E+01
3	3rd Pressure Coefficient	a2	4.229E+00	4.229E+00	1.221E+01	1.221E+01
4	4th Pressure Coefficient	a1	-1.387E+00	-1.387E+00	-1.634E+00	-1.634E+00
5	5th Pressure Coefficient	a0	4.290E+00	4.290E+00	4.194E+00	4.194E+00
6	1st Efficiency Coefficient	e4	-1.971E-01	-1.971E-01	-3.375E+00	-3.375E+00
7	2nd Efficiency Coefficient	e3	7.664E-01	7.664E-01	6.168E+00	6.168E+00
8	3rd Efficiency Coefficient	e2	-1.483E+00	-1.483E+00	-5.755E+00	-5.755E+00
9	4th Efficiency Coefficient	e1	1.540E+00	1.540E+00	3.142E+00	3.142E+00
10	5th Efficiency Coefficient	e0	1.162E-01	1.162E-01	6.190E-02	6.190E-02
11	Diameter [in] (m)		27.00	6.858E-01	44.50	1.130E+00
12	Mode 1 = air & 2 = water		1	1	1	1
13	Lowest Valid Normalized Flow		0.00	0.00	0.00	0.00
14	Highest Valid Normalized Flow		1.00	1.00	1.00	1.00

Note: The supply & return fans are characterized by equations which calculate the pressure rise and efficiency as a function of dimensionless mass flow rate.

Dimensionless Pressure (Cf) = a0 + a1 * Cf + a2 * Cf^2 + a3 * Cf^3 + a4 * Cf^4
Dimensionless Efficiency (Cf) = e0 + e1 * Cf + e2 * Cf^2 + e3 * Cf^3 + e4 * Cf^4

where Cf = dimensionless flow

Supply duct air flow resistance calculations

air density - rho 0.075 [lbm/ft3]

length 3.2808 [ft/m]	pressure 248.8 [Pa/in wg]	mass 32.2 [lbm/slug]
mass 2.2 [lbm/kg]	pressure 6895 [Pa/psi]	force 1 [(slug-ft/s2)/lbf]
area 144 [in2/ft2]	time 60 [s/min]	pressure 167 [(lbm/ft-s2)/(in wg)]

		Ftg Resistance					Straight Duct							Grills, Diffusers & Other Obstructions						Total
		variables =>	k	A	R (english)	R (SI)	variables =>	C	l	v	A	R (english)	R (SI)	variables =>	del P	v	A	R (english)	R (SI)	R (SI)
Zone	Resis	Description	loss coeff [n/a]	cross section [ft2]	flow resis [1/lbm*ft]	SI convert [1/kg*m]	Description	friction loss [in wg/ft]	duct length [ft]	flow speed [ft/sec]	cross section [ft2]	flow resis [1/lbm*ft]	SI convert [1/kg*m]	Description	pres drop [in wg]	flow speed [ft/sec]	cross section [ft2]	flow resis [1/lbm*ft]	SI convert [1/kg*m]	[1/kg*m]
MR	RsA	bird screen	0.08	48.00	2.31E-04	1.67E-03	---	---	---	---	---	---	---	intake grill	0.020	5.00	48.00	1.03E-02	7.44E-02	4.12E-01
---	---	transition	4.55	48.00	1.32E-02	9.50E-02	---	---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	90 deg corner	0.50	10.00	3.33E-02	2.41E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MR	Rmb	transition	0.38	40.88	1.52E-03	1.09E-02	---	---	---	---	---	---	---	---	---	---	---	---	---	1.09E-02
MR	RsF	---	---	---	---	---	---	---	---	---	---	---	---	hi-cap filters	0.050	3.51	88.16	1.55E-02	1.12E-01	6.25E-01
---	---	---	---	---	---	---	---	---	---	---	---	---	---	cooling coil	0.230	9.68	32.00	7.11E-02	5.13E-01	---
MR	RsB	90 deg L ++	0.90	13.75	3.17E-02	2.29E-01	12 ft duct	0.00075	12	25.7	6.03	1.11E-02	8.04E-02	---	---	---	---	---	---	3.09E-01
MR	Rs1	---	---	---	---	---	---	---	---	---	---	---	---	air measuring	0.060	25.70	12.06	1.86E-02	1.34E-01	2.88E-01
---	---	---	---	---	---	---	---	---	---	---	---	---	---	mech room	0.069	25.70	12.06	2.13E-02	1.54E-01	---
III	Rs2	tee branch	0.52	5.44	1.17E-01	8.44E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	1.11E+00
---	---	transition	0.16	5.44	3.64E-02	2.63E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
III-V	Rs4	tee main	0.05	6.03	9.17E-03	6.62E-02	---	---	---	---	---	---	---	---	---	---	---	---	---	6.62E-02
III	Rs7	bends (bal'd)	2.80	5.33	6.56E-01	4.74E+00	128 ft duct	0.00150	128	28.7	2.67	9.74E-01	7.03E+00	---	---	---	---	---	---	1.18E+01
III	Rs8	10 deg diverge	0.20	5.33	4.69E-02	3.38E-01	---	---	---	---	---	---	---	louvre	0.117	7.65	20.00	1.48E-01	1.07E+00	1.41E+00
III-V	Rs11	---	---	---	---	---	5 ft duct	0.00110	5	25.7	6.03	6.80E-03	4.91E-02	---	---	---	---	---	---	4.91E-02
V-I	Rs12	tee main	0.05	2.85	4.11E-02	2.97E-01	1.5 ft duct	0.00160	1.5	25.1	2.92	1.33E-02	9.62E-02	---	---	---	---	---	---	1.35E+00
---	---	sq-rd trans	0.17	2.92	1.33E-01	9.62E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
V	Rs13	tee branch	0.52	3.11	3.58E-01	2.59E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	2.59E+00
V	Rs14	transition	0.04	3.11	2.76E-02	1.99E-01	140 ft duct	0.00200	140	31.4	2.67	1.19E+00	8.58E+00	---	---	---	---	---	---	2.10E+01
---	---	bends (bal'd)	1.80	2.67	1.69E+00	1.22E+01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
V	Rs15	10 deg diverge	0.20	2.67	1.88E-01	1.35E+00	---	---	---	---	---	---	---	louvre	0.117	8.37	10.00	4.96E-01	3.58E+00	4.93E+00
V-I	Rs16	---	---	---	---	---	1.5 ft duct	0.00110	1.5	23.3	3.14	9.17E-03	6.62E-02	---	---	---	---	---	---	6.62E-02
I	Rs17	tee branch	0.52	1.40	1.78E+00	1.28E+01	---	---	---	---	---	---	---	---	---	---	---	---	---	1.28E+01
I-IV	Rs18	tee main	0.18	1.97	3.09E-01	2.23E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	2.23E+00
I	Rs19	bends	7.64	1.40	2.61E+01	1.89E+02	51 ft duct	0.00145	51	21.2	1.40	2.52E+00	1.82E+01	---	---	---	---	---	---	2.07E+02
I	Rs20	10 deg diverge	0.14	1.40	4.79E-01	3.46E+00	---	---	---	---	---	---	---	louvre	0.117	8.45	3.50	3.97E+00	2.87E+01	3.21E+01
I-IV	Rs21	---	---	---	---	---	5 ft duct	0.00130	5	22.2	1.97	1.01E-01	7.30E-01	---	---	---	---	---	---	7.30E-01
IV	Rs22	tee branch	0.52	1.40	1.78E+00	1.28E+01	---	---	---	---	---	---	---	---	---	---	---	---	---	1.28E+01
IV-VI	Rs23	tee main	0.12	0.78	1.30E+00	9.38E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	9.38E+00
IV	Rs24	bends	7.42	1.40	2.54E+01	1.83E+02	124 ft duct	0.00145	124	20.3	1.40	6.68E+00	4.82E+01	---	---	---	---	---	---	2.31E+02
IV	Rs25	10 deg diverge	0.14	1.40	4.79E-01	3.46E+00	---	---	---	---	---	---	---	louvre	0.117	8.08	3.50	4.34E+00	3.13E+01	3.46E+01
IV-VI	Rs26	---	---	---	---	---	5 ft duct	0.00160	5	19.5	0.78	1.01E+00	7.31E+00	---	---	---	---	---	---	7.31E+00
VI	Rs27	tee branch	0.56	0.55	1.24E+01	8.95E+01	---	---	---	---	---	---	---	---	---	---	---	---	---	8.95E+01
VI-II	Rs28	tee main	0.14	0.27	1.31E+01	9.42E+01	---	---	---	---	---	---	---	---	---	---	---	---	---	9.42E+01
VI	Rs29	bends	6.22	0.55	1.38E+02	9.94E+02	102 ft duct	0.00210	102	19.6	0.55	5.53E+01	3.99E+02	---	---	---	---	---	---	1.39E+03
VI	Rs30	10 deg diff	0.14	0.55	3.10E+00	2.24E+01	---	---	---	---	---	---	---	louvre	0.168	8.53	1.28	4.18E+01	3.02E+02	3.24E+02
II	Rs31	90 deg L	0.19	0.27	1.77E+01	1.28E+02	41 ft duct	0.00250	41	17.5	0.27	1.40E+02	1.01E+03	---	---	---	---	---	---	3.63E+04
---	---	bends	4.20	0.27	3.92E+02	2.83E+03	---	---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	perf plate	7.70	0.11	4.48E+03	3.24E+04	---	---	---	---	---	---	---	---	---	---	---	---	---	---
II	Rs32	10 deg diff	0.14	0.27	1.31E+01	9.42E+01	---	---	---	---	---	---	---	louvre	0.117	8.33	0.56	1.58E+02	1.14E+03	1.24E+03

R = k / (2 * rho * A * A)

R = C * l / [(rho * v * A) * (rho * v * A)]

R = delta P / [(rho * v * A) * (rho * v * A)]

Figure 198: Megazone Supply Duct System Airflow Resistance Schedule

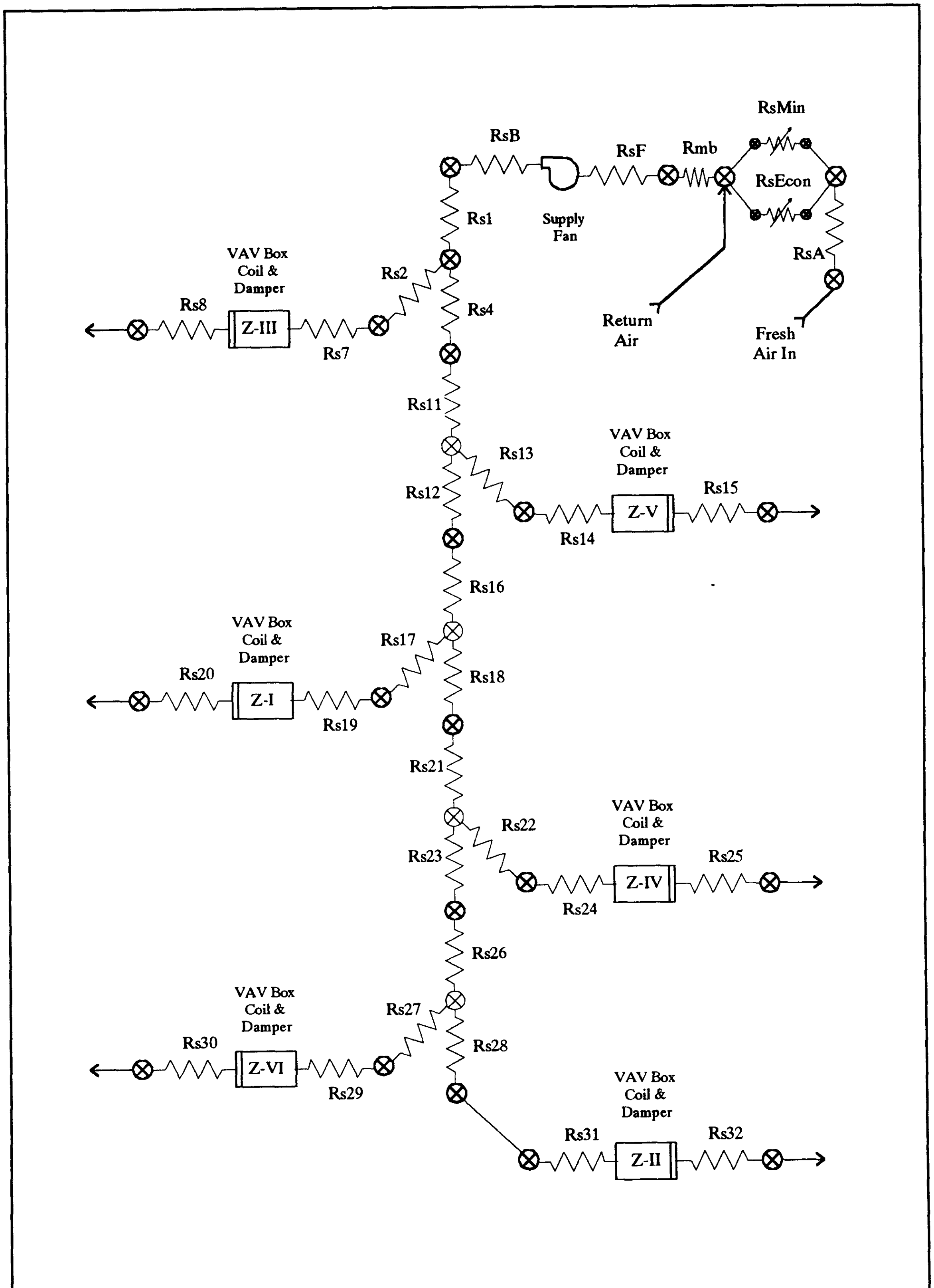

Figure 199: Supply Airflow Resistance Network

High Capacity Filter Airflow Resistance Calculation

Variable	English		SI	
	Value	Units	Value	Units
Density (rho)	0.075	[lbm/ft3]	1.22	[kg/m3]
Area (A)	88.16	[ft2]	8.19	[m2]
Flow (Q)	18,590	[cfm]	8.77	[m3/s]
Velocity (v)	211	[ft/min]	1.07	[m/s]
Pressure (delP)	0.05	[in wg]	12.44	[Pa]

R = delP/(rho*rho*v*v*A*A)

R (SI) = 1.09E-01 [1/(kg-m)]
R (English) = 1.50E-02 [1/(lbm-ft)]

Reference: Trane DS CLCH-1/June 1981 Central Station Air Handlers 600-65,000 cfm

file: filters.wq2 12/27/95 Page 1

Figure 200: High Capacity Filter Airflow Resistance Calculation

Figure 201: Megazone Return Duct System Airflow Resistance Schedule

Return duct air flow resistance calculations
FILE: res_rtn.wq2
air density at STP 0.075 [lbm/ft3]

length	3.2808	[ft/m]
mass	2.2	[lbm/kg]
area	144	[in2/ft2]
pressur	248.8	[Pa/in wg]
pressur	6895	[Pa/psi]
time	60	[s/min]
mass	32.2	[lbm/slug]
force	1	[(slug-ft/s2)/lbf]
pressure	167	[(lbm/ft-s2)/(in wg)]

		Ftg Resistance					Straight Duct							Grills, Diffusers & Other Obstructions						Total
		variables =>	k	A	R (english	R (SI)	variables =>	C	l	v	A	R (english	R (SI)	variables =>	del P	v	A	R (english	R (SI)	R (SI)
Zone	Resis	Description	loss coeff [n/a]	cross section [ft2]	flow resis [1/lbm*ft]	SI convert [1/kg*m]	Description	friction loss [in wg/ft]	duct length [ft]	flow speed [ft/sec]	cross section [ft2]	flow resis [1/lbm*ft]	SI convert [1/kg*m]	Description	pres drop [in wg]	flow speed [ft/sec]	cross section [ft2]	flow resis [1/lbm*ft]	SI convert [1/kg*m]	[1/kg*m]
MR	Rr1	exit bend	0.140	11.25	7.37E-03	5.32E-02	exit duct	0.00055	1.00	24.2	11.25	2.20E-04	1.59E-03	exhaust diff	0.02	11.67	45.00	2.15E-03	1.55E-02	1.64E-01
----	----	bird screen	0.080	45.00	2.63E-04	1.90E-03	----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	transition	0.240	11.25	1.26E-02	9.12E-02	----	----	----	----	----	----	----	----	----	----	----	----	----	----
MR	Rr2	outlet/main	0.000	11.25	0.00E+00	0.00E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	0.00E+00
MR	Rr3	outlet branch	1.000	11.25	5.27E-02	3.80E-01	----	----	----	----	----	----	----	----	----	----	----	----	----	3.80E-01
MR	Rr4	bend to MB	0.750	11.25	3.95E-02	2.85E-01	----	----	----	----	----	----	----	----	----	----	----	----	----	2.85E-01
MR	Rr5	45 deg bend	0.290	11.88	1.37E-02	9.90E-02	duct & trans	0.00055	12.00	24.2	11.25	2.64E-03	1.91E-02	----	----	----	----	----	----	1.18E-01
MR	Rr6	bend 2	0.180	12.06	8.26E-03	5.96E-02	duct 1	0.00055	4.00	25.1	12.06	7.12E-04	5.14E-03	air measure	0.06	25.1	12.06	1.94E-02	1.40E-01	7.89E-01
----	----	bend 3	0.110	12.06	5.05E-03	3.64E-02	duct 4	0.00055	4.75	25.1	12.06	8.46E-04	6.11E-03	----	----	----	----	----	----	----
----	----	bend 5	0.110	12.06	5.05E-03	3.64E-02	duct 6	0.00055	6.50	25.1	12.06	1.16E-03	8.36E-03	----	----	----	----	----	----	----
----	----	bend 7	0.750	12.06	3.44E-02	2.48E-01	----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	bend 8	0.750	12.06	3.44E-02	2.48E-01	----	----	----	----	----	----	----	----	----	----	----	----	----	----
III	Rr7	inlet branch	0.000	5.42	0.00E+00	0.00E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	0.00E+00
III	Rr8	bends (actual)	1.380	5.42	3.14E-01	2.26E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	2.26E+00
III	Rr9	convergence	0.200	16.00	5.21E-03	3.76E-02	106 ft duct	0.00075	106	23.3	5.42	1.48E-01	1.07E+00	grill	0.046	7.88	16.00	8.58E-02	6.20E-01	1.73E+00
V-II	Rr10	inlet main	-0.040	5.42	-9.1E-03	-6.6E-02	----	----	----	----	----	----	----	----	----	----	----	----	----	-6.56E-02
V-II	Rr11	outlet main	----	----	----	----	5 ft duct	0.00080	5	24.5	5.96	5.57E-03	4.02E-02	----	----	----	----	----	----	4.02E-02
V	Rr12	inlet branch	0.160	3.61	8.18E-02	5.90E-01	----	----	----	----	----	----	----	----	----	----	----	----	----	5.90E-01
V	Rr13	bends (actual)	1.629	3.61	8.33E-01	6.01E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	6.01E+00
V	Rr14	convergence	0.200	11.11	1.08E-02	7.80E-02	59 ft duct	0.00082	59	22.0	3.61	2.28E-01	1.65E+00	grill	0.046	8.32	11.11	1.60E-01	1.15E+00	2.88E+00
I-V	Rr15	inlet main	-0.080	2.89	-6.4E-02	-4.6E-01	1.5 ft duct	0.00100	1.5	23.1	2.89	1.00E-02	7.24E-02	----	----	----	----	----	----	3.44E-01
----	----	rd-sq trans	0.150	3.14	1.01E-01	7.33E-01	----	----	----	----	----	----	----	----	----	----	----	----	----	----
I-V	Rr16	outlet main	----	----	----	----	1.5 ft duct	0.00031	1.5	21.2	3.14	3.11E-03	2.25E-02	----	----	----	----	----	----	2.25E-02
I	Rr17	inlet branch	0.350	1.40	1.20E+00	8.64E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	1.15E+01
----	----	45 deg bend	0.114	1.40	3.90E-01	2.82E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	----
I	Rr18	bends (actual)	1.716	1.40	5.87E+00	4.24E+01	----	----	----	----	----	----	----	----	----	----	----	----	----	4.24E+01
I	Rr19	convergence	0.200	3.36	1.18E-01	8.52E-01	40 ft duct	0.00120	40	19.9	1.40	1.86E+00	1.34E+01	grill	0.046	8.32	3.30	1.81E+00	1.31E+01	2.73E+01
VI-I	Rr20	inlet main	0.080	1.97	1.37E-01	9.90E-01	----	----	----	----	----	----	----	----	----	----	----	----	----	9.90E-01
VI-I	Rr21	outlet main	----	----	----	----	5 ft duct	0.00100	5	19.8	1.97	9.77E-02	7.05E-01	----	----	----	----	----	----	7.05E-01
VI	Rr22	inlet branch	-0.070	0.66	-1.1E+00	-7.7E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	4.86E+00
----	----	45 deg bend	0.114	0.66	1.75E+00	1.26E+01	----	----	----	----	----	----	----	----	----	----	----	----	----	----
VI	Rr23	bends (actual)	2.649	0.66	4.06E+01	2.93E+02	----	----	----	----	----	----	----	----	----	----	----	----	----	2.93E+02
VI	Rr24	convergence	0.200	1.36	7.20E-01	5.19E+00	69 ft duct	0.00120	69	15.5	0.66	2.36E+01	1.70E+02	grill	0.046	8.30	1.23	1.31E+01	9.46E+01	2.70E+02
II-VI	Rr25	inlet main	0.020	1.58	5.37E-02	3.87E-01	----	----	----	----	----	----	----	----	----	----	----	----	----	3.87E-01
II-VI	Rr26	outlet main	----	----	----	----	5 ft duct	0.00100	5	18.2	1.58	1.80E-01	1.30E+00	----	----	----	----	----	----	1.30E+00
II	Rr27	inlet branch	-0.250	0.35	-1.4E+01	-1.0E+02	----	----	----	----	----	----	----	----	----	----	----	----	----	-5.43E+01
----	----	45 deg bend	0.114	0.35	6.30E+00	4.55E+01	----	----	----	----	----	----	----	----	----	----	----	----	----	----
II	Rr28	bends (actual)	6.014	0.35	3.33E+02	2.40E+03	----	----	----	----	----	----	----	----	----	----	----	----	----	6.36E+03
----	----	perf plate	3.000	0.19	5.48E+02	3.96E+03	----	----	----	----	----	----	----	----	----	----	----	----	----	----
II	Rr29	convergence	0.200	0.56	4.21E+00	3.04E+01	8 ft duct	0.00120	8	12.7	0.35	1.47E+01	1.06E+02	grill	0.046	8.35	0.53	6.97E+01	5.03E+02	6.40E+02
IV-II	Rr30	inlet main	0.200	1.40	6.84E-01	4.94E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	4.94E+00
IV	Rr31	sm 90 deg L	0.120	1.40	4.11E-01	2.96E+00	----	----	----	----	----	----	----	----	----	----	----	----	----	3.32E+01
----	----	bends (actual)	1.224	1.40	4.19E+00	3.02E+01	----	----	----	----	----	----	----	----	----	----	----	----	----	----
IV	Rr32	convergence	0.200	0.56	4.21E+00	3.04E+01	123 ft duct	0.00095	123	17.4	1.40	5.89E+00	4.25E+01	grill	0.046	8.37	2.90	2.32E+00	1.67E+01	8.97E+01

R = k / (2 * rho * A * A)

R = C * l / [(rho * v * A) * (rho * v * A)]

R = delta P / [(rho * v * A) * (rho * v * A)]

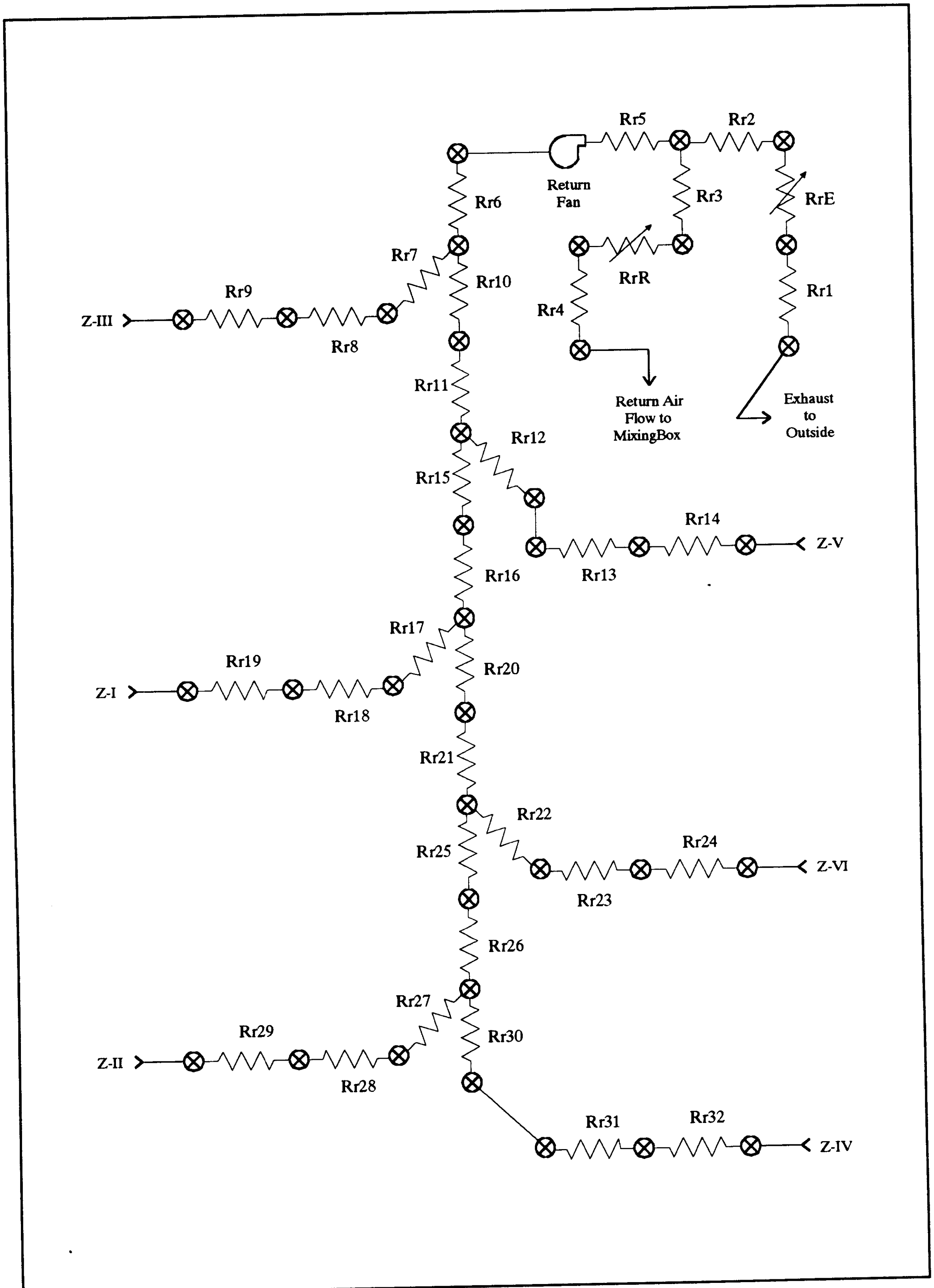

Figure 202: Return Airflow Resistance Network

Type 204: Flow Merge

a	b	c	d	e	f	g
Parameter Number		P3		P1		P2
Description	Flow Resistances					
	Outlet		Inlet 1 (Branch)		Inlet 2 (Main)	
	Designation	Value [1/(kg*m)]	Designation	Value [1/(kg*m)]	Designation	Value [1/(kg*m)]
Rtn [IV - II]	Rr26	1.30E+00	Rr27	-5.43E+01	Rr30	4.94E+00
Rtn [II - VI]	Rr21	7.05E-01	Rr22	4.86E+00	Rr25	3.87E-01
Rtn [VI - I]	Rr16	2.25E-02	Rr17	1.15E+01	Rr20	9.90E-01
Rtn [I - V]	Rr11	4.02E-02	Rr12	5.90E-01	Rr15	3.44E-01
Rtn [V - III]	Rr6	7.89E-01	Rr7	0.00E+00	Rr10	-6.56E-02

a = description of flow merge for zones A & B
b = resistance designation per airflow resistance diagram for flow merge outlet
c = resistance value (see file: res_rtn.wq2) type_204: P3
d = resistance designation per airflow diagram for flow merge inlet branch from immediate zone
e = resistance value (see file: res_rtn.wq2) type_204: P1
f = resistance designation per airflow diagram for flow merge inlet main coming from upstream zones
g = resistance value (see file: res_rtn.wq2) type_204: P2

file: type_204.wq2 12/27/95 Page 1

Figure 203: E51 Parameters - Type 204 (Flow Merge)

Type 207: Flow Split - Different Resistances, Linearized at Low Flow

a	b	c	d	e	f	g
Parameter Number		P1		P2		P3
Description	Air FlowFlow Resistances [Rs = Supply Resistances & Rr = Return Resistances]					
	Inlet		Outlet 1 (Branch)		Outlet 2 (Main)	
	Designation	Value [1/(kg*m)]	Designation	Value [1/(kg*m)]	Designation	Value [1/(kg*m)]
Sup [III - V]	Rs1	2.88E-01	Rs2	1.11E+00	Rs4	6.62E-02
Sup [V - I]	Rs11	4.91E-02	Rs13	2.59E+00	Rs12	1.35E+00
Sup [I - IV]	Rs16	6.62E-02	Rs17	1.28E+01	Rs18	2.23E+00
Sup [IV - VI]	Rs21	7.30E-01	Rs22	1.28E+01	Rs23	9.38E+00
Sup [VI - II]	Rs26	7.31E+00	Rs27	8.95E+01	Rs28	9.42E+01
Rtn [Mix Box]	Rr5	1.18E-01	Rr3	3.80E-01	Rr2	0.00E+00

a = description of flow split from zone A to zone B
b = resistance designation for flow split inlet
c = resistance value (see file: res_sup.wq2) type_207: P1
d = resistance designation for flow split branch feeding zone
e = resistance value (see file: res_sup.wq2) type_207: P2
f = resistance designation for flow split main trunk going to next zone
g = resistance value (see file: res_sup.wq2) type_207: P3

Refer to airflow resistance diagrams for supply & return networks.

file: type_207.wq2 12/27/95 Page 1

Figure 204: E51 Parameters - Type 207 (Flow Split)

Figure 205: E51 Parameters - Type 210 (Zone Pressure Balance, w/ Leakage)

External Windows & Wall Surface Areas plus Resistance Values for Air Flow Leakage to Outside

a	b	c	d	e	f	g	h	i	j	k	l	m
Type 210 Parameter Nu												
Zone Number	External Surface Compass Heading	External Surface Area Heading Room [ft2]	Heading Plenum [ft2]	Heading Total [ft2]	Tot Ext Surface Area [ft2]	Window Area Unit Area per Hdg [ft2]	Number of Units per Hdg	Unit Total per Hdg [ft2]	Hdg Window Area [ft2]	Tot Window Area [ft2]	Hdg Ext Wall Area [ft2]	Tot Ext Wall Area [ft2]
I	South	386	107	493		21.4	6	128	128		365	
I	West	96	27	123		11.6	2	23	23		100	
I	North	171	47	218	834	8.6	2	17	17	169	201	665
II	North	183	51	234	234	11.6	2	23				
						8.6	2	17	40	40	194	194
III	South	3.567	991	4,558		21.4	6	128				
						41.6	3	125				
						15.8	43	679				
						12.2	10	122				
						20.2	3	61	1,115		3,443	
III	West	1,181	328	1,509		0.0	0	0	0		1,509	
III	North	340	94	434	6,501	15.8	4	63				
						12.2	1	12	75	1,191	359	5,310
IV	West	737	205	942		15.8	10	158	158		784	
IV	North	679	189	868	1,810	15.8	8	126				
						12.2	2	24	151	309	717	1,501
V	North	2,659	739	3,398	3,398	15.8	42	664				
						12.2	12	146	810	810	2,588	2,588
VI	South	146	40	186		15.8	2	32	32		154	
VI	West	276	77	353	539	15.8	5	79	79	111	274	428
Chk Sums		10,421	2,895	13,316	13,316			2,629	2,629	2,629	10,687	10,687
			13,316						10,687		13,316	13,316

Figure 206: E51 Parameters - Type 210 continued (Zone Pressure Balance, w/ Leakage)

External Windows & Wall Surface Areas plus Resistance Values for Air Flow Leakage to Outside

a	b	c	d	e	f	n	o	p	q	r	s	t	u
Type 210 Parameter Nu													P1
Zone Number	External Surface Compass Heading	External Surface Area (Wall & Window)			Tot Ext Surface Area [ft2]	Leakage Resistance w/rate=1200 cm3/s-m2 @ 75 Pa ASHRAE Fundamentals, F23.16.							
		Heading Room [ft2]	Heading Plenum [ft2]	Heading Total [ft2]		Compass Heading Room		Compass Heading Plenum		Hdg Zone Leakage [1/(lbm-ft)]	Tot Zone Leakage [1/(lbm-ft)]	Hdg Zone Leakage [1/(kg-m)]	Tot Zone Leakage [1/(kg-m)]
						Leakage [1/(lbm-ft)]	Leakage [1/(kg-m)]	Leakage [1/(lbm-ft)]	Leakage [1/(kg-m)]				
I	South	386	107	493		3.77E+03	2.72E+04	4.89E+04	3.53E+05	2.31E+03		1.67E+04	
I	West	96	27	123		6.06E+04	4.38E+05	7.86E+05	5.67E+06	3.71E+04		2.68E+05	
I	North	171	47	218	834	1.93E+04	1.39E+05	2.50E+05	1.81E+06	1.18E+04	8.08E+02	8.53E+04	5.83E+03
II	North	183	51	234	234	1.67E+04	1.21E+05	2.17E+05	1.57E+06	1.03E+04	1.03E+04	7.40E+04	7.40E+04
III	South	3,567	991	4,558		4.41E+01	3.19E+02	5.72E+02	4.13E+03	2.70E+01		1.95E+02	
III	West	1,181	328	1,509		4.03E+02	2.91E+03	5.22E+03	3.77E+04	2.47E+02		1.78E+03	
III	North	340	94	434	6,501	4.87E+03	3.51E+04	6.31E+04	4.55E+05	2.98E+03	1.33E+01	2.15E+04	9.59E+01
IV	West	737	205	942		1.03E+03	7.46E+03	1.34E+04	9.67E+04	6.33E+02		4.57E+03	
IV	North	679	189	868	1,810	1.22E+03	8.79E+03	1.58E+04	1.14E+05	7.46E+02	1.71E+02	5.38E+03	1.24E+03
V	North	2,659	739	3,398	3,398	7.94E+01	5.73E+02	1.03E+03	7.43E+03	4.86E+01	4.86E+01	3.51E+02	3.51E+02
VI	South	146	40	186		2.65E+04	1.91E+05	3.44E+05	2.48E+06	1.62E+04		1.17E+05	
VI	West	276	77	353	539	7.36E+03	5.31E+04	9.54E+04	6.88E+05	4.51E+03	1.93E+03	3.25E+04	1.40E+04
Chk Sums		10,421	2,895	13,316	13,316	Basic Formula: R = delP/[rho^2*(Ql*A)^2] where rho = 1.22 kg/m3; Ql = 1200 cm3/s-m2; delP = 75 Pa							
			13,316										

a = zone number designation
b = compass heading of wall within a particular zone
c = room external curtain wall surface area for zone heading
d = plenum external curtain wall surface area for zone heading
e = total external curtain wall surface area for zone heading [c+d]
f = total exterior curtain wall surface area for the zone (includes walls and windows)
g = unit area of a specified window configuration type (reference E51 Elevation Drawings)
h = unit quantity for the window type
i = total area for each window type for each heading [g*h]
j = total window area, including all types, for each compass heading
k = total window area for the zone
l = exterior wall surace for each heading [e-j]
m = total exterior wall surface area for the zone (excluding glass area)
n = air leakage resistance for room per heading and zone (english) derived from SI calculation [o/(3.2808*2.2)]
o = air leakage resistance for room per heading and zone (SI) ref 1993 ASHRAE F23.14 & F23.16
    R = [75/((1.22*1.22)*(1200/1000000)*(1200/1000000)*(c/10.7636)*(c/10.7636))]
p = air leakage resistance for plenum per heading and zone (english) derived from SI calculation [q/(3.2808*2.2)]
q = air leakage resistance for plenum per heading and zone (SI) ref 1993 ASHRAE F23.14 & F23.16
    R = [75/((1.22*1.22)*(1200/1000000)*(1200/1000000)*(d/10.7636)*(d/10.7636))]
r = air leakage resistance (for room & plenum as one volume) per heading and zone (english) derived from SI calculation [t/(3.2808*2.2)]
s = air leakage resistance for entire zone (considering room & plenum a single volume) (english) derived from SI calculation [u/(3.2808*2.2)]
t = air leakage resistance (for room & plenum as one volume) per heading and zone (SI) ref 1993 ASHRAE F23.14 & F23.16
    R = [75/((1.22*1.22)*(1200/1000000)*(1200/1000000)*(e/10.7636)*(e/10.7636))]
u = air leakage resistance for entire zone (SI) considering room and plenum as one volume (type_210: P1)
    R = [75/((1.22*1.22)*(1200/1000000)*(1200/1000000)*(f/10.7636)*(f/10.7636))]

Figure 207: E51 Parameters - Type 210 continued (Zone Pressure Balance, w/ Leakage)

Type 228: Constant Flow Resistance - Linearized at Low Flow

a	b	c1	c2	d	e	f
Type ID	Location	Reference	Airflow Resistances			
			Component Designations	Values		
				First Components [1/(kg-m)]	Second Components [1/(kg-m)]	Total [1/(kg-m)]
228-III-1	Z-III	res_sup.wq2	Rs8 + Rs7	1.41E+00	1.18E+01	1.32E+01
228-III-2	Z-III	res_rtn.wq2	Rr9 + Rr8	1.73E+00	1.28E+00	3.01E+00
228-V-1	Z-V	res_sup.wq2	Rs15 + Rs14	4.93E+00	2.10E+01	2.59E+01
228-V-2	Z-V	res_rtn.wq2	Rr14 + Rr13	2.88E+00	4.01E+00	6.88E+00
228-I-1	Z-I	res_sup.wq2	Rs20 + Rs19	3.21E+01	2.07E+02	2.39E+02
228-I-2	Z-I	res_rtn.wq2	Rr19 + Rr18	2.73E+01	2.67E+01	5.40E+01
228-IV-1	Z-IV	res_sup.wq2	Rs25 + Rs24	3.48E+01	2.31E+02	2.66E+02
228-IV-2	Z-IV	res_rtn.wq2	Rr32 + Rr31	8.97E+01	8.89E+00	9.86E+01
228-VI-1	Z-VI	res_sup.wq2	Rs30 + Rs29	3.24E+02	1.39E+03	1.72E+03
228-VI-2	Z-VI	res_rtn.wq2	Rr24 + Rr23	2.70E+02	1.39E+02	4.09E+02
228-II-1	Z-II	res_sup.wq2	Rs32 + Rs31	1.24E+03	3.63E+04	3.76E+04
228-II-2	Z-II	res_rtn.wq2	Rr29 + Rr28	6.40E+02	4.39E+03	5.03E+03
228-MR-1	MR	res_sup.wq2	RsB	3.09E-01	0.00E+00	3.09E-01

Note: There are two of these types per zone; one for the supply duct and one for the return duct. In addition, there is one type 228 unit used in the mechanical room.

a = identifies a specific constant flow resistance (type - location - tag number)
b = location of the constant flow resistance
c1 = spreadsheet where calculation is made
c2 = resistance components making up total value
d = first component value
e = second component value
f = total constant flow resistance value [d + e]

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Figure 208: E51 Parameters - Type 228 (Constant Flow Resistance)

Figure 209: E51 Parameters - Type 229 (Inlet Constant Flow Resistance)

Interzone Shared Wall Area and Air Flow Resistance Values

a	b	c	d	e	f	g	h	i	j		k	l
Type 229 Parameter Number												P1
Level	Zone A	Zone B	Shared Wall Area: Linear Dim [ft]	Shared Wall Area: 9 ft Room Height [ft2]	Shared Wall Area: 2.5 ft Ceil'g Height [ft2]	Number of Doors	Crack Length [ft]	Loss Coefficient 1/Cd2	Crack Area [ft2]	Crack Area [m2]	flow resis [1/lbm*ft]	SI convert [1/kg*m]
0th	I	II	36	324	90	2	40	2.78	0.83	0.077	2.67E+01	1.92E+02
	I	III	72	648	180	3	60	2.78	1.25	0.116	1.19E+01	8.55E+01
1st	III	IV	40	594	100	2	40	2.78	0.83	0.077	4.27E+00	3.08E+01
	III	V	66	594	165	5	100	2.78	2.08	0.194	7.41E-01	5.35E+00
2nd	III	IV	33	297	83	3	60	2.78	1.25	0.116	see first level	
	III	V	58	522	145	5	100	2.78	2.08	0.194	see first level	
	III	VI	30	270	75	0	----	----	----	----	no openings	
	IV	VI	12	108	30	1	20	2.78	0.42	0.039	1.07E+02	7.70E+02
3rd	III	V	72	648	180	2	40	2.78	0.83	0.077	see first level	

door size: 7'0" x 3'0"
crack width: 0.25 inches

rho: 0.075 lbm/ft3
1.220 kg/m3

a = level shared wall area & air flow resistance is evaluated
b = zone sharing contact area and air flow
c = zone sharing contact area and air flow
d = linear dimension of shared wall area
e = ceiling height [ft]
f = height of volume above suspended ceiling [ft]
g = number of doors in shared wall

h = resulting crack length based on the number of shared doors
i = loss coefficient (k) based on commonly accepted discharge coefficient for airflow thru cracks in a bldg envelop (93 ASHRAE Fundamentals F23.12) Cd=0.60 & k=1/Cd2
j = effective crack area based on a 0.25 inch crack width
k = air flow resistance [English Units] R = k / (2 * rho * A * A)
l = air flow resistance [SI Units] type_229: P1 R(SI) = R * 3.2808 * 2.2

Appendix W - E51 Simulation: Thermal Components

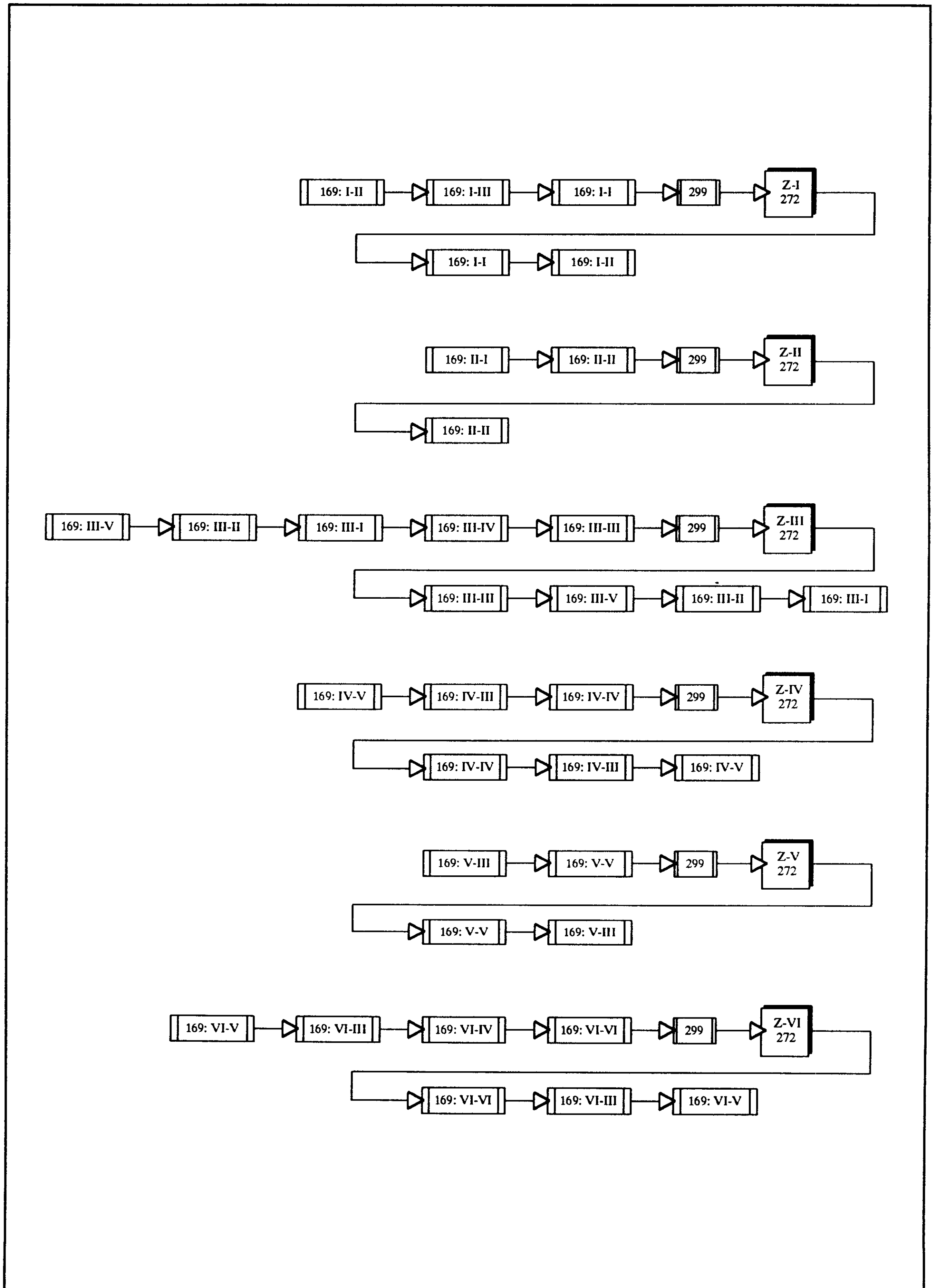

Figure 210: Network for Type 169 (Moist Air Duct - Heat Lose as Output)

Figure 211: E51 Parameters - Type 169 (Moist Air Duct w/ Heat Loss)

Type 169: Moist Air Duct, Heat Loss As Output

a	b	c	d	e	f	g1	g2	h1	h2	i1	i2	j	k1	k2
Parameter Number		P1					P2		P3		P4	P5		P6
Component Identification Code	Supply or Return	Shape 0=round 1=square	Duct Size & Equivalent Diameter					Duct Length	Duct Length	Wall Thickness 0.0625 in	Wall Thickness 1.59e-3 m	Mat'l al=1 cu=2 fe=3	Thermal Resistance R-value	Thermal Resistance R-value
			VAV Box	Duct Dimensions		Equivalent Diameter	Equivalent Diameter							
			[in x in]	h [in]	w [in]	[ft]	[m]	[ft]	[m]	[ft]	[m]		[F-ft2-hr/Btu]	[K-m2/W]
169: I - II	Supply	0	16	16	---	1.33	0.41	15	4.57	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: I - III	Supply	0	16	16	---	1.33	0.41	1	0.30	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: I - I	Supply	0	16	16	---	1.33	0.41	35	10.67	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: I - I	Return	0	---	16	---	1.33	0.41	29	8.84	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: I - II	Return	0	---	16	---	1.33	0.41	11	3.35	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: II - I	Supply	0	7	7	---	0.58	0.18	6	1.83	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: II - II	Supply	0	7	7	---	0.58	0.18	35	10.67	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: II - II	Return	0	---	8	---	0.67	0.20	8	2.44	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: III - V	Supply	0	48 x 16	16	48	2.44	0.74	48	14.63	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: III - II	Supply	0	48 x 16	16	48	2.44	0.74	10	3.05	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: III - I	Supply	0	48 x 16	16	48	2.44	0.74	20	6.10	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: III - IV	Supply	0	48 x 16	16	48	2.44	0.74	1	0.30	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: III - III	Supply	0	48 x 16	16	48	2.44	0.74	50	15.24	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: III - III	Return	0	---	26	30	2.54	0.77	46	14.02	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: III - V	Return	0	---	26	30	2.54	0.77	40	12.19	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: III - II	Return	0	---	26	30	2.54	0.77	2	0.61	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: III - I	Return	0	---	26	30	2.54	0.77	19	5.79	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: IV - V	Supply	0	16	16	---	1.33	0.41	20	6.10	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: IV - III	Supply	0	16	16	---	1.33	0.41	41	12.50	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: IV - IV	Supply	0	16	16	---	1.33	0.41	63	19.20	5.21E-03	1.59E-03	3	3.10	5.46E-01

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Type 169: Moist Air Duct, Heat Loss As Output

a	b	c	d	e	f	g1	g2	h1	h2	i1	i2	j	k1	k2
Parameter Number		P1					P2		P3		P4	P5		P6
Component Identification Code	Supply or Return	Shape 0=round 1=square	Duct Size & Equivalent Diameter					Duct Length	Duct Length	Wall Thickness 0.0625 in	Wall Thickness 1.59e-3 m	Mat'l al=1 cu=2 fe=3	Thermal Resistance R-value	Thermal Resistance R-value
			VAV Box [in x in]	Duct Dimensions h [in]	Duct Dimensions w [in]	Equivalent Diameter [ft]	Equivalent Diameter [m]	[ft]	[m]	[ft]	[m]		[F-ft2-hr/Btu]	[K-m2/W]
169: IV - IV	Return	0	---	16	---	1.33	0.41	31	9.45	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: IV - III	Return	0	---	16	---	1.33	0.41	84	25.60	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: IV - V	Return	0	---	16	---	1.33	0.41	8	2.44	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: V - III	Supply	0	24 x 16	16	24	1.78	0.54	50	15.24	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: V - V	Supply	0	24 x 16	16	24	1.78	0.54	90	27.43	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: V - V	Return	0	---	26	20	2.07	0.63	50	15.24	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: V - III	Return	0	---	26	20	2.07	0.63	8	2.44	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: VI - V	Supply	0	10	10	---	0.83	0.25	16	4.88	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: VI - III	Supply	0	10	10	---	0.83	0.25	22	6.71	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: VI - IV	Supply	0	10	10	---	0.83	0.25	46	14.02	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: VI - VI	Supply	0	10	10	---	0.83	0.25	17	5.18	5.21E-03	1.59E-03	3	3.10	5.46E-01
169: VI - VI	Return	0	---	11	---	0.92	0.28	13	3.96	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: VI - III	Return	0	---	11	---	0.92	0.28	51	15.54	5.21E-03	1.59E-03	3	0.00	0.00E+00
169: VI - V	Return	0	---	11	---	0.92	0.28	5	1.52	5.21E-03	1.59E-03	3	0.00	0.00E+00

Type 169: Moist Air Duct, Heat Loss As Output

a	b	c	d	e	f	g1	g2	h1	h2	i1	i2	j	k1	k2
Parameter Number		P1					P2		P3		P4	P5		P6
Component Identification Code	Supply or Return	Shape 0=round 1=square	Duct Size & Equivalent Diameter					Duct Length	Duct Length	Wall Thickness 0.0625 in	Wall Thickness 1.59e-3 m	Mat'l al=1 cu=2 fe=3	Thermal Resistance R-value	Thermal Resistance R-value
			VAV Box	Duct Dimensions		Equivalent Diameter	Equivalent Diameter							
				h	w									
			[in x in]	[in]	[in]	[ft]	[m]	[ft]	[m]	[ft]	[m]		[F-ft2-hr/Btu]	[K-m2/W]

a = identifies a specific moist air duct (type: primary zone - secondary zone)

b = direction of duct flow - into or out of zone (supply or return)

c = duct shape (all ducts are considered to be round; an equivalent diameter is used for rectangular ducts) type_169: P1

d = VAV box size [in x in]

e = duct height (for round ducts this number represents the diameter) [in]

f = duct width [in]

g = equivalent diameter (for round ducts this value is the diameter) [ft]; An equivalent diameter is calculated based on the Equation 25 in 1993 ASHRAE Handbook - Fundamentals, F32.6. De = 1.3[(ab)^.0625]/[(a+b)^0.25] type_169.wq2:P2

h = length of primary zone duct exposed to secondary zone plenum [ft] (reference file: area_169.wq2) type_169: P3

i = duct wall thickness [ft] type_169: P4

j = duct wall material type_169: p5

k = resistance value for duct insulation [[F-ft2-hr/Btu] (return ducts are uninsulated) type_169: P6

Note: Parameter numbers 7 & 8 are zero. Pressure drop due flow resistance is calculated in the airflow component network.

Supply & Return Moist Air Duct Area Contact Calculation (reference file: area_tal.wq2)

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Zone	Duct Type	Req'd Duct Length [ft]	Duct Length within Each Zone												Duct Length Check Sums [ft]
			Zone I		Zone II		Zone III		Zone IV		Zone V		Zone VI		
			Percent of Duct in Zone	Actual Length [ft]	Percent of Duct in Zone	Actual Length [ft]	Percent of Duct in Zone	Actual Length [ft]	Percent of Duct in Zone	Actual Length [ft]	Percent of Duct in Zone	Actual Length [ft]	Percent of Duct in Zone	Actual Length [ft]	
I	Supply	51	0.69	35	0.29	15	0.02	1	0.00		0.00		0.00		51
	Return	40	0.72	29	0.28	11	0.00		0.00		0.00		0.00		40
II	Supply	41	0.15	6	0.85	35	0.00		0.00		0.00		0.00		41
	Return	8	0.00		1.00	8	0.00		0.00		0.00		0.00		8
III	Supply	128	0.16	20	0.08	10	0.39	50	0.01	1	0.37	48	0.00		128
	Return	106	0.18	19	0.02	2	0.43	46	0.00		0.37	40	0.00		106
IV	Supply	124	0.00		0.00		0.33	41	0.51	63	0.16	20	0.00		124
	Return	123	0.00		0.00		0.68	84	0.25	31	0.07	8	0.00		123
V	Supply	140	0.00		0.00		0.36	50	0.00		0.64	90	0.00		140
	Return	59	0.00		0.00		0.14	8	0.00		0.86	50	0.00		59
VI	Supply	102	0.00		0.00		0.22	22	0.45	46	0.16	16	0.17	17	102
	Return	69	0.00		0.00		0.74	51	0.00		0.08	5	0.18	13	69

a = zone supplied or serviced by duct
b = defines duct use - either as a supply conduit or return conduit
c = duct length req'd for the mega-zone duct system (ref: area_tal.wq2 [q])
d = % of req'd duct length in contact w/ this zone (ref: area_tal.wq2 [d/o])
e = duct length in contact w/ this zone [c*d]
f = % of req'd duct length in contact w/ this zone (ref: area_tal.wq2 [f/o])
g = duct length in contact w/ this zone [c*f]
h = % of req'd duct length in contact w/ this zone (ref: area_tal.wq2 [h/o])
i = duct length in contact w/ this zone [c*h]
j = % of req'd duct length in contact w/ this zone (ref: area_tal.wq2 [j/o])
k = duct length in contact w/ this zone [c*j]
l = % of req'd duct length in contact w/ this zone (ref: area_tal.wq2 [l/o])
m = duct length in contact w/ this zone [c*l]
n = % of req'd duct length in contact w/ this zone (ref: area_tal.wq2 [n/o])
m = duct length in contact w/ this zone [c*n]
p = check sum must equal column "c"

file: area_169.wq2 12/27/95 Page 1

Figure 212: Supply & Return Moist Air Duct Area Contact Calculation Summary

Figure 213: E51 Parameters - Type 272 (2 Node Room Plenum)

Type 272 - 2 Node Room/Plenum - Interzone and Leakage, Ducted Return

a	b	c	d1	d2	d3	d4	d5	d6
Num-ber	Parameter Description		Megazone Designation					
			I	II	III	IV	V	VI
1		Room Capcity Multiplier [-]	-----	-----	-----	-----	-----	-----
2		Zone Number (Parameter File = zoneN.par, N>0)	-----	-----	-----	-----	-----	-----
3	R01	RWSR: Direct Resistance Room Air Node <-> Ambient [K/kW]	3.27E+01	1.37E+02	4.64E+00	1.79E+01	6.82E+00	5.00E+01
4	R02	RISR: Resistance Room Air Node <-> Room Mass Node [K/kW]	2.64E-03	1.80E-02	3.76E-03	3.15E-02	5.99E-03	4.61E-01
5	R03	ROSR: Resistance Ambient <-> Room Mass Node [K/kW]	2.34E-01	1.12E+00	9.56E-02	5.08E-01	1.76E-01	3.43E+00
6	R21	RWSP: Direct Resistance, Plenum Air Node <-> Ambient [K/kW]	infinite	infinite	infinite	infinite	infinite	infinite
7	R22	RISP: Resistance Plenum Air Node <-> plenum Mass Node [K/kW]	7.45E-03	7.97E-03	2.54E-02	2.09E-02	5.77E-03	3.57E-01
8	R23	ROSP: Resistance Ambient <-> plenum Mass Node [K/kW]	6.41E-01	1.26E+00	3.12E-01	7.17E-01	2.53E-01	5.23E+00
9	R11	RR: Resistance Room Air Node <-> Plenum Air Node [K/kW]	3.26E+00	9.47E+00	1.14E+00	3.81E+00	1.33E+00	3.06E+01
10	C03	CSR: Capacitance of Room Mass Node [kJ/K]	5.85E+04	1.07E+04	2.79E+05	7.60E+04	2.14E+05	2.08E+04
11	C02	CR: Capacitance of Room Air Node (unmodifed) [kJ/K]	9.41E+03	2.03E+03	2.58E+04	7.24E+03	1.78E+04	6.77E+02
12	C23	CSP: Capacitance of Plenum Mass Node [kJ/K]	4.81E+04	1.63E+04	1.25E+05	5.18E+04	1.52E+05	1.08E+04
13	C22	CP: Capacitance of Plenum Air Node [kJ/K]	2.45E+03	7.03E+02	6.87E+03	2.36E+03	5.49E+03	2.32E+02
14		Volume of Room [m3]	6.47E+02	1.55E+02	1.82E+03	3.85E+02	1.21E+03	4.80E+01
15		Volume of Plenum [m3]	1.25E+02	4.30E+01	3.96E+02	1.07E+02	3.30E+02	1.30E+01
16		Number of Occupants	-----	-----	-----	-----	-----	-----
17		Lighting Heat Gain [kW]	-----	-----	-----	-----	-----	-----
18		Fraction of Lighting Heat Gain to Plenum	-----	-----	-----	-----	-----	-----
19		Equipment Heat Gain [kW]	-----	-----	-----	-----	-----	-----

a = parameter number (heat input parameters to be changed to heat input variables)
b = 2C3R model global element designation
c = parameter description
d1 - d6 = parameter value (reference file: global01.wq2 pages 3,6, and 7)

file: type_272.wq2 12/27/95 Page 1

Figure 214: E51 Parameters - Type 299 (Liege Coil and L&G Valve)

Type 299: Liege Coil and L&G Valve, Water Pressure I/P

a	b	c	d	e	f	g	h	i	j
		Coil Location							
	Parameter Description	Mechanical Room		Zone I (Size 16)		Zone II (Size 7)		Zone III (Size 48 x 16)	
		English	SI	English	SI	English	SI	English	SI
1	method: 0= steady state; 1 = dynamic	1	1	1	1	1	1	1	1
2	fault: 0 = no faults	0	0	0	0	0	0	0	0
3	psycho: 0 = no psychrometric output calculations	0	0	0	0	0	0	0	0
4	number of rows of tubes	4	4	1	1	1	1	1	1
5	number of tubes per row	36	36	14	14	8	8	14	14
6	number of parallel water circuits	1	1	1	1	1	1	1	1
7	length of finned section in air flow direction [in] & [m]	9.5	2.41E-01	2.16	5.49E-02	2.16	5.49E-02	2.16	5.49E-02
8	height of finned section [in] & [m]	54	1.37E+00	18	4.57E-01	10	2.54E-01	18	4.57E-01
9	width of finned section [in] & [m]	109	2.77E+00	24	6.10E-01	12	3.05E-01	56	1.42E+00
10	tube outside diameter [in] & [m]	0.625	1.59E-02	0.5	1.27E-02	0.5	1.27E-02	0.5	1.27E-02
11	tube wall thickness [in] & [m]	0.020	0.02	0.016	4.06E-04	0.016	4.06E-04	0.016	4.06E-04
12	tube material (Al = 1, Cu = 2, Fe = 3, CaCo3 = 4)	2	2	2	2	2	2	2	2
13	fin spacing (pitch) [in] & [m]	0.0833	2.12E-03	0.1000	2.54E-03	0.1000	2.54E-03	0.1000	2.54E-03
14	fin thickness [in] & [m]	0.0085	2.16E-04	0.0060	1.52E-04	0.0060	1.52E-04	0.0060	1.52E-04
15	fin material (Al = 1, Cu = 2, Fe = 3)	1	1	1	1	1	1	1	1
16	flow resistance parameter on air side [1/(lbm-ft)] & [0.001/(kg	6.92E-02	4.99E-01	2.74E+00	1.98E+01	4.50E+01	3.25E+02	3.48E-01	2.51E+00
17	Kv: valve capacity index [ft3/hr @ 1 psi] or [m3/hr @ 1 bar]	38	32.68	0.74	0.64	0.29	0.25	2.92	2.51
18	valve mode: (0=lin/lin, 1=exp/lin, 2=exp/exp, 3=lin/exp)	1	1	1	1	1	1	1	1
19	valve characteristic exponent Ngl (-)	3.54	3.54	3.22	3.22	3.22	3.22	3.22	3.22
20	adjusting ratio (>1)	35	35	50	50	50	50	100	100
21	valve leakage (fractional when valve is closed)	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
22	coil hydraulic resistance [1/[lbm-ft] or [0.001/(kg-m)]	2.88E+00	2.08E+01	6.06E+02	4.38E+03	6.93E+03	5.00E+04	4.33E+02	3.13E+03
23	3-way valve bypass hydraulic resistance [1/[lbm-ft] or [0.001/(	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06

Figure 215: E51 Parameters - Type 299 continued (Liege Coil and L&G Valve)

Type 299: Liege Coil and L&G Valve, Water Pressure I/P

a	b	k	l	m	n	o	p
	Parameter Description	Coil Location					
		Zone IV (Size 16)		Zone V (Size 24 x 16)		Zone VI (Size 10)	
		English	SI	English	SI	English	SI
1	method: 0= steady state; 1 = dynamic	1	1	1	1	1	1
2	fault: 0 = no faults	0	0	0	0	0	0
3	psycho: 0 = no psychrometric output calculations	0	0	0	0	0	0
4	number of rows of tubes	1	1	1	1	1	1
5	number of tubes per row	14	14	14	14	10	10
6	number of parallel water circuits	1	1	1	1	1	1
7	length of finned section in air flow direction [in] & [m]	2.16	5.49E-02	2.16	5.49E-02	2.16	5.49E-02
8	height of finned section [in] & [m]	18	4.57E-01	18	4.57E-01	12.5	3.18E-01
9	width of finned section [in] & [m]	24	6.10E-01	28	7.11E-01	14	3.56E-01
10	tube outside diameter [in] & [m]	0.500	1.27E-02	0.500	1.27E-02	0.500	1.27E-02
11	tube wall thickness [in] & [m]	0.016	4.06E-04	0.016	4.06E-04	0.016	4.06E-04
12	tube material (Al = 1, Cu = 2, Fe = 3, CaCo3 = 4)	2	2	2	2	2	2
13	fin spacing (pitch) [in] & [m]	0.1000	2.54E-03	0.1000	2.54E-03	0.1000	2.54E-03
14	fin thickness [in] & [m]	0.0060	1.52E-04	0.0060	1.52E-04	0.0060	1.52E-04
15	fin material (Al = 1, Cu = 2, Fe = 3)	1	1	1	1	1	1
16	flow resistance parameter on air side [1/(lbm-ft)] & [0.001/(kg	2.74E+00	1.98E+01	1.39E+00	1.00E+01	2.19E+01	1.58E+02
17	Kv: valve capacity index [ft3/hr @ 1 psi] or [m3/hr @ 1 bar]	0.74	0.64	1.87	1.61	0.47	0.40
18	valve mode: (0=lin/lin, 1=exp/lin, 2=exp/exp, 3=lin/exp)	1	1	1	1	1	1
19	valve characteristic exponent Ngl (-)	3.22	3.22	3.22	3.22	3.54	3.54
20	adjusting ratio (>1)	50	50	100	100	50	50
21	valve leakage (fractional when valve is closed)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
22	coil hydraulic resistance [1/[lbm-ft] or [0.001 (kg-m)]	6.06E+02	4.38E+03	7.80E+02	5.63E+03	1.21E+03	8.75E+03
23	3-way valve bypass hydraulic resistance [1/[lbm-ft] or [0.001/(	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06

Appendix X - E51 Simulation: Sensors

Appendix Y - Internal and External Heat Gains

Heat Input Profiles - Occupancy, Equipment, and Lighting

Heat Gain Profile: Occupants, Equipment & Lighting

	Zone Number		1	2	3	4	5	6
		Tot Internal Heat Gain	Prof/Stud Offices	Computer Data/Proc	Admin Offices	Prof/Stud Offices	Classroom & Confer	Admin Offices
i	Area [ft2]	16,139	2,369	607	6,799	1,510	4,666	188
	1	4,150	490	3,100	310	240	0	10
	2	3,870	490	2,820	310	240	0	10
	3	3,590	490	2,540	310	240	0	10
	4	3,310	490	2,260	310	240	0	10
	5	3,310	490	2,260	310	240	0	10
	6	3,310	490	2,260	310	240	0	10
	7	12,660	490	2,260	9,410	240	0	260
	8	15,890	490	2,260	12,560	240	0	340
	9	32,820	1,240	2,480	15,710	610	12,350	430
	10	34,390	590	2,480	15,710	290	14,890	430
	11	34,620	490	2,480	15,710	240	15,270	430
	12	25,910	2,080	2,480	10,980	1,020	9,050	300
	13	26,130	1,990	2,480	10,980	980	9,400	300
	14	33,410	990	2,480	15,710	490	13,310	430
	15	32,950	1,180	2,480	15,710	580	12,570	430
	16	31,910	1,700	2,710	15,710	840	10,520	430
	17	30,340	2,430	2,930	15,710	1,200	7,640	430
	18	21,800	2,850	3,160	8,150	1,400	6,020	220
	19	18,200	1,530	3,380	7,670	750	4,660	210
	20	12,740	1,310	3,380	7,200	650	0	200
	21	11,780	990	3,380	6,730	490	0	190
	22	4,680	660	3,380	310	320	0	10
	23	4,190	330	3,380	310	160	0	10
	24	4,430	490	3,380	310	240	0	10

Min Value W	3,310	330	2,260	310	160	0	10
Max Value W	34,620	2,850	3,380	15,710	1,400	15,270	430
Avg Value W	17,100	1,032	2,758	7,768	508	4,820	213
Min Gain W/ft2	0.21	0.14	3.72	0.05	0.11	0.00	0.05
Max Gain W/ft2	2.15	1.20	5.57	2.31	0.93	3.27	2.29
Avg Gain W/ft2	1.06	0.44	4.54	1.14	0.34	1.03	1.13
Baseline W	4,012	492	2,960	310	240	0	10

file: heat_oel.wq2 01/18/96 Page 4

Figure 216: Internal Heat Gain - Data: Total Occupancy, Equipment & Lighting

Heat Input Profiles - Occupancy, Equipment, and Lighting

Heat/Person: 75 [W/person]

Heat Gain Profile: Occupants

	Zone Number		1	2	3	4	5	6
	Type		Prof/Stud Offices	Computer Data/Proc	Admin Offices	Prof/Stud Offices	Classroom & Confer	Admin Offices
i	Area	[ft2]	2,369	607	6,799	1,510	4,666	188
ii	Occ Density	[ft2/person]	70	40	170	70	15	170
iii	Max Occup	[persons]	34	15	40	22	311	1
iv	Max Heat	[W]	2,550	1,125	3,000	1,650	23,325	75
	1		0.07	0.75	0.00	0.07	0.00	0.00
	2		0.07	0.50	0.00	0.07	0.00	0.00
	3		0.07	0.25	0.00	0.07	0.00	0.00
	4		0.07	0.00	0.00	0.07	0.00	0.00
	5		0.07	0.00	0.00	0.07	0.00	0.00
	6		0.07	0.00	0.00	0.07	0.00	0.00
	7		0.07	0.00	0.33	0.07	0.00	0.33
	8		0.07	0.00	0.67	0.07	0.00	0.67
	9		0.18	0.20	1.00	0.18	0.35	1.00
	10		0.08	0.20	1.00	0.08	0.45	1.00
	11		0.07	0.20	1.00	0.07	0.47	1.00
	12		0.30	0.20	0.50	0.30	0.20	0.50
	13		0.28	0.20	0.50	0.28	0.22	0.50
	14		0.14	0.20	1.00	0.14	0.39	1.00
	15		0.17	0.20	1.00	0.17	0.35	1.00
	16		0.24	0.40	1.00	0.24	0.27	1.00
	17		0.35	0.60	1.00	0.35	0.14	1.00
	18		0.41	0.80	0.20	0.41	0.07	0.20
	19		0.22	1.00	0.15	0.22	0.02	0.15
	20		0.19	1.00	0.10	0.19	0.00	0.10
	21		0.14	1.00	0.05	0.14	0.00	0.05
	22		0.09	1.00	0.00	0.09	0.00	0.00
	23		0.05	1.00	0.00	0.05	0.00	0.00
	24		0.07	1.00	0.00	0.07	0.00	0.00

i = area of megazone (ref file: heatin.wq2)

ii = occupancy density based on survey data recorded in files: heatin.wq2 & classocc.wq2

iii = based on i & ii

iv = based on iii & 75 watts/person

file: heat_oel.wq2 01/18/96 Page 1

Figure 217: Internal Heat Gain - Occupancy Distribution Profiles, Megazones 1 thru 6

Heat Input Profiles - Occupancy, Equipment, and Lighting

Heat Gain Profile: Equipment

	Zone Number		1	2	3	4	5	6
	Type		Prof/Stud Offices	Computer Data/Proc	Admin Offices	Prof/Stud Offices	Classroom & Confer	Admin Offices
i	Area	[ft2]	2,369	607	6,799	1,510	4,666	188
vi	Eqt. Density	[W/ft2]	0.95	2.80	0.95	0.26	0.00	0.95
vii	Max Heat	[W]	2,251	1,700	6,459	396	0	179
	1		0.07	1.00	0.00	0.07	0.00	0.00
	2		0.07	1.00	0.00	0.07	0.00	0.00
	3		0.07	1.00	0.00	0.07	0.00	0.00
	4		0.07	1.00	0.00	0.07	0.00	0.00
	5		0.07	1.00	0.00	0.07	0.00	0.00
	6		0.07	1.00	0.00	0.07	0.00	0.00
	7		0.07	1.00	0.33	0.07	0.00	0.33
	8		0.07	1.00	0.67	0.07	0.00	0.67
	9		0.18	1.00	1.00	0.18	0.00	1.00
	10		0.08	1.00	1.00	0.08	0.00	1.00
	11		0.07	1.00	1.00	0.07	0.00	1.00
	12		0.30	1.00	0.50	0.30	0.00	0.50
	13		0.28	1.00	0.50	0.28	0.00	0.50
	14		0.14	1.00	1.00	0.14	0.00	1.00
	15		0.17	1.00	1.00	0.17	0.00	1.00
	16		0.24	1.00	1.00	0.24	0.00	1.00
	17		0.35	1.00	1.00	0.35	0.00	1.00
	18		0.41	1.00	0.20	0.41	0.00	0.20
	19		0.22	1.00	0.15	0.22	0.00	0.15
	20		0.19	1.00	0.10	0.19	0.00	0.10
	21		0.14	1.00	0.05	0.14	0.00	0.05
	22		0.09	1.00	0.00	0.09	0.00	0.00
	23		0.05	1.00	0.00	0.05	0.00	0.00
	24		0.07	1.00	0.00	0.07	0.00	0.00

vi = based on surveys reviewed in Section 3.2.1 & survey data recorded in file heatin.wq2
vii = based on i & vi

file: heat_oel.wq2 01/18/96 Page 2

Figure 218: Internal Heat Gain - Equipment Usage Profiles, Megazones 1 thru 6

Heat Input Profiles - Occupancy, Equipment, and Lighting

Heat Gain Profile: Lighting

	Zone Number		1	2	3	4	5	6
	Type		Prof/Stud Offices	Computer Data/Proc	Admin Offices	Prof/Stud Offices	Classroom & Confer	Admin Offices
i	Area	[ft2]	2,369	607	6,799	1,510	4,666	188
viii	Lite Density	[W/ft2]	0.92	0.92	0.92	0.92	0.92	0.92
ix	Max Heat	[W]	2,179	558	6,255	1,389	4,293	173
	1		0.07	1.00	0.05	0.07	0.00	0.05
	2		0.07	1.00	0.05	0.07	0.00	0.05
	3		0.07	1.00	0.05	0.07	0.00	0.05
	4		0.07	1.00	0.05	0.07	0.00	0.05
	5		0.07	1.00	0.05	0.07	0.00	0.05
	6		0.07	1.00	0.05	0.07	0.00	0.05
	7		0.07	1.00	1.00	0.07	0.00	1.00
	8		0.07	1.00	1.00	0.07	0.00	1.00
	9		0.18	1.00	1.00	0.18	1.00	1.00
	10		0.08	1.00	1.00	0.08	1.00	1.00
	11		0.07	1.00	1.00	0.07	1.00	1.00
	12		0.30	1.00	1.00	0.30	1.00	1.00
	13		0.28	1.00	1.00	0.28	1.00	1.00
	14		0.14	1.00	1.00	0.14	1.00	1.00
	15		0.17	1.00	1.00	0.17	1.00	1.00
	16		0.24	1.00	1.00	0.24	1.00	1.00
	17		0.35	1.00	1.00	0.35	1.00	1.00
	18		0.41	1.00	1.00	0.41	1.00	1.00
	19		0.22	1.00	1.00	0.22	1.00	1.00
	20		0.19	1.00	1.00	0.19	0.00	1.00
	21		0.14	1.00	1.00	0.14	0.00	1.00
	22		0.09	1.00	0.05	0.09	0.00	0.05
	23		0.05	1.00	0.05	0.05	0.00	0.05
	24		0.07	1.00	0.05	0.07	0.00	0.05

viii = based on survey data recorded in file: heatin.wq2
ix = based on i & viii

Figure 219: Internal Heat Gain - Lighting Usage Profiles, Megazones 1 thru 6

Figure 220: External Heat Gain - Solair Temperatures Averaged Over All Surfaces

Sol-air Temperatures (averaged over south, west, and north faces + roof)

from file: global01.wq2												ASHRAE		yes	SAMSON		no
K(ext,m)	25.1	10.5	7.1	2.6	15.0	4.6	23.2	0.0	4.2	0.0	3.1	0.0	0.0	77.8	17.7	
K(ext)	77.8	17.7	77.8	17.7	77.8	17.7	77.8	17.7	77.8	17.7	77.8	17.7	17.7	77.8	17.7	
														Zone 1	Data Date:	20-Jul-90
Time	Vert Wall - South		Vert Wall - West		Vert Wall - North		Vert Glaz - South		Vert Glaz - West		Vert Glaz - North		Roof	Solair Temp ASHRAE		Ambient
of Day	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum		Room	Plenum	Temp
[hr]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]
1	7.3	13.4	2.1	3.3	4.4	5.9	6.7	0.0	1.2	0.0	0.9	0.0	0.0	22.6	22.6	23.6
2	7.4	13.5	2.1	3.4	4.4	6.0	6.8	0.0	1.2	0.0	0.9	0.0	0.0	22.9	22.9	23.9
3	7.2	13.2	2.0	3.3	4.3	5.8	6.6	0.0	1.2	0.0	0.9	0.0	0.0	22.3	22.3	23.3
4	6.9	12.5	1.9	3.1	4.1	5.5	6.3	0.0	1.1	0.0	0.8	0.0	0.0	21.2	21.2	22.2
5	6.9	12.5	1.9	3.1	4.1	5.5	6.3	0.0	1.1	0.0	0.8	0.0	0.0	21.2	21.2	22.2
6	7.5	13.6	2.1	3.4	4.5	6.1	7.1	0.0	1.3	0.0	1.0	0.0	0.0	23.4	23.1	23.9
7	8.4	15.3	2.3	3.7	4.9	6.6	9.4	0.0	1.5	0.0	1.1	0.0	0.0	27.5	25.6	25.6
8	9.8	17.9	2.6	4.1	5.4	7.4	12.9	0.0	1.7	0.0	1.3	0.0	0.0	33.7	29.4	28.3
9	10.5	19.3	2.7	4.4	5.8	7.8	14.4	0.0	1.8	0.0	1.3	0.0	0.0	36.6	31.5	30.0
10	11.7	21.5	2.9	4.7	6.2	8.4	18.1	0.0	2.0	0.0	1.5	0.0	0.0	42.4	34.5	31.7
11	13.2	24.2	3.1	5.0	6.5	8.8	24.1	0.0	2.3	0.0	1.7	0.0	0.0	51.0	38.0	32.8
12	12.6	23.0	3.1	5.1	6.5	8.9	20.3	0.0	2.3	0.0	1.6	0.0	0.0	46.5	36.9	33.3
13	12.1	22.1	3.4	5.4	6.6	8.9	17.0	0.0	2.9	0.0	1.6	0.0	0.0	43.5	36.5	33.9
14	11.5	21.1	3.6	5.7	6.4	8.7	15.6	0.0	3.7	0.0	1.6	0.0	0.0	42.4	35.5	32.8
15	10.7	19.5	3.2	5.2	6.3	8.6	10.8	0.0	2.6	0.0	1.4	0.0	0.0	35.1	33.3	33.3
16	10.2	18.7	3.2	5.1	6.2	8.4	10.0	0.0	2.7	0.0	1.4	0.0	0.0	33.7	32.2	32.2
17	9.8	17.9	3.0	4.8	6.0	8.1	9.4	0.0	2.3	0.0	1.4	0.0	0.0	31.9	30.9	31.1
18	9.7	17.7	3.0	4.8	6.0	8.2	9.2	0.0	2.5	0.0	1.6	0.0	0.0	32.0	30.7	30.6
19	9.0	16.5	2.6	4.1	5.4	7.3	8.3	0.0	1.5	0.0	1.1	0.0	0.0	28.0	28.0	28.9
20	6.5	11.9	1.8	3.0	3.9	5.3	6.0	0.0	1.1	0.0	0.8	0.0	0.0	20.1	20.1	21.1
21	7.4	13.5	2.1	3.4	4.4	6.0	6.8	0.0	1.2	0.0	0.9	0.0	0.0	22.9	22.9	23.9
22	7.6	13.8	2.1	3.5	4.5	6.1	7.0	0.0	1.3	0.0	0.9	0.0	0.0	23.4	23.4	24.4
23	7.6	13.8	2.1	3.5	4.5	6.1	7.0	0.0	1.3	0.0	0.9	0.0	0.0	23.4	23.4	24.4
24	7.4	13.5	2.1	3.4	4.4	6.0	6.8	0.0	1.2	0.0	0.9	0.0	0.0	22.9	22.9	23.9

Sol-air Temperatures (averaged over south, west, and north faces + roof)

from file: global01.wq2											ASHRAE		yes	SAMSON		no
K(ext,m)	0.0	0.0	0.0	0.0	13.9	5.0	0.0	0.0	0.0	0.0	7.3	0.0	0.0	21.2	5.0	
K(ext)	21.2	5.0	21.2	5.0	21.2	5.0	21.2	5.0	21.2	5.0	21.2	5.0	5.0	21.2	5.0	
														Zone 2	Data Date:	20-Jul-90
Time	Vert Wall - South		Vert Wall - West		Vert Wall - North		Vert Glaz - South		Vert Glaz - West		Vert Glaz - North		Roof	Solair Temp ASHRAE		Ambient
of Day	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum		Room	Plenum	Temp
[hr]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]
1	0.0	0.0	0.0	0.0	14.8	22.6	0.0	0.0	0.0	0.0	7.7	0.0	0.0	22.6	22.6	23.6
2	0.0	0.0	0.0	0.0	15.0	22.9	0.0	0.0	0.0	0.0	7.8	0.0	0.0	22.9	22.9	23.9
3	0.0	0.0	0.0	0.0	14.6	22.3	0.0	0.0	0.0	0.0	7.6	0.0	0.0	22.3	22.3	23.3
4	0.0	0.0	0.0	0.0	13.9	21.2	0.0	0.0	0.0	0.0	7.3	0.0	0.0	21.2	21.2	22.2
5	0.0	0.0	0.0	0.0	13.9	21.2	0.0	0.0	0.0	0.0	7.3	0.0	0.0	21.2	21.2	22.2
6	0.0	0.0	0.0	0.0	15.2	23.2	0.0	0.0	0.0	0.0	8.4	0.0	0.0	23.7	23.2	23.9
7	0.0	0.0	0.0	0.0	16.6	25.2	0.0	0.0	0.0	0.0	9.6	0.0	0.0	26.2	25.2	25.6
8	0.0	0.0	0.0	0.0	18.5	28.2	0.0	0.0	0.0	0.0	11.0	0.0	0.0	29.5	28.2	28.3
9	0.0	0.0	0.0	0.0	19.6	29.9	0.0	0.0	0.0	0.0	11.6	0.0	0.0	31.2	29.9	30.0
10	0.0	0.0	0.0	0.0	21.0	32.0	0.0	0.0	0.0	0.0	12.9	0.0	0.0	33.8	32.0	31.7
11	0.0	0.0	0.0	0.0	22.2	33.8	0.0	0.0	0.0	0.0	14.7	0.0	0.0	36.9	33.8	32.8
12	0.0	0.0	0.0	0.0	22.2	33.9	0.0	0.0	0.0	0.0	14.0	0.0	0.0	36.3	33.9	33.3
13	0.0	0.0	0.0	0.0	22.4	34.2	0.0	0.0	0.0	0.0	13.6	0.0	0.0	36.1	34.2	33.9
14	0.0	0.0	0.0	0.0	21.8	33.3	0.0	0.0	0.0	0.0	13.6	0.0	0.0	35.4	33.3	32.8
15	0.0	0.0	0.0	0.0	21.5	32.8	0.0	0.0	0.0	0.0	12.0	0.0	0.0	33.5	32.8	33.3
16	0.0	0.0	0.0	0.0	21.0	32.1	0.0	0.0	0.0	0.0	12.3	0.0	0.0	33.4	32.1	32.2
17	0.0	0.0	0.0	0.0	20.4	31.1	0.0	0.0	0.0	0.0	12.1	0.0	0.0	32.5	31.1	31.1
18	0.0	0.0	0.0	0.0	20.6	31.4	0.0	0.0	0.0	0.0	13.5	0.0	0.0	34.1	31.4	30.6
19	0.0	0.0	0.0	0.0	18.4	28.0	0.0	0.0	0.0	0.0	9.8	0.0	0.0	28.2	28.0	28.9
20	0.0	0.0	0.0	0.0	13.2	20.1	0.0	0.0	0.0	0.0	6.9	0.0	0.0	20.1	20.1	21.1
21	0.0	0.0	0.0	0.0	15.0	22.9	0.0	0.0	0.0	0.0	7.8	0.0	0.0	22.9	22.9	23.9
22	0.0	0.0	0.0	0.0	15.4	23.4	0.0	0.0	0.0	0.0	8.0	0.0	0.0	23.4	23.4	24.4
23	0.0	0.0	0.0	0.0	15.4	23.4	0.0	0.0	0.0	0.0	8.0	0.0	0.0	23.4	23.4	24.4
24	0.0	0.0	0.0	0.0	15.0	22.9	0.0	0.0	0.0	0.0	7.8	0.0	0.0	22.9	22.9	23.9

Sol-air Temperatures (averaged over south, west, and north faces + roof)

from file: global01.wq2												ASHRAE		yes	SAMSON		no
K(ext,m)	239.5	96.8	115.3	32.0	25.8	9.2	201.8	0.0	0.0	0.0	13.6	0.0	86.1	596.0	224.1	
K(ext)	596.0	224.1	596.0	224.1	596.0	224.1	596.0	224.1	596.0	224.1	596.0	224.1	224.1	596.0	224.1	
														Zone 3	Data Date:	20-Jul-90
Time	Vert Wall - South		Vert Wall - West		Vert Wall - North		Vert Glaz - South		Vert Glaz - West		Vert Glaz - North		Roof	Solair Temp ASHRAE		Ambient
of Day	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum		Room	Plenum	Temp
[hr]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]
1	9.1	9.8	4.4	3.2	1.0	0.9	7.6	0.0	0.0	0.0	0.5	0.0	8.3	22.6	22.2	23.6
2	9.2	9.9	4.4	3.3	1.0	0.9	7.7	0.0	0.0	0.0	0.5	0.0	8.4	22.9	22.5	23.9
3	9.0	9.6	4.3	3.2	1.0	0.9	7.5	0.0	0.0	0.0	0.5	0.0	8.2	22.3	21.9	23.3
4	8.5	9.2	4.1	3.0	0.9	0.9	7.1	0.0	0.0	0.0	0.5	0.0	7.7	21.2	20.8	22.2
5	8.5	9.2	4.1	3.0	0.9	0.9	7.1	0.0	0.0	0.0	0.5	0.0	7.8	21.2	20.8	22.2
6	9.3	10.0	4.5	3.3	1.0	1.0	8.0	0.0	0.0	0.0	0.6	0.0	8.6	23.3	22.8	23.9
7	10.4	11.2	4.9	3.6	1.1	1.0	10.6	0.0	0.0	0.0	0.6	0.0	10.1	27.6	25.9	25.6
8	12.2	13.1	5.4	4.0	1.2	1.2	14.6	0.0	0.0	0.0	0.7	0.0	12.0	34.2	30.2	28.3
9	13.1	14.1	5.8	4.3	1.3	1.2	16.4	0.0	0.0	0.0	0.8	0.0	12.8	37.3	32.4	30.0
10	14.6	15.7	6.2	4.6	1.4	1.3	20.5	0.0	0.0	0.0	0.9	0.0	14.6	43.5	36.2	31.7
11	16.4	17.7	6.6	4.9	1.5	1.4	27.3	0.0	0.0	0.0	1.0	0.0	17.3	52.8	41.2	32.8
12	15.6	16.8	6.6	4.9	1.5	1.4	23.0	0.0	0.0	0.0	0.9	0.0	16.4	47.7	39.5	33.3
13	15.0	16.1	7.1	5.3	1.5	1.4	19.3	0.0	0.0	0.0	0.9	0.0	15.6	43.8	38.5	33.9
14	14.3	15.4	7.5	5.5	1.4	1.4	17.7	0.0	0.0	0.0	0.9	0.0	15.5	41.9	37.8	32.8
15	13.3	14.3	6.9	5.1	1.4	1.3	12.2	0.0	0.0	0.0	0.8	0.0	13.2	34.6	33.8	33.3
16	12.7	13.7	6.7	5.0	1.4	1.3	11.3	0.0	0.0	0.0	0.8	0.0	12.5	33.0	32.5	32.2
17	12.2	13.1	6.3	4.7	1.3	1.3	10.6	0.0	0.0	0.0	0.8	0.0	11.7	31.3	30.7	31.1
18	12.0	12.9	6.4	4.7	1.4	1.3	10.5	0.0	0.0	0.0	0.9	0.0	11.4	31.1	30.3	30.6
19	11.2	12.1	5.4	4.0	1.2	1.2	9.4	0.0	0.0	0.0	0.7	0.0	10.3	27.9	27.6	28.9
20	8.1	8.7	3.9	2.9	0.9	0.8	6.8	0.0	0.0	0.0	0.5	0.0	7.3	20.1	19.7	21.1
21	9.2	9.9	4.4	3.3	1.0	0.9	7.7	0.0	0.0	0.0	0.5	0.0	8.4	22.9	22.5	23.9
22	9.4	10.1	4.5	3.3	1.0	1.0	7.9	0.0	0.0	0.0	0.5	0.0	8.6	23.4	23.0	24.4
23	9.4	10.1	4.5	3.3	1.0	1.0	7.9	0.0	0.0	0.0	0.5	0.0	8.6	23.4	23.0	24.4
24	9.2	9.9	4.4	3.3	1.0	0.9	7.7	0.0	0.0	0.0	0.5	0.0	8.4	22.9	22.5	23.9

Sol-air Temperatures (averaged over south, west, and north faces + roof)

from file: global01.wq2											ASHRAE	yes		SAMSON	no	
K(ext,m)	0.0	0.0	56.6	20.0	51.6	18.4	0.0	0.0	28.6	0.0	27.3	0.0	0.0	164.1	38.4	
K(ext)	164.1	38.4	164.1	38.4	164.1	38.4	164.1	38.4	164.1	38.4	164.1	38.4	38.4	164.1	38.4	
														Zone 4	Data Date:	20-Jul-90
Time	Vert Wall - South		Vert Wall - West		Vert Wall - North		Vert Glaz - South		Vert Glaz - West		Vert Glaz - North		Roof	Solair Temp ASHRAE		Ambient
of Day	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum		Room	Plenum	Temp
[hr]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]
1	0.0	0.0	7.8	11.8	7.1	10.8	0.0	0.0	3.9	0.0	3.7	0.0	0.0	22.6	22.6	23.6
2	0.0	0.0	7.9	11.9	7.2	11.0	0.0	0.0	4.0	0.0	3.8	0.0	0.0	22.9	22.9	23.9
3	0.0	0.0	7.7	11.6	7.0	10.7	0.0	0.0	3.9	0.0	3.7	0.0	0.0	22.3	22.3	23.3
4	0.0	0.0	7.3	11.0	6.7	10.2	0.0	0.0	3.7	0.0	3.5	0.0	0.0	21.2	21.2	22.2
5	0.0	0.0	7.3	11.0	6.7	10.2	0.0	0.0	3.7	0.0	3.5	0.0	0.0	21.2	21.2	22.2
6	0.0	0.0	8.0	12.0	7.3	11.1	0.0	0.0	4.1	0.0	4.1	0.0	0.0	23.5	23.1	23.9
7	0.0	0.0	8.7	13.1	7.9	12.1	0.0	0.0	4.8	0.0	4.6	0.0	0.0	26.1	25.2	25.6
8	0.0	0.0	9.7	14.6	8.9	13.5	0.0	0.0	5.5	0.0	5.3	0.0	0.0	29.4	28.2	28.3
9	0.0	0.0	10.3	15.5	9.4	14.3	0.0	0.0	5.8	0.0	5.6	0.0	0.0	31.1	29.9	30.0
10	0.0	0.0	11.0	16.6	10.1	15.3	0.0	0.0	6.5	0.0	6.2	0.0	0.0	33.8	31.9	31.7
11	0.0	0.0	11.7	17.7	10.7	16.2	0.0	0.0	7.5	0.0	7.1	0.0	0.0	37.0	33.9	32.8
12	0.0	0.0	11.8	17.8	10.7	16.3	0.0	0.0	7.5	0.0	6.8	0.0	0.0	36.8	34.1	33.3
13	0.0	0.0	12.7	19.2	10.8	16.4	0.0	0.0	9.4	0.0	6.6	0.0	0.0	39.5	35.6	33.9
14	0.0	0.0	13.4	20.2	10.5	16.0	0.0	0.0	12.1	0.0	6.6	0.0	0.0	42.5	36.1	32.8
15	0.0	0.0	12.2	18.4	10.3	15.7	0.0	0.0	8.5	0.0	5.8	0.0	0.0	36.9	34.2	33.3
16	0.0	0.0	12.0	18.1	10.1	15.4	0.0	0.0	8.7	0.0	6.0	0.0	0.0	36.8	33.5	32.2
17	0.0	0.0	11.2	17.0	9.8	14.9	0.0	0.0	7.6	0.0	5.9	0.0	0.0	34.4	31.9	31.1
18	0.0	0.0	11.3	17.1	9.9	15.1	0.0	0.0	8.2	0.0	6.5	0.0	0.0	35.9	32.1	30.6
19	0.0	0.0	9.7	14.6	8.8	13.4	0.0	0.0	5.0	0.0	4.7	0.0	0.0	28.2	28.1	28.9
20	0.0	0.0	6.9	10.5	6.3	9.6	0.0	0.0	3.5	0.0	3.3	0.0	0.0	20.1	20.1	21.1
21	0.0	0.0	7.9	11.9	7.2	11.0	0.0	0.0	4.0	0.0	3.8	0.0	0.0	22.9	22.9	23.9
22	0.0	0.0	8.1	12.2	7.4	11.2	0.0	0.0	4.1	0.0	3.9	0.0	0.0	23.4	23.4	24.4
23	0.0	0.0	8.1	12.2	7.4	11.2	0.0	0.0	4.1	0.0	3.9	0.0	0.0	23.4	23.4	24.4
24	0.0	0.0	7.9	11.9	7.2	11.0	0.0	0.0	4.0	0.0	3.8	0.0	0.0	22.9	22.9	23.9

Sol-air Temperatures (averaged over south, west, and north faces + roof)

from file: global01.wq2											ASHRAE		yes	SAMSON		no
K(ext,m)	0.0	0.0	0.0	0.0	180.6	72.1	0.0	0.0	0.0	0.0	146.5	0.0	13.9	327.2	86.1	
K(ext)	327.2	86.1	327.2	86.1	327.2	86.1	327.2	86.1	327.2	86.1	327.2	86.1	86.1	327.2	86.1	
														Zone 5	Data Date:	20-Jul-90
Time	Vert Wall - South		Vert Wall - West		Vert Wall - North		Vert Glaz - South		Vert Glaz - West		Vert Glaz - North		Roof	Solair Temp ASHRAE		Ambient
of Day	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum		Room	Plenum	Temp
[hr]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]
1	0.0	0.0	0.0	0.0	12.5	18.9	0.0	0.0	0.0	0.0	10.1	0.0	3.5	22.5	22.4	23.6
2	0.0	0.0	0.0	0.0	12.6	19.2	0.0	0.0	0.0	0.0	10.2	0.0	3.5	22.8	22.7	23.9
3	0.0	0.0	0.0	0.0	12.3	18.7	0.0	0.0	0.0	0.0	9.9	0.0	3.4	22.2	22.1	23.3
4	0.0	0.0	0.0	0.0	11.7	17.8	0.0	0.0	0.0	0.0	9.4	0.0	3.3	21.1	21.0	22.2
5	0.0	0.0	0.0	0.0	11.7	17.8	0.0	0.0	0.0	0.0	9.5	0.0	3.3	21.2	21.1	22.2
6	0.0	0.0	0.0	0.0	12.8	19.5	0.0	0.0	0.0	0.0	11.0	0.0	3.6	23.8	23.1	23.9
7	0.0	0.0	0.0	0.0	13.9	21.2	0.0	0.0	0.0	0.0	12.5	0.0	4.3	26.5	25.4	25.6
8	0.0	0.0	0.0	0.0	15.6	23.6	0.0	0.0	0.0	0.0	14.4	0.0	5.0	29.9	28.7	28.3
9	0.0	0.0	0.0	0.0	16.5	25.0	0.0	0.0	0.0	0.0	15.1	0.0	5.4	31.6	30.5	30.0
10	0.0	0.0	0.0	0.0	17.6	26.8	0.0	0.0	0.0	0.0	16.7	0.0	6.2	34.4	33.0	31.7
11	0.0	0.0	0.0	0.0	18.7	28.4	0.0	0.0	0.0	0.0	19.1	0.0	7.3	37.8	35.7	32.8
12	0.0	0.0	0.0	0.0	18.7	28.4	0.0	0.0	0.0	0.0	18.3	0.0	6.9	37.0	35.3	33.3
13	0.0	0.0	0.0	0.0	18.9	28.6	0.0	0.0	0.0	0.0	17.8	0.0	6.6	36.6	35.2	33.9
14	0.0	0.0	0.0	0.0	18.4	27.9	0.0	0.0	0.0	0.0	17.7	0.0	6.5	36.1	34.4	32.8
15	0.0	0.0	0.0	0.0	18.1	27.5	0.0	0.0	0.0	0.0	15.6	0.0	5.5	33.7	33.0	33.3
16	0.0	0.0	0.0	0.0	17.7	26.9	0.0	0.0	0.0	0.0	16.0	0.0	5.3	33.7	32.2	32.2
17	0.0	0.0	0.0	0.0	17.2	26.1	0.0	0.0	0.0	0.0	15.8	0.0	4.9	33.0	31.0	31.1
18	0.0	0.0	0.0	0.0	17.3	26.3	0.0	0.0	0.0	0.0	17.6	0.0	4.8	34.9	31.1	30.6
19	0.0	0.0	0.0	0.0	15.5	23.5	0.0	0.0	0.0	0.0	12.8	0.0	4.4	28.2	27.8	28.9
20	0.0	0.0	0.0	0.0	11.1	16.8	0.0	0.0	0.0	0.0	8.9	0.0	3.1	20.0	19.9	21.1
21	0.0	0.0	0.0	0.0	12.6	19.2	0.0	0.0	0.0	0.0	10.2	0.0	3.5	22.8	22.7	23.9
22	0.0	0.0	0.0	0.0	12.9	19.6	0.0	0.0	0.0	0.0	10.4	0.0	3.6	23.3	23.2	24.4
23	0.0	0.0	0.0	0.0	12.9	19.6	0.0	0.0	0.0	0.0	10.4	0.0	3.6	23.3	23.2	24.4
24	0.0	0.0	0.0	0.0	12.6	19.2	0.0	0.0	0.0	0.0	10.2	0.0	3.5	22.8	22.7	23.9

Sol-air Temperatures (averaged over south, west, and north faces + roof)

from file: global01.wq2													ASHRAE yes	SAMSON		no
K(ext,m)	11.1	3.9	19.3	7.5	0.0	0.0	5.7	0.0	14.3	0.0	0.0	0.0	0.0	50.4	11.4	
K(ext)	50.4	11.4	50.4	11.4	50.4	11.4	50.4	11.4	50.4	11.4	50.4	11.4	11.4	50.4	11.4	
														Zone 6	Data Date:	20-Jul-90
Time	Vert Wall - South		Vert Wall - West		Vert Wall - North		Vert Glaz - South		Vert Glaz - West		Vert Glaz - North		Roof	Solair Temp ASHRAE		Ambient
of Day	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum		Room	Plenum	Temp
[hr]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]	[C]
1	5.0	7.8	8.6	14.8	0.0	0.0	2.5	0.0	6.4	0.0	0.0	0.0	0.0	22.6	22.6	23.6
2	5.1	7.9	8.8	15.0	0.0	0.0	2.6	0.0	6.5	0.0	0.0	0.0	0.0	22.9	22.9	23.9
3	4.9	7.7	8.5	14.6	0.0	0.0	2.5	0.0	6.3	0.0	0.0	0.0	0.0	22.3	22.3	23.3
4	4.7	7.3	8.1	13.9	0.0	0.0	2.4	0.0	6.0	0.0	0.0	0.0	0.0	21.2	21.2	22.2
5	4.7	7.3	8.1	13.9	0.0	0.0	2.4	0.0	6.0	0.0	0.0	0.0	0.0	21.2	21.2	22.2
6	5.1	8.0	8.8	15.1	0.0	0.0	2.7	0.0	6.7	0.0	0.0	0.0	0.0	23.3	23.1	23.9
7	5.7	8.9	9.6	16.5	0.0	0.0	3.6	0.0	7.8	0.0	0.0	0.0	0.0	26.7	25.4	25.6
8	6.7	10.4	10.8	18.4	0.0	0.0	4.9	0.0	9.0	0.0	0.0	0.0	0.0	31.3	28.9	28.3
9	7.2	11.3	11.4	19.5	0.0	0.0	5.5	0.0	9.5	0.0	0.0	0.0	0.0	33.6	30.8	30.0
10	8.0	12.5	12.2	20.9	0.0	0.0	6.9	0.0	10.6	0.0	0.0	0.0	0.0	37.7	33.4	31.7
11	9.0	14.1	13.0	22.2	0.0	0.0	9.2	0.0	12.2	0.0	0.0	0.0	0.0	43.4	36.3	32.8
12	8.6	13.4	13.1	22.5	0.0	0.0	7.7	0.0	12.2	0.0	0.0	0.0	0.0	41.6	35.9	33.3
13	8.3	12.9	14.1	24.1	0.0	0.0	6.5	0.0	15.3	0.0	0.0	0.0	0.0	44.1	37.0	33.9
14	7.9	12.3	14.8	25.4	0.0	0.0	5.9	0.0	19.6	0.0	0.0	0.0	0.0	48.3	37.7	32.8
15	7.3	11.4	13.5	23.2	0.0	0.0	4.1	0.0	13.9	0.0	0.0	0.0	0.0	38.8	34.6	33.3
16	7.0	10.9	13.3	22.8	0.0	0.0	3.8	0.0	14.2	0.0	0.0	0.0	0.0	38.3	33.7	32.2
17	6.7	10.5	12.5	21.3	0.0	0.0	3.6	0.0	12.3	0.0	0.0	0.0	0.0	35.0	31.8	31.1
18	6.6	10.3	12.5	21.5	0.0	0.0	3.5	0.0	13.3	0.0	0.0	0.0	0.0	35.9	31.8	30.6
19	6.2	9.6	10.7	18.4	0.0	0.0	3.2	0.0	8.1	0.0	0.0	0.0	0.0	28.2	28.0	28.9
20	4.4	6.9	7.7	13.2	0.0	0.0	2.3	0.0	5.7	0.0	0.0	0.0	0.0	20.1	20.1	21.1
21	5.1	7.9	8.8	15.0	0.0	0.0	2.6	0.0	6.5	0.0	0.0	0.0	0.0	22.9	22.9	23.9
22	5.2	8.1	8.9	15.3	0.0	0.0	2.6	0.0	6.6	0.0	0.0	0.0	0.0	23.4	23.4	24.4
23	5.2	8.1	8.9	15.3	0.0	0.0	2.6	0.0	6.6	0.0	0.0	0.0	0.0	23.4	23.4	24.4
24	5.1	7.9	8.8	15.0	0.0	0.0	2.6	0.0	6.5	0.0	0.0	0.0	0.0	22.9	22.9	23.9

Figure 221: Support Calculations - Solair Temperature, Vertical Walls

Solair Temperature Calculation, Vertical Walls

h(out):	28.3	[W/K-m2]	1993 ASHRAE F22.1, Table 1	I(r,h):	63	W/m2	
alpha:	0.63	surface absorptance	Mills, p.818	sigma:	90	deg	
epsilon:	0.90	emittance	Mills, p.818	C:	0.136	Table 7 F27.9	
rho(g):	0.14	ground reflectance	1993 ASHRAE F27.27, Table 19	Y:	0.45	ASHRAE F27.28	

Solair Temperatures, South Vertical Wall

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
hour of day	solar altitude beta	incident angle south	global horz radiation	direct normal radiation	diffuse radiation	total solar heat gain components					net solar radiation		ambient air temp	sol-air temperature	
							E(ds)		E(dg)						
						E(D)	ASHRAE	SAMSON	ASHRAE	SAMSON	ASHRAE	SAMSON		ASHRAE	SAMSON
[hr]	[deg]	[deg]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[C]	[C]	[C]
1	-27	144	0	0	0	0	0	0	0	0	0	0	23.6	22.6	22.6
2	-23	134	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9
3	-17	124	0	0	0	0	0	0	0	0	0	0	23.3	22.3	22.3
4	-9	114	0	0	0	0	0	0	0	0	0	0	22.2	21.2	21.2
5	-0	103	11	4	11	0	0	6	0	1	0	6	22.2	21.2	21.3
6	10	94	69	89	53	0	6	27	2	8	8	35	23.9	23.1	23.7
7	21	85	228	279	127	25	22	64	10	27	57	116	25.6	25.9	27.2
8	32	77	392	372	195	83	34	98	17	50	134	231	28.3	30.3	32.4
9	43	71	521	340	289	109	33	145	19	84	162	338	30.0	32.6	36.5
10	54	68	647	456	280	174	47	140	30	89	251	403	31.7	36.3	39.7
11	63	66	819	711	187	284	75	94	51	64	409	441	32.8	40.9	41.6
12	68	68	843	543	340	202	56	170	40	123	298	495	33.3	38.9	43.3
13	67	72	718	427	325	129	41	163	32	124	202	416	33.9	37.4	42.2
14	60	79	742	489	318	95	43	159	34	127	172	381	32.8	35.6	40.3
15	50	87	412	168	282	9	13	141	11	114	33	264	33.3	33.0	38.2
16	39	96	321	165	216	0	11	108	9	84	20	192	32.2	31.7	35.5
17	28	106	253	108	201	0	7	101	5	69	11	170	31.1	30.3	33.9
18	17	116	154	140	112	0	8	56	4	30	12	86	30.6	29.9	31.5
19	7	127	42	8	41	0	0	21	0	7	1	27	28.9	27.9	28.5
20	-3	137	0	0	0	0	0	0	0	0	0	0	21.1	20.1	20.1
21	-12	146	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9
22	-20	152	0	0	0	0	0	0	0	0	0	0	24.4	23.4	23.4
23	-25	155	0	0	0	0	0	0	0	0	0	0	24.4	23.4	23.4
24	-27	151	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9

Solair Temperature Calculation, Vertical Walls

h(out):	28.3	[W/K-m2]	1993 ASHRAE F22.1, Table 1
alpha:	0.63	surface absorptance	Mills, p.818
epsilon:	0.90	emittance	Mills, p.818
rho(g):	0.14	ground reflectance	1993 ASHRAE F27.27, Table 19

I(r,h):	63	W/m2
sigma:	90	deg
C:	0.136	Table 7 F27.9
Y:	0.45	ASHRAE F27.28

Solair Temperatures, West Vertical Wall

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
hour of day	solar altitude beta	incident angle west	global horz radiation	direct normal radiation	diffuse radiation	total solar heat gain components					net solar radiation		ambient air temp	sol-air temperature	
							E(ds)		E(dg)						
						E(D)	ASHRAE	SAMSON	ASHRAE	SAMSON	ASHRAE	SAMSON		ASHRAE	SAMSON
[hr]	[deg]	[deg]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[C]	[C]	[C]
1	-27	113	0	0	0	0	0	0	0	0	0	0	23.6	22.6	22.6
2	-23	127	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9
3	-17	141	0	0	0	0	0	0	0	0	0	0	23.3	22.3	22.3
4	-9	154	0	0	0	0	0	0	0	0	0	0	22.2	21.2	21.2
5	-0	167	11	4	11	0	0	6	0	1	0	6	22.2	21.2	21.3
6	10	169	69	89	53	0	5	27	2	10	7	37	23.9	23.1	23.7
7	21	158	228	279	127	0	16	64	10	39	25	102	25.6	25.2	26.9
8	32	145	392	372	195	0	20	98	17	83	38	180	28.3	28.1	31.3
9	43	131	521	340	289	0	18	145	19	153	38	297	30.0	29.8	35.6
10	54	117	647	456	280	0	26	140	30	163	56	303	31.7	31.9	37.4
11	63	103	819	711	187	0	45	94	51	106	96	199	32.8	33.9	36.2
12	68	89	843	543	340	8	41	170	40	167	89	345	33.3	34.3	40.0
13	67	76	718	427	325	106	39	163	32	130	177	399	33.9	36.8	41.8
14	60	63	742	489	318	225	54	159	34	100	314	485	32.8	38.8	42.6
15	50	50	412	168	282	107	22	141	11	69	140	317	33.3	35.4	39.3
16	39	40	321	165	216	126	24	108	9	40	159	274	32.2	34.7	37.3
17	28	33	253	108	201	90	17	101	5	28	112	219	31.1	32.6	35.0
18	17	32	154	140	112	119	22	56	4	11	145	186	30.6	32.8	33.7
19	7	37	42	8	41	6	1	21	0	2	8	29	28.9	28.1	28.6
20	-3	47	0	0	0	0	0	0	0	0	0	0	21.1	20.1	20.1
21	-12	59	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9
22	-20	71	0	0	0	0	0	0	0	0	0	0	24.4	23.4	23.4
23	-25	85	0	0	0	0	0	0	0	0	0	0	24.4	23.4	23.4
24	-27	99	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9

Solair Temperature Calculation, Vertical Walls

h(out):	28.3	[W/K-m2]	1993 ASHRAE F22.1, Table 1
alpha:	0.63	surface absorptance	Mills, p.818
epsilon:	0.90	emittance	Mills, p.818
rho(g):	0.14	ground reflectance	1993 ASHRAE F27.27, Table 19

I(r,h):	63	W/m2
sigma:	90	deg
C:	0.136	Table 7 F27.9
Y:	0.45	ASHRAE F27.28

Solair Temperatures, North Vertical Wall

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
hour of day	solar altitude beta	incident angle north	global horz radiation	direct normal radiation	diffuse radiation	total solar heat gain components					net solar radiation		ambient air temp	sol-air temperature	
							E(ds)		E(dg)						
						E(D)	ASHRAE	SAMSON	ASHRAE	SAMSON	ASHRAE	SAMSON		ASHRAE	SAMSON
[hr]	[deg]	[deg]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[C]	[C]	[C]
1	-27	36	0	0	0	0	0	0	0	0	0	0	23.6	22.6	22.6
2	-23	46	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9
3	-17	56	0	0	0	0	0	0	0	0	0	0	23.3	22.3	22.3
4	-9	66	0	0	0	0	0	0	0	0	0	0	22.2	21.2	21.2
5	-0	77	11	4	11	1	0	6	0	1	1	7	22.2	21.2	21.4
6	10	86	69	89	53	6	7	27	2	7	15	40	23.9	23.2	23.8
7	21	95	228	279	127	0	19	64	10	31	29	95	25.6	25.2	26.7
8	32	103	392	372	195	0	24	98	17	71	41	169	28.3	28.2	31.1
9	43	109	521	340	289	0	20	145	19	138	40	282	30.0	29.9	35.3
10	54	112	647	456	280	0	27	140	30	158	57	298	31.7	32.0	37.3
11	63	114	819	711	187	0	41	94	51	116	92	209	32.8	33.8	36.5
12	68	112	843	543	340	0	32	170	40	216	72	386	33.3	33.9	40.9
13	67	108	718	427	325	0	26	163	32	198	58	360	33.9	34.2	40.9
14	60	101	742	489	318	0	32	159	34	172	66	331	32.8	33.3	39.2
15	50	93	412	168	282	0	12	141	11	125	23	266	33.3	32.8	38.2
16	39	84	321	165	216	17	13	108	9	72	39	197	32.2	32.1	35.6
17	28	74	253	108	201	29	10	101	5	46	44	176	31.1	31.1	34.0
18	17	64	154	140	112	62	15	56	4	16	81	133	30.6	31.4	32.6
19	7	53	42	8	41	5	1	21	0	3	6	28	28.9	28.0	28.5
20	-3	43	0	0	0	0	0	0	0	0	0	0	21.1	20.1	20.1
21	-12	34	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9
22	-20	28	0	0	0	0	0	0	0	0	0	0	24.4	23.4	23.4
23	-25	25	0	0	0	0	0	0	0	0	0	0	24.4	23.4	23.4
24	-27	29	0	0	0	0	0	0	0	0	0	0	23.9	22.9	22.9

Figure 222: Support Calculations - Solair Temperature, Glazing

Solair Temperature Calculation, Glazing

h(out):	23.90	[W/K-m2]	I(r,h):	63	W/m2	
alpha:	0.15	surface absorptance	sigma:	90	deg	
epsilon:	0.85	emissivity	C:	0.136	Table 7 F27.9	
rho(g):	0.14	ground reflectance	Y:	0.45	ASHRAE F27.28	
SHGC(m):	0.23	1993 F27.19, Ex-8	U:	1.95	rescap03.wq2	

Solair Temperature, South Glazing

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
hour of day	solar altitude beta	incident angle south	global horz radiation	direct normal radiation	diffuse radiation	total solar heat gain components					net solar radiation		ambient air temp	sol-air temperature	
						E(D)	E(ds) ASHRAE	E(ds) SAMSON	E(dg) ASHRAE	E(dg) SAMSON	ASHRAE	SAMSON		ASHRAE	SAMSON
[hr]	[deg]	[deg]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[C]	[C]	[C]
1	-27	144	0	0	0	0	0	0	0	0	0	0	23.6	22.5	22.5
2	-23	134	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8
3	-17	124	0	0	0	0	0	0	0	0	0	0	23.3	22.2	22.2
4	-9	114	0	0	0	0	0	0	0	0	0	0	22.2	21.1	21.1
5	-0	103	11	4	11	0	0	6	0	1	0	6	22.2	21.1	21.8
6	10	94	69	89	53	0	6	27	2	8	8	35	23.9	23.8	26.9
7	21	85	228	279	127	25	22	64	10	27	57	116	25.6	31.3	38.4
8	32	77	392	372	195	83	34	98	17	50	134	231	28.3	43.2	54.8
9	43	71	521	340	289	109	33	145	19	84	162	338	30.0	48.3	69.4
10	54	68	647	456	280	174	47	140	30	89	251	403	31.7	60.7	78.8
11	63	66	819	711	187	284	75	94	51	64	409	441	32.8	80.7	84.5
12	68	68	843	543	340	202	56	170	40	123	298	495	33.3	67.9	91.5
13	67	72	718	427	325	129	41	163	32	124	202	416	33.9	56.9	82.6
14	60	79	742	489	318	95	43	159	34	127	172	381	32.8	52.3	77.3
15	50	87	412	168	282	9	13	141	11	114	33	264	33.3	36.1	63.9
16	39	96	321	165	216	0	11	108	9	84	20	192	32.2	33.5	54.1
17	28	106	253	108	201	0	7	101	5	69	11	170	31.1	31.3	50.3
18	17	116	154	140	112	0	8	56	4	30	12	86	30.6	30.9	39.8
19	7	127	42	8	41	0	0	21	0	7	1	27	28.9	27.8	31.0
20	-3	137	0	0	0	0	0	0	0	0	0	0	21.1	20.0	20.0
21	-12	146	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8
22	-20	152	0	0	0	0	0	0	0	0	0	0	24.4	23.3	23.3
23	-25	155	0	0	0	0	0	0	0	0	0	0	24.4	23.3	23.3
24	-27	151	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8

file: sa3_glaz.wq2

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Solair Temperature Calculation, Glazing

h(out):	23.90	[W/K-m2]	I(r,h):	63	W/m2
alpha:	0.15	surface absorptance	sigma:	90	deg
epsilon:	0.85	emissivity	C:	0.136	Table 7 F27.9
rho(g):	0.14	ground reflectance	Y:	0.45	ASHRAE F27.28
SHGC(m):	0.23	1993 F27.19, Ex-8	U:	1.95	rescap03.wq2

Solair Temperature, West Glazing

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
hour	solar	incident	global	direct		total solar heat gain components					net solar radiation		ambient	sol-air temperature	
of	altitude	angle	horz	normal	diffuse		E(ds)		E(dg)				air		
day	beta	west	radiation	radiation	radiation	E(D)	ASHRAE	SAMSON	ASHRAE	SAMSON	ASHRAE	SAMSON	temp	ASHRAE	SAMSON
[hr]	[deg]	[deg]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[C]	[C]	[C]
1	-27	113	0	0	0	0	0	0	0	0	0	0	23.6	22.5	22.5
2	-23	127	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8
3	-17	141	0	0	0	0	0	0	0	0	0	0	23.3	22.2	22.2
4	-9	154	0	0	0	0	0	0	0	0	0	0	22.2	21.1	21.1
5	-0	167	11	4	11	0	0	6	0	1	0	6	22.2	21.1	21.8
6	10	169	69	89	53	0	5	27	2	10	7	37	23.9	23.6	27.2
7	21	158	228	279	127	0	16	64	10	39	25	102	25.6	27.5	36.7
8	32	145	392	372	195	0	20	98	17	83	38	180	28.3	31.7	48.8
9	43	131	521	340	289	0	18	145	19	153	38	297	30.0	33.4	64.5
10	54	117	647	456	280	0	26	140	30	163	56	303	31.7	37.3	66.9
11	63	103	819	711	187	0	45	94	51	106	96	199	32.8	43.2	55.5
12	68	89	843	543	340	8	41	170	40	167	89	345	33.3	42.9	73.5
13	67	76	718	427	325	106	39	163	32	130	177	399	33.9	54.0	80.6
14	60	63	742	489	318	225	54	159	34	100	314	485	32.8	69.3	89.7
15	50	50	412	168	282	107	22	141	11	69	140	317	33.3	48.9	70.1
16	39	40	321	165	216	126	24	108	9	40	159	274	32.2	50.1	63.9
17	28	33	253	108	201	90	17	101	5	28	112	219	31.1	43.4	56.2
18	17	32	154	140	112	119	22	56	4	11	145	186	30.6	46.8	51.7
19	7	37	42	8	41	6	1	21	0	2	8	29	28.9	28.7	31.3
20	-3	47	0	0	0	0	0	0	0	0	0	0	21.1	20.0	20.0
21	-12	59	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8
22	-20	71	0	0	0	0	0	0	0	0	0	0	24.4	23.3	23.3
23	-25	85	0	0	0	0	0	0	0	0	0	0	24.4	23.3	23.3
24	-27	99	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8

Solair Temperature Calculation, Glazing

h(out):	23.90	[W/K-m2]	I(r,h):	63	W/m2
alpha:	0.15	surface absorptance	sigma:	90	deg
epsilon:	0.85	emissivity	C:	0.136	Table 7 F27.9
rho(g):	0.14	ground reflectance	Y:	0.45	ASHRAE F27.28
SHGC(m):	0.23	1993 F27.19, Ex-8	U:	1.95	rescap03.wq2

Solair Temperature, North Glazing

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
hour	solar	incident	global	direct		total solar heat gain components					net solar radiation		ambient	sol-air temperature	
of	altitude	angle	horz	normal	diffuse		E(ds)		E(dg)				air		
day	beta	north	radiation	radiation	radiation	E(D)	ASHRAE	SAMSON	ASHRAE	SAMSON	ASHRAE	SAMSON	temp	ASHRAE	SAMSON
[hr]	[deg]	[deg]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[C]	[C]	[C]
1	-27	36	0	0	0	0	0	0	0	0	0	0	23.6	22.5	22.5
2	-23	46	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8
3	-17	56	0	0	0	0	0	0	0	0	0	0	23.3	22.2	22.2
4	-9	66	0	0	0	0	0	0	0	0	0	0	22.2	21.1	21.1
5	-0	77	11	4	11	1	0	6	0	1	1	7	22.2	21.2	21.9
6	10	86	69	89	53	6	7	27	2	7	15	40	23.9	24.5	27.5
7	21	95	228	279	127	0	19	64	10	31	29	95	25.6	28.0	35.8
8	32	103	392	372	195	0	24	98	17	71	41	169	28.3	32.1	47.4
9	43	109	521	340	289	0	20	145	19	138	40	282	30.0	33.7	62.7
10	54	112	647	456	280	0	27	140	30	158	57	298	31.7	37.4	66.3
11	63	114	819	711	187	0	41	94	51	116	92	209	32.8	42.7	56.8
12	68	112	843	543	340	0	32	170	40	216	72	386	33.3	40.8	78.4
13	67	108	718	427	325	0	26	163	32	198	58	360	33.9	39.7	75.9
14	60	101	742	489	318	0	32	159	34	172	66	331	32.8	39.6	71.3
15	50	93	412	168	282	0	12	141	11	125	23	266	33.3	34.9	64.0
16	39	84	321	165	216	17	13	108	9	72	39	197	32.2	35.8	54.6
17	28	74	253	108	201	29	10	101	5	46	44	176	31.1	35.3	51.0
18	17	64	154	140	112	62	15	56	4	16	81	133	30.6	39.2	45.4
19	7	53	42	8	41	5	1	21	0	3	6	28	28.9	28.5	31.2
20	-3	43	0	0	0	0	0	0	0	0	0	0	21.1	20.0	20.0
21	-12	34	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8
22	-20	28	0	0	0	0	0	0	0	0	0	0	24.4	23.3	23.3
23	-25	25	0	0	0	0	0	0	0	0	0	0	24.4	23.3	23.3
24	-27	29	0	0	0	0	0	0	0	0	0	0	23.9	22.8	22.8

Figure 223: Support Calculations - Solair Temperature, Roof

Solair Temperature Calculation, Roof

h(out):	28	[W/K-m2]	I(r,h):	63	W/m2
alpha:	0.55	surface absorptance	sigma:	0	deg
epsilon:	0.9	emissivity	C:	0.136	Table 7 F27.9
rho(g):	0.14	ground reflectance	Y:	0.45	ASHRAE F27.28

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
hour of day	solar altitude beta	incident angle horizontal	global horz radiation	direct normal radiation	diffuse radiation	total solar heat gain components					net solar radiation		ambient air temp	sol-air temperature	
							E(ds)		E(dg)						
						E(D)	ASHRAE	SAMSON	ASHRAE	SAMSON	ASHRAE	SAMSON		ASHRAE	SAMSON
[hr]	[deg]	[deg]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[C]	[C]	[C]
1	-27	117	0	0	0	0	0	0	0	0	0	0	23.6	21.6	21.6
2	-23	113	0	0	0	0	0	0	0	0	0	0	23.9	21.9	21.9
3	-17	107	0	0	0	0	0	0	0	0	0	0	23.3	21.3	21.3
4	-9	99	0	0	0	0	0	0	0	0	0	0	22.2	20.2	20.2
5	-0	90	11	4	11	0	1	11	0	0	1	11	22.2	20.2	20.4
6	10	80	69	89	53	16	12	53	0	0	28	69	23.9	22.4	23.2
7	21	69	228	279	127	99	38	127	0	0	137	226	25.6	26.3	28.0
8	32	58	392	372	195	197	51	195	0	0	247	392	28.3	31.1	34.0
9	43	47	521	340	289	232	46	289	0	0	278	521	30.0	33.4	38.2
10	54	36	647	456	280	367	62	280	0	0	429	647	31.7	38.1	42.4
11	63	27	819	711	187	632	97	187	0	0	729	819	32.8	45.1	46.9
12	68	22	843	543	340	504	74	340	0	0	578	844	33.3	42.6	47.9
13	67	23	718	427	325	393	58	325	0	0	451	718	33.9	40.7	46.0
14	60	30	742	489	318	424	67	318	0	0	490	742	32.8	40.4	45.3
15	50	40	412	168	282	129	23	282	0	0	152	411	33.3	34.3	39.4
16	39	51	321	165	216	105	22	216	0	0	127	321	32.2	32.7	36.5
17	28	62	253	108	201	51	15	201	0	0	66	252	31.1	30.4	34.0
18	17	73	154	140	112	42	19	112	0	0	61	154	30.6	29.8	31.6
19	7	83	42	8	41	1	1	41	0	0	2	42	28.9	26.9	27.7
20	-3	93	0	0	0	0	0	0	0	0	0	0	21.1	19.1	19.1
21	-12	102	0	0	0	0	0	0	0	0	0	0	23.9	21.9	21.9
22	-20	110	0	0	0	0	0	0	0	0	0	0	24.4	22.4	22.4
23	-25	115	0	0	0	0	0	0	0	0	0	0	24.4	22.4	22.4
24	-27	117	0	0	0	0	0	0	0	0	0	0	23.9	21.9	21.9

Figure 224: Support Calculations - Local Sun Angles & Normals to Building Surfaces

Solar Altitude - Solar Azimuth - Solar Component Normal to Bldg Surface

Location:	Boston		Data Date:	20-Jul-90		
Local Latitude:	42	N				
Local Longitude:	71	W	Local Standard Meri	67.5	W	Eastern Standard Time
Solar Declination-Jul	20.6	deg	Equation of Time:	-6.2	mins	
Bldg Surface Azimut	-15	deg	75 deg	165	deg	

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
Time	Hour Angle	Apparent Solar Time	sin(beta)	beta	cos(Phi)	absolute value PHI	solar azimuth value PHI	incident angle horz	cos(IA) vert South	incident angle vert South	cos(IA) vert West	incident angle vert West	cos(IA) vert North	incident angle vert North
[hr]	[deg]			[deg]		[deg]	[deg]	[deg]		[deg]		[deg]		[deg]
1	170	0.7	-0.45	-27	-0.98	170	-170	117	-0.81	144	-0.38	113	0.81	36
2	155	1.7	-0.40	-23	-0.90	155	-155	113	-0.70	134	-0.60	127	0.70	46
3	140	2.7	-0.30	-17	-0.78	141	-141	107	-0.56	124	-0.77	141	0.56	56
4	125	3.7	-0.16	-9	-0.63	129	-129	99	-0.40	114	-0.90	154	0.40	66
5	110	4.7	-0.00	-0	-0.48	118	-118	90	-0.23	103	-0.97	167	0.23	77
6	95	5.7	0.17	10	-0.32	109	-109	80	-0.06	94	-0.98	169	0.06	86
7	80	6.7	0.36	21	-0.16	99	-99	69	0.09	85	-0.93	158	-0.09	95
8	65	7.7	0.53	32	0.00	90	-90	58	0.22	77	-0.82	145	-0.22	103
9	50	8.7	0.68	43	0.19	79	-79	47	0.32	71	-0.66	131	-0.32	109
10	35	9.7	0.80	54	0.42	65	-65	36	0.38	68	-0.45	117	-0.38	112
11	20	10.7	0.89	63	0.71	44	-44	27	0.40	66	-0.23	103	-0.40	114
12	5	11.7	0.93	68	0.98	13	-13	22	0.37	68	0.01	89	-0.37	112
13	-10	12.7	0.92	67	0.91	24	24	23	0.30	72	0.25	76	-0.30	108
14	-25	13.7	0.87	60	0.61	52	52	30	0.19	79	0.46	63	-0.19	101
15	-40	14.7	0.77	50	0.34	70	70	40	0.06	87	0.64	50	-0.06	93
16	-55	15.7	0.63	39	0.13	83	83	51	-0.10	96	0.77	40	0.10	84
17	-70	16.7	0.47	28	-0.05	93	93	62	-0.27	106	0.84	33	0.27	74
18	-85	17.7	0.30	17	-0.22	102	102	73	-0.44	116	0.85	32	0.44	64
19	-100	18.7	0.12	7	-0.37	112	112	83	-0.60	127	0.79	37	0.60	53
20	-115	19.7	-0.06	-3	-0.53	122	122	93	-0.73	137	0.68	47	0.73	43
21	-130	20.7	-0.21	-12	-0.68	133	133	102	-0.83	146	0.52	59	0.83	34
22	-145	21.7	-0.33	-20	-0.82	145	145	110	-0.89	152	0.32	71	0.89	28
23	-160	22.7	-0.42	-25	-0.94	159	159	115	-0.90	155	0.09	85	0.90	25
24	-175	23.7	-0.46	-27	-1.00	175	175	117	-0.88	151	-0.15	99	0.88	29

file: sa5_suna.wq2

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Solar Radiation and Temperature Data

Data Date: 20-Jul-90
Location: Blue Hill Observatory, Canton, Massachusetts

Data Time	SAMSON Data Field					
	1 Extra Horz	2 Extra Direct	3 Global Horz	4 Direct Normal	5 Diffuse Horz	8 Ambient Temp
[hr]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[C]
1	0	0	0	0	0	23.6
2	0	0	0	0	0	23.9
3	0	0	0	0	0	23.3
4	0	0	0	0	0	22.2
5	62	683	11	4	11	22.2
6	238	1323	69	89	53	23.9
7	475	1323	228	279	127	25.6
8	702	1323	392	372	195	28.3
9	903	1323	521	340	289	30.0
10	1064	1323	647	456	280	31.7
11	1175	1323	819	711	187	32.8
12	1227	1323	843	543	340	33.3
13	1217	1323	718	427	325	33.9
14	1146	1323	742	489	318	32.8
15	1018	1323	412	168	282	33.3
16	842	1323	321	165	216	32.2
17	631	1323	253	108	201	31.1
18	399	1323	154	140	112	30.6
19	163	1323	42	8	41	28.9
20	30	265	0	0	0	21.1
21	0	0	0	0	0	23.9
22	0	0	0	0	0	24.4
23	0	0	0	0	0	24.4
24	0	0	0	0	0	23.9

file: sa6_data.wq2 01/18/96 Page 1

Figure 225: Support Calculations - Solar Radiation and Ambient Air Temperature Data

Appendix Z - HVACSIM+ Type Models

TYPE 007: TEMPERATURE SENSOR

Inputs:

1. TEMPERATURE - INPUT TEMPERATURE
2. CONTROL - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

Outputs:

1. CONTROL - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

Parameters:

1. SENSOR TIME CONSTANT (SEC)
2. TEMPERATURE OFFSET (C)
3. TEMPERATURE RANGE (C)

TYPE 087: 8-WAY PATCHBOARD

Inputs:

1. Input 1
2. Input 2
3. Input 3
4. Input 4
5. Input 5
6. Input 6
7. Input 7
8. Input 8

Outputs:

1. Output 1
2. Output 2
3. Output 3
4. Output 4
5. Output 5
6. Output 6
7. Output 7
8. Output 8

Parameters:

1. Input connected to output 1 (-)
2. Input connected to output 2 (-)
3. Input connected to output 3 (-)
4. Input connected to output 4 (-)
5. Input connected to output 5 (-)
6. Input connected to output 6 (-)
7. Input connected to output 7 (-)
8. Input connected to output 8 (-)

TYPE 102: MIXING BOX + DAMPERS

Inputs:

1. Fresh air dry bulb temperature [C]
2. Fresh air humidity ratio [kg/kg]
3. Extract air dry bulb temperature [C]
4. Extract air humidity ratio [kg/kg]
5. Fresh air intake gauge static pressure [kPa]
6. Exhaust air outlet gauge static pressure [kPa]
7. Supply air gauge static pressure [kPa]
8. Extract dry air mass flow rate [kg/s]
9. Fresh air damper position (0=closed, 1=open)
10. Return air damper position (0=open if PAR(15)=0)

11. Extract air damper position (0=closed, 1=open)

Outputs:

1. Supply air dry bulb temperature [C]
2. Supply air humidity ratio [kg/kg]
3. Supply dry air mass flow rate [kg/s]
4. Supply air specific enthalpy [kJ/kg]
5. Supply air relative humidity [%]
6. Supply humid air mass flow rate [kg/s]
7. Extract air gauge static pressure [kPa]
8. Fresh dry air mass flow rate [kg/s]
9. Return dry air mass flow rate [kg/s]
10. Exhaust dry air mass flow rate [kg/s]

Parameters:

1. Auxiliary psychometric outputs (0 = no, 1 = yes)
2. Fault: 0=no faults, 1=100% oversized, 2=20% leakage, 3=both
3. Fresh air damper: opposed (0) or parallel (1)
4. Return air damper: opposed (0) or parallel (1)
5. Exhaust air damper: opposed (0) or parallel (1)
6. Open resist. for fresh air damper (p.d. (kPa) at 1 m3/s)
7. Open resist. for return air damper (p.d. (kPa) at 1 m3/s)
8. Open resist. for exhaust air damper (p.d. (kPa) at 1 m3/s)
9. Leakage for fresh air damper (fraction of full flow)
10. Leakage for return air damper (fraction of full flow)
11. Leakage for exhaust air damper (fraction of full flow)
12. Authority of fresh air damper
13. Authority of return air damper
14. Authority of exhaust air damper
15. 0=invert return air damper, 1=not inverted

TYPE 133: PSYCHROMETRICS

Inputs:

1. Inlet air dry bulb temperature (C)
2. Inlet relative humidity (%) (used if mode=1)
3. Inlet humidity ratio (kg/kg) (used if mode=2)
4. Inlet air wet bulb temperature(C) (Mode=3)
5. Atmospheric pressure (Pa)

Outputs:

1. Air dry bulb temperature (C)
2. Relative humidity (%)
3. Air humidity ratio (kg/kg)
4. Air enthalpy (kJ/kg)
5. Dew point temperature (C)
6. Air wet bulb temperature (C)
   (If par(3)= 0, twb = 0.)

Parameters:

1. Nothing
2. Mode(1 or 2 or 3)
3. If 0:twb not included in the outputs
   1:twb included in the outputs

TYPE 134: PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLLER)

Inputs:

1. Mair : Air mass flow rate (kg/s)
2. Pout : Outlet pressure (kPa)
3. Fflowset : Demanded flowrate (norm to nom) (0-1)

Outputs:

1. Pin : Inlet pressure (kPa)
2. Damppos : Damper position (0=closed, 1=open)
3. Fsped : Fractional motor velocity (0-1)
4. Tssrev : Number of stops/starts/reversals (-)
5. Ttrav : Total distance travelled by valve/damper (-)

Parameters:

1. Volumnom : Nominal volumetric flow rate (m3/s)
2. Farea : Face area of damper(s) (m2)
3. Pdadd : Additional pressure drop at nominal flow (kPa)
4. Ttran : Travel time (0-90 deg) (s)
5. Fspedmin : Minimum fractional motor speed (-)
6. Hys : Hysteresis (-)
7. Kp : Controller gain (frac speed/frac error)

TYPE 135: REAL-TIME GRAPHS of PRESSURE, FLOW & CONTROL SIGNALS

Inputs:

1. PRESSURE - FIRST PRESSURE TO BE PLOTTED
2. PRESSURE - SECOND PRESSURE TO BE PLOTTED
3. PRESSURE - THIRD PRESSURE TO BE PLOTTED
4. PRESSURE - FOURTH PRESSURE TO BE PLOTTED
5. FLOW - FIRST FLOW TO BE PLOTTED
6. FLOW - SECOND FLOW TO BE PLOTTED
7. FLOW - THIRD FLOW TO BE PLOTTED
8. FLOW - FOURTH FLOW TO BE PLOTTED
9. CONTROL - FIRST CONTROL SIGNAL TO BE PLOTTED
10. CONTROL - SECOND CONTROL SIGNAL TO BE PLOTTED
11. CONTROL - THIRD CONTROL SIGNAL TO BE PLOTTED
12. CONTROL - FOURTH CONTROL SIGNAL TO BE PLOTTED

Outputs:

1. CONTROL - DUMMY OUTPUT (DO NOT USE CONTROL 0)

Parameters:

1. TIME INTERVAL FOR PLOTTING (S)
2. STOPPING TIME (S)
3. SCALING FACTOR FOR TIME AXIS (3600. -> HOURS) [-]
4. MAXIMUM PRESSURE (KPA)
5. MINIMUM PRESSURE (KPA)
6. MAXIMUM FLOW RATE (KG/S)
7. MINIMUM FLOW RATE (KG/S)
8. MAXIMUM CONTROL SIGNAL (-)
9. MINIMUM CONTROL SIGNAL (-)
10. NUMBER OF PRESSURES TO PLOT (-)
11. NUMBER OF FLOW RATES TO PLOT (-)
12. NUMBER OF CONTROL SIGNALS TO PLOT (-)
13. INDEX OF FIRST PRESSURE (-)
14. INDEX OF SECOND PRESSURE (-)
15. INDEX OF THIRD PRESSURE (-)
16. INDEX OF FOURTH PRESSURE (-)
17. INDEX OF FIRST FLOW RATE (-)
18. INDEX OF SECOND FLOW RATE (-)
19. INDEX OF THIRD FLOW RATE (-)
20. INDEX OF FOURTH FLOW RATE (-)
21. INDEX OF FIRST CONTROL SIGNAL (-)
22. INDEX OF SECOND CONTROL SIGNAL (-)
23. INDEX OF THIRD CONTROL SIGNAL (-)
24. INDEX OF FOURTH CONTROL SIGNAL (-)

TYPE 169: MOIST AIR DUCT, HEAT LOSS AS OUTPUT, HUMIDITY DELAYED

Inputs:

1.	FLOW:	kg/s	(Air mass flow rate)
2.	P2:	kPa	(Pressure at conduit outlet)
3.	TIN:	C	(Air inlet temperature)
4.	WIN:	kg/kg	(Air inlet humidity ratio)
5.	TEXT:	C	(External temperature)

Outputs:

1.	TOUT:	C	(Air outlet temperature)
2.	WOUT:	kg/kg	(Air outlet temperature)
3.	P1:	kPa	(Pressure at conduit inlet)
4.	QEXT:	kW	(Heat loss to exterior)

Parameters:

1.	ISHAPE:	Shape of duct (round=0, square=1)
2.	SIZE:	Size of duct - round: diameter, square: side (m)
3.	LEN:	Length of duct (m)
4.	THICK:	Wall thickness (m)
5.	IMAT:	Wall material (Al=1, Cu=2, Fe=3)
6.	RVAL:	Insulation R-value (K.m2/W)
7.	K:	Flow resistance (0.001 kg.m)
8.	H:	Height of outlet above inlet (m)

TYPE 189: FIRST ORDER VELOCITY SENSOR MODEL

Inputs:

1. Mass flow rate
2. Sensor output (modified by gain and offset)

Outputs:

1. Sensor output (modified by gain and offset)

Parameters:

1. Cross sectional area of duct (m^2)
2. Mode: 1 = air, 2 = water
3. Sensor time constant (s)
4. Velocity offset (m/s)
5. Velocity range (m/s)

TYPE 196: READ FROM UNIX SOCKET (16 REALS)

Inputs:

1. CONTROL - DUMMY (MUST NOT BE CONTROL 0!)

Outputs:

1. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 1
2. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 2
3. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 3
4. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 4
5. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 5
6. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 6
7. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 7
8. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 8
9. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 9

10. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 10
11. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 11
12. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 12
13. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 13
14. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 14
15. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 15
16. CONTROL - SIMULATION INPUT / SOCKET OUTPUT 16

Parameters:

1. SOCKET NUMBER (0-4)
2. SAMPLE TIME (INTERVAL BETWEEN TRANSFERS) [S]
3. REAL TIME SCALING FACTOR (0=NO WAIT, 0.5=DOUBLE SPEED)
4. WAIT FOR DATA (0=NO WAIT, 1=WAIT)

TYPE 197: WRITE TO UNIX SOCKET (16 REALS)

Inputs:

1. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 1
2. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 2
3. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 3
4. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 4
5. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 5
6. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 6
7. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 7
8. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 8
9. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 9
10. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 10
11. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 11
12. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 12
13. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 13
14. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 14
15. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 15
16. CONTROL - SIMULATION OUTPUT / SOCKET INPUT 16

Outputs:

1. CONTROL - DUMMY (MUST NOT BE CONTROL 0!)

Parameters:

1. SOCKET NUMBER (0-4)
2. SAMPLE TIME (INTERVAL BETWEEN TRANSFERS) [S]
3. REAL TIME SCALING FACTOR (0=NO WAIT, 0.5=DOUBLE SPEED)

TYPE 200: FAN CONTROLLER WITH TRACKING (P.Haves - LUT - 7.9.93)

Inputs:

1. CPM : control signal from static pressure sensor ("kPa")
2. CPS : static pressure set-point ("kPa")
3. CMODE : control mode (0=open loop, 1=closed loop) (-)
4. CMANS : manual output for supply fan (0-1)
5. CMANR : manual output for return fan (0-1)

Outputs:

1. RSUP : supply fan rotation speed (rev/s)
2. REXT : extract fan rotation speed (rev/s)

Parameters:

1. PROPG : proportional gain (kPa.s/rev)

2. TINT : integral time (s)
3. TSAMP : sample time (s)
4. RMAX : maximum rotation speed (rev/s)
5. TTRAN : time from zero to full speed (s)
6. ACOEFF : A coeff in CEXT = ACOEFF + BCOEFF*CSUP
7. BCOEFF : A coeff in CEXT = ACOEFF + BCOEFF*CSUP
8. ICONT : controller number

TYPE 201: FAN or PUMP MODEL

Inputs:

1. mass flow rate of fluid
2. outlet pressure
3. Fan or pump rotational speed
4. inlet fluid temperature

Outputs:

1. Inlet pressure
2. Outlet fluid temperature
3. Power consumption

Parameters:

1. 1st Pressure coefficient
2. 2nd Pressure coefficient
3. 3rd Pressure coefficient
4. 4th Pressure coefficient
5. 5th Pressure coefficient
6. 1st Efficiency coefficient
7. 2nd Efficiency coefficient
8. 3rd Efficiency coefficient
9. 4th Efficiency coefficient
10. 5th Efficiency coefficient
11. Fan wheel diameter [m]
12. Mode: 1 = air, 2 = water
13. Lowest valid normalized flow
14. Highest valid normalized flow

TYPE 203: FIRST ORDER STATIC PRESSURE SENSOR MODEL

Inputs:

1. Input total pressure
2. Mass flow rate
3. Sensor output (modified by gain & offset)

Outputs:

1. Sensor output (modified by gain & offset)

Parameters:

1. Sensor time constant
2. Pressure offset
3. Pressure Range
4. Cross sectional area [m^2]
5. Mode: 1 = air, 2 = water

TYPE 204: FLOW MERGE MODEL

Inputs:

1. Inlet mass flow rate 1
2. Inlet mass flow rate 2
3. Outlet pressure

Outputs:

1. Outlet mass flow rate
2. Inlet pressure 1
3. Inlet pressure 2

Parameters:

1. Inlet flow resistance 1 [0.001/(kg - m)]
2. Inlet flow resistance 2 [0.001/(kg - m)]
3. Outlet flow resistance [0.001/(kg - m)]

TYPE 205: FAN OR PUMP MODEL - POWER & TEMPERATURE RISE ONLY

Inputs:

1. Inlet mass flow rate 1
2. Inlet mass flow rate 2
3. Outlet pressure

Outputs:

1. Outlet mass flow rate
2. Inlet pressure 1
3. Inlet pressure 2

Parameters:

1. Inlet flow resistance 1 [0.001/(kg - m)]
2. Inlet flow resistance 2 [0.001/(kg - m)]
3. Outlet flow resistance [0.001/(kg - m)]

TYPE 207: FLOW SPLIT MODEL - DIFFERENT RESISTANCES, TREATS NEAR-ZERO FLOW (Ph Haves - LUT - 4/8/93)

Inputs:

1. Inlet mass flow rate
2. Outlet pressure 1
3. Outlet pressure 2

Outputs:

1. Outlet mass flow rate 1
2. Outlet mass flow rate 2
3. Inlet pressure

Parameters:

1. Inlet flow resistance [0.001/(kg - m)]
2. Outlet flow resistance 1 [0.001/(kg - m)]
3. Outlet flow resistance 2 [0.001/(kg - m)]

TYPE 210: MIXING OF THREE AIR FLOWS WITH LEAKAGE

Inputs:

1. Inlet mass flow rate (positive in) - stream 1
2. Inlet mass flow rate (positive in) - stream 2
3. Inlet mass flow rate (positive out) - stream 3
4. Room pressure
5. Ambient pressure

Outputs:

1. Outlet dry air mass flow rate
2. dry air mass flow rate lost

Parameters:

1. leakage resistance [0.001/(kg - m)]
2. Local extract fan mass flow rate [kg/s]

TYPE 211: SIMULATES THE MIXING OF TWO AIR FLOWS

Inputs:

1. Inlet air dry bulb temperature - stream 1
2. Inlet air humidity ratio - stream 1
3. inlet dry air mass flow rate - stream 1
4. Inlet air dry bulb temperature - stream 2
5. Inlet air humidity ratio - stream 2
6. inlet dry air mass flow rate - stream 2

Outputs:

1. Outlet air dry bulb temperature
2. Outlet air humidity
3. outlet dry air mass flow rate

Parameters:

0. none

TYPE 212: SIMULATES THE MIXING OF FIVE AIR FLOWS

Inputs:

1. Inlet air dry bulb temperature - stream 1
2. Inlet air humidity ratio - stream 1
3. inlet dry air mass flow rate - stream 1
4. Inlet air dry bulb temperature - stream 2
5. Inlet air humidity ratio - stream 2
6. inlet dry air mass flow rate - stream 2
7. Inlet air dry bulb temperature - stream 3
8. Inlet air humidity ratio - stream 3
9. inlet dry air mass flow rate - stream 3
10. Inlet air dry bulb temperature - stream 4
11. Inlet air humidity ratio - stream 4
12. inlet dry air mass flow rate - stream 4
13. Inlet air dry bulb temperature - stream 5
14. Inlet air humidity ratio - stream 5
15. inlet dry air mass flow rate - stream 5

Outputs:

1. Outlet air dry bulb temperature
2. Outlet air humidity

3. outlet dry air mass flow rate

Parameters:

0. none

TYPE 228: CONSTANT FLOW RESISTANCE MODEL Linearised at low flow (Ph Haves - University of Oxford - August 1992) Modified 20/9/93 to use FUNCTION DPTURLAM

Inputs:

1. Fluid mass flow rate
2. Outlet pressure

Outputs:

1. Inlet pressure

Parameters:

1. Flow resistance [0.001/(kg - m)]

TYPE 229: INLET CONSTANT FLOW RESISTANCE MODEL - NEG. O/P

Inputs:

1. Inlet pressure
2. Outlet pressure

Outputs:

1. Fluid mass flow rate
2. Negative of fluid mass flow rate

Parameters:

1. Flow resistance [0.001/(kg - m)]

TYPE 272: 2 NODE ROOM/PLENUM MODEL - Rs AND Cs AS PARAMETERS, DUCTED RETURN

Inputs:

1. Supply air dry bulb temperature
2. Supply air humidity ratio
3. Supply dry air mass flow rate
4. Interzone 1 air dry bulb temperature
5. Interzone 1 air humidity ratio
6. Interzone 1 dry air mass flow rate
7. Interzone 2 air dry bulb temperature
8. Interzone 2 air humidity ratio
9. Interzone 2 dry air mass flow rate
10. Extract dry air mass flow rate
11. Equivalent "sol-air" outdoor temperature for room
12. Equivalent "sol-air" outdoor temperature for plenum
13. Ambient dry bulb temperature
14. Ambient humidity ratio
15. Fractional occupancy
16. Fractional lighting heat gain
17. Fractional equipment heat gain
18. Heat gain from supply duct

19. Heat gain from extract duct
20. Room temperature
21. Room structure temperature
22. Plenum temperature
23. Plenum structure temperature
24. Room humidity ratio
25. Plenum humidity ratio

Outputs:

1. Room temperature
2. Room structure temperature
3. Plenum temperature
4. Plenum structure temperature
5. Room humidity ratio
6. Plenum humidity ratio
7. Return temperature
8. Leakage dry air mass flow rate
9. Sensible heat gains of room
10. sensible heat gains of plenum
11. water gains of room

Parameters:

1. Room air capacity multiplier
2. Zone number (parameter file='zoneN.par', N > 0)
3. RWSR: direct resistance room air node <-> ambient (K/kW)
4. RISR: resistance room air node <-> room mass node (K/kW)
5. ROSR: resistance ambient <-> room mass node (K/kW)
6. RWSP: direct resistance plenum air node <-> ambient (K/kW)
7. RISP: resistance plenum air node <-> plenum mass node (K/kW)
8. ROSP: resistance ambient <-> plenum mass node (K/kW)
9. RR: resistance room air node <-> plenum air node (K/kW)
10. CSR: capacitance of room mass node (kJ/K)
11. CR: capacitance of room air node (unmodified) (kJ/K)
12. CSP: capacitance of plenum mass node (kJ/K)
13. CP: capacitance of plenum air node (kJ/K)
14. Volume of room (m3)
15. Volume of plenum (m3)
16. Number of occupants (-)
17. Lighting heat gain (kW)
18. Fraction of lighting heat gain to extract air
19. Equipment heat gain (kW)

TYPE 275: C-1-1 Simple Reversing Control for Mixing Dampers w/ Cooling Demand - Separate Manual Control of Each Damper

Inputs:

1. Ambient temperature sensor (C)
2. Return temperature sensor (C)
3. Cooling demand for dampers (0-1)
4. OSS: (0=outside OPT start and stop, 1=between OSS)
5. OTP: (0=non-occupied, >0=occupied)
6. Open/closed loop (0=open, 1=closed)
7. Open loop fresh air damper position (0-1)
8. Open loop recirc air damper position (0-1)
9. Open loop exhaust air damper position (0-1)

Outputs:

1. Fresh air damper demanded position (0-1)
2. Recirc air damper demanded position (0-1)
3. Exhaust air damper demanded position (0-1)

Parameters:

1. Minimum demanded damper position (0-1)
2. Reschedule time (sec)
3. Number of times entered in sequence table

4. Controller number (parameter file='contN.par', N > 0)

TYPE 276: VAV Terminal Box with Reheat

Inputs:

1. Supply air temperature sensor (C)
2. Space temperature (C)
3. OSS: (0=outside OPT start and stop, 1=between OSS)
4. OTP: (0=occupied, 1=non-occupied)
5. Fan: (1=ahu fan(s) on, 0=fan(s) off)
6. Mode: (0=auto, 1=closed, 2=min, 3=max, 4=open)

Outputs:

1. Normalised velocity setpoint (0-1)
2. Reheat coil demand (0-1)
3. Room demand (heating and cooling) (-1 - +1)

Parameters:

1. Cooling setpoint for space (C)
2. Deadband: cooling setpoint - heating setpoint (C)
3. Night set back setpoint (heating) (C)
4. Proportional gain for heating demand (%/C)
5. Integral time for heating demand (sec)
6. Proportional gain for cooling demand (%/C)
7. Integral time for cooling demand (sec)
8. Maximum velocity setpoint (m3/s)
9. Minimum velocity setpoint (m3/s)
10. Reschedule time (sec)
11. Number of times entered in sequence table
12. Controller number (parameter file='contN.par', N > 0)

TYPE 281: Generation of Supply Temp SP for VAV AHU w/ Heating

Inputs:

1. demand from 1st zone (-1 - +1)
2. demand from 2nd zone (-1 - +1)
3. demand from 3rd zone (-1 - +1)
4. demand from 4th zone (-1 - +1)
5. demand from 5th zone (-1 - +1)
6. AHU status (0=off, 1=on)

Outputs:

1. supply air temperature setpoint ("C")
2. boost mode (0=off, 1=on)

Parameters:

1. number of zones
2. maximum supply air temperature setpoint (cooling) (C)
3. minimum supply air temperature setpoint (cooling) (C)
4. boost supply air temperature setpoint (heating) (C)
5. maximum rate of change of temperature setpoint (C/s)
6. proportional gain (%/C)
7. integral time (sec)
8. reschedule time (sec)
9. number of times entered in sequence table
10. controller number (parameter file="contN.par", N > 0)

TYPE 282: Generation of AHU Plant Demands with boost over-ride on cooling coil

Inputs:

1. Supply air temperature sensor (C)
2. Supply air temperature setpoint (C)
3. Oss: (0=outside opt start and stop, 1=between oss)
4. Boost mode (0=off, 1=on)
5. Open/closed loop (0=open, 1=closed)' '-'
6. Manual heating coil demand' '-'
7. Manual cooling coil demand' '-'

Outputs:

1. Ahu heating coil demand (0-1)
2. Damper cooling demand (0-1)
3. Cooling coil demand (0-1)

Parameters:

1. Proportional gain (%/C)
2. Integral time for (sec)
3. Breakpoint between free and pay cooling demand (0-1)
4. Deadband (offset in cooling setpoint) (C)
5. Time delay for boost mode over-ride of cooling coil (s)
6. Reschedule time (sec)
7. Number of times entered in sequence table
8. Controller number (parameter file="contN.par", N > 0)

TYPE 283: Component on/off controller - uses up to six demands to switch component on and off - includes delay and hysteresis

Inputs:

1) = 1st demand (heating demand 0 - +1)
2) = 2nd demand (heating demand 0 - +1)
3) = 3rd demand (heating demand 0 - +1)
4) = 4th demand (heating demand 0 - +1)
5) = 5th demand (heating demand 0 - +1)
6) = 6th demand (heating demand 0 - +1)
7) = plant enable (0=off, 1=on)

Outputs:

1)= component status (0=off, 1=on)

Parameters:

1) = number of demands
2) = sign of demand to act on (+1=heating, -1=cooling)
3) = threshhold to switch on (upper limit of deadband) (0-1)
4) = threshhold to switch off (lower limit of deadband) (0-1)
5) = off delay (s)
6) = reschedule time (sec)
7) = number of times entered in sequence table

TYPE 299: HEATING/COOLING COIL WITH L&G 3 PORT VALVE, WATER PRESSURE I/P

Inputs:

1. TAI : inlet air dry bulb temperature (C)
2. GI : inlet air humidity ratio (kg/kg)

```
3. PO     : outlet air gauge static pressure (kPa)
4. MA     : dry air mass flow rate (kg/s)
5. TWI    : inlet water temperature (C)
6. Y1     : valve stem position (-)
7. PWI    : inlet water pressure (kPa)
8. PWO    : outlet water pressure (kPa)
9. TSDYN  : effective coil surface temperature (C)
```

Outputs:

```
 1. TS     : effective coil surface temperature (C)
 2. TAO    : outlet air dry bulb temperature (C)
 3. GO     : outlet air humidity ratio (kg/kg)
 4. PI     : inlet air gauge static pressure (Pa)
 5. TWO    : outlet water temperature (C)
 6. TRET   : mixed return water temperature (C)
 7. MW     : coil water mass flow rate (kg/s)
 8. MWS    : supply water mass flow rate (kg/s)
 9. QTOTAL : total heat transfer to the air (kW)
10. SHR    : sensible heat ratio (-)
11. EFFECT : coil effectiveness (-)
12. BF     : coil by-pass factor (-)
13. HO     : outlet air specific enthalpy (kJ/kg)
14. RHO    : outlet air relative humidity (%)
15. HS     : air spec. enthalpy in coil surface condition (kJ/kg)
16. TWBO   : outlet air wet-bulb temperature  (C)
```

Parameters:

```
 1. DYNAMIC : 0 for steady state, 1 for dynamic
 2. FAULT   : 0 for no faults, ...
 3. PSYCHO  : 0 for no psychometric output calcs, 1 for calcs
 4. NROW    : number of rows of tubes (-)
 5. NTPR    : number of tubes per row (-)
 6. NCIR    : number of parallel water circuits (-)
 7. LCOIL   : length of finned section in direction of flow (m)
 8. HCOIL   : heigth of finned section (m)
 9. WCOIL   : width of finned section (m)
10. DOTUBE  : tube outside diameter (m)
11. THITUBE : tube wall thickness (m)
12. MATUBE  : tube material (Al=1,Cu=2,Fe=3,CaCO3=4)
13. SPAFIN  : fin spacing (pitch) (m)
14. THIFIN  : fin thickness (m)
15. MAFIN   : fin material (Al=1,Cu=2,Fe=3)
16. X       : flow resistance parameter on air side (0.001 kg.m)
17. Kv      : valve capacity index          (cu. m/hr at 1 bar)
             -> resistance K=1296/(Kv)**2   (0.001 kg.m)
18. ISEL    : valve mode: 0=>lin/lin,
                   1=>exp/lin, 2=>exp/exp, 3=>lin/exp        (-)
19. NGL     : coefficient of exponential valve characteristic
20. SV      : valve adjusting ratio ( > 1)
21. CL      : valve leakage (closed flow/open flow at const P) (-)
22. KC  :    resistance of coil circuit      (0.001 kg.m)
23. KB  :    resistance of bypass circuit    (0.001 kg.m)
```

TYPE 300: RATE LIMIT ACTUATOR MODEL WITH "DEADBAND" AND HYSTERESIS (Adapted from TYPE100 by Ph Haves - LUT - 16.6.94)

INPUTS:

```
1. C    :  control signal input to actuator (-)
```

OUTPUTS

```
1.  Y       : valve/damper position (-)
2.  CV      : actuator position (-)
3.  TSSREV  : number of stop/starts/reversals (-)
4.  TTRAV   : total distance travelled by valve/damper (-)
```

PARAMETERS

1. DIRECTN : 1=forward, -1=reverse, 0=stuck
2. STARTPOS : starting position (0-1)
3. TTRAN : travel time (lim-lim) (s)
4. RESTART: minimum change in demanded position for movement (-)
5. HYS : hysteresis (-)
6. CRANG : crank travel angle (0 for linear)
7. A : coefficient in range transformation CC=A*C+B
8. B : coefficient in range transformation CC=A*C+B

Appendix AA - Sample HVACSIM+ Simulation "ACREF2" w/ Explicit Air Flow [149]

149 Simulation prepared and executed by Phil Haves, Loughborough University of Technology, Loughborough England, 1995.

ACREF2

```
SUPERBLOCK 1
     BLOCK 1
         UNIT  1      TYPE196 - READ FROM UNIX SOCKET (16 REALS)
         UNIT  2      TYPE133 - PSYCHROMETRICS

SUPERBLOCK 2
     BLOCK 2
         UNIT  3      TYPE282 - AHU PLANT DEMANDS WITH MANUAL MODE (BOOST OVE
         UNIT  4      TYPE275 - MIXING BOX CONTROL, INDEPENDENT MANUAL CONTRO
         UNIT  5      TYPE200 - FAN CONTROLLER WITH TRACKING
         UNIT  6      TYPE276 - TREND E-3-4  VAV TERMINAL BOX WITH REHEAT
         UNIT  7      TYPE276 - TREND E-3-4  VAV TERMINAL BOX WITH REHEAT
         UNIT  8      TYPE276 - TREND E-3-4  VAV TERMINAL BOX WITH REHEAT
         UNIT  9      TYPE276 - TREND E-3-4  VAV TERMINAL BOX WITH REHEAT
         UNIT 10      TYPE276 - TREND E-3-4  VAV TERMINAL BOX WITH REHEAT
         UNIT 11      TYPE283 - COMPONENT ON/OFF CONTROL WITH HYSTERESIS AND
         UNIT 12      TYPE281 - SUPPLY AIR TEMPERATURE RESET CONTROLLER - 5 Z

SUPERBLOCK 3
     BLOCK 3
         UNIT 13      TYPE 87 - 8-WAY PATCHBOARD
         UNIT 14      TYPE 87 - 8-WAY PATCHBOARD
         UNIT 15      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 16      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 17      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 18      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 19      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 20      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 21      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 22      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 23      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE
         UNIT 24      TYPE300 - ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (RE

SUPERBLOCK 4
     BLOCK 4
         UNIT 25      TYPE102 - Mixing box: par/opp dampers, calculates suppl
         UNIT 26      TYPE228 - CONSTANT FLOW RESISTANCE - LINEARISED AT LOW
         UNIT 27      TYPE201 - FAN OR PUMP - TEMP RISE CORRECTED FOR WORK DO
         UNIT 28      TYPE228 - CONSTANT FLOW RESISTANCE - LINEARISED AT LOW
         UNIT 29      TYPE207 - FLOW SPLIT - DIFFERENT RESISTANCES, LINEARISE
         UNIT 30      TYPE207 - FLOW SPLIT - DIFFERENT RESISTANCES, LINEARISE
         UNIT 31      TYPE207 - FLOW SPLIT - DIFFERENT RESISTANCES, LINEARISE
         UNIT 32      TYPE207 - FLOW SPLIT - DIFFERENT RESISTANCES, LINEARISE
         UNIT 33      TYPE134 - PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLL
         UNIT 34      TYPE134 - PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLL
         UNIT 35      TYPE134 - PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLL
         UNIT 36      TYPE134 - PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLL
         UNIT 37      TYPE134 - PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLL
         UNIT 38      TYPE210 - MIXING OF THREE MOIST AIR STREAMS WITH LEAKAG
         UNIT 39      TYPE210 - MIXING OF THREE MOIST AIR STREAMS WITH LEAKAG
         UNIT 40      TYPE210 - MIXING OF THREE MOIST AIR STREAMS WITH LEAKAG
         UNIT 41      TYPE210 - MIXING OF THREE MOIST AIR STREAMS WITH LEAKAG
         UNIT 42      TYPE210 - MIXING OF THREE MOIST AIR STREAMS WITH LEAKAG
         UNIT 43      TYPE229 - INLET CONSTANT FLOW RESISTANCE + NEG. O/P
         UNIT 44      TYPE229 - INLET CONSTANT FLOW RESISTANCE + NEG. O/P
         UNIT 45      TYPE229 - INLET CONSTANT FLOW RESISTANCE + NEG. O/P
         UNIT 46      TYPE229 - INLET CONSTANT FLOW RESISTANCE + NEG. O/P
         UNIT 47      TYPE229 - INLET CONSTANT FLOW RESISTANCE + NEG. O/P
         UNIT 48      TYPE204 - FLOW MERGE
         UNIT 49      TYPE204 - FLOW MERGE
         UNIT 50      TYPE204 - FLOW MERGE
         UNIT 51      TYPE204 - FLOW MERGE
         UNIT 52      TYPE201 - FAN OR PUMP - TEMP RISE CORRECTED FOR WORK DO
         UNIT 53      TYPE228 - CONSTANT FLOW RESISTANCE - LINEARISED AT LOW

SUPERBLOCK 5
     BLOCK 5
         UNIT 54      TYPE 26 - CONTROL SIGNAL INVERTER

SUPERBLOCK 6
     BLOCK 6
         UNIT 55      TYPE299 - LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P
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        UNIT 56     TYPE299 - LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P
        UNIT 57     TYPE205 - FAN OR PUMP - POWER AND TEMP RISE ONLY
        UNIT 58     TYPE212 - MIXING OF FIVE MOIST AIR STREAMS
        UNIT 59     TYPE205 - FAN OR PUMP - POWER AND TEMP RISE ONLY
        UNIT 60     TYPE211 - MIXING OF TWO MOIST AIR STREAMS
    BLOCK 7
        UNIT 61     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
        UNIT 62     TYPE299 - LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P
        UNIT 63     TYPE272 - 2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, D
        UNIT 64     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
    BLOCK 8
        UNIT 65     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
        UNIT 66     TYPE299 - LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P
        UNIT 67     TYPE272 - 2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, D
        UNIT 68     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
    BLOCK 9
        UNIT 69     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
        UNIT 70     TYPE299 - LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P
        UNIT 71     TYPE272 - 2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, D
        UNIT 72     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
    BLOCK10
        UNIT 73     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
        UNIT 74     TYPE299 - LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P
        UNIT 75     TYPE272 - 2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, D
        UNIT 76     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
    BLOCK11
        UNIT 77     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT
        UNIT 78     TYPE299 - LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P
        UNIT 79     TYPE272 - 2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, D
        UNIT 80     TYPE169 - MOIST AIR DUCT, HEAT LOSS AS OUTPUT

SUPERBLOCK 7
    BLOCK12
        UNIT 81     TYPE 26 - CONTROL SIGNAL INVERTER

SUPERBLOCK 8
    BLOCK13
        UNIT 82     TYPE  7 - TEMPERATURE SENSOR
        UNIT 83     TYPE  7 - TEMPERATURE SENSOR
        UNIT 84     TYPE  7 - TEMPERATURE SENSOR
        UNIT 85     TYPE  7 - TEMPERATURE SENSOR
        UNIT 86     TYPE  7 - TEMPERATURE SENSOR
        UNIT 87     TYPE  7 - TEMPERATURE SENSOR
        UNIT 88     TYPE203 - STATIC PRESSURE SENSOR
        UNIT 89     TYPE189 - VELOCITY SENSOR
        UNIT 90     TYPE189 - VELOCITY SENSOR
        UNIT 91     TYPE203 - STATIC PRESSURE SENSOR
        UNIT 92     TYPE  7 - TEMPERATURE SENSOR
        UNIT 93     TYPE  7 - TEMPERATURE SENSOR
        UNIT 94     TYPE  7 - TEMPERATURE SENSOR
        UNIT 95     TYPE  7 - TEMPERATURE SENSOR
        UNIT 96     TYPE  7 - TEMPERATURE SENSOR

SUPERBLOCK 9
    BLOCK14
        UNIT 97     TYPE197 - WRITE TO UNIX SOCKET (16 REALS)
        UNIT 98     TYPE135 - REAL TIME GRAPHS OF PRESSURE, FLOW AND CONTRO

SUPERBLOCK10
    BLOCK15
        UNIT 99     TYPE 26 - CONTROL SIGNAL INVERTER
----------------------------------------------------

UNIT   1      TYPE 196
READ FROM UNIX SOCKET (16 REALS)

1     INPUTS:

2     OUTPUTS:
       CONTROL          1 - SIMULATION INPUT / SOCKET OUTPUT  1
       CONTROL          2 - SIMULATION INPUT / SOCKET OUTPUT  2
       CONTROL          3 - SIMULATION INPUT / SOCKET OUTPUT  3
       CONTROL          4 - SIMULATION INPUT / SOCKET OUTPUT  4
       CONTROL          5 - SIMULATION INPUT / SOCKET OUTPUT  5
       CONTROL          6 - SIMULATION INPUT / SOCKET OUTPUT  6
       CONTROL          7 - SIMULATION INPUT / SOCKET OUTPUT  7
       CONTROL          8 - SIMULATION INPUT / SOCKET OUTPUT  8
       CONTROL          9 - SIMULATION INPUT / SOCKET OUTPUT  9
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       CONTROL          10 - SIMULATION INPUT / SOCKET OUTPUT  10
       CONTROL          11 - SIMULATION INPUT / SOCKET OUTPUT  11
       CONTROL          12 - SIMULATION INPUT / SOCKET OUTPUT  12
       CONTROL          13 - SIMULATION INPUT / SOCKET OUTPUT  13
       CONTROL          14 - SIMULATION INPUT / SOCKET OUTPUT  14
       CONTROL          15 - SIMULATION INPUT / SOCKET OUTPUT  15
       CONTROL          16 - SIMULATION INPUT / SOCKET OUTPUT  16

3      PARAMETERS:
          1.00000      SOCKET NUMBER (0-4)
          5.00000      SAMPLE TIME (INTERVAL BETWEEN TRANSFERS) [S]
               0.      REAL TIME SCALING FACTOR (0=NO WAIT, 0.5=DOUBLE SPEED)
               0.      WAIT FOR DATA (0=NO WAIT, 1=WAIT)
----------------------------------------------------

UNIT   2      TYPE 133
PSYCHROMETRICS

1      INPUTS:
       TEMPERATURE       1 - DRY BULB TEMPERATURE
       CONTROL         117 - RELATIVE HUMIDITY (USED IF MODE=1)
       HUMIDITY RATIO    1 - HUMIDITY RATIO (USED IF MODE=2)
       TEMPERATURE      79 - WET BULB TEMPERATURE (USED IF MODE=3)
       PRESSURE         27 - ATMOSPHERIC PRESSURE

2      OUTPUTS:
       TEMPERATURE       0 - DRY BULB TEMPERATURE
       CONTROL           0 - RELATIVE HUMIDITY
       HUMIDITY RATIO    0 - HUMIDITY RATIO
       ENERGY            0 - SPECIFIC ENTHALPY
       TEMPERATURE       0 - DEW POINT TEMPERATURE
       TEMPERATURE       0 - WET BULB TEMPERATURE (TWB=0 IF PAR(3)=0)

3      PARAMETERS:
               0.      (NOT USED)
          1.00000      MODE: 1 -> RH AS I/P, 2 -> H RATIO AS I/P, 3 -> WET BUL
               0.      0 -> TWB NOT INCLUDED IN O/P, 1 -> TWB INCLUDED IN O/P
----------------------------------------------------

UNIT   3      TYPE 282
AHU PLANT DEMANDS WITH MANUAL MODE (BOOST OVER-RIDE ON COOLING)

1      INPUTS:
       CONTROL          20 - SUPPLY AIR TEMPERATURE SENSOR
       CONTROL           6 - SUPPLY AIR TEMPERATURE SETPOINT
       CONTROL         118 - OSS: (0=OUTSIDE OPT START AND STOP, 1=BETWEEN OSS
       CONTROL          59 - BOOST MODE (0=OFF, 1=ON)
       CONTROL           7 - OPEN/CLOSED LOOP (0=OPEN, 1=CLOSED)
       CONTROL           5 - MANUAL HEATING COIL DEMAND
       CONTROL           4 - MANUAL COOLING COIL DEMAND

2      OUTPUTS:
       CONTROL          40 - AHU HEATING COIL DEMAND (0-1)
       CONTROL          35 - DAMPERS COOLING DEMAND (0-1)
       CONTROL          39 - COOLING COIL DEMAND (0-1)

3      PARAMETERS:
          1.00000      PROPORTIONAL GAIN (%/C)
          120.000      INTEGRAL TIME (SEC)
         0.500000      BREAKPOINT BETWEEN FREE AND PAY COOLING DEMAND (0-1)
          1.00000      DEADBAND (OFFSET IN COOLING SETPOINT) (C)
          600.000      TIME DELAY FOR BOOST MODE OVER-RIDE OF COOLING COIL (S)
          5.00000      RESCHEDULE TIME (SEC)
          1.00000      NUMBER OF TIMES ENTERED IN SEQUENCE TABLE
          1.00000      CONTROLLER NUMBER (PARAMETER FILE="contN.par" IF N > 0)
----------------------------------------------------

UNIT   4      TYPE 275
MIXING BOX CONTROL, INDEPENDENT MANUAL CONTROL

1      INPUTS:
       CONTROL          17 - AMBIENT TEMPERATURE SENSOR
       CONTROL          18 - RETURN TEMPERATURE SENSOR
       CONTROL          35 - COOLING DEMAND FOR DAMPERS (0-1)
       CONTROL         118 - OSS: (0=OUTSIDE OPT START AND STOP, 1=BETWEEN OSS
       CONTROL         119 - OTP: (1=OCCUPIED, 0=NON-OCCUPIED)
       CONTROL           7 - OPEN/CLOSED LOOP (0=OPEN, 1=CLOSED)
       CONTROL           1 - OPEN LOOP FRESH AIR DAMPER POSITION (0-1)
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       CONTROL            2 - OPEN LOOP RECIRC AIR DAMPER POSITION (0-1)
       CONTROL            3 - OPEN LOOP EXHAUST AIR DAMPER POSITION (0-1)

2      OUTPUTS:
       CONTROL           36 - FRESH AIR DAMPER DEMANDED POSITION (0-1)
       CONTROL           37 - RECIRC AIR DAMPER DEMANDED POSITION (0-1)
       CONTROL           38 - EXHAUST AIR DAMPER DEMANDED POSITION (0-1)

3      PARAMETERS:
          0.200000     MINIMUM DEMANDED DAMPER POSITION (0-1)
           5.00000     RESCHEDULE TIME (SEC)
           1.00000     NUMBER OF TIMES ENTERED IN SEQUENCE TABLE
           2.00000     CONTROLLER NUMBER (PARAMETER FILE="contN.par" IF N > 0)
---------------------------------------------------

UNIT   5      TYPE 200
FAN CONTROLLER WITH TRACKING

1      INPUTS:
       CONTROL           23 - STATIC PRESSURE SENSOR SIGNAL
       CONTROL           10 - STATIC PRESSURE SETPOINT
       CONTROL           11 - CONTROL MODE: (0=OPEN LOOP, 1=CLOSED LOOP)
       CONTROL            8 - MANUAL OUTPUT FOR SUPPLY FAN (0-1)
       CONTROL            9 - MANUAL OUTPUT FOR EXTRACT FAN (0-1)

2      OUTPUTS:
       RVPS               1 - SUPPLY FAN ROTATION SPEED
       RVPS               2 - EXTRACT FAN ROTATION SPEED

3      PARAMETERS:
          0.300000     PROPORTIONAL GAIN (KPA.S/REV)
           300.000     INTEGRAL TIME (SEC)
           5.00000     SAMPLE TIME (SEC)
           30.0000     MAXIMUM ROTATION SPEED (REV/S)
           40.0000     TIME FROM ZERO TO FULL SPEED (S)
                0.     A COEFF IN CEXT = ACOEFF + BCOEFF*CSUP (-)
          0.950000     B COEFF IN CEXT = ACOEFF + BCOEFF*CSUP (-)
           3.00000     CONTROLLER NUMBER (PARAMETER FILE=
---------------------------------------------------

UNIT   6      TYPE 276
TREND E-3-4  VAV TERMINAL BOX WITH REHEAT

1      INPUTS:
       CONTROL           20 - SUPPLY AIR TEMPERATURE SENSOR
       CONTROL           28 - SPACE TEMPERATURE SENSOR
       CONTROL          118 - OSS: (0=OUTSIDE OPT START AND STOP, 1=BETWEEN OSS
       CONTROL          119 - OTP: (0=OCCUPIED, 1=NON-OCCUPIED)
       CONTROL          120 - FAN: (1=AHU FAN(S) ON, 0=FAN(S) OFF)
       CONTROL           12 - MODE: (0=AUTO, 1=CLOSED, 2=MIN, 3=MAX)

2      OUTPUTS:
       CONTROL           42 - NORMALISED VELOCITY SETPOINT
       CONTROL           43 - REHEAT COIL DEMAND
       CONTROL           44 - ROOM DEMAND (HEATING AND COOLING)

3      PARAMETERS:
           24.0000     COOLING SETPOINT FOR SPACE (C)
           2.00000     DEADBAND: COOLING SETPOINT - HEATING SETPOINT (C)
           10.0000     NIGHT SET BACK SETPOINT (HEATING) (C)
          0.300000     PROPORTIONAL GAIN FOR HEATING DEMAND (%/C)
           300.000     INTEGRAL TIME FOR HEATING DEMAND (SEC)
          0.300000     PROPORTIONAL GAIN FOR COOLING DEMAND (%/C)
           300.000     INTEGRAL TIME FOR COOLING DEMAND (SEC)
           2.05000     MAXIMUM VELOCITY SETPOINT (M3/S)
          0.820000     MINIMUM VELOCITY SETPOINT (M3/S)
           5.00000     RESCHEDULE TIME (SEC)
           1.00000     NUMBER OF TIMES ENTERED IN SEQUENCE TABLE
           4.00000     CONTROLLER NUMBER (PARAMETER FILE="contN.par" IF N > 0)
---------------------------------------------------

UNIT   7      TYPE 276
TREND E-3-4  VAV TERMINAL BOX WITH REHEAT

1      INPUTS:
       CONTROL           20 - SUPPLY AIR TEMPERATURE SENSOR
       CONTROL           29 - SPACE TEMPERATURE SENSOR
       CONTROL          118 - OSS: (0=OUTSIDE OPT START AND STOP, 1=BETWEEN OSS
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        CONTROL         119 - OTP: (0=OCCUPIED, 1=NON-OCCUPIED)
        CONTROL         120 - FAN: (1=AHU FAN(S) ON, 0=FAN(S) OFF)
        CONTROL          13 - MODE: (0=AUTO, 1=CLOSED, 2=MIN, 3=MAX)

2      OUTPUTS:
        CONTROL          45 - NORMALISED VELOCITY SETPOINT
        CONTROL          46 - REHEAT COIL DEMAND
        CONTROL          47 - ROOM DEMAND (HEATING AND COOLING)

3      PARAMETERS:
           24.0000      COOLING SETPOINT FOR SPACE (C)
           2.00000      DEADBAND: COOLING SETPOINT - HEATING SETPOINT (C)
           10.0000      NIGHT SET BACK SETPOINT (HEATING) (C)
          0.300000      PROPORTIONAL GAIN FOR HEATING DEMAND (%/C)
           300.000      INTEGRAL TIME FOR HEATING DEMAND (SEC)
          0.300000      PROPORTIONAL GAIN FOR COOLING DEMAND (%/C)
           300.000      INTEGRAL TIME FOR COOLING DEMAND (SEC)
          0.990000      MAXIMUM VELOCITY SETPOINT (M3/S)
          0.400000      MINIMUM VELOCITY SETPOINT (M3/S)
           5.00000      RESCHEDULE TIME (SEC)
           1.00000      NUMBER OF TIMES ENTERED IN SEQUENCE TABLE
           5.00000      CONTROLLER NUMBER (PARAMETER FILE="contN.par" IF N > 0)
---------------------------------------------------

UNIT   8      TYPE 276
TREND E-3-4  VAV TERMINAL BOX WITH REHEAT

1      INPUTS:
        CONTROL          20 - SUPPLY AIR TEMPERATURE SENSOR
        CONTROL          30 - SPACE TEMPERATURE SENSOR
        CONTROL         118 - OSS: (0=OUTSIDE OPT START AND STOP, 1=BETWEEN OSS
        CONTROL         119 - OTP: (0=OCCUPIED, 1=NON-OCCUPIED)
        CONTROL         120 - FAN: (1=AHU FAN(S) ON, 0=FAN(S) OFF)
        CONTROL          14 - MODE: (0=AUTO, 1=CLOSED, 2=MIN, 3=MAX)

2      OUTPUTS:
        CONTROL          48 - NORMALISED VELOCITY SETPOINT
        CONTROL          49 - REHEAT COIL DEMAND
        CONTROL          50 - ROOM DEMAND (HEATING AND COOLING)

3      PARAMETERS:
           24.0000      COOLING SETPOINT FOR SPACE (C)
           2.00000      DEADBAND: COOLING SETPOINT - HEATING SETPOINT (C)
           10.0000      NIGHT SET BACK SETPOINT (HEATING) (C)
          0.300000      PROPORTIONAL GAIN FOR HEATING DEMAND (%/C)
           300.000      INTEGRAL TIME FOR HEATING DEMAND (SEC)
          0.300000      PROPORTIONAL GAIN FOR COOLING DEMAND (%/C)
           300.000      INTEGRAL TIME FOR COOLING DEMAND (SEC)
          0.990000      MAXIMUM VELOCITY SETPOINT (M3/S)
          0.400000      MINIMUM VELOCITY SETPOINT (M3/S)
           5.00000      RESCHEDULE TIME (SEC)
           1.00000      NUMBER OF TIMES ENTERED IN SEQUENCE TABLE
           6.00000      CONTROLLER NUMBER (PARAMETER FILE="contN.par" IF N > 0)
---------------------------------------------------

UNIT   9      TYPE 276
TREND E-3-4  VAV TERMINAL BOX WITH REHEAT

1      INPUTS:
        CONTROL          20 - SUPPLY AIR TEMPERATURE SENSOR
        CONTROL          31 - SPACE TEMPERATURE SENSOR
        CONTROL         118 - OSS: (0=OUTSIDE OPT START AND STOP, 1=BETWEEN OSS
        CONTROL         119 - OTP: (0=OCCUPIED, 1=NON-OCCUPIED)
        CONTROL         120 - FAN: (1=AHU FAN(S) ON, 0=FAN(S) OFF)
        CONTROL          15 - MODE: (0=AUTO, 1=CLOSED, 2=MIN, 3=MAX)

2      OUTPUTS:
        CONTROL          51 - NORMALISED VELOCITY SETPOINT
        CONTROL          52 - REHEAT COIL DEMAND
        CONTROL          53 - ROOM DEMAND (HEATING AND COOLING)

3      PARAMETERS:
           24.0000      COOLING SETPOINT FOR SPACE (C)
           2.00000      DEADBAND: COOLING SETPOINT - HEATING SETPOINT (C)
           10.0000      NIGHT SET BACK SETPOINT (HEATING) (C)
          0.300000      PROPORTIONAL GAIN FOR HEATING DEMAND (%/C)
           300.000      INTEGRAL TIME FOR HEATING DEMAND (SEC)
          0.300000      PROPORTIONAL GAIN FOR COOLING DEMAND (%/C)
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         300.000      INTEGRAL TIME FOR COOLING DEMAND (SEC)
        0.990000      MAXIMUM VELOCITY SETPOINT (M3/S)
        0.400000      MINIMUM VELOCITY SETPOINT (M3/S)
         5.00000      RESCHEDULE TIME (SEC)
         1.00000      NUMBER OF TIMES ENTERED IN SEQUENCE TABLE
         7.00000      CONTROLLER NUMBER (PARAMETER FILE="contN.par" IF N > 0)
----------------------------------------------------

UNIT  10      TYPE 276
TREND E-3-4  VAV TERMINAL BOX WITH REHEAT

1      INPUTS:
        CONTROL          20 - SUPPLY AIR TEMPERATURE SENSOR
        CONTROL          32 - SPACE TEMPERATURE SENSOR
        CONTROL         118 - OSS: (0=OUTSIDE OPT START AND STOP, 1=BETWEEN OSS
        CONTROL         119 - OTP: (0=OCCUPIED, 1=NON-OCCUPIED)
        CONTROL         120 - FAN: (1=AHU FAN(S) ON, 0=FAN(S) OFF)
        CONTROL          16 - MODE: (0=AUTO, 1=CLOSED, 2=MIN, 3=MAX)

2      OUTPUTS:
        CONTROL          54 - NORMALISED VELOCITY SETPOINT
        CONTROL          55 - REHEAT COIL DEMAND
        CONTROL          56 - ROOM DEMAND (HEATING AND COOLING)

3      PARAMETERS:
         24.0000      COOLING SETPOINT FOR SPACE (C)
         2.00000      DEADBAND: COOLING SETPOINT - HEATING SETPOINT (C)
         10.0000      NIGHT SET BACK SETPOINT (HEATING) (C)
        0.300000      PROPORTIONAL GAIN FOR HEATING DEMAND (%/C)
         300.000      INTEGRAL TIME FOR HEATING DEMAND (SEC)
        0.300000      PROPORTIONAL GAIN FOR COOLING DEMAND (%/C)
         300.000      INTEGRAL TIME FOR COOLING DEMAND (SEC)
        0.990000      MAXIMUM VELOCITY SETPOINT (M3/S)
        0.400000      MINIMUM VELOCITY SETPOINT (M3/S)
         5.00000      RESCHEDULE TIME (SEC)
         1.00000      NUMBER OF TIMES ENTERED IN SEQUENCE TABLE
         8.00000      CONTROLLER NUMBER (PARAMETER FILE="contN.par" IF N > 0)
----------------------------------------------------

UNIT  11      TYPE 283
COMPONENT ON/OFF CONTROL WITH HYSTERESIS AND DELAY - 6 I/Ps

1      INPUTS:
        CONTROL          40 - 1st demand (heating demand 0 - +1)
        CONTROL          43 - 2nd demand (heating demand 0 - +1)
        CONTROL          46 - 3rd demand (heating demand 0 - +1)
        CONTROL          49 - 4th demand (heating demand 0 - +1)
        CONTROL          52 - 5th demand (heating demand 0 - +1)
        CONTROL          55 - 6th demand (heating demand 0 - +1)
        CONTROL         121 - plant enable (0=off, 1=on)

2      OUTPUTS:
        CONTROL          57 - component status (0=off, 1=on)

3      PARAMETERS:
         6.00000      number of demands
         1.00000      sign of demand to act on (+1=heating, -1=cooling)
        0.500000E-01  threshhold to switch on (upper limit of deadband) (0-1)
        0.250000E-01  threshhold to switch off (lower limit of deadband) (0-1
         600.000      off delay (s)
         5.00000      reschedule time (sec)
         1.00000      number of times entered in sequence table
----------------------------------------------------

UNIT  12      TYPE 281
SUPPLY AIR TEMPERATURE RESET CONTROLLER - 5 ZONES

1      INPUTS:
        CONTROL          44 - DEMAND FROM 1ST ZONE (-1 - +1)
        CONTROL          47 - DEMAND FROM 2ND ZONE (-1 - +1)
        CONTROL          50 - DEMAND FROM 3RD ZONE (-1 - +1)
        CONTROL          53 - DEMAND FROM 4TH ZONE (-1 - +1)
        CONTROL          56 - DEMAND FROM 5TH ZONE (-1 - +1)
        CONTROL         121 - AHU STATUS (0=OFF, 1=ON)

2      OUTPUTS:
        CONTROL          58 - SUPPLY AIR TEMPERATURE SETPOINT
        CONTROL          59 - BOOST MODE (0=OFF, 1=ON)
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3       PARAMETERS:
            5.00000      NUMBER OF ZONES
            17.0000      MAXIMUM SUPPLY AIR TEMPERATURE SETPOINT (COOLING) (C)
            12.0000      MINIMUM SUPPLY AIR TEMPERATURE SETPOINT (COOLING) (C)
            28.0000      BOOST SUPPLY AIR TEMPERATURE SETPOINT (HEATING) (C)
          0.167000E-02 MAXIMUM RATE OF CHANGE OF TEMPERATURE SETPOINT (C/S)
            1.00000      PROPORTIONAL GAIN (%/C)
            2700.00      INTEGRAL TIME (SEC)
            5.00000      RESCHEDULE TIME (SEC)
            1.00000      NUMBER OF TIMES CONTROLLER ENTERED IN SEQUENCE TABLE
            9.00000      CONTROLLER NUMBER (PARAMETER FILE="contN.par" IF N > 0)
----------------------------------------------------

UNIT 13      TYPE  87
8-WAY PATCHBOARD

1       INPUTS:
         CONTROL          36 - INPUT 1
         CONTROL          37 - INPUT 2
         CONTROL          38 - INPUT 3
         CONTROL          39 - INPUT 4
         CONTROL          40 - INPUT 5
         CONTROL          41 - INPUT 6
         CONTROL          42 - INPUT 7
         CONTROL          43 - INPUT 8

2       OUTPUTS:
         CONTROL          60 - OUTPUT 1
         CONTROL          61 - OUTPUT 2
         CONTROL          62 - OUTPUT 3
         CONTROL          63 - OUTPUT 4
         CONTROL          64 - OUTPUT 5
         CONTROL          65 - OUTPUT 6
         CONTROL          66 - OUTPUT 7
         CONTROL          67 - OUTPUT 8

3       PARAMETERS:
            1.00000      INPUT CONNECTED TO OUTPUT 1 (-)
            2.00000      INPUT CONNECTED TO OUTPUT 2 (-)
            3.00000      INPUT CONNECTED TO OUTPUT 3 (-)
            4.00000      INPUT CONNECTED TO OUTPUT 4 (-)
            5.00000      INPUT CONNECTED TO OUTPUT 5 (-)
            6.00000      INPUT CONNECTED TO OUTPUT 6 (-)
            7.00000      INPUT CONNECTED TO OUTPUT 7 (-)
            8.00000      INPUT CONNECTED TO OUTPUT 8 (-)
----------------------------------------------------

UNIT 14      TYPE  87
8-WAY PATCHBOARD

1       INPUTS:
         CONTROL          45 - INPUT 1
         CONTROL          46 - INPUT 2
         CONTROL          48 - INPUT 3
         CONTROL          49 - INPUT 4
         CONTROL          51 - INPUT 5
         CONTROL          52 - INPUT 6
         CONTROL          54 - INPUT 7
         CONTROL          55 - INPUT 8

2       OUTPUTS:
         CONTROL          68 - OUTPUT 1
         CONTROL          69 - OUTPUT 2
         CONTROL          70 - OUTPUT 3
         CONTROL          71 - OUTPUT 4
         CONTROL          72 - OUTPUT 5
         CONTROL          73 - OUTPUT 6
         CONTROL          74 - OUTPUT 7
         CONTROL          75 - OUTPUT 8

3       PARAMETERS:
            1.00000      INPUT CONNECTED TO OUTPUT 1 (-)
            2.00000      INPUT CONNECTED TO OUTPUT 2 (-)
            3.00000      INPUT CONNECTED TO OUTPUT 3 (-)
            4.00000      INPUT CONNECTED TO OUTPUT 4 (-)
            5.00000      INPUT CONNECTED TO OUTPUT 5 (-)
            6.00000      INPUT CONNECTED TO OUTPUT 6 (-)
            7.00000      INPUT CONNECTED TO OUTPUT 7 (-)
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          8.00000     INPUT CONNECTED TO OUTPUT 8 (-)
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UNIT  15      TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          60 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          76 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
           1.00000      DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
           1.00000      STARTING POSITION (0-1)
           200.000      ACTUATOR TRAVEL TIME (LIM-LIM) (S)
                0.      MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
                0.      HYSTERESIS (-)
                0.      CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
           1.00000      A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
                0.      B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
---------------------------------------------------

UNIT  16      TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          61 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          77 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
           1.00000      DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
                0.      STARTING POSITION (0-1)
           200.000      ACTUATOR TRAVEL TIME (LIM-LIM) (S)
                0.      MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
                0.      HYSTERESIS (-)
                0.      CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
           1.00000      A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
                0.      B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
---------------------------------------------------

UNIT  17      TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          62 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          78 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
           1.00000      DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
           1.00000      STARTING POSITION (0-1)
           200.000      ACTUATOR TRAVEL TIME (LIM-LIM) (S)
                0.      MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
                0.      HYSTERESIS (-)
                0.      CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
           1.00000      A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
                0.      B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
---------------------------------------------------

UNIT  18      TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          63 - CONTROL SIGNAL INPUT TO ACTUATOR
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2      OUTPUTS:
        CONTROL          79 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
           1.00000     DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
                0.     STARTING POSITION (0-1)
           200.000     ACTUATOR TRAVEL TIME (LIM-LIM) (S)
                0.     MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
                0.     HYSTERESIS (-)
                0.     CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
           1.00000     A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
                0.     B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
----------------------------------------------------

UNIT  19      TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          64 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          80 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
           1.00000     DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
                0.     STARTING POSITION (0-1)
           200.000     ACTUATOR TRAVEL TIME (LIM-LIM) (S)
                0.     MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
                0.     HYSTERESIS (-)
                0.     CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
           1.00000     A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
                0.     B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
----------------------------------------------------

UNIT  20      TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          67 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          81 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
           1.00000     DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
                0.     STARTING POSITION (0-1)
           200.000     ACTUATOR TRAVEL TIME (LIM-LIM) (S)
                0.     MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
                0.     HYSTERESIS (-)
                0.     CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
           1.00000     A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
                0.     B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
----------------------------------------------------

UNIT  21      TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          69 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          82 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
           1.00000     DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
                0.     STARTING POSITION (0-1)
```

```
          200.000      ACTUATOR TRAVEL TIME (LIM-LIM) (S)
               0.      MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
               0.      HYSTERESIS (-)
               0.      CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
          1.00000      A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
               0.      B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
----------------------------------------------------

UNIT  22       TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          71 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          83 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
          1.00000      DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
               0.      STARTING POSITION (0-1)
          200.000      ACTUATOR TRAVEL TIME (LIM-LIM) (S)
               0.      MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
               0.      HYSTERESIS (-)
               0.      CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
          1.00000      A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
               0.      B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
----------------------------------------------------

UNIT  23       TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          73 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          84 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
          1.00000      DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
               0.      STARTING POSITION (0-1)
          200.000      ACTUATOR TRAVEL TIME (LIM-LIM) (S)
               0.      MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
               0.      HYSTERESIS (-)
               0.      CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
          1.00000      A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
               0.      B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
----------------------------------------------------

UNIT  24       TYPE 300
ACTUATOR W/ FAULTS, DEADBAND & HYSTERESIS (REVISED)

1      INPUTS:
        CONTROL          75 - CONTROL SIGNAL INPUT TO ACTUATOR

2      OUTPUTS:
        CONTROL          85 - VALVE/DAMPER POSITION
        CONTROL           0 - ACTUATOR POSITION
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
          1.00000      DIRECTION: 1=FORWARD, -1=REVERSE, 0=STUCK
               0.      STARTING POSITION (0-1)
          200.000      ACTUATOR TRAVEL TIME (LIM-LIM) (S)
               0.      MINIMUM CHANGE IN DEMANDED POSITION FOR MOVEMENT (-)
               0.      HYSTERESIS (-)
               0.      CRANK TRAVEL ANGLE (0 FOR LINEAR) (DEG)
          1.00000      A :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
               0.      B :  COEFFICIENT IN RANGE TRANSFORMATION CC=A*C+B
----------------------------------------------------
```

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UNIT  25      TYPE 102
Mixing box: par/opp dampers, calculates supply flow

1      INPUTS:
        TEMPERATURE       1 - Fresh air dry bulb temperature
        HUMIDITY RATIO    1 - Fresh air humidity ratio
        TEMPERATURE      78 - Extract air dry bulb temperature
        HUMIDITY RATIO   24 - Extract air humidity ratio
        PRESSURE          1 - Fresh air intake gauge pressure
        PRESSURE         25 - Exhaust air outlet gauge pressure
        PRESSURE          2 - Mixed air gauge pressure
        FLOW             24 - Extract dry air mass flow rate
        CONTROL          76 - Fresh air damper position (0=closed, 1=open)
        CONTROL          77 - Return air damper position (0=open if PAR(15)=0)
        CONTROL          78 - Extract air damper position (0=closed, 1=open)

2      OUTPUTS:
        TEMPERATURE       0 - Mixed air dry bulb temperature
        HUMIDITY RATIO    0 - Mixed air humidity ratio
        FLOW              2 - Mixed dry air mass flow rate
        ENERGY            0 - Mixed air specific enthalpy
        CONTROL           0 - Mixed air relative humidity
        FLOW              0 - Mixed humid air mass flow rate
        PRESSURE         24 - Extract air gauge pressure
        FLOW              1 - Fresh dry air mass flow rate
        FLOW             25 - Return dry air mass flow rate
        FLOW              0 - Exhaust dry air mass flow rate

3      PARAMETERS:
                0.      Auxiliary psychometric outputs (0 = no, 1 = yes)
                0.      0=no faults, 1=100% oversized, 2=20% leakage, 3=both
                0.      Fresh air damper: opposed (0) or parallel (1)
                0.      Return air damper: opposed (0) or parallel (1)
                0.      Exhaust air damper: opposed (0) or parallel (1)
          0.127000E-03 Open resist. for fresh air damper (p.d. (kPa) at 1 m3/s
          0.223000E-03 Open resist. for return air damper (p.d. (kPa) at 1 m3/
          0.223000E-03 Open resist. for exhaust air damper (p.d. (kPa) at 1 m3
          0.100000E-01 Leakage for fresh air damper (fraction of full flow)
          0.100000E-01 Leakage for return air damper (fraction of full flow)
          0.100000E-01 Leakage for exhaust air damper (fraction of full flow)
          0.109000     Authority of fresh air damper
          0.129000     Authority of return air damper
          0.700000E-01 Authority of exhaust air damper
           1.00000     0=invert return air damper, 1=not inverted
----------------------------------------------------

UNIT  26      TYPE 228
CONSTANT FLOW RESISTANCE - LINEARISED AT LOW FLOW

1      INPUTS:
        FLOW              2 - FLUID MASS FLOW RATE
        PRESSURE          3 - OUTLET PRESSURE

2      OUTPUTS:
        PRESSURE          2 - INLET PRESSURE

3      PARAMETERS:
          0.562400E-02 FLOW RESISTANCE  [0.001/(KG M)]
----------------------------------------------------

UNIT  27      TYPE 201
FAN OR PUMP - TEMP RISE CORRECTED FOR WORK DONE

1      INPUTS:
        FLOW              2 - MASS FLOW RATE OF FLUID
        PRESSURE          4 - OUTLET PRESSURE
        RVPS              1 - FAN OR PUMP ROTATIONAL SPEED
        TEMPERATURE       4 - INLET FLUID TEMPERATURE

2      OUTPUTS:
        PRESSURE          3 - INLET PRESSURE
        TEMPERATURE       0 - OUTLET FLUID TEMPERATURE
        POWER             1 - POWER CONSUMPTION

3      PARAMETERS:
           4.47318     1ST PRESSURE COEFFICIENT
          -1.30791     2ND PRESSURE COEFFICIENT
           6.16939     3RD PRESSURE COEFFICIENT
```

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         -5.75617      4TH PRESSURE COEFFICIENT
         0.505184      5TH PRESSURE COEFFICIENT
         0.105200E-01 1ST EFFICIENCY COEFFICIENT
          2.10726      2ND EFFICIENCY COEFFICIENT
         -1.75750      3RD EFFICIENCY COEFFICIENT
         0.536622      4TH EFFICIENCY COEFFICIENT
        -0.127430      5TH EFFICIENCY COEFFICIENT
         0.570000      DIAMETER (M)
          1.00000      MODE: AIR=1, WATER=2
         0.800000      LOWEST VALID NORMALISED FLOW (-)
          1.50000      HIGHEST VALID NORMALISED FLOW (-)
----------------------------------------------------

UNIT  28      TYPE 228
CONSTANT FLOW RESISTANCE - LINEARISED AT LOW FLOW

1      INPUTS:
        FLOW             2 - FLUID MASS FLOW RATE
        PRESSURE         5 - OUTLET PRESSURE

2      OUTPUTS:
        PRESSURE         4 - INLET PRESSURE

3      PARAMETERS:
          0.740000E-03 FLOW RESISTANCE  [0.001/(KG M)]
----------------------------------------------------

UNIT  29      TYPE 207
FLOW SPLIT - DIFFERENT RESISTANCES, LINEARISED AT LOW FLOW

1      INPUTS:
        FLOW             2 - INLET MASS FLOW RATE
        PRESSURE         6 - OUTLET PRESSURE 1
        PRESSURE         7 - OUTLET PRESSURE 2

2      OUTPUTS:
        FLOW             3 - OUTLET MASS FLOW RATE 1
        FLOW             4 - OUTLET MASS FLOW RATE 2
        PRESSURE         5 - INLET PRESSURE

3      PARAMETERS:
          0.503000E-03 INLET FLOW RESISTANCE [0.001/(KG M)]
          0.184900E-02 OUTLET FLOW RESISTANCE 1 [0.001/(KG M)]
          0.178000E-02 OUTLET FLOW RESISTANCE 2 [0.001/(KG M)]
----------------------------------------------------

UNIT  30      TYPE 207
FLOW SPLIT - DIFFERENT RESISTANCES, LINEARISED AT LOW FLOW

1      INPUTS:
        FLOW             3 - INLET MASS FLOW RATE
        PRESSURE         8 - OUTLET PRESSURE 1
        PRESSURE         9 - OUTLET PRESSURE 2

2      OUTPUTS:
        FLOW             6 - OUTLET MASS FLOW RATE 1
        FLOW             7 - OUTLET MASS FLOW RATE 2
        PRESSURE         6 - INLET PRESSURE

3      PARAMETERS:
          0.261000E-02 INLET FLOW RESISTANCE [0.001/(KG M)]
          0.123950E-01 OUTLET FLOW RESISTANCE 1 [0.001/(KG M)]
          0.308200E-01 OUTLET FLOW RESISTANCE 2 [0.001/(KG M)]
----------------------------------------------------

UNIT  31      TYPE 207
FLOW SPLIT - DIFFERENT RESISTANCES, LINEARISED AT LOW FLOW

1      INPUTS:
        FLOW             4 - INLET MASS FLOW RATE
        PRESSURE        18 - OUTLET PRESSURE 1
        PRESSURE        17 - OUTLET PRESSURE 2

2      OUTPUTS:
        FLOW             5 - OUTLET MASS FLOW RATE 1
        FLOW            10 - OUTLET MASS FLOW RATE 2
        PRESSURE         7 - INLET PRESSURE
```

```
3      PARAMETERS:
          0.144000E-02 INLET FLOW RESISTANCE [0.001/(KG M)]
          0.744500E-02 OUTLET FLOW RESISTANCE 1 [0.001/(KG M)]
          0.272100E-01 OUTLET FLOW RESISTANCE 2 [0.001/(KG M)]
----------------------------------------------------

UNIT  32       TYPE 207
FLOW SPLIT - DIFFERENT RESISTANCES, LINEARISED AT LOW FLOW

1      INPUTS:
        FLOW              5 - INLET MASS FLOW RATE
        PRESSURE         15 - OUTLET PRESSURE 1
        PRESSURE         16 - OUTLET PRESSURE 2

2      OUTPUTS:
        FLOW              8 - OUTLET MASS FLOW RATE 1
        FLOW              9 - OUTLET MASS FLOW RATE 2
        PRESSURE         18 - INLET PRESSURE

3      PARAMETERS:
          0.744500E-02 INLET FLOW RESISTANCE [0.001/(KG M)]
          0.718600E-01 OUTLET FLOW RESISTANCE 1 [0.001/(KG M)]
          0.192390E-01 OUTLET FLOW RESISTANCE 2 [0.001/(KG M)]
----------------------------------------------------

UNIT  33       TYPE 134
PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLLER)

1      INPUTS:
        FLOW              6 - AIR MASS FLOW RATE
        PRESSURE         10 - OUTLET PRESSURE
        CONTROL          66 - DEMANDED FLOWRATE (NORM TO NOM)

2      OUTPUTS:
        PRESSURE          8 - INLET PRESSURE
        CONTROL         122 - DAMPER POSITION (0=CLOSED, 1=OPEN)
        CONTROL           0 - FRACTIONAL MOTOR VELOCITY
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
           2.05000      NOMINAL VOLUMETRIC FLOW RATE (M3/S)
           1.04000      FACE AREA OF DAMPER(S) (M2)
          0.108800      ADDITIONAL PRESSURE DROP AT NOMINAL FLOW (KPA)
           125.000      ACTUATOR TRAVEL TIME (0-90 DEG) (S)
          0.500000E-01 MINIMUM FRACTIONAL MOTOR SPEED (-)
                0.      HYSTERESIS (-)
           10.0000      CONTROLLER GAIN (FRAC SPEED/FRAC ERROR)
----------------------------------------------------

UNIT  34       TYPE 134
PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLLER)

1      INPUTS:
        FLOW              7 - AIR MASS FLOW RATE
        PRESSURE         11 - OUTLET PRESSURE
        CONTROL          68 - DEMANDED FLOWRATE (NORM TO NOM)

2      OUTPUTS:
        PRESSURE          9 - INLET PRESSURE
        CONTROL         123 - DAMPER POSITION (0=CLOSED, 1=OPEN)
        CONTROL           0 - FRACTIONAL MOTOR VELOCITY
        CONTROL           0 - NUMBER OF STOPS/STARTS/REVERSALS
        CONTROL           0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3      PARAMETERS:
          0.990000      NOMINAL VOLUMETRIC FLOW RATE (M3/S)
          0.505000      FACE AREA OF DAMPER(S) (M2)
          0.997000E-01 ADDITIONAL PRESSURE DROP AT NOMINAL FLOW (KPA)
           125.000      ACTUATOR TRAVEL TIME (0-90 DEG) (S)
          0.500000E-01 MINIMUM FRACTIONAL MOTOR SPEED (-)
                0.      HYSTERESIS (-)
           10.0000      CONTROLLER GAIN (FRAC SPEED/FRAC ERROR)
----------------------------------------------------
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UNIT  35       TYPE 134
PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLLER)

1       INPUTS:
         FLOW                 8 - AIR MASS FLOW RATE
         PRESSURE            12 - OUTLET PRESSURE
         CONTROL             70 - DEMANDED FLOWRATE (NORM TO NOM)

2       OUTPUTS:
         PRESSURE            15 - INLET PRESSURE
         CONTROL            124 - DAMPER POSITION (0=CLOSED, 1=OPEN)
         CONTROL              0 - FRACTIONAL MOTOR VELOCITY
         CONTROL              0 - NUMBER OF STOPS/STARTS/REVERSALS
         CONTROL              0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3       PARAMETERS:
            0.792000      NOMINAL VOLUMETRIC FLOW RATE (M3/S)
            0.404000      FACE AREA OF DAMPER(S) (M2)
            0.116300      ADDITIONAL PRESSURE DROP AT NOMINAL FLOW (KPA)
             125.000      ACTUATOR TRAVEL TIME (0-90 DEG) (S)
            0.500000E-01 MINIMUM FRACTIONAL MOTOR SPEED (-)
                  0.      HYSTERESIS (-)
             10.0000      CONTROLLER GAIN (FRAC SPEED/FRAC ERROR)
----------------------------------------------------

UNIT  36       TYPE 134
PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLLER)

1       INPUTS:
         FLOW                 9 - AIR MASS FLOW RATE
         PRESSURE            13 - OUTLET PRESSURE
         CONTROL             72 - DEMANDED FLOWRATE (NORM TO NOM)

2       OUTPUTS:
         PRESSURE            16 - INLET PRESSURE
         CONTROL            125 - DAMPER POSITION (0=CLOSED, 1=OPEN)
         CONTROL              0 - FRACTIONAL MOTOR VELOCITY
         CONTROL              0 - NUMBER OF STOPS/STARTS/REVERSALS
         CONTROL              0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3       PARAMETERS:
             1.11000      NOMINAL VOLUMETRIC FLOW RATE (M3/S)
            0.565000      FACE AREA OF DAMPER(S) (M2)
            0.126300      ADDITIONAL PRESSURE DROP AT NOMINAL FLOW (KPA)
             125.000      ACTUATOR TRAVEL TIME (0-90 DEG) (S)
            0.500000E-01 MINIMUM FRACTIONAL MOTOR SPEED (-)
                  0.      HYSTERESIS (-)
             10.0000      CONTROLLER GAIN (FRAC SPEED/FRAC ERROR)
----------------------------------------------------

UNIT  37       TYPE 134
PRESSURE-INDEPENDENT VAV BOX (BELIMO CONTROLLER)

1       INPUTS:
         FLOW                10 - AIR MASS FLOW RATE
         PRESSURE            14 - OUTLET PRESSURE
         CONTROL             74 - DEMANDED FLOWRATE (NORM TO NOM)

2       OUTPUTS:
         PRESSURE            17 - INLET PRESSURE
         CONTROL            126 - DAMPER POSITION (0=CLOSED, 1=OPEN)
         CONTROL              0 - FRACTIONAL MOTOR VELOCITY
         CONTROL              0 - NUMBER OF STOPS/STARTS/REVERSALS
         CONTROL              0 - TOTAL DISTANCE TRAVELLED BY VALVE/DAMPER

3       PARAMETERS:
             1.03000      NOMINAL VOLUMETRIC FLOW RATE (M3/S)
            0.527000      FACE AREA OF DAMPER(S) (M2)
            0.897000E-01 ADDITIONAL PRESSURE DROP AT NOMINAL FLOW (KPA)
             125.000      ACTUATOR TRAVEL TIME (0-90 DEG) (S)
            0.500000E-01 MINIMUM FRACTIONAL MOTOR SPEED (-)
                  0.      HYSTERESIS (-)
             10.0000      CONTROLLER GAIN (FRAC SPEED/FRAC ERROR)
----------------------------------------------------
```

```
UNIT  38      TYPE 210
MIXING OF THREE MOIST AIR STREAMS WITH LEAKAGE

1      INPUTS:
        FLOW              6 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 1
        FLOW             11 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 2
        FLOW             15 - INLET MASS FLOW RATE (POSITIVE OUT) - STREAM 3
        PRESSURE         10 - ROOM PRESSURE
        PRESSURE         27 - AMBIENT PRESSURE

2      OUTPUTS:
        FLOW             16 - OUTLET DRY AIR MASS FLOW RATE
        FLOW              0 - DRY AIR MASS FLOW RATE LOST

3      PARAMETERS:
           1.00000     LEAKAGE RESISTANCE [0.001/(KG M)]
                0.     LOCAL EXTRACT FAN MASS FLOW RATE [KG/S]
----------------------------------------------------

UNIT  39      TYPE 210
MIXING OF THREE MOIST AIR STREAMS WITH LEAKAGE

1      INPUTS:
        FLOW              7 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 1
        FLOW             12 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 2
        FLOW             11 - INLET MASS FLOW RATE (POSITIVE OUT) - STREAM 3
        PRESSURE         11 - ROOM PRESSURE
        PRESSURE         27 - AMBIENT PRESSURE

2      OUTPUTS:
        FLOW             17 - OUTLET DRY AIR MASS FLOW RATE
        FLOW              0 - DRY AIR MASS FLOW RATE LOST

3      PARAMETERS:
           1.00000     LEAKAGE RESISTANCE [0.001/(KG M)]
                0.     LOCAL EXTRACT FAN MASS FLOW RATE [KG/S]
----------------------------------------------------

UNIT  40      TYPE 210
MIXING OF THREE MOIST AIR STREAMS WITH LEAKAGE

1      INPUTS:
        FLOW              8 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 1
        FLOW             13 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 2
        FLOW             12 - INLET MASS FLOW RATE (POSITIVE OUT) - STREAM 3
        PRESSURE         12 - ROOM PRESSURE
        PRESSURE         27 - AMBIENT PRESSURE

2      OUTPUTS:
        FLOW             18 - OUTLET DRY AIR MASS FLOW RATE
        FLOW              0 - DRY AIR MASS FLOW RATE LOST

3      PARAMETERS:
           1.00000     LEAKAGE RESISTANCE [0.001/(KG M)]
                0.     LOCAL EXTRACT FAN MASS FLOW RATE [KG/S]
----------------------------------------------------

UNIT  41      TYPE 210
MIXING OF THREE MOIST AIR STREAMS WITH LEAKAGE

1      INPUTS:
        FLOW              9 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 1
        FLOW             14 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 2
        FLOW             13 - INLET MASS FLOW RATE (POSITIVE OUT) - STREAM 3
        PRESSURE         13 - ROOM PRESSURE
        PRESSURE         27 - AMBIENT PRESSURE

2      OUTPUTS:
        FLOW             19 - OUTLET DRY AIR MASS FLOW RATE
        FLOW              0 - DRY AIR MASS FLOW RATE LOST

3      PARAMETERS:
           1.00000     LEAKAGE RESISTANCE [0.001/(KG M)]
                0.     LOCAL EXTRACT FAN MASS FLOW RATE [KG/S]
----------------------------------------------------
```

```
UNIT  42       TYPE 210
MIXING OF THREE MOIST AIR STREAMS WITH LEAKAGE

1      INPUTS:
        FLOW               10 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 1
        FLOW               15 - INLET MASS FLOW RATE (POSITIVE IN) - STREAM 2
        FLOW               14 - INLET MASS FLOW RATE (POSITIVE OUT) - STREAM 3
        PRESSURE           14 - ROOM PRESSURE
        PRESSURE           27 - AMBIENT PRESSURE

2      OUTPUTS:
        FLOW               20 - OUTLET DRY AIR MASS FLOW RATE
        FLOW                0 - DRY AIR MASS FLOW RATE LOST

3      PARAMETERS:
           1.00000     LEAKAGE RESISTANCE [0.001/(KG M)]
                0.     LOCAL EXTRACT FAN MASS FLOW RATE [KG/S]
----------------------------------------------------

UNIT  43       TYPE 229
INLET CONSTANT FLOW RESISTANCE + NEG. O/P

1      INPUTS:
        PRESSURE           11 - INLET PRESSURE
        PRESSURE           10 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW               11 - FLUID MASS FLOW RATE
        FLOW                0 - NEGATIVE OF FLUID MASS FLOW RATE

3      PARAMETERS:
          0.100000E-01 FLOW RESISTANCE  [0.001/(KG M)]
----------------------------------------------------

UNIT  44       TYPE 229
INLET CONSTANT FLOW RESISTANCE + NEG. O/P

1      INPUTS:
        PRESSURE           12 - INLET PRESSURE
        PRESSURE           11 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW               12 - FLUID MASS FLOW RATE
        FLOW                0 - NEGATIVE OF FLUID MASS FLOW RATE

3      PARAMETERS:
          0.100000E-01 FLOW RESISTANCE  [0.001/(KG M)]
----------------------------------------------------

UNIT  45       TYPE 229
INLET CONSTANT FLOW RESISTANCE + NEG. O/P

1      INPUTS:
        PRESSURE           13 - INLET PRESSURE
        PRESSURE           12 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW               13 - FLUID MASS FLOW RATE
        FLOW                0 - NEGATIVE OF FLUID MASS FLOW RATE

3      PARAMETERS:
          0.100000E-01 FLOW RESISTANCE  [0.001/(KG M)]
----------------------------------------------------

UNIT  46       TYPE 229
INLET CONSTANT FLOW RESISTANCE + NEG. O/P

1      INPUTS:
        PRESSURE           14 - INLET PRESSURE
        PRESSURE           13 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW               14 - FLUID MASS FLOW RATE
        FLOW                0 - NEGATIVE OF FLUID MASS FLOW RATE

3      PARAMETERS:
          0.100000E-01 FLOW RESISTANCE  [0.001/(KG M)]
----------------------------------------------------
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UNIT  47      TYPE 229
INLET CONSTANT FLOW RESISTANCE + NEG. O/P

1      INPUTS:
        PRESSURE          10 - INLET PRESSURE
        PRESSURE          14 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW              15 - FLUID MASS FLOW RATE
        FLOW               0 - NEGATIVE OF FLUID MASS FLOW RATE

3      PARAMETERS:
          0.100000E-01 FLOW RESISTANCE  [0.001/(KG M)]
----------------------------------------------------

UNIT  48      TYPE 204
FLOW MERGE

1      INPUTS:
        FLOW              16 - INLET MASS FLOW RATE 1
        FLOW              17 - INLET MASS FLOW RATE 2
        PRESSURE          20 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW              22 - OUTLET MASS FLOW RATE
        PRESSURE          10 - INLET PRESSURE 1
        PRESSURE          11 - INLET PRESSURE 2

3      PARAMETERS:
          0.163910E-01 INLET FLOW RESISTANCE 1 [0.001/(KG M)]
          0.354950E-01 INLET FLOW RESISTANCE 2 [0.001/(KG M)]
          0.326800E-02 OUTLET FLOW RESISTANCE [0.001/(KG M)]
----------------------------------------------------

UNIT  49      TYPE 204
FLOW MERGE

1      INPUTS:
        FLOW              18 - INLET MASS FLOW RATE 1
        FLOW              19 - INLET MASS FLOW RATE 2
        PRESSURE          19 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW              21 - OUTLET MASS FLOW RATE
        PRESSURE          12 - INLET PRESSURE 1
        PRESSURE          13 - INLET PRESSURE 2

3      PARAMETERS:
          0.108100     INLET FLOW RESISTANCE 1 [0.001/(KG M)]
          0.162170E-01 INLET FLOW RESISTANCE 2 [0.001/(KG M)]
          0.649300E-02 OUTLET FLOW RESISTANCE [0.001/(KG M)]
----------------------------------------------------

UNIT  50      TYPE 204
FLOW MERGE

1      INPUTS:
        FLOW              21 - INLET MASS FLOW RATE 1
        FLOW              20 - INLET MASS FLOW RATE 2
        PRESSURE          21 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW              23 - OUTLET MASS FLOW RATE
        PRESSURE          19 - INLET PRESSURE 1
        PRESSURE          14 - INLET PRESSURE 2

3      PARAMETERS:
          0.649300E-02 INLET FLOW RESISTANCE 1 [0.001/(KG M)]
          0.680600E-01 INLET FLOW RESISTANCE 2 [0.001/(KG M)]
          0.114200E-02 OUTLET FLOW RESISTANCE [0.001/(KG M)]
----------------------------------------------------

UNIT  51      TYPE 204
FLOW MERGE

1      INPUTS:
        FLOW              22 - INLET MASS FLOW RATE 1
        FLOW              23 - INLET MASS FLOW RATE 2
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        PRESSURE         22 - OUTLET PRESSURE

2      OUTPUTS:
        FLOW             24 - OUTLET MASS FLOW RATE
        PRESSURE         20 - INLET PRESSURE 1
        PRESSURE         21 - INLET PRESSURE 2

3      PARAMETERS:
          0.129800E-02 INLET FLOW RESISTANCE 1 [0.001/(KG M)]
          0.212000E-03 INLET FLOW RESISTANCE 2 [0.001/(KG M)]
          0.621000E-02 OUTLET FLOW RESISTANCE [0.001/(KG M)]
----------------------------------------------------

UNIT  52      TYPE 201
FAN OR PUMP - TEMP RISE CORRECTED FOR WORK DONE

1      INPUTS:
        FLOW             24 - MASS FLOW RATE OF FLUID
        PRESSURE         23 - OUTLET PRESSURE
        RVPS              2 - FAN OR PUMP ROTATIONAL SPEED
        TEMPERATURE      77 - INLET FLUID TEMPERATURE

2      OUTPUTS:
        PRESSURE         22 - INLET PRESSURE
        TEMPERATURE       0 - OUTLET FLUID TEMPERATURE
        POWER             2 - POWER CONSUMPTION

3      PARAMETERS:
           4.47318      1ST PRESSURE COEFFICIENT
          -1.30791      2ND PRESSURE COEFFICIENT
           6.16939      3RD PRESSURE COEFFICIENT
          -5.75617      4TH PRESSURE COEFFICIENT
          0.505184      5TH PRESSURE COEFFICIENT
          0.105200E-01 1ST EFFICIENCY COEFFICIENT
           2.10726      2ND EFFICIENCY COEFFICIENT
          -1.75750      3RD EFFICIENCY COEFFICIENT
          0.536622      4TH EFFICIENCY COEFFICIENT
         -0.127430      5TH EFFICIENCY COEFFICIENT
          0.518000      DIAMETER (M)
           1.00000      MODE: AIR=1, WATER=2
          0.800000      LOWEST VALID NORMALISED FLOW (-)
           1.50000      HIGHEST VALID NORMALISED FLOW (-)
----------------------------------------------------

UNIT  53      TYPE 228
CONSTANT FLOW RESISTANCE - LINEARISED AT LOW FLOW

1      INPUTS:
        FLOW             24 - FLUID MASS FLOW RATE
        PRESSURE         24 - OUTLET PRESSURE

2      OUTPUTS:
        PRESSURE         23 - INLET PRESSURE

3      PARAMETERS:
          0.267400E-02 FLOW RESISTANCE  [0.001/(KG M)]
----------------------------------------------------

UNIT  54      TYPE  26
CONTROL SIGNAL INVERTER

1      INPUTS:
        CONTROL           1 - INPUT CONTROL SIGNAL

2      OUTPUTS:
        CONTROL           0 - OUTPUT CONTROL SIGNAL

3      PARAMETERS:
                0.     MULTIPLIER [DIMENSIONLESS]
----------------------------------------------------

UNIT  55      TYPE 299
LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P

1      INPUTS:
        TEMPERATURE       1 - INLET AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    1 - INLET AIR HUMIDITY RATIO
        PRESSURE          1 - OUTLET AIR GAUGE PRESSURE
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        FLOW              2 - DRY AIR MASS FLOW RATE
        TEMPERATURE      56 - INLET WATER TEMPERATURE
        CONTROL          79 - VALVE STEM POSITION
        PRESSURE         28 - INLET WATER PRESSURE
        PRESSURE         29 - OUTLET WATER PRESSURE
        TEMPERATURE      58 - EFFECTIVE COIL SURFACE TEMPERATURE (SAME AS 1ST O

2      OUTPUTS:
        TEMPERATURE      58 - EFFECTIVE COIL SURFACE TEMPERATURE
        TEMPERATURE       3 - OUTLET DRY BULB AIR TEMPERATURE
        HUMIDITY RATIO    3 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET AIR GAUGE PRESSURE
        TEMPERATURE       0 - COIL OUTLET WATER TEMPERATURE
        TEMPERATURE      57 - RETURN MIXED WATER TEMPERATURE
        FLOW             27 - COIL WATER MASS FLOW RATE
        FLOW             26 - SUPPLY WATER MASS FLOW RATE
        POWER             0 - TOTAL HEAT TRANSFER TO THE AIR
        CONTROL           0 - SENSIBLE HEAT RATIO
        CONTROL           0 - COIL EFFECTIVENESS
        CONTROL           0 - COIL BY-PASS FACTOR
        ENERGY            0 - OUTLET AIR SPECIFIC ENTHALPY
        CONTROL           0 - OUTLET AIR RELATIVE HUMIDITY
        ENERGY            0 - AIR SPECIFIC ENTHALPY IN COIL SURFACE CONDITION
        TEMPERATURE       0 - OUTLET AIR WET-BULB TEMPERATURE

3      PARAMETERS:
           1.00000     METHOD : 0 FOR STEADY STATE, 1 FOR LIEGE DYNAMICS
                0.     FAULT  : 0 FOR NO FAULTS, ...
                0.     PSYCHO : 0 FOR NO PSYCHOMETRIC OUTPUT CALCS
           6.00000     NUMBER OF ROWS OF TUBES
           45.0000     NUMBER OF TUBES PER ROW
           45.0000     NUMBER OF PARALLEL WATER CIRCUITS
          0.192000     LENGTH OF FINNED SECTION IN DIRECTION OF FLOW (M)
           1.44000     HEIGHT OF FINNED SECTION (M)
           1.36000     WIDTH OF FINNED SECTION (M)
          0.127000E-01 TUBE OUTSIDE DIAMETER (M)
          0.430000E-03 TUBE WALL THICKNESS (M)
           2.00000     TUBE MATERIAL (AL=1,CU=2,FE=3,CaCO3=4)
          0.210000E-02 FIN SPACING (PITCH) (M)
          0.140000E-03 FIN THICKNESS (M)
           1.00000     FIN MATERIAL (AL=1,CU=2,FE=3)
          0.486000E-02 FLOW RESISTANCE PARAMETER ON AIR SIDE (0.001 KG.M)
           31.0000     Kv: VALVE CAPACITY INDEX (CU. M/HR AT 1 BAR)
           1.00000     VALVE MODE: (0=LIN/LIN, 1=EXP/LIN, 2=EXP/EXP, 3=LIN/EXP
           3.00000     VALVE CHARACTERISTIC EXPONENT Ngl (-)
           100.000     ADJUSTING RATIO (>1) (-)
          0.200000E-03 VALVE LEAKAGE (FRACTIONAL FLOW WHEN CLOSED) (-)
          0.522000     COIL HYDRAULIC RESISTANCE (0.001 KG.M)
          0.522000     BYPASS HYDRAULIC RESISTANCE (0.001 KG.M)
----------------------------------------------------

UNIT  56      TYPE 299
LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P

1      INPUTS:
        TEMPERATURE       3 - INLET AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    3 - INLET AIR HUMIDITY RATIO
        PRESSURE          1 - OUTLET AIR GAUGE PRESSURE
        FLOW              2 - DRY AIR MASS FLOW RATE
        TEMPERATURE      59 - INLET WATER TEMPERATURE
        CONTROL          80 - VALVE STEM POSITION
        PRESSURE         30 - INLET WATER PRESSURE
        PRESSURE         31 - OUTLET WATER PRESSURE
        TEMPERATURE      61 - EFFECTIVE COIL SURFACE TEMPERATURE (SAME AS 1ST O

2      OUTPUTS:
        TEMPERATURE      61 - EFFECTIVE COIL SURFACE TEMPERATURE
        TEMPERATURE       4 - OUTLET DRY BULB AIR TEMPERATURE
        HUMIDITY RATIO    0 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET AIR GAUGE PRESSURE
        TEMPERATURE       0 - COIL OUTLET WATER TEMPERATURE
        TEMPERATURE      60 - RETURN MIXED WATER TEMPERATURE
        FLOW             29 - COIL WATER MASS FLOW RATE
        FLOW             28 - SUPPLY WATER MASS FLOW RATE
        POWER             0 - TOTAL HEAT TRANSFER TO THE AIR
        CONTROL           0 - SENSIBLE HEAT RATIO
        CONTROL           0 - COIL EFFECTIVENESS
        CONTROL           0 - COIL BY-PASS FACTOR
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        ENERGY            0 - OUTLET AIR SPECIFIC ENTHALPY
        CONTROL           0 - OUTLET AIR RELATIVE HUMIDITY
        ENERGY            0 - AIR SPECIFIC ENTHALPY IN COIL SURFACE CONDITION
        TEMPERATURE       0 - OUTLET AIR WET-BULB TEMPERATURE

3      PARAMETERS:
           1.00000      METHOD : 0 FOR STEADY STATE, 1 FOR LIEGE DYNAMICS
                0.      FAULT  : 0 FOR NO FAULTS, ...
                0.      PSYCHO : 0 FOR NO PSYCHOMETRIC OUTPUT CALCS
           1.00000      NUMBER OF ROWS OF TUBES
           48.0000      NUMBER OF TUBES PER ROW
           6.00000      NUMBER OF PARALLEL WATER CIRCUITS
          0.380000E-01 LENGTH OF FINNED SECTION IN DIRECTION OF FLOW (M)
           1.44000      HEIGHT OF FINNED SECTION (M)
           1.36000      WIDTH OF FINNED SECTION (M)
          0.127000E-01 TUBE OUTSIDE DIAMETER (M)
          0.430000E-03 TUBE WALL THICKNESS (M)
           2.00000      TUBE MATERIAL (AL=1,CU=2,FE=3,CaCO3=4)
          0.250000E-02 FIN SPACING (PITCH) (M)
          0.160000E-03 FIN THICKNESS (M)
           1.00000      FIN MATERIAL (AL=1,CU=2,FE=3)
          0.328000E-03 FLOW RESISTANCE PARAMETER ON AIR SIDE (0.001 KG.M)
           10.0000      Kv: VALVE CAPACITY INDEX (CU. M/HR AT 1 BAR)
           1.00000      VALVE MODE: (0=LIN/LIN, 1=EXP/LIN, 2=EXP/EXP, 3=LIN/EXP
           3.00000      VALVE CHARACTERISTIC EXPONENT Ngl (-)
           100.000      ADJUSTING RATIO (>1) (-)
          0.200000E-03 VALVE LEAKAGE (FRACTIONAL FLOW WHEN CLOSED) (-)
           11.0400      COIL HYDRAULIC RESISTANCE (0.001 KG.M)
           11.0400      BYPASS HYDRAULIC RESISTANCE (0.001 KG.M)
-----------------------------------------------------

UNIT  57      TYPE 205
FAN OR PUMP - POWER AND TEMP RISE ONLY

1      INPUTS:
        CONTROL         120 - ON/OFF SWITCH
        TEMPERATURE       4 - INLET FLUID TEMPERATURE
        FLOW              2 - MASS FLOW RATE OF FLUID

2      OUTPUTS:
        PRESSURE         42 - TOTAL PRESSURE RISE
        TEMPERATURE       5 - OUTLET FLUID TEMPERATURE
        POWER             3 - POWER CONSUMPTION
        RVPS              3 - ROTATION SPEED

3      PARAMETERS:
           4.47318      1ST PRESSURE COEFFICIENT
          -1.30791      2ND PRESSURE COEFFICIENT
           6.16939      3RD PRESSURE COEFFICIENT
          -5.75617      4TH PRESSURE COEFFICIENT
          0.505184      5TH PRESSURE COEFFICIENT
          0.105200E-01 1ST EFFICIENCY COEFFICIENT
           2.10726      2ND EFFICIENCY COEFFICIENT
          -1.75750      3RD EFFICIENCY COEFFICIENT
          0.536622      4TH EFFICIENCY COEFFICIENT
         -0.127430      5TH EFFICIENCY COEFFICIENT
          0.570000      DIAMETER (M)
           1.00000      MODE: AIR=1, WATER=2
          0.800000      LOWEST VALID NORMALISED FLOW (-)
           1.50000      HIGHEST VALID NORMALISED FLOW (-)
          0.300000      STATIC PRESSURE SET-POINT (ZERO FOR RETURN FAN) [KPA]
          0.158000      DUCT/PIPE CROSS SECTIONAL AREA AT SENSOR (M2)
          0.830000E-02 RESISTANCE OF DUCT/PIPE SYSTEM UPSTREAM OF SENSOR (0.00
-----------------------------------------------------

UNIT  58      TYPE 212
MIXING OF FIVE MOIST AIR STREAMS

1      INPUTS:
        TEMPERATURE      51 - INLET AIR DRY BULB TEMPERATURE - STREAM 1
        HUMIDITY RATIO   19 - INLET AIR HUMIDITY RATIO - STREAM 1
        FLOW             16 - INLET DRY AIR MASS FLOW RATE - STREAM 1
        TEMPERATURE      52 - INLET AIR DRY BULB TEMPERATURE - STREAM 2
        HUMIDITY RATIO   20 - INLET AIR HUMIDITY RATIO - STREAM 2
        FLOW             17 - INLET DRY AIR MASS FLOW RATE - STREAM 2
        TEMPERATURE      53 - INLET AIR DRY BULB TEMPERATURE - STREAM 3
        HUMIDITY RATIO   21 - INLET AIR HUMIDITY RATIO - STREAM 3
        FLOW             18 - INLET DRY AIR MASS FLOW RATE - STREAM 3
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       TEMPERATURE      54 - INLET AIR DRY BULB TEMPERATURE - STREAM 4
       HUMIDITY RATIO   22 - INLET AIR HUMIDITY RATIO - STREAM 4
       FLOW             19 - INLET DRY AIR MASS FLOW RATE - STREAM 4
       TEMPERATURE      54 - INLET AIR DRY BULB TEMPERATURE - STREAM 5
       HUMIDITY RATIO   23 - INLET AIR HUMIDITY RATIO - STREAM 5
       FLOW             20 - INLET DRY AIR MASS FLOW RATE - STREAM 5

2      OUTPUTS:
       TEMPERATURE      77 - OUTLET AIR DRY BULB TEMPERATURE
       HUMIDITY RATIO   24 - OUTLET AIR HUMIDITY RATIO
       FLOW              0 - OUTLET DRY AIR MASS FLOW RATE

3      PARAMETERS:
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UNIT  59       TYPE 205
FAN OR PUMP - POWER AND TEMP RISE ONLY

1      INPUTS:
       CONTROL         120 - ON/OFF SWITCH
       TEMPERATURE      77 - INLET FLUID TEMPERATURE
       FLOW             24 - MASS FLOW RATE OF FLUID

2      OUTPUTS:
       PRESSURE         43 - TOTAL PRESSURE RISE
       TEMPERATURE      78 - OUTLET FLUID TEMPERATURE
       POWER             4 - POWER CONSUMPTION
       RVPS              4 - ROTATION SPEED

3      PARAMETERS:
          4.47318      1ST PRESSURE COEFFICIENT
         -1.30791      2ND PRESSURE COEFFICIENT
          6.16939      3RD PRESSURE COEFFICIENT
         -5.75617      4TH PRESSURE COEFFICIENT
         0.505184      5TH PRESSURE COEFFICIENT
         0.105200E-01 1ST EFFICIENCY COEFFICIENT
          2.10726      2ND EFFICIENCY COEFFICIENT
         -1.75750      3RD EFFICIENCY COEFFICIENT
         0.536622      4TH EFFICIENCY COEFFICIENT
        -0.127430      5TH EFFICIENCY COEFFICIENT
         0.519000      DIAMETER (M)
          1.00000      MODE: AIR=1, WATER=2
         0.800000      LOWEST VALID NORMALISED FLOW (-)
          1.50000      HIGHEST VALID NORMALISED FLOW (-)
               0.      STATIC PRESSURE SET-POINT (ZERO FOR RETURN FAN) [KPA]
          999.000      DUCT/PIPE CROSS SECTIONAL AREA AT SENSOR (M2)
         0.170000E-01 RESISTANCE OF DUCT/PIPE SYSTEM UPSTREAM OF SENSOR (0.00
---------------------------------------------------

UNIT  60       TYPE 211
MIXING OF TWO MOIST AIR STREAMS

1      INPUTS:
       TEMPERATURE       1 - INLET AIR DRY BULB TEMPERATURE - STREAM 1
       HUMIDITY RATIO    1 - INLET AIR HUMIDITY RATIO - STREAM 1
       FLOW              1 - INLET DRY AIR MASS FLOW RATE - STREAM 1
       TEMPERATURE      78 - INLET AIR DRY BULB TEMPERATURE - STREAM 2
       HUMIDITY RATIO   24 - INLET AIR HUMIDITY RATIO - STREAM 2
       FLOW             25 - INLET DRY AIR MASS FLOW RATE - STREAM 2

2      OUTPUTS:
       TEMPERATURE       2 - OUTLET AIR DRY BULB TEMPERATURE
       HUMIDITY RATIO    2 - OUTLET AIR HUMIDITY RATIO
       FLOW              0 - OUTLET DRY AIR MASS FLOW RATE

3      PARAMETERS:
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UNIT  61       TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1      INPUTS:
       FLOW              6 - AIR MASS FLOW RATE
       PRESSURE          1 - OUTLET PRESSURE
       TEMPERATURE       5 - INLET AIR TEMPERATURE
       HUMIDITY RATIO    3 - INLET AIR HUMIDITY RATIO
       TEMPERATURE      31 - EXTERNAL TEMPERATURE
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2      OUTPUTS:
        TEMPERATURE      6 - OUTLET AIR TEMPERATURE
        HUMIDITY RATIO   4 - OUTLET AIR HUMIDITY RATIO
        PRESSURE         0 - INLET PRESSURE
        POWER            5 - HEAT LOSS RATE

3      PARAMETERS:
           1.00000     SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
          0.500000     SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
           20.0000     LENGTH OF CONDUIT (M)
         0.200000E-02  WALL THICKNESS  (M)
           3.00000     WALL MATERIAL (AL=1, CU=2, FE=3)
          0.173300     R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
                0.     FLOW RESISTANCE (0.001 KG.M)
                0.     HEIGHT OF OUTLET ABOVE INLET (M)
----------------------------------------------------

UNIT  62      TYPE 299
LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P

1      INPUTS:
        TEMPERATURE      6 - INLET AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO   4 - INLET AIR HUMIDITY RATIO
        PRESSURE         1 - OUTLET AIR GAUGE PRESSURE
        FLOW             6 - DRY AIR MASS FLOW RATE
        TEMPERATURE     62 - INLET WATER TEMPERATURE
        CONTROL         81 - VALVE STEM POSITION
        PRESSURE        32 - INLET WATER PRESSURE
        PRESSURE        37 - OUTLET WATER PRESSURE
        TEMPERATURE     72 - EFFECTIVE COIL SURFACE TEMPERATURE (SAME AS 1ST O

2      OUTPUTS:
        TEMPERATURE     72 - EFFECTIVE COIL SURFACE TEMPERATURE
        TEMPERATURE     11 - OUTLET DRY BULB AIR TEMPERATURE
        HUMIDITY RATIO   0 - OUTLET AIR HUMIDITY RATIO
        PRESSURE         0 - INLET AIR GAUGE PRESSURE
        TEMPERATURE      0 - COIL OUTLET WATER TEMPERATURE
        TEMPERATURE     67 - RETURN MIXED WATER TEMPERATURE
        FLOW             0 - COIL WATER MASS FLOW RATE
        FLOW            30 - SUPPLY WATER MASS FLOW RATE
        POWER            0 - TOTAL HEAT TRANSFER TO THE AIR
        CONTROL          0 - SENSIBLE HEAT RATIO
        CONTROL          0 - COIL EFFECTIVENESS
        CONTROL          0 - COIL BY-PASS FACTOR
        ENERGY           0 - OUTLET AIR SPECIFIC ENTHALPY
        CONTROL          0 - OUTLET AIR RELATIVE HUMIDITY
        ENERGY           0 - AIR SPECIFIC ENTHALPY IN COIL SURFACE CONDITION
        TEMPERATURE      0 - OUTLET AIR WET-BULB TEMPERATURE

3      PARAMETERS:
           1.00000     METHOD : 0 FOR STEADY STATE, 1 FOR LIEGE DYNAMICS
                0.     FAULT  : 0 FOR NO FAULTS, ...
                0.     PSYCHO : 0 FOR NO PSYCHOMETRIC OUTPUT CALCS
           1.00000     NUMBER OF ROWS OF TUBES
           24.0000     NUMBER OF TUBES PER ROW
           3.00000     NUMBER OF PARALLEL WATER CIRCUITS
         0.380000E-01  LENGTH OF FINNED SECTION IN DIRECTION OF FLOW (M)
         0.720000      HEIGHT OF FINNED SECTION (M)
         0.680000      WIDTH OF FINNED SECTION (M)
         0.127000E-01  TUBE OUTSIDE DIAMETER (M)
         0.430000E-03  TUBE WALL THICKNESS (M)
           2.00000     TUBE MATERIAL (AL=1,CU=2,FE=3,CaCO3=4)
         0.250000E-02  FIN SPACING (PITCH) (M)
         0.160000E-03  FIN THICKNESS (M)
           1.00000     FIN MATERIAL (AL=1,CU=2,FE=3)
                0.     FLOW RESISTANCE PARAMETER ON AIR SIDE (0.001 KG.M)
           5.54000     Kv: VALVE CAPACITY INDEX (CU. M/HR AT 1 BAR)
           1.00000     VALVE MODE: (0=LIN/LIN, 1=EXP/LIN, 2=EXP/EXP, 3=LIN/EXP
           3.00000     VALVE CHARACTERISTIC EXPONENT Ngl (-)
           100.000     ADJUSTING RATIO (>1) (-)
         0.100000E-01  VALVE LEAKAGE (FRACTIONAL FLOW WHEN CLOSED) (-)
           42.2000     COIL HYDRAULIC RESISTANCE (0.001 KG.M)
           42.2000     BYPASS HYDRAULIC RESISTANCE (0.001 KG.M)
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UNIT  63       TYPE 272
2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, DUCTED RETURN

1      INPUTS:
        TEMPERATURE     11 - SUPPLY AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO   4 - SUPPLY AIR HUMIDITY RATIO
        FLOW             6 - SUPPLY DRY AIR MASS FLOW RATE
        TEMPERATURE     17 - INTERZONE 1 AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO  10 - INTERZONE 1 AIR HUMIDITY RATIO
        FLOW            11 - INTERZONE 1 DRY AIR MASS FLOW RATE
        TEMPERATURE     20 - INTERZONE 2 AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO  13 - INTERZONE 2 AIR HUMIDITY RATIO
        FLOW            15 - INTERZONE 2 DRY AIR MASS FLOW RATE
        FLOW            16 - EXTRACT DRY AIR MASS FLOW RATE
        TEMPERATURE     26 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR ROOM
        TEMPERATURE     41 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR PLENUM
        TEMPERATURE      1 - AMBIENT DRY BULB TEMPERATURE
        HUMIDITY RATIO   1 - AMBIENT HUMIDITY RATIO
        CONTROL         86 - FRACTIONAL OCCUPANCY
        CONTROL         91 - FRACTIONAL LIGHTING HEAT GAIN
        CONTROL         96 - FRACTIONAL EQUIPMENT HEAT GAIN
        POWER            5 - HEAT GAIN FROM SUPPLY DUCT
        POWER           10 - HEAT GAIN FROM EXTRACT DUCT
        TEMPERATURE     16 - ROOM TEMPERATURE (SAME AS 1ST OUTPUT)
        TEMPERATURE     21 - ROOM STRUCTURE TEMPERATURE (SAME AS 2ND OUTPUT)
        TEMPERATURE     31 - PLENUM TEMPERATURE (SAME AS 3RD OUTPUT)
        TEMPERATURE     36 - PLENUM STRUCTURE TEMPERATURE (SAME AS 4TH OUTPUT)
        HUMIDITY RATIO   9 - ROOM HUMIDITY RATIO (SAME AS 5TH OUTPUT)
        HUMIDITY RATIO  14 - PLENUM HUMIDITY RATIO (SAME AS 6TH OUTPUT)

2      OUTPUTS:
        TEMPERATURE     16 - ROOM TEMPERATURE (SAME AS 11TH INPUT)
        TEMPERATURE     21 - ROOM STRUCTURE TEMPERATURE (SAME AS 12TH INPUT)
        TEMPERATURE     31 - PLENUM TEMPERATURE (SAME AS 13TH INPUT)
        TEMPERATURE     36 - PLENUM STRUCTURE TEMPERATURE (SAME AS 14TH INPUT)
        HUMIDITY RATIO   9 - ROOM HUMIDITY RATIO (SAME AS 15TH INPUT)
        HUMIDITY RATIO  14 - PLENUM HUMIDITY RATIO (SAME AS 16TH INPUT)
        TEMPERATURE     46 - RETURN TEMPERATURE
        FLOW             0 - LEAKAGE DRY AIR MASS FLOW RATE (NET)
        POWER            0 - SENSIBLE HEAT GAINS OF ROOM
        POWER            0 - SENSIBLE HEAT GAINS OF PLENUM
        FLOW             0 - WATER GAINS OF ROOM

3      PARAMETERS:
          5.00000     ROOM AIR CAPACITY MULTIPLIER (-)
          1.00000     ZONE NUMBER (PARAMETER FILE=zoneN.par, N > 0)
          4.06000     RWSR: DIRECT RESISTANCE ROOM AIR NODE <-> AMBIENT (K/KW
          8.23000     RISR: RESISTANCE ROOM AIR NODE <-> ROOM MASS NODE (K/KW
          10000.0     ROSR: RESISTANCE AMBIENT <-> ROOM MASS NODE (K/KW)
          10000.0     RWSP: DIRECT RESISTANCE PLENUM AIR NODE <-> AMBIENT (K/
         0.410000     RISP: RESISTANCE PLENUM AIR NODE <-> PLENUM MASS NODE (
          10000.0     ROSP: RESISTANCE AMBIENT <-> PLENUM MASS NODE (K/KW)
          2.28000     RR: RESISTANCE ROOM AIR NODE <-> PLENUM AIR NODE (K/KW)
          22828.1     CSR: CAPACITANCE OF ROOM MASS NODE (KJ/K)
          667.640     CR: CAPACITANCE OF ROOM AIR NODE (UNMODIFIED) (KJ/K)
          17428.0     CSP: CAPACITANCE OF PLENUM MASS NODE (KJ/K)
          255.830     CP: CAPACITANCE OF PLENUM AIR NODE (KJ/K)
          575.500     VOLUME OF ROOM (M3)
          220.500     VOLUME OF PLENUM (M3)
          22.0000     NUMBER OF OCCUPANTS (-)
          2.15200     LIGHTING HEAT GAIN (KW)
         0.500000     FRACTION OF LIGHTING HEAT GAIN TO PLENUM
               0.     EQUIPMENT HEAT GAIN (KW)
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UNIT  64       TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1      INPUTS:
        FLOW            16 - AIR MASS FLOW RATE
        PRESSURE         1 - OUTLET PRESSURE
        TEMPERATURE     46 - INLET AIR TEMPERATURE
        HUMIDITY RATIO   9 - INLET AIR HUMIDITY RATIO
        TEMPERATURE     31 - EXTERNAL TEMPERATURE

2      OUTPUTS:
        TEMPERATURE     51 - OUTLET AIR TEMPERATURE
        HUMIDITY RATIO  19 - OUTLET AIR HUMIDITY RATIO
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        PRESSURE          0 - INLET PRESSURE
        POWER            10 - HEAT LOSS RATE

3      PARAMETERS:
          1.00000      SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
         0.500000      SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
          20.0000      LENGTH OF CONDUIT (M)
         0.200000E-02  WALL THICKNESS  (M)
          3.00000      WALL MATERIAL (AL=1, CU=2, FE=3)
         0.173300      R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
               0.      FLOW RESISTANCE (0.001 KG.M)
               0.      HEIGHT OF OUTLET ABOVE INLET (M)
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UNIT  65      TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1      INPUTS:
        FLOW              7 - AIR MASS FLOW RATE
        PRESSURE          1 - OUTLET PRESSURE
        TEMPERATURE       5 - INLET AIR TEMPERATURE
        HUMIDITY RATIO    3 - INLET AIR HUMIDITY RATIO
        TEMPERATURE      32 - EXTERNAL TEMPERATURE

2      OUTPUTS:
        TEMPERATURE       7 - OUTLET AIR TEMPERATURE
        HUMIDITY RATIO    5 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET PRESSURE
        POWER             6 - HEAT LOSS RATE

3      PARAMETERS:
          1.00000      SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
         0.500000      SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
          20.0000      LENGTH OF CONDUIT (M)
         0.200000E-02  WALL THICKNESS  (M)
          3.00000      WALL MATERIAL (AL=1, CU=2, FE=3)
         0.173300      R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
               0.      FLOW RESISTANCE (0.001 KG.M)
               0.      HEIGHT OF OUTLET ABOVE INLET (M)
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UNIT  66      TYPE 299
LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P

1      INPUTS:
        TEMPERATURE       7 - INLET AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    5 - INLET AIR HUMIDITY RATIO
        PRESSURE          1 - OUTLET AIR GAUGE PRESSURE
        FLOW              7 - DRY AIR MASS FLOW RATE
        TEMPERATURE      63 - INLET WATER TEMPERATURE
        CONTROL          82 - VALVE STEM POSITION
        PRESSURE         33 - INLET WATER PRESSURE
        PRESSURE         38 - OUTLET WATER PRESSURE
        TEMPERATURE      73 - EFFECTIVE COIL SURFACE TEMPERATURE (SAME AS 1ST O

2      OUTPUTS:
        TEMPERATURE      73 - EFFECTIVE COIL SURFACE TEMPERATURE
        TEMPERATURE      12 - OUTLET DRY BULB AIR TEMPERATURE
        HUMIDITY RATIO    0 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET AIR GAUGE PRESSURE
        TEMPERATURE       0 - COIL OUTLET WATER TEMPERATURE
        TEMPERATURE      68 - RETURN MIXED WATER TEMPERATURE
        FLOW              0 - COIL WATER MASS FLOW RATE
        FLOW             31 - SUPPLY WATER MASS FLOW RATE
        POWER             0 - TOTAL HEAT TRANSFER TO THE AIR
        CONTROL           0 - SENSIBLE HEAT RATIO
        CONTROL           0 - COIL EFFECTIVENESS
        CONTROL           0 - COIL BY-PASS FACTOR
        ENERGY            0 - OUTLET AIR SPECIFIC ENTHALPY
        CONTROL           0 - OUTLET AIR RELATIVE HUMIDITY
        ENERGY            0 - AIR SPECIFIC ENTHALPY IN COIL SURFACE CONDITION
        TEMPERATURE       0 - OUTLET AIR WET-BULB TEMPERATURE

3      PARAMETERS:
          1.00000      METHOD : 0 FOR STEADY STATE, 1 FOR LIEGE DYNAMICS
               0.      FAULT  : 0 FOR NO FAULTS, ...
               0.      PSYCHO : 0 FOR NO PSYCHOMETRIC OUTPUT CALCS
          1.00000      NUMBER OF ROWS OF TUBES
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         24.0000      NUMBER OF TUBES PER ROW
         3.00000      NUMBER OF PARALLEL WATER CIRCUITS
        0.380000E-01 LENGTH OF FINNED SECTION IN DIRECTION OF FLOW (M)
        0.720000      HEIGHT OF FINNED SECTION (M)
        0.680000      WIDTH OF FINNED SECTION (M)
        0.127000E-01 TUBE OUTSIDE DIAMETER (M)
        0.430000E-03 TUBE WALL THICKNESS (M)
         2.00000      TUBE MATERIAL (AL=1,CU=2,FE=3,CaCO3=4)
        0.250000E-02 FIN SPACING (PITCH) (M)
        0.160000E-03 FIN THICKNESS (M)
         1.00000      FIN MATERIAL (AL=1,CU=2,FE=3)
              0.      FLOW RESISTANCE PARAMETER ON AIR SIDE (0.001 KG.M)
         2.68000      Kv: VALVE CAPACITY INDEX (CU. M/HR AT 1 BAR)
         1.00000      VALVE MODE: (0=LIN/LIN, 1=EXP/LIN, 2=EXP/EXP, 3=LIN/EXP
         3.00000      VALVE CHARACTERISTIC EXPONENT Ngl (-)
         100.000      ADJUSTING RATIO (>1) (-)
        0.100000E-02 VALVE LEAKAGE (FRACTIONAL FLOW WHEN CLOSED) (-)
         180.200      COIL HYDRAULIC RESISTANCE (0.001 KG.M)
         180.200      BYPASS HYDRAULIC RESISTANCE (0.001 KG.M)
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UNIT 67      TYPE 272
2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, DUCTED RETURN

1      INPUTS:
        TEMPERATURE      12 - SUPPLY AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    5 - SUPPLY AIR HUMIDITY RATIO
        FLOW              7 - SUPPLY DRY AIR MASS FLOW RATE
        TEMPERATURE      18 - INTERZONE 1 AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO   11 - INTERZONE 1 AIR HUMIDITY RATIO
        FLOW             12 - INTERZONE 1 DRY AIR MASS FLOW RATE
        TEMPERATURE      16 - INTERZONE 2 AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    9 - INTERZONE 2 AIR HUMIDITY RATIO
        FLOW             11 - INTERZONE 2 DRY AIR MASS FLOW RATE
        FLOW             17 - EXTRACT DRY AIR MASS FLOW RATE
        TEMPERATURE      27 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR ROOM
        TEMPERATURE      42 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR PLENUM
        TEMPERATURE       1 - AMBIENT DRY BULB TEMPERATURE
        HUMIDITY RATIO    1 - AMBIENT HUMIDITY RATIO
        CONTROL          87 - FRACTIONAL OCCUPANCY
        CONTROL          92 - FRACTIONAL LIGHTING HEAT GAIN
        CONTROL          97 - FRACTIONAL EQUIPMENT HEAT GAIN
        POWER             6 - HEAT GAIN FROM SUPPLY DUCT
        POWER            11 - HEAT GAIN FROM EXTRACT DUCT
        TEMPERATURE      17 - ROOM TEMPERATURE (SAME AS 1ST OUTPUT)
        TEMPERATURE      22 - ROOM STRUCTURE TEMPERATURE (SAME AS 2ND OUTPUT)
        TEMPERATURE      32 - PLENUM TEMPERATURE (SAME AS 3RD OUTPUT)
        TEMPERATURE      37 - PLENUM STRUCTURE TEMPERATURE (SAME AS 4TH OUTPUT)
        HUMIDITY RATIO   10 - ROOM HUMIDITY RATIO (SAME AS 5TH OUTPUT)
        HUMIDITY RATIO   15 - PLENUM HUMIDITY RATIO (SAME AS 6TH OUTPUT)

2      OUTPUTS:
        TEMPERATURE      17 - ROOM TEMPERATURE (SAME AS 11TH INPUT)
        TEMPERATURE      22 - ROOM STRUCTURE TEMPERATURE (SAME AS 12TH INPUT)
        TEMPERATURE      32 - PLENUM TEMPERATURE (SAME AS 13TH INPUT)
        TEMPERATURE      37 - PLENUM STRUCTURE TEMPERATURE (SAME AS 14TH INPUT)
        HUMIDITY RATIO   10 - ROOM HUMIDITY RATIO (SAME AS 15TH INPUT)
        HUMIDITY RATIO   15 - PLENUM HUMIDITY RATIO (SAME AS 16TH INPUT)
        TEMPERATURE      47 - RETURN TEMPERATURE
        FLOW              0 - LEAKAGE DRY AIR MASS FLOW RATE (NET)
        POWER             0 - SENSIBLE HEAT GAINS OF ROOM
        POWER             0 - SENSIBLE HEAT GAINS OF PLENUM
        FLOW              0 - WATER GAINS OF ROOM

3      PARAMETERS:
         5.00000      ROOM AIR CAPACITY MULTIPLIER (-)
         2.00000      ZONE NUMBER (PARAMETER FILE=zoneN.par, N > 0)
         9.65000      RWSR: DIRECT RESISTANCE ROOM AIR NODE <-> AMBIENT (K/KW
         17.9400      RISR: RESISTANCE ROOM AIR NODE <-> ROOM MASS NODE (K/KW
         10000.0      ROSR: RESISTANCE AMBIENT <-> ROOM MASS NODE (K/KW)
         10000.0      RWSP: DIRECT RESISTANCE PLENUM AIR NODE <-> AMBIENT (K/
        0.560000      RISP: RESISTANCE PLENUM AIR NODE <-> PLENUM MASS NODE (
         10000.0      ROSP: RESISTANCE AMBIENT <-> PLENUM MASS NODE (K/KW)
         3.09000      RR: RESISTANCE ROOM AIR NODE <-> PLENUM AIR NODE (K/KW)
         15269.3      CSR: CAPACITANCE OF ROOM MASS NODE (KJ/K)
         491.980      CR: CAPACITANCE OF ROOM AIR NODE (UNMODIFIED) (KJ/K)
         12842.5      CSP: CAPACITANCE OF PLENUM MASS NODE (KJ/K)
         188.520      CP: CAPACITANCE OF PLENUM AIR NODE (KJ/K)
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          424.100      VOLUME OF ROOM (M3)
          162.500      VOLUME OF PLENUM (M3)
          16.0000      NUMBER OF OCCUPANTS (-)
          1.58600      LIGHTING HEAT GAIN (KW)
         0.500000      FRACTION OF LIGHTING HEAT GAIN TO PLENUM
               0.      EQUIPMENT HEAT GAIN (KW)
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UNIT  68      TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1      INPUTS:
        FLOW             17 - AIR MASS FLOW RATE
        PRESSURE          1 - OUTLET PRESSURE
        TEMPERATURE      47 - INLET AIR TEMPERATURE
        HUMIDITY RATIO   10 - INLET AIR HUMIDITY RATIO
        TEMPERATURE      32 - EXTERNAL TEMPERATURE

2      OUTPUTS:
        TEMPERATURE      52 - OUTLET AIR TEMPERATURE
        HUMIDITY RATIO   20 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET PRESSURE
        POWER             0 - HEAT LOSS RATE

3      PARAMETERS:
          1.00000      SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
         0.500000      SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
          20.0000      LENGTH OF CONDUIT (M)
         0.200000E-02  WALL THICKNESS  (M)
          3.00000      WALL MATERIAL (AL=1, CU=2, FE=3)
         0.173000      R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
               0.      FLOW RESISTANCE (0.001 KG.M)
               0.      HEIGHT OF OUTLET ABOVE INLET (M)
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UNIT  69      TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1      INPUTS:
        FLOW              8 - AIR MASS FLOW RATE
        PRESSURE          1 - OUTLET PRESSURE
        TEMPERATURE       5 - INLET AIR TEMPERATURE
        HUMIDITY RATIO    3 - INLET AIR HUMIDITY RATIO
        TEMPERATURE      33 - EXTERNAL TEMPERATURE

2      OUTPUTS:
        TEMPERATURE       8 - OUTLET AIR TEMPERATURE
        HUMIDITY RATIO    6 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET PRESSURE
        POWER             7 - HEAT LOSS RATE

3      PARAMETERS:
          1.00000      SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
         0.500000      SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
          20.0000      LENGTH OF CONDUIT (M)
         0.200000E-02  WALL THICKNESS  (M)
          3.00000      WALL MATERIAL (AL=1, CU=2, FE=3)
         0.173300      R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
               0.      FLOW RESISTANCE (0.001 KG.M)
               0.      HEIGHT OF OUTLET ABOVE INLET (M)
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UNIT  70      TYPE 299
LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P

1      INPUTS:
        TEMPERATURE       8 - INLET AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    6 - INLET AIR HUMIDITY RATIO
        PRESSURE          1 - OUTLET AIR GAUGE PRESSURE
        FLOW              8 - DRY AIR MASS FLOW RATE
        TEMPERATURE      64 - INLET WATER TEMPERATURE
        CONTROL          83 - VALVE STEM POSITION
        PRESSURE         34 - INLET WATER PRESSURE
        PRESSURE         39 - OUTLET WATER PRESSURE
        TEMPERATURE      74 - EFFECTIVE COIL SURFACE TEMPERATURE (SAME AS 1ST O
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2      OUTPUTS:
        TEMPERATURE      74 - EFFECTIVE COIL SURFACE TEMPERATURE
        TEMPERATURE      13 - OUTLET DRY BULB AIR TEMPERATURE
        HUMIDITY RATIO    0 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET AIR GAUGE PRESSURE
        TEMPERATURE       0 - COIL OUTLET WATER TEMPERATURE
        TEMPERATURE      69 - RETURN MIXED WATER TEMPERATURE
        FLOW              0 - COIL WATER MASS FLOW RATE
        FLOW             32 - SUPPLY WATER MASS FLOW RATE
        POWER             0 - TOTAL HEAT TRANSFER TO THE AIR
        CONTROL           0 - SENSIBLE HEAT RATIO
        CONTROL           0 - COIL EFFECTIVENESS
        CONTROL           0 - COIL BY-PASS FACTOR
        ENERGY            0 - OUTLET AIR SPECIFIC ENTHALPY
        CONTROL           0 - OUTLET AIR RELATIVE HUMIDITY
        ENERGY            0 - AIR SPECIFIC ENTHALPY IN COIL SURFACE CONDITION
        TEMPERATURE       0 - OUTLET AIR WET-BULB TEMPERATURE

3      PARAMETERS:
           1.00000     METHOD : 0 FOR STEADY STATE, 1 FOR LIEGE DYNAMICS
                0.     FAULT  : 0 FOR NO FAULTS, ...
                0.     PSYCHO : 0 FOR NO PSYCHOMETRIC OUTPUT CALCS
           1.00000     NUMBER OF ROWS OF TUBES
           24.0000     NUMBER OF TUBES PER ROW
           3.00000     NUMBER OF PARALLEL WATER CIRCUITS
          0.380000E-01 LENGTH OF FINNED SECTION IN DIRECTION OF FLOW (M)
          0.720000     HEIGHT OF FINNED SECTION (M)
          0.680000     WIDTH OF FINNED SECTION (M)
          0.127000E-01 TUBE OUTSIDE DIAMETER (M)
          0.430000E-03 TUBE WALL THICKNESS (M)
           2.00000     TUBE MATERIAL (AL=1,CU=2,FE=3,CaCO3=4)
          0.250000E-02 FIN SPACING (PITCH) (M)
          0.160000E-03 FIN THICKNESS (M)
           1.00000     FIN MATERIAL (AL=1,CU=2,FE=3)
                0.     FLOW RESISTANCE PARAMETER ON AIR SIDE (0.001 KG.M)
           2.14000     Kv: VALVE CAPACITY INDEX (CU. M/HR AT 1 BAR)
           1.00000     VALVE MODE: (0=LIN/LIN, 1=EXP/LIN, 2=EXP/EXP, 3=LIN/EXP
           3.00000     VALVE CHARACTERISTIC EXPONENT Ngl (-)
           100.000     ADJUSTING RATIO (>1) (-)
          0.100000E-02 VALVE LEAKAGE (FRACTIONAL FLOW WHEN CLOSED) (-)
           282.150     COIL HYDRAULIC RESISTANCE (0.001 KG.M)
           282.150     BYPASS HYDRAULIC RESISTANCE (0.001 KG.M)
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UNIT  71      TYPE 272
2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, DUCTED RETURN

1      INPUTS:
        TEMPERATURE      13 - SUPPLY AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    6 - SUPPLY AIR HUMIDITY RATIO
        FLOW              8 - SUPPLY DRY AIR MASS FLOW RATE
        TEMPERATURE      19 - INTERZONE 1 AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO   12 - INTERZONE 1 AIR HUMIDITY RATIO
        FLOW             13 - INTERZONE 1 DRY AIR MASS FLOW RATE
        TEMPERATURE      17 - INTERZONE 2 AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO   10 - INTERZONE 2 AIR HUMIDITY RATIO
        FLOW             12 - INTERZONE 2 DRY AIR MASS FLOW RATE
        FLOW             18 - EXTRACT DRY AIR MASS FLOW RATE
        TEMPERATURE      28 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR ROOM
        TEMPERATURE      43 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR PLENUM
        TEMPERATURE       1 - AMBIENT DRY BULB TEMPERATURE
        HUMIDITY RATIO    1 - AMBIENT HUMIDITY RATIO
        CONTROL          88 - FRACTIONAL OCCUPANCY
        CONTROL          93 - FRACTIONAL LIGHTING HEAT GAIN
        CONTROL          98 - FRACTIONAL EQUIPMENT HEAT GAIN
        POWER             7 - HEAT GAIN FROM SUPPLY DUCT
        POWER            12 - HEAT GAIN FROM EXTRACT DUCT
        TEMPERATURE      18 - ROOM TEMPERATURE (SAME AS 1ST OUTPUT)
        TEMPERATURE      23 - ROOM STRUCTURE TEMPERATURE (SAME AS 2ND OUTPUT)
        TEMPERATURE      33 - PLENUM TEMPERATURE (SAME AS 3RD OUTPUT)
        TEMPERATURE      38 - PLENUM STRUCTURE TEMPERATURE (SAME AS 4TH OUTPUT)
        HUMIDITY RATIO   11 - ROOM HUMIDITY RATIO (SAME AS 5TH OUTPUT)
        HUMIDITY RATIO   16 - PLENUM HUMIDITY RATIO (SAME AS 6TH OUTPUT)
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 2      OUTPUTS:
         TEMPERATURE      18 - ROOM TEMPERATURE (SAME AS 11TH INPUT)
         TEMPERATURE      23 - ROOM STRUCTURE TEMPERATURE (SAME AS 12TH INPUT)
         TEMPERATURE      33 - PLENUM TEMPERATURE (SAME AS 13TH INPUT)
         TEMPERATURE      38 - PLENUM STRUCTURE TEMPERATURE (SAME AS 14TH INPUT)
         HUMIDITY RATIO   11 - ROOM HUMIDITY RATIO (SAME AS 15TH INPUT)
         HUMIDITY RATIO   16 - PLENUM HUMIDITY RATIO (SAME AS 16TH INPUT)
         TEMPERATURE      48 - RETURN TEMPERATURE
         FLOW              0 - LEAKAGE DRY AIR MASS FLOW RATE (NET)
         POWER             0 - SENSIBLE HEAT GAINS OF ROOM
         POWER             0 - SENSIBLE HEAT GAINS OF PLENUM
         FLOW              0 - WATER GAINS OF ROOM

 3      PARAMETERS:
            5.00000     ROOM AIR CAPACITY MULTIPLIER (-)
            3.00000     ZONE NUMBER (PARAMETER FILE=zoneN.par, N > 0)
            7.88000     RWSR: DIRECT RESISTANCE ROOM AIR NODE <-> AMBIENT (K/KW
            24.1900     RISR: RESISTANCE ROOM AIR NODE <-> ROOM MASS NODE (K/KW
            10000.0     ROSR: RESISTANCE AMBIENT <-> ROOM MASS NODE (K/KW)
            10000.0     RWSP: DIRECT RESISTANCE PLENUM AIR NODE <-> AMBIENT (K/
           0.480000     RISP: RESISTANCE PLENUM AIR NODE <-> PLENUM MASS NODE (
            10000.0     ROSP: RESISTANCE AMBIENT <-> PLENUM MASS NODE (K/KW)
            2.65000     RR: RESISTANCE ROOM AIR NODE <-> PLENUM AIR NODE (K/KW)
            16736.3     CSR: CAPACITANCE OF ROOM MASS NODE (KJ/K)
            572.970     CR: CAPACITANCE OF ROOM AIR NODE (UNMODIFIED) (KJ/K)
            14956.7     CSP: CAPACITANCE OF PLENUM MASS NODE (KJ/K)
            219.550     CP: CAPACITANCE OF PLENUM AIR NODE (KJ/K)
            493.900     VOLUME OF ROOM (M3)
            189.300     VOLUME OF PLENUM (M3)
            18.0000     NUMBER OF OCCUPANTS (-)
            1.84700     LIGHTING HEAT GAIN (KW)
           0.500000     FRACTION OF LIGHTING HEAT GAIN TO PLENUM
                 0.     EQUIPMENT HEAT GAIN (KW)
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UNIT  72       TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1       INPUTS:
         FLOW             18 - AIR MASS FLOW RATE
         PRESSURE          1 - OUTLET PRESSURE
         TEMPERATURE      48 - INLET AIR TEMPERATURE
         HUMIDITY RATIO   11 - INLET AIR HUMIDITY RATIO
         TEMPERATURE      33 - EXTERNAL TEMPERATURE

2       OUTPUTS:
         TEMPERATURE      53 - OUTLET AIR TEMPERATURE
         HUMIDITY RATIO   21 - OUTLET AIR HUMIDITY RATIO
         PRESSURE          0 - INLET PRESSURE
         POWER            12 - HEAT LOSS RATE

3       PARAMETERS:
            1.00000     SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
           0.500000     SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
            20.0000     LENGTH OF CONDUIT (M)
       0.200000E-02     WALL THICKNESS  (M)
            3.00000     WALL MATERIAL (AL=1, CU=2, FE=3)
           0.173300     R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
                 0.     FLOW RESISTANCE (0.001 KG.M)
                 0.     HEIGHT OF OUTLET ABOVE INLET (M)
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UNIT  73       TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1       INPUTS:
         FLOW              9 - AIR MASS FLOW RATE
         PRESSURE          1 - OUTLET PRESSURE
         TEMPERATURE       5 - INLET AIR TEMPERATURE
         HUMIDITY RATIO    3 - INLET AIR HUMIDITY RATIO
         TEMPERATURE      34 - EXTERNAL TEMPERATURE

2       OUTPUTS:
         TEMPERATURE       9 - OUTLET AIR TEMPERATURE
         HUMIDITY RATIO    7 - OUTLET AIR HUMIDITY RATIO
         PRESSURE          0 - INLET PRESSURE
         POWER             8 - HEAT LOSS RATE
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3      PARAMETERS:
          1.00000      SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
         0.500000      SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
          20.0000      LENGTH OF CONDUIT (M)
         0.200000E-02 WALL THICKNESS  (M)
               0.      WALL MATERIAL (AL=1, CU=2, FE=3)
         0.173300      R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
               0.      FLOW RESISTANCE (0.001 KG.M)
               0.      HEIGHT OF OUTLET ABOVE INLET (M)
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UNIT  74      TYPE 299
LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P

1      INPUTS:
        TEMPERATURE      9 - INLET AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO   7 - INLET AIR HUMIDITY RATIO
        PRESSURE         1 - OUTLET AIR GAUGE PRESSURE
        FLOW             9 - DRY AIR MASS FLOW RATE
        TEMPERATURE     65 - INLET WATER TEMPERATURE
        CONTROL         84 - VALVE STEM POSITION
        PRESSURE        35 - INLET WATER PRESSURE
        PRESSURE        40 - OUTLET WATER PRESSURE
        TEMPERATURE     75 - EFFECTIVE COIL SURFACE TEMPERATURE (SAME AS 1ST O

2      OUTPUTS:
        TEMPERATURE     75 - EFFECTIVE COIL SURFACE TEMPERATURE
        TEMPERATURE     14 - OUTLET DRY BULB AIR TEMPERATURE
        HUMIDITY RATIO   0 - OUTLET AIR HUMIDITY RATIO
        PRESSURE         0 - INLET AIR GAUGE PRESSURE
        TEMPERATURE      0 - COIL OUTLET WATER TEMPERATURE
        TEMPERATURE     70 - RETURN MIXED WATER TEMPERATURE
        FLOW             0 - COIL WATER MASS FLOW RATE
        FLOW            33 - SUPPLY WATER MASS FLOW RATE
        POWER            0 - TOTAL HEAT TRANSFER TO THE AIR
        CONTROL          0 - SENSIBLE HEAT RATIO
        CONTROL          0 - COIL EFFECTIVENESS
        CONTROL          0 - COIL BY-PASS FACTOR
        ENERGY           0 - OUTLET AIR SPECIFIC ENTHALPY
        CONTROL          0 - OUTLET AIR RELATIVE HUMIDITY
        ENERGY           0 - AIR SPECIFIC ENTHALPY IN COIL SURFACE CONDITION
        TEMPERATURE      0 - OUTLET AIR WET-BULB TEMPERATURE

3      PARAMETERS:
          1.00000      METHOD : 0 FOR STEADY STATE, 1 FOR LIEGE DYNAMICS
               0.      FAULT  : 0 FOR NO FAULTS, ...
               0.      PSYCHO : 0 FOR NO PSYCHOMETRIC OUTPUT CALCS
          1.00000      NUMBER OF ROWS OF TUBES
          24.0000      NUMBER OF TUBES PER ROW
          3.00000      NUMBER OF PARALLEL WATER CIRCUITS
         0.380000E-01 LENGTH OF FINNED SECTION IN DIRECTION OF FLOW (M)
         0.720000      HEIGHT OF FINNED SECTION (M)
         0.680000      WIDTH OF FINNED SECTION (M)
         0.127000E-01 TUBE OUTSIDE DIAMETER (M)
         0.430000E-03 TUBE WALL THICKNESS (M)
          2.00000      TUBE MATERIAL (AL=1,CU=2,FE=3,CaCO3=4)
         0.250000E-02 FIN SPACING (PITCH) (M)
         0.160000E-03 FIN THICKNESS (M)
          1.00000      FIN MATERIAL (AL=1,CU=2,FE=3)
               0.      FLOW RESISTANCE PARAMETER ON AIR SIDE (0.001 KG.M)
          2.99000      Kv: VALVE CAPACITY INDEX (CU. M/HR AT 1 BAR)
          1.00000      VALVE MODE: (0=LIN/LIN, 1=EXP/LIN, 2=EXP/EXP, 3=LIN/EXP
          3.00000      VALVE CHARACTERISTIC EXPONENT Ngl (-)
          100.000      ADJUSTING RATIO (>1) (-)
         0.100000E-02 VALVE LEAKAGE (FRACTIONAL FLOW WHEN CLOSED) (-)
          145.200      COIL HYDRAULIC RESISTANCE (0.001 KG.M)
          145.200      BYPASS HYDRAULIC RESISTANCE (0.001 KG.M)
---------------------------------------------------

UNIT  75      TYPE 272
2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, DUCTED RETURN

1      INPUTS:
        TEMPERATURE     14 - SUPPLY AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO   7 - SUPPLY AIR HUMIDITY RATIO
        FLOW             9 - SUPPLY DRY AIR MASS FLOW RATE
        TEMPERATURE     20 - INTERZONE 1 AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO  13 - INTERZONE 1 AIR HUMIDITY RATIO
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        FLOW              14 - INTERZONE 1 DRY AIR MASS FLOW RATE
        TEMPERATURE       18 - INTERZONE 2 AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    11 - INTERZONE 2 AIR HUMIDITY RATIO
        FLOW              13 - INTERZONE 2 DRY AIR MASS FLOW RATE
        FLOW              19 - EXTRACT DRY AIR MASS FLOW RATE
        TEMPERATURE       29 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR ROOM
        TEMPERATURE       44 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR PLENUM
        TEMPERATURE        1 - AMBIENT DRY BULB TEMPERATURE
        HUMIDITY RATIO     1 - AMBIENT HUMIDITY RATIO
        CONTROL           89 - FRACTIONAL OCCUPANCY
        CONTROL           94 - FRACTIONAL LIGHTING HEAT GAIN
        CONTROL           99 - FRACTIONAL EQUIPMENT HEAT GAIN
        POWER              8 - HEAT GAIN FROM SUPPLY DUCT
        POWER             13 - HEAT GAIN FROM EXTRACT DUCT
        TEMPERATURE       19 - ROOM TEMPERATURE (SAME AS 1ST OUTPUT)
        TEMPERATURE       24 - ROOM STRUCTURE TEMPERATURE (SAME AS 2ND OUTPUT)
        TEMPERATURE       34 - PLENUM TEMPERATURE (SAME AS 3RD OUTPUT)
        TEMPERATURE       39 - PLENUM STRUCTURE TEMPERATURE (SAME AS 4TH OUTPUT)
        HUMIDITY RATIO    12 - ROOM HUMIDITY RATIO (SAME AS 5TH OUTPUT)
        HUMIDITY RATIO    17 - PLENUM HUMIDITY RATIO (SAME AS 6TH OUTPUT)

 2      OUTPUTS:
        TEMPERATURE       19 - ROOM TEMPERATURE (SAME AS 11TH INPUT)
        TEMPERATURE       24 - ROOM STRUCTURE TEMPERATURE (SAME AS 12TH INPUT)
        TEMPERATURE       34 - PLENUM TEMPERATURE (SAME AS 13TH INPUT)
        TEMPERATURE       39 - PLENUM STRUCTURE TEMPERATURE (SAME AS 14TH INPUT)
        HUMIDITY RATIO    12 - ROOM HUMIDITY RATIO (SAME AS 15TH INPUT)
        HUMIDITY RATIO    17 - PLENUM HUMIDITY RATIO (SAME AS 16TH INPUT)
        TEMPERATURE       49 - RETURN TEMPERATURE
        FLOW               0 - LEAKAGE DRY AIR MASS FLOW RATE (NET)
        POWER              0 - SENSIBLE HEAT GAINS OF ROOM
        POWER              0 - SENSIBLE HEAT GAINS OF PLENUM
        FLOW               0 - WATER GAINS OF ROOM

 3      PARAMETERS:
            5.00000     ROOM AIR CAPACITY MULTIPLIER (-)
            4.00000     ZONE NUMBER (PARAMETER FILE=zoneN.par, N > 0)
            5.24000     RWSR: DIRECT RESISTANCE ROOM AIR NODE <-> AMBIENT (K/KW
            16.0100     RISR: RESISTANCE ROOM AIR NODE <-> ROOM MASS NODE (K/KW
            10000.0     ROSR: RESISTANCE AMBIENT <-> ROOM MASS NODE (K/KW)
            10000.0     RWSP: DIRECT RESISTANCE PLENUM AIR NODE <-> AMBIENT (K/
           0.330000     RISP: RESISTANCE PLENUM AIR NODE <-> PLENUM MASS NODE (
            10000.0     ROSP: RESISTANCE AMBIENT <-> PLENUM MASS NODE (K/KW)
            1.82000     RR: RESISTANCE ROOM AIR NODE <-> PLENUM AIR NODE (K/KW)
            24479.7     CSR: CAPACITANCE OF ROOM MASS NODE (KJ/K)
            834.740     CR: CAPACITANCE OF ROOM AIR NODE (UNMODIFIED) (KJ/K)
            21789.8     CSP: CAPACITANCE OF PLENUM MASS NODE (KJ/K)
            319.850     CP: CAPACITANCE OF PLENUM AIR NODE (KJ/K)
            719.600     VOLUME OF ROOM (M3)
            275.700     VOLUME OF PLENUM (M3)
            27.0000     NUMBER OF OCCUPANTS (-)
            2.70000     LIGHTING HEAT GAIN (KW)
           0.500000     FRACTION OF LIGHTING HEAT GAIN TO PLENUM
                 0.     EQUIPMENT HEAT GAIN (KW)
--------------------------------------------------

UNIT  76      TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

 1      INPUTS:
        FLOW              19 - AIR MASS FLOW RATE
        PRESSURE           1 - OUTLET PRESSURE
        TEMPERATURE       49 - INLET AIR TEMPERATURE
        HUMIDITY RATIO    12 - INLET AIR HUMIDITY RATIO
        TEMPERATURE       34 - EXTERNAL TEMPERATURE

 2      OUTPUTS:
        TEMPERATURE       54 - OUTLET AIR TEMPERATURE
        HUMIDITY RATIO    22 - OUTLET AIR HUMIDITY RATIO
        PRESSURE           0 - INLET PRESSURE
        POWER             13 - HEAT LOSS RATE

 3      PARAMETERS:
            1.00000     SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
           0.500000     SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
            20.0000     LENGTH OF CONDUIT (M)
         0.200000E-02   WALL THICKNESS  (M)
            3.00000     WALL MATERIAL (AL=1, CU=2, FE=3)
```

```
         0.173300     R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
               0.     FLOW RESISTANCE (0.001 KG.M)
               0.     HEIGHT OF OUTLET ABOVE INLET (M)
----------------------------------------------------

UNIT  77      TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1      INPUTS:
        FLOW             10 - AIR MASS FLOW RATE
        PRESSURE          1 - OUTLET PRESSURE
        TEMPERATURE       5 - INLET AIR TEMPERATURE
        HUMIDITY RATIO    3 - INLET AIR HUMIDITY RATIO
        TEMPERATURE      35 - EXTERNAL TEMPERATURE

2      OUTPUTS:
        TEMPERATURE      10 - OUTLET AIR TEMPERATURE
        HUMIDITY RATIO    8 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET PRESSURE
        POWER             9 - HEAT LOSS RATE

3      PARAMETERS:
          1.00000     SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
         0.500000     SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
          20.0000     LENGTH OF CONDUIT (M)
         0.200000E-02 WALL THICKNESS  (M)
          3.00000     WALL MATERIAL (AL=1, CU=2, FE=3)
         0.173300     R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
               0.     FLOW RESISTANCE (0.001 KG.M)
               0.     HEIGHT OF OUTLET ABOVE INLET (M)
----------------------------------------------------

UNIT  78      TYPE 299
LIEGE COIL AND L&G VALVE, WATER PRESSURE I/P

1      INPUTS:
        TEMPERATURE      10 - INLET AIR DRY BULB TEMPERATURE
        HUMIDITY RATIO    8 - INLET AIR HUMIDITY RATIO
        PRESSURE          1 - OUTLET AIR GAUGE PRESSURE
        FLOW             10 - DRY AIR MASS FLOW RATE
        TEMPERATURE      66 - INLET WATER TEMPERATURE
        CONTROL          85 - VALVE STEM POSITION
        PRESSURE         36 - INLET WATER PRESSURE
        PRESSURE         41 - OUTLET WATER PRESSURE
        TEMPERATURE      76 - EFFECTIVE COIL SURFACE TEMPERATURE (SAME AS 1ST O

2      OUTPUTS:
        TEMPERATURE      76 - EFFECTIVE COIL SURFACE TEMPERATURE
        TEMPERATURE      15 - OUTLET DRY BULB AIR TEMPERATURE
        HUMIDITY RATIO    0 - OUTLET AIR HUMIDITY RATIO
        PRESSURE          0 - INLET AIR GAUGE PRESSURE
        TEMPERATURE       0 - COIL OUTLET WATER TEMPERATURE
        TEMPERATURE      71 - RETURN MIXED WATER TEMPERATURE
        FLOW              0 - COIL WATER MASS FLOW RATE
        FLOW             34 - SUPPLY WATER MASS FLOW RATE
        POWER             0 - TOTAL HEAT TRANSFER TO THE AIR
        CONTROL           0 - SENSIBLE HEAT RATIO
        CONTROL           0 - COIL EFFECTIVENESS
        CONTROL           0 - COIL BY-PASS FACTOR
        ENERGY            0 - OUTLET AIR SPECIFIC ENTHALPY
        CONTROL           0 - OUTLET AIR RELATIVE HUMIDITY
        ENERGY            0 - AIR SPECIFIC ENTHALPY IN COIL SURFACE CONDITION
        TEMPERATURE       0 - OUTLET AIR WET-BULB TEMPERATURE

3      PARAMETERS:
          1.00000     METHOD : 0 FOR STEADY STATE, 1 FOR LIEGE DYNAMICS
               0.     FAULT  : 0 FOR NO FAULTS, ...
               0.     PSYCHO : 0 FOR NO PSYCHOMETRIC OUTPUT CALCS
          1.00000     NUMBER OF ROWS OF TUBES
          24.0000     NUMBER OF TUBES PER ROW
          3.00000     NUMBER OF PARALLEL WATER CIRCUITS
         0.380000E-01 LENGTH OF FINNED SECTION IN DIRECTION OF FLOW (M)
         0.720000     HEIGHT OF FINNED SECTION (M)
         0.680000     WIDTH OF FINNED SECTION (M)
         0.127000E-01 TUBE OUTSIDE DIAMETER (M)
         0.430000E-03 TUBE WALL THICKNESS (M)
          2.00000     TUBE MATERIAL (AL=1,CU=2,FE=3,CaCO3=4)
         0.250000E-02 FIN SPACING (PITCH) (M)
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          0.160000E-03 FIN THICKNESS (M)
           1.00000     FIN MATERIAL (AL=1,CU=2,FE=3)
                0.     FLOW RESISTANCE PARAMETER ON AIR SIDE (0.001 KG.M)
           2.79000     Kv: VALVE CAPACITY INDEX (CU. M/HR AT 1 BAR)
           1.00000     VALVE MODE: (0=LIN/LIN, 1=EXP/LIN, 2=EXP/EXP, 3=LIN/EXP
           3.00000     VALVE CHARACTERISTIC EXPONENT Ngl (-)
           100.000     ADJUSTING RATIO (>1) (-)
          0.100000E-02 VALVE LEAKAGE (FRACTIONAL FLOW WHEN CLOSED) (-)
           166.500     COIL HYDRAULIC RESISTANCE (0.001 KG.M)
           166.500     BYPASS HYDRAULIC RESISTANCE (0.001 KG.M)
---------------------------------------------------

UNIT  79      TYPE 272
2 NODE ROOM/PLENUM - INTERZONE AND LEAKAGE, DUCTED RETURN

1      INPUTS:
         TEMPERATURE      15 - SUPPLY AIR DRY BULB TEMPERATURE
         HUMIDITY RATIO    8 - SUPPLY AIR HUMIDITY RATIO
         FLOW             10 - SUPPLY DRY AIR MASS FLOW RATE
         TEMPERATURE      16 - INTERZONE 1 AIR DRY BULB TEMPERATURE
         HUMIDITY RATIO    9 - INTERZONE 1 AIR HUMIDITY RATIO
         FLOW             15 - INTERZONE 1 DRY AIR MASS FLOW RATE
         TEMPERATURE      19 - INTERZONE 2 AIR DRY BULB TEMPERATURE
         HUMIDITY RATIO   12 - INTERZONE 2 AIR HUMIDITY RATIO
         FLOW             14 - INTERZONE 2 DRY AIR MASS FLOW RATE
         FLOW             20 - EXTRACT DRY AIR MASS FLOW RATE
         TEMPERATURE      30 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR ROOM
         TEMPERATURE      45 - EQUIVALENT SOL-AIR OUTDOOR TEMPERATURE FOR PLENUM
         TEMPERATURE       1 - AMBIENT DRY BULB TEMPERATURE
         HUMIDITY RATIO    1 - AMBIENT HUMIDITY RATIO
         CONTROL          90 - FRACTIONAL OCCUPANCY
         CONTROL          95 - FRACTIONAL LIGHTING HEAT GAIN
         CONTROL         100 - FRACTIONAL EQUIPMENT HEAT GAIN
         POWER             9 - HEAT GAIN FROM SUPPLY DUCT
         POWER            14 - HEAT GAIN FROM EXTRACT DUCT
         TEMPERATURE      20 - ROOM TEMPERATURE (SAME AS 1ST OUTPUT)
         TEMPERATURE      25 - ROOM STRUCTURE TEMPERATURE (SAME AS 2ND OUTPUT)
         TEMPERATURE      35 - PLENUM TEMPERATURE (SAME AS 3RD OUTPUT)
         TEMPERATURE      40 - PLENUM STRUCTURE TEMPERATURE (SAME AS 4TH OUTPUT)
         HUMIDITY RATIO   13 - ROOM HUMIDITY RATIO (SAME AS 5TH OUTPUT)
         HUMIDITY RATIO   18 - PLENUM HUMIDITY RATIO (SAME AS 6TH OUTPUT)

2      OUTPUTS:
         TEMPERATURE      20 - ROOM TEMPERATURE (SAME AS 11TH INPUT)
         TEMPERATURE      25 - ROOM STRUCTURE TEMPERATURE (SAME AS 12TH INPUT)
         TEMPERATURE      35 - PLENUM TEMPERATURE (SAME AS 13TH INPUT)
         TEMPERATURE      40 - PLENUM STRUCTURE TEMPERATURE (SAME AS 14TH INPUT)
         HUMIDITY RATIO   13 - ROOM HUMIDITY RATIO (SAME AS 15TH INPUT)
         HUMIDITY RATIO   18 - PLENUM HUMIDITY RATIO (SAME AS 16TH INPUT)
         TEMPERATURE      50 - RETURN TEMPERATURE
         FLOW              0 - LEAKAGE DRY AIR MASS FLOW RATE (NET)
         POWER             0 - SENSIBLE HEAT GAINS OF ROOM
         POWER             0 - SENSIBLE HEAT GAINS OF PLENUM
         FLOW              0 - WATER GAINS OF ROOM

3      PARAMETERS:
           5.00000     ROOM AIR CAPACITY MULTIPLIER (-)
           5.00000     ZONE NUMBER (PARAMETER FILE=zoneN.par, N > 0)
           6.84000     RWSR: DIRECT RESISTANCE ROOM AIR NODE <-> AMBIENT (K/KW
           7.35000     RISR: RESISTANCE ROOM AIR NODE <-> ROOM MASS NODE (K/KW
           10000.0     ROSR: RESISTANCE AMBIENT <-> ROOM MASS NODE (K/KW)
           10000.0     RWSP: DIRECT RESISTANCE PLENUM AIR NODE <-> AMBIENT (K/
          0.460000     RISP: RESISTANCE PLENUM AIR NODE <-> PLENUM MASS NODE (
           10000.0     ROSP: RESISTANCE AMBIENT <-> PLENUM MASS NODE (K/KW)
           2.54000     RR: RESISTANCE ROOM AIR NODE <-> PLENUM AIR NODE (K/KW)
           21760.3     CSR: CAPACITANCE OF ROOM MASS NODE (KJ/K)
           598.850     CR: CAPACITANCE OF ROOM AIR NODE (UNMODIFIED) (KJ/K)
           15632.2     CSP: CAPACITANCE OF PLENUM MASS NODE (KJ/K)
           229.470     CP: CAPACITANCE OF PLENUM AIR NODE (KJ/K)
           516.300     VOLUME OF ROOM (M3)
           197.000     VOLUME OF PLENUM (M3)
           19.0000     NUMBER OF OCCUPANTS (-)
           1.93000     LIGHTING HEAT GAIN (KW)
          0.500000     FRACTION OF LIGHTING HEAT GAIN TO PLENUM
                0.     EQUIPMENT HEAT GAIN (KW)
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UNIT  80       TYPE 169
MOIST AIR DUCT, HEAT LOSS AS OUTPUT

1      INPUTS:
        FLOW              20 - AIR MASS FLOW RATE
        PRESSURE           1 - OUTLET PRESSURE
        TEMPERATURE       50 - INLET AIR TEMPERATURE
        HUMIDITY RATIO    13 - INLET AIR HUMIDITY RATIO
        TEMPERATURE       35 - EXTERNAL TEMPERATURE

2      OUTPUTS:
        TEMPERATURE       55 - OUTLET AIR TEMPERATURE
        HUMIDITY RATIO    23 - OUTLET AIR HUMIDITY RATIO
        PRESSURE           0 - INLET PRESSURE
        POWER             14 - HEAT LOSS RATE

3      PARAMETERS:
           1.00000       SHAPE OF CONDUIT (ROUND=0, SQUARE=1)
          0.500000       SIZE OF CONDUIT - ROUND: DIAMETER, SQUARE: SIDE (M)
           20.0000       LENGTH OF CONDUIT (M)
          0.200000E-02   WALL THICKNESS  (M)
           3.00000       WALL MATERIAL (AL=1, CU=2, FE=3)
          0.173300       R-VALUE OF INSULATION BASED ON INSIDE AREA (K.M2/W)
                0.       FLOW RESISTANCE (0.001 KG.M)
                0.       HEIGHT OF OUTLET ABOVE INLET (M)
---------------------------------------------------

UNIT  81       TYPE  26
CONTROL SIGNAL INVERTER

1      INPUTS:
        CONTROL            1 - INPUT CONTROL SIGNAL

2      OUTPUTS:
        CONTROL            0 - OUTPUT CONTROL SIGNAL

3      PARAMETERS:
                0.       MULTIPLIER [DIMENSIONLESS]
---------------------------------------------------

UNIT  82       TYPE   7
TEMPERATURE SENSOR

1      INPUTS:
        TEMPERATURE        1 - INPUT TEMPERATURE
        CONTROL           17 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL           17 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
           30.0000       SENSOR TIME CONSTANT (SEC)
                0.       TEMPERATURE OFFSET (C)
           1.00000       TEMPERATURE RANGE (C)
---------------------------------------------------

UNIT  83       TYPE   7
TEMPERATURE SENSOR

1      INPUTS:
        TEMPERATURE       77 - INPUT TEMPERATURE
        CONTROL           18 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL           18 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
           30.0000       SENSOR TIME CONSTANT (SEC)
                0.       TEMPERATURE OFFSET (C)
           1.00000       TEMPERATURE RANGE (C)
---------------------------------------------------

UNIT  84       TYPE   7
TEMPERATURE SENSOR

1      INPUTS:
        TEMPERATURE        2 - INPUT TEMPERATURE
        CONTROL           19 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)
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2       OUTPUTS:
         CONTROL            19 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3       PARAMETERS:
             30.0000      SENSOR TIME CONSTANT (SEC)
                  0.      TEMPERATURE OFFSET (C)
             1.00000      TEMPERATURE RANGE (C)
----------------------------------------------------

UNIT  85        TYPE   7
TEMPERATURE SENSOR

1       INPUTS:
         TEMPERATURE         5 - INPUT TEMPERATURE
         CONTROL            20 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2       OUTPUTS:
         CONTROL            20 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3       PARAMETERS:
             30.0000      SENSOR TIME CONSTANT (SEC)
                  0.      TEMPERATURE OFFSET (C)
             1.00000      TEMPERATURE RANGE (C)
----------------------------------------------------

UNIT  86        TYPE   7
TEMPERATURE SENSOR

1       INPUTS:
         TEMPERATURE        56 - INPUT TEMPERATURE
         CONTROL            21 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2       OUTPUTS:
         CONTROL            21 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3       PARAMETERS:
             30.0000      SENSOR TIME CONSTANT (SEC)
                  0.      TEMPERATURE OFFSET (C)
             1.00000      TEMPERATURE RANGE (C)
----------------------------------------------------

UNIT  87        TYPE   7
TEMPERATURE SENSOR

1       INPUTS:
         TEMPERATURE        59 - INPUT TEMPERATURE
         CONTROL            22 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2       OUTPUTS:
         CONTROL            22 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3       PARAMETERS:
             30.0000      SENSOR TIME CONSTANT (SEC)
                  0.      TEMPERATURE OFFSET (C)
             1.00000      TEMPERATURE RANGE (C)
----------------------------------------------------

UNIT  88        TYPE 203
STATIC PRESSURE SENSOR

1       INPUTS:
         PRESSURE           15 - INPUT (TOTAL) PRESSURE
         FLOW                8 - MASS FLOW RATE
         CONTROL            23 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2       OUTPUTS:
         CONTROL            23 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3       PARAMETERS:
                  0.      SENSOR TIME CONSTANT (SEC)
                  0.      PRESSURE OFFSET (C)
             1.00000      PRESSURE RANGE (C)
            0.158000      CROSS SECTIONAL AREA (M2)
             1.00000      MODE: AIR=1, WATER=2
----------------------------------------------------
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UNIT  89      TYPE 189
VELOCITY SENSOR

1      INPUTS:
        FLOW               2 - MASS FLOW RATE
        CONTROL           24 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL           24 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
          1.96000       CROSS SECTIONAL AREA OF DUCT OR PIPE (m2)
          1.00000       MODE: 1=AIR, 2=WATER (-)
               0.       SENSOR TIME CONSTANT (SEC)
               0.       VELOCITY OFFSET (m/s)
          1.00000       VELOCITY RANGE (m/s)
----------------------------------------------------

UNIT  90      TYPE 189
VELOCITY SENSOR

1      INPUTS:
        FLOW              24 - MASS FLOW RATE
        CONTROL           25 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL           25 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
          1.96000       CROSS SECTIONAL AREA OF DUCT OR PIPE (m2)
          1.00000       MODE: 1=AIR, 2=WATER (-)
               0.       SENSOR TIME CONSTANT (SEC)
               0.       VELOCITY OFFSET (m/s)
          1.00000       VELOCITY RANGE (m/s)
----------------------------------------------------

UNIT  91      TYPE 203
STATIC PRESSURE SENSOR

1      INPUTS:
        PRESSURE          12 - INPUT (TOTAL) PRESSURE
        FLOW               8 - MASS FLOW RATE
        CONTROL           26 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL           26 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
               0.       SENSOR TIME CONSTANT (SEC)
               0.       PRESSURE OFFSET (C)
          1.00000       PRESSURE RANGE (C)
          999.000       CROSS SECTIONAL AREA (M2)
          1.00000       MODE: AIR=1, WATER=2
----------------------------------------------------

UNIT  92      TYPE   7
TEMPERATURE SENSOR

1      INPUTS:
        TEMPERATURE       16 - INPUT TEMPERATURE
        CONTROL           28 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL           28 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
          300.000       SENSOR TIME CONSTANT (SEC)
               0.       TEMPERATURE OFFSET (C)
          1.00000       TEMPERATURE RANGE (C)
----------------------------------------------------

UNIT  93      TYPE   7
TEMPERATURE SENSOR

1      INPUTS:
        TEMPERATURE       17 - INPUT TEMPERATURE
        CONTROL           29 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)
```

```
2      OUTPUTS:
        CONTROL            29 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
            300.000      SENSOR TIME CONSTANT (SEC)
                 0.      TEMPERATURE OFFSET (C)
            1.00000      TEMPERATURE RANGE (C)
---------------------------------------------------

UNIT  94       TYPE   7
TEMPERATURE SENSOR

1      INPUTS:
        TEMPERATURE        18 - INPUT TEMPERATURE
        CONTROL            30 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL            30 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
            300.000      SENSOR TIME CONSTANT (SEC)
                 0.      TEMPERATURE OFFSET (C)
            1.00000      TEMPERATURE RANGE (C)
---------------------------------------------------

UNIT  95       TYPE   7
TEMPERATURE SENSOR

1      INPUTS:
        TEMPERATURE        19 - INPUT TEMPERATURE
        CONTROL            31 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL            31 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
            300.000      SENSOR TIME CONSTANT (SEC)
                 0.      TEMPERATURE OFFSET (C)
            1.00000      TEMPERATURE RANGE (C)
---------------------------------------------------

UNIT  96       TYPE   7
TEMPERATURE SENSOR

1      INPUTS:
        TEMPERATURE        20 - INPUT TEMPERATURE
        CONTROL            32 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

2      OUTPUTS:
        CONTROL            32 - SENSOR OUTPUT (MODIFIED BY GAIN AND OFFSET)

3      PARAMETERS:
            300.000      SENSOR TIME CONSTANT (SEC)
                 0.      TEMPERATURE OFFSET (C)
            1.00000      TEMPERATURE RANGE (C)
---------------------------------------------------

UNIT  97       TYPE 197
WRITE TO UNIX SOCKET (16 REALS)

1      INPUTS:
        CONTROL            17 - SIMULATION OUTPUT / SOCKET INPUT  1
        CONTROL            18 - SIMULATION OUTPUT / SOCKET INPUT  2
        CONTROL            19 - SIMULATION OUTPUT / SOCKET INPUT  3
        CONTROL            20 - SIMULATION OUTPUT / SOCKET INPUT  4
        CONTROL            21 - SIMULATION OUTPUT / SOCKET INPUT  5
        CONTROL            22 - SIMULATION OUTPUT / SOCKET INPUT  6
        CONTROL            23 - SIMULATION OUTPUT / SOCKET INPUT  7
        CONTROL            24 - SIMULATION OUTPUT / SOCKET INPUT  8
        CONTROL            25 - SIMULATION OUTPUT / SOCKET INPUT  9
        CONTROL            26 - SIMULATION OUTPUT / SOCKET INPUT  10
        CONTROL            27 - SIMULATION OUTPUT / SOCKET INPUT  11
        CONTROL            28 - SIMULATION OUTPUT / SOCKET INPUT  12
        CONTROL            29 - SIMULATION OUTPUT / SOCKET INPUT  13
        CONTROL            30 - SIMULATION OUTPUT / SOCKET INPUT  14
        CONTROL            31 - SIMULATION OUTPUT / SOCKET INPUT  15
        CONTROL            32 - SIMULATION OUTPUT / SOCKET INPUT  16
```

```
2      OUTPUTS:
        CONTROL          33 - DUMMY (MUST NOT BE CONTROL 0!)

3      PARAMETERS:
           1.00000     SOCKET NUMBER (0-4)
           5.00000     SAMPLE TIME (INTERVAL BETWEEN TRANSFERS) [S]
                0.     REAL TIME SCALING FACTOR (0=NO WAIT, 0.5=DOUBLE SPEED)
---------------------------------------------------

UNIT  98      TYPE 135
REAL TIME GRAPHS OF PRESSURE, FLOW AND CONTROL

1      INPUTS:
        PRESSURE          2 - FIRST PRESSURE TO BE PLOTTED
        PRESSURE          4 - SECOND PRESSURE TO BE PLOTTED
        PRESSURE         15 - THIRD PRESSURE TO BE PLOTTED
        PRESSURE         12 - FOURTH PRESSURE TO BE PLOTTED
        FLOW              2 - FIRST FLOW TO BE PLOTTED
        FLOW              6 - SECOND FLOW TO BE PLOTTED
        FLOW              7 - THIRD FLOW TO BE PLOTTED
        FLOW             24 - FOURTH FLOW TO BE PLOTTED
        CONTROL          36 - FIRST CONTROL SIGNAL TO BE PLOTTED
        CONTROL           8 - SECOND CONTROL SIGNAL TO BE PLOTTED
        CONTROL           9 - THIRD CONTROL SIGNAL TO BE PLOTTED
        CONTROL         122 - FOURTH CONTROL SIGNAL TO BE PLOTTED

2      OUTPUTS:
        CONTROL          34 - DUMMY OUTPUT (DO NOT USE CONTROL 0)

3      PARAMETERS:
           1.00000     TIME INTERVAL FOR PLOTTING (S)
                0.     STOPPING TIME (S)
           1.00000     SCALING FACTOR FOR TIME AXIS (3600. -> HOURS) [-]
           1.00000     MAXIMUM PRESSURE (KPA)
         -0.500000     MINIMUM PRESSURE (KPA)
           10.0000     MAXIMUM FLOW RATE (KG/S)
          -1.00000     MINIMUM FLOW RATE (KG/S)
           1.10000     MAXIMUM CONTROL SIGNAL (-)
         -0.100000     MINIMUM CONTROL SIGNAL (-)
           4.00000     NUMBER OF PRESSURES TO PLOT (-)
           4.00000     NUMBER OF FLOW RATES TO PLOT (-)
           4.00000     NUMBER OF CONTROL SIGNALS TO PLOT (-)
           2.00000     INDEX OF FIRST PRESSURE (-)
           4.00000     INDEX OF SECOND PRESSURE (-)
           15.0000     INDEX OF THIRD PRESSURE (-)
           12.0000     INDEX OF FOURTH PRESSURE (-)
           2.00000     INDEX OF FIRST FLOW RATE (-)
           6.00000     INDEX OF SECOND FLOW RATE (-)
           7.00000     INDEX OF THIRD FLOW RATE (-)
           24.0000     INDEX OF FOURTH FLOW RATE (-)
           36.0000     INDEX OF FIRST CONTROL SIGNAL (-)
           8.00000     INDEX OF SECOND CONTROL SIGNAL (-)
           9.00000     INDEX OF THIRD CONTROL SIGNAL (-)
           122.000     INDEX OF FOURTH CONTROL SIGNAL (-)
---------------------------------------------------

UNIT  99      TYPE  26
CONTROL SIGNAL INVERTER

1      INPUTS:
        CONTROL           1 - INPUT CONTROL SIGNAL

2      OUTPUTS:
        CONTROL           0 - OUTPUT CONTROL SIGNAL

3      PARAMETERS:
                0.     MULTIPLIER [DIMENSIONLESS]
---------------------------------------------------
Initial Variable Values:

PRESSURE         1 ->          0.     (kPa)
PRESSURE         2 ->          0.     (kPa)
PRESSURE         3 ->          0.     (kPa)
PRESSURE         4 ->          0.     (kPa)
PRESSURE         5 ->          0.     (kPa)
PRESSURE         6 ->          0.     (kPa)
PRESSURE         7 ->          0.     (kPa)
PRESSURE         8 ->          0.     (kPa)
```

PRESSURE	9 ->	0.	(kPa)
PRESSURE	10 ->	0.	(kPa)
PRESSURE	11 ->	0.	(kPa)
PRESSURE	12 ->	0.	(kPa)
PRESSURE	13 ->	0.	(kPa)
PRESSURE	14 ->	0.	(kPa)
PRESSURE	15 ->	0.	(kPa)
PRESSURE	16 ->	0.	(kPa)
PRESSURE	17 ->	0.	(kPa)
PRESSURE	18 ->	0.	(kPa)
PRESSURE	19 ->	0.	(kPa)
PRESSURE	20 ->	0.	(kPa)
PRESSURE	21 ->	0.	(kPa)
PRESSURE	22 ->	0.	(kPa)
PRESSURE	23 ->	0.	(kPa)
PRESSURE	24 ->	0.	(kPa)
PRESSURE	25 ->	0.	(kPa)
PRESSURE	26 ->	0.	(kPa)
PRESSURE	27 ->	0.	(kPa)
PRESSURE	28 ->	74.2400	(kPa)
PRESSURE	29 ->	0.	(kPa)
PRESSURE	30 ->	49.1000	(kPa)
PRESSURE	31 ->	0.	(kPa)
PRESSURE	32 ->	8.00000	(kPa)
PRESSURE	33 ->	8.00000	(kPa)
PRESSURE	34 ->	8.00000	(kPa)
PRESSURE	35 ->	8.00000	(kPa)
PRESSURE	36 ->	8.00000	(kPa)
PRESSURE	37 ->	0.	(kPa)
PRESSURE	38 ->	0.	(kPa)
PRESSURE	39 ->	0.	(kPa)
PRESSURE	40 ->	0.	(kPa)
PRESSURE	41 ->	0.	(kPa)
PRESSURE	42 ->	0.	(kPa)
PRESSURE	43 ->	0.	(kPa)
FLOW	1 ->	0.	(kg/s)
FLOW	2 ->	0.	(kg/s)
FLOW	3 ->	0.	(kg/s)
FLOW	4 ->	0.	(kg/s)
FLOW	5 ->	0.	(kg/s)
FLOW	6 ->	0.	(kg/s)
FLOW	7 ->	0.	(kg/s)
FLOW	8 ->	0.	(kg/s)
FLOW	9 ->	0.	(kg/s)
FLOW	10 ->	0.	(kg/s)
FLOW	11 ->	0.	(kg/s)
FLOW	12 ->	0.	(kg/s)
FLOW	13 ->	0.	(kg/s)
FLOW	14 ->	0.	(kg/s)
FLOW	15 ->	0.	(kg/s)
FLOW	16 ->	0.	(kg/s)
FLOW	17 ->	0.	(kg/s)
FLOW	18 ->	0.	(kg/s)
FLOW	19 ->	0.	(kg/s)
FLOW	20 ->	0.	(kg/s)
FLOW	21 ->	0.	(kg/s)
FLOW	22 ->	0.	(kg/s)
FLOW	23 ->	0.	(kg/s)
FLOW	24 ->	0.	(kg/s)
FLOW	25 ->	0.	(kg/s)
FLOW	26 ->	0.	(kg/s)
FLOW	27 ->	0.	(kg/s)
FLOW	28 ->	0.	(kg/s)
FLOW	29 ->	0.	(kg/s)
FLOW	30 ->	0.	(kg/s)
FLOW	31 ->	0.	(kg/s)
FLOW	32 ->	0.	(kg/s)
FLOW	33 ->	0.	(kg/s)
FLOW	34 ->	0.	(kg/s)
TEMPERATURE	1 ->	14.0000	(C)
TEMPERATURE	2 ->	14.0000	(C)
TEMPERATURE	3 ->	14.0000	(C)
TEMPERATURE	4 ->	14.0000	(C)
TEMPERATURE	5 ->	14.0000	(C)
TEMPERATURE	6 ->	14.0000	(C)
TEMPERATURE	7 ->	14.0000	(C)
TEMPERATURE	8 ->	14.0000	(C)
TEMPERATURE	9 ->	14.0000	(C)

TEMPERATURE	10	->	14.0000	(C)
TEMPERATURE	11	->	14.0000	(C)
TEMPERATURE	12	->	14.0000	(C)
TEMPERATURE	13	->	14.0000	(C)
TEMPERATURE	14	->	14.0000	(C)
TEMPERATURE	15	->	14.0000	(C)
TEMPERATURE	16	->	20.0000	(C)
TEMPERATURE	17	->	20.0000	(C)
TEMPERATURE	18	->	20.0000	(C)
TEMPERATURE	19	->	20.0000	(C)
TEMPERATURE	20	->	20.0000	(C)
TEMPERATURE	21	->	20.0000	(C)
TEMPERATURE	22	->	20.0000	(C)
TEMPERATURE	23	->	20.0000	(C)
TEMPERATURE	24	->	20.0000	(C)
TEMPERATURE	25	->	20.0000	(C)
TEMPERATURE	26	->	20.0000	(C)
TEMPERATURE	27	->	20.0000	(C)
TEMPERATURE	28	->	20.0000	(C)
TEMPERATURE	29	->	20.0000	(C)
TEMPERATURE	30	->	20.0000	(C)
TEMPERATURE	31	->	20.0000	(C)
TEMPERATURE	32	->	20.0000	(C)
TEMPERATURE	33	->	20.0000	(C)
TEMPERATURE	34	->	20.0000	(C)
TEMPERATURE	35	->	20.0000	(C)
TEMPERATURE	36	->	20.0000	(C)
TEMPERATURE	37	->	20.0000	(C)
TEMPERATURE	38	->	20.0000	(C)
TEMPERATURE	39	->	20.0000	(C)
TEMPERATURE	40	->	20.0000	(C)
TEMPERATURE	41	->	20.0000	(C)
TEMPERATURE	42	->	20.0000	(C)
TEMPERATURE	43	->	20.0000	(C)
TEMPERATURE	44	->	20.0000	(C)
TEMPERATURE	45	->	20.0000	(C)
TEMPERATURE	46	->	20.0000	(C)
TEMPERATURE	47	->	20.0000	(C)
TEMPERATURE	48	->	20.0000	(C)
TEMPERATURE	49	->	20.0000	(C)
TEMPERATURE	50	->	20.0000	(C)
TEMPERATURE	51	->	20.0000	(C)
TEMPERATURE	52	->	20.0000	(C)
TEMPERATURE	53	->	20.0000	(C)
TEMPERATURE	54	->	20.0000	(C)
TEMPERATURE	55	->	20.0000	(C)
TEMPERATURE	56	->	7.00000	(C)
TEMPERATURE	57	->	14.0000	(C)
TEMPERATURE	58	->	14.0000	(C)
TEMPERATURE	59	->	82.0000	(C)
TEMPERATURE	60	->	14.0000	(C)
TEMPERATURE	61	->	14.0000	(C)
TEMPERATURE	62	->	82.0000	(C)
TEMPERATURE	63	->	82.0000	(C)
TEMPERATURE	64	->	82.0000	(C)
TEMPERATURE	65	->	82.0000	(C)
TEMPERATURE	66	->	82.0000	(C)
TEMPERATURE	67	->	14.0000	(C)
TEMPERATURE	68	->	14.0000	(C)
TEMPERATURE	69	->	14.0000	(C)
TEMPERATURE	70	->	14.0000	(C)
TEMPERATURE	71	->	14.0000	(C)
TEMPERATURE	72	->	14.0000	(C)
TEMPERATURE	73	->	14.0000	(C)
TEMPERATURE	74	->	14.0000	(C)
TEMPERATURE	75	->	14.0000	(C)
TEMPERATURE	76	->	14.0000	(C)
TEMPERATURE	77	->	20.0000	(C)
TEMPERATURE	78	->	20.0000	(C)
TEMPERATURE	79	->	0.	(C)
CONTROL	1	->	1.00000	(-)
CONTROL	2	->	0.	(-)
CONTROL	3	->	1.00000	(-)
CONTROL	4	->	0.	(-)
CONTROL	5	->	0.	(-)
CONTROL	6	->	13.0000	(-)
CONTROL	7	->	0.	(-)
CONTROL	8	->	1.00000	(-)

CONTROL	9	->	1.00000	(-)
CONTROL	10	->	0.300000	(-)
CONTROL	11	->	0.	(-)
CONTROL	12	->	3.00000	(-)
CONTROL	13	->	3.00000	(-)
CONTROL	14	->	3.00000	(-)
CONTROL	15	->	3.00000	(-)
CONTROL	16	->	3.00000	(-)
CONTROL	17	->	14.0000	(-)
CONTROL	18	->	20.0000	(-)
CONTROL	19	->	14.0000	(-)
CONTROL	20	->	14.0000	(-)
CONTROL	21	->	7.00000	(-)
CONTROL	22	->	82.0000	(-)
CONTROL	23	->	0.	(-)
CONTROL	24	->	0.	(-)
CONTROL	25	->	0.	(-)
CONTROL	26	->	0.	(-)
CONTROL	27	->	0.	(-)
CONTROL	28	->	20.0000	(-)
CONTROL	29	->	20.0000	(-)
CONTROL	30	->	20.0000	(-)
CONTROL	31	->	20.0000	(-)
CONTROL	32	->	20.0000	(-)
CONTROL	33	->	0.	(-)
CONTROL	34	->	0.	(-)
CONTROL	35	->	1.00000	(-)
CONTROL	36	->	1.00000	(-)
CONTROL	37	->	0.	(-)
CONTROL	38	->	1.00000	(-)
CONTROL	39	->	0.	(-)
CONTROL	40	->	0.	(-)
CONTROL	41	->	0.	(-)
CONTROL	42	->	0.	(-)
CONTROL	43	->	0.	(-)
CONTROL	44	->	0.	(-)
CONTROL	45	->	0.	(-)
CONTROL	46	->	0.	(-)
CONTROL	47	->	0.	(-)
CONTROL	48	->	0.	(-)
CONTROL	49	->	0.	(-)
CONTROL	50	->	0.	(-)
CONTROL	51	->	0.	(-)
CONTROL	52	->	0.	(-)
CONTROL	53	->	0.	(-)
CONTROL	54	->	0.	(-)
CONTROL	55	->	0.	(-)
CONTROL	56	->	0.	(-)
CONTROL	57	->	0.	(-)
CONTROL	58	->	0.	(-)
CONTROL	59	->	0.	(-)
CONTROL	60	->	0.	(-)
CONTROL	61	->	0.	(-)
CONTROL	62	->	0.	(-)
CONTROL	63	->	0.	(-)
CONTROL	64	->	0.	(-)
CONTROL	65	->	0.	(-)
CONTROL	66	->	0.	(-)
CONTROL	67	->	0.	(-)
CONTROL	68	->	0.	(-)
CONTROL	69	->	0.	(-)
CONTROL	70	->	0.	(-)
CONTROL	71	->	0.	(-)
CONTROL	72	->	0.	(-)
CONTROL	73	->	0.	(-)
CONTROL	74	->	0.	(-)
CONTROL	75	->	0.	(-)
CONTROL	76	->	0.	(-)
CONTROL	77	->	0.	(-)
CONTROL	78	->	0.	(-)
CONTROL	79	->	0.	(-)
CONTROL	80	->	0.	(-)
CONTROL	81	->	0.	(-)
CONTROL	82	->	0.	(-)
CONTROL	83	->	0.	(-)
CONTROL	84	->	0.	(-)
CONTROL	85	->	0.	(-)
CONTROL	86	->	0.	(-)

CONTROL	87	->	0.	(-)
CONTROL	88	->	0.	(-)
CONTROL	89	->	0.	(-)
CONTROL	90	->	0.	(-)
CONTROL	91	->	0.	(-)
CONTROL	92	->	0.	(-)
CONTROL	93	->	0.	(-)
CONTROL	94	->	0.	(-)
CONTROL	95	->	0.	(-)
CONTROL	96	->	0.	(-)
CONTROL	97	->	0.	(-)
CONTROL	98	->	0.	(-)
CONTROL	99	->	0.	(-)
CONTROL	100	->	0.	(-)
CONTROL	101	->	14.0000	(-)
CONTROL	102	->	20.0000	(-)
CONTROL	103	->	14.0000	(-)
CONTROL	104	->	14.0000	(-)
CONTROL	105	->	7.00000	(-)
CONTROL	106	->	82.0000	(-)
CONTROL	107	->	0.	(-)
CONTROL	108	->	0.	(-)
CONTROL	109	->	0.	(-)
CONTROL	110	->	0.	(-)
CONTROL	111	->	0.	(-)
CONTROL	112	->	20.0000	(-)
CONTROL	113	->	20.0000	(-)
CONTROL	114	->	20.0000	(-)
CONTROL	115	->	20.0000	(-)
CONTROL	116	->	20.0000	(-)
CONTROL	117	->	0.	(-)
CONTROL	118	->	1.00000	(-)
CONTROL	119	->	0.	(-)
CONTROL	120	->	1.00000	(-)
CONTROL	121	->	1.00000	(-)
CONTROL	122	->	0.	(-)
CONTROL	123	->	0.	(-)
CONTROL	124	->	0.	(-)
CONTROL	125	->	0.	(-)
CONTROL	126	->	0.	(-)
RVPS	1	->	0.	(rev/s)
RVPS	2	->	0.	(rev/s)
RVPS	3	->	0.	(rev/s)
RVPS	4	->	0.	(rev/s)
POWER	1	->	0.	(kW)
POWER	2	->	0.	(kW)
POWER	3	->	0.	(kW)
POWER	4	->	0.	(kW)
POWER	5	->	0.	(kW)
POWER	6	->	0.	(kW)
POWER	7	->	0.	(kW)
POWER	8	->	0.	(kW)
POWER	9	->	0.	(kW)
POWER	10	->	0.	(kW)
POWER	11	->	0.	(kW)
POWER	12	->	0.	(kW)
POWER	13	->	0.	(kW)
POWER	14	->	0.	(kW)
HUMIDITY RATIO	1	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	2	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	3	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	4	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	5	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	6	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	7	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	8	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	9	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	10	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	11	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	12	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	13	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	14	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	15	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	16	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	17	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	18	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	19	->	0.400000E-02	(kg/kg)
HUMIDITY RATIO	20	->	0.400000E-02	(kg/kg)

```
HUMIDITY RATIO  21 ->    0.400000E-02(kg/kg)
HUMIDITY RATIO  22 ->    0.400000E-02(kg/kg)
HUMIDITY RATIO  23 ->    0.400000E-02(kg/kg)
HUMIDITY RATIO  24 ->    0.400000E-02(kg/kg)
---------------------------------------------------
Simulation Error Tolerances:

1       RTOLX=   0.100000E-03      ATOLX=   0.100000E-04
        XTOL=    0.200000E-03      TTIME=    1.00000

SUPERBLOCK 1
2       FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK 2
3       FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK 3
4       FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK 4
5       FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK 5
6       FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK 6
7       FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK 7
8       FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK 8
9       FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK 9
10      FREEZE OPTION 0      SCAN OPTION 0

SUPERBLOCK10
11      FREEZE OPTION 0      SCAN OPTION 0
---------------------------------------------------
The following are Boundary Variables in the simulation:

---------------------------------------------------
The following are the reported variables:


SUPERBLOCK 1       REPORTING INTERVAL    5.00000
CONTROL           1
CONTROL           2
CONTROL           3
CONTROL           4
CONTROL           5
CONTROL           6
CONTROL           7
CONTROL           8
CONTROL           9
CONTROL          10
CONTROL          11
CONTROL          12
CONTROL          13
CONTROL          14
CONTROL          15
CONTROL          16

SUPERBLOCK 2       REPORTING INTERVAL    5.00000
CONTROL          36
CONTROL          37
CONTROL          38
CONTROL          39
CONTROL          40

SUPERBLOCK 3       REPORTING INTERVAL         0.

SUPERBLOCK 4       REPORTING INTERVAL    5.00000
PRESSURE          2
PRESSURE          3
PRESSURE          8
PRESSURE          9
```

```
PRESSURE        15
PRESSURE        16
PRESSURE        17
PRESSURE        10
PRESSURE        11
PRESSURE        12
PRESSURE        13
PRESSURE        14
FLOW             2
FLOW             6
FLOW             7
FLOW             8
FLOW             9
FLOW            10
FLOW            11
FLOW            12
FLOW            13
FLOW            14
FLOW            15
FLOW            16
FLOW            17
FLOW            18
FLOW            19
FLOW            20

SUPERBLOCK 5       REPORTING INTERVAL    5.00000
CONTROL        122
CONTROL        123
CONTROL        124
CONTROL        125
CONTROL        126

SUPERBLOCK 6       REPORTING INTERVAL    5.00000
TEMPERATURE      2
TEMPERATURE      3
TEMPERATURE      4
TEMPERATURE      5
TEMPERATURE     11
TEMPERATURE     12
TEMPERATURE     13
TEMPERATURE     14
TEMPERATURE     15
TEMPERATURE     16
TEMPERATURE     17
TEMPERATURE     18
TEMPERATURE     19
TEMPERATURE     20
TEMPERATURE     77
TEMPERATURE     78
RVPS             1
RVPS             2
RVPS             3
RVPS             4

SUPERBLOCK 7       REPORTING INTERVAL          0.
SUPERBLOCK 8       REPORTING INTERVAL          0.
SUPERBLOCK 9       REPORTING INTERVAL          0.
SUPERBLOCK10       REPORTING INTERVAL          0.
```

Appendix BB - Corrected 2C3R LPM Values per §2.2.3

Table - 51: Corrected Global Parameter Summary for Megazone I - III (refer to Figure 165)

Parameter	Megazone - Global Parameters (rounded)					
	I		II		III	
	Room	Plenum	Room	Plenum	Room	Plenum
$1/R_{wi}$ [W/°K]	30	0	10	0	220	0
$1/R_i$ [W/°K]	47	18	14	5	381	224
θ_i	0.011	0.011	0.016	0.006	0.038	0.076
$Cdot_{i,out}$ [W/°K]	0	0	0	0	0	0
K_i [W/°K]	80	20	20	5	600	220
ξ_i	0.39	0	0.34	0	0.36	0
$1/R_{eq}$ [W/°K]	4,270	1,540	890	790	10,280	2,970
C_{si} [J/°K]	5.85e+07	4.81e+07	1.07e+07	1.63e+07	2.79e+08	1.25e+08
τ_i [hr]	210	750	140	910	130	160
C_i [J/°K]	9.41e+06	2.18e+06	2.03e+06	7.03e+05	2.58e+07	6.87e+06

Table - 52: Corrected Global Parameter Summary for Megazone IV - VI (refer to Figure 165)

Parameter	Megazone - Global Parameters (rounded)					
	IV		V		VI	
	Room	Plenum	Room	Plenum	Room	Plenum
$1/R_{wi}$ [W/°K]	56	0	147	0	20	0
$1/R_i$ [W/°K]	108	38	181	86	30	11
θ_i	0.058	0.028	0.033	0.022	0.118	0.064
$\dot{C}_{i,out}$ [W/°K]	0	0	0	0	0	0
K_i [W/°K]	164	38	327	86	50	11
ξ_i	0.34	0	0.45	0	0.4	0
$1/R_{eq}$ [W/°K]	1,900	1,360	5,640	3,860	280	180
C_{si} [J/°K]	7.60e+07	5.18e+07	5.14e+08	1.52e+08	2.08e+07	1.08e+07
τ_i [hr]	130	370	180	490	120	260
C_i [J/°K]	7.24e+06	7.24e+06	1.78e+07	5.49e+06	6.77e+05	2.32e+05

Table - 53: Corrected 2C3R LPM Characteristics (refer to Figure 2 & 165)

Parameter	2C3R Lumped Parameter Model Characteristics for Each Zone i *					
	I	II	III	IV	V	VI
$R_{01,i}$ [°K/kW]	3.27e+01	1.37e+03	4.64e+00	1.79e+01	6.82e+00	5.00e+00
$R_{02,i}$ [°K/kW]	2.36e-01	1.14e+00	9.94e-02	5.40e-01	1.82e-01	3.89e+00
$R_{03,i}$ [°K/kW]	2.09e+01	7.06e+01	2.53e+00	8.70e+00	5.35e+00	2.90e+01
$C_{02,i}$ [kJ/°K]	9.41e+03	2.03e+03	2.58e+04	7.24e+03	1.78e+04	6.77e+02
$C_{03,i}$ [kJ/°K]	5.85e+04	1.07e+04	2.79e+05	7.60e+04	2.14e+05	2.08e+04
$R_{11,i}$ [°K/kW]	3.26e+00	9.47e+00	1.14e+00	3.81e+00	1.33e+00	3.06e+00
$R_{21,i}$ [°K/kW]	infinite	infinite	infinite	infinite	infinite	infinite
$R_{22,i}$ [°K/kW]	6.49e-01	1.27e+00	3.37e-01	7.37e-01	2.59e-01	5.58e+00
$R_{23,i}$ [°K/kW]	5.58e+01	2.00e+02	4.13e+00	2.53e+01	1.14e+01	8.18e+01
$C_{22,i}$ [kJ/°K]	2.18e+03	7.03e+02	6.87e+03	2.36e+03	5.49e+03	2.32e+02
$C_{23,i}$ [kJ/°K]	4.81e+04	1.63e+04	1.25e+05	5.18e+04	1.52e+05	1.08e+04

* The parameters in this table, expressed in terms of the variable names used in the Annex 10 report, are shown in the following list:

$R_{01,i} = R_{wi,room}$ $R_{02,i} = R_{i,room}\theta_{i,room}$ $R_{03,i} = R_{i,room}(1 - \theta_{i,room})$

$C_{02,i} = C_{i,room}$ $C_{03,i} = C_{si,room}$

$R_{21,i} = R_{wi,plenum}$ $R_{22,i} = R_{i,plenum}\theta_{i,plenum}$ $R_{23,i} = R_{i,plenum}(1 - \theta_{i,plenum})$

$C_{22,i} = C_{i,plenum}$ $C_{23,i} = C_{si,plenum}$

$R_{11,i} = R_{i,j,connecting}$

Global Parameters

Annex 10 Terms		K(hvy,ext,inner) External Shell				K(hvy,internal) Horizontal				K(hvy,inner)		K(i)*[1-xi(i)]	
		Room		Plenum		Horizontal Room		Horizontal Plenum		K(hvy,inner) Total Sum		1/R(i) Total Sum	
Mega-Zone Num-ber	External Surface Compass Heading	Sub-Tot [W/K]	Total [W/K]	Sub-Tot [W/K]	Total [W/K]	Ka [W/K]	Kb [W/K]	Ka [W/K]	Kb [W/K]	Room [W/K]	Plenum [W/K]	Room [W/K]	Plenum [W/K]
I	South	38.68		16.10									
I	West	10.98		4.02									
I	North	23.05	72.71	7.12	27.24	2,081	2,081	757	757	4,234	1,542	47	18
II	North	21.45	21.45	7.64	7.64	429	429	521	261	880	790	14	5
III	South	368.43		148.89									
III	West	177.45		49.29									
III	North	39.71		14.18									
III	Roof		585.59	286.88	499.24	4,737	4,737	1,234	1,234	10,059	2,968	381	224
IV	West	87.03		30.77									
IV	North	79.41	166.45	28.35	59.13	843	843	648	648	1,853	1,356	108	38
V	North	277.88		111.00									
V	Roof		277.88	46.44	157.43	2,606	2,606	1,852	1,852	5,490	3,861	181	86
VI	South	17.12		6.08									
VI	West	29.64	46.77	11.53	17.61	105	105	81	81	257	179	30	11

Alert: Corrected calculation for 1/R(i). See Section 2.2.3 in text for explanation.

Global Parameters

Annex 10 Terms		K(ext)				theta(i)								
Mega-	External	Room		Plenum		Accessibility - theta(i)		Global Resistances						
Zone	Surface	K(window) + K(wall)		K(wall)		K(hvy,ext)/K(hvy,inner)		R01	R21	R02	R22	R03	R23	R11
Num-	Compass	Sub-Tot	Total	Sub-Tot	Total	Room	Plenum	Room	Plenum	Room	Plenum	Room	Plenum	Plenum
ber	Heading	[W/K]	[W/K]	[W/K]	[W/K]	-----	-----	[K/kW]	[K/kW]	[K/kW]	[K/kW]	[K/kW]	[K/kW]	[K/kW]
I	South	48.37		10.47		47	18							
I	West	11.33		2.61		4,234	1,542							
I	North	18.10	77.80	4.63	17.71	0.01116	0.01149	3.27E+01	0	2.36E-01	6.49E-01	2.09E+01	5.58E+01	3.26E+00
II	North	21.25	21.25	4.97	4.97	0.01585	0.00629	1.37E+02	0	1.14E+00	1.27E+00	7.06E+01	2.00E+02	9.47E+00
III	South	441.24		96.78										
III	West	115.34		32.04		381	224							
III	North	39.45		9.22		10,059	2,968							
III	Roof		596.03	86.06	224.10	0.03784	0.07551	4.64E+00	0	9.94E-02	3.37E-01	2.53E+00	4.13E+00	1.14E+00
IV	West	85.16		20.00		108 1,853	38 1,356							
IV	North	78.90	164.06	18.43	38.43	0.05838	0.02834	1.79E+01	0	5.40E-01	7.37E-01	8.70E+00	2.53E+01	3.81E+00
V	North	327.16		72.15		181 5,490	86 3,861							
V	Roof		327.16	13.93	86.08	0.03290	0.02229	6.82E+00	0	1.82E-01	2.59E-01	5.35E+00	1.14E+01	1.33E+00
VI	South	16.85		3.95		30 257	11 179							
VI	West	33.56	50.41	7.50	11.44	0.11839	0.06390	5.00E+01	0	3.89E+00	5.58E+00	2.90E+01	8.18E+01	3.06E+01

Alert: Corrected calculations for LPM parameters using the corrected 1/R(i). See Section 2.2.3 in text for explanation.