NATURAL DAYLIGHTING AND ENERGY CONSERVATION
Innovative Solutions for Office Buildings

By James E. Rosen

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—Innovative Solutions For Office Buildings

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Artificial lighting often represents the single largest component of energy use in commercial office buildings. In addition to the large energy consumption associated with the lighting, large cooling loads result from the waste heat produced by these lights. This fact and rising energy costs have provoked a resurgence of interest in daylighting and lighting control devices.

This thesis proposes and evaluates a three part daylighting system The first component, commercial heat mirror, is a newly developed glass coating. Like many low transmission glazings, this product has a very low solar heat gain (less than 30%). Unlike these conventional glazings, it also has a relatively high transmission of visible light (45%). Finally, its high reflectivity in the infrared spectrum increases the insulating characteristics of the window assembly, and reduces thermal transmission roughly equal to an additional glazing layer.

As the second component of the proposed system, inverted reflective blinds, are used to control the glare which results when direct sunlight enters a room. These blinds were evaluated using a daylighting model and were shown to substantially improve lighting quality while increasing interior daylight levels.

The third component is a lighting control system which automatically dims the artificial lighting system in response to interior daylight levels. This results in substantial energy savings, since electrical consumption is reduced.

The energy impact of this system was analyzed using the DOE-2 computer program. When applied to a contemporary office building, the system outlined above reduces energy consumption and peak electrical loads, as well as required boiler and chiller capacities.

Thesis Supervisor: Harvey Bryan

Title: Assistant Professor of Architecture

Contents

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Professor Harvey Bryan, my thesis advisor, provided much input and opened many doors for me. Without his contacts, this thesis research would be much, much thinner.

William King of Kinetic Coatings developed the heat mirror coating that is described herein. He provided glass samples and technical data used in my analysis. This took some venturousness, since his proprietary coating had yet to be marketed.

Steven Selkowitz, Group Leader of the Windows and Daylighting program at Lawrence Berkeley provided helpful comments and suggestions during several discussions.

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grown procedures, he was kind enough to tell me how to do things the right way.

Alexander Lohr, Christopher Mathis, and I build the daylighting model used in this thesis as part of William Lam's lighting course at the Harvard's Graduate School of Design. Funding for this model was provided by Harvey Bryan by way of an LBL grant.

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I. Energy Use in Internal Load Dominated Buildings

Office buildings, motels, warehouses, hospitals, schools, and other "commercial buildings" provide a wide range of services. When speaking of an energy crises we must also speak of an architectural crisis since the two are interwoven. The buildings in which we work consume over 14% of the total United States energy consumption. This energy consumption is likely to expand, since per capita commercial floor area is predicted to increase 36% by the year 2000 (SERI, 1981).

This chapter discusses how commercial buildings use energy, beginning with the major factors that distinguish commercial building energy use; large lighting loads, small surface to volume ratios, and inefficient HVAC equipment. The next section outlines the difference between power and energy. The chapter ends by discussing the effect of the building envelope and windows on commercial building energy use.

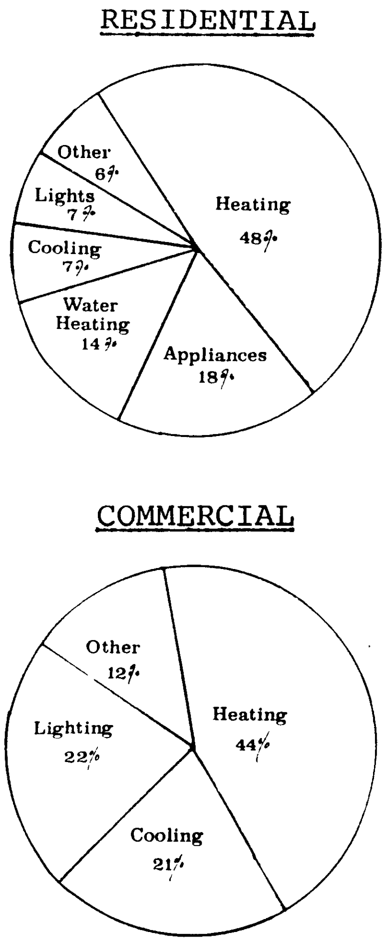
The basic premise of this thesis is that windows are not necessarily detrimental from an energy point of view. In fact, properly designed, windows in large office buildings, can actually be net energy producers.

Lighting and Energy Use

Modern office buildings are greatly influenced by real estate economics. Economic optimization of commercial buildings has led to compact volumes with a large percentage of the floor area far from windows and natural light. As a result, artificial lighting is required throughout the day.

Required lighting levels have risen along with building depths. In 1952, the Illuminating Engineering Society (IES) required office light levels of 30 to 50 footcandles (depending on the task). By 1971, these requirements had risen to 100 to 200 footcandles. The roots of these increases are political and economic. First, falling electrical prices have softened the economic impact of higher lighting loads. Second, the IES was dominated by utility companies, and lighting manufacturers, all of whom were fully aware of the the huge markets for lighting equipment and electricity that were created by increased light standards (see Stein 1977).

The result of modern codes, and real estate economics, lighting systems now consume 22% of the commercial sector's energy requirements (figure I.1). For example, the measured energy consump-


RESIDENTIAL

COMMERCIAL

FIGURE I.1:
Components of U.S. building energy consumption by sector and end use - 1977 (source: SERI, 1981)

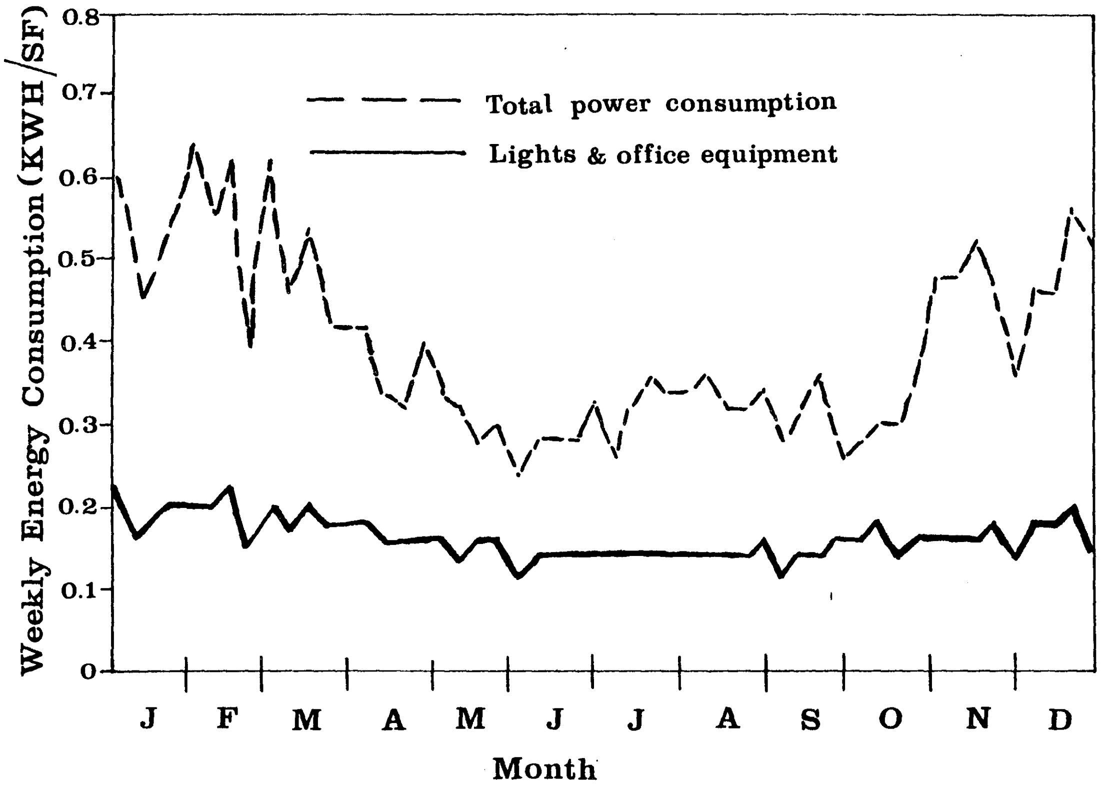


FIGURE I.2:
Measured weekly energy consumption of a Boston highrise (175 Federal Street). (source: Beacon Companies)

tion from a typical Boston office building is shown in figure I.2. The lighting and equipment electrical use accounts for nearly 40% of the total building energy consumption. Since this particular building has 2 watts/square foot of installed lighting, and a 1/2 watt/square foot equipment load, we can assume that 80% of this tenant electrical use is directly attributable to office lighting. In truth, the energy penalty is larger than this figure indicates, since waste heat from the lights adds significantly to the cooling loads.

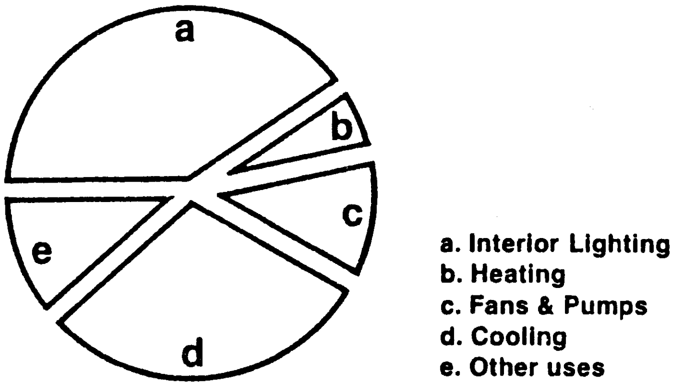
The building, discussed above, is better than most. Throughout the 1950's and 1960's, it was quite common for buildings to have 5 to 6 watts of installed lighting. As a result, well over half the energy consumption of many larger buildings, is directly attributable to their lighting systems.

Skin Dominated vs. Internal Load Dominated Buildings

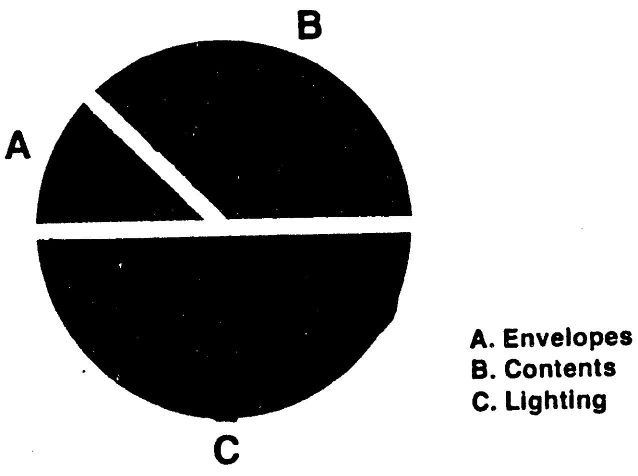
The heating loads of small residential buildings are composed primarily of heat loss through the building envelope and the infiltration of outdoor air. Since the energy consumption of these smaller buildings is so sensitive to climate, we refer to them as "skin" dominated buildings. Not surprisingly, carefully sealing and insulating the building envelope is the most effective way to reduce their heating loads.

Large commercial buildings have significantly different energy consumption patterns. In these larger buildings, small surface to

Actual Audit



Conceptual Estimate



Predicted Allotments for Basic Model

		BTU/s.f./yr.
A. Building Envelope	**10.5%**	**6.825**
1. Walls + Windows	9.0%	5.850
2. Roof, Floor – Skylights	1.5%	975
B. Building Contents	**39.5%**	**25,675**
3. Occupants	2.5%	1,625
4. Ventilation	12.0%	7,800
5. Appliances	5.0%	3.250
6. Elevators, Motors, Fans + Misc.	15.0%	9.750
7. Water Heating	5.0%	3.250
C. Lighting Systems	**50.0%**	**32,500**
8. Task + General Illumination	48.0%	31,200
9. Outdoor + Special	2.0%	1.300
D. Total Energy Budget	**100.0%**	**65,000**

FIGURE I.3:
The components of annual energy use in office buildings (source: Caudill, Rowlett, Scott).

volume ratios, and large internal heat gains from lighting, people, and equipment commonly result in buildings dominated by lighting and cooling loads; not the skin effects which dominate residential buildings (figure I.3). For this reason, we refer to commercial buildings as "internal load" dominated buildings.

Energy and Power

In order to fully understand commercial building energy consumption, one must understand the difference between energy and power. Energy is the capacity to do work, or in other words, the capacity to change a physical situation from one state to another. In the case of buildings, it is the change in temperature that concerns us here. The units used to measure heat are btu (British Thermal Units). Kilowatt hours (kwh) are used to measure electrical consumption. These two units can be used interchangeably; 3412 btu equal 1 kilowatt hour.

Power is the rate of energy flow (power = energy/time). It is commonly measured in btuh (British Thermal Units per Hour) and kilowatts (kw). Thus, the transfer of 141,000 btu (equal to one gallon of heating oil) refers to the amount of energy used, whereas a 60 watt bulb refers to the rate at which energy is used. We would need to know how long the bulb was lit in order to know the amount of energy consumed (kwh).

These two measures have different implications for a residential building owner and a commercial building owner. Energy is a residential owners greatest concern since it is the source of his monthly fuel bills. Unlike home owners, commercial real estate developers have traditionally been more interested in power than energy.

Most commercial building owners have little financial incentive to reduce energy consumption since utility bills are usually passed on to tenants. Thus an owner's main incentive to control energy consumption is his desire to please tenants, not a desire to save money. The importance of energy consumption is further reduced by the fact that tenants deduct energy costs from their taxable income. This nearly halves the energy costs of a corporation which pays the maximum federal tax rate of 46% (soon to be lowered).

Fifty percent of a typical commercial client's electrical bill can often be traced to power requirements. Commercial electrical rates consist of two components, an energy charge, and a peak charge. The energy charge is a flat rate paid for each kilowatt of electricity used. The peak power rate is an additional charge based on the buildings monthly peak electrical use. This peak charge is levied because peak power consumption affects the utility's cost of producing power, by determining the number of power plants required on line.

In the future, power will undoubtedly play a larger role in utility rate structures. Time of day price structures are common throughout Europe, and will undoubtedly be adopted in this country.

Tax shelters are central to real estate economics. These tax shelters result from the practices of depreciation, and interest payment deduction. The net result of these practices is that commercial buildings are often sold after 7 to 15 years, when allowable tax losses have been used up. As a result, the developers of commercial real estate are primarily interested in first cost. This further increases the importance of power over energy, since peak loads determine the size and cost of the auxiliary heating and cooling equipment.

Windows and Daylighting

What role do the window's play in the energy consumption a large internal load dominated building? In some ways their role is very small. Conduction losses and gains play a relatively minor role in the annual energy consumption of larger buildings. As long as glass areas are limited, and opaque walls are moderately well insulated (R-10 is usually adequate), the energy load resulting from the building envelope will be overshadowed by loads from the lighting, ventilation, infiltration, fans, and pumps.

However, if the daylight admitted through windows is utilized, windows can have a significant impact on an office building's energy consumption. By dimming the artificial lighting systems in response to available daylight, both electrical use and cooling loads can be reduced.

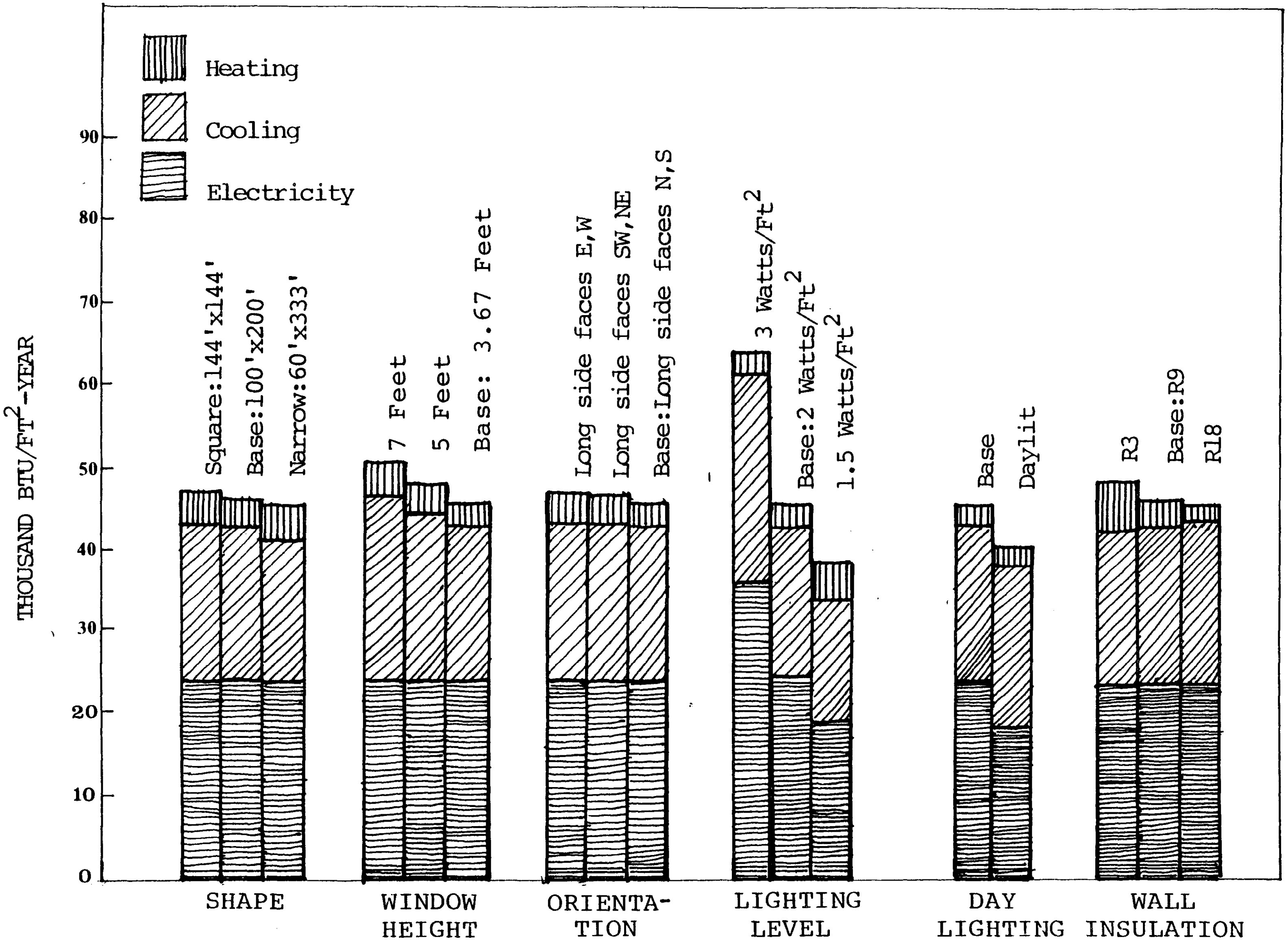


FIGURE I.4
Sensitivity of a typical Albuquerque office building to various parametric changes

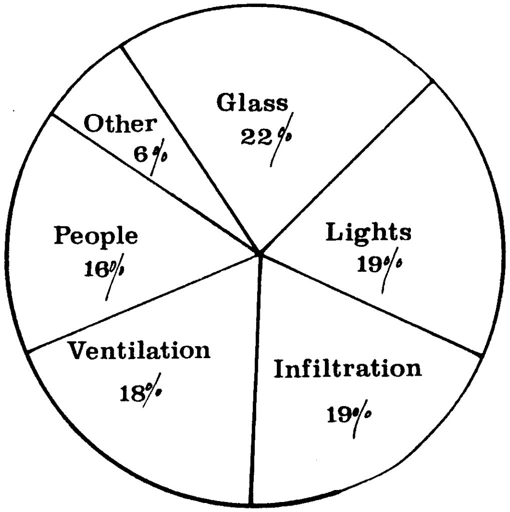


FIGURE I.5:
Peak cooling components of a typical Boston office building.

Figure I.4 shows the unpublished results of a study conducted by the author in 1980. A five story office building was the base case for this study. The building was rectangular (100 feet by 200 feet) with its long faces oriented due north and south. This building was subjected to a series of parametric changes, each analyzed with the DOE-2 computer program. The buildings shape was changed, the glass area was altered, the building was rotated, and the connected lighting load was varied. In addition, daylighting control devices were installed on the building.

As can be seem, these changes had very little impact on the buildings heating and cooling loads. In fact, the only changes that had a large impact on this base building's energy consumption was changing the connected lighting load or installing lighting control devices (figure I.4). Thus, in terms of annual energy consumption, daylighting is the most effective strategy to improve the energy efficiency of windows in large buildings.

The thermal impact of windows, is substantially greater on peak loads than on the annual energy consumption. Figure I.5 shows the components of the peak cooling loads in a typical Boston office building (the graph is drawn from the energy analysis presented in chapter V). As can be seen, the windows and artificial lighting account for over 40% of the peak load. Obviously peak loads can be substantially reduced by improving the thermal properties of the window and utilizing the available daylight.

As shown above, window must meet diverse and often conflicting criteria to achieve energy efficiency. First, solar heat gain must be limited in order to control air conditioning loads and insure occupant comfort. Second, daylight must be carefully modulated to control glare and increase potential energy savings from lighting control devices. Finally, the window must be a good thermal insulator to reduce winter heating loads. All of these factors, daylighting, solar heat gain, and heat loss must be addressed to accurately assess a window's energy impact.

Currently, many engineers regard windows as a necessary evil. This attitude is supported by ASHRAE 90-75, the building energy code adapted by most states. This code ignores the benefits of daylight and looks at windows mainly as sources of winter heat loss, and excessive summer solar heat gain. As a result, it encourages small glass areas, and low transmission glass, and most contemporary office buildings are being built with three to four foot high strip windows.

The codes currently governing commercial building energy use date from before 1975. Since that time, our understanding of commercial building energy use has increased to an extent that it challenges some of the conventional wisdom regarding large commercial buildings. In addition, improved glazing materials, lighting control devices, and energy management systems are becoming available.

II. A Proposed Daylighting System

This chapter describes the design of a daylighting system which maximizes energy savings. The first component of this system, a commercial heat mirror, selectively transmits solar energy to minimize solar heat gain while maintaining adequate daylight transmission. In addition, the film reduces window heat loss by reflecting radiant heat. The second component, inverted reflective blinds, is used to control the glare which results when direct sunlight enters a room unimpeded. The blinds distribute daylight evenly and effectively throughout a room. The third component is a lighting control system that automatically dims the artificial lighting system in response to interior daylight levels. This results in substantial energy savings since electrical power consumption is also reduced.

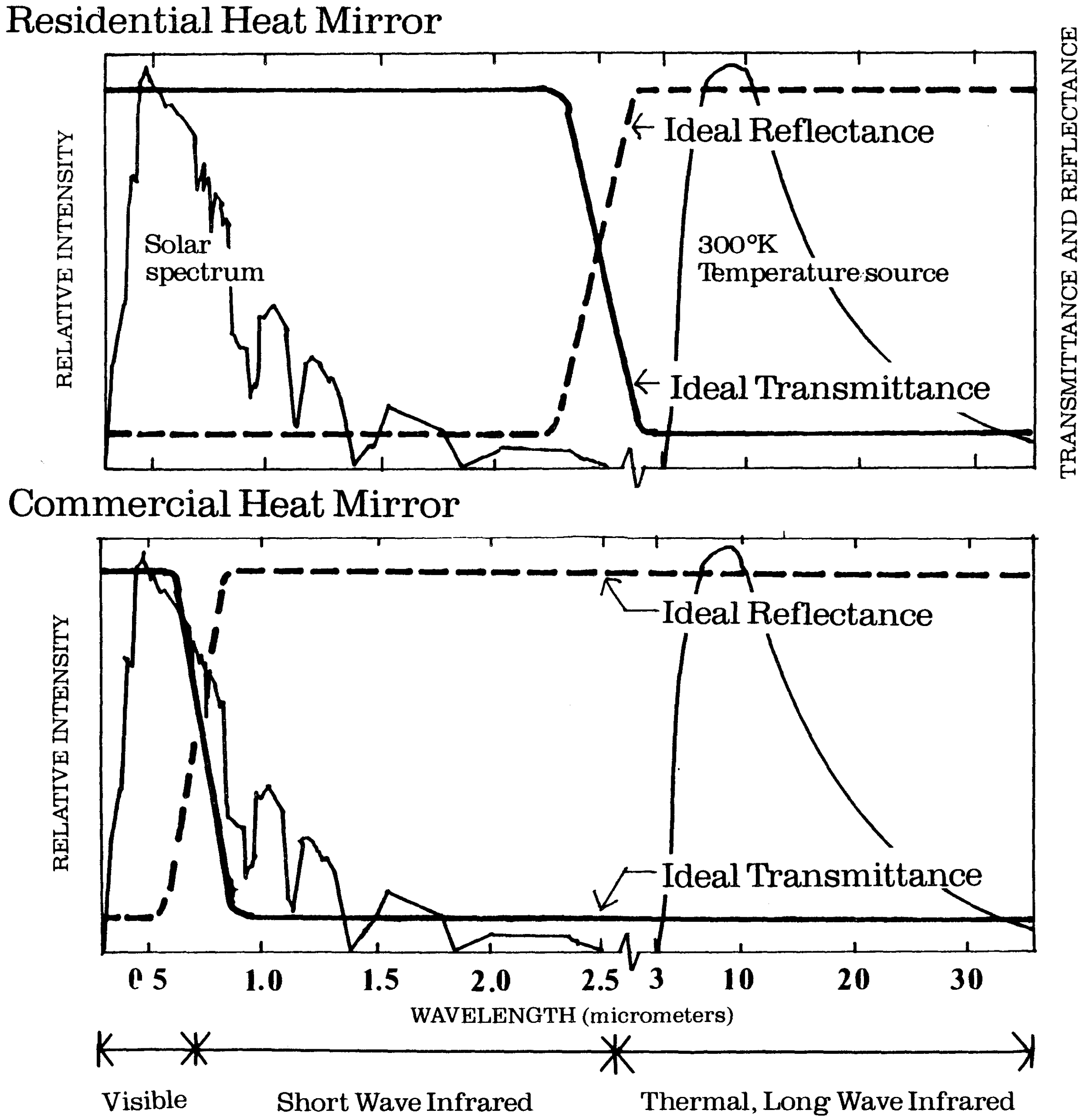
Glass

The backbone of this system is a recently developed glass coating known as "commercial heat mirror." This is a transparent film which reduces heat loss by reflecting the long wave infrared radiation emitted by all room surfaces back into a room. Such films have been successfully demonstrated in a number of buildings including MIT's Solar building . Most researchers to date have focused on heat mirror coatings for heating dominated buildings. These films have high solar transmission in order to maximize passive solar heating (figure II.1).

One would expect a heat mirror coating for large cooling dominated commercial buildings to differ from a small heating dominated residential building, since the two building types have different energy use patterns.

The small surface to volume ratios and large internal gains often result in buildings whose energy use is dominated by their cooling and lighting loads, not the skin effects which dominate residential buildings. Thus what they need is low solar heat transmission and high daylight transmission.

These conflicting goals can be resolved since the visible portions of the solar spectrum contains less than 50% of the sun's energy. The remaining solar energy is contained in the near-infrared region which is invisible to the human eye. Therefore, a selective coatings with high transmission of visible light and low transmission of near-infrared energy can combine the benefits of both clear glass



Residential Heat Mirror

Commercial Heat Mirror

FIGURE II.1:
Ideal heat mirror transmission characteristics.

and low transmission glass with few of their drawbacks (figure II.1).

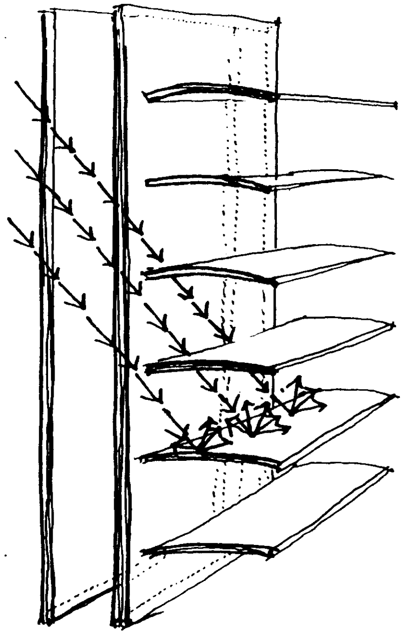


FIGURE II.2:
Conventional horizontal blinds diffuse daylight.

Window Blinds

The commercial heat mirror controls solar heat gain but not glare. If window glare isn't properly controlled, daylighting savings may not be realized, since occupants are likely to close blinds or curtains. In fact, excessive window glare could even increase energy consumption, if additional interior lights are installed to counterbalance excessive daylight at the perimeter.

There are two distinct types of glare that can result from daylighting; disability glare and discomfort glare. The first, disability glare, is caused by excessive sunlight. A view of the sun or sky through a window at the end of a long corridor, may cause a scattering of light in the eye and so introduce a "veiling" effect. This direct sunlight can be blocked with shading devices or reduced with low transmission glass. The second type of glare, discomfort glare, is caused by contrast. A typical example of discomfort glare would be the view of an excessively bright sky near the line of sight of a worker. This source may not be uncomfortable in itself, but because it is in darker surroundings, discomfort results. Discomfort glare can be controlled by both reducing the sky brightness viewed through the window, and increasing the reflectances of adjacent room surfaces. These goals can be accomplished with a variety of shading devices; overhangs, fins, lightshelves, drapes, and blinds are all effective.

Horizontal louvered blinds were investigated for this thesis. They were chosen over the other options for two reasons. First, they take up little room; second, they are inexpensive. The first is important since office buildings are rented on the basis of usable floor area, and any shading device that reduces a building's floor area reduces that building's income.

Two types of louvered blinds were investigated during the course of this thesis; conventional white blinds (figure II.2) and inverted reflective blinds (figure II.3). Reflective blinds been used in several passive solar applications, most notably in MIT's solar 5 building, where they were used to beam direct solar radiation to the ceiling plane. In this thesis, a very different tack was taken; reflective blinds were used on the north face to reflect diffuse daylight to the rear of the room. In fact, reflective blinds were not used on southern exposures, since they would beam sunlight into the occupant's eyes.

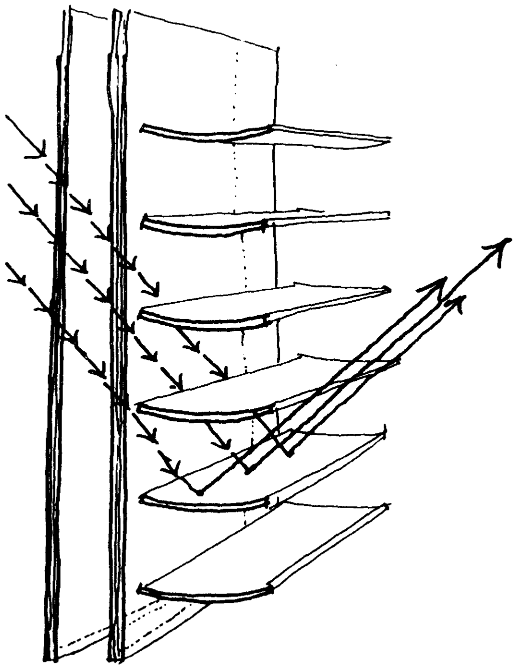


FIGURE II.3:
Inverted reflective blinds can be used to direct skylight.

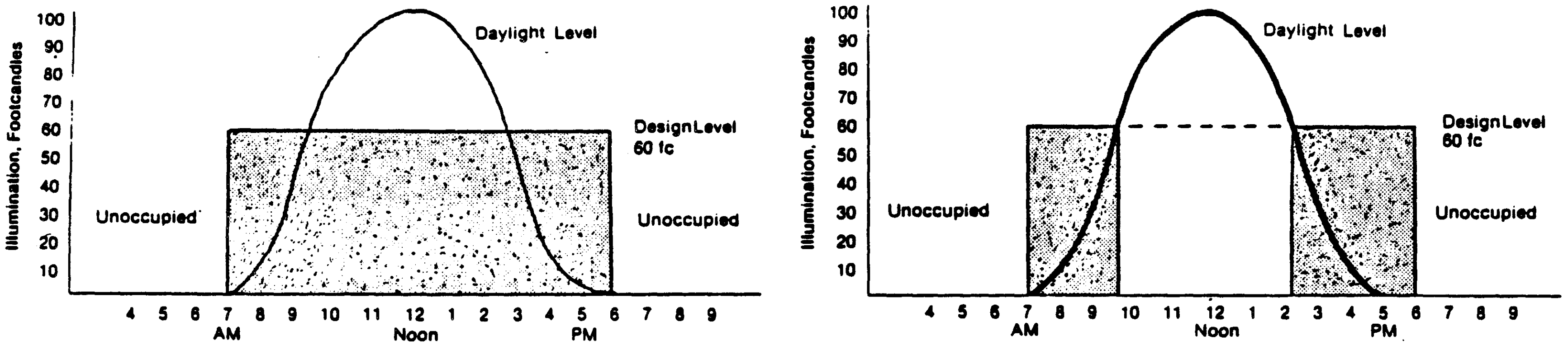
Lighting Controls

A daylighting system must be carefully integrated with the artificial lighting system if energy savings are to be realized. No matter how much daylight is available, no energy will be saved unless the electric lighting system is dimmed or turned off.

There are a variety of automatic controls developed for this purpose. Most fall into one of three categories (figure II.4). The first category, an on/off system utilizes a photo cell to turn off artificial lighting when available daylight exceeds a predetermined level. The second category, a stepped system utilizes a two stepped switching system controlled by a photo cell. Stepped systems consume less energy than a simple on/off systems since track changing daylight levels more closely. Occupants usually prefer this type of system to the simple on/off system, since changes in electric lighting levels are more subtle. The final category is a photo cell controlled continuous dimming system. Utilizing a florescent dimmer to precisely match artificial lighting output to available daylight, this system minimizes electrical consumption.

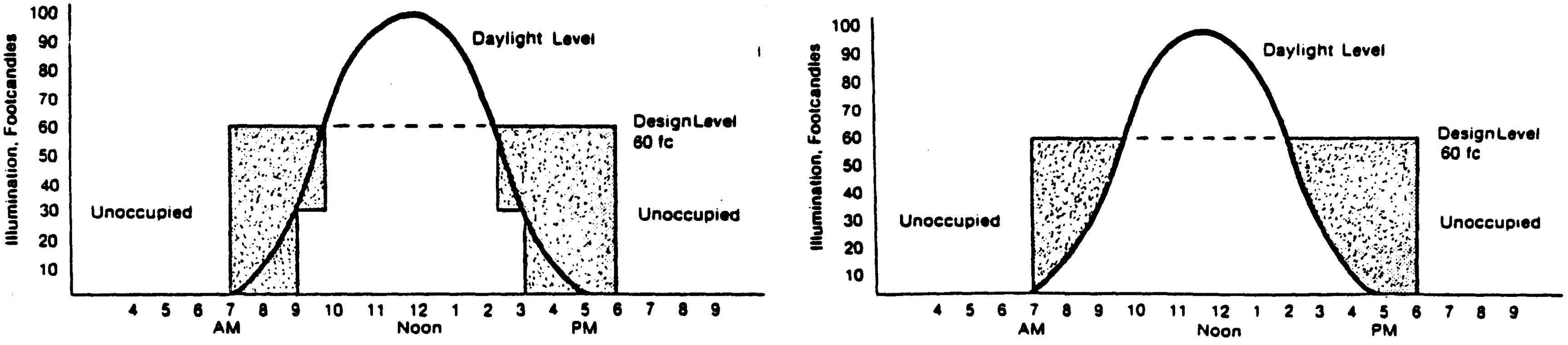
The choice of an appropriate system depends on many factors, including cost, reliability, user acceptability, and energy efficiency. Occupant acceptability is a critical factor often overlooked by researchers. An acceptable lighting control system should operate nearly invisibly. In several demonstration projects, building occupants have rejected on/off controls. Understandably, they have objected to lighting fixtures turning themselves on and off independent of human control.

The power consumption characteristics of each system are shown graphically in figure II.4. As can be seen, the chosen control strategy will markedly affect energy consumption. For example, if there were 40 footcandles of daylight in a room with a design light-



NO LIGHTING CONTROLS

ON/OFF SWITCHING



STEPPED SWITCHING
(2 Steps:30 and 60 fc)

CONTINUOUS DIMMING

FIGURE II.4
Generic lighting control devices. Shaded area represents energy required for supplementary (Ternoey et. al., 1981).

ing level of 60 footcandles, each type of lighting control system would result in a different electrical power consumption. The on/off system would be the lease efficient. It would turn the artificial lighting system completely on. The stepped system would be more efficient. It would reduce power consumption to 1/2 design level. The dimming system would be the most efficient, since it would reduce electrical consumption to 1/3 of the design level.

A stepped system was assumed in this thesis. Though continuous dimming systems use less energy then stepped systems, they are currently less expensive and more reliable. The continuous dimming systems now available are first generation systems bench made by the manufactures. As dimmers and solid-state ballasts improve during the next few years, continuous dimming systems will undoubtedly be the preferred daylighting control device. In the meantime, stepped switching systems are adequate.

For the purposes of analysis, the lighting control system was assumed to separately control the first three rows of the perimeter lighting (figure II.5). This corresponds to the front, middle, and back rows of lighting fixtures in a twenty foot wide perimeter zone.

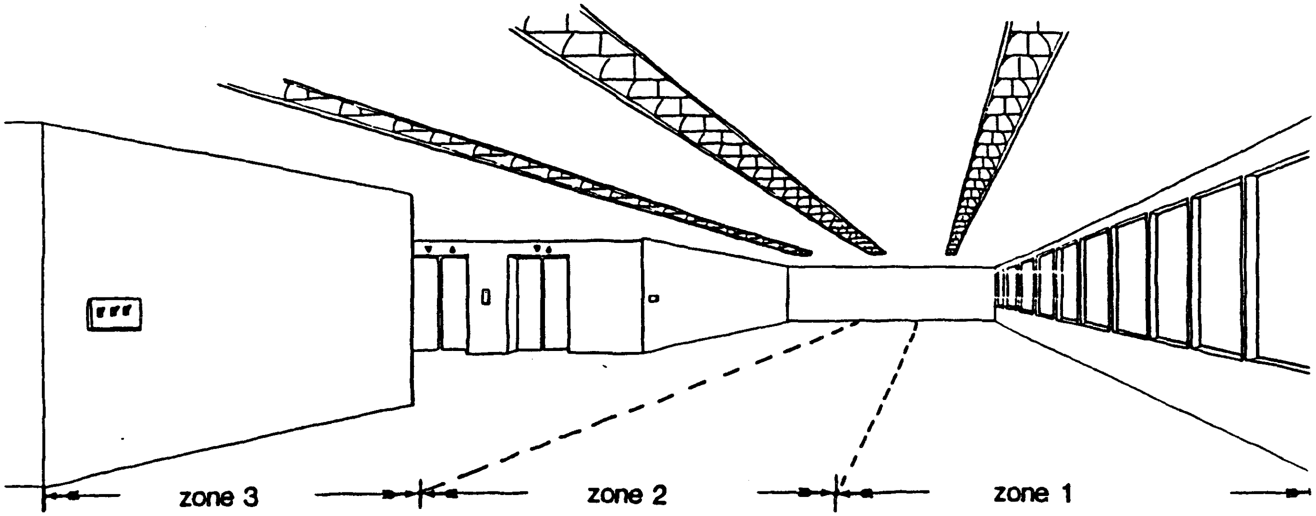


FIGURE II.5:
Lighting control devices control the front, middle, and back rows of perimeter lights separately (Ternoey et. al., 1981).

III. Heat Mirror Coatings

One of the most promising developments for improving the energy efficiency of windows is an optically transparent film known as a "heat mirror." This film reduces window heat loss by suppressing radiation heat transfer. In addition, it can be tailored to selectively transmit solar energy. Most recent literature has focused on coatings developed for residential buildings, coatings designed to have high solar transmission in order to maximize passive solar heating (figure II.1).

This chapter describes a different type of heat mirror coating, one optimized for internal load dominated buildings. The chapter begins with a description of window heat transfer. Next, the ideal properties of a heat mirror coating developed for internal load dominated buildings are described. Finally, measured data for an experimental heat mirror film with these characteristics is presented, along with the relevant performance data.

The Solar Spectrum

The solar spectrum can be divided into three distinct regions, each of which must be considered individually when discussing a window's thermal performance (figure III.1). The first region, the ultraviolet, consists of all wavelengths less then 0.4 micrometers. Since this region typically contains less than 5% of the total solar energy, it has little impact on a building's energy consumption. It is still desirable to reduce ultraviolet transmission since these wavelengths cause the fading of fabrics, rugs, and furniture.

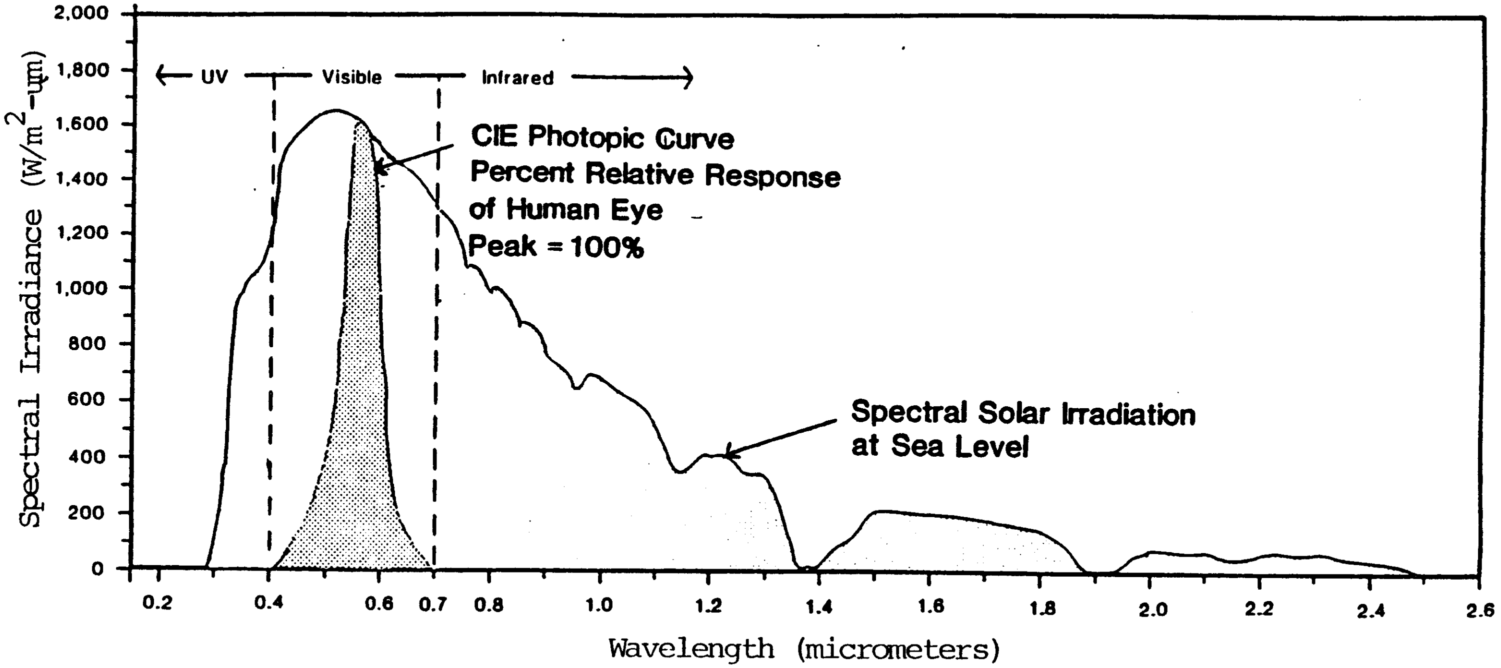


FIGURE III.1: Spectral distribution of sunlight.

The second region of, the visible portion of the solar spectrum, extends from 0.4 - 0.7 micrometers. This is the only portion spectrum that we can see. This region typically contains 40-50% of the sun's energy. The remaining 50-60 % of the sun's energy is contained in the short wave infrared region (0.7 -3.0 micrometers) which is completely invisible to the human eye.

Though not part of the solar spectrum, the long wave infrared region (all wavelengths greater than 3.0 micrometers) also plays an important role in a window's thermal performance. Emitted by all interior walls, it is a major source of window heat loss.

Selective Transmitters

Heat mirror coatings are so named for their ability to reflect long-wave infrared radiation. The coatings can also be tailored to selectively transmit solar energy.

As discussed earlier, the energy consumption of most large commercial buildings is dominated by cooling and lighting loads, not by heat loss through the building skin. Current energy codes recognize these cooling loads by encouraging the use of low transmission glass. The resulting low interior daylight levels minimize the potential energy savings from daylighting, and sacrifice its psychological and visual benefits.

Heat mirror coatings, with their ability to selectively transmit solar radiation, can be used to balance the need for low solar heat gain and high daylight transmission A selective coating which transmits visible light and rejects the near-infrared wavelengths can combine the benefits of clear glass and low transmission glass.

Performance Issues

In developing a heat mirror coating for internal load dominated buildings, one must balance the needs to transmit visible light while reducing solar heat gain. One must also determine which window surface the film must be affixed to, since each possible location defines a unique pattern of glass absorption and heat transfer coefficients which, in turn, determine the U value of the glazing assembly as well as the total solar heat gain. Finally, one should design a film that can be retrofitted. Retrofit applications cannot be overemphasized since the majority of the current building stock will be standing in the year 2000. In order to be effective as a retrofit product, the film must be durable when exposed to indoor or outdoor conditions, and must be applicable to plastic films.

These issues were studied in the course of this thesis. The study was based on performance data supplied by William King of Kinetic Coatings (Burlington, MA). Kinetic Coatings has developed a proprietary heat mirror coating that can be optimized for a variety of building types. It consists of an ion beam sputtered metal-dielectric coating that can be applied to either glass or plastic substrates.

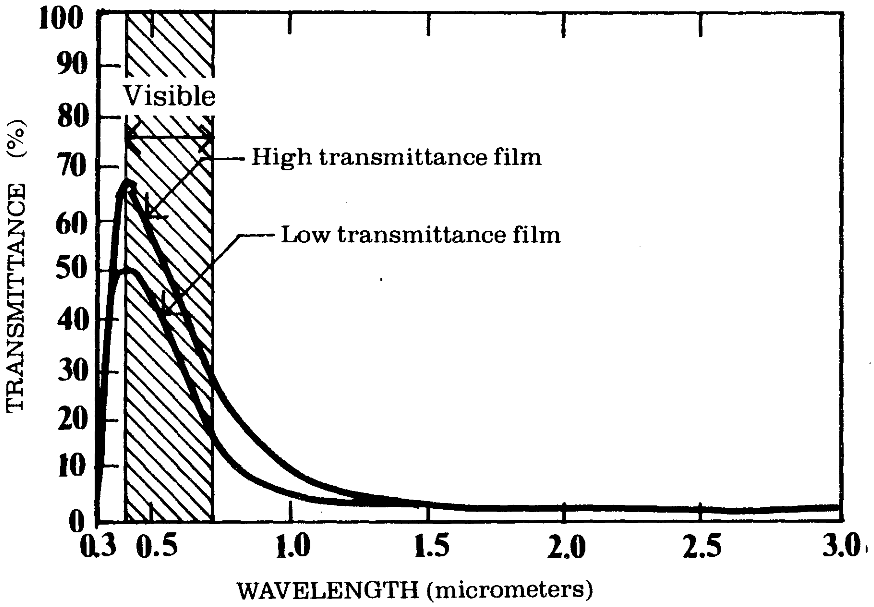


FIGURE III.2:
Typical transmission curves for commercial heat mirror film on 1/4 inch glass.

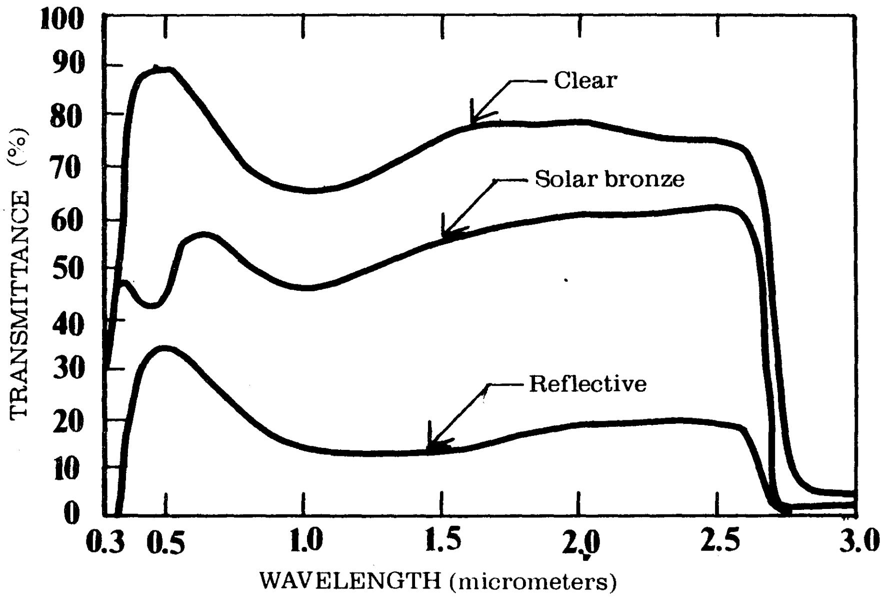


FIGURE III.3:
Typical transmission curves for three conventional glass types (all single layers, 1/4 inch thick).

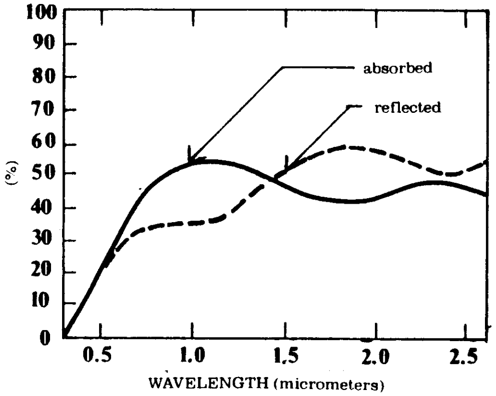


FIGURE III.4:
Reflection and absorption characteristics of high transmittance film on 1/4 inch thick clear glass.

There are several United States firms currently developing heat mirror coatings, each with unique properties. Of course, the results of this study are particular to the process developed by Kinetic Coatings, since film properties are determined by the details of the deposition process and composition of the coating itself and there is no general relationship between visible transmission, near-infrared transmission, and emissivity. This study should, at least, provide insight into the trade-offs in producing such a film.

The data supplied by Kinetic Coatings consisted of output from a spectro-reflectometer; the reflectivity and transmission of the glazing is given for all wavelengths between 0.36 and 2.5 micrometers.

In order to study the tradeoffs between daylight transmission and solar gain, two different laboratory samples were provided, one having higher solar and daylight transmission than the other (figure III.2-4). These two different films will be referred to as the "high" transmission film and the "low" transmission film. In both cases, the coating was applied to a polyester film laminated to 1/4 inch thick glass. For each of the two films, spectrometer data was supplied for all possible film locations on both single and double glass. In addition, coated and uncoated solar bronze glass were also tested.

Obviously, this laboratory data was not in the form needed to study the film's impact on a building's energy consumption. Therefore, the basic thermal properties of typical coated window assemblies had to be determined. Four fundamental properties were calculated: the solar transmission, daylight transmission, thermal conductivity (U value), and shading coefficient.

Solar Transmission

The solar transmission was calculated using a tabular approach developed by Wiebelt and Henderson (1979). Their tables divide the terrestrial spectrum into twenty equal increments of energy, with a mean wavelength which divides the increment into two equal parts. The table used in this analysis (figure III.5) represents a typical distribution for beam radiation (relatively clear atmosphere at air mass two).

To calculate the solar transmission, first, the transmission and reflection for each band was determined from the spectrometer output. The overall solar transmission was then determined by simply averaging all twenty bands.

The daylight transmission was determined using an even simpler procedure. Figure III.6 shows a standard spectral distribution curve for visible light. As can be seen, it is a nearly perfectly symmetrical bell curve bounded between 0.4 and 0.7 micrometers. Therefore the mean visible transmission will equal the transmission at 0.55 micrometers.

Energy Band Number	Wavelength Range μm	Midpoint Wavelength, μm
1	0.300–0.434	0.402
2	0.434–0.479	0.458
3	0.479–0.517	0.498
4	0.517–0.557	0.537
5	0.557–0.595	0.576
6	0.595–0.633	0.614
7	0.633–0.670	0.652
8	0.670–0.710	0.690
9	0.710–0.752	0.730
10	0.752–0.799	0.775
11	0.799–0.845	0.820
12	0.845–0.894	0.869
13	0.894–0.975	0.923
14	0.975–1.035	1.003
15	1.035–1.101	1.064
16	1.101–1.212	1.170
17	1.212–1.310	1.258
18	1.310–1.603	1.532
19	1.603–2.049	1.689
20	2.049–5.000	2.292

FIGURE III.5:
Spectral distribution of terrestrial beam radiation of air mass 2 and 23 km visibility, in twenty equal increments of energy (Weibelt and Henderson, 1979).

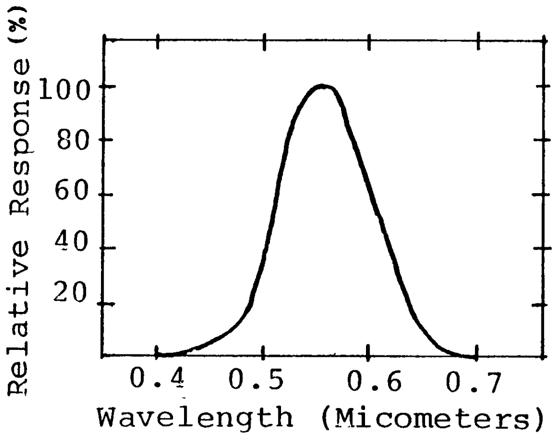


FIGURE III.6:
Spectral distribution of standard CIE photopic curve.

Thermal Conductivity

The U-value represents the rate of heat flow per hour (in Btu) through one square foot of window for each degree (F) of difference between the indoor and outdoor air temperatures. The lower the U-value, the lower the rate of heat flow through the glass. Heat transfer coefficients for glass are determined using an iterative approach. Since the procedure is tedious to do by hand, a computer program was written to perform these calculations. Since it is outside the scope of this chapter to document the program and its algorithms, the reader is referred to Appendix A for a full discussion.

Shading Coefficient

The shading coefficient accounts for solar transmission and absorption gains in one simple dimensionless ratio. Originally proposed by D.J. Vild of the Libby Owens Ford Glass Company, it is now a standard measure throughout the glass industry. It is defined as the ratio of the solar heat gain through a glazing system under a specific set of conditions to the solar heat gain through a single light of double-strength sheet glass (0.87 under standard summer conditions). This ratio, a unique characteristic of each type of fenestration is represented by:

$$SC = \frac{\text{Solar Heat Gain of Fenestration}}{\text{Solar Heat Gain of Double Strength Glass}}$$

Results

The heat mirror coating may be applied to any available surface of single or double glazing. Each possible heat mirror location defines a unique pattern of glass absorption and heat transfer coefficients which, in turn, determine the absorption heating gains. The goal of this study was to determine the optimal location of the heat mirror film and to explore the trade-offs between single and double glazing.

Table III.1 and Figure III.7 shows that the various film positions result in a wide variation of the total heat gain. For maximum solar rejection and minimum heat loss, a single layer of glass should be coated on the inner surface; a double layer on the outer surface of the air gap. Coating surface 2 (surfaces are numbered from the outside in) gives both the highest thermal resistance and the lowest solar heat gain for both single and double glass. With surface 2 coated, the commercial heat mirror outperforms most currently available low transmission glazings (table III.2). Only the most highly reflective glazings have comparably low thermal transmission.

One of the most surprising results of this study is the excellent performance of single glass. A single layer of coated glass has comparable performance to a double layer of most conventional low transmission glazings. In addition to the economic advantage of sin-

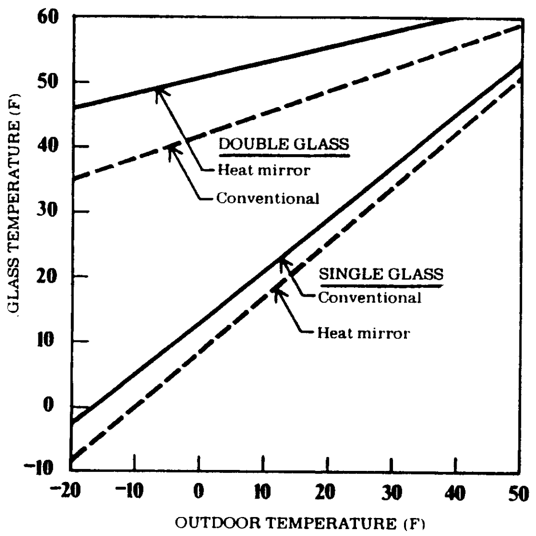


FIGURE III.8:
Temperature of inner glass surface versus outdoor temperature for unilluminated glass (wind-speed=15 mph, indoor temperature=68°F). The heat mirror coating is applied to surface 2 of both the single and double glass units.

gle glazing over double glazing, these findings also suggest that commercial heat mirror film will be useful in retrofitting existing single glazed buildings.

Condensation problems may limit single glazed heat mirrors to warmer climates, however. A single layer of glass coated with heat mirror will be colder than an identical uncoated glass, since the additional thermal resistance provided by the heat mirror film will result in a glass temperature closer to the outdoor temperature. This has been observed experimentally when coated and uncoated glass samples were installed side by side in the author's house. This phenomenon is shown graphically in figure III.8. The chart is based on calculations carried out with the computer program documented in appendix A. As can be seen, the heat mirror film lowers the surface temperature of a single pane of glass by 5-7°F.

When comparing shading coefficients for the various glass assemblies, keep in mind that they do not include the conduction gains through glass. Total heat gain is the sum of this conduction gain and the solar heat gain:

$$Q_A = (SC)(SHGF) + U_w(T_o - T_i)$$

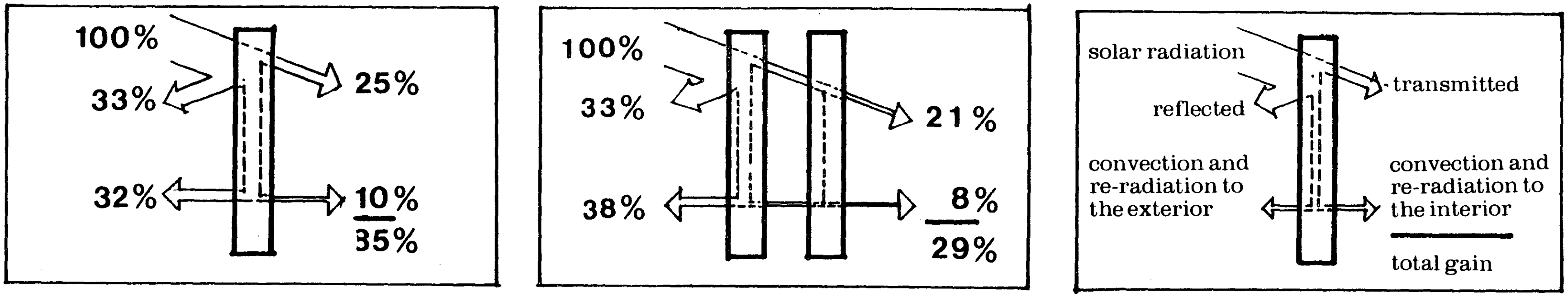
Where:

Q_A = Total heat gain through glass (Btu/ft^2)

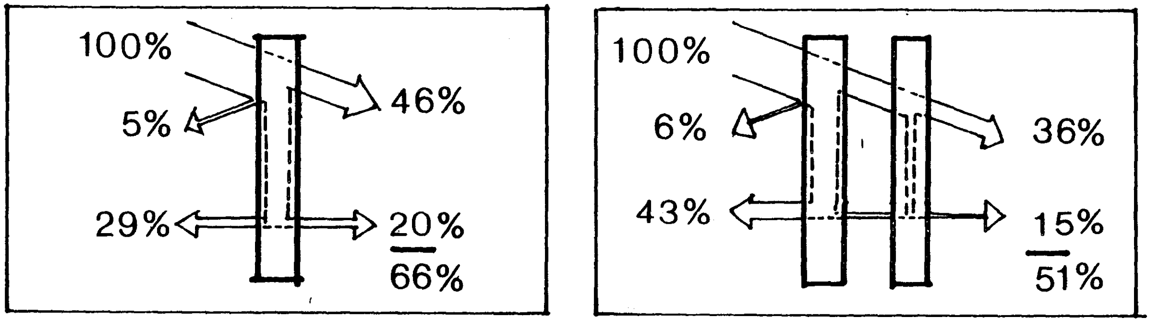
SHGF = Solar heat gain through double strength glass (Btu/ft^2)

U_w = Loss coefficient of window (Btu/ft^2-F)

Commercial Heat Mirror



Solar Bronze Glass



Reflective Glass

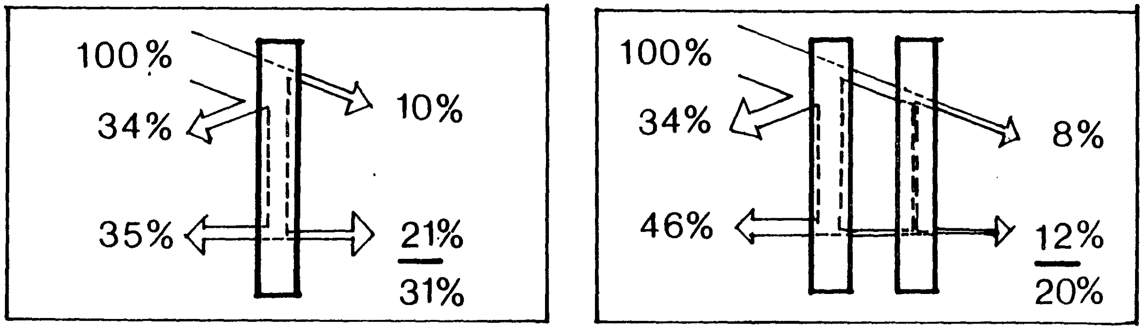


FIGURE III.7:
Solar heat gain through low transmission glazings. Based on a solar intensity of 250 Btu/hr-ft^2, an outdoor temperature of 90°F, an indoor temperature of 75°F, and a 7.5 mph wind velocity.

TABLE III.1: HEAT MIRROR TECHNICAL DATA

Panes (1)	Film(2) Location e=0.5	Daylight Trans. (%)	Solar Trans. (%)	Solar Reflec. (%)	Solar Absorp. (%) Outer	Inner	Winter U Value(3) (Btu/hr-ft2-F)	Summer U Value(4) (Btu/hr-ft2-F)	Shading Coef. (%)	Relative Heat Gain(5) (Btu/hr-ft2)
High Transmittance Film										
1	1	48	25	53	22	-	1.03	0.92	36	85
1	2	48	25	33	42	-	0.67	0.57	36	80
2	1	43	21	54	22	3	0.46	0.50	30	67
2	2	43	21	33	42	4	0.29	0.28	31	66
2	3	43	21	37	25	17	0.29	0.29	42	88
2	4	43	21	25	21	33	0.35	0.43	43	92
Low Transmittance Film										
1	1	34	16	65	19	-	1.03	0.91	25	63
1	2	34	16	44	40	-	0.67	0.56	25	58
2	1	32	14	65	19	2	0.46	0.50	21	49
2	2	32	14	44	40	2	0.29	0.28	21	46
2	3	32	14	45	27	14	0.29	0.29	31	66
2	4	32	14	33	23	30	0.35	0.43	34	74

TABLE III.2: COMPARATIVE GLASS VALUES

Panes (1)	Film(2) Location e=0.5	Daylight Trans. (%)	Solar Trans. (%)	Solar Reflec. (%)	Solar Absorp. (%) Outer	Inner	Winter U Value(3) (Btu/hr-ft2-F)	Summer U Value(4) (Btu/hr-ft2-F)	Shading Coef. (%)	Relative Heat Gain(5) (Btu/hr-ft2)
Clear:										
1	-	88	77	7	16	-	1.05	0.96	93	199
2	-	78	60	11	17	12	0.47	0.53	80	167
Solar Bronze:										
1	-	50	46	5	49	-	1.05	1.03	68	150
2	-	44	36	6	51	7	0.47	0.55	54	116
Reflective:										
1	-	8-20	8-20	-	-	-	0.90-1.02	0.89-1.02	26-41	64-96
2	-	7-18	6-16	-	-	-	0.41-0.45	0.47-0.54	18-30	43-68

TABLE III.3: HEAT MIRROR FILM ON 3/16 INCH SOLAR BRONZE GLASS

Panes (1)	Film(2) Location e=0.5	Daylight Trans. (%)	Solar Trans. (%)	Solar Reflec. (%)	Solar Absorp. (%) Outer	Solar Absorp. (%) Inner	Winter U Value(3) (Btu/hr-ft2-F)	Summer U Value(4) (Btu/hr-ft2-F)	Shading Coef. (%)	Relative Heat Gain(5) (Btu/hr-ft2)
High Transmittance:										
1	2	-	16	17	67	-	0.68	0.61	30	69
Low Transmittance:										
1	2	-	10	22	68	-	0.68	0.62	24	57
Substrate:										
1	-	-	52	4	44	-	1.07	1.03	73	160

(1) Film is deposited on clear 1/4 inch glass with a transmittance of 78%. Insulating units consist of two layers of clear 1/4 inch glass with a 1/2 inch wide air space.
(2) Glass surfaces are numbered from the outer glass surface to the inner glass surface.
(3) Winter U Values are based on an outdoor temperature of 0 F, an indoor temperture of 70 F, and fifteen mph wind, and no sun.
(4) Summer U Values and shading coefficients are based on an outdoor temperature of 90 F, an indoor temperature of 75 F, a solar intensity of 250 Btu/hr-ft2 and a 7.5 mph wind velocity.
(5) Based on an ASHRAE Solar Heat Gain Factor of 200 Btu/hr-ft2 and an outdoor temperature 14 F higher than the indoor temperature.

T_o = Outdoor air temperature (F)
T_i = Indoor air temperature (F)

The "relative heat gain" shown in Table III.1 is the sum of the conduction gains, transmitted solar energy, and the inward flowing solar energy absorbed by the glass. It is a useful figure for comparing the heat gain characteristics of the different glazing assemblies.

Building Retrofit

The most likely candidates for retrofit are single glazed buildings with either clear or low transmission glass, and double glazed buildings with clear glass. The data in tables III.1-3 indicates that commercial heat mirror film can significantly improve performance in all these cases.

For single glazed applications, the film should be applied to the inner surface. This minimizes the U value of the window assembly and minimizes abrasion to the film. When applied to a single layer of 1/4 inch clear glass, thermal transmission is reduced by 61-73%. When applied to a single layer of solar bronze glass, thermal transmission is reduced by 36%. The shading coefficient is reduced by 59-67%.

For double glazed window retrofits, significant improvements are still possible even though the film cannot be applied to the optimum location; the outer surface of the air gap. When applied to the inner surface of clear double glass, thermal losses are reduced by 38%, and the shading coefficient is reduced by 46-58%.

IV. Daylighting Model Experiments

This chapter describes how a daylighting model was used to test several window control strategies. In the first section, the construction of the daylighting model is briefly outlined. In the second section, the procedure for measuring daylight levels is described along with the equipment used to take these measurements. Finally, the procedure used to analyze the data and results are given.

The Model

The physics of light is such that a scale model which duplicates the geometry and reflectivity of a full size space will yield identical light levels when tested under identical skies. Physical scale modeling was chosen for this study since it has several advantages over graphic and computational methods. First, daylighting models are the only design tool that can be used to study daylighting quality. Graphic and computational approaches predict only daylighting quantity (i.e. how many footcandles). Second, models can be used to study light shelves, reflective blinds, and other innovative approaches, while simplified design tools are generally restricted to more conventional window treatments.

Model Parameter	Value
Room depth	20 feet
Room length	30 feet
Ceiling height	8.7 feet
Sill height	2.0 feet
Window height	5.5 feet
Wall reflectance	75%
Ceiling reflectance	50%
Floor reflectance	70%
Ground reflectance	20%
Window transmittance	48%

TABLE IV.I:
Daylighting model parameters

The model built for this study was based on a small commercial office space at Wellesley Office Park. This particular location was chosen since it resembles many other medium scale commercial office buildings and because it was made accessible by both the tenant and building owner. The model was initially built by the author, Alexander Lohr, and Christopher Mathis for William Lam's lighting course at the Harvard Graduate School of Design. Funding for the model was received from the Windows and Lighting Program at Lawrence Berkeley Laboratory.

The model was constructed in a modular fashion to insure maximum flexibility. The primary structure consisted of a post and beam framework. Any combination of foamcore walls or windows could be installed in this framework.

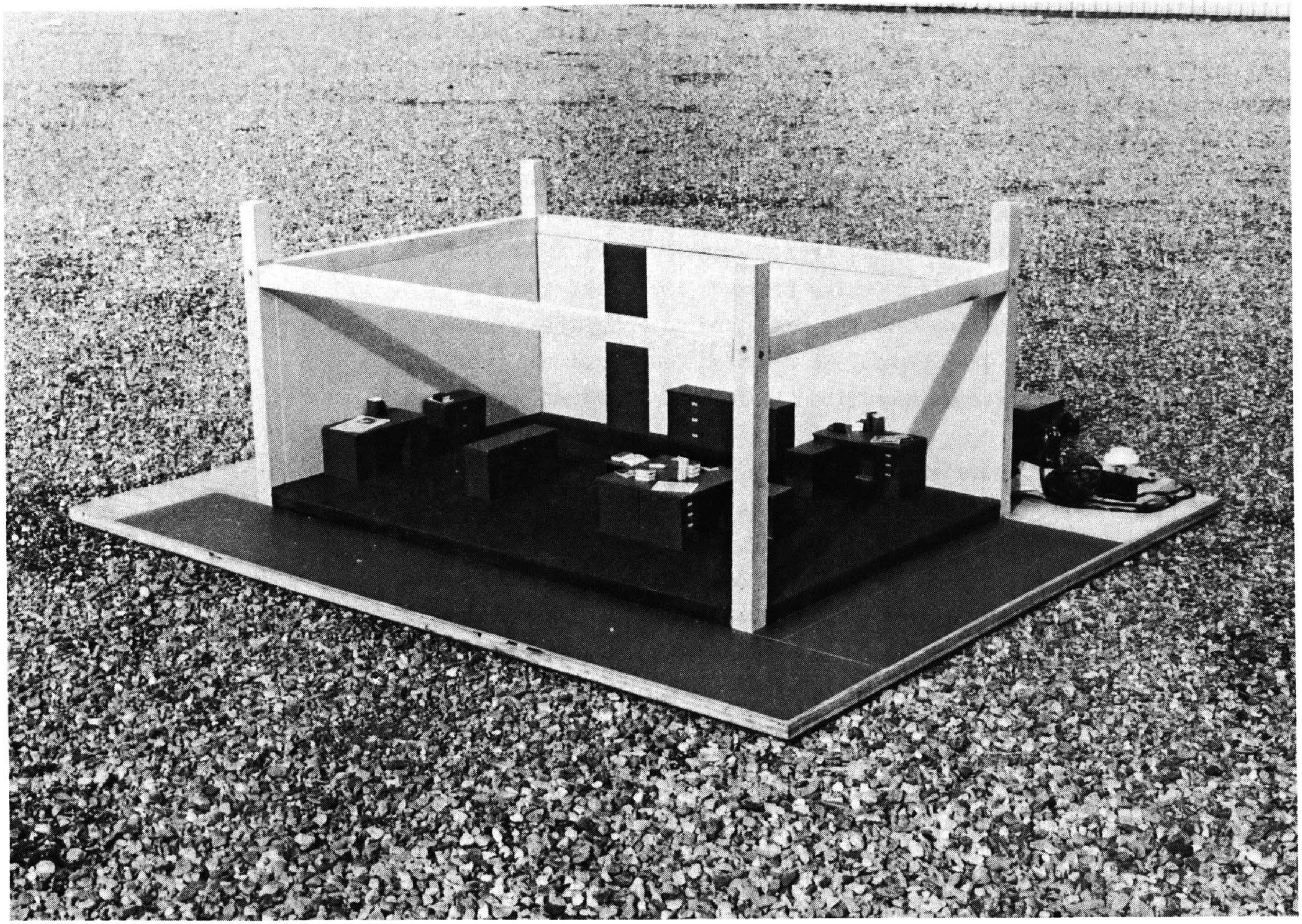
Model testing was carried out in several stages. During the first stage, the real office was modelled as closely as possible (figures IV.1-4). In the model, surface reflectivity and colors of the wall, ceiling, and floor planes were matched as closely as possible. Scale furniture was built. This was done so that light levels in the model could be compared with light levels in the real space.

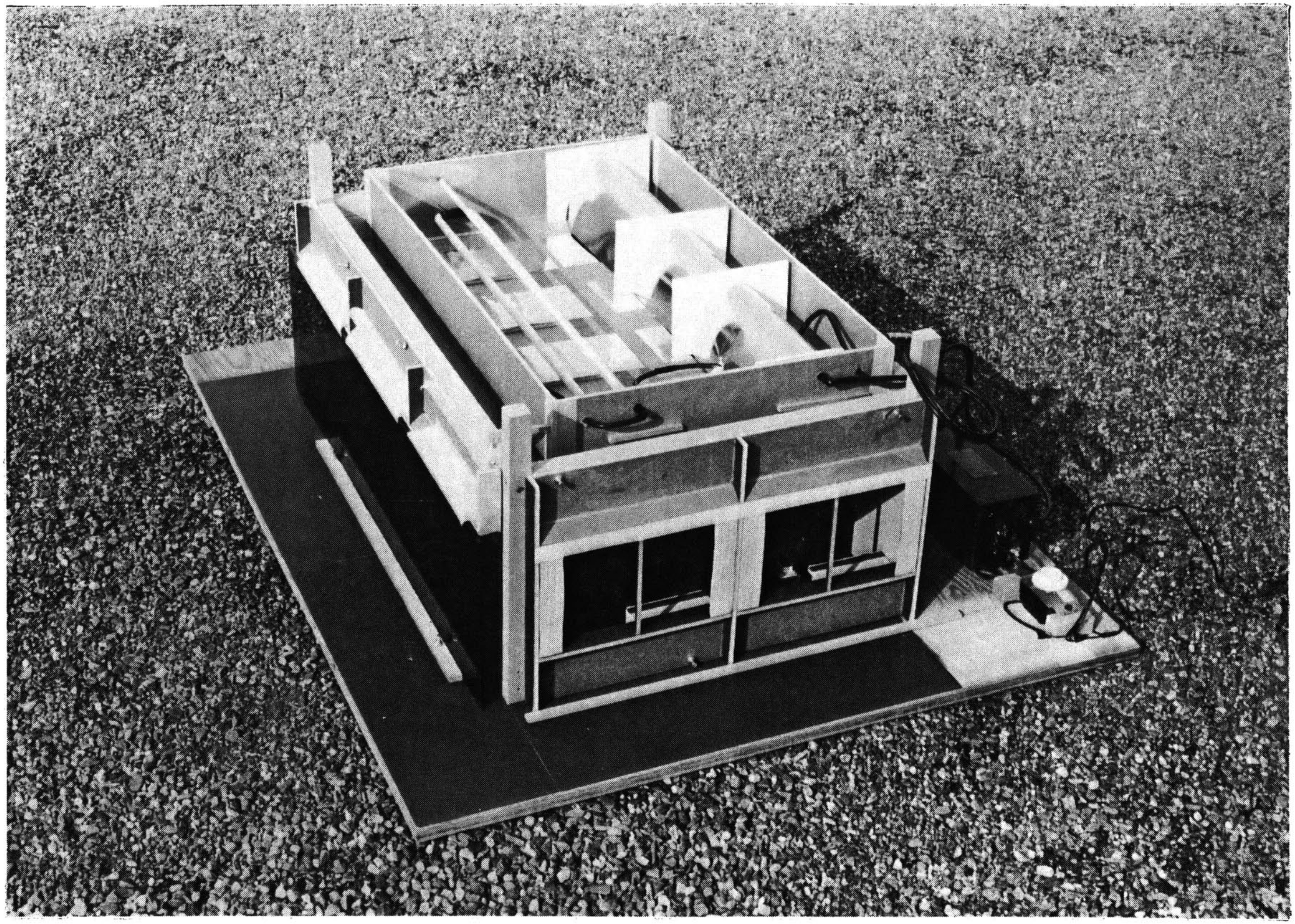
The same window glass was used in the model as was used in the building (3/16 solar bronze glass with a reflective film). In this first generation model, the artificial lighting was also modelled.

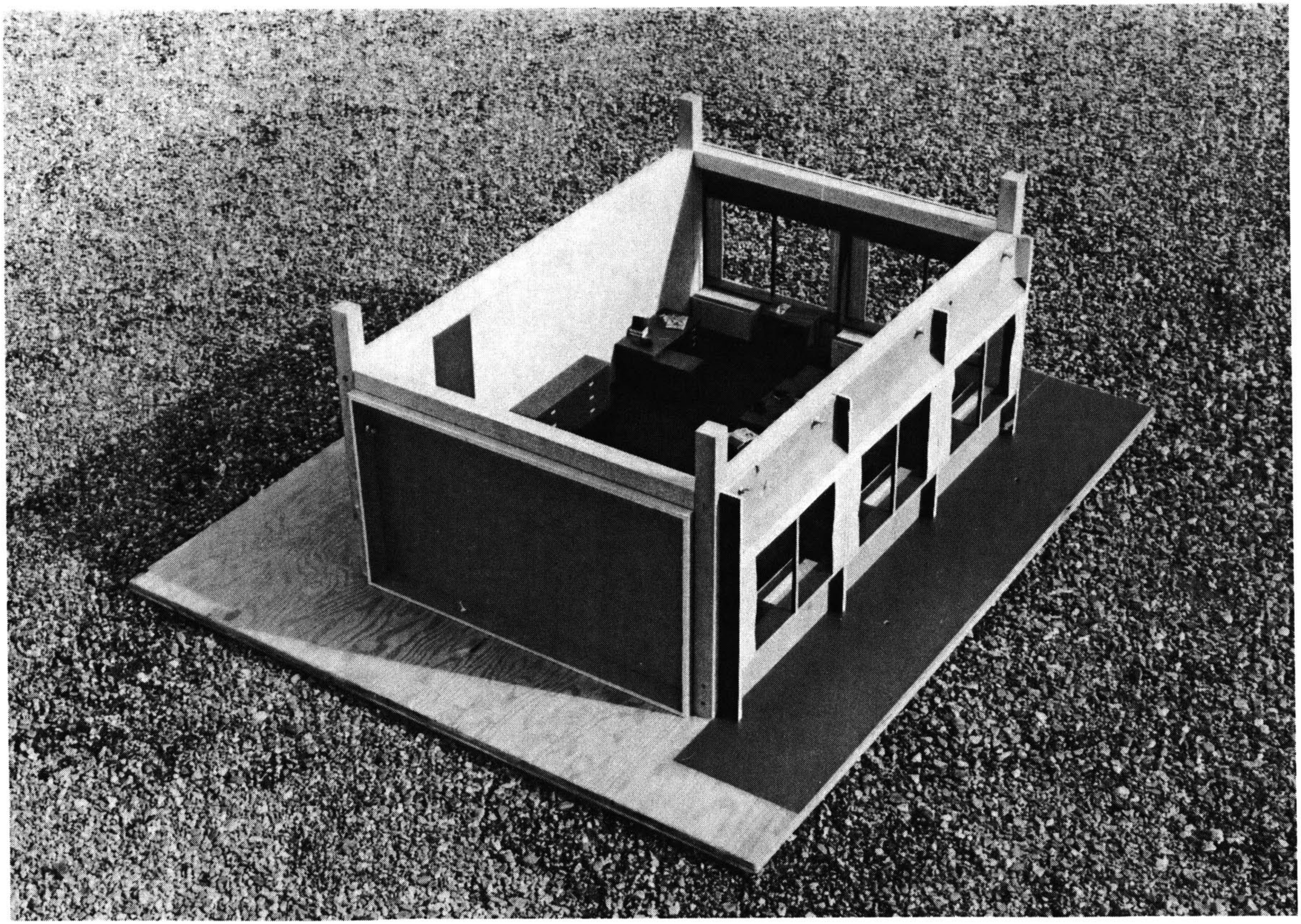
The daylighting measurements were carried out informally during this stage. The model was brought out to Wellesley and spot measurements were taken with a hand held light meter Several refinements were made at this stage. For instance, it was found that the plywood model base was reflecting too much light into the room. This was corrected by cutting back the base, and covering the remaining surface with dark grey paper. It was also found that the presence of furniture or curtains significantly lowered lighting levels in the space.

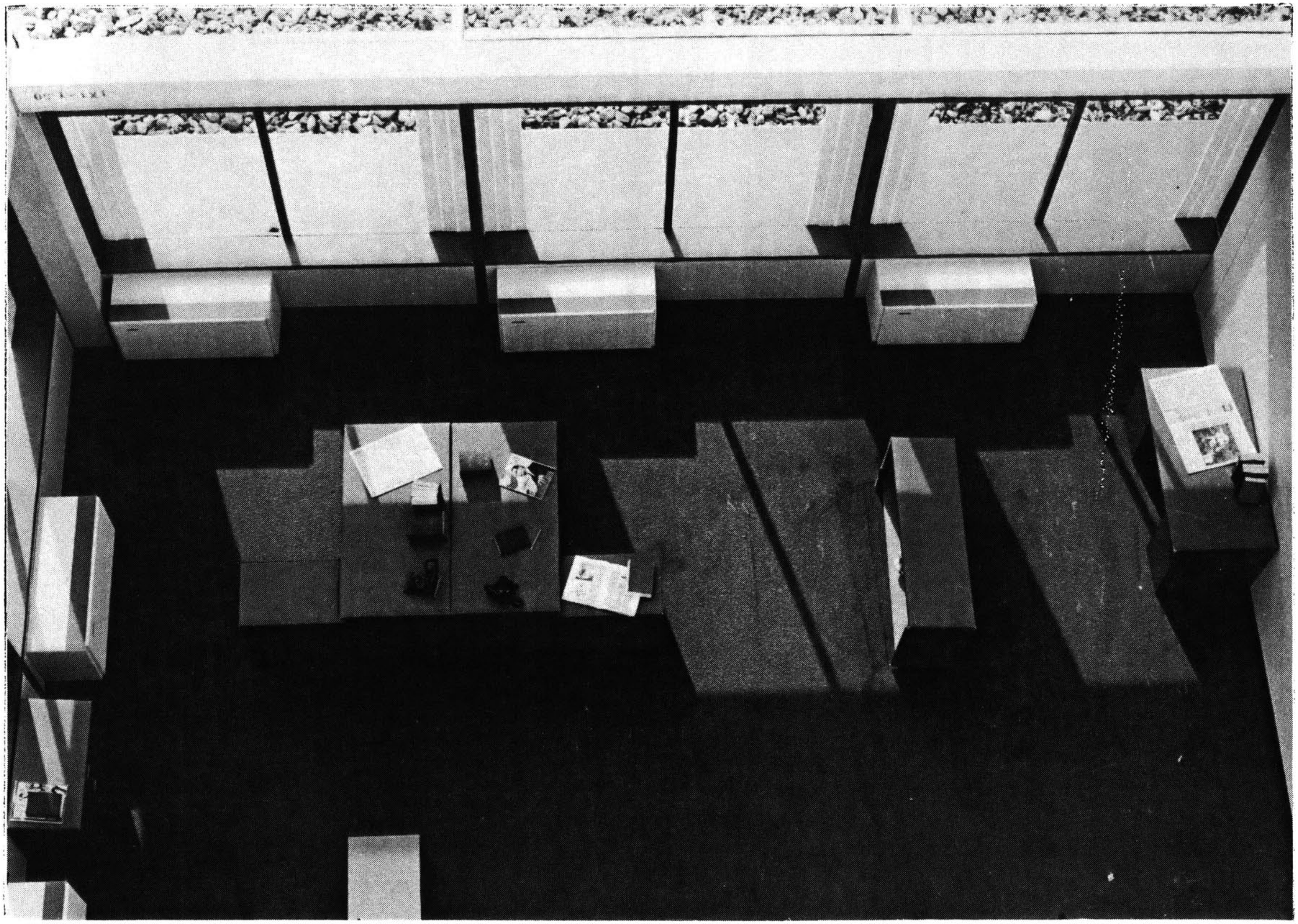
After this first phase of model testing was complete, the model was altered so that various configurations of the proposed daylighting scheme could be tested (table IV.1). A adjustable window wall was built so that various window sizes could be tested. A support structure also was built for the louvered blinds. This structure allowed the blinds to altered easily in order to compare reflective and non-reflective blinds. The spacing of the blinds was identical to that of those made by Levalor. No provision was made to tilt the blinds, since optimum control of the blinds was unlikely to occur in practice.

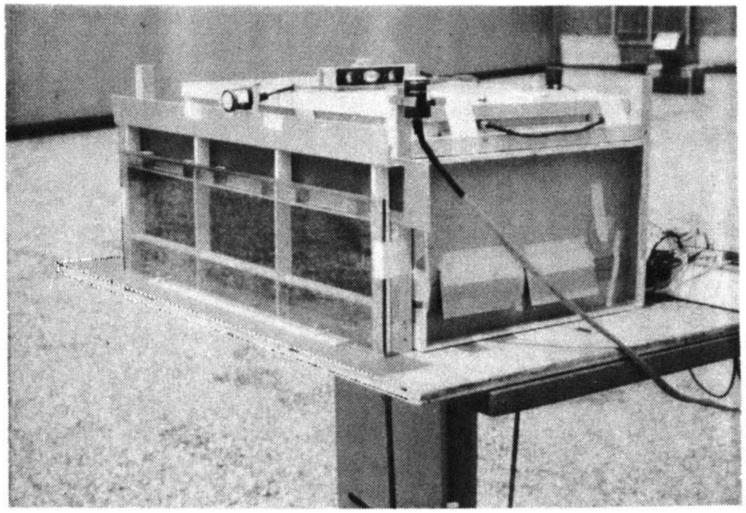
FIGURES IV.1-4:
Following Pages: Modular assembly of the daylighting model.

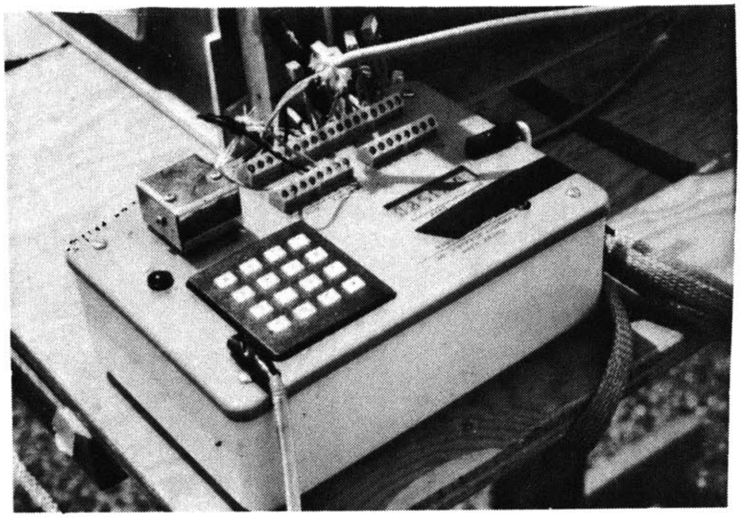












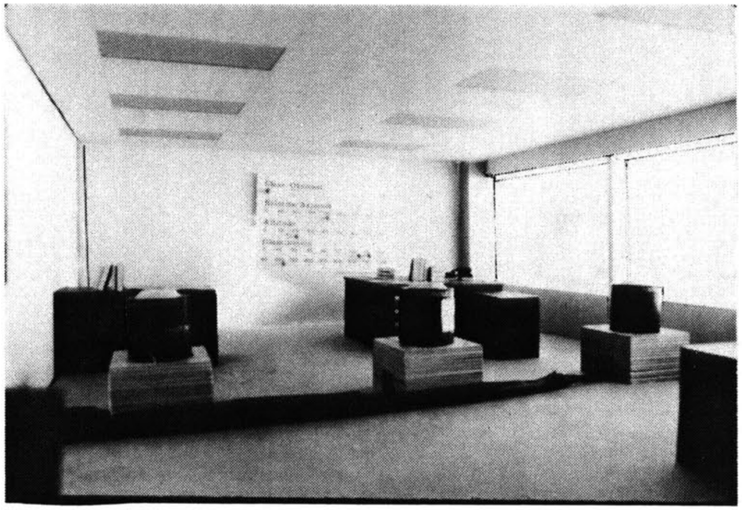
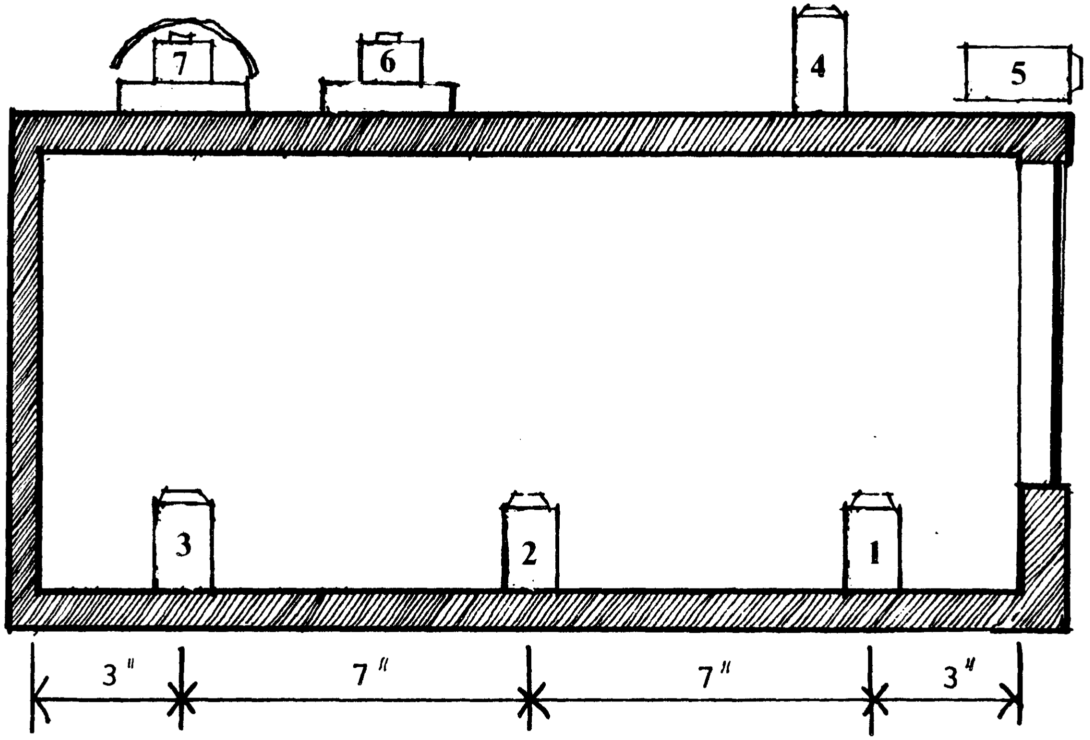


FIGURE IV.5:
Datalogger and sensors on the model.



Sensor	Recorded Data	Units
1	Interior illumination at front of room	Footcandles
2	Interior illumination at middle of room	Footcandles
3	Interior illumination at back of room	Footcandles
4	Horizontal illumination	Footcandles
5	Vertical illumination on the window plane	Footcandles
6	Global solar radiation	Btu/ft^2
7	Diffuse solar radiation	Btu/ft^2

FIGURE IV.7:
Sensor placement in daylighting model. The sensors inside the model are placed so as to correspond to desk height (3 feet). Since the model is built at a scale of one inch equals one foot, the sensors are placed at 3 feet, 10 feet, and 17 feet back from the window plane, along the room's center line.

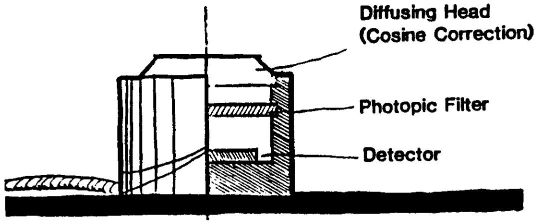


FIGURE IV.6:
Typical photometric sensor.

Measuring Light Levels

Light levels inside and outside the model were measured with a data collection system (figure IV.5). An automatic was used so that the various sensors could all be sampled within a short time span. Daylighting levels can fluctuate rapidly enough to make it difficult to compare measurements taken as little as ten seconds apart. The datalogger, mad by Campbell Scientific of Logan, Utah, was borrowed from the Northeast Solar Energy Center (NESEC).

The Campbell micrologger is a low cost acquisition system built specifically to record environmental data. It can be programmed to accept input from up to seven sensors. I used both pyronometers and photometric sensors (figure IV.6) were to gather data. Two Licor pyronometers (Lambda Instruments, Lincoln, Nebrasca) were borrowed from NESEC to measure solar radiation. Five photometric sensors were borrowed from Leo Dwyer at the Solar Energy Research Institute (SERI) to measure lighting levels. These sensors are manufactured by United Detector Technology (UDT) of Culver City, California.

The photometers and pyronometers were located on the daylight models as shown in figures IV.5 and IV.7.

Testing The Model

The daylighting model was used to compare the daylight levels resulting from different window sizes with and without louvered blinds. Reflective blinds were tested to see if they would yield higher light levels than conventional white blinds. In total, four

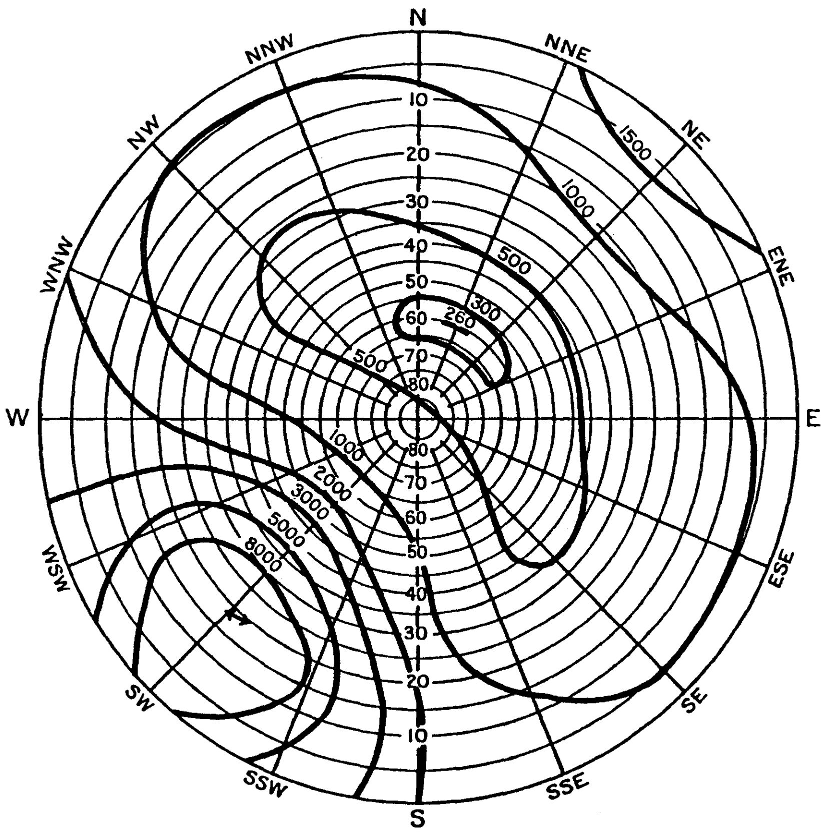


FIGURE IV.8:
Luminance distribution of a blue clear sky at Stockholm, October 2, 1953 (position of sun indicated by arrows). From Hopkinson et. al. (1966).

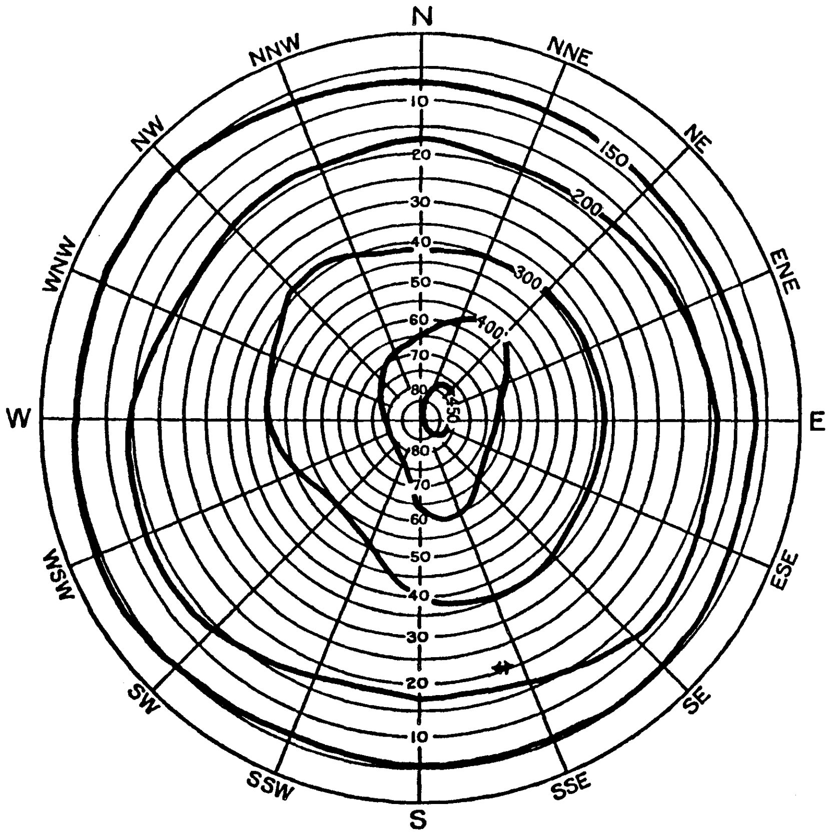


FIGURE IV.9:
Luminance distribution of a fully overcast sky at Stockholm, October 10, 1953. No individual clouds or bright patches were visible. From Hopkinson et. al. (1966).

different window configurations were tested. The first configuration was a simple 5 1/2 foot tall window without shading devices. The second configuration had white louvered blinds. It was also 5 1/2 feet tall. In the third window configuration, the louvered blinds were turned upside down and given mirrored surfaces. The fourth window configuration had a combination of white and mirrored blinds. The mirrored blinds were placed above eye level. To avoid glare, white blinds were installed below this height.

By testing the model I wanted to predict interior illumination for any day of the year for either clear or overcast skies. The model was tested outdoors. Outdoor testing is complex since interior illumination is dependent on both cloud cover and the sun's location (figure IV.8). Strictly speaking, the best way to test a model would be to monitor it continuously for six months to a year. The practical alternative was to take measurements on one heavily overcast day and one clear day, reorienting model during the day to simulate the correct relative solar position for any time of the year.

Simply by rotating the model in plan, I was able to simulate a number of solar azimuth's. During the clear day testing, five different relative solar azimuth's were tested (0°,45°,90°,135°,180°). During the cloudy day testing, only one solar azimuth was necessary since the distribution of light from an overcast sky is independent of the sun's azimuth (figure IV.9).

Achieving the proper solar altitudes can be difficult. If test-

SOLAR ALT	INTERIOR ILLUMINATION MEASURED			SOLAR RAD	DAYLIGHT		INTERIOR ILLUMINATION NORMALIZED		
	FRONT	MIDDLE	BACK	GLOBAL	HORIZONTAL	VERTICAL	FRONT	MIDDLE	BACK
NO WINDOW BLINDS:									
64	347	120	83	137	4722	1894	286	99	68
43	226	77	50	61	2220	1180	196	67	43
27	53	15	10	14	566	262	40	11	8
WHITE WINDOW BLINDS:									
64	149	82	63	126	4378	1854	132	73	56
43	93	54	40	62	2224	1188	81	47	35
26	14	11	9	12	392	194	12	10	8
REFLECTIVE WINDOW BLINDS:									
64	143	111	79	109	3988	1810	139	108	77
43	95	74	51	72	1602	1214	114	89	61
27	24	19	15	16	484	252	21	17	13
REFLECTIVE BLINDS ABOVE, WHITE BLINDS BELOW:									
64	136	87	66	122	4236	1830	125	80	61
43	91	59	42	67	2430	1214	72	47	33
27	17	12	9	13	424	218	17	12	9

TABLE IV.2: Daylighting model data taken under heavily overcast skies.

SUN POSITION		INTERIOR ILLUMINATION MEASURED			SOLAR RADIATION		DAYLIGHT		INTERIOR ILLUMINATION NORMALIZED		
ALTITUDE	AZIMUTH	FRONT	MIDDLE	BACK	GLOBAL	DIFFUSE	HORIZ	VERTICAL	FRONT	MIDDLE	BACK
NO WINDOW BLINDS:											
69	0	426	190	129	302	34	9714	4688	392	175	119
69	45	341	144	100	304	32	9706	3602	314	133	92
69	90	212	99	74	303	31	9768	2082	194	91	68
69	135	190	102	76	303	31	9948	1408	171	92	68
69	180	199	106	86	305	33	10092	1322	176	94	76
58	0	739	248	173	276	55	8544	6114	641	215	150
58	45	468	199	132	279	56	8206	4650	422	180	119
58	90	221	100	73	282	57	8314	2196	197	89	65
58	135	171	99	78	283	55	8674	1258	146	85	67
58	180	170	106	88	287	61	9144	1274	138	86	71
41	0	1720	297	77	178	26	5502	7052	1572	272	70
41	45	1717	240	70	180	26	5400	5410	1599	224	65
41	90	182	91	50	183	26	5472	1874	167	84	46
41	135	147	87	49	187	24	5758	588	128	76	43
41	180	142	93	56	187	25	5990	1012	119	78	47
16	0	296	321	409	49	17	1606	4106	283	306	390
16	45	400	253	86	51	18	1530	2928	401	253	86
16	90	104	51	41	54	17	1554	1066	103	50	40
16	135	85	50	50	54	17	1652	544	79	46	46
16	180	81	46	42	52	16	1762	504	70	40	37

TABLE IV.3: Clear sky data: NO BLINDS

SUN POSITION		INTERIOR ILLUMINATION MEASURED			SOLAR RADIATION		DAYLIGHT		INTERIOR ILLUMINATION NORMALIZED		
ALTITUDE	AZIMUTH	FRONT	MIDDLE	BACK	GLOBAL	DIFFUSE	HORIZ	VERTICAL	FRONT	MIDDLE	BACK
WHITE WINDOW BLINDS:											
69	0	262	123	95	301	33	9682	4680	242	114	88
69	45	207	95	75	303	32	9658	3710	192	88	69
69	90	151	69	57	302	30	9726	2158	139	63	52
69	135	158	74	61	303	31	9862	1382	143	67	55
69	180	158	75	66	303	31	9986	1318	142	67	59
60	0	361	176	143	277	50	8682	5998	320	156	127
60	45	269	127	100	280	51	8340	4632	248	117	92
60	90	149	70	57	282	49	8406	2102	136	64	52
60	135	148	70	60	281	49	8700	1294	131	62	53
60	180	158	77	67	282	49	9102	1326	133	65	57
43	0	489	240	83	187	28	5804	6874	447	220	76
43	45	338	160	68	190	27	5440	5216	330	156	66
43	90	123	63	40	192	27	5466	1668	119	61	39
43	135	121	62	38	195	26	5796	1020	111	57	35
43	180	122	68	43	194	27	6224	1018	104	58	37
28	0	778	337	198	116	32	3626	6472	689	298	175
28	45	399	181	125	119	30	3522	4796	364	165	114
28	90	104	59	52	123	30	3582	1546	93	53	47
28	135	99	56	52	123	27	3768	916	84	48	44
28	180	99	59	55	122	28	3948	920	81	48	45
17	0	537	542	415	53	18	1752	4374	513	518	396
17	45	399	332	97	56	18	1664	3162	401	334	98
17	90	66	42	38	61	18	1734	1092	64	41	37
17	135	65	43	45	60	16	1866	606	58	39	40
17	180	58	38	38	58	16	1992	556	49	32	32

TABLE IV.4: Clear sky data: WHITE BLINDS

SUN POSITION		INTERIOR ILLUMINATION MEASURED			SOLAR RADIATION		DAYLIGHT		INTERIOR ILLUMINATION NORMALIZED		
ALTITUDE	AZIMUTH	FRONT	MIDDLE	BACK	GLOBAL	DIFFUSE	HORIZ	VERTICAL	FRONT	MIDDLE	BACK
REFLECTIVE WINDOW BLINDS:											
69	0	293	133	103	302	34	9660	4620	271	123	95
69	45	161	103	80	302	31	9640	3610	149	96	74
69	90	105	73	60	301	29	9708	2022	97	67	55
69	135	104	74	61	302	30	9858	1164	94	67	55
69	180	107	78	68	303	31	10010	1092	96	70	61
59	0	508	293	193	278	57	8604	6064	446	257	169
59	45	307	150	110	275	54	8124	4636	285	139	102
59	90	108	75	57	275	51	8166	2066	100	69	53
59	135	98	69	59	277	51	8490	1272	87	61	52
59	180	102	76	67	278	54	8892	1280	87	65	57
42	0	651	606	100	181	27	5622	7146	599	557	92
42	45	436	362	83	184	27	5518	5406	409	339	78
42	90	94	71	44	187	27	5588	1746	87	66	41
42	135	84	65	43	189	26	5866	1018	74	57	38
42	180	87	70	47	190	26	6096	1014	74	59	40
26	0	899	883	357	101	23	3200	6320	824	809	327
26	45	411	304	179	104	23	3114	4620	387	286	169
26	90	83	66	57	109	23	3198	1406	76	61	52
26	135	74	60	56	110	22	3406	866	64	52	48
26	180	69	56	53	107	19	3592	806	56	46	43
16	0	554	445	375	51	17	1656	4262	513	412	347
16	45	345	342	103	53	17	1582	2878	334	331	100
16	90	53	44	37	54	16	1608	1002	51	42	35
16	135	50	44	45	55	16	1716	554	45	39	40
16	180	47	41	39	55	16	1800	518	40	35	33

TABLE IV.5: Clear sky data: INVERTED REFLECTIVE BLINDS

SUN POSITION		INTERIOR ILLUMINATION MEASURED			SOLAR RADIATION		DAYLIGHT		INTERIOR ILLUMINATION NORMALIZED		
ALTITUDE	AZIMUTH	FRONT	MIDDLE	BACK	GLOBAL	DIFFUSE	HORIZ	VERTICAL	FRONT	MIDDLE	BACK
REFLECTIVE BLINDS ABOVE, WHITE BLINDS BELOW:											
69	0	236	122	95	302	33	9684	4590	218	113	88
69	45	193	95	75	304	33	9610	3762	180	88	70
69	90	134	65	54	304	33	9852	2032	122	59	49
69	135	139	69	60	308	36	10034	1402	124	62	53
69	180	141	72	66	309	36	10184	1302	124	63	58
59	0	361	193	149	275	53	8574	5980	318	170	131
59	45	236	127	98	278	54	8238	4460	216	116	90
59	90	132	69	57	280	54	8320	2020	120	63	52
59	135	129	67	58	282	54	8638	1260	113	59	51
59	180	137	73	66	281	55	9030	1308	115	61	55
43	0	507	325	100	182	27	5662	6990	475	305	94
43	45	333	196	73	186	28	5548	5220	319	188	70
43	90	111	63	44	189	27	5604	1768	105	60	42
43	135	107	60	43	192	26	5916	1018	96	54	39
43	180	110	66	44	191	27	6132	1016	95	57	38
27	0	738	624	231	109	28	3434	6428	660	558	207
27	45	426	222	145	111	25	3328	4860	393	205	134
27	90	95	60	53	116	26	3394	1540	86	54	48
27	135	88	55	52	116	24	3794	854	71	45	42
27	180	88	57	54	116	24	3794	854	71	46	44
17	0	554	481	592	54	17	1762	4474	526	457	562
17	45	363	347	96	56	17	1674	3078	363	347	96
17	90	60	44	39	59	17	1708	1048	59	43	38
17	135	58	44	46	59	17	1806	592	54	41	43
17	180	53	39	38	57	15	1936	544	46	34	33

TABLE IV.6: Clear sky data: WHITE BLINDS BELOW, REFLECTIVE BLINDS ABOVE ed during the winter, the model must be tilted to duplicate high summer sun angles. Tilting can cause two sources of error. When tilted, the model "sees" a piece of the ground plane where it should "see" the sky. This can strongly influence results, especially if the ground plane is significantly brighter or darker than the sky it replaces. The second problem is that the intensity of the sunlight varies with the solar altitude since the thickness of the air mass varies. Fortunately, the model did not have to be tilted since testing was conducted during the month of August, which has a peak solar altitude was 70°.

The final test data was taken over two days, one clear (July 23, 1981), the other heavily overcast (August 8, 1981). On both days, the model was tested every hour from solar noon until sunset. On the clear day the model was rotated during each test period to achieve six different relative solar azimuth's. The result of this testing was a matrix of measured light values corresponding to virtually any solar position. Tables IV.2-6 contain the data collected during both of these test days.

Data Analysis

In order to compare the different window strategies, I used the raw data from the physical scale model to predict interior light levels over the course of two spring days; one clear, the other overcast. First, I had to "normalize" this test data, since exterior

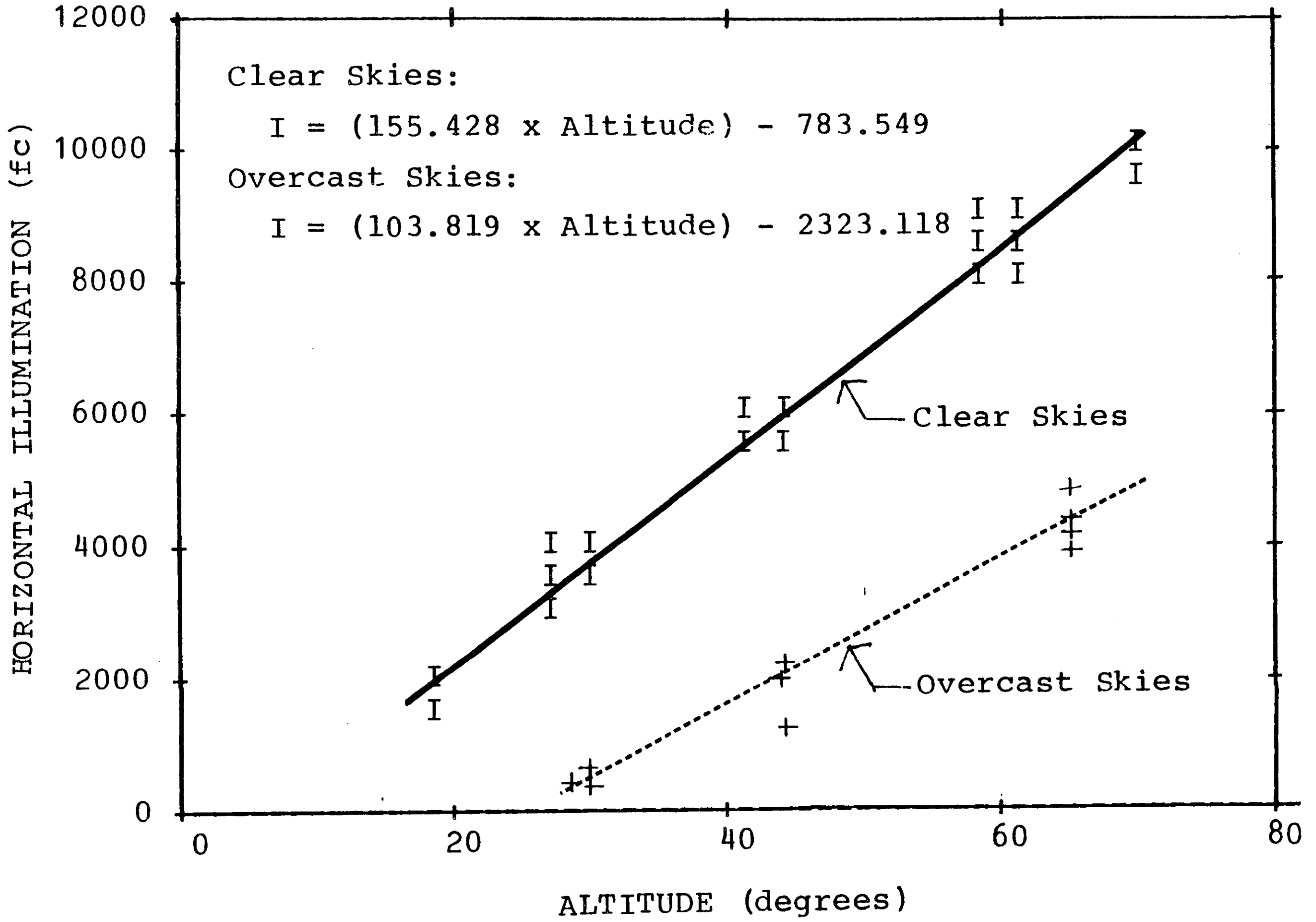


FIGURE IV.10:
Measured horizontal illumination under clear and overcast skies. Results from a linear regression of the data are also given.

light levels fluctuate rapidly. Though invisible to the human eye, these fluctuations are large enough to interfere with model measurements. Since the four alternative window treatments are tested one after the other, fluctuating ambient light levels often made it impossible to directly compare each alternative.

To reduce the "flutter" created by changing light levels, all measurements were expressed as a daylight factor. The daylight factor has traditionally been defined as the ratio of interior illumination to the outdoor illumination from the sky (excluding direct sun). The daylight factor was developed in England, where overcast sky conditions prevail. Since it is inappropriate for clear sky measurements, for this study I redefined the daylight factor as the ratio of interior illumination to the total daylight on a horizontal surface (including direct sun).

After the daylight factor was calculated, a linear regression was performed to correlate horizontal light levels with the solar altitude. The regression analysis was performed for both the clear and overcast day measurements; as can be seen in figure IV.10, the fit is quite good.

The next step in normalizing the measurements, was to recalculate all of the interior illumination levels. This was done by multiplying the previously determined daylight factors by exterior illumination levels calculated from the regression analysis results. In effect, the measured interior light levels were readjusted so that

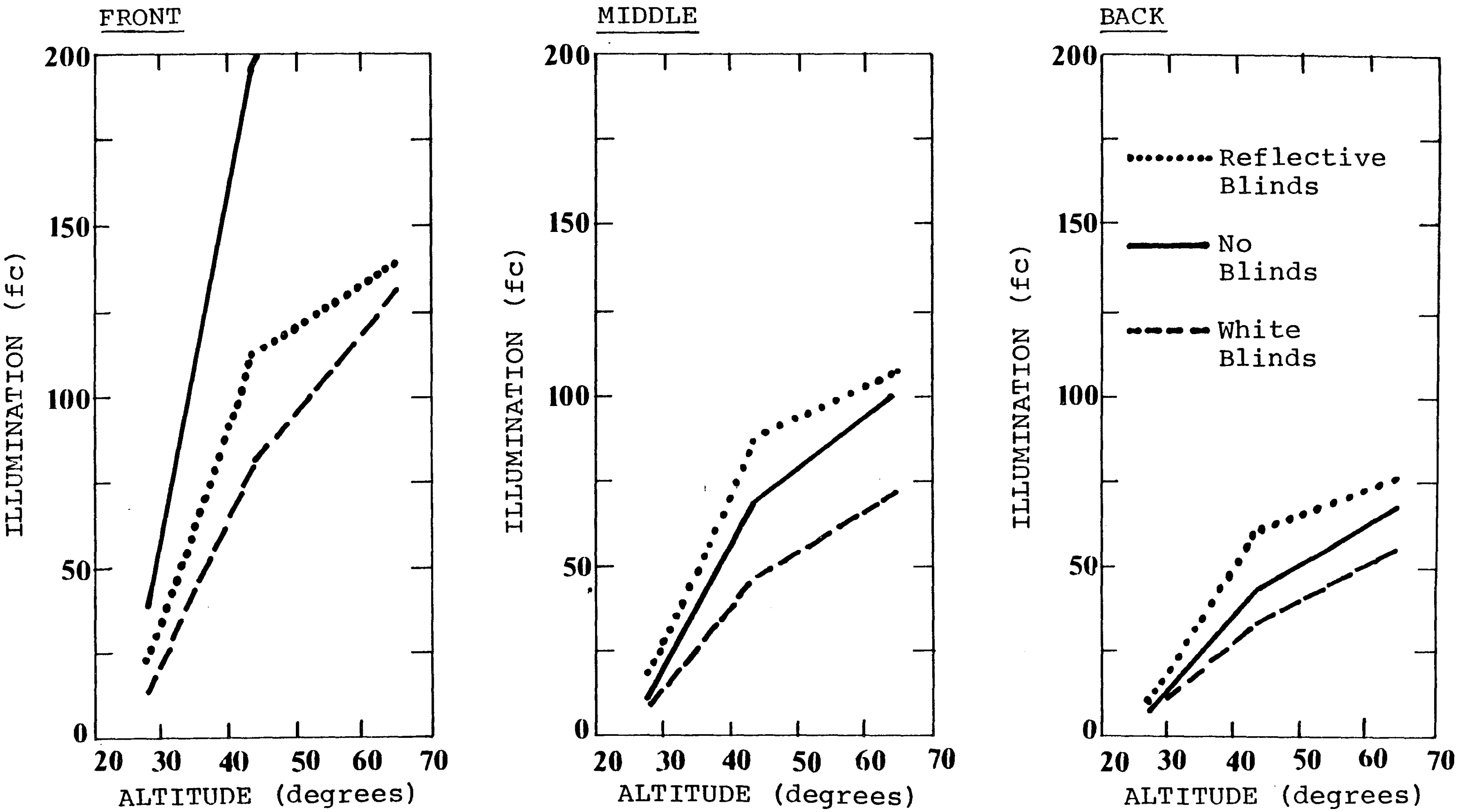
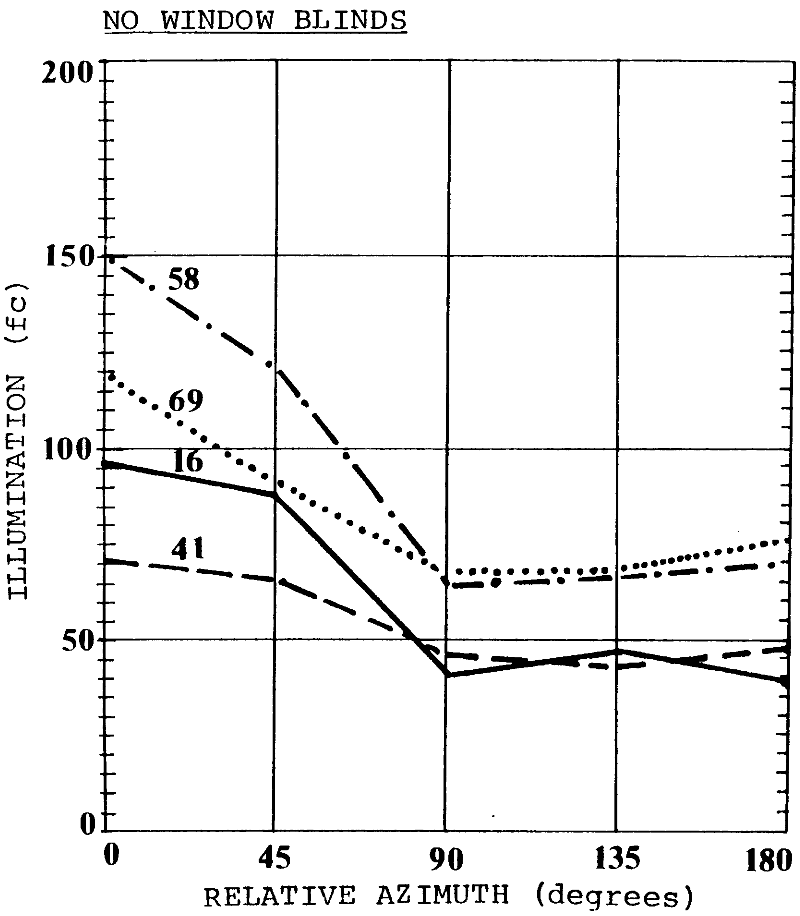
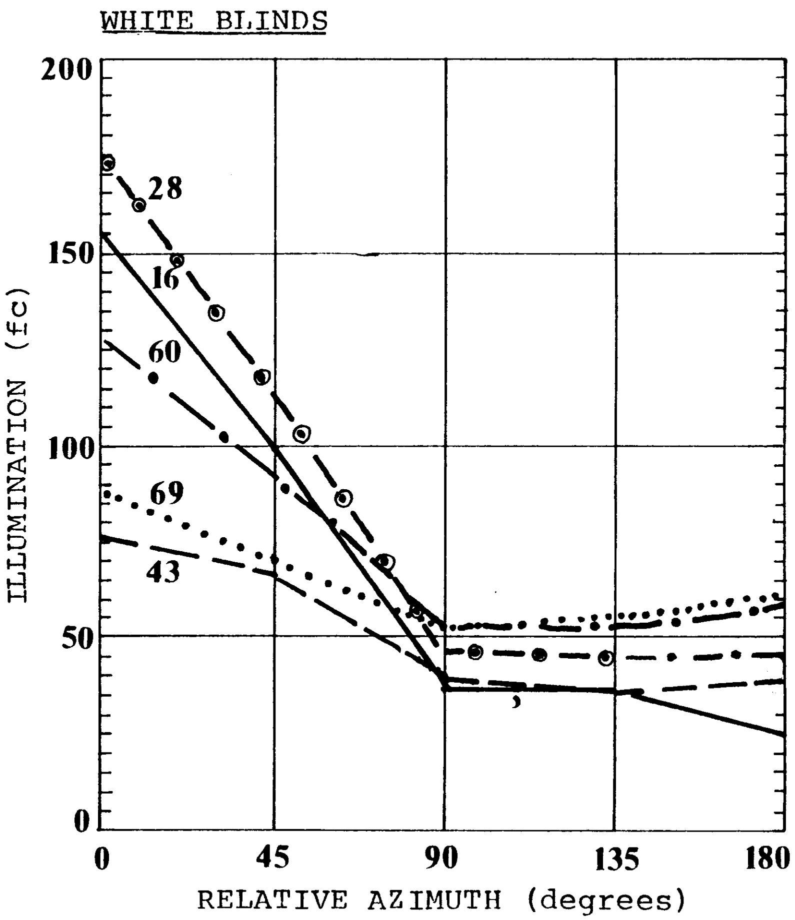


FIGURE IV.11:
Interior illumination under overcast skies.


NO WINDOW BLINDS
200
150
100
50
0
ILLUMINATION (fc)
58
69
16
41
0
45
90
135
180
RELATIVE AZIMUTH (degrees)


WHITE BLINDS
200
150
100
50
0
ILLUMINATION (fc)
28
16
60
69
43
0
45
90
135
180
RELATIVE AZIMUTH (degrees)

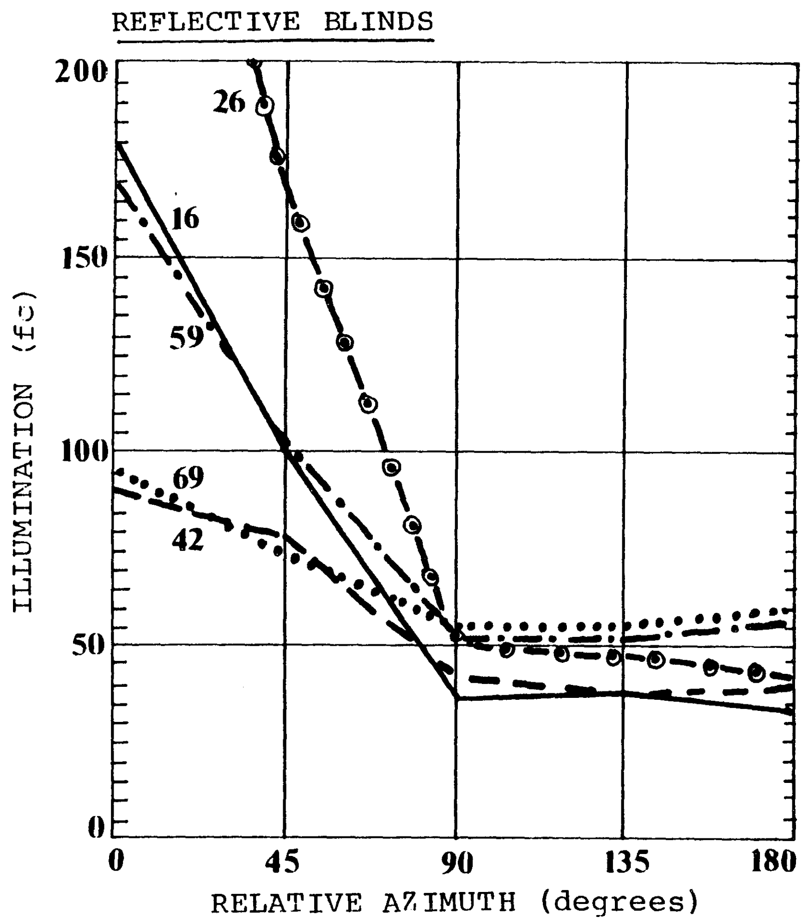


FIGURE IV.12:
Clear sky illumination at the back of a room as a function of the sun's altitude and azimuth.

closely spaced measurements would be directly comparable.

Since testing was carried out with a single layer of heat mirror glass, the calculated interior light levels were reduced to account for a second layer of clear glass. All values were multiplied by 0.90; the ratio of daylight transmission through a single layer of heat mirror glass to the daylight transmission through an insulated unit with a heat mirror coating (0.43/0.48 = 0.9).

The actual calculations were done using the Consistent System, an interactive statistics package on MIT's computer system. The normalized measurements are shown along with the measured values in tables IV.2-6. Though the differences between the measured values and the calculated values is small (typically less than 20%), a little cross checking between window strategies will show that this readjustment was critical.

Simple design graphs were prepared to increase the usefulness of this tabular data. The graphs show the normalized data as a function of the solar altitude and the relative azimuth. Using these graphs (figures IV.11-12) one can determine the interior light levels for any hour by simply calculating the sun's altitude and azimuth. For example, to compute the interior light level at 2 pm, September 21 for the back of an east facing Boston office with reflective blinds, first determine the sun angles for this hour and then look up the interior illumination from the charts. In this case, the solar altitude is 44°. The solar azimuth is 30° west of south (the east facing window has a relative azimuth of 120°). Using these angles, figure IV.12 shows that the interior illumination will be 40 footcandles during a clear day.

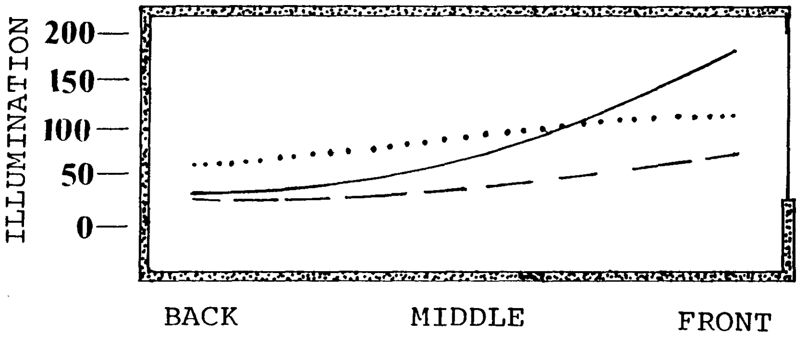
The procedure for overcast days is similar, except that the illumination is a function of the sun's altitude and not its azimuth. Figure IV.11 shows that the interior illumination will be about 60 footcandles at the back of a room.

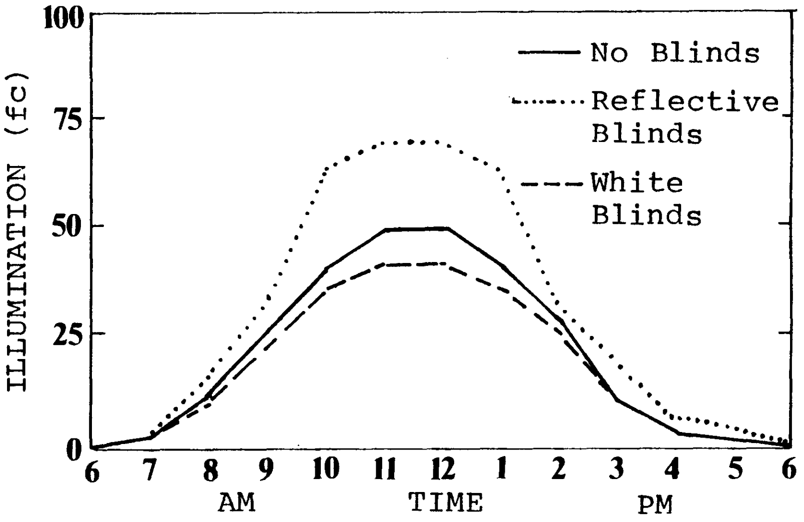
Results

In order to evaluate the various proposed window blind configurations, I determined interior light levels for two Boston spring days; one clear, the other overcast. From figure IV.13, the following conclusions may be drawn:

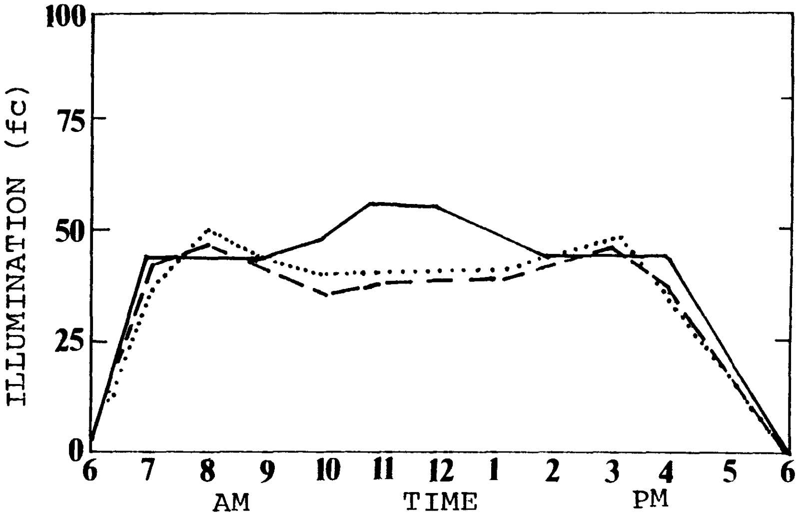
1. Under overcast skies, reflective blinds outperform conventional white blinds. The reflective blinds are clearly able to reflect diffuse skylight. They result in improved daylight distribution and increased light levels at the rear of the room. With the sun greater than 25 degrees, daylight levels at the room's rear were increased by more than 20 footcandles.
2. Under clear skies, the reflective blinds greatly increase interior light levels when direct sun is on the windows. However, when there is no direct sun on the windows, the reflective blinds have little effect on interior light levels.
3. The combination of reflective blinds and white blinds wasn't notably better than using all white blinds.

ALL ORIENTATIONS: Overcast Skies

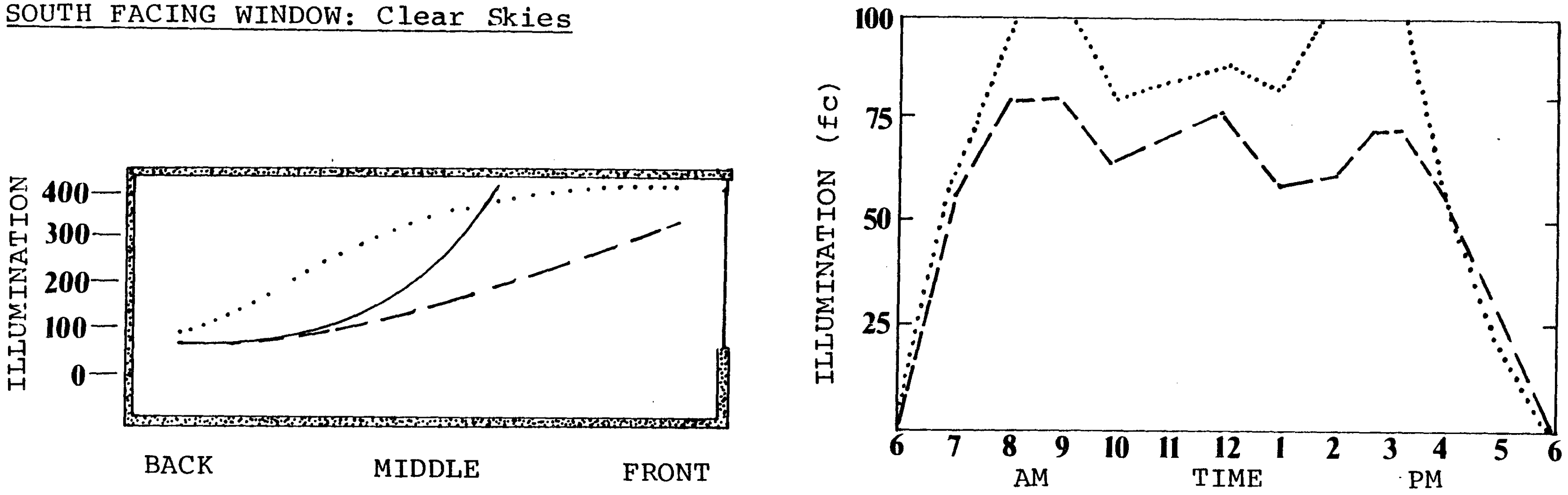




NORTH FACING WINDOW: Clear Skies



SOUTH FACING WINDOW: Clear Skies



EAST FACING WINDOW: Clear Skies

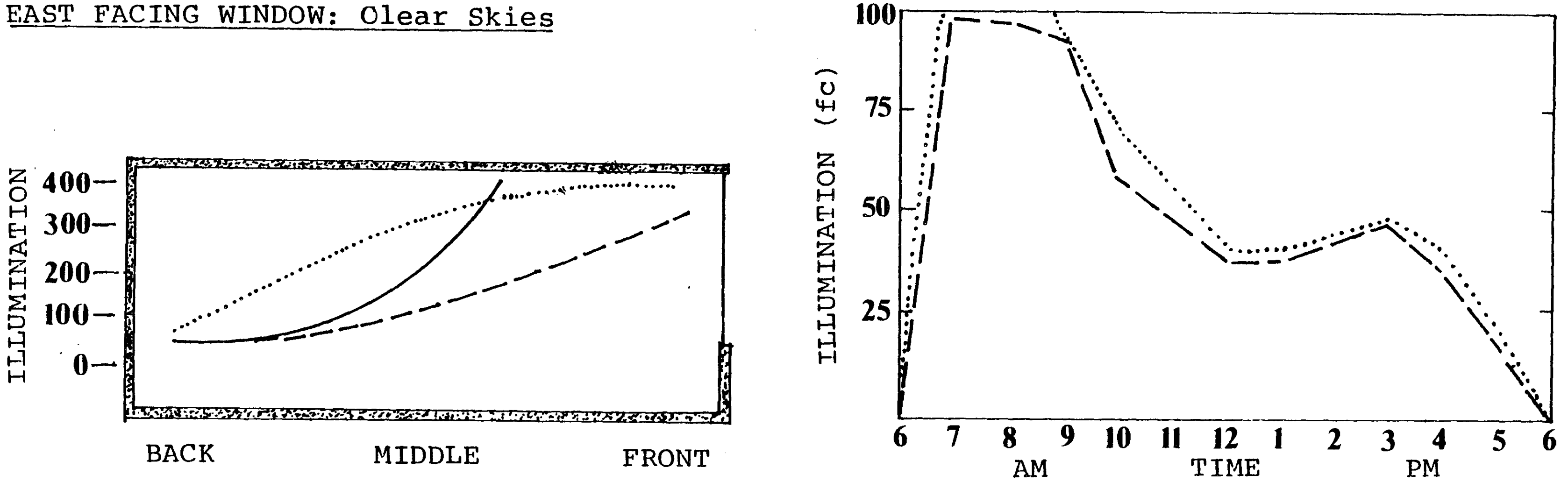


FIGURE IV.13: Interior illumination under spring skies. The daylong plot shows light levels at the back of the room. The section shows light distribution at 10 a.m.

V. Energy Analysis

This section describes how potential savings from the commercial heat mirror and the daylighting control devices were determined. Two hypothetical buildings were analyzed. The first was square (120 feet by 120 feet), and was patterned after a typical office building (figure V.1). This building is hereafter referred to as the "base" building.

The second building differed from the base building in two major ways. First, it was long and thin (60 feet by 240 feet) with its major facades facing due north and south (figure V.1). Second, it was designed to utilize natural daylight. The windows were enlarged and equipped with horizontal blinds to control glare. In addition, lighting control devices were installed to automatically dim the artificial lights when daylight was available. This building is hereafter referred to as the "thin daylit" building.

Both of these buildings were analyzed with a large computer based energy analysis program. This chapter begins with a brief review of this program, DOE-2. Then, a detailed description of the buildings is given along with a description of the methodology used to estimate daylight levels. Finally, results for the simulations are given along with conclusions.

Computer Analysis

The DOE-2 computer program was selected for this study because of its sophisticated ability to analyze the complex energy flows occurring in large commercial buildings. Using a building description and a weather tape, the program simulates hour-by-hour performance of a building for each of the 8760 hours in a year. DOE-2 was developed by the Department of Energy at Los Alamos Scientific Laboratory and Lawrence Berkeley Laboratory, and is regularly updated. Though several other energy simulation programs have been developed, DOE-2 is one of the few in the public domain. As a result, it is relatively inexpensive to use and well documented.

The DOE-2 program consists of seven sub-programs which prepare input data, compute energy use, and perform economic analysis. The modules (BDL, LOADS, SYSTEMS, PLANT, and ECONOMICS) are sperate entities that can be used individually. Thus, it is possible to run a full-scale simulation of a building's performance, or simulate onlysome of its aspects.

The building can be described in great architectural detail. This is accomplished using the Building Design Language (BDL), an English like set of commands, which describe the building. If the user does not specify a particular input value, the program assumes a default value.

The LOADS program, calculates heat gains and losses through the building skin. It computes heat transfer by conduction and radiation response factors and considers the effects of thermal mass, placement of insulation, sun angle, cloud cover, building location, orientation, and shading.

Internal use of energy for lighting and equipment is computed according to schedules assigned by the user for each piece of equipment. The latent and sensible heat from people is calculated hourly based on building occupancy.

LOADS computations assume a fixed temperature for each space. Because the LOADS module calculates thermal loads with an artificialy fixed space temperature, the output may have little resemblance to the actual thermal requirements of the building. The SYSTEMS module modifies the output of the LOADS module, to produce actual thermal loads based on a hourly variable indoor temperature.

SYSTEMS also contains algorithms for simulating performance of the secondary HVAC equipment used to control the temperature and humidity for each zone within the building. The user can choose from over 20 preprogrammed HVAC systems, which include, variable or constant volume fan systems, induction systems, various fan coil systems, residential systems etc. Required input varies from system to system. Generally it includes thermostat settings and set-backs, operating schedules, air flow rates, fan characteristics, etc.

The SYSTEMS module uses the system characteristics and the output from the LOADS module to calculate the hour-by-hour energy requirements of the secondary HVAC systems. Unlike the LOADS module, energy requirements are based on variable temperature conditions for each zone.

Output from this program includes heating, and cooling loads, electrical use by the fans, lights, and equipment, as well as the required CFM for individual units. However, it is difficult to compare the relative importance of heating and cooling loads since the efficiency of the boilers, chillers, etc. have not yet been simulated.

The PLANT module calculates the energy consumption of the primary energy conversion equipment. The operation of each plant component (e.g. boiler, absorption chiller, cooling tower, solar heater, thermal storage tank) is modeled on the basis of operating conditions and part-load performance characteristics.

Building Description

In order to establish a benchmark against which to measure energy savings, two hypothetical buildings were defined (figure V.1). This base building is patterned after a typical commercial office

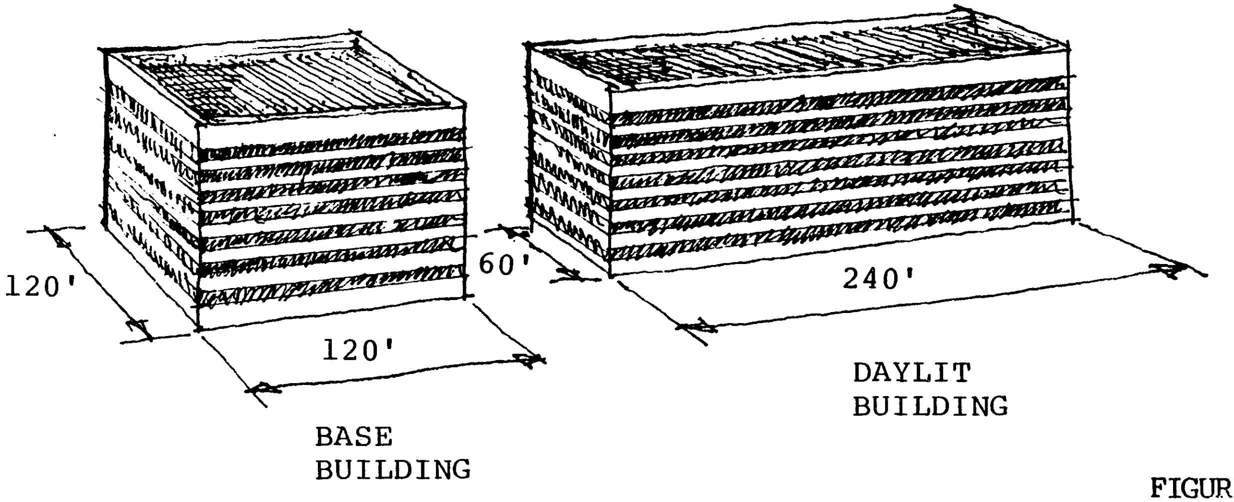


FIGURE V.1: Building configuration

building. It is square; each side measures 120 feet. The facade consists of insulated precast concrete panels with four foot high strip windows, glazed with insulated units of either solar bronze glass or commercial heat mirror glass.

This base building. was compared with a long thin daylit building. The daylit building was 240 feet long by 60 feet wide with its major facades facing due north and south. The 5 1/2 foot tall windows were identical to those detailed in chapter IV of this thesis. The north facing windows had reflective blinds; the south facing windows, white blinds.

For the energy analysis, each of these buildings was divided into core and perimeter zones. Each perimeter zone was twenty feet wide, and conditioned with separate four pipe fan coil systems. Insulated pipes carried both chilled and heated water to the zones, where fans passed recirculated room air across the coils. The core zones were conditioned with a constant volume system. Insulated ducts supplied air through ceiling outlets. Return air was taken from a common ceiling plenum.

Two different plant simulations were carried out, to investigate the effect of primary energy source on peak loads. An all-electric plant was simulated first. Heating was provided by an electric hot water boiler; cooling by a hermetic centrifugal chiller with a conventional cooling tower. In the second plant simulation, the cooling equipment was identical to the first run. The heating plant was, however, replaced with a gas hot water boiler.

Appendix B contains a more detailed description of both these buildings.

Daylighting Analysis

Unfortunately, the current version of DOE-2 cannot simulate daylighting control devices. Ideally, the electric lighting requirements should be determined using daylight levels calculated on an hour by hour basis. As an alternative, a lighting schedule based on "average" electrical consumption was determined for each of the four seasons. This approach should be adequate since daylighting calculations have an intrinsically high level of uncertainty.

In order to estimate equipment sizes and electrical demand charges, one needs accurate estimates of peak loads. Although average lighting profiles should accurately predict annual energy consumption, they will not accurately predict these peak loads. To better estimate peak building consumption, two additional simulations were carried out for each daylit building. The building was analyzed first with overcast sky lighting profiles and then using clear sky profiles.

The results from the simulations were then examined to determine the day and hour of the building peak. Finally, the weather data used by the program was examined to determine whether the peak loads occurred during a clear and overcast day. In general, both the clear and overcast runs were found to peak at the same time. In addition, the peak days were nearly all clear. This was somewhat surprising since, I had hypothesized that the cooling peaks would occur on cloudy days, when the lights were dimmed least. However, these results were not so surprising when the data was examined more closely. The peaks always occurred on the hottest or coldest day of the month which, in turn, was almost always clear. The coldest winter days occur during clear skies, since these skies allow the greatest nightime radiative cooling of the earth. The warmest summer days occur when the skies are clear, since the sun's gain is greatest.

The procedure used to calculate lighting electrical use is outlined below. The actual numbers used in the analysis are shown in tables V.1-4.

WINTER SEASON

Time	Clear Skies				Overcast Skies				Ave. Day Room Ave.
	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	
8	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
9	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
10	0.5	0.5	0.5	0.50	0.5	0.5	0.5	0.50	0.50
11	0.5	0.5	0.0	0.34	0.5	0.5	0.5	0.50	0.42
12	0.5	0.5	0.0	0.34	0.5	0.5	0.5	0.50	0.42
1	0.5	0.5	0.0	0.34	0.5	0.5	0.5	0.50	0.42
2	1.0	1.0	1.0	1.00	0.5	0.5	0.5	0.50	0.25
3	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
4	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
5	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
6	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00

SPRING SEASON

Time	Clear Skies				Overcast Skies				Ave. Day Room Ave.
	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	
8	0.5	0.5	0.0	0.34	1.0	1.0	1.0	1.00	0.67
9	0.5	0.0	0.0	0.17	0.5	0.0	0.0	0.17	0.17
10	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
11	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
12	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
1	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
2	0.5	0.0	0.0	0.17	0.5	0.0	0.0	0.00	0.08
3	0.5	0.5	0.0	0.34	1.0	1.0	0.5	0.83	0.59
4	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
5	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
6	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00

SUMMER SEASON

Time	Clear Skies				Overcast Skies				Ave. Day Room Ave.
	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	
8	0.5	0.5	0.0	0.34	1.0	1.0	0.5	0.83	0.59
9	0.5	0.5	0.0	0.34	0.0	0.0	0.0	0.00	0.17
10	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
11	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
12	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
1	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
2	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
3	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
4	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
5	1.0	1.0	1.0	1.00	0.5	0.0	0.0	0.00	0.08
6	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00

FALL SEASON

Time	Clear Skies				Overcast Skies				Ave. Day Room Ave.
	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	
8	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
9	0.5	0.5	0.0	0.34	1.0	1.0	1.0	1.00	0.67
10	0.5	0.0	0.0	0.17	0.5	0.0	0.0	0.17	0.17
11	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
12	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
1	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
2	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.00	0.08
3	0.5	0.0	0.0	0.17	0.5	0.0	0.0	0.00	0.08
4	0.5	0.5	0.0	0.34	1.0	1.0	0.5	0.83	0.59
5	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
6	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00

TABLE V.1: BOSTON BUILDING - NORTH FACING ZONE WITH REFLECTIVE BLINDS

WINTER SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.5
11	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.5
12	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.5
1	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.5
2	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.5
3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

SPRING SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	0.0	0.0	0.0	0.00	1.0	1.0	0.5	0.83	0.41
9	0.0	0.0	0.0	0.00	1.0	0.5	0.0	0.50	0.25
10	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
11	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
12	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
1	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
2	0.0	0.0	0.0	0.00	1.0	0.5	0.5	0.67	0.33
3	0.0	0.0	0.0	0.00	1.0	1.0	1.0	1.00	0.50
4	0.5	0.0	0.0	0.17	1.0	1.0	1.0	1.00	0.59
5	0.0	0.0	0.0	1.00	1.0	1.0	1.0	1.00	1.00
6	0.0	0.0	0.0	1.00	1.0	1.0	1.0	1.00	1.00
7	0.0	0.0	0.0	1.00	1.0	1.0	1.0	1.00	1.00

SUMMER SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	0.5	0.5	0.0	0.34	1.0	1.0	0.0	0.66	0.50
9	0.5	0.0	0.0	0.17	1.0	0.5	0.0	0.50	0.33
10	0.5	0.0	0.0	0.17	0.5	0.5	0.0	0.34	0.25
11	0.0	0.0	0.0	0.00	0.5	0.0	0.0	0.17	0.08
12	0.0	0.0	0.0	0.00	0.5	0.0	0.0	0.17	0.08
1	0.0	0.0	0.0	0.00	0.5	0.0	0.0	0.17	0.08
2	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.17	0.08
3	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
4	0.5	0.0	0.0	0.17	0.5	0.5	0.0	0.34	0.25
5	0.5	0.5	0.0	0.34	1.0	1.0	1.0	0.83	0.54
6	0.5	0.5	0.0	0.34	1.0	1.0	1.0	1.00	0.67
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00

FALL SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	0.5	0.5	0.0	0.34	1.0	1.0	1.0	1.00	0.67
9	0.0	0.0	0.0	0.00	1.0	1.0	0.5	0.83	0.41
10	0.0	0.0	0.0	0.00	1.0	0.5	0.5	0.50	0.25
11	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
12	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
1	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
2	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.34	0.17
3	0.0	0.0	0.0	0.00	0.5	0.5	0.5	0.67	0.33
4	0.0	0.0	0.0	0.00	1.0	1.0	1.0	1.00	0.50
5	0.5	0.0	0.0	0.17	1.0	1.0	1.0	1.00	0.59
6	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00

TABLE V.2: BOSTON BUILDING - SOUTH FACING ZONE WITH WHITE BLINDS

WINTER SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00
9	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
10	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
11	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
12	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
1	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
2	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
3	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
4	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00
5	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00
6	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00

SPRING SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
9	0.5	0.5	0.0	0.33	0.0	0.0	0.0	0.0	0.22
10	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
11	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
12	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
1	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
2	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
3	0.5	0.5	0.0	0.17	0.0	0.0	0.0	0.0	0.11
4	0.5	0.5	0.0	0.17	0.0	0.0	0.0	0.0	0.11
5	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00
6	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00

SUMMER SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	0.0	0.0	0.0	0.00	1.0	1.0	1.0	1.0	0.33
9	0.5	0.5	0.0	0.33	0.0	0.0	0.0	0.0	0.22
10	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
11	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
12	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.00
1	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.00
2	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.00
3	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
4	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
5	0.5	0.5	0.0	0.35	0.0	0.0	0.0	0.0	0.22
6	0.0	0.0	0.0	0.00	1.0	1.0	1.0	1.0	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00

FALL SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00
9	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.0	0.55
10	0.5	0.5	0.0	0.33	0.0	0.0	0.0	0.0	0.33
11	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
12	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
1	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
2	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
3	0.5	0.0	0.0	0.17	0.0	0.0	0.0	0.0	0.11
4	0.5	0.5	0.0	0.33	0.0	0.0	0.0	0.0	0.11
5	0.5	0.5	0.0	0.33	0.0	0.0	0.0	0.0	0.11
6	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.0	1.00

TABLE V.3: LOS ANGELES AND PHOENIX BUILDINGS - NORTH FACING ZONE WITH REFLECTIVE BLINDS

WINTER SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00
9	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.33
10	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.33
11	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.33
12	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.33
1	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.33
2	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.33
3	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.33
4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00
7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00

SPRING SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.00	1.00
9	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.83	0.28
10	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.33	0.28
11	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.33	0.11
12	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.33	0.11
1	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.33	0.11
2	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.66	0.11
3	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.83	0.22
4	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.00	0.33
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00	1.00
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00	1.00
7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00	1.00

SUMMER SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.00	0.30
9	0.5	0.5	0.0	0.33	0.5	0.5	0.0	0.17	0.27
10	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.33	0.11
11	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.33	0.11
12	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.33	0.11
1	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.33	0.11
2	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.33	0.11
3	0.0	0.0	0.0	0.00	0.5	0.5	0.0	0.33	0.11
4	0.0	0.0	0.0	0.00	1.0	1.0	0.0	0.66	0.22
5	0.5	0.5	0.0	0.33	1.0	1.0	0.0	0.66	0.33
6	0.5	0.5	0.0	0.33	1.0	1.0	1.0	1.00	0.55
7	1.0	1.0	1.0	1.00	1.0	1.0	1.0	1.00	1.00

FALL SEASON

	Clear Skies				Overcast Skies				Ave. Day
Time	Back Row	Mid. Row	Front Row	Room Ave.	Back Row	Mid. Row	Front Row	Room Ave.	Room Ave.
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00	1.00
9	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.00	0.33
10	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.83	0.28
11	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.83	0.28
12	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.33	0.11
1	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.33	0.11
2	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.33	0.11
3	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.33	0.11
4	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.66	0.22
5	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.00	0.33
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00	1.00
7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00	1.00

TABLE V.4: LOS ANGELES AND PHOENIX BUILDINGS - SOUTH FACING ZONE WITH WHITE BLINDS

1. First, the sun's position was determined for each of the city locations being analyzed. For each of the four seasons, the sun's altitude, azimuth, and relative azimuth was determined for each of the four compass directions. Standard ASHRAE tables were used to determine these figures.

2. Daylighting levels were then determined for daylit spaces. The daylit zones were assumed to be 20 feet wide. Light levels were calculated for the front, middle and back of the rooms using the graphs shown in chapter IV. These graphs were derived from the measurements taken from the scale model.

   Electrical consumption was then calculated for the front, middle, and back rows. For light levels over 60 footcandles, the fluorescent fixtures were turned completely off. When the light level was below 60 footcandles, but above 30 footcandles, the artificial lights were dimmed to 50% capacity. The lights were left fully on when the daylighting level fell below 30 footcandles. As a final constraint, artificial lights were turned on at dusk or dawn no matter what interior daylight levels were. Dusk and dawn occur roughly when the sun's altitude is below 20°.

BOSTON Elevation 15 Ft.

	Temperature Average			Temperature Extreme		Degree Days (Base 65°)		Prec. Hum	Prec. Nor.		Wind			Average Number of Days of Sunup/Sundown							
	Maximum	Minimum	Monthly	Highest	Lowest	Heating	Cooling	1:00 p.m.	Total	Snow Total	Speed	Direction	% Poss. Sunshine	Clr.	P. C.	Cldy.	Rain .01"	Snow 1.0"	Thunder	Fog	Percent IFR
J	37	23	30	62	-4	1088	0	57	4	12	52	sw	53	9	7	15	12	3	*	2	18
F	37	23	30	58	-3	972	0	60	3	12	57	s	57	8	7	13	11	3	*	2	14
M	45	31	38	66	6	846	0	58	4	9	55	sw	58	8	8	15	12	2	°	2	15
A	56	40	48	83	22	513	0	55	4	1	52	nw	56	7	9	14	12	*	1	2	10
M	67	50	59	93	37	208	6	57	3	T	50	ne	58	6	11	14	11	0	2	3	16
J	76	59	68	95	46	36	155	58	3	0	44	nnw	64	7	11	12	10	0	4	2	10
J	82	65	74	98	54	0	269	55	3	0	45	n	65	7	12	12	9	0	5	2	7
A	80	63	72	94	47	9	271	56	4	0	65	nnw	66	10	10	11	10	0	4	2	7
S	73	57	65	95	38	60	132	61	3	0	57	s	64	11	8	11	9	0	2	2	7
O	63	47	55	86	30	316	15	58	3	T	46	nw	61	11	8	12	9	0	1	2	13
N	52	38	45	76	21	603	1	64	4	1	58	sw	51	8	7	15	12	*	*	2	11
D	40	26	33	70	-3	983	0	61	4	8	49	nw	54	9	8	14	11	2	*	1	1
Y	59	44	51	98	-4	5634	849	58	42	43	65	nnw	60	101	106	158	127	11	19	23	12

PHOENIX Elevation 1117 Ft.

	Temperature Average			Temperature Extreme		Degree Days (Base 65°)		Rel. Hum	Prec. Nor.		Wind			Average Number of Days of Sunup/Sundown							
	Maximum	Minimum	Monthly	Highest	Lowest	Heating	Cooling	11:00 a.m.	Total	Snow Total	Speed	Direction	% Poss. Sunshine	Clr.	P. C.	Cldy.	Rain .01"	Snow 1.0"	Thunder	Fog	Percent IFR
J	64	35	50	88	19	474	7	44	1	T	5	wnw	78	14	7	10	4	0	*	1	*
F	68	39	53	89	26	328	2	39	1	T	5	sse	80	13	6	9	4	0	1	*	*
M	75	43	59	95	25	217	76	33	1	0	6	wnw	83	15	7	9	3	0	1	*	*
A	84	50	67	101	37	75	107	24	0	T	6	nw	88	17	7	6	2	0	1	0	*
M	93	57	75	108	40	0	265	18	0	0	7	sse	93	21	6	4	1	0	*	0	*
J	102	65	84	116	51	0	614	18	0	0	7	sw	94	23	5	2	1	0	1	0	*
J	105	75	90	114	67	0	934	29	1	0	7	n	84	16	11	4	4	0	6	0	*
A	102	73	87	114	61	0	773	36	1	0	6	ssw	85	17	10	4	5	0	8	0	*
S	98	67	83	110	47	0	623	33	1	0	6	sw	89	22	5	3	3	0	3	0	*
O	87	55	71	102	34	22	220	28	0	0	5	ssw	88	21	6	4	3	0	1	0	*
N	74	42	58	92	31	234	30	38	0	0	5	wsw	84	18	6	6	2	0	*	*	*
D	66	37	52	82	24	415	0	49	1	T	5	w	77	15	6	10	4	0	1	1	*
Y	85	53	69	116	19	1765	3651	32	7	T	6	sw	86	212	82	71	35	0	23	2	*

LOS ANGELES Elevation 97 Ft.

	Temperature Average			Temperature Extreme		Degree Days (Base 65°)		Rel. Hum	Prec. Nor.		Wind			Average Number of Days of Sunup/Sundown							
	Maximum	Minimum	Monthly	Highest	Lowest	Heating	Cooling	10:00 a.m.	Total	Snow Total	Speed	Direction	% Poss. Sunshine	Clr.	P. C.	Cldy.	Rain .01"	Snow 1.0"	Thunder	Fog	Percent IFR
J	64	45	54	86	30	347	23	53	3	T	7	w	na	12	8	11	6	0	*	5	22
F	64	47	55	92	37	277	8	56	3	T	7	w	na	12	6	10	6	0	*	4	16
M	65	49	57	88	39	264	0	59	2	0	8	w	na	12	8	11	5	0	*	4	12
A	67	52	59	95	43	177	13	60	1	0	8	wsw	na	11	9	10	4	0	°	3	19
M	69	55	62	96	45	121	23	64	.1	0	8	wsw	na	10	11	10	1	0	0	2	32
J	71	58	65	88	50	54	33	70	0	0	8	wsw	na	9	11	10	1	0	0	2	17
J	76	62	69	92	55	19	148	68	0	0	7	wsw	na	12	13	6	1	0	*	2	25
A	75	63	69	91	59	16	292	68	0	0	7	wsw	na	13	12	6	°	0	*	3	35
S	76	61	68	110	55	36	184	64	.2	0	7	wsw	na	13	11	6	1	0	*	4	35
O	73	57	65	106	43	62	101	58	.4	0	7	w	na	13	10	8	2	0	°	6	36
N	71	51	61	101	38	159	14	60	1	0	7	w	na	14	8	8	4	0	*	6	28
D	66	47	57	88	32	267	0	55	2	T	7	w	na	12	9	10	6	0	*	6	21
Y	70	54	62	110	30	1799	839	61	13	T	7	w	na	143	116	106	35	0	3	5	25

TABLE V.5:
NOAA normals, means and extremes charts with daylight availability data (Conway and Liston, 1974).

3. Next, the electrical consumption for all the rows was totaled to yield the total energy consumption for the zone. This was done for both clear and overcast days.

4. Finally, the clear and overcast day profiles were averaged. These weighted averages were then used to create schedules in the DOE-2 program. National Oceanic and Atmospheric Administration (NOAA) charts were examined to determined the relative distribution of clear and overcast days (table V.5). Based on these charts, a simple average was taken of the Boston figures, since clear and overcast days occur with equal frequency. Los Angeles and Phoenix have significantly more clear days than overcast days. Therefore, a weighted average was taken, with clear sky consumption being given twice the weight of overcast day consumption.

The Study

Nine DOE-2 simulations were carried out for this study. First, the square base building was simulated. It had four foot high solar bronze windows and no lighting control devices. The second simulation was identical to the first with one exception; commercial heat mirror glass was substituted for the solar bronze glass. This simulation was carried out to test the effectiveness of the commercial heat mirror glass without a daylighting strategy. Finally, the thin daylit building was simulated to evaluate the combination of the commercial heat mirror glass with a daylighting strategy.

These three simulations were carried out for three different cities; Boston, Los Angeles, and Phoenix. These cities were chosen because they met the following criteria. First, each is located in a distinctly different climate. Second, each of these cities has a significant cooling load. Finally each of the cities is located in a relatively dry climate (this simplified energy analysis since no explicit humidity control was required).

Each cities' climate is summarized in table V.5. As can be seen, Phoenix is the hottest of the three. It is characterized by extremely hot summers and moderately cold winters. Cooling loads dominate energy use in this climate. Los Angeles has mild winters and summers. Boston, the coldest of the three cities, still has a significant cooling load.

Results

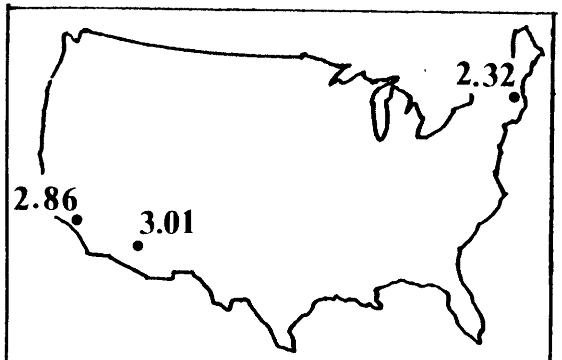
The actual output from the DOE-2 runs is too voluminous to be included in its entirety. Therefore, a concise summary of relevant results was prepared for each run (Appendix D).

Before discussing these results, I would like to make two important points. First, one should look for relative differences not absolute answers in the energy analysis. This stems from uncertainties in the computer analysis and the fact that virtually identical buildings can have very different energy use. This is true for both skin dominated buildings, and internal load dominated buildings. For example, researchers at the town of Twin Rivers in New Jersey found that the energy consumption in identical town houses varied by a factor greater than 2 to 1. Spielvogel (see Watson, 1979) showed similar results for larger commercial buildings. These large discrepancies can be attributed to several factors. First, energy use in all building types is very sensitive to occupant behavior. For smaller residential buildings, an occupant leaving a window slightly ajar, can radically alter energy consumption. For larger commercial buildings, it is the building manager who has the greatest influence on energy consumption. In addition, the infiltration rate, is difficult to predict. Engineers have traditionally ignored infiltration in larger buildings because they believed that pressures induced by the fans would cause the building to breath "out", not "in." However, the few large office buildings which have been monitored have had infiltration rates of 0.6-0.8 air changes per hour independent of the system fans.

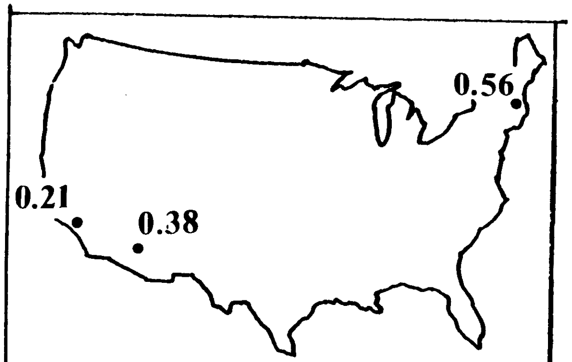
Despite this high level of uncertainty, several studies have shown excellent agreement between measured energy consumption and calculated energy use (Diamond and Hunn, 1981). In order to achieve this agreement, however, building characteristics, operating schedules, etc. must be accurately determined, and the building description must be refined with several computer simulations. This thesis study, based on a hypothetical building, required many assumptions. These uncertainties and the limitations inherent in the computer program have an important consequence; one should use the programs parametrically, to investigate, rather than solve a particular question.

A second important point when interpreting commercial building energy use, is the need to distinguish between environmental loads, energy extraction, and energy consumption. The environmental load represents the heat that must be added or extracted to a space. Energy extraction represents the loads imposed on the space's air handling equipment. This often differs from the environmental loads. For example, a reheat system will often require more energy to extract a cooling load than the simple environmental load would suggest. The energy consumption represents the actual electricity, oil, or gas consumed by the heating or cooling plant. This almost always differs significantly from the environmental load, and the energy extraction since, heating and cooling plant efficiencys are accounted for. It is particularily important to distinguish which method is used when comparing heating and cooling requirements, since heating and cooling equipment have very different efficiencies. Boilers commonly operate at efficiencies of 70-80%. In contrast, centrifugal chillers, being heat pumps, generally operate at system wide efficiencies of 300-400%.

All of the energy analysis presented in this chapter is given in



Base vs.
Daylit



Base with bronze vs.
Base with heat mirror

FIGURE V.2:
Reduction in annual energy consumption.(KWH/square foot)

terms of the actual energy consumption of the building on a unit basis (killowat-hours/square foot). This method was chosen since it best represents the true balance between heating and cooling requirements. The following conclusions can be drawn from the energy analysis presented in appendix D:

1: The use of heat mirror glass will reduce the annual energy requirements of a conventional office building when compared with solar bronze glass (figure V.2). The savings are small and depend on the local climate. The savings for the three cities studied ranged from 0.2 to 0.6 KWH/square foot, with Boston having the highest savings and Los Angeles the lowest. As can be expected, the greatest savings occur in the most extreme climates.

2: When the heat mirror glass is used in conjunction with a daylighting strategy, the savings will be substantially greater. The savings in each of the three cities are remarkably constant, ranging from 2.3 to 3.0 KWH/square foot. From figures V.2 and V.3 we can see that the combination of heat mirror glass and daylighting control devices are most effective in cooling dominated buildings. In cities such as Boston, where there are substantial heating loads, electric lighting provides useful heat to the building. In these cases reducing lighting levels increases heating loads.

3: The use of heat mirror glass will reduce heating plant size

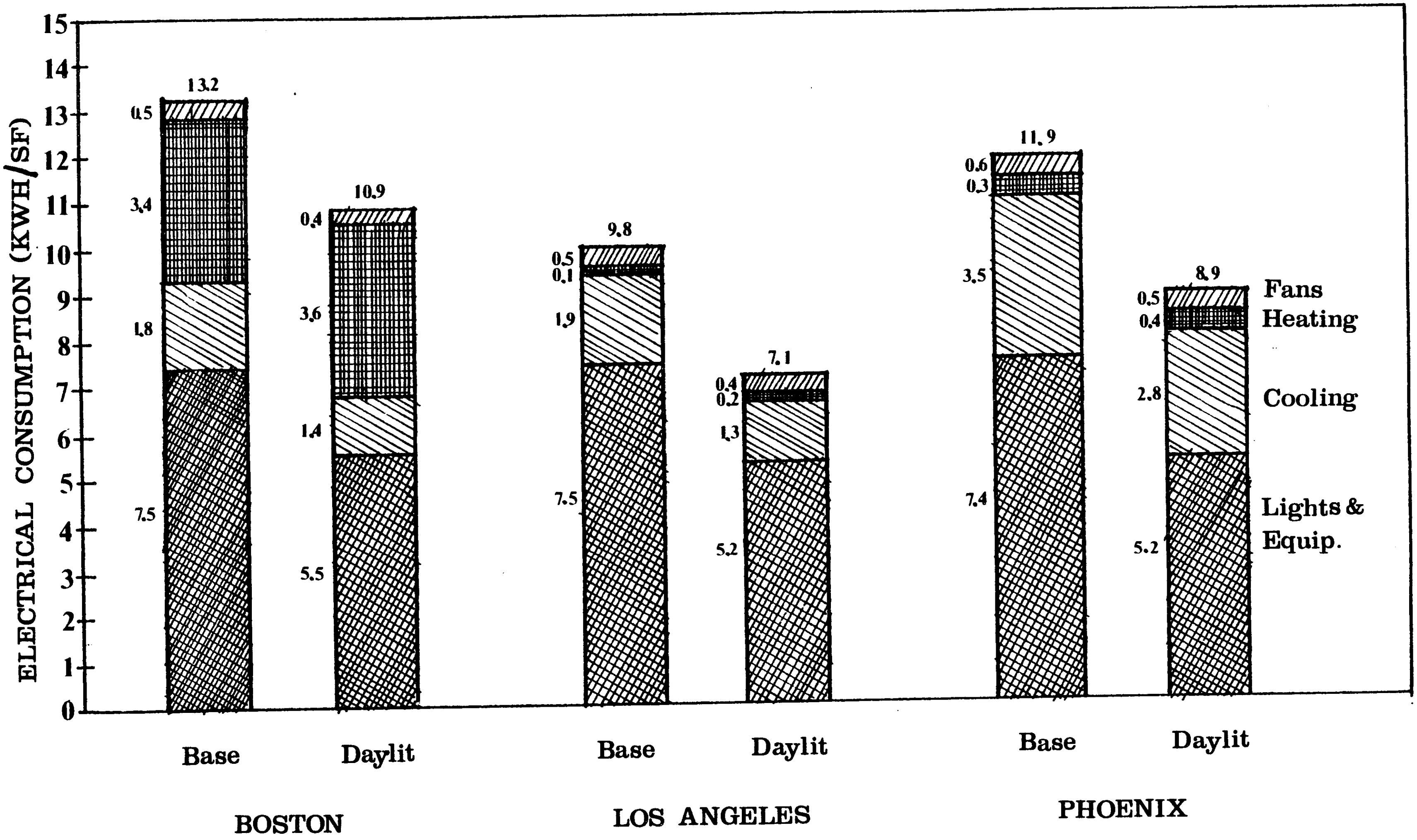


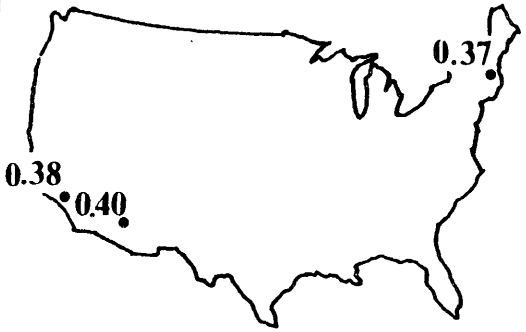
FIGURE V.3: Components of annual energy consumption for an all-electric building in three cities.

whether or not a daylighting strategy is used. The savings will be approximately 0.1 tons per thousand square feet. These savings are largely due to decreased conduction losses through the window (figure V.4).

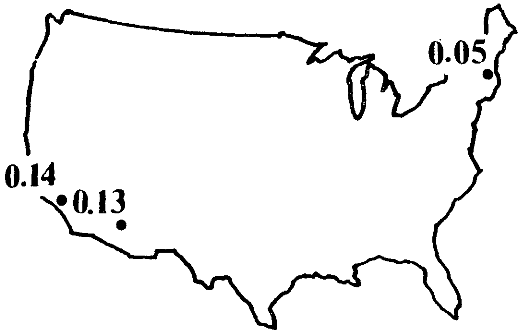
4: The reduction of the cooling plant size is more dramatic (figure V.4). When the heat mirror glass is used without a daylighting strategy savings will be approximately 0.2 tons per thousand square feet. The savings are still greater when daylighting control devices are used. Here the savings will equal approximately 0.4 tons per thousand square feet. In all cases, the savings are remarkable consistent in all cities. This isn't surprising since peak solar heat gain does not differ greatly from city to city.

4: Peak loads are were reduced in both Boston and Los Angeles (the Phoenix data was lost). From figure V.5, several general conclusions can be drawn. First, the peaks were reduced roughly proportionaly to the reduction in energy use. Second, when used without the daylighting strategy, the heat mirror was significantly better at reducing cooling peaks than heating peaks. Third, daylighting was, by far, the most effective strategy for reducing peaks.

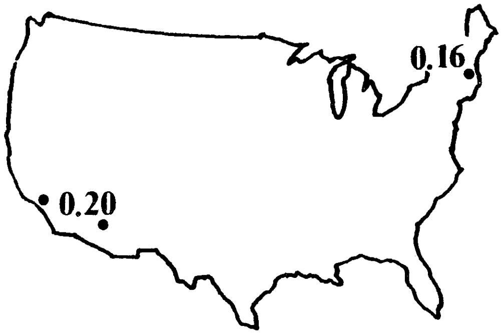
In theory, daylighting benefit from time of day electric rate structures. This appears to be true. In addition to the reduction in the cooling peak, there was also a significant



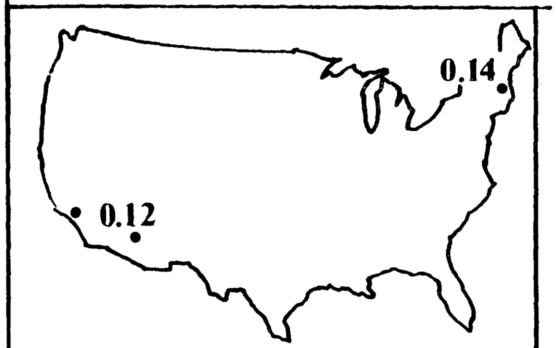
CHILLER
Base Building
vs.
Daylit Building



BOILER
Base Building
vs.
Daylit Building



CHILLER
Base with solar bronze
vs.
Base with heat mirror



BOILER
Base with solar bronze
vs.
Base with heat mirror

FIGURE V.4:
Reduction in heating and cooling plant size for Boston, Los Angeles, and Phoenix. All figures are given in tons/thousand square feet.

shift in the time of the peak. During the summer months, the base building generally peak between the hours of 12 noon and 3 p.m. The daylit building peaked later, generally between 4 and 6 p.m.

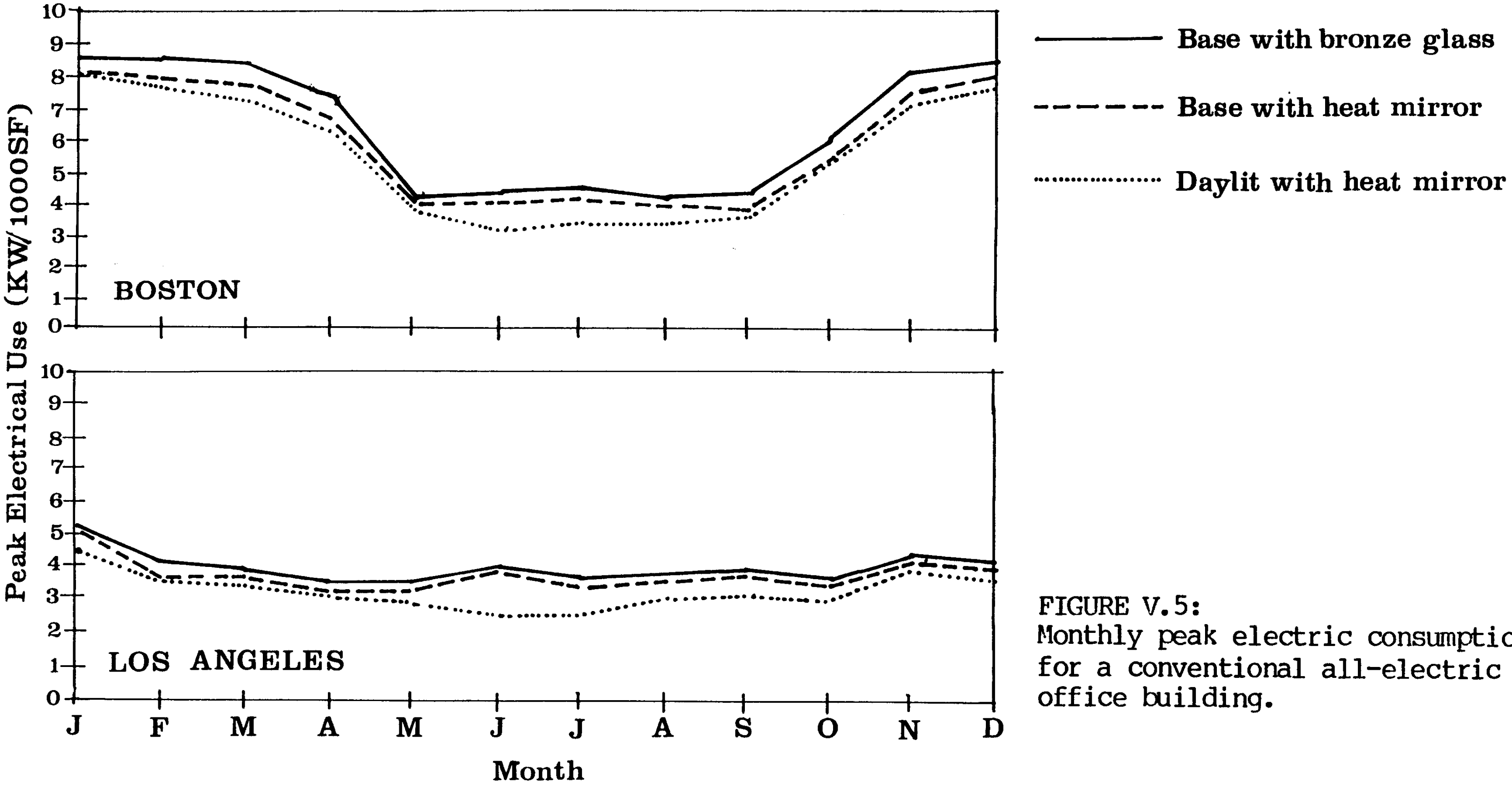


FIGURE V.5:
Monthly peak electric consumption for a conventional all-electric office building.

VI. Conclusion

Large building energy use is complex and often counterintuitive. Their energy use is often dominated by the lighting systems. In addition, the heating and cooling systems are notoriously inefficient. The soaring energy costs of recent years have, however, prompted a fresh look at these buildings. A number of appropriate strategies have emerged. Off-peak cooling, more efficient lighting systems, better HVAC systems, reduced ventilation, and daylighting all hold promise. The particular strategy proposed in this thesis focuses on daylighting.

Existing codes and conventional wisdom say that windows are undesirable from an energy point of view. In this thesis, I have attempted to counter these arguments with evidence showing that windows can have a beneficial impact on large buildings, if daylight is used to reduce lighting electrical use.

The system proposed in this thesis utilizes a new selectively transmitting glazing that has been optimized for daylighting. This glass reduces unwanted solar heat gain and thermal losses while admitting adequate daylight to a space.

When used alone, computer simulations have shown that the heatmirror coating reduces energy consumption. Not suprisingly, the savings are substantially higher when daylighting control devices are utilized with the commercial heat mirror. This results in significant reductions in heating, cooling and electrical use, as well as a reduction in both equipment sizes and peak loads.

The thesis has also demonstrated that reflective blinds can be an effective daylighting control device. Though several other researchers have demonstrated that the blinds are useful for beaming direct sunlight to a ceiling, this thesis has further demonstrated that the blinds are also capable of reflecting diffuse daylight. In either case, the blinds cut glare and increase daylight penetration.

APPENDIX A: CALCULATING THE THERMAL PROPERTIES OF GLAZING SYSTEMS

When sunshine strikes a glass assembly, three processes occur simultaneously. Some of the radiant energy is transmitted, some is reflected from the front and rear surfaces of the glass, and some is absorbed within the glass. The absorbed energy raises the glass temperature and is, in turn, reradiated and convected to the outdoor and indoor air.

These absorption heating gains often represent a significant portion of the total solar heat gained through low transmission glazings. Because subtle differences in glass properties can radically affect the net energy performance of a window, it is important to accurately evaluate the performance characteristics of window assemblies.

This section details a mathematical model for evaluating the energy transfer through windows. The procedure though limited to single or double layers of vertical glass, is based on a more generalized procedure developed by Rubin (1981). It could easily be extended to account for an arbitrary number of glazing layers with any low conductivity gas between. An interactive computer program for determining the thermal properties of glazing materials is given at the end of this appendix. The program is written in basic and is easily adaptable to most microcomputers.

Calculating Window Heat Transfer

The U value of a window is defined by:

$$U_w = (1/h_o + 1/C + 1/h_i)$$

Where h_o and h_i are the outside and inside surface heat transfer coefficients and C is the net conductance of the window system. Both h_o and h_i have convective and radiative components. Changes in wind speed, outdoor and indoor temperatures, surface emissivities, etc. all affect their values. C may have several series and parallel heat transfer paths. For single glazing C consists solely of the conductivity of the glass itself. Since glass has virtually no insulating value, nearly all the window's insulating abilities comes from the surface air films. Thus its U value can fluctuate by 40%. For insulated window systems, the importance of the air films diminish, since the air space has substantial insulating value.

Heat transfer coefficients are determined with an iterative procedure. This is necessary, since both convective and radiative components are non-linear functions of the glass temperature. The procedure is simple. First glass temperature must be be assumed so that the surface and airspace heat transfer coefficients may be calculated. Then, using these calculated heat transfer coefficients, the glass temperature may be calculated from an instantaneous steady state heat balance. The calculated glass temperature is them compared with the initial assumption. If the difference between the two values exceeds a specified range, then the heat transfer coefficients are recalculated based on the newly determined glass temperatures. This process is repeated iteratively until the two values converge.

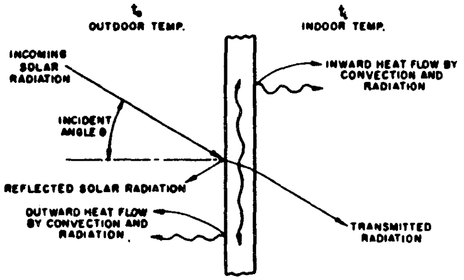


FIGURE A1.1:
Instantaneous heat balance for sunlit glazing material (ASHRAE, 1977).

The equations used to calculate glass temperatures and the various heat transfer coefficients are outlined in the following section. They are followed by the equations used to calculate the U values and shading coefficients.

GLASS TEMPERATURES

The temperature of the inner glass surface may be calculated from a simple heat balance (figure A1.1) which may be written as follows:

$$A_i I = (T_i - T_{out})h_o + (T_i - T_{in})h_i$$

$$T_i = (A_i I + T_{out}h_o + T_{in}h_i)/(h_o + h_i)$$

Where:

A_i = Radiation absorbed in the inner glass pane (fraction)

I = Incident solar radiation (W/m²)

T_i = Temperature of inner glass surface (C)

T_{out} = Outdoor air temperature (C)

h_o = Outer air film heat transfer coefficient (W/m²-C)

T_{in} = Indoor air temperature (C)

h_i = Inner surface combined radiative and convective heat transfer coefficient (W/m²-C)

The heat balance on the inner and outer panes of double glazing may be calculated as follows:

Outer pane:

$$A_oI = (T_o - T_i)h_s + (T_o - T_{out})h_o$$

Inner pane:

$$A_iI = (T_i - T_o)h_s + (T_i - T_{in})h_i$$

Where:

T_o = Temperature of outer glass surface (C)

h_s = Air space heat transfer coefficient (W/m²-C)

A_o = Radiation absorbed in the outer glass pane

The outer and inner glass temperatures may be calculated by solving the previous two equations:

$$T_o = [(h_s + h_i)(A_oI + T_{out}h_o) + h_s(A_iI + T_{in}h_i)]/$$
$$[(h_s + h_o)(h_s + h_i) - h_s^2]$$

$$T_i = [T_o(h_s + h_o) - A_oI - T_{out}h_o]/h_s$$

AIR SPACE CONDUCTANCE

The air space conductance contains both radiative and conductive/convective components. With air and other non-participating media, these two components may simply be added to obtain the air space conductance:

$$h_s = h_c + h_r$$

Where:

h_s = air space heat transfer coefficient (W/m²-C)
h_c = convective heat transfer coefficient (W/m²-C)
h_r = radiative heat transfer coefficient (W/m²-C)

Radiative Heat Transfer:

The general case of infrared radiation heat transfer between surfaces is is not presented here since it may be found in most heat transfer textbooks. For the specific case of radiation heat transfer between infinite parallel plates, the radiative heat transfer coefficient is given by the following equation (Selkowitz 1979):

$$h_r = \sigma(T_2^2 + T_1^2)(T_2 + T_1)/(1/e_1 + 1/e_2 - 1)$$

Where:
e = emissivity
T = temperature of surface one or two (°K)
σ = Stefan-Boltzman constant (5.6697×10^{-8} W/m^2K^4)

In this analysis the emissivity of uncoated glass was assumed to be 0.84. Glass with heat mirror coating was assumed to have an emissivity of 0.05.

Convective Heat Transfer:

Free convective heat transfer is correlated in terms of two dimensionless parameters, the Nusselt number, Nu, and the Grashof number, Gr. The conduction/convection heat flow is given by the following expression:

$$h_c = kN_u/w$$

Where:

k = thermal conductivity of gas (W/m-C)

Nu = Nusselt number

w = width of gap (m)

The correlation between these dimensionless parameters and free convection between parallel plates has been investigated by several researchers. The correlation developed by DeGraff and Van Der Held (1952) was used in this analysis. The original correlations contained discontinuities which have been eliminated by Rubin (1981) to yield the following results:

$$Nu = \begin{cases} 1 & Gr<7 \text{ X } 10^{3} \\ 0.0384\ Gr^{0.37} & 10^{3}<Gr<8 \text{ X } 10^{4} \\ 0.41\ Gr^{0.16} & 8 \text{ X } 10^{4}<Gr<2 \text{ X } 10^{5} \\ 0.0317\ Gr^{0.37} & Gr>2 \text{ X } 10^{5} \end{cases}$$

Three types of flow are distinguished: pure conduction, transition, and boundary layer. The type of flow is determined by the Grashof number:

$$Gr = gBp^{2}w^{3}dt/u^{2}$$

Where:

g = gravitational acceleration (9.8 m/s^{2})

B = coefficient of thermal expansion (1/K)

p = density (Kg/m^{3})

w = width of gap (m)
u = viscosity (Kg/m-s)
dt = temperature difference across gap (K)

In this analysis, the following physical properties of air (at 0°C) were used:

$B = 3.67 \times 10^{-3} K^{-1}$
$p = 1.29$ Kg/m^3
$u = 1.86 \times 10^{-5}$ Kg/m-s
$k = 2.50 \times 10^{-2}$ W/m-K

INNER SURFACE HEAT TRANSFER COEFFICIENT

The inner surface heat transfer coefficient contains both radiative and convective components:

$$h_i = h_c + h_r$$

Radiative Component:

The radiative component (h_r) is calculated using the same expression presented for the air space radiative conductance. The room's effective emissivity is assumed to be 0.9.

Convective Component:

The convective component (h_c) is calculated with correlations developed by McAdams (1954) for free convective heat flow on vertical surfaces:

Turbulent flow:

$h_c = 1.31\ dt^{1/3}$

Laminar flow:

$h_c = 1.42\ (dt/z)^{1/4}$

Where:

dt = temperature difference between the window surface and the room air (C)

z = height of surface (m)

Turbulent air flow was assumed throughout this analysis.

OUTSIDE SURFACE HEAT TRANSFER COEFFICIENT

The outer surface heat transfer coefficient contains both radiative and convective components:

$$h_o = h_c + h_r$$

Radiative Component:

The radiative component is calculated using the same expression presented for the air space radiative conductance. The effective emissivity of the outdoors (including both the sky and the ground) is assumed to be 0.9.

Convective Component:

The forced convection at a window surface has been studied by Ito and Kimura (1968). Results from these experiments were used by Lokmanhekim (1975) to calculate the outdoor convection coefficient in W/m²-C.

On the windward side of a building, the convection is a function of v, the wind speed in m/s:

$$h_c = 8.07v^{0.605} \qquad \text{when } v>2 \text{ m/s}$$
$$= 12.27 \qquad \text{when } v<2 \text{ m/s}$$

WINDOW HEAT TRANSFER COEFFICIENT

Once all air space and surface heat transfer coefficients are calculated, the overall window heat transfer coefficient is calculated using standard ASHRAE (1977) equations:

Single Glass:

$$U_w = (1/h_o + 1/h_i + R_g)^{-1}$$

Double Glass:

$$U_w = (1/h_o + 1/h_i + 1/h_s + R_g)^{-1}$$

Where:

U_w = window heat transfer coefficient (W/m²-C)

R_g = thermal resistance of glass (m²-C/W)

SHADING COEFFICIENT

The shading coefficient may then be calculated using standard ASHRAE procedures:

$SC = F/0.87 = 1.15\ F$

Single glass:

$F = I_t + U_w A_i / h_o$

Double glass:

$F = I_t + U_w A_o / h_o + [(U_w/h_o) + (U_w/h_s)] A_i$

Where:

I_t = Transmitted solar radiation (W/m²)

F = The dimensionless ratio of solar heat gains to the incident solar radiation.

Computer Program

This section contains instructions for using the computer program that was developed to calculate the thermal properties of glazing assemblies. The program is based on the equations outlined above, and is written in BASIC. Although written for the Apple3 microcomputer, it should be easily adaptable to most CP/M based microcomputers, since the Apple3 version of the BASIC language is

glazing material	**thermal conductivity** $\frac{W}{m\,K}$
glass	**0.9**
polyester film	**0.14**
acrylic or polycarbonate sheet	**0.19**

TABLE A1.1:
Conduction of heat in glazing materials (Rubin, 1981).

nearly identical to Microsoft BASIC. A summary of all required input values is given below, along with a summary of the required units:

GLAZING TRANSMISSION (Fraction) : Fraction of incident solar radiation transmitted by the entire glazing assembly.

INCIDENT SOLAR RADIATION (W/m^2) : The solar energy that strikes the window's surface.

OUTDOOR AIR TEMPERATURE (C) : Outdoor ambient temperature.

INDOOR AIR TEMPERATURE (C) : Temperature of air at inner glass surface.

WIND SPEED (m/s) : Speed of wind on outer glazing surface.

GLAZING THERMAL CONDUCTANCE (W/m^2-C) : Combined heat conductance of glazing material. For example, if one layer of 1/4 inch glass is being used, enter the thermal conductance for 1/4 inch of glass; if two layers are being used, enter the thermal conductance for 1/2 inch of glass. The thermal conductivities of typical glazing materials are shown in table A1.1.

EMISSIVITY (Fraction) : The emissivity of each surface must be entered. Surfaces are numbered from the outside in. Double glazing has four surfaces, with surface number 4 being the inner surface.

OUTER GLASS ABSORPTION (Fraction) : Fraction of solar radiation absorbed by the outermost glass layer.

INNER GLASS ABSORPTION (Fraction) : Fraction of solar radiation absorbed by the innermost glass layer.

SPACING OF GLAZING LAYERS (cm) : Distance between each glazing layer. Applies only to double glass calculations.

When the program is first entered, you will be queried whether or not you want to have printed output. The query will look like this:

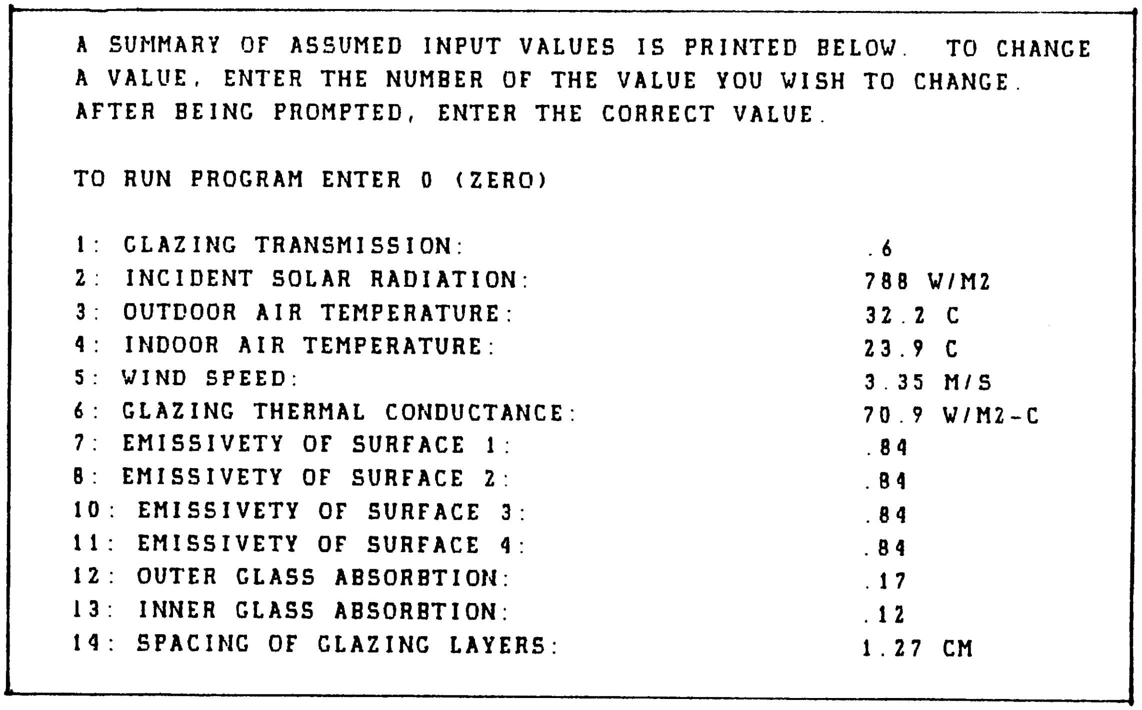
```
ENTER:    0 FOR NO PRINTER OUTPUT
          1 FOR PRINTED OUTPUT
```

If the number "1" is entered then a printed summery of the output as well as all calculated results will be sent to the printer. If the number "0" is entered then no output will be sent to the printer. In either of the above cases the summary and results will both appear on the screen.

After specifying whether or not you want printed output, the following menu will appear on the screen:

```
ENTER:  1 FOR SINGLE GLASS CALCULATIONS
        2 FOR DOUBLE GLASS CALCULATIONS
        3 TO END CALCULATIONS
```

After choosing the option of single or double glazing, a summary of default values will appear on the screen along with some program instructions (the default values stored by the program correspond to two layers of 1/4 inch clear glass). The double glass option should yield the following display:



```
A SUMMARY OF ASSUMED INPUT VALUES IS PRINTED BELOW.  TO CHANGE
A VALUE, ENTER THE NUMBER OF THE VALUE YOU WISH TO CHANGE.
AFTER BEING PROMPTED, ENTER THE CORRECT VALUE.

TO RUN PROGRAM ENTER 0 (ZERO)

1: GLAZING TRANSMISSION:                          .6
2: INCIDENT SOLAR RADIATION:                      788 W/M2
3: OUTDOOR AIR TEMPERATURE:                       32.2 C
4: INDOOR AIR TEMPERATURE:                        23.9 C
5: WIND SPEED:                                    3.35 M/S
6: GLAZING THERMAL CONDUCTANCE:                   70.9 W/M2-C
7: EMISSIVETY OF SURFACE 1:                       .84
8: EMISSIVETY OF SURFACE 2:                       .84
10: EMISSIVETY OF SURFACE 3:                      .84
11: EMISSIVETY OF SURFACE 4:                      .84
12: OUTER GLASS ABSORBTION:                       .17
13: INNER GLASS ABSORBTION:                       .12
14: SPACING OF GLAZING LAYERS:                    1.27 CM
```

Notice that all input values are given in metric units. English units should not be entered into the program. If you want to change any of these default values simply enter the value's number. You will then be prompted for a new value. When all the correct values have been entered, simply enter the number "0" to run the program.

If none of the double glass default values are changed, you should get the following output:

```
1: GLAZING TRANSMISSION:                         .6
2: INCIDENT SOLAR RADIATION:                     788 W/M2
3: OUTDOOR AIR TEMPERATURE:                      32.2 C
4: INDOOR AIR TEMPERATURE:                       23.9 C
5: WIND SPEED:                                   3.35 M/S
6: GLAZING THERMAL CONDUCTANCE:                  70.9 W/M2-C
7: EMISSIVETY OF SURFACE 1:                      .84
8: EMISSIVETY OF SURFACE 2:                      .84
10: EMISSIVETY OF SURFACE 3:                     .84
11: EMISSIVETY OF SURFACE 4:                     .84
12: OUTER GLASS ABSORBTION:                      .17
13: INNER GLASS ABSORBTION:                      .12
14: SPACING OF GLAZING LAYERS:                   1.27 CM

THERMAL CONDUCTANCE:                             3.02058 W/M2-C
                                                 .532226 BTU/HR-FT2-F

SHADING COEFFICIENT:                             .796255
TEMPERATURE OF INNER SURFACE:                    36.8058 C
                                                 98.2504 F

INNER SURFACE HEAT TRANSFER COEFFICIENT:         7.94368 W/M2-C
                                                 1.39968 BTU/HR-FT2-F

OUTER SURFACE HEAT TRANSFER COEFFICIENT:         21.8654 W/M2-C
                                                 3.85269 BTU/HR-FT2-F
```

```
10  DATA 0.60,788,32.2,23.9,3.35,70.9,0.84,0.84,0.16, 0.84,0.84,0.17,0.12,1.27
20  READ TRAN,I,TOUT,TIN,V,GC,E1,E2,ABS1,E3,E4,ABS1,ABS2,L
22  PRINT"ENTER:    0 FOR NO PRINTED OUTPUT"
23  PRINT"          1 FOR PRINTED OUTPUT"
24  INPUT P
30  PRINT
40  PRINT
50  PRINT"ENTER:  1 FOR SINGLE GLASS CALCULATIONS"
60  PRINT"        2 FOR DOUBLE GLASS CALCULATIONS"
70  PRINT"        3 TO END CALCULATIONS"
80  INPUT X
90  ON X GOTO 1000,2000,9999
100  PRINT"INVALID ENTRY, TRY AGAIN"
110  GOTO 30
1000  REM   SINGLE GLASS CALCULATIONS
1005  REM   INPUT NECESSARY VALUES
1010  GOSUB 3260
1020  GOSUB 3010
1030  GOSUB 3100
1040  INPUT X
1050  ON X GOSUB 3310,3330,3350,3370,3390,3410,3430,3450,3470,3490,3510,3530,3550,3570
1060  IF X=0 THEN GOTO 1100:ELSE GOTO 1040
1090  REM   GUESS GLASS TEMPERATURE
1100  TGIN=((TOUT+TIN)/2)
1110  REM  CALCULATE INNER SURFACE HEAT TRANSFER COEFFICIENTS
1120  T1=TGIN+273
1130  T2=TIN+273
1131  EM1=0.9
1132  EM2=E2
1140  GOSUB 4010
1150  GOSUB 4080
1160  HI=HRAD+HCONVI
1170  REM   CALCULATE OUTER SURFACE HEAT TRANSFER COEFFICIENT
```

```
1180  T1=TGIN+273
1190  T2=TOUT+273
1191  EM1=E1
1192  EM2=0.9
1200  GOSUB 4010
1210  GOSUB 4040
1220  HO=HRAD+HCONVO
1230  REM   CALCULATE GLASS TEMPERATURE
1240  TGLASS=(ABS1*I+TOUT*HO+TIN*HI)/(HO+HI)
1250  REM   CHECK TO SEE IF ASSUMED GLASS TEMP. WAS CORRECT, IT NOT ITERATE
1260  DT=ABS(TGIN-TGLASS)
1270  IF DT>0.1 THEN TGIN=TGLASS:GOTO 1120
1280  REM   CALCULATE U VALUE
1290  COND=1/(1/HO+1/GC+1/HI)
1300  REM   CALCULATE SHADING COEFFICIENT
1310  F=TRAN+COND*ABS1/HO
1320  SC=F/0.87
1330  REM   PRINT OUTPUT VALUES OF SCREEN
1340  GOSUB 3010
1350  GOSUB 3100
1360  GOSUB 3190
1370  REM   PRINT OUTPUT VALUES ON PRINTER
1375  IF P=0 THEN GOTO 30
1380  OPEN#1 AS OUTPUT,".PRINTER"
1390  OUTPUT#1
1400  GOSUB 3010
1410  GOSUB 3100
1420  GOSUB 3190
1430  OUTPUT#0
1440  REM   END OF SINGLE GLASS CALCULATIONS, RETURN TO BEGINNING
1450  GOTO 30
2000  REM   DOUBLE GLASS CALCULATIONS
2010  REM   INPUT NECESSARY VALUES
```

```
2020  GOSUB 3260
2030  GOSUB 3010
2040  GOSUB 3120
2050  INPUT X
2060  ON X GOSUB 3310,3330,3350,3370,3390,3410,3430,3450,3470,3490,3510,3530,3550,3570
2070  IF X=0 THEN GOTO 2090:ELSE GOTO 2050
2080  REM   GUESS GLASS TEMPERATURES
2090  TGIN=TIN
2100  TGOUT=TOUT
2110  REM   CALCULATE INNER SURFACE HEAT TRANSFER COEFFICIENT
2120  T1=TGIN+273
2130  T2=TIN+273
2131  EM1=E4
2132  EM2=0.9
2140  GOSUB 4010
2150  GOSUB 4080
2160  HI=HRAD+HCONVI
2170  REM   CALCULATE OUTER SURFACE HEAT TRANSFER COEFFICIENT
2180  T1=TGOUT+273
2190  T2=TOUT+273
2191  EM1=0.9
2192  EM2=E1
2200  GOSUB 4010
2210  GOSUB 4040
2220  HO=HRAD+HCONVO
2230  REM   CALCULATE AIR SPACE HEAT TRANSFER COEFFICIENT
2240  T1=TGOUT+273
2250  T2=TGIN+273
2251  EM1=E3
2252  EM2=E2
2260  GOSUB 4010
2270  GOSUB 4120
2280  HS=HRAD+HCON
```

```
2290  REM   CALCULATE GLASS TEMPERATURES
2300  TGLASSO=((HS+HI)*(ABS1*I+TOUT*HO)+HS*(ABS2*I+TIN*HI))/((HS+HO)*(HS+HI)-HS*HS)
2310  TGLASS=(TGLASSO*(HS+HO)-ABS1*I-TOUT*HO)/HS
2320  REM   CHECK TO SEE IF ASSUMED GLASS TEMPERATURES WERE CORRECT.
2321  REM   IF THEY'RE NOT ITERATE
2330  D1=ABS(TGIN-TGLASS)
2340  D2=ABS(TGOUT-TGLASSO)
2350  IF D1<0.1 AND D2<0.1 THEN GOTO 2400
2360  TGIN=TGLASS
2370  TGOUT=TGLASSO
2380  GOTO 2120
2390  REM   CLACULATE U VALUE
2400  COND=1/(1/HO+1/HI+1/HS+1/GC)
2410  REM   CALCULATE SHADING COEFFICIENT
2420  F=TRAN+COND*ABS1/HO+(COND/HO+COND/HS)*ABS2
2430  SC=F/0.87
2440  REM   PRINT OUTPUT VALUES ON SCREEN
2450  GOSUB 3010
2460  GOSUB 3120
2470  GOSUB 3190
2480  PRINT"AIR GAP HEAT TRANSFER COEFFICIENT: ",HS;" W/M2-C"
2481  PRINT,,,(HS*0.1762);" BTU/HR-FT2-F"
2490  REM   PRINT OUTPUT VALUES ON PRINTER
2495  IF P=0 THEN GOTO 30
2500  OPEN#1 AS OUTPUT,".PRINTER"
2510  OUTPUT#1
2520  GOSUB 3010
2530  GOSUB 3120
2540  GOSUB 3190
2550  PRINT"AIR GAP HEAT TRANSFER COEFFICIENT:",HS;" W/M2-C"
2551  PRINT,,,(HS*0.1762);" BTU/HR-FT2-F"
2560  OUTPUT#0
2570  REM   RETURN TO BEGINNING, END OF DOUBLE GLASS CALCULATIONSJ
```

```
2580  GOTO 30
3000  REM   THIS SECTION PRINTS OUT A SUMMARY OF INPUT VALUES
3010  PRINT
3011  PRINT
3012  PRINT"1: GLAZING TRANSMISSION:",,TRAN
3020  PRINT"2: INCIDENT SOLAR RADIATION:",,I;" W/M2"
3030  PRINT"3: OUTDOOR AIR TEMPERATURE:",,TOUT;" C"
3040  PRINT"4: INDOOR AIR TEMPERATURE:",,TIN;" C"
3050  PRINT"5: WIND SPEED:",,,V;" M/S"
3060  PRINT"6: GLAZING THERMAL CONDUCTANCE:",,GC;" W/M2-C"
3070  PRINT"7: EMISSIVETY OF SURFACE 1:",,E1
3080  PRINT"8: EMISSIVETY OF SURFACE 2:",,E2
3090  RETURN
3100  PRINT"9: GLASS ABSORBTION:",,ABS1
3110  RETURN
3120  PRINT"10: EMISSIVETY OF SURFACE 3:",,E3
3130  PRINT"11: EMISSIVETY OF SURFACE 4:",,E4
3140  PRINT"12: OUTER GLASS ABSORBTION:",,ABS1
3150  PRINT"13: INNER GLASS ABSORBTION:",,ABS2
3160  PRINT"14: SPACING OF GLAZING LAYERS:",,L;" CM"
3170  RETURN
3180  REM   THIS SECTION PRINTS OUT A SUMMARY OF OUTPUT VALUES
3190  PRINT
3200  PRINT
3210  PRINT"THERMAL CONDUCTANCE:",,COND;" W/M2-C"
3211  PRINT,,,(COND*0.1762);" BTU/HR-FT2-F"
3220  PRINT"SHADING COEFFICIENT:",,SC
3230  PRINT"TEMPERATURE OF INNER SURFACE:",,TGLASS;" C"
3231  PRINT,,,(TGLASS*1.8+32);" F"
3235  PRINT"INNER SURFACE HEAT TRANSFER COEFFICIENT:",HI;" W/M2-C"
3236  PRINT,,,(HI*.1762);" BTU/HR-FT2-F"
3240  PRINT"OUTER SURFACE HEAT TRANSFER COEFFICIENT:",HO;" W/M2-C"
3241  PRINT,,,(HO*0.1762);" BTU/HR-FT2-F"
```

```
3245  RETURN
3250  REM   INSTRUCTIONS SUBROUTINE
3260  PRINT"A SUMMARY OF ASSUMED INPUT VALUES IS PRINTED BELOW.  TO CHANGE"
3270  PRINT"A VALUE, ENTER THE NUMBER OF THE VALUE YOU WISH TO CHANGE."
3280  PRINT"AFTER BEING PROMPTED, ENTER THE CORRECT VALUE."
3290  PRINT
3300  PRINT"TO RUN PROGRAM ENTER 0 (ZERO)
3305  RETURN
3309  REM INPUT SUBROUTINES
3310  INPUT"ENTER GLAZING TRANSMISSION:";TRAN
3320  RETURN
3330  INPUT"ENTER INCIDENT SOLAR RADIATION:";I
3340  RETURN
3350  INPUT"ENTER OUTDOOR AIR TEMPERATURE:";TOUT
3360  RETURN
3370  INPUT"ENTER INDOOR AIR TEMPERATURE:";TIN
3380  RETURN
3390  INPUT"ENTER WIND SPEED:";V
3400  RETURN
3410  INPUT"ENTER CONDUCTIVITY OF GLAZING:";GC
3420  RETURN
3430  INPUT"ENTER EMISSIVETY OF SURFACE 1:";E1
3440  RETURN
3450  INPUT"ENTER EMISSIVETY OF SURFACE 2:";E2
3460  RETURN
3470  INPUT"ENTER GLASS ABSORBTION:";ABS1
3480  RETURN
3490  INPUT"ENTER EMISSIVETY OF SURFACE 3:";E3
3500  RETURN
3510  INPUT"ENTER EMISSIVETY OF SURFACE 4:";E4
3520  RETURN
3530  INPUT"ENTER OUTER GLASS ABSORBTION:";ABS1
3540  RETURN
```

```
3550  INPUT"ENTER INNER GLASS ABSORBTION:";ABS2
3560  RETURN
3570  INPUT"ENTER GLAZING SPACING:";L
3580  RETURN
4000  REM   CALCULATE RADIATIVE HEAT TRANSFER
4010  HRAD=5.6697*10^-8*(T1^2+T2^2)*(T1+T2)/(1/EM1+1/EM2-1)
4020  RETURN
4030  REM    CALCULATE OUTER SURFACE CONVECTIVE HEAT TRANSFER COEFFICIENT
4040  IF V>2 THEN HCONVO=8.07*V^0.605
4050  IF V<=2 THEN HCONVO=12.27
4060  RETURN
4070  REM   CALCULATE INNER SURFACE CONVECTIVE HEAT TRANSFER COEFFICIENT
4080  DT=ABS(TIN-TGIN)
4090  HCONVI=1.31*DT^0.333333
4100  RETURN
4110  REM   CALCULATE CONVECTIVE HEAT TRANSFER ACCROSS GAP
4120  DT=ABS(TGIN-TGOUT)
4130  GR=173*L^3*DT
4140  IF GR<=7000 THEN NU=1
4150  IF GR>7000 AND GR<=80000 THEN NU=0.0384*GR^0.37
4160  IF GR>80000 AND GR<=200000 THEN NU=0.41*GR^0.16
4170  IF GR>200000 THEN NU=0.0317*GR^0.37
4180  HCON=NU*2.5/L
4190  RETURN
9999  END
```

APPENDIX B: DETAILED DESCRIPTION OF BASE BUILDING

This section contains a detailed description of the two buildings analyzed with the DOE-2 computer program. The input files submitted to DOE-2 may be found in Appendix C.

Building Description

Height:	The floor to ceiling height is 9 feet. A 3 1/2 foot high plenum above the ceiling yields a floor to floor height of twelve feet ten inches.
Area:	A total floor area of 14,400 ft^2 was used. Ten identical floors were modeled to yield a total building area of 144,000 ft^2.
Structure:	Steel frame with four inch thick concrete floors.

Windows: Several different types of windows were modeled. The base building was assumed to have double glazing with an outer light of solar bronze glass (U Value=0.52 Btu/ft^2-°F, SC=0.54). The daylit building was assumed to be glazed with the commercial heat mirror on the outer and standard quarter inch clear glass on the inner light (U Value=0.29 Btu/ft^2-°F, SC=0.42).

Exterior Walls: External walls were built of five inch thick precast concrete panels with two inches of rigid insulation (U = 0.10 Btu/ft^2-°F).

Partitions: Floors and partitions separating zones were not modeled since heat transfer between adjacent zones was assumed to be negligible.

INTERIOR CONDITIONS

Lighting: Recessed fluorescent fixtures at 2 watts/ft^2.

Receptacles: The power consumption of office equipment (typewriters, clocks, etc.) was assumed to be 0.5 watts/ft^2.

People: One person per one hundred square feet of floor area is assumed. Each person gives off 250 Btu/hour sensible heat, and 215 Btu/hour latent heat.

SCHEDULES

Occupancy: On weekdays, the building is 95% occupied from 10 a.m. to 5 p.m., except for a slight dip at noon. It is partially occupied for the two hours before and after this period, and unoccupied from 9 p.m. to 7 a.m. the next morning. On weekends and holidays, the building is completely unoccupied.

Lighting: On weekdays, 100% of the building lights are on from 9 a.m. to 6 p.m. Fifty percent of the building lights are on during the hour before and after this period. One quarter of the lights are on from 8 p.m. to midnight for the cleaning crews. All lights are turned off from midnight to 7 a.m. On weekends and holidays, lights are turned off all day and night.

Equipment: On weekdays, office equipment use steadily rises, and then falls from 8 a.m. to 5 p.m. No office equipment is used from 5 p.m. to 7 p.m. the next morning. All equipment is off during weekends and holidays.

ENVIRONMENTAL CONTROL SYSTEMS

Description:	Individual four-pipe fan coil units condition the perimeter zones. Insulated pipes carry both chilled and heated water to the zones, where fans pass recirculated room air across the coils. The perimeter zone is assumed to be 20 feet wide. The interior zone is serviced with a constant volume system. Insulated ducts supply air through ceiling outlets. Return air is taken from a common ceiling plenum.
Thermostat:	A deadband thermostat with a 2 degree throttling range was used. For heating, it was set at 70° during the day (8 a.m. to 6 p.m.). and was set back to 55°F during nights and weekends. The cooling thermostat was set at 75°F. No explicit humidity control was employed.
Supply Air:	In both the interior and perimeter zones air was supplied at a maximum of 90°F and a minimum of 50°F. The constant volume interior system has 4.0 inches of water static pressure and 66% efficient fans. The perimeter fan coil system has 0.35 inches of water static pressure and 75% efficient fans.

Return Air: The interior zones have 1.5 inches of water static pressure and 63% efficient fans. Since the perimeter zones are supplied with fan coil units, no return air fans are modeled.

Ventilation: When the system fans are on, 10 CFM/person minimum outside air is supplied.

Controls: The fans and chiller operate only on weekdays (8 a.m. to 6 p.m.). The boiler is operated 24 hours a day during the winter months. It is off during summer months (the off schedule differs from city to city).

PLANT COMPONENTS

Description: Since peak electrical power consumption is a function of the type of energy source, three simulation of each modeled building were run: an all electric building, a building with gas heat and electric cooling, and an all gas building.

Run 1: An all-electric plant was simulated first. Heating was provided by an electric hot water boiler; cooling by a hermetic centrifugal chiller with a conventional cooling tower.

Run 2: In the second plant simulation the cooling equipment was identical to run one. The heating plant, however was replaced with a gas hot water boiler.

Run 3: The third plant simulated was all gas. A gas hot water boiler powered an absorption chiller and provided heat to the building.

APPENDIX C: TYPICAL DOE-2 INPUT FILE

This appendix contains a listing of two input files submitted to the DOE-2 computer program. The first listing describes the fat base building that was used as a benchmark for the energy analysis in Chapter V. The second listing describes the thin daylit building used in the same energy analysis. This listings are supplied simply to document the energy analysis, and will be difficult to read for those not familiar with DOE-2's input language. For a more accessible description, the reader is referred to Chapter V, which contains, a brief qualitative description of the buildings and the parametric study, and to Appendix B, which contains a detailed english language description of both the base building and the daylit building.

Many changes were made in both input decks throughout the study. In particular, the following items were changed:

1: The glass type in the base run was altered from solar bronze glass to heat mirror glass.

2: The city location was changed in both the base and the daylit building runs.

3: The seasonal lighting schedules were changed for the daylit building.

Those areas of the input deck that were changed, have been called out on the right hand side of each page.

BASE BUILDING:

```
input  loads       ..
title line-1    fat building-no daylighting     ..
title line-2    thesis study    ..
title line-3    bronze glass-4 feet high    ..
title line-4    phoenix weather data    ..
title line-5    loads simulation    ..
                diagnostic cautions  ..
                abort errors  ..
                loads-report summary=(ls-b,ls-c,ls-d)  ..
                run-period jan 1 1965 thru dec 31 1965  ..
                building-location latitude 33.43  longitude 112.02
                             heat-peak-period = (7,18)
                             cool-peak-period = (7,18)
                             time-zone 6  azimuth 0  altitude 1117 ..
```

Location

```
                   $ parameters to change $

$ installed lighting capacity (watts/sf) $
parameter   llevel=2.0  ..

$ glazing type $
$ glass type 7 represents solar bronze glass $
$ glass type 10 represents the heat mirror glass $
parameter   panes-par=2  :.
parameter   glass-type-par=7  ..
```

Glass Type

```
$ window height (feet) $
parameter   window-height=4  ..

$ parameters used to change building shape $
$ one person per 100 square feet is assumed $

$ north and south zones $
parameter   ns-width=120  ..
parameter   ns-area=2000  ..
parameter   ns-volume=18000  ..
parameter   ns-people=20  ..

$ east and west zones $
parameter   ew-width=120  ..
parameter   ew-area=2000  ..
parameter   ew-volume=18000  ..
```

```
parameter   ew-people=20  ..

$ core zone $
parameter   c-area=6400  ..
parameter   c-volume=57600  ..
parameter   c-people=64  ..

             $ compute response factors $

$ exterior walls $
concrete-wall1   =material          th=.4167 cond=.7580 dens=140 s-h=.2  ..
insulation-wall1 =material          th=.1667 cond=.0200 dens=16  s-h=.2  ..
precastwall      =layers            mat=(concrete-wall1,
                                    insulation-wall1)  i-f-r=.685  ..
concrete         =construction      layers=precastwall ..

             $ glass description $

midfloor-glass   =glass-type        panes=panes-par
                                    glass-type-code=glass-type-par  ..

             $ schedules $

$ occupance schedules $
oc1              =day-schedule      (1,7) (0)
                                    (8,19) (.15,.75,.95,.95,.95,.90,.95,
                                    .95,.95,.95,.6,.2)
                                    (20,24) (0)  ..
oc2              =day-schedule      (1,24) (0)  ..
people           =week-schedule     (wd) oc1 (weh) oc2  ..
occup            =schedule          thru dec 31 people  ..

$ equipment schedule $

es1              =day-schedule      (1,7) (0) (8,20) (.25,.55,.50,
                                    .55,.9,.6,.8,.7,.75,.75,.3,.5,.05)
                                    (21,24) (0)  ..
es2              =day-schedule      (1,24) (0)  ..

equip            =week-schedule     (wd) es1 (weh) es2  ..
eq1              =schedule          thru dec 31 equip  ..

$ lighting schedules $

$ weekend schedule $

week-ends = day-schedule (1,24) (.05)  ..
```

```
$ core zone schedule $

light-1= day-schedule    (1,7) (0)
                         (8,19) (.5,1,1,1,1,1,1,1,1,1,1,.5)
                         (20,24) (.25)  ..

lights = week-schedule  (wd) light-1 (weh) week-ends  ..

light-core = schedule   thru dec 31 lights  ..

$ south zone schedule $

s-winter = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

s-spring = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

s-summer = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

s-fall   = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

light-s  = schedule    thru feb 7,(wd) s-winter
                                  (weh) week-ends
                       thru may 6,(wd) s-spring
                                  (weh) week-ends
                       thru aug 5,(wd) s-summer
                                  (weh) week-ends
                       thru nov 5,(wd) s-fall
                                  (weh) week-ends
                       thru dec 31,(wd) s-winter
                                  (weh) week-ends  ..

$ east zone schedule $

e-winter = day-schedule (1,7) (.05)
```

```
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

e-spring = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

e-summer = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

e-fall   = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

light-e  = schedule    thru feb 7,(wd) e-winter
                                  (weh) week-ends
                       thru may 6,(wd) e-spring
                                  (weh) week-ends
                       thru aug 5,(wd) e-summer
                                  (weh) week-ends
                       thru nov 5,(wd) e-fall
                                  (weh) week-ends
                       thru dec 31,(wd) e-winter
                                  (weh) week-ends  ..

$ north zone schedule $

n-winter = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

n-spring = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

n-summer = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..
```

```
n-fall   = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

light-n  = schedule    thru feb 7,(wd) n-winter
                                  (weh) week-ends
                       thru may 6,(wd) n-spring
                                  (weh) week-ends
                       thru aug 5,(wd) n-summer
                                  (weh) week-ends
                       thru nov 5,(wd) n-fall
                                  (weh) week-ends
                       thru dec 31,(wd) n-winter
                                  (weh) week-ends  ..

$ west zone schedule $

w-winter = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

w-spring = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

w-summer = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

w-fall   = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,1,1,1,1,1,1,1,1,1,1,1,.5)
                        (20,24) (.25)  ..

light-w  = schedule    thru feb 7,(wd) w-winter
                                  (weh) week-ends
                       thru may 6,(wd) w-spring
                                  (weh) week-ends
                       thru aug 5,(wd) w-summer
                                  (weh) week-ends
                       thru nov 5,(wd) w-fall
                                  (weh) week-ends
                       thru dec 31,(wd) w-winter
```

```
                                  (weh) week-ends  ..

                $ space desciptions $

$ a constant 0.5 air changes per hour (including plenum) is assumed $
$ floor to floor height equals 12.6 feet $

office           =space-conditions  temperature (75)
                                    people-schedule   = occup
                                    people-hg-lat     = 215
                                    people-hg-sens    = 250
                                    lighting-type     = rec-fluor-rv
                                    lighting-w/sqft   = llevel
                                    light-to-space    = 1.0
                                    equipment-w/sqft  = 0.5
                                    equip-schedule    = eq1
                                    equip-sensible    = 1
                                    inf-method        = air-change
                                    floor-weight      = 50
                                    zone-type         = conditioned
                                    inf-cfm/sqft      = 0.104  ..

$ zones are named according to the direction they face        $
$ the following 5 zones make up a typical office floor without $
$ a roof or ground contact floor                               $
$ occupance is assumed to be one person per 100 square feet    $
$ the loads for the floor are multiplied by 10 so that plant   $
$ will receive appropriately large loads to simulate large     $
$ cooling plants                                               $

south-system       =space           space-conditions = office
                                    area             = ns-area
                                    volume           = ns-volume
                                    number-of-people = ns-people
                                    multiplier       = 10
                                    lighting-schedule= light-s  ..

s-precastwall    =exterior-wall     construction     = concrete
                                    height           = 12.6
                                    width            = ns-width
                                    azimuth          = 180
                                    sky-form-factor  = 0.5
                                    gnd-form-factor  = 0.5  ..

s-window         =window            height           = window-height
                                    width            = ns-width
                                    glass-type       = midfloor-glass  ..
```

```
east-system          =space          like south-system
                                     area              = ew-area
                                     volume            = ew-volume
                                     number-of-people = ew-people
                                     lighting-schedule= light-e  ..

e-precastwall      =exterior-wall    like s-precastwall
                                     width             = ew-width
                                     azimuth           = 90  ..

e-window           =window           like s-window
                                     width             = ew-width  ..

north-system         =space          like south-system
                                     lighting-schedule=light-n  ..

n-precastwall      =exterior-wall    like s-precastwall
                                     azimuth           = 0  ..

n-window           =window           like s-window  ..

west-system        =space            like east-system
                                     lighting-schedule=light-w  ..

w-precastwall      =exterior-wall    like s-precastwall
                                     width             = ew-width
                                     azimuth           = 270  ..

w-window           =window           like e-window  ..

core-system          =space          space-conditions = office
                                     light-to-space= 0.6
                                     area              = c-area
                                     volume            = c-volume
                                     number-of-people = c-people
                                     multiplier        = 10
                                     lighting-schedule= light-core  ..

end  ..
compute loads  ..
input systems  ..

title line-5  systems simulation    ..
abort errors  ..
diagnostic cautions  ..
systems-report     summary=(ss-c,ss-f,ss-d,ss-h)
```

```
                    verification=(sv-a)  ..

$ economizer cycle: "fixed" means that no economizer is  $
$ is used,  "temp" means that a temperature controlled  $
$ economizer is used in the core zone                    $
parameter control-par=fixed  ..

$ outside air (cfm/person) $
parameter outside-air-par=10  ..

              $ systems schedules $

$ heating thermostat temperature schedule $

heat1             =day-schedule (1,7) (55) (8,18) (70) (19,24) (55)  ..
heat2             =day-schedule (1,24) (55)  ..
dayheat           =week-schedule (wd) heat1 (weh) heat2  ..
heat-thermostat   =schedule       thru dec 31  dayheat  ..

$ cooling thermostat schedules $

cool-thermostat   =schedule       thru dec 31 (all) (1,24) (75)  ..

$ operating schedule of heating system $
$ the boiler is turned off from april 1 to october 1 $

boiler-schedule   =schedule       thru mar 31 (all) (1,24) (1)
                                  thru sep 30 (all) (1,24) (0)
                                  thru dec 31 (all) (1,24) (1)  ..

$ operating schedule of fans and chillers $

cool1             =day-schedule   (1,7) (0) (8,18) (1) (19,24) (0)  ..
cool2             =day-schedule   (1,24) (0)  ..
cool3             =day-schedule   (1,4) (0) (5,18) (1) (19,24) (0)  ..
daycool           =week-schedule  (mon) cool3 (tue,fri) cool1 (weh) cool2  ..
fans+chiller-sch  =schedule       thru dec 31 daycool  ..

$ perimeter zones $

south-system      =zone           design-heat-t   = 70
                                  heat-temp-sch   = heat-thermostat
                                  design-cool-t   = 75
                                  cool-temp-sch   = cool-thermostat
                                  thermostat-type = proportional
                                  exhaust-cfm     = 0
                                  zone-type       = conditioned
```

```
                                  throttling-range= 2
                                  oa-cfm/per      = outside-air-par
                                  multiplier      = 10  ..

east-system       =zone           like south-system  ..

north-system      =zone           like south-system  ..

west-system       =zone           like east-system  ..

core-system       =zone           like south-system  ..

                 $ systems description $

south-fan-coil    =system          max-supply-t    = 90
                                   min-supply-t    = 50
                                   heating-schedule= boiler-schedule
                                   cooling-schedule= fans+chiller-sch
                                   fan-schedule    = fans+chiller-sch
                                   supply-static   = 0.35
                                   supply-eff      = 0.75
                                   system-type     = fpfc
                                   zone-names      = (south-system)  ..

east-fan-coil     =system          like south-fan-coil
                                   zone-names      = (east-system)  ..

north-fan-coil    =system          like south-fan-coil
                                   zone-names      = (north-system)  ..

west-fan-coil     =system          like east-fan-coil
                                   zone-names      = (west-system)  ..

core-con-volume   =system          max-supply-t    = 90
                                   min-supply-t    = 50
                                   heating-schedule= boiler-schedule
                                   cooling-schedule= fans+chiller-sch
                                   fan-schedule    = fans+chiller-sch
                                   fan-control     = cycling
                                   system-type     = rhfs
                                   cool-control    = warmest
                                   preheat-t       = 40
                                   econo-limit-t   = 55
                                   oa-control      = control-par
                                   reheat-delta-t  = 27
                                   return-air-path = duct
                                   return-static   = 1.5
```

```
                                           return-eff      = 0.63
                                           zone-names      = (core-system)
                                           supply-static   = 4
                                           supply-eff      = 0.66  ..


building-systems =plant-assignment system-names = (south-fan-coil,
                                   east-fan-coil, north-fan-coil,
                                   west-fan-coil, core-con-volume)  ..

end  ..
compute systems  ..
input  plant  ..

title line-5   plant - all electric    ..
abort errors  ..
diagnostic cautions  ..

plant-report     summary = (ps-a,ps-c,ps-d,ps-g)
                 verification = (pv-a,pv-d)  ..
building-systems =plant-assignment  ..

$ equipment description $
$ all equipment has been set up to size itself $

cooling-plant    = plant-equipment   type = herm-cent-chlr
                   size = -999  ..

cooling-tower    = plant-equipment   type = cooling-twr
                   size = -999  ..

heating-plant    = plant-equipment   type = elec-hw-boiler
                   size = -999  ..


energy-cost              resource = electricity
                         unit     = 3413
                         uniform-cost = .07
                         peak-load-chg = 1.60  ..
end  ..
compute plant  ..
input  plant  ..

title line-5   plant - gas heat,elec cooling    ..
abort errors  ..
diagnostic cautions  ..
```

```
plant-report     summary = (ps-a,ps-c,ps-d,ps-g)
                 verification = (pv-a,pv-d)  ..
building-systems =plant-assignment  ..

$ equipment description $
$ all equipment has been set up to size itself $

cooling-plant     = plant-equipment   type = herm-cent-chlr
                    size = -999  ..

cooling-tower     = plant-equipment   type = cooling-twr
                    size = -999  ..

heating-plant     = plant-equipment   type = hw-boiler
                    size = -999  ..
      plant-parameters    boiler-fuel = natural-gas  ..


energy-cost             resource = electricity
                        unit     = 3413
                        uniform-cost = .07
                        peak-load-chg = 1.60  ..
energy-cost             resource = natural-gas
                        unit       = 100000
                        uniform-cost= 0.45  ..
end  ..
compute plant  ..
input  plant  ..

title line-5   plant - gas heating and cooling    ..
abort errors  ..
diagnostic cautions  ..

plant-report     summary = (ps-a,ps-c,ps-d,ps-g)
                 verification = (pv-a,pv-d)  ..
building-systems =plant-assignment  ..

$ equipment description $
$ all equipment has been set up to size itself $

cooling-plant     = plant-equipment   type = absor1-chlr
                    size = -999  ..

cooling-tower     = plant-equipment   type = cooling-twr
                    size = -999  ..

heating-plant     = plant-equipment   type = hw-boiler
```

```
                      size = -999  ..
    plant-parameters     boiler-fuel = natural-gas  ..


energy-cost            resource = electricity
                       unit     = 3413
                       uniform-cost = .07
                       peak-load-chg = 1.60  ..

energy-cost            resource = natural-gas
                       unit     = 100000
                       uniform-cost= 0.45  ..
end  ..
compute plant  ..
stop  ..
```

THIN DAYLIT BUILDING:

```
input  loads   ..
title line-1   thin building-daylighting    ..
title line-2   thesis study    ..
title line-3   heat mirror glass-5.5 feet high    ..
title line-4   phoenix weather data    ..
title line-5   loads simulation    ..
               diagnostic cautions  ..
               abort errors  ..
               loads-report summary=(ls-b,ls-c,ls-d)  ..
               run-period jan 1 1965 thru dec 31 1965  ..
               building-location latitude 33.43  longitude 112.02
                                 heat-peak-period = (7,18)
                                 cool-peak-period = (7,18)
                                 time-zone 6  azimuth 0  altitude 1117 ..
```

Location

```
                   $ parameters to change $

$ installed lighting capacity (watts/sf) $
parameter   llevel=2.0  ..

$ glazing type $
$ glass type 7 represents solar bronze, glass type 10 heat mirror $
parameter   panes-par=2  ..
parameter   glass-type-par=10  ..

$ window height (feet) $
parameter   window-height=5.5  ..

$ parameters used to change building shape $
$ one person per 100 square feet is assumed $

$ north and south zones $
parameter   ns-width=240  ..
parameter   ns-area=4800  ..
parameter   ns-volume=43200  ..
parameter   ns-people=48  ..

$ core zone $
parameter   c-area=4800  ..
parameter   c-volume=43200  ..
parameter   c-people=48  ..
```

```
            $ compute response factors $

$ exterior walls $
concrete-wall1    =material          th=.4167 cond=.7580 dens=140 s-h=.2  ..
insulation-wall1 =material           th=.1667 cond=.0200 dens=16  s-h=.2  ..
precastwall       =layers            mat=(concrete-wall1,
                                     insulation-wall1)  i-f-r=.685  ..
concrete          =construction      layers=precastwall ..

            $ glass description $

midfloor-glass    =glass-type        panes=panes-par
                                     glass-type-code=glass-type-par  ..

            $ schedules $

$ occupance schedules $
oc1               =day-schedule      (1,7) (0)
                                     (8,19) (.15,.75,.95,.95,.95,.90,.95,
                                     .95,.95,.95,.6,.2)
                                     (20,24) (0)  ..
oc2               =day-schedule      (1,24) (0)  ..
people            =week-schedule     (wd) oc1 (weh) oc2  ..
occup             =schedule          thru dec 31 people  ..

$ equipment schedule $

es1               =day-schedule      (1,7) (0) (8,20) (.25,.55,.50,
                                     .55,.9,.6,.8,.7,.75,.75,.3,.5,.05)
                                     (21,24) (0)  ..
es2               =day-schedule      (1,24) (0)  ..

equip             =week-schedule     (wd) es1 (weh) es2  ..
eq1               =schedule          thru dec 31 equip  ..

$ lighting schedules $

$ weekend schedule $

week-ends = day-schedule (1,24) (.05)  ..

$ core zone schedule $

light-1= day-schedule    (1,7) (0)
                         (8,19) (.5,1,1,1,1,1,1,1,1,1,1,1,.5)
                         (20,24) (.25)  ..
```

Lighting
Schedule

```
lights = week-schedule  (wd) light-1 (weh) week-ends  ..

light-core = schedule   thru dec 31 lights  ..

$ south zone schedule $

s-winter = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,.33,.33,.33,.33,.33,.33,.33,1,1,1,.5)
                        (20,24) (.25)  ..

s-spring = day-schedule (1,7) (.05)
                        (8,19)
                        (.17,.28,.11,.11,.11,.11,.11,.22,.33,1,1,.5)
                        (20,24) (.25)  ..

s-summer = day-schedule (1,7) (.05)
                        (8,19)
                        (.15,.27,.11,.11,.11,.11,.11,.11,.22,.33,.55,.5)
                        (20,24) (.25)  ..

s-fall   = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,.33,.28,.11,.11,.11,.11,.11,.22,.33,1,.5)
                        (20,24) (.25)  ..

light-s  = schedule    thru feb 7,(wd) s-winter
                                  (weh) week-ends
                       thru may 6,(wd) s-spring
                                  (weh) week-ends
                       thru aug 5,(wd) s-summer
                                  (weh) week-ends
                       thru nov 5,(wd) s-fall
                                  (weh) week-ends
                       thru dec 31,(wd) s-winter
                                  (weh) week-ends  ..

$ north zone schedule $

n-winter = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,.55,.55,.55,.55,.55,.55,.55,1,1,1,.5)
                        (20,24) (.25)  ..

n-spring = day-schedule (1,7) (.05)
                        (8,19)
                        (.27,.22,.11,.11,.11,.11,.11,.11,.11,1,1,.5)
```

Lighting
Schedule

```
                           (20,24) (.25)  ..

n-summer = day-schedule (1,7) (.05)
                        (8,19)
                        (.17,.22,.11,.11,0,0,0,.11,.11,.22,1,.5)
                        (20,24) (.25)  ..

n-fall   = day-schedule (1,7) (.05)
                        (8,19)
                        (.5,.55,.22,.11,.11,.11,.11,.11,.11,.11,1,.5)
                        (20,24) (.25)  ..
```

Lighting
Schedule

```
light-n  = schedule    thru feb 7,(wd) n-winter
                                  (weh) week-ends
                       thru may 6,(wd) n-spring
                                  (weh) week-ends
                       thru aug 5,(wd) n-summer
                                  (weh) week-ends
                       thru nov 5,(wd) n-fall
                                  (weh) week-ends
                       thru dec 31,(wd) n-winter
                                  (weh) week-ends . ..

               $ space desciptions $

$ a constant 0.5 air changes per hour (including plenum) is assumed $
$ floor to floor height equals 12.6 feet $

office           =space-conditions  temperature (75)
                                    people-schedule  = occup
                                    people-hg-lat    = 215
                                    people-hg-sens   = 250
                                    lighting-type    = rec-fluor-rv
                                    lighting-w/sqft  = llevel
                                    light-to-space   = 1.0
                                    equipment-w/sqft = 0.5
                                    equip-schedule   = eq1
                                    equip-sensible   = 1
                                    inf-method       = air-change
                                    floor-weight     = 50
                                    zone-type        = conditioned
                                    inf-cfm/sqft     = 0.104  ..

$ zones are named according to the direction they face       $
$ the following 3 zones make up a typical office floor without $
$ a roof or ground contact floor                              $
$ occupance is assumed to be one person per 100 square feet   $
```

```
$ the loads for the floor are multiplied by 10 so that plant   $
$ will receive appropriately large loads to simulate large     $
$ cooling plants                                               $

south-system       =space           space-conditions = office
                                    area             = ns-area
                                    volume           = ns-volume
                                    number-of-people = ns-people
                                    multiplier       = 10
                                    lighting-schedule= light-s  ..

s-precastwall    =exterior-wall     construction     = concrete
                                    height           = 12.6
                                    width            = ns-width
                                    azimuth          = 180
                                    sky-form-factor  = 0.5
                                    gnd-form-factor  = 0.5  ..

s-window         =window            height           = window-height
                                    width            = ns-width
                                    glass-type       = midfloor-glass  ..

north-system       =space           like south-system
                                    lighting-schedule=light-n  ..

n-precastwall    =exterior-wall     like s-precastwall
                                    azimuth          = 0  ..

n-window         =window            like s-window  ..

core-system        =space           space-conditions = office
                                    light-to-space= 0.6
                                    area             = c-area
                                    volume           = c-volume
                                    number-of-people = c-people
                                    multiplier       = 10
                                    lighting-schedule= light-core  ..

end  ..
compute loads  ..
input systems  ..

title line-5   systems simulation    ..
abort errors  ..
diagnostic cautions  ..
systems-report     summary=(ss-c,ss-f,ss-d,ss-h)
                   verification=(sv-a)  ..
```

```
$ economizer cycle: "fixed" means that no economizer is  $
$ is used,  "temp" means that a temperature controlled   $
$ economizer is used in the core zone                    $
parameter control-par=fixed  ..

$ outside air (cfm/person) $
parameter outside-air-par=10  ..

              $ systems schedules $

$ heating thermostat temperature schedule $

heat1               =day-schedule (1,7) (55) (8,18) (70) (19,24) (55)  ..
heat2               =day-schedule (1,24) (55)  ..
dayheat             =week-schedule (wd) heat1 (weh) heat2  ..
heat-thermostat     =schedule       thru dec 31  dayheat  ..

$ cooling thermostat schedules $

cool-thermostat     =schedule       thru dec 31 (all) (1,24) (75)  ..

$ operating schedule of heating system $
$ the boiler is turned off from april 1 to october 1 $

boiler-schedule     =schedule       thru mar 31 (all) (1,24) (1)
                                    thru sep 30 (all) (1,24) (0)
                                    thru dec 31 (all) (1,24) (1)  ..

$ operating schedule of fans and chillers $

cool1               =day-schedule   (1,7) (0) (8,18) (1) (19,24) (0)  ..
cool2               =day-schedule   (1,24) (0)  ..
cool3               =day-schedule   (1,4) (0) (5,18) (1) (19,24) (0)  ..
daycool             =week-schedule  (mon) cool3 (tue,fri) cool1 (weh) cool2  ..
fans+chiller-sch    =schedule       thru dec 31 daycool  ..

$ perimeter zones $

south-system        =zone           design-heat-t    = 70
                                    heat-temp-sch    = heat-thermostat
                                    design-cool-t    = 75
                                    cool-temp-sch    = cool-thermostat
                                    thermostat-type = proportional
                                    exhaust-cfm      = 0
                                    zone-type        = conditioned
                                    throttling-range= 2
```

```
                                  oa-cfm/per       = outside-air-par
                                  multiplier       = 10  ..

north-system      =zone           like south-system  ..

core-system       =zone           like south-system  ..

             $ systems description $

south-fan-coil    =system           max-supply-t     = 90
                                    min-supply-t     = 50
                                    heating-schedule= boiler-schedule
                                    cooling-schedule= fans+chiller-sch
                                    fan-schedule     = fans+chiller-sch
                                    supply-static    = 0.35
                                    supply-eff       = 0.75
                                    system-type      = fpfc
                                    zone-names       = (south-system)  ..

north-fan-coil    =system           like south-fan-coil
                                    zone-names       = (north-system)  ..

core-con-volume   =system           max-supply-t     = 90
                                    min-supply-t     = 50
                                    heating-schedule= boiler-schedule
                                    cooling-schedule= fans+chiller-sch
                                    fan-schedule     = fans+chiller-sch
                                    fan-control      = cycling
                                    system-type      = rhfs
                                    cool-control     = warmest
                                    preheat-t        = 40
                                    econo-limit-t    = 55
                                    oa-control       = control-par
                                    reheat-delta-t   = 27
                                    return-air-path  = duct
                                    return-static    = 1.5
                                    return-eff       = 0.63
                                    zone-names       = (core-system)
                                    supply-static    = 4
                                    supply-eff       = 0.66  ..


building-systems =plant-assignment system-names = (south-fan-coil,
                                    north-fan-coil, core-con-volume)  ..

end  ..
compute systems  ..
```

```
input  plant  ..

title line-5   plant - all electric    ..
abort errors  ..
diagnostic cautions  ..

plant-report     summary = (ps-a,ps-b,ps-c,ps-d,ps-g,ps-h)
                 verification = (pv-a,pv-d)  ..
building-systems =plant-assignment  ..

$ equipment description $
$ all equipment has been set up to size itself $

cooling-plant    = plant-equipment   type = herm-cent-chlr
                   size = -999  ..

cooling-tower    = plant-equipment   type = cooling-twr
                   size = -999  ..

heating-plant    = plant-equipment   type = elec-hw-boiler
                   size = -999  ..


energy-cost            resource = electricity
                       unit     = 3413
                       uniform-cost = .07
                       peak-load-chg = 1.60  ..
end  ..
compute plant  ..
input  plant  ..

title line-5   plant - gas heat,elec cooling    ..
abort errors  ..
diagnostic cautions  ..

plant-report     summary = (ps-a,ps-b,ps-c,ps-d,ps-g,ps-h)
                 verification = (pv-a,pv-d)  ..
building-systems =plant-assignment  ..

$ equipment description $
$ all equipment has been set up to size itself $

cooling-plant    = plant-equipment   type = herm-cent-chlr
                   size = -999  ..

cooling-tower    = plant-equipment   type = cooling-twr
                   size = -999  ..
```

```
heating-plant     = plant-equipment   type = hw-boiler
                    size = -999  ..
      plant-parameters     boiler-fuel = natural-gas  ..


energy-cost             resource = electricity
                        unit     = 3413
                        uniform-cost = .07
                        peak-load-chg = 1.60  ..
energy-cost             resource = natural-gas
                        unit       = 100000
                        uniform-cost= 0.45  ..
end  ..
compute plant  ..
input  plant  ..

title line-5   plant - gas heating and cooling    ..
abort errors  ..
diagnostic cautions  ..

plant-report     summary = (ps-a,ps-b,ps-c,ps-d,ps-g,ps-h)
                 verification = (pv-a,pv-d)  ..
building-systems =plant-assignment  ..

$ equipment description $
$ all equipment has been set up to size itself $

cooling-plant     = plant-equipment   type = absor1-chlr
                    size = -999  ..

cooling-tower     = plant-equipment   type = cooling-twr
                    size = -999  ..

heating-plant     = plant-equipment   type = hw-boiler
                    size = -999  ..
      plant-parameters     boiler-fuel = natural-gas  ..


energy-cost             resource = electricity
                        unit     = 3413
                        uniform-cost = .07
                        peak-load-chg = 1.60  ..

energy-cost             resource = natural-gas
                        unit     = 100000
                        uniform-cost= 0.45  ..
end  ..
compute plant  ..
stop  ..
```

APPENDIX D: SUMMARY OF COMPUTERIZED ENERGY ANALYSIS

This appendix contains a summary of the results from the DOE-2 computer program. Four tables are given for each building simulation. The first table, the building summary sheet, details both annual energy consumption and the size of the heating and cooling plants. This summary report was compiled by myself from several DOE-2 reports. The final three reports are standard DOE-2 output reports. They detail monthly consumption and peaks of both the building loads, and the plant consumption. Each of these four reports is described in detail below. The output data follows these summaries.

Building Summary Sheet

In this summary, consumption is broken down into five major components: heating, cooling, lights, equipment, and fans. The cooling and heating energy is further broken down into their various components; boiler, chiller, cooling tower, and pumps. Three figures are given for each of these components. The first column contains the energy consumption in million Btu (MBTU) computed by DOE-2 for the ten story building (144,000 square feet). The second column shows the percentage of the total load represented by this figure. The third column gives the electrical consumption on a per square foot basis (KWH/SF). The second major section of this summary is the equipment sizes. It details heating and cooling plant sizes for the entire ten story building as well as the capacity in tons/thousand square foot.

Report SS-D: Plant Monthly Loads Summary

In this report, the cooling, heating, and electrical energy required by the building are reported monthly along with the peak cooling, heating, and electrical loads. Note that these are the loads that the central plant must provide, not the actual energy consumption of the plant.

A definition of the various report headings is provided below:

1. COOLING ENERGY (millions of Btu) is the sensible and latent monthly cooling required by the central chiller.
2. TIME OF MAX gives the day and hour of the maximum cooling load.
3. DRY-BULB TEMP and WET-BULB TEMP are the outside dry-bulb and wet-bulb temperatures during the peak cooling load.

4. MAXIMUM COOLING LOAD (thousands of Btu/hr) gives the peak cooling load for each month and for the year. Note: the peaks reported for the daylit buildings are not accurate.
5. HEATING ENERGY (millions of Btu) is the total monthly heating required by the central boiler.
6. TIME OF MAX gives the day and hour that the maximum heating load occurs.
7. MAXIMUM HEATING LOAD (thousands of Btu/hr) gives the peak heating load for each month and for the year.
8. ELECTRICAL ENERGY (in kWh) is the monthly electrical requirement for lights and convenience outlets. In addition, the electrical energy contains the fan energy requirement for the HVAC system. It does not include the electrical energy associated with pumps, cooling towers, chillers, and electrical heating.
9. MAXIMUM ELEC LOAD (kW) gives the monthly peak electrical consumption in a one-hour period for lights and convenience outlets.

Report PS-B: Monthly Peaks and Total Energy Use

This report details the monthly peak and total consumption of electricity and natural gas in thousands of Btu. Two versions of this report are given, one for an all electric building, and one for a building with electric cooling and gas heating. The electrical consumption includes power consumed by the lights, convenience outlets, cooling towers, fans, pumps, and chiller. For the all-electric building only, power for the boiler is also included. Natural gas consumption is shown only for the building with gas heating.

BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Boston

Size: 120'x120' Lighting: Artificial

Glass Type: bronze Glass Height: 4'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	491.0	7.6	1.00
	Tower	281.8	4.3	0.57
	Pumps	113.6	1.8	0.23
	Sub-total	886.4	13.7	1.80
HEATING	Boiler	1671.3	25.8	3.40
	Pumps	13.9	0.2	0.03
	Sub-total	1685.2	26.0	3.43
LIGHTS & EQUIPMENT		3661.1	56.4	7.45
FANS		255.1	3.9	0.52
TOTAL		6487.8	100	13.20

EQUIPMENT SIZES

	MBTU	TONS/1000SF
BOILER	2.720	1.575
CHILLER	3.772	2.184

```
1 FAT BUILDING-NO DAYLIGHTING            THESIS STUDY                                 DOE+2.1A   21 NOV 81   09.45.17   SDL RUN 1
 BRONZE GLASS-4 FEET HIGH                BOSTON WEATHER DATA                     SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
 ---------------------------------------------------------------------------------------------------------------------------------


          - - - - - - - - C O O L I N G - - - - - - - -       - - - - - - - - H E A T I N G - - - - - - - -      - - - - E L E C - - -

                                                 MAXIMUM                                                MAXIMUM       ELEC-    MAXIMUM
          COOLING    TIME    DRY-  WET-          COOLING         HEATING    TIME    DRY-  WET-          HEATING      TRICAL       ELEC
           ENERGY  OF MAX    BULB  BULB             LOAD          ENERGY  OF MAX    BULB  BULB             LOAD      ENERGY       LOAD
 MONTH     (MBTU)  DY  HR    TEMP  TEMP        (KBTU/HR)          (MBTU)  DY  HR    TEMP  TEMP        (KBTU/HR)       (KWH)       (KW)


 JAN      1.86518  20   8     30F   25F           48.277        -412.836   3  11     22F   19F        -2702.068      99863.      378.4

 FEB      1.61638   7  16     34F   28F           53.791        -344.001  18  12     30F   28F        -2692.516      86634.      378.4

 MAR      2.04890  28  17     46F   35F          159.442        -262.609   3  11     30F   30F        -2684.096      95901.      378.4

 APR     80.64790  17  17     76F   62F         1825.682         -52.150   1   8     27F   23F        -2441.432      99517.      378.4

 MAY    149.13613  28  17     78F   63F         1633.587          -4.358  27   8     47F   39F        -1122.187      95748.      378.4

 JUN    380.15811  27  17     94F   78F         3477.919          0.                                    0.         95555.      378.4

 JUL    478.44594  17  16     94F   77F         3698.305          0.                                    0.         99863.      378.4

 AUG    530.32623  18  15     88F   74F         3411.768          0.                                    0.         95824.      378.4

 SEP    255.86707   2  11     80F   71F         3398.597          0.                                    0.         95479.      378.4

 OCT     99.04665   9  17     67F   54F         1502.161         -33.817  24   8     32F   27F        -2053.943      99786.      378.4

 NOV      7.35243   5  17     56F   56F          336.374        -114.610  17   9     36F   32F        -2536.010      83364.      378.4

 DEC      3.07152  12  15     49F   41F          191.809        -346.540  26  11     35F   35F        -2679.080      99939.      378.4
        ---------                              ----------      ---------                            ----------    --------    -------

 TOTAL   1989.582                                              -1570.921                                         1147473.

 MAX                                            3698.305                                            -2702.068                 378.4
```

```
1 FAT BUILDING-NO DAYLIGHTING             THESIS STUDY
  BRONZE GLASS-4 FEET HIGH                BOSTON WEATHER DATA
 REPORT- PS-B  MONTHLY PEAK AND TOTAL ENERGY USE
--------------------------------------------------------------------------------------------------------

       MO        UTILITY-     ELECTRICITY

             TOTAL(MBTU)        813.549
      JAN     PEAK(MBTU)          4.217
                   DY/HR           2/12

             TOTAL(MBTU)        691.209
      FEB     PEAK(MBTU)          4.237
                   DY/HR          18/12

             TOTAL(MBTU)        647.092
      MAR     PEAK(MBTU)          4.196
                   DY/HR           3/12

             TOTAL(MBTU)        461.549
      APR     PEAK(MBTU)          3.583
                   DY/HR           1/ 9

             TOTAL(MBTU)        410.123
      MAY     PEAK(MBTU)          2.031
                   DY/HR          27/ 8

             TOTAL(MBTU)        445.123
      JUN     PEAK(MBTU)          2.180
                   DY/HR          27/17

             TOTAL(MBTU)        480.114
      JUL     PEAK(MBTU)          2.234
                   DY/HR          17/16

             TOTAL(MBTU)        471.724
      AUG     PEAK(MBTU)          2.126
                   DY/HR          18/14

             TOTAL(MBTU)        421.824
      SEP     PEAK(MBTU)          2.138
                   DY/HR           2/12

             TOTAL(MBTU)        449.570
      OCT     PEAK(MBTU)          2.953
                   DY/HR          24/ 8

             TOTAL(MBTU)        447.440
      NOV     PEAK(MBTU)          4.000
                   DY/HR          17/ 9

             TOTAL(MBTU)        748.485
      DEC     PEAK(MBTU)          4.195
                   DY/HR          26/12

               ONE YEAR        6487.802
               USE/PEAK           4.237
```

ELECTRIC BOILER
ELECTRIC CHILLER

```
       MO        UTILITY-     ELECTRICITY    NATURAL-GAS

             TOTAL(MBTU)        396.859         561.018
      JAN     PEAK(MBTU)          1.532           3.400
                   DY/HR           6/12            3/11

             TOTAL(MBTU)        344.227         470.881
      FEB     PEAK(MBTU)          1.532           3.390
                   DY/HR           3/12           18/12

             TOTAL(MBTU)        378.835         383.890
      MAR     PEAK(MBTU)          1.532           3.381
                   DY/HR          10/12            3/11

             TOTAL(MBTU)        404.159          97.472
      APR     PEAK(MBTU)          1.765           3.125
                   DY/HR          17/17            1/ 8

             TOTAL(MBTU)        403.911          14.739
      MAY     PEAK(MBTU)          1.733           1.654
                   DY/HR          29/12           27/ 8

             TOTAL(MBTU)        445.123           0.
      JUN     PEAK(MBTU)          2.180           0.
                   DY/HR          27/17           30/ 1

             TOTAL(MBTU)        480.114           0.
      JUL     PEAK(MBTU)          2.234           0.
                   DY/HR          17/16           31/ 1

             TOTAL(MBTU)        471.724           0.
      AUG     PEAK(MBTU)          2.126           0.
                   DY/HR          18/14           31/ 1

             TOTAL(MBTU)        421.824           0.
      SEP     PEAK(MBTU)          2.138           0.
                   DY/HR           2/12           30/ 1

             TOTAL(MBTU)        410.047          74.956
      OCT     PEAK(MBTU)          1.721           2.706
                   DY/HR           3/17           24/ 8

             TOTAL(MBTU)        327.115         187.329
      NOV     PEAK(MBTU)          1.575           3.225
                   DY/HR           4/17           17/ 9

             TOTAL(MBTU)        397.453         484.338
      DEC     PEAK(MBTU)          1.531           3.376
                   DY/HR          29/12           26/11

               ONE YEAR        4881.392        2274.624
               USE/PEAK           2.234           3.400
```

GAS BOILER
ELECTRIC CHILLER

BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Boston

Size: 120'x120' Lighting: Artificial

Glass Type: heat-mirror Glass Height: 4'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	451.4	7.3	0.92
	Tower	258.6	4.2	0.53
	Pumps	105.2	1.7	0.21
	Sub-total	815.2	13.1	1.66
HEATING	Boiler	1464.6	23.6	2.98
	Pumps	12.2	0.2	0.02
	Sub-total	1476.8	23.8	3.01
LIGHTS & EQUIPMENT		3661.1	59.0	7.45
FANS		250.4	4.0	0.51
TOTAL		6203.5	100	12.64

EQUIPMENT SIZES

	MBTU	TONS/1000SF
BOILER	2.475	1.433
CHILLER	3.499	2.026

```
1 FAT BUILDING-NO DAYLIGHTING          THESIS STUDY                         DOE+2.1A   21 NOV 81   09.46.57   SDL RUN 1
  HEATMIRROR GLASS-4 FEET HIGH         BOSTON WEATHER DATA                 SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
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            - - - - - - - - C O O L I N G - - - - - - - -      - - - - - - - - H E A T I N G - - - - - - - -     - - - E L E C - - -

                                                MAXIMUM                                            MAXIMUM      ELEC-     MAXIMUM
           COOLING    TIME    DRY-  WET-        COOLING     HEATING    TIME    DRY-  WET-          HEATING     TRICAL        ELEC
            ENERGY  OF MAX    BULB  BULB           LOAD      ENERGY  OF MAX    BULB  BULB             LOAD     ENERGY        LOAD
MONTH       (MBTU)  DY  HR    TEMP  TEMP      (KBTU/HR)      (MBTU)  DY  HR    TEMP  TEMP        (KBTU/HR)      (KWH)        (KW)


JAN        1.86518  20   8    30F   25F          48.277    -368.192   2  18    22F   18F         -2458.020     99683.       377.7

FEB        1.49231  18   8    29F   26F          48.719    -302.237  18  11    30F   27F         -2434.813     86480.       377.7

MAR        1.76317  28  17    46F   35F          57.066    -232.616   3  11    30F   30F         -2425.465     95727.       377.7

APR       71.72358  17  17    76F   62F        1653.629     -46.114   1   8    27F   23F         -2263.668     99337.       377.7

MAY      133.69389  28  17    78F   63F        1458.839      -3.683  27   8    47F   39F         -1223.879     95578.       377.7

JUN      346.06086  27  17    94F   78F        3242.620      0.                                         0.     95382.       377.7

JUL      439.99173  17  16    94F   77F        3427.570      0.                                         0.     99683.       377.7

AUG      488.96421  18  15    88F   74F        3126.115      0.                                         0.     95653.       377.7

SEP      239.60632   2  11    80F   71F        3128.333      0.                                         0.     95307.       377.7

OCT       92.07339   3  17    69F   66F        1437.602     -26.277  24   8    32F   27F         -1749.322     99608.       377.7

NOV        7.26057   5  17    56F   56F         449.692     -96.663  17   9    36F   32F         -2339.632     83216.       377.7

DEC        2.62144  11  16    55F   51F         121.877    -304.216  26  10    34F   34F         -2418.305     99758.       377.7
         ---------                           ----------   ---------                            ----------   --------     -------

TOTAL     1827.117                                        -1379.997                                        1145412.

MAX                                            3427.570                                         -2458.020                 377.7
```

```
1 FAT BUILDING-NO DAYLIGHTING             THESIS STUDY
  HEATMIRROR GLASS-4 FEET HIGH            BOSTON WEATHER DATA
 REPORT- PS-B  MONTHLY PEAK AND TOTAL ENERGY USE
 -------------------------------------------------------------------------------------------------------------------------------

          MO       UTILITY-     ELECTRICITY                      MO       UTILITY-     ELECTRICITY    NATURAL-GAS

                 TOTAL(MBTU)      763.350                                TOTAL(MBTU)      391.434        501.545
         JAN      PEAK(MBTU)        3.945                        JAN      PEAK(MBTU)        1.510          3.093
                       DY/HR         2/12                                      DY/HR         6/12           2/18

                 TOTAL(MBTU)      644.606                                TOTAL(MBTU)      339.543        415.999
         FEB      PEAK(MBTU)        3.956                        FEB      PEAK(MBTU)        1.510          3.069
                       DY/HR        18/12                                      DY/HR         3/12          18/11

                 TOTAL(MBTU)      611.584                                TOTAL(MBTU)      373.549        341.393
         MAR      PEAK(MBTU)        3.908                        MAR      PEAK(MBTU)        1.510          3.059
                       DY/HR         3/12                                      DY/HR        10/12           3/11

                 TOTAL(MBTU)      447.817                                TOTAL(MBTU)      397.156         85.293
         APR      PEAK(MBTU)        3.370                        APR      PEAK(MBTU)        1.719          2.888
                       DY/HR         1/ 9                                      DY/HR        17/17           1/ 8

                 TOTAL(MBTU)      400.883                                TOTAL(MBTU)      395.849         11.381
         MAY      PEAK(MBTU)        2.110                        MAY      PEAK(MBTU)        1.698          1.739
                       DY/HR        27/ 8                                      DY/HR        29/12          27/ 8

                 TOTAL(MBTU)      434.741                                TOTAL(MBTU)      434.741         0.
         JUN      PEAK(MBTU)        2.115                        JUN      PEAK(MBTU)        2.115          0.
                       DY/HR        27/17                                      DY/HR        27/17          30/ 1

                 TOTAL(MBTU)      468.657                                TOTAL(MBTU)      468.657         0.
         JUL      PEAK(MBTU)        2.163                        JUL      PEAK(MBTU)        2.163          0.
                       DY/HR        17/17                                      DY/HR        17/17          31/ 1

                 TOTAL(MBTU)      460.072                                TOTAL(MBTU)      460.072         0.
         AUG      PEAK(MBTU)        2.055                        AUG      PEAK(MBTU)        2.055          0.
                       DY/HR        18/17                                      DY/HR        18/17          31/ 1

                 TOTAL(MBTU)      414.164                                TOTAL(MBTU)      414.164         0.
         SEP      PEAK(MBTU)        2.066                        SEP      PEAK(MBTU)        2.066          0.
                       DY/HR         2/12                                      DY/HR         2/12          30/ 1

                 TOTAL(MBTU)      433.790                                TOTAL(MBTU)      402.849         59.150
         OCT      PEAK(MBTU)        2.629                        OCT      PEAK(MBTU)        1.699          2.330
                       DY/HR        24/ 9                                      DY/HR         3/17          24/ 8

                 TOTAL(MBTU)      423.950                                TOTAL(MBTU)      322.382        157.240
         NOV      PEAK(MBTU)        3.780                        NOV      PEAK(MBTU)        1.565          2.968
                       DY/HR        17/ 9                                      DY/HR         4/17          17/ 9

                 TOTAL(MBTU)      699.888                                TOTAL(MBTU)      391.635        425.949
         DEC      PEAK(MBTU)        3.899                        DEC      PEAK(MBTU)        1.509          3.051
                       DY/HR        26/12                                      DY/HR        29/12          26/10

                    ONE YEAR     6203.502                                   ONE YEAR     4792.032       1997.950
                    USE/PEAK        3.956                                   USE/PEAK        2.163          3.093
```

ELECTRIC BOILER
ELECTRIC CHILLER

GAS BOILER
ELECTRIC CHILLER

BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Boston

Size: 240'x60' Lighting: Daylit

Glass Type: heat-mirror Glass Height: 5½'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	357.6	6.7	0.73
	Tower	218.5	4.1	0.44
	Pumps	89.7	1.7	0.18
	Sub-total	665.7	12.5	1.35
HEATING	Boiler	1757.0	32.9	3.58
	Pumps	14.3	0.3	0.03
	Sub-total	1771.4	33.1	3.61
LIGHTS & EQUIPMENT		2713.7	50.8	5.52
FANS		196.8	3.7	0.40
TOTAL		5347.6	100.2	10.88

EQUIPMENT SIZES

	MBTU	TONS/1000SF
BOILER	2.628	1.521
CHILLER	3.131	1.813

```
1 THIN BUILDING-DAYLIT                      THESIS STUDY                                  DOE+2.1A    30 SEP 81    14.30.58    SDL RUN 1
  HEAT MIRROR GLASS-5.5 FEET HIGH           BOSTON WEATHER DATA                       SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
 ---------------------------------------------------------------------------------------------------------------------------------


            - - - - - - - - C O O L I N G - - - - - - - -         - - - - - - - - H E A T I N G - - - - - - - -         - - - E L E C - - -

                                                MAXIMUM                                                 MAXIMUM        ELEC-      MAXIMUM
          COOLING     TIME    DRY-  WET-        COOLING        HEATING     TIME    DRY-  WET-           HEATING       TRICAL        ELEC
           ENERGY   OF MAX    BULB  BULB           LOAD         ENERGY   OF MAX    BULB  BULB              LOAD       ENERGY        LOAD
 MONTH     (MBTU)   DY   HR   TEMP  TEMP      (KBTU/HR)         (MBTU)   DY   HR   TEMP  TEMP         (KBTU/HR)        (KWH)        (KW)


 JAN      1.39917   20    8    30F   25F         36.069       -399.228    2   18    22F   18F         -2537.655       87025.       361.7

 FEB      1.11966   18    8    29F   26F         36.426       -357.554   10   11    29F   29F         -2521.308       66739.       361.7

 MAR      1.13544   24    8    37F   33F         38.593       -299.535    3   13    31F   31F         -2514.661       70401.       361.7

 APR     46.85152   17   17    76F   62F       1468.582        -79.286    1    8    27F   23F         -2342.936       72825.       361.7

 MAY     66.69267   28   18    78F   64F       1048.700        -11.384   27    8    47F   39F         -1381.178       63576.       361.7

 JUN    252.66991   27   18    93F   78F       2715.106         0.                                          0.       61770.       297.6

 JUL    342.15963   17   18    93F   77F       2935.589         0.                                          0.       64490.       297.6

 AUG    412.73320   18   17    89F   74F       2908.228         0.                                          0.       67932.       329.3

 SEP    185.04604    2    9    75F   69F       2897.112         0.                                          0.       68565.       329.3

 OCT     59.93998    9   17    67F   54F       1166.491        -50.902   24    8    32F   27F         -2015.185       71612.       329.3

 NOV      5.27383   13   15    53F   42F        244.185       -119.377   17    9    36F   32F         -2386.421       70754.       361.7

 DEC      2.23866   12   15    49F   41F        190.544       -336.133   26   10    34F   34F         -2516.131       87084.       361.7
        ---------                               ----------     ---------                               ----------     --------     -------

 TOTAL   1377.260                                             -1653.400                                              852773.

 MAX                                           2935.589                                               -2537.655                    361.7
```

```
1 THIN BUILDING-DAYLIT                    PEAK-RUN  CLEAR
  HEAT MIRROR GLASS-5.5 FEET HIGH         BOSTON WEATHER DATA
 REPORT- PS-B  MONTHLY PEAK AND TOTAL ENERGY USE
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```
        MO       UTILITY-      ELECTRICITY

               TOTAL(MBTU)        745.468
       JAN      PEAK(MBTU)          3.968
                     DY/HR           2/17

               TOTAL(MBTU)        627.036
       FEB      PEAK(MBTU)          3.858
                     DY/HR           3/ 9

               TOTAL(MBTU)        586.178
       MAR      PEAK(MBTU)          3.397
                     DY/HR           3/17

               TOTAL(MBTU)        374.551
       APR      PEAK(MBTU)          3.207
                     DY/HR           1/ 9

               TOTAL(MBTU)        282.712
       MAY      PEAK(MBTU)          2.034
                     DY/HR          27/ 8

               TOTAL(MBTU)        300.958
       JUN      PEAK(MBTU)          1.764
                     DY/HR          27/17

               TOTAL(MBTU)        329.066
       JUL      PEAK(MBTU)          1.838
                     DY/HR          17/17

               TOTAL(MBTU)        329.191
       AUG      PEAK(MBTU)          1.840
                     DY/HR          18/18

               TOTAL(MBTU)        288.501
       SEP      PEAK(MBTU)          1.667
                     DY/HR          17/18

               TOTAL(MBTU)        339.833
       OCT      PEAK(MBTU)          2.806
                     DY/HR          24/ 8

               TOTAL(MBTU)        400.209
       NOV      PEAK(MBTU)          3.805
                     DY/HR          17/ 9

               TOTAL(MBTU)        683.217
       DEC      PEAK(MBTU)          3.857
                     DY/HR          24/ 9

                  ONE YEAR       5286.920
                  USE/PEAK          3.968
```

ELECTRIC BOILER
ELECTRIC CHILLER

```
        MO       UTILITY-      ELECTRICITY     NATURAL-GAS

               TOTAL(MBTU)        330.893         553.405
       JAN      PEAK(MBTU)          1.440           3.202
                     DY/HR           3/16           28/10

               TOTAL(MBTU)        255.958         493.407
       FEB      PEAK(MBTU)          1.440           3.186
                     DY/HR          18/17            3/10

               TOTAL(MBTU)        269.884         438.209
       MAR      PEAK(MBTU)          1.438           3.167
                     DY/HR           3/17            3/13

               TOTAL(MBTU)        282.661         148.827
       APR      PEAK(MBTU)          1.644           3.050
                     DY/HR          17/17            1/ 9

               TOTAL(MBTU)        268.353          30.285
       MAY      PEAK(MBTU)          1.536           1.953
                     DY/HR           5/17           27/ 8

               TOTAL(MBTU)        300.958          0.
       JUN      PEAK(MBTU)          1.764          0.
                     DY/HR          27/17          30/ 1

               TOTAL(MBTU)        329.066          0.
       JUL      PEAK(MBTU)          1.838          0.
                     DY/HR          17/17          31/ 1

               TOTAL(MBTU)        329.191          0.
       AUG      PEAK(MBTU)          1.840          0.
                     DY/HR          18/18          31/ 1

               TOTAL(MBTU)        288.501          0.
       SEP      PEAK(MBTU)          1.667          0.
                     DY/HR          17/18          30/ 1

               TOTAL(MBTU)        278.139         108.329
       OCT      PEAK(MBTU)          1.473           2.698
                     DY/HR           3/18           24/ 8

               TOTAL(MBTU)        265.706         207.441
       NOV      PEAK(MBTU)          1.449           3.047
                     DY/HR           7/17           17/ 9

               TOTAL(MBTU)        331.114         481.194
       DEC      PEAK(MBTU)          1.439           3.182
                     DY/HR          29/16           26/10

                  ONE YEAR       3530.425        2461.096
                  USE/PEAK          1.840           3.202
```

GAS BOILER
ELECTRIC CHILLER

BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Los Angeles

Size: 120'x 120' Lighting: Artificial

Glass Type: Bronze Glass Height: 4'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	592.6	12.1	1.21
	Tower	246.0	5.0	0.50
	Pumps	90.8	1.9	0.18
	Sub-total	929.3	19.0	1.89
HEATING	Boiler	60.5	1.2	0.12
	Pumps	1.7	0.0	0.00
	Sub-total	62.2	1.3	0.13
LIGHTS & EQUIPMENT		3661.1	74.7	7.45
FANS		249.1	5.1	0.51
TOTAL		4901.7	100	9.97

EQUIPMENT SIZES

	MBTU	TONS/1000SF
BOILER	1.673	0.969
CHILLER	2.923	1.692

```
1 FAT BUILDING-NO DAYLIGHTING             THESIS STUDY                                 DOE+2.1A   30 SEP 81   14.40.48   SDL RUN 1
  BRONZE GLASS-4 FEET HIGH                LOS ANGELES WEATHER DATA                   SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
 ---------------------------------------------------------------------------------------------------------------------------------


        - - - - - - - - C O O L I N G - - - - - - - -     - - - - - - - - H E A T I N G - - - - - - - -     - - - E L E C - - -

                                                MAXIMUM                                                MAXIMUM      ELEC-   MAXIMUM
            COOLING    TIME   DRY-  WET-        COOLING      HEATING    TIME   DRY-  WET-              HEATING     TRICAL      ELEC
             ENERGY  OF MAX   BULB  BULB           LOAD       ENERGY  OF MAX   BULB  BULB                 LOAD     ENERGY      LOAD
MONTH        (MBTU)  DY  HR   TEMP  TEMP      (KBTU/HR)       (MBTU)  DY  HR   TEMP  TEMP            (KBTU/HR)      (KWH)      (KW)


JAN        90.61416  12  16    65F   58F       1096.406      -18.493   8   8    44F   41F            -1662.218     99713.     377.8

FEB       118.70469  16  17    68F   57F       1470.441       -5.980   5   8    49F   48F            -1132.060     86506.     377.8

MAR       134.78642  15  16    65F   55F       1339.153       -5.956  12   8    48F   46F            -1084.470     99713.     377.8

APR       196.54011   4  16    78F   51F       1934.460      0.                                        0.          95411.     377.8

MAY       230.02639  29  17    72F   65F       1981.566      0.                                        0.          99638.     377.8

JUN       329.82852  21  12    86F   70F       2865.378      0.                                        0.          95336.     377.8

JUL       347.28454  26  16    78F   68F       2364.253      0.                                        0.          95756.     377.8

AUG       420.17272  20  16    78F   69F       2550.773      0.                                        0.         103745.     377.8

SEP       293.94311  27  15    94F   60F       2724.053      0.                                        0.          87197.     377.8

OCT       285.14149  19  14    87F   63F       2284.109       -.262    9   8    55F   53F             -180.957     99713.     377.8

NOV       153.84020   7  16    69F   62F       1700.986       -7.143  26   8    48F   44F            -1378.467     91229.     377.8

DEC       107.35614  10  14    82F   57F       1829.362      -10.235  24   8    46F   45F            -1192.648     91725.     377.8
          ---------                          ----------    ---------                               ----------   --------   -------

TOTAL      2708.238                                          -48.071                                           1145680.

MAX                                            2865.378                                            -1662.218                377.8
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1 FAT BUILDING-NO DAYLIGHTING             THESIS STUDY
  BRONZE GLASS-4 FEET HIGH                LOS ANGELES WEATHER DATA
 REPORT- PS-B  MONTHLY PEAK AND TOTAL ENERGY USE
 ---------------------------------------------------------------------------------------------------------------------

   MO        UTILITY-     ELECTRICITY                   MO        UTILITY-     ELECTRICITY     NATURAL-GAS

           TOTAL(MBTU)        419.185                            TOTAL(MBTU)        398.045          38.048
   JAN      PEAK(MBTU)          2.570                   JAN       PEAK(MBTU)          1.597           2.092
                 DY/HR           8/ 9                                  DY/HR          12/16            8/ 8

           TOTAL(MBTU)        357.362                            TOTAL(MBTU)        350.242          13.763
   FEB      PEAK(MBTU)          1.960                   FEB       PEAK(MBTU)          1.650           1.520
                 DY/HR           5/ 8                                  DY/HR          16/14            5/ 8

           TOTAL(MBTU)        410.908                            TOTAL(MBTU)        403.267          16.193
   MAR      PEAK(MBTU)          1.915                   MAR       PEAK(MBTU)          1.639           1.467
                 DY/HR          12/ 8                                  DY/HR          15/12           12/ 8

           TOTAL(MBTU)        397.168                            TOTAL(MBTU)        397.168          0.
   APR      PEAK(MBTU)          1.719                   APR       PEAK(MBTU)          1.719           0.
                 DY/HR           4/17                                  DY/HR           4/17           30/ 1

           TOTAL(MBTU)        418.894                            TOTAL(MBTU)        418.894          0.
   MAY      PEAK(MBTU)          1.766                   MAY       PEAK(MBTU)          1.766           0.
                 DY/HR          29/12                                  DY/HR          29/12           31/ 1

           TOTAL(MBTU)        421.707                            TOTAL(MBTU)        421.707          0.
   JUN      PEAK(MBTU)          2.009                   JUN       PEAK(MBTU)          2.009           0.
                 DY/HR          20/12                                  DY/HR          20/12           30/ 1

           TOTAL(MBTU)        427.232                            TOTAL(MBTU)        427.232          0.
   JUL      PEAK(MBTU)          1.855                   JUL       PEAK(MBTU)          1.855           0.
                 DY/HR           3/12                                  DY/HR           3/12           31/ 1

           TOTAL(MBTU)        470.101                            TOTAL(MBTU)        470.101          0.
   AUG      PEAK(MBTU)          1.883                   AUG       PEAK(MBTU)          1.883           0.
                 DY/HR          20/16                                  DY/HR          20/16           31/ 1

           TOTAL(MBTU)        384.022                            TOTAL(MBTU)        384.022          0.
   SEP      PEAK(MBTU)          1.916                   SEP       PEAK(MBTU)          1.916           0.
                 DY/HR          28/14                                  DY/HR          28/14           30/ 1

           TOTAL(MBTU)        431.084                            TOTAL(MBTU)        430.191           3.123
   OCT      PEAK(MBTU)          1.819                   OCT       PEAK(MBTU)          1.819            .410
                 DY/HR          19/14                                  DY/HR          19/14            9/ 8

           TOTAL(MBTU)        383.339                            TOTAL(MBTU)        374.762          16.637
   NOV      PEAK(MBTU)          2.211                   NOV       PEAK(MBTU)          1.694           1.790
                 DY/HR          26/ 8                                  DY/HR           7/16           26/ 8

           TOTAL(MBTU)        380.670                            TOTAL(MBTU)        368.729          22.222
   DEC      PEAK(MBTU)          2.022                   DEC       PEAK(MBTU)          1.713           1.587
                 DY/HR          24/ 8                                  DY/HR          10/14           24/ 8

              ONE YEAR       4901.672                               ONE YEAR       4844.360         109.985
              USE/PEAK          2.570                               USE/PEAK          2.009           2.092
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ELECTRIC BOILER
ELECTRIC CHILLER

ELECTRIC BOILER

ELECTRIC CHILLER

BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Los-Angeles

Size: 120'x120' Lighting: Artificial

Glass Type: Heat-mirror Glass Height: 4'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	529.0	11.0	1.08
	Tower	222.5	4.6	0.45
	Pumps	82.0	1.7	0.17
	Sub-total	833.5	17.4	1.70
HEATING	Boiler	50.3	1.1	0.10
	Pumps	1.5	0.0	0.00
	Sub-total	51.8	1.1	0.11
LIGHTS & EQUIPMENT		3661.1	76.3	7.45
FANS		250.7	5.2	0.51
TOTAL		4797.1	100	9.76

EQUIPMENT SIZES

	MBTU	TONS/1000SF	
BOILER			lost
CHILLER			

```
1 FAT BUILDING-NO DAYLIGHTING            THESIS STUDY                          DOE+2.1A   21 NOV 81   20.07.35   SDL RUN 1
  HEATMIRROR-4 FEET HIGH                 LOS ANGELES WEATHER DATA           SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
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        - - - - - - - - C O O L I N G - - - - - - - -      - - - - - - - - H E A T I N G - - - - - - - -     - - - E L E C - - -

                                               MAXIMUM                                              MAXIMUM      ELEC-     MAXIMUM
          COOLING    TIME    DRY-   WET-       COOLING      HEATING     TIME    DRY-   WET-         HEATING    TRICAL       ELEC
           ENERGY  OF MAX    BULB   BULB          LOAD       ENERGY   OF MAX    BULB   BULB            LOAD    ENERGY       LOAD
 MONTH     (MBTU)  DY  HR    TEMP   TEMP     (KBTU/HR)       (MBTU)   DY  HR    TEMP   TEMP       (KBTU/HR)     (KWH)       (KW)


 JAN     76.08652  12  16     65F    58F       980.285      -15.634    8   8     44F    41F       -1661.182    99496.      376.9

 FEB    108.54465  16  17     68F    57F      1290.846       -4.967    5   8     49F    48F       -1023.115    86320.      376.9

 MAR    119.10952  15  16     65F    55F      1205.662       -5.296   12   8     48F    46F       -1050.659    99496.      376.9

 APR    172.19373   4  16     78F    51F      1748.302       0.                                          0.    95200.      376.9

 MAY    205.17019  29  17     72F    65F      1764.488       0.                                          0.    99423.      376.9

 JUN    298.26075  21  12     86F    70F      2628.125       0.                                          0.    95128.      376.9

 JUL    316.92159  26  16     78F    68F      2214.158       0.                                          0.    95546.      376.9

 AUG    389.28734  21  15     77F    69F      2303.112       0.                                          0.   103518.      376.9

 SEP    268.32325  28  14     89F    66F      2490.505       0.                                          0.    87011.      376.9

 OCT    254.42251  19  14     87F    63F      2051.547        -.269    9   8     55F    53F        -206.407    99496.      376.9

 NOV    135.92401   7  16     69F    62F      1482.713       -6.208   26   8     48F    44F       -1365.614    91033.      376.9

 DEC     96.33895  10  14     82F    57F      1529.175       -8.594   24   8     46F    45F       -1120.945    91524.      376.9
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 TOTAL  2440.583                                            -40.967                                         1143191.

 MAX                                          2628.125                                            -1661.182                376.9
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1 FAT BUILDING-NO DAYLIGHTING             THESIS STUDY
  HEATMIRROR-4 FEET HIGH                  LOS ANGELES WEATHER DATA
 REPORT- PS-B  MONTHLY PEAK AND TOTAL ENERGY USE
---------------------------------------------------------------------------------------------------------------------------------

      MO       UTILITY-     ELECTRICITY                           MO       UTILITY-     ELECTRICITY      NATURAL-GAS

             TOTAL(MBTU)       408.399                                   TOTAL(MBTU)       390.430           32.313
     JAN      PEAK(MBTU)         2.559                           JAN      PEAK(MBTU)         1.562            2.090
                   DY/HR         8/ 9                                          DY/HR         12/16             8/ 8

             TOTAL(MBTU)       350.803                                   TOTAL(MBTU)       344.804           11.792
     FEB      PEAK(MBTU)         1.874                           FEB      PEAK(MBTU)         1.606            1.398
                   DY/HR         5/ 9                                          DY/HR         16/14             5/ 8

             TOTAL(MBTU)       403.108                                   TOTAL(MBTU)       396.410           13.878
     MAR      PEAK(MBTU)         1.868                           MAR      PEAK(MBTU)         1.602            1.429
                   DY/HR        12/ 8                                          DY/HR         15/12            12/ 8

             TOTAL(MBTU)       388.751                                   TOTAL(MBTU)       388.751           0.
     APR      PEAK(MBTU)         1.675                           APR      PEAK(MBTU)         1.675           0.
                   DY/HR         4/17                                          DY/HR          4/17           30/ 1

             TOTAL(MBTU)       410.214                                   TOTAL(MBTU)       410.214           0.
     MAY      PEAK(MBTU)         1.696                           MAY      PEAK(MBTU)         1.696           0.
                   DY/HR        29/12                                          DY/HR         29/12           31/ 1

             TOTAL(MBTU)       412.282                                   TOTAL(MBTU)       412.282           0.
     JUN      PEAK(MBTU)         1.953                           JUN      PEAK(MBTU)         1.953           0.
                   DY/HR        20/12                                          DY/HR         20/12           30/ 1

             TOTAL(MBTU)       417.628                                   TOTAL(MBTU)       417.628           0.
     JUL      PEAK(MBTU)         1.802                           JUL      PEAK(MBTU)         1.802           0.
                   DY/HR         3/12                                          DY/HR          3/12           31/ 1

             TOTAL(MBTU)       460.434                                   TOTAL(MBTU)       460.434           0.
     AUG      PEAK(MBTU)         1.836                           AUG      PEAK(MBTU)         1.836           0.
                   DY/HR        21/12                                          DY/HR         21/12           31/ 1

             TOTAL(MBTU)       375.845                                   TOTAL(MBTU)       375.845           0.
     SEP      PEAK(MBTU)         1.856                           SEP      PEAK(MBTU)         1.856           0.
                   DY/HR        28/14                                          DY/HR         28/14           30/ 1

             TOTAL(MBTU)       421.783                                   TOTAL(MBTU)       420.884            3.128
     OCT      PEAK(MBTU)         1.761                           OCT      PEAK(MBTU)         1.761             .441
                   DY/HR        19/14                                          DY/HR         19/14             9/ 8

             TOTAL(MBTU)       374.963                                   TOTAL(MBTU)       367.469           14.561
     NOV      PEAK(MBTU)         2.184                           NOV      PEAK(MBTU)         1.646            1.776
                   DY/HR        26/ 8                                          DY/HR          1/14            26/ 8

             TOTAL(MBTU)       372.856                                   TOTAL(MBTU)       362.574           19.667
     DEC      PEAK(MBTU)         1.937                           DEC      PEAK(MBTU)         1.648            1.507
                   DY/HR        24/ 8                                          DY/HR         10/14            24/ 8

                ONE YEAR      4797.065
                USE/PEAK         2.559                                      ONE YEAR      4747.725           95.340
                                                                            USE/PEAK         1.953            2.090
```

ELECTRIC BOILER
ELECTRIC CHILLER

GAS BOILER
ELECTRIC CHILLER

BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Los-Angeles

Size: 240'X60' Lighting: Daylit

Glass Type: Heat-mirror Glass Height: 5½'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	396.8	11.4	0.81
	Tower	188.1	5.4	0.38
	Pumps	69.1	2.0	0.14
	Sub-total	654.0	18.7	1.33
HEATING	Boiler	85.4	2.4	0.17
	Pumps	2.1	0.1	0.01
	Sub-total	87.5	2.5	0.18
LIGHTS & EQUIPMENT		2567.4	73.4	5.22
FANS		187.5	54	0.38
TOTAL		3496.3	100	7.11

EQUIPMENT SIZES

	MBTU	TONS/1000SF
BOILER	1.433	0.830
CHILLER	2.275	1.317

```
1 THIN BUILDING-DAYLIGHTING            THESIS STUDY                          DOE+2.1A   21 NOV 81   23.16.12   SDL RUN 1
  HEAT MIRROR GLASS-5.5 FEET HIGH      LOS ANGELES WEATHER DATA            SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
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        - - - - - - - - C O O L I N G - - - - - - - -    - - - - - - - - H E A T I N G - - - - - - - -     - - - E L E C - - -

                                              MAXIMUM                                            MAXIMUM      ELEC-    MAXIMUM
          COOLING    TIME   DRY-  WET-        COOLING    HEATING    TIME   DRY-  WET-            HEATING      TRICAL     ELEC
           ENERGY  OF MAX   BULB  BULB           LOAD     ENERGY  OF MAX   BULB  BULB               LOAD      ENERGY     LOAD
 MONTH     (MBTU)  DY  HR   TEMP  TEMP      (KBTU/HR)     (MBTU)  DY  HR   TEMP  TEMP          (KBTU/HR)       (KWH)     (KW)


 JAN     67.44403  12  16    65F   58F        928.148    -22.260  22   8    41F   39F        -1409.082      81828.    360.8

 FEB     70.61532  16  17    68F   57F       1127.285    -11.201   5   8    49F   48F        -1042.609      62533.    360.8

 MAR     69.82474   2  17    63F   59F        968.264    -15.835  12   8    48F   46F        -1163.366      68417.    360.8

 APR    101.54605   4  17    78F   50F       1515.528     0.                                        0.      65515.    360.8

 MAY    112.60656  29  17    72F   65F       1185.359     0.                                        0.      63902.    360.8

 JUN    195.74424  21  12    86F   70F       2026.120     0.                                        0.      60257.    285.2

 JUL    207.97407  26  16    78F   68F       1605.153     0.                                        0.      60659.    285.2

 AUG    282.56357  20  18    77F   69F       1864.602     0.                                        0.      69211.    328.4

 SEP    199.66778  28  14    89F   66F       2196.645     0.                                        0.      59155.    328.4

 OCT    194.28873  19  14    87F   63F       1771.331      -.322   9   8    55F   53F         -201.795      67234.    328.4

 NOV    116.24647   7  16    69F   62F       1522.328     -8.905  26   8    48F   44F        -1254.965      72991.    360.8

 DEC     78.82227  10  14    82F   57F       1528.710    -11.504  24   8    46F   45F        -1080.045      75440.    360.8
        ---------                          ----------  ---------                            ----------    --------  -------

 TOTAL   1697.344                                        -70.026                                         807142.

 MAX                                         2196.645                                        -1409.082               360.8
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1 THIN BUILDING-DAYLIGHTING           PEAK RUN   CLEAR                         DOE+2.1A   08 DEC 81   13.56.01   PDL RUN 1
  HEAT MIRROR GLASS-5.5 FEET HIGH     LOS ANGELES WEATHER DATA              PLANT - ALL ELECTRIC
 REPORT- PS-B  MONTHLY PEAK AND TOTAL ENERGY USE
----------------------------------------------------------------------------------------------------------------------------

          MO       UTILITY-     ELECTRICITY                       MO       UTILITY-     ELECTRICITY    NATURAL-GAS

                TOTAL(MBTU)        325.896                              TOTAL(MBTU)        294.050         56.006
         JAN     PEAK(MBTU)          2.198                        JAN     PEAK(MBTU)          1.492          1.792
                      DY/HR          22/ 8                                     DY/HR          12/16          22/ 8

                TOTAL(MBTU)        254.967                              TOTAL(MBTU)        240.808         25.786
         FEB     PEAK(MBTU)          1.827                        FEB     PEAK(MBTU)          1.528          1.403
                      DY/HR           5/ 8                                     DY/HR          16/17           5/ 8

                TOTAL(MBTU)        286.358                              TOTAL(MBTU)        268.059         34.645
         MAR     PEAK(MBTU)          1.703                        MAR     PEAK(MBTU)          1.508          1.561
                      DY/HR          12/ 8                                     DY/HR           2/17          12/ 8

                TOTAL(MBTU)        261.738                              TOTAL(MBTU)        261.738         0.
         APR     PEAK(MBTU)          1.588                        APR     PEAK(MBTU)          1.588          0.
                      DY/HR           4/17                                     DY/HR           4/17          30/ 1

                TOTAL(MBTU)        256.179                              TOTAL(MBTU)        256.179         0.
         MAY     PEAK(MBTU)          1.541                        MAY     PEAK(MBTU)          1.541          0.
                      DY/HR           3/17                                     DY/HR           3/17          31/ 1

                TOTAL(MBTU)        256.335                              TOTAL(MBTU)        256.335         0.
         JUN     PEAK(MBTU)          1.263                        JUN     PEAK(MBTU)          1.263          0.
                      DY/HR          20/17                                     DY/HR          20/17          30/ 1

                TOTAL(MBTU)        260.180                              TOTAL(MBTU)        260.180         0.
         JUL     PEAK(MBTU)          1.186                        JUL     PEAK(MBTU)          1.186          0.
                      DY/HR          26/17                                     DY/HR          26/17          31/ 1

                TOTAL(MBTU)        308.203                              TOTAL(MBTU)        308.203         0.
         AUG     PEAK(MBTU)          1.583                        AUG     PEAK(MBTU)          1.583          0.
                      DY/HR          20/18                                     DY/HR          20/18          31/ 1

                TOTAL(MBTU)        256.463                              TOTAL(MBTU)        256.463         0.
         SEP     PEAK(MBTU)          1.617                        SEP     PEAK(MBTU)          1.617          0.
                      DY/HR          27/18                                     DY/HR          27/18          30/ 1

                TOTAL(MBTU)        287.167                              TOTAL(MBTU)        286.210          3.153
         OCT     PEAK(MBTU)          1.481                        OCT     PEAK(MBTU)          1.481           .405
                      DY/HR          19/18                                     DY/HR          19/18           9/ 8

                TOTAL(MBTU)        284.973                              TOTAL(MBTU)        272.671         22.458
         NOV     PEAK(MBTU)          2.036                        NOV     PEAK(MBTU)          1.589          1.625
                      DY/HR          26/ 8                                     DY/HR           7/16          26/ 8

                TOTAL(MBTU)        289.879                              TOTAL(MBTU)        272.508         31.721
         DEC     PEAK(MBTU)          1.868                        DEC     PEAK(MBTU)          1.574          1.446
                      DY/HR          24/ 8                                     DY/HR          10/16          24/ 8

                   ONE YEAR       3328.339                                 ONE YEAR       3233.405        173.769
                   USE/PEAK          2.198                                 USE/PEAK          1.617          1.792
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ELECTRIC BOILER
ELECTRIC CHILLER

GAS BOILER
ELECTRIC CHILLER

BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Phoenix

Size: 120' x 120' Lighting: Artificial

Glass Type: Bronze Glass Height: 4'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	1167.4	20.0	2.38
	Tower	395.9	6.8	0.81
	Pumps	146.1	2.5	0.30
	Sub-total	1709.4	29.3	3.48
HEATING	Boiler	164.3	2.8	0.33
	Pumps	3.8	0.1	0.01
	Sub-total	168.2	2.9	0.34
LIGHTS & EQUIPMENT		3648.2	62.6	7.42
FANS		302.2	5.2	0.61
TOTAL		5828.0	100	11.86

EQUIPMENT SIZES

	MBTU	TONS/1000SF
BOILER	2.739	1.586
CHILLER	4.693	2.717

```
1 FAT BUILDING-NO DAYLIGHTING              THESIS STUDY                                DOE+2.1A   08 DEC 81   13.58.06    SDL RUN 1
  BRONZE GLASS-4 FEET HIGH                 PHOENIX WEATHER DATA                    SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
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       - - - - - - - - C O O L I N G - - - - - - - -      - - - - - - - - H E A T I N G - - - - - - - -     - - - E L E C - - -

                                             MAXIMUM                                           MAXIMUM       ELEC-     MAXIMUM
         COOLING     TIME    DRY-   WET-     COOLING       HEATING     TIME    DRY-   WET-     HEATING      TRICAL        ELEC
          ENERGY   OF MAX    BULB   BULB        LOAD        ENERGY   OF MAX    BULB   BULB        LOAD      ENERGY        LOAD
 MONTH    (MBTU)   DY  HR    TEMP   TEMP   (KBTU/HR)        (MBTU)   DY  HR    TEMP   TEMP   (KBTU/HR)       (KWH)        (KW)


 JAN   115.02019   25  17     84F    55F    1825.988       -51.565    4   9     33F    29F   -2718.354      92915.       383.3

 FEB   135.41965   10  17     87F    62F    2292.262       -21.783    1   8     36F    34F   -2496.468      87695.       383.3

 MAR   276.49958   24  17     88F    57F    2457.179       -10.015    1   8     40F    37F   -1608.550     105282.       383.3

 APR   406.78699   23  16     95F    63F    2872.309        0.                                 0.         100753.       383.3

 MAY   545.12262   28  17    105F    67F    3704.827        0.                                 0.          92915.       383.3

 JUN   739.75557   29  17    104F    76F    4182.450        0.                                 0.         100753.       383.3

 JUL   936.27556   23  15    101F    81F    4601.304        0.                                 0.          96916.       383.3

 AUG   901.12229   16  15    105F    76F    4304.716        0.                                 0.         101190.       383.3

 SEP   725.78495    7  12     91F    74F    4376.764        0.                                 0.          96570.       383.3

 OCT   440.40717    1  15     93F    73F    3394.565        -.063   27   8     43F    43F     -53.413      92824.       383.3

 NOV   192.74051    5  16     80F    60F    2059.348       -9.961   29   8     37F    36F   -1647.308      92661.       383.3

 DEC    91.34424    1  17     74F    59F    1742.001      -43.347   20   8     40F    35F   -2157.483      97007.       383.3
       ---------                           ----------    ---------                         ----------    ---------     -------

 TOTAL  5506.279                                          -136.733                                       1157482.

 MAX                                        4601.304                                       -2718.354                   383.3
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BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Phoenix

Size: 120'x120' Lighting: Artificial

Glass Type: heat-mirror Glass Height: 4'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	1054.4	18.7	2.15
	Tower	364.6	6.5	0.74
	Pumps	134.7	2.4	0.27
	Sub-total	1553.8	26.6	3.16
HEATING	Boiler	142.8	2.5	0.29
	Pumps	3.3	0.1	0.01
	Sub-total	146.1	2.6	0.30
LIGHTS & EQUIPMENT		3648.2	64.7	7.42
FANS		292.1	5.2	0.59
TOTAL		5640.2	100	11.48

EQUIPMENT SIZES

	MBTU	TONS/1000SF
BOILER	2.539	1.470
CHILLER	4.348	2.517

```
1 FAT BUILDING-NO DAYLIGHTING            THESIS STUDY                           DOE+2.1A   21 NOV 81   20.00.03   SDL RUN 1
  HEATMIRROR GLASS-4 FEET HIGH           PHOENIX WEATHER DATA                SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
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           - - - - - - - - C O O L I N G - - - - - - - -      - - - - - - - - H E A T I N G - - - - - - - -     - - - E L E C - - -

                                                 MAXIMUM                                              MAXIMUM       ELEC-    MAXIMUM
          COOLING    TIME   DRY-  WET-          COOLING     HEATING    TIME   DRY-  WET-             HEATING      TRICAL       ELEC
           ENERGY  OF MAX   BULB  BULB             LOAD      ENERGY  OF MAX   BULB  BULB                LOAD      ENERGY       LOAD
 MONTH     (MBTU)  DY  HR   TEMP  TEMP       (KBTU/HR)      (MBTU)  DY  HR   TEMP  TEMP           (KBTU/HR)       (KWH)       (KW)


 JAN     94.66583  26  16    78F   55F        1523.300     -46.352   4   9    33F   29F           -2522.364      92679.      382.2

 FEB    118.12256  10  17    87F   62F        2046.321     -18.925   1   8    36F   34F           -2289.536      87473.      382.2

 MAR    243.58836  24  17    88F   57F        2196.170      -8.655   1   8    40F   37F           -1596.586     105009.      382.2

 APR    360.60063  23  16    95F   63F        2555.438      0.                                     0.           100494.      382.2

 MAY    484.78857  26  12    97F   73F        3409.826      0.                                     0.            92679.      382.2

 JUN    665.41090  29  17   104F   76F        3820.715      0.                                     0.           100494.      382.2

 JUL    861.82441  23  15   101F   81F        4262.789      0.                                     0.            96671.      382.2

 AUG    832.18766  12  12    98F   80F        3997.362      0.                                     0.           100928.      382.2

 SEP    663.41275   7  12    91F   74F        3965.038      0.                                     0.            96326.      382.2

 OCT    394.41620   1  17    94F   73F        3135.290     -.013    18   7    56F   47F              -3.784      92591.      382.2

 NOV    163.90787   5  16    80F   60F        1788.857     -8.458   29   8    37F   36F           -1608.771      92422.      382.2

 DEC     74.68545   1  17    74F   59F        1491.133    -36.664   27   8    39F   37F           -2053.747      96759.      382.2
        ---------                            ----------  ---------                                ----------    --------    -------

 TOTAL   4957.611                                         -119.067                                            1154525.

 MAX                                          4262.789                                            -2522.364                 382.2
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BUILDING SUMMARY SHEET: DOE 2.1A

Building Location: Phoenix

Size: 240' x 60' Lighting: Daylit

Glass Type: heat-mirror Glass Height: 5½'

Comments:

ANNUAL ENERGY CONSUMPTION: All-electric bldg.

		MBTU	%	KWH/SFG
COOLING:	Chiller	910.4	20.9	1.85
	Tower	326.4	7.5	0.66
	Pumps	121.1	2.8	0.25
	Sub-total	1357.9	31.2	2.76
HEATING	Boiler	200.3	4.6	0.41
	Pumps	4.5	0.1	0.01
	Sub-total	204.8	4.7	0.42
LIGHTS & EQUIPMENT		2552.9	58.7	5.20
FANS		231.6	5.3	0.47
TOTAL		4347.2	100	8.85

EQUIPMENT SIZES

	MBTU	TONS/1000SF
BOILER	2.496	1.445
CHILLER	4.003	2.318

```
1 THIN BUILDING-DAYLIGHTING               THESIS STUDY                                 DOE+2.1A   21 NOV 81   23.00.15   SDL RUN 1
  HEAT MIRROR GLASS-5.5 FEET HIGH         PHOENIX WEATHER DATA                    SYSTEMS SIMULATION
 REPORT- SS-D  PLANT MONTHLY LOADS SUMMARY FOR   BUILDING-SYSTEMS
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        - - - - - - - - C O O L I N G - - - - - - - -      - - - - - - - - H E A T I N G - - - - - - - -      - - - E L E C - - -

                                             MAXIMUM                                            MAXIMUM         ELEC-    MAXIMUM
         COOLING     TIME   DRY-  WET-       COOLING        HEATING     TIME   DRY-  WET-       HEATING        TRICAL       ELEC
          ENERGY   OF MAX   BULB  BULB          LOAD         ENERGY   OF MAX   BULB  BULB          LOAD        ENERGY       LOAD
MONTH     (MBTU)   DY  HR   TEMP  TEMP     (KBTU/HR)         (MBTU)   DY  HR   TEMP  TEMP     (KBTU/HR)         (KWH)       (KW)


JAN     90.07872   25  17    84F   55F      1680.306        -56.248    4   9    33F   29F     -2554.937        76436.      365.3

FEB     86.50518   10  17    87F   62F      1946.018        -30.282    1   8    36F   34F     -2246.798        63522.      365.3

MAR    187.06201   24  17    88F   57F      2084.796        -18.928    1   8    40F   37F     -1578.663        72301.      365.3

APR    283.38848   23  17    95F   63F      2401.802          0.                                  0.           69223.      365.3

MAY    391.51375   28  18   107F   67F      2999.461          0.                                  0.           60281.      365.3

JUN    551.56802   29  17   104F   76F      3355.385          0.                                  0.           63774.      289.7

JUL    755.40780   19   5    78F   73F      3833.883          0.                                  0.           61635.      289.7

AUG    727.16006    2   5    86F   74F      3824.755          0.                                  0.           67680.      332.9

SEP    581.27190    7  12    91F   74F      3638.229          0.                                  0.           55362.      332.9

OCT    342.57954    1  18    94F   72F      2746.175          -.183   27   8    43F   43F      -117.674        63098.      332.9

NOV    147.04300    9  17    80F   57F      1848.387        -12.098   29   8    37F   36F     -1395.430        72843.      365.3

DEC     67.33234    1  17    74F   59F      1536.719        -50.091   20   8    40F   35F     -1950.337        79708.      365.3
       ---------                          ----------      ---------                           ---------      --------    -------

TOTAL   4210.911                                           -167.830                                           815863.

MAX                                         3833.883                                          -2554.937                    365.3
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1 THIN BUILDING-DAYLIGHTING              PEAK RUN   CLEAR
  HEAT MIRROR GLASS-5.5 FEET HIGH        PHOENIX WEATHER DATA
 REPORT- PS-B  MONTHLY PEAK AND TOTAL ENERGY USE
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          MO       UTILITY-     ELECTRICITY                              MO       UTILITY-     ELECTRICITY     NATURAL-GAS

                TOTAL(MBTU)        368.042                                     TOTAL(MBTU)        300.073         109.742
         JAN     PEAK(MBTU)          3.412                              JAN     PEAK(MBTU)          1.725           3.149
                      DY/HR           4/ 9                                           DY/HR          25/17            4/ 9

                TOTAL(MBTU)        304.105                                     TOTAL(MBTU)        267.058          66.508
         FEB     PEAK(MBTU)          3.124                              FEB     PEAK(MBTU)          1.777           2.846
                      DY/HR           1/ 8                                           DY/HR          10/17            1/ 8

                TOTAL(MBTU)        349.083                                     TOTAL(MBTU)        326.462          43.618
         MAR     PEAK(MBTU)          2.204                              MAR     PEAK(MBTU)          1.785           2.144
                      DY/HR           1/ 8                                           DY/HR          24/17            1/ 8

                TOTAL(MBTU)        330.858                                     TOTAL(MBTU)        330.858          0.
         APR     PEAK(MBTU)          1.856                              APR     PEAK(MBTU)          1.856          0.
                      DY/HR          23/17                                           DY/HR          23/17          30/ 1

                TOTAL(MBTU)        309.053                                     TOTAL(MBTU)        309.053          0.
         MAY     PEAK(MBTU)          1.870                              MAY     PEAK(MBTU)          1.870          0.
                      DY/HR           4/17                                           DY/HR           4/17          31/ 1

                TOTAL(MBTU)        350.481                                     TOTAL(MBTU)        350.481          0.
         JUN     PEAK(MBTU)          1.690                              JUN     PEAK(MBTU)          1.690          0.
                      DY/HR          29/17                                           DY/HR          29/17          30/ 1

                TOTAL(MBTU)        391.492                                     TOTAL(MBTU)        391.492          0.
         JUL     PEAK(MBTU)          1.762                              JUL     PEAK(MBTU)          1.762          0.
                      DY/HR          26/17                                           DY/HR          26/17          31/ 1

                TOTAL(MBTU)        411.940                                     TOTAL(MBTU)        411.940          0.
         AUG     PEAK(MBTU)          2.057                              AUG     PEAK(MBTU)          2.057          0.
                      DY/HR          16/18                                           DY/HR          16/18          31/ 1

                TOTAL(MBTU)        368.628                                     TOTAL(MBTU)        368.628          0.
         SEP     PEAK(MBTU)          2.066                              SEP     PEAK(MBTU)          2.066          0.
                      DY/HR           7/18                                           DY/HR           7/18          30/ 1

                TOTAL(MBTU)        316.404                                     TOTAL(MBTU)        315.777           2.194
         OCT     PEAK(MBTU)          1.861                              OCT     PEAK(MBTU)          1.861            .428
                      DY/HR           1/18                                           DY/HR           1/18          27/ 8

                TOTAL(MBTU)        320.429                                     TOTAL(MBTU)        302.641          36.837
         NOV     PEAK(MBTU)          2.267                              NOV     PEAK(MBTU)          1.749           1.916
                      DY/HR          26/ 8                                           DY/HR           9/17          26/ 8

                TOTAL(MBTU)        372.404                                     TOTAL(MBTU)        308.071         109.864
         DEC     PEAK(MBTU)          2.820                              DEC     PEAK(MBTU)          1.711           2.523
                      DY/HR          20/ 8                                           DY/HR           1/17          20/ 8

                   ONE YEAR       4192.918                                        ONE YEAR       3982.534         368.763
                   USE/PEAK          3.412                                        USE/PEAK          2.066           3.149
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ELECTRIC BOILER
ELECTRIC CHILLER

GAS BOILER
ELECTRIC CHILLER

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