LOW ENERGY COOLING IN MULTI-STOREY BUILDINGS FOR HOT, ARID CLIMATES

by

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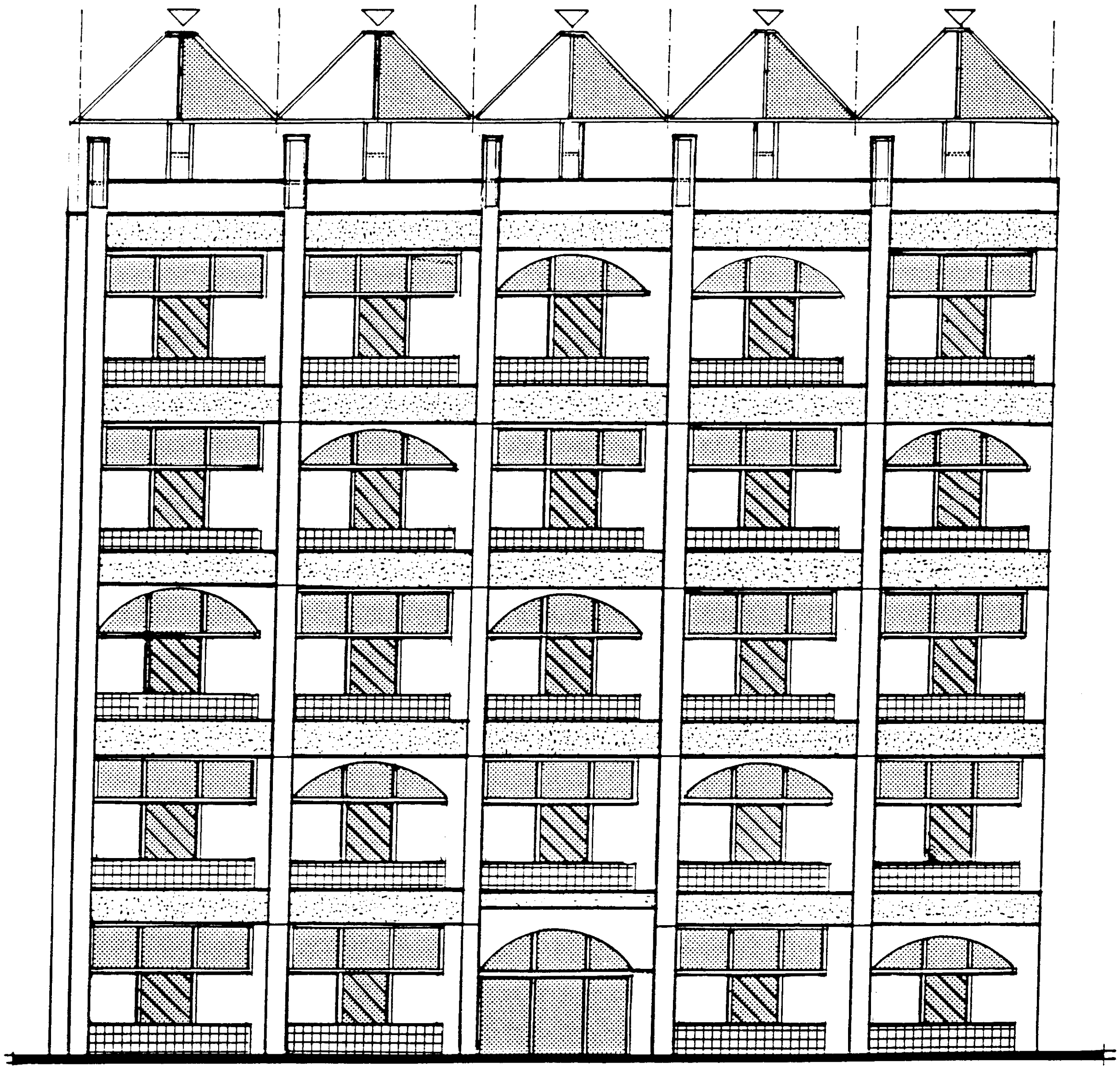

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ABSTRACT

This thesis discusses passive and low energy cooling strategies and systems in hot arid climates. The choice of a certain strategy, as well as determining the appropriate cooling schemes for such a context becomes of prime importance in developing the optimum energy conscious building design.

The motivation for working in this area of research stems for the need facing architects to start developing a serious sense for energy considerations in their architectural design, especially in existing and multi-storey buildings.

Here, in this research, the different factors that govern the control of heat gain through the envelope of the building will be analyzed. Also, solutions to minimize the cooling load for dwellings will be suggested/provided; by means of selecting the adequate cooling systems (evaporative, convective, and radiative) that promote the optimum desired thermal comfort.

This research concludes its technical analysis with an architectural design for two schemes; The first is a cooling system that can be applied to new buildings, or retrofitted to existing ones. It uses evaporative coolers and solar chimney systems at day-time. It also uses night-time forced ventilation to cool the ordinary slab. The second can be applied in new buildings. It uses evaporative coolers and solar chimney systems at day-time. It also uses night-time forced ventilation through cored slabs.

This design, and these schemes, are perceived as a starting point for further development and more research.

Thesis Advisor: **Prof. Timothy Johnson**
Title: **Principal Research Associate of Architecture**

To my love, best friend, husband, and father of my ***Mariam*** and ***Muhammad***... ***Yasser El-Quessny.***
The one who taught me to live and think *Art* and *Architecture*.
If it wasn't for his support, love, help, encouragement I would not have reached this state of accomplishment.

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CHAPTER.3. **APPLICATION OF COOLING SYSTEMS**

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PREFACE

For the last two decades, much research has been done in the area of energy conscious building design in various climatic contexts. Surprisingly, though, most of its application is directed towards either building new buildings, and hence, we don't rectify the mistakes done to the preceded models, or enhance and improve on low rise, existing and new.

In this research, technical information shall be crystallized into a comprehensive coherent building model. I chose to take my model in Cairo/Egypt, and apply it to an existing multi-story residential building.

Egypt has a variegated climate, however, the prevailing zone in which most of the urban fringe falls is in the hot-arid zone. It also has a housing problem. This problem could be expressed not only in terms of *units* shortage, but also in terms of quality of the existing units and how they respond to the universal energy concerns, and by expansion, the problem of designers' tendency to ignore energy concerns.

This thesis addresses the question of energy conscious building designs in a multi-disciplinary fashion. It discusses passive and low energy cooling strategies and systems in context of other pilot projects that have been done elsewhere. The problems and opportunities that arise in each aspect of cooling and comfort problem in the building design and the operational processes are also examined. The reader of this thesis will be able to understand means of providing thermal comfort other than strict temperature control; means to reduce heat gain to the building in order to reduce cooling system loads; means of using ventilation and air movement as a substitute for, and/or a supplement to, selected cooling systems. The choice of a certain strategy, as well as determining the appropriate cooling system for a given context becomes of prime importance as it is explained in chapters two and three.

This thesis takes an unorthodox approach to conclude the research work. It could have recommended some strategies for application, or state some design guide lines for future research and applications; Instead, it tries to put the research hypothesis to the direct ultimate test by designing a building. I chose to test my ideas for an urban common, middle-class, multi-storey residential building in the hot arid climatic context of Cairo / Egypt.

Nevertheless, I cannot claim that my hypothesis is correct, but certainly hope that such synthesis of ideas and design thinking efforts could pave the way to further development and enhancement to the chosen model and similar encountered models in any given context.

This thesis is comprised of:
Chapter-1 reviews some of the recent architectural and technical examples that helped pave the way for perceiving energy conscious designs. In each of the illustrated examples, I shall be discussing the design's major technical strategies chosen for it, together with the implementation's pros.

Chapter-2 explores the various strategies for supplementing passive and low energy systems, using two-stage evaporative coolers, natural ventilation (achieved by the stack-effect and the solar chimney), and the cooling effect of night ventilation of the thermal mass (we use this mass to radiate its coolth to the interior of the dwelling). Also the mechanisms for heat gain and comfort determination are reviewed in order to arrive to an optimum solution/strategy. This theory is applied analytically in chapter.3 to generate the recommended schemes.

In Chapter-3, application of cooling systems is discussed in context of a multi-storey residential building in Cairo/Egypt. Schemes for cooling systems are also discussed in terms of: Peak heat gain per hour in the building (which is reduced by 45% after redesigning some elements of the building's envelope), and application of four different cooling schemes (each combines different cooling systems, to the selected multi-storey model).
Two optimum schemes are then chosen for architectural considerations and their architectural elements are sized so that they will be active parts of a comprehensive cooling scheme (ex: evaporative cooling tower and solar-atrium chimney).

Chapter-4 concludes the analysis, ideas, strategies and schemes. Two comprehensive architectural solution are presented; serving as an introduction for other research work and design efforts.

CHAPTER ONE

EXAMPLES OF PASSIVE AND LOW ENERGY SOLAR DESIGN

A

HISTORICAL RESPONSES TO COOLING NEEDS

Throughout history, climatic and energy requirements have been fundamental to the art and craft of Architecture. Climatic design dates back to very early historical times. It was used by the ancient Egyptians in the houses of Tal -Al Amarna and is presented in wall paintings of the Thebes' tombs [Fathy '86]. One example is the pharaonic house of Neb-Amun painted on his tomb, and dates back to the nineteenth dynasty (1300 B.C). It has two openings; one facing windward and the other leeward, in order to evacuate the air [fig.1].

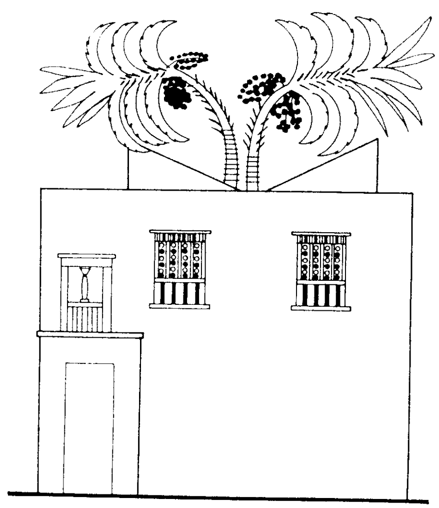

Fig.1. Wind Tower of the Pharaonic House of Neb-Amun from a painting on his tomb, Nineteenth Dynasty (1300 B.C)

Traditional and vernacular buildings, at their best, are direct expressions of adaptations to the climate. The human shelter, prior to the Industrial Revolution, has always reflected a rational understanding of the sun's solar power, generosity, as well as cruelty. It has also been perceived as an art when it comes to the building design and orientation.

Centuries ago, primitive people learned, by trial and error, the influence of solar energy on the design of their dwellings. In hot arid regions, for example, the characteristic problem is high day time temperatures, as well as fairly low temperatures during night times. There are numerous architectural examples that used natural forces in these regions (hot arid) that can be found in Egypt, Turkey, Iran, Iraq. Shown in fig.2 is the house of Muhibb Al-Din Muwaggi in Cairo /Egypt [Steele '88].

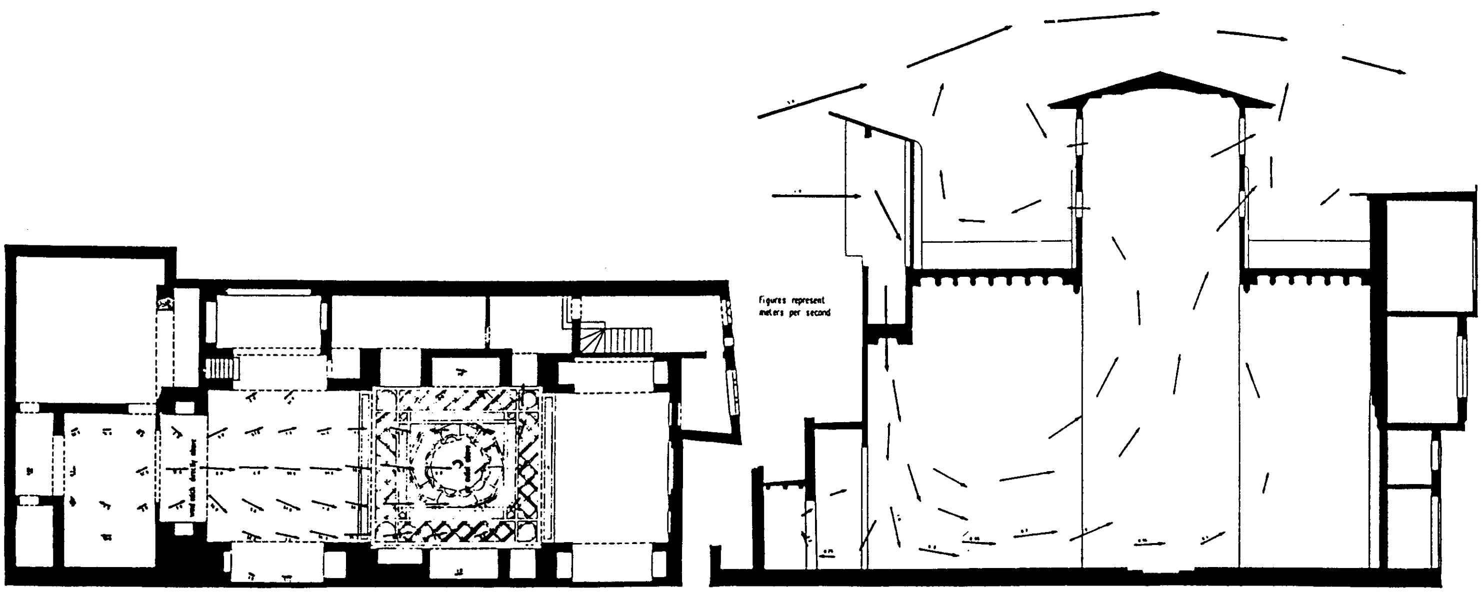

Fig.2. House of Muhibb Al-Din Muwaggi Air Movement Study

Residential buildings in these hot arid regions are literally labeled as being "The Traditional Courtyard House", simply because of the use of the "courtyard" as an element for solving climatic problems, and also the courtyard's recognized aesthetical values.

In this type of houses, many ways of using solar radiation and climatological considerations for cooling are applied in these types of houses. The courtyard house has an introverted plan to a courtyard, where this courtyard acts like a reservoir for cool night air.

At night, the cool air flows into the courtyard to replace the warm/hot day-time air. Accordingly, the air inside the courtyard is kept cool by the shade of the walls surrounding it. Wind towers were developed basically to operate using the evaporative process to cool the air effectively before it enters the house. Cool air from the wind tower and the courtyard is drawn inside the house by *suction forces* * [Fathy '86].

Nowadays, modern buildings in any part of the world show a striking uniformity. They are the product of modern mans' energy consuming civilization that substituted the convenience of machines for a design that helps create comfort with minimum use of energy and maximum use of the natural forces (wind and sun).

In the seventies, people became aware that energy was a problem. Shortages of natural gas turned up, in some parts of the United States, to be very serious. Shaky supplies of oil from overseas lead architects, engineers, manufacturers, and building owners to react to this growing problem by trying to find other substitutes for energy, and by reducing energy consumption in buildings as well. Several attempts to reduce energy for cooling and heating were applied to public and residential buildings. The following section illustrates some examples of such buildings that have already applied different aspects of "energy conscious building design".

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* *This technique of using suction forces causes low air pressure in order to generate steady air movement indoors (explained in chapter 2).*

B

PASSIVE AND LOW ENERGY COOLING (RECENT SOLUTIONS)

Storage of Heat and Coolth

B.1. Bateson Building

The Bateson building is a four-story office building in Sacramento California [Brown '85]. This building was designed by Peter Calthorpe during the time when Sim Van der Ryn (Berkeley professor of Architecture, known for his work in solar energy), was appointed by the governor to work with the office staff on this pilot project. Sim Van der Ryn assembled an "Energy Ethic Team" that comprised the staff team of the California State Architect's office together with the architect. They developed a variety of approaches and solutions for the building's envelope and equipment which made this building quite a distinguished one.

In this example ***mechanical ventilation*** was used to insure adequate night time air movement over the interior mass, and thereby improve the building's cooling potential. Scheme for night ventilation of the thermal mass is designed to absorb heat during the day into the mass of the building and give up this heat to the cool ventilating air during the night. Because the rate of air movement is frequently low at night, its flow is often poorly distributed and the amount of thermal mass area is limited, the cooling potentials in this passive systems were limited. Therefore by using fans, the amount of heat removed during the night was increased significantly.

Mechanical night ventilation of the thermal mass in this building is an important cooling strategy. The cooling effect of this night ventilation satisfies about 65% of the building's cooling load [Brown '89]. The building uses extensive shading devices and its offices are lit by natural day light admitted by an interior atrium [figs. 3&4].

Summer Day Operation

Summer Night Operation

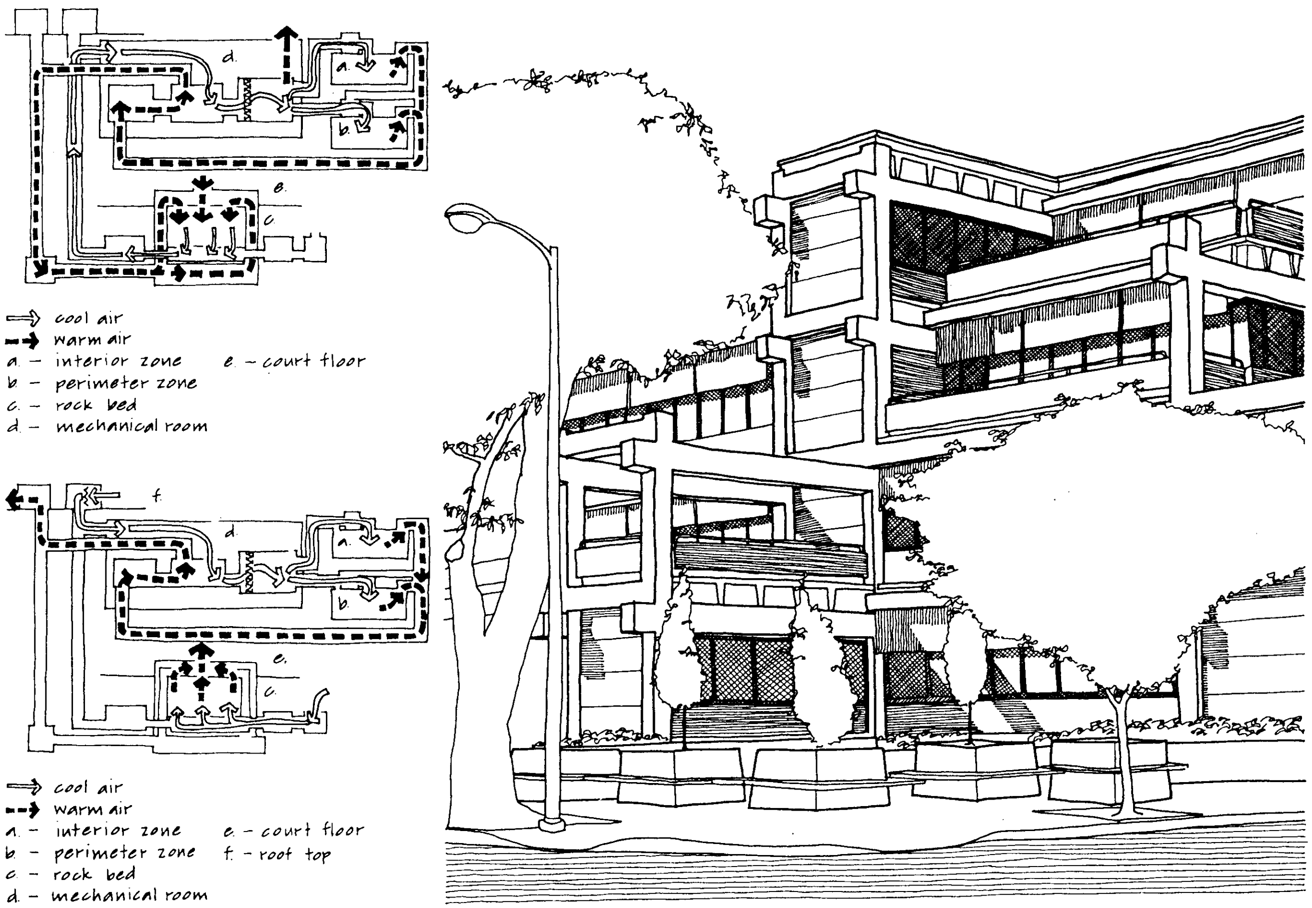


Fig.3a. The Bateson Building (Sacramento, California Office of the State Architect)

Fig.3b. The Bateson Building: Central Atrium

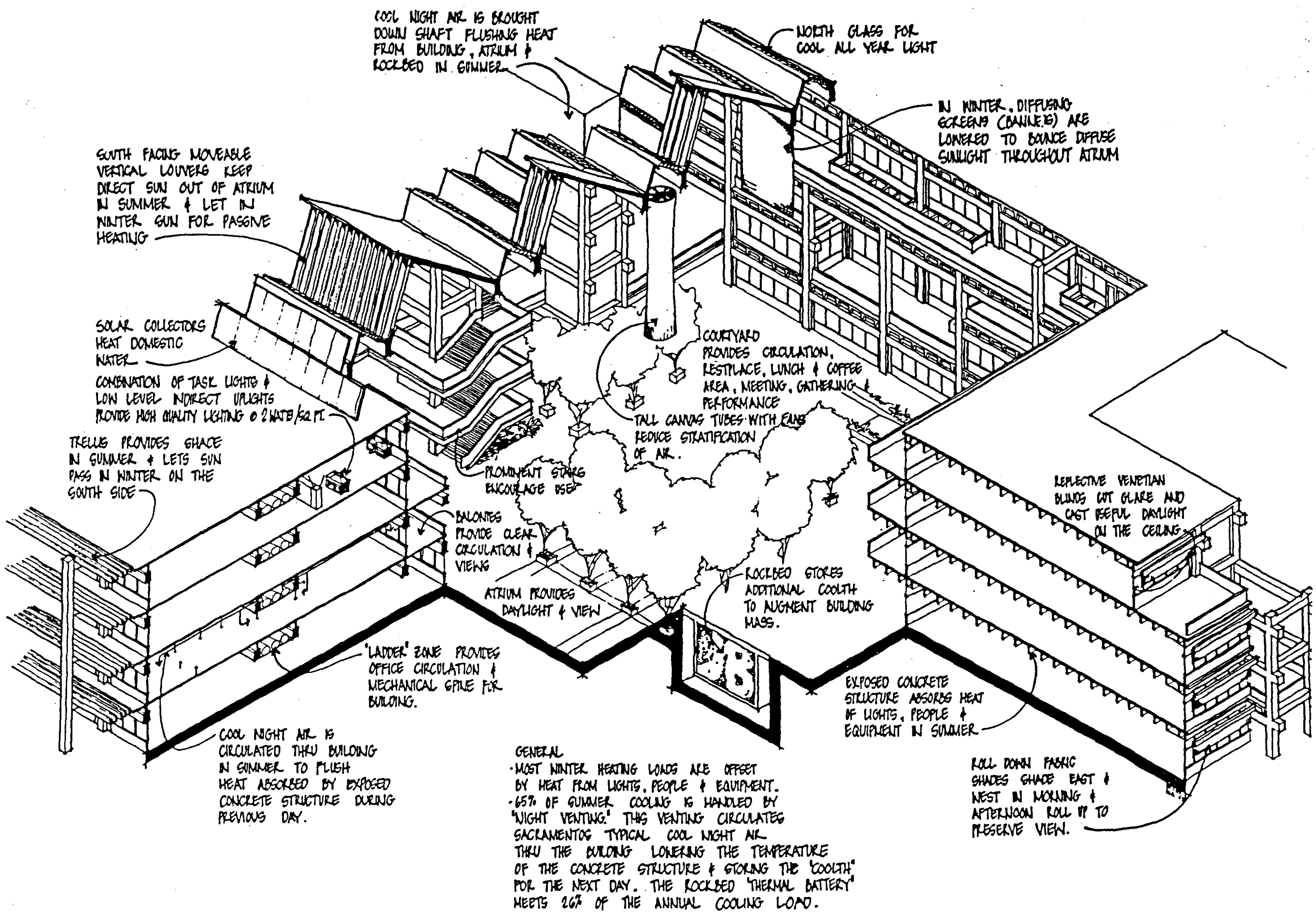


Fig.4. The Bateson Building Heating and Cooling Devices:
Solar Collectors for Heating Water, Rock Bed, and Building Mass to Store Coolth

The night ventilating system works by pulling cold outside air down the ventilation shaft at night, and distributing it to each space by HVAC systems. It then picks up heat from the structure and is exhausted to the outside. The major mass area in this building is the ceiling, where the pre-cast concrete double-T's are left exposed.

The thermal mass of the building is supplemented with a rock-bed storage system. Rock beds increase the thermal storage beyond what is available in the building structure. This implies enlarging the thermal mass of the building, and accordingly, increasing its ability to store energy [McGuiness & Stein '86].

In the heating system, air is drawn by fans and ducts though a bed of rocks. Heat is then given off to the rocks, and the air is recirculated to a location in the hot space to collect more heat. At night, when heat is needed, air is drawn from the occupied space through the rock-bed, where it picks up heat and is distributed back to the occupied space. The fans are required to charge and discharge the rock-bed frequently as part of the conventional HVAC system.

The size of the rock bed is a function of the input air temperature, heat storage requirements, rock sizes, and the air flow rate [Jones '84]. Rock beds for cooling are similar to those for heating, except that the source of cool air is frequently outside the building.

In climates that experience a large durinal temperature swing, cool outside air could be drawn through the bed at night. In hot arid climates, the rocks may be cooled by evaporation.

3.2. Princeton Professional Park

In Princeton N.J. [Brown '85], Harrison Fraker designed an under-floor rock bed for the purpose of storing both heat and coolth. During winter days, hot air is drawn from the top of the solar heated atrium into an underfloor rock bed, where the air gives off its heat to the rocks and is returned back to the atrium to be re-heated. At night, heat is transferred from the rock bed to the space in two modes [fig.5]:

Heating

Cooling

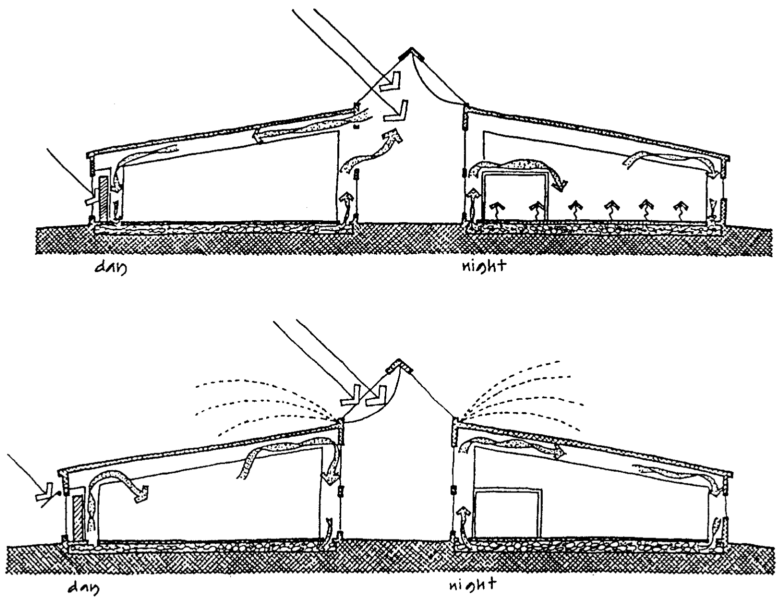


Fig.5. Princeton Professional Park

Heating the floor slab directly by conduction and warming the air by an active forced air system: (1) In summer, at night, the roof is cooled by radiation to the night sky and by metal evaporation of the water spray. Air from the rock bed is blown under the metal roof, loading its heat to the roof, then the air is recirculated through the roof, and it goes through further recirculation through the rock bed cooling the rocks. (2) During the day, air from the space circulates through the rock-bed to cool it.

B.3. Office Block in the Egyptian Sahara

This block is designed by O.A. Barra & L. Franceschi [Brown '85]. The designing architects applied what is known to be the ***Barra thermosyphon*** Air System. It is a low energy and passive solar system suitable for single and multi-storey residential, agricultural, and industrial buildings. It was conceived, modelled, and set up in the 1970s as an evolution of the Tromb-wall. As such, it was supposed to overcome most of its limits. The Barra system was installed in over 100 houses throughout the world. Its application included an office building in Egypt.

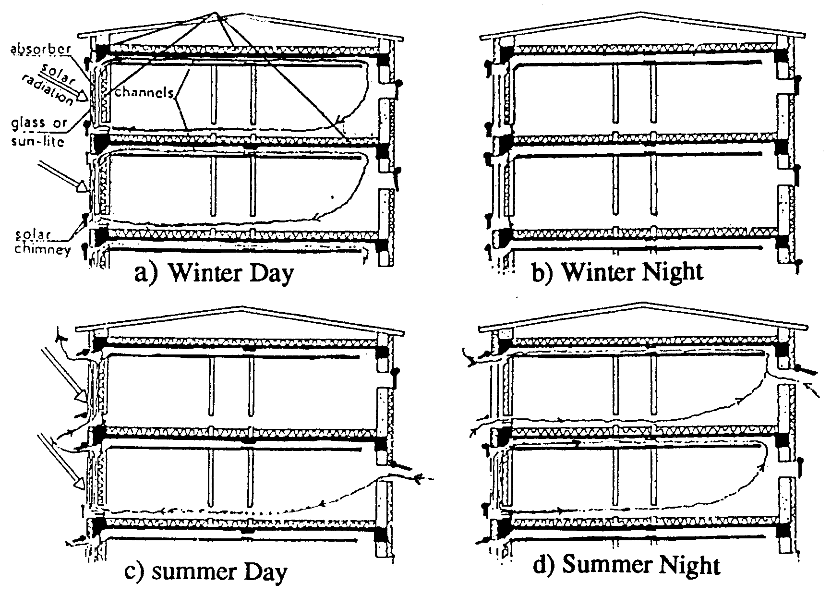


Fig.6. Office Block in the Egyptian Sahara

In Egypt, the main elements of the designated system are: the thermal mass storage for heat and coolth, air ducts (embedded in the ceiling), and insulated solar chimney on the south facade.

The system uses the forced night ventilation to cool the cored concrete ceiling slab*. The cooled mass of the slab provides a heat sink for the following day's cooling requirement (coolth reservoir). This system reduces the consumption of air conditioning systems and lowers the cooling load demand. Besides, lower radiant temperature of the ceiling improves the thermal comfort conditions in the dwellings.

From experimenting on this building, and other similar ones, it was concluded that with the use of propers dampers, the system can achieve a high overall efficiency in any climatic conditions. Cool air distribution through the ceiling is possible with no architectural limits.

---

* *This system is very useful in climates with large durinal swings of air temperatures.*

CHAPTER TWO

STRATEGIES FOR SUPPLEMENTING PASSIVE/LOW ENERGY

A

HEAT GAIN IN BUILDINGS

Inside a building, energy is consumed for various functions to augment comfort and increase utility. Energy is used for heating, cooling, lighting, providing power for equipment as well as heating for domestic hot water. The classification by use is readily understood and useful for comparison purposes. However, there is also a somewhat different classification that is equally useful in managing energy flows within buildings.This classification labels energy consumed as **loads*** [Dubin '78]. Building loads are energy requirements for the environmental control of temperature, humidity, and ventilation, as well as for the building's lighting energy inside the building envelope. The term **building load** is used to specify energy (in Btu or Kilo-watt hour/kwh) that is required to maintain desired indoor space conditions and to operate building equipment.

A.1. Heat Gain from the Building Envelope

The building envelope consists of walls, windows, doors, roofs, and floor surfaces. It is always subjected to varying influences of climate on each of its orientations. The qualities of the building envelope directly influence the heating and cooling peaks as well as the average requirements of the cooling loads.

**This classification is the framework on which the feasibility study of different cooling systems will follow later (in this chapter & the appendix).*

The thermal properties of the envelope are determined by the combination of wall mass, thermal resistance, exterior surface color and texture, and also the type and location of glazing. The effect of each property depends upon the mode of operation of the heating and cooling systems. The building wall must retard heat flow in and out (ex: Massive Walls). On exterior surfaces, however, light colors decrease solar heat gain, whereas dark colors increase solar heat gain. Also, wall textures or vines can shade and maintain a still-air film on building surfaces to reduce heat loss and heat gain.

Windows have a major effect on buildings' cooling and heating loads. These loads are generally affected by the solar radiation transmission through the glass, solar heat gain by conduction, and the window's air infiltration. Heat transmission is much greater through glass than through most opaque walls. However, the overall coefficient of heat transmission *(U values)* for walls can be reduced to 0.04 or less, where single glass has a U value of about 1.15, double glass of 0.55 to 0.69, and triple glass of 0.35 to 0.47.

A.1.1. Windows

Perhaps of all the building envelope's elements, windows are perceived to be the main element that governs the envelope's configuration. They are frequently provided in *gross* excess of any requirement for natural light, ventilation, or view. Large glass areas can cause discomfort for persons who must sit in front of them, because of the sun's heat and radiation. On the other hand, the elimination of all windows could exclude natural light and vision, and could also create somewhat incompletely understood psychological problems, even though windowless buildings would reduce the problem of solar heat gain in summer, air infiltration, and heat loss. The percentage of window to opaque wall can be reduced if the window shape, placement in the wall, type of glazing, and use of shading devices are designed with an awareness of their combined impact on energy consumption and user needs. The shape of window (the tilting angle of the glass, and the window's orientation) can be important, even where the window's area remains constant, due to the effect of its shape on the amount of solar radiation transmitted through the glass.

A.1.2. Solar Control and Shading Devices for Windows

The use of shading devices to reduce heat gain in the summer is most effective when located on the exterior of the building, and is particularly effective when the shading device can be moved to respond to the changing sun elevations. Fixed solar fins and overhangs eliminate direct solar penetration in the summer time. Nevertheless, they also block out some of the solar rays in the late spring and early fall, when rays could be useful for heating. Solar control is most effective when designed specifically for each facade, since time and duration of solar radiation vary with the sun's altitude and azimuth.

A.2. Heat Gain from Ventilation and Infiltration Loads

Operable windows permit the use of natural ventilation, but unless they are properly equipped with weather stripping and tight locking devices, these same windows may increase infiltration loads. Ventilation is delightful when outdoor conditions are such that the air is clean enough, pure enough, and dry enough to be enjoyed. However, natural ventilation cannot penetrate deeply into a building that is not cross ventilated [Dubin '78]. Building plans should respond in such a way so as to allow adequate ventilation needed. The number of hours in a year in which natural ventilation can be effectively used must be analyzed to reduce the possible increased infiltration, heat loss, and heat gain, when natural ventilation is not useful.

A.3. Heat Gain from Electric Lighting (and its contribution to the building's heating and cooling loads requirements)

Electric Lighting contributes heat to occupied spaces as an inevitable by-product of its function (illumination). And unless special heat removal techniques are used, all of the electric power fed into the lights, eventually, generates heat in the occupied space.

The amount of heat generated from lights is a function of the illumination level and the efficiency of the light source. Day light can substitute for artificial lighting when windows and rooms are properly proportioned and finished.

A.4. Internal Heat Gain from Building Occupants (and their Contribution to the building's heating and cooling loads requirements)

The metabolic energy of people can contribute substantially to the amount of heat generated in the building. This heat may increase the cooling requirement in a hot climate or in a building that has a cooling load due to other internal sources of heat gain. It may also decrease the heating requirements of a building in a cool climate.

The total sensible heat gain from people in Btu*, is found by multiplying the average number of occupants in the building by the rate of heat gain per person.

The amount of heat and moisture generated by people is a function of age, sex, activity, etc. Most passive cooling systems cannot remove water vapor from the air; therefore, only the sensible heat gains (which raise the air temperature) are considered in determining the internal heat gains from occupants. However, conventional mechanical refrigeration systems that remove moisture from the air in the cooling process, require additional energy to condense the water vapor and to prevent an uncomfortable increase in humidity in the lower temperatures. This additional load on the cooling system is called **latent heat, and should be added to the sensible heat gain to determine the total gain for systems that remove water vapor in addition to cooling the air.*

B

THERMAL COMFORT FOR PEOPLE INSIDE THEIR DWELLINGS

The Bioclimatic chart [fig.7] shows the relationship of the four major climatic variables that determine human comfort. By plotting temperature and relative humidity values, we can determine whether the resulting conditions are comfortable or not, and accordingly, proceed for a design strategy [Brown '78].

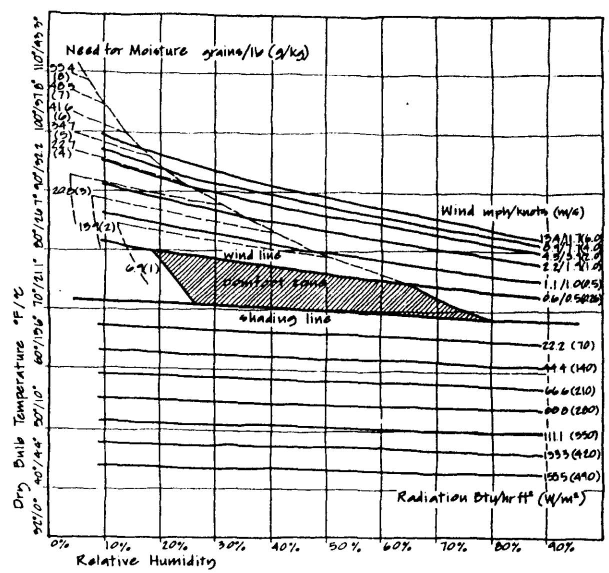


Fig.7a. Bioclimatic Chart
Showing Relation Between Relative Humidity, Dry Bulb Temperature

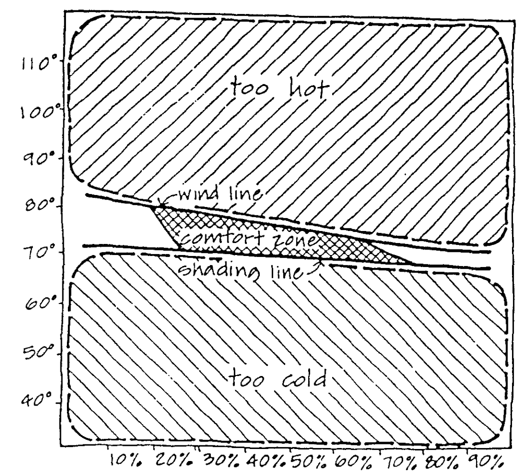


Fig.7b. Bioclimatic Chart
Showing Comfort Zone and Shading Line and Wind Line

PASSIVE / LOW ENERGY SOLAR STRATEGIES

Low energy and/or passive solar strategies for attaining *Thermal Comfort* can be determined by the Bioclimatic Chart: The Bioclimatic chart is subdivided into zones that define heating and cooling strategies. The zones crossed by the lines plotted indicate the strategies that may be appropriate for a particular climate [fig.8].

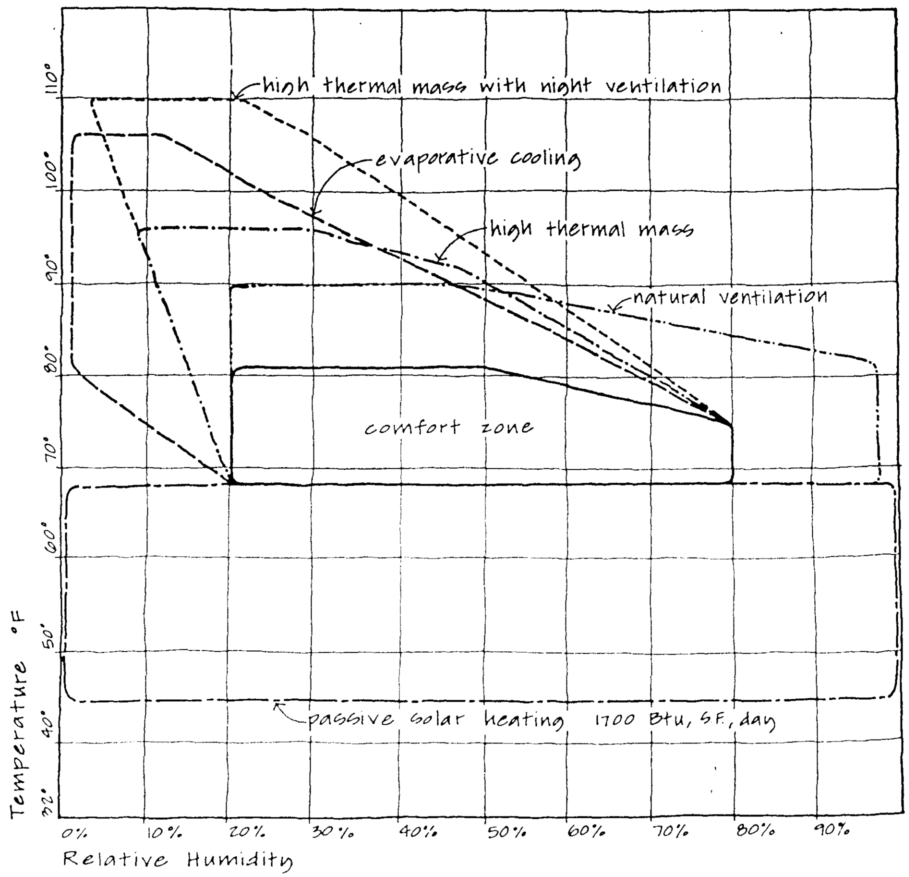


Fig.8. Bioclimatic chart with Design Strategies.

In most climates, there is a seasonal change from one strategy to another. Furthermore, some months may have several different strategies, but in most cases the designer should select a few strategies that are compatible with each other and with other design issues, and that is for economical reasons.

Passive solar heating is usually an appropriate strategy for months when the plotted lines fall below the comfort zone. The passive solar heating zone is based on clear day radiation values and certain assumptions about glazing areas and insulation levels. The zone may be extended to lower temperatures, depending on the building design, radiation levels, and the desired percentage of the annual heating load to be supplied by solar energy.

There are four cooling strategies represented by four, somewhat, overlapping zones above the comfort zone. These are: *Natural ventilation*, which depends solely on air movement to cool occupants; *Large thermal mass*, which depends on the building's materials to store heat during the night and re-radiate it at day; *Large thermal mass (combined with night ventilation)*, which relies on mass-heat storage during the day and ventilation at night to cool the mass; *Evaporative cooling,* which lowers the indoor air temperature by evaporating water in the space.

All of these strategies fall into one of three general categories: ***open, closed, and open/closed.*** The ***open*** building mode, means that the building's windows are open to the outside space. The effectiveness of cooling when using this mode depends on the size of the window and the outside air temperature, in addition to wind speed and direction. The ***closed*** building depends on its isolation from the exterior temperature environment. The ***open/closed*** building operates in different modes at different times of the day.

As an example, when plotting the climatic conditions of Alexandria/Egypt on the Bio-climatic chart [fig.9], the temperature-humidity combination falls above the shading line. These conditions can be made comfortable by natural ventilation.

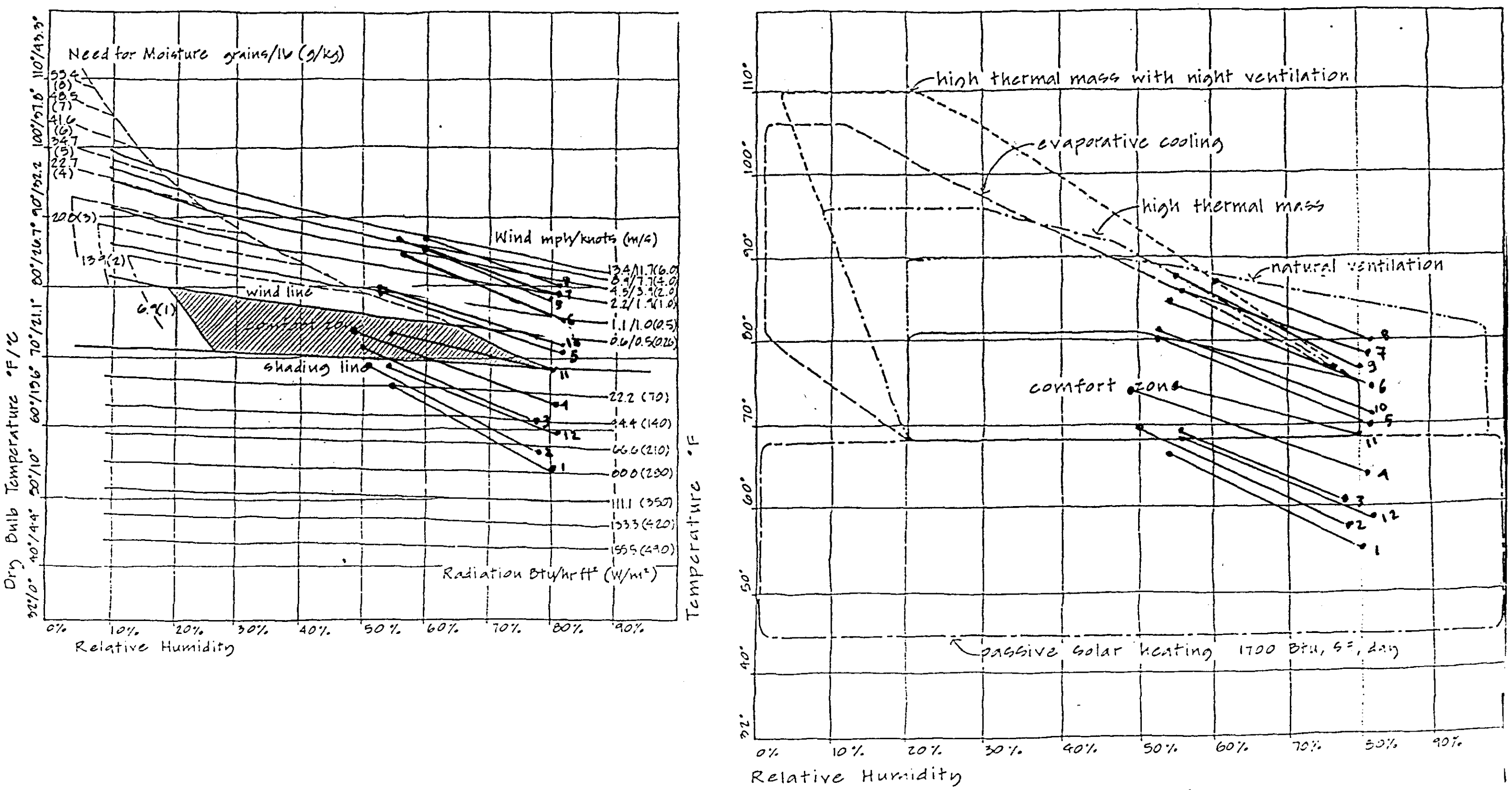


Fig.9. Plotting Monthly Maximum and Minimum Dry Bulb Temperature and the Relative Humidity of Alexandria /Egypt

C

COOLING STRATEGIES

C.1. EVAPORATIVE COOLING

Evaporative cooling equipment [Abrams '86] may use either a direct or indirect cooling process. Evaporative coolers may also be either single-stage or multi-stage. Multi-stage evaporative systems use two evaporation processes, whereas the first system supplies pre-cooled air to the second.

C.1.1. Direct Evaporative Coolers

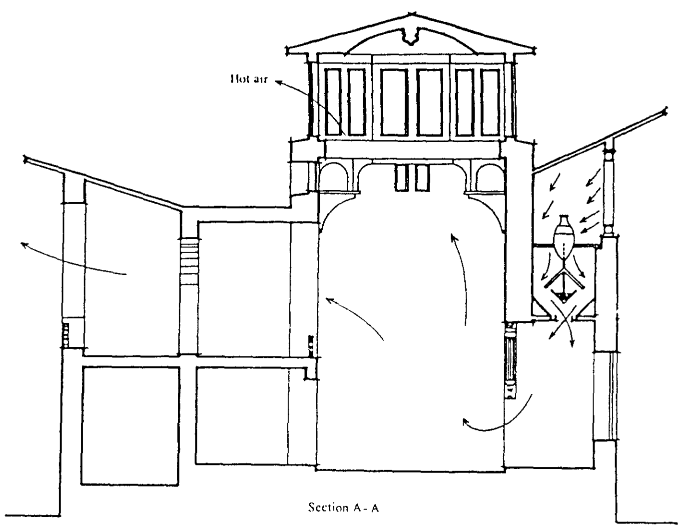
Evaporative cooling was probably one of the first mechanical cooling measures used by man. Egyptian paintings from 2500 B.C. show slaves fanning porous clay jars to provide a cooling effect. Both the American Indians of the southwest and the ancient Persians cooled their tents with damp felt or grass mats. Leonardo da Vinci built a water-power evaporative cooler for the bedroom of his patron's wife.

The classic example of evaporative cooling used in elementary school science books is the cooling effect felt when a moistened hand is waved in the air. The evaporative process simply removes sensible heat (that cools your skin) and replaces it with latent heat (that increases the moisture content in the air).

Evaporation is described as an *adiabatic process*, meaning that the total amount of heat in the thermal system remains constant (i.e. dry-bulb temperature falls, but moisture content rises). The limit of temperature reduction by an evaporative cooler is the air's wet-bulb temperature at the beginning of the evaporation process. Direct evaporation cannot cool below the wet-bulb temperature. The process stops when the relative humidity reaches 100%.

A simple measure of the potential for evaporative cooling at any given air condition is the wet-bulb depression, or the difference between the dry-bulb temperature and the wet-bulb temperature. It provides an upper limit for the temperature change that can be achieved by direct evaporation. And because evaporation makes use of the phase change of water from liquid to vapor, it can be a powerful cooling source. But as in all thermal processes, the amount of heat that can be transferred is only one part of the cooling problem. Temperature is the other.
In most climates, evaporative cooling cannot provide cooling at temperatures low enough to be useful in general building cooling applications. Even so, in almost all climates there are specialized cases where it can be effective.

Direct Evaporative Coolers are familiar devices in hot arid climates [fig.10 a&b]. They could also be termed as "desert coolers" and "swamp coolers".



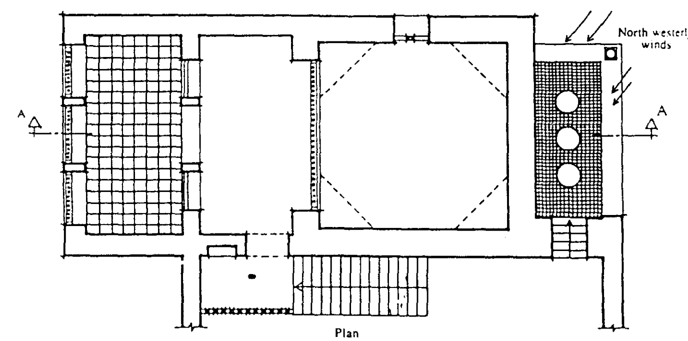


Fig.10a. Evaporative Cooling Tower with Wetted Baffles
Design by Hassan Fathy

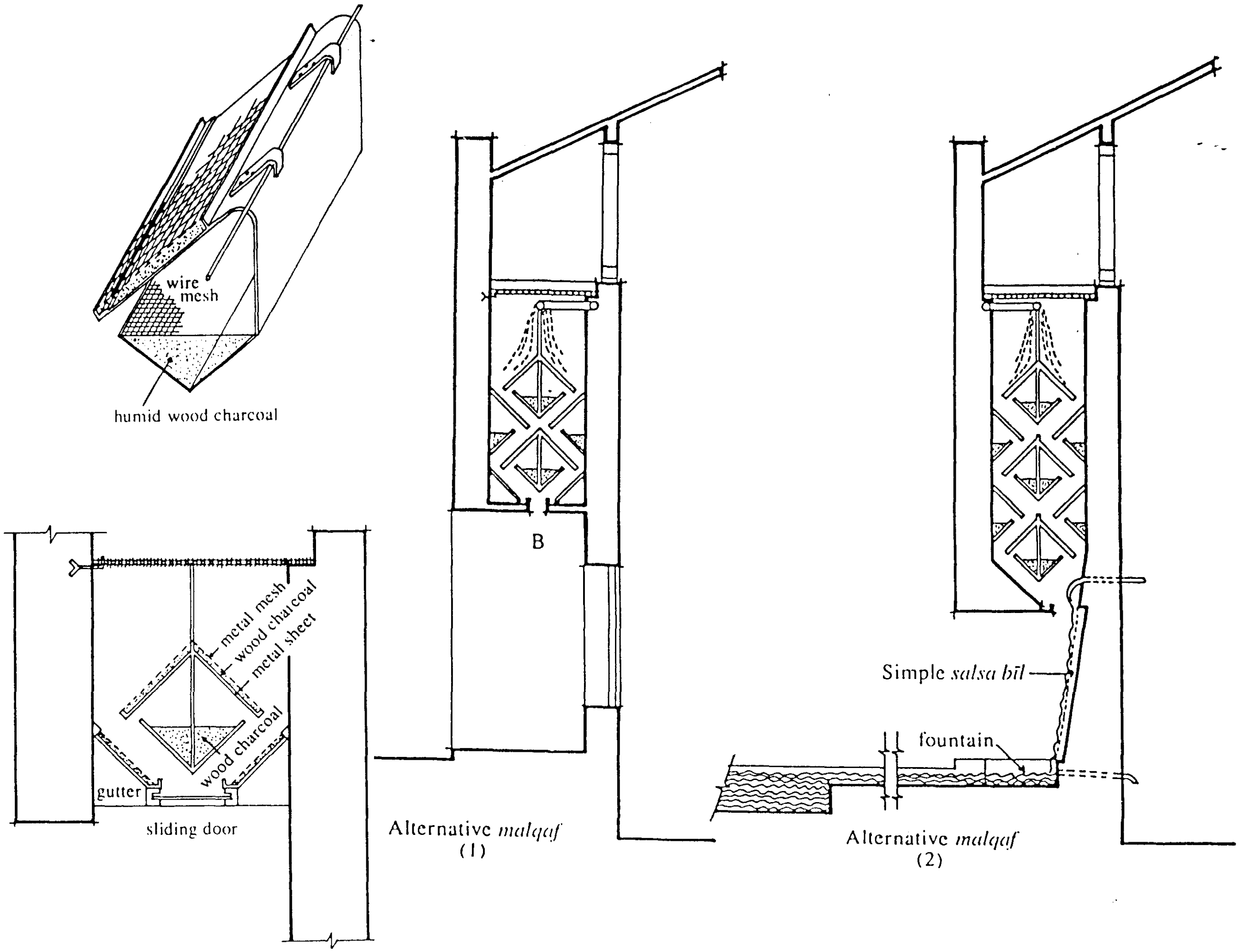
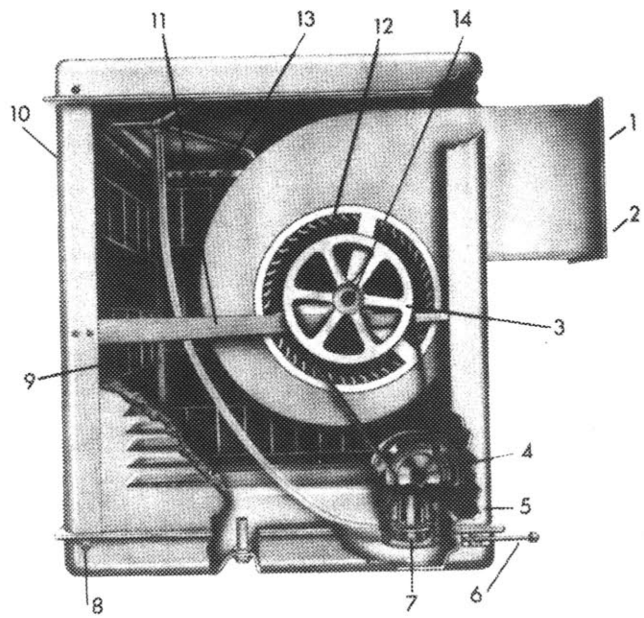


Fig.10b. Details of Cooling System by Evaporation in Courtyard Houses

In a direct evaporative cooler [fig 11], water is supplied through a float valve to a small reservoir and then flows down through fibrous pads. A fan draws large volumes of outside air through the pads, where air is cooled by evaporation, and then supplied to the building interior to provide "actual cooling ". As the humidified air flows through the space, it removes some heat, where its own temperature will keep increasing.



1 Control for air volume
2 Switches
3 Blower pulley (quiet action)
4 Motor
5 Weather resistant exterior finish
6 Supports
7 Water pump, plastic impeller
8 Bolts
9 Snap–shut type pad frames
10 Blower mount support
11 Blower wheel
12 Even–drip water trough
13 Bronze bearings
14 Blower shaft

Fig.11. Direct Evaporative Cooler

The sensible cooling provided by such air is determined by the ventilation formula:

Qv = CFM x (1.08)(Δt) [McGuiness & Stein '86]

where:

Qv sensible heat exchange due to ventilation (Btu/hr).

CFM volume flow rate in one cubic foot per minute of outdoor air introduced.

Δt the difference between outdoor air supply and exhaust temperature within the space.

Typically, evaporative cooling units are roughly the same size or slightly larger than an air-conditioner's condensing unit of similar cooling capacity. They are normally mounted on the roof to blow down into the building, however, some units are window mounted.

Realistic Evaporative Cooling Processes [Abrams '86]

The capacity of an evaporative cooler to cool and humidify the air it supplies is measured by the saturation efficiency*

$$E_s = \frac{DBT_{in} - DBT_{out}}{WB_{depression}} \times 100\%$$

where:

	E_s	= saturation efficiency %
	DBT_{in}	= dry bulb temperature of entering air °F
	DBT_{out}	= dry-bulb temperature of leaving air °F
	$WB_{depression}$	= wet-bulb depression for entering air °F
		= (dry bulb temp - wet bulb temp) for entering air °F.

The temperature of the air delivered by an evaporative cooler may be estimated with the following equation:

$$T_{supply} = TDB_{out} - (WB_{depression} \times E_s)$$

OR

$$T_{supply} = TDB_{out} - (TDB_{out} - TWB_{out}) \times E_s$$

where:

	T_{supply}	= dry-bulb temperature of air supplied by cooler °F
	TDB_{out}	= outdoor dry-bulb temperature °F
	TWB_{out}	= outdoor wet-bulb temperature °F
	WBD	= wet-bulb temperature depression °F.

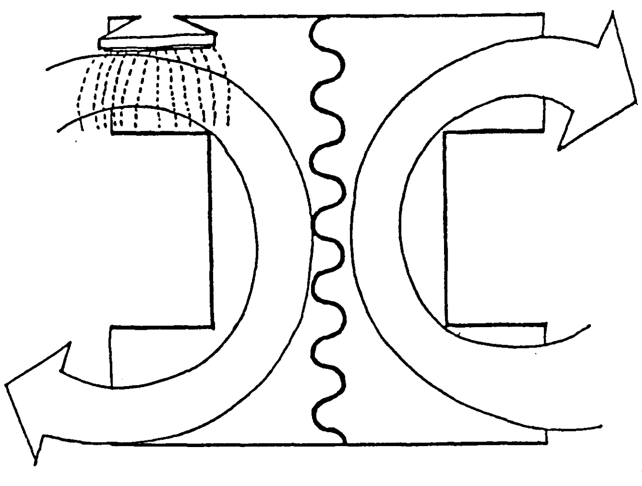
Using the typical saturation efficiency of most cores, this equation can be rewritten as:

$$T_{supply} = 0.2\ TDB_{out} + 0.8\ TWB_{out}$$

**Commercially produced systems provide saturation efficiencies of about 80%, with some types as low as 50% and others as high as 90%.*

C.1.2. Indirect Evaporative Coolers

Indirect Evaporative Coolers attempt to make use of the evaporation cooling process without increasing the amount of moisture in the air supplied to the building [fig.12]. Indirect coolers use a heat exchanger to separate the direct evaporation process from the air to be delivered to the building. A direct evaporation process cools air that flows across the side of the heat exchanger, removing heat, and is then exhausted to the outdoors. The air to be supplied to the building flows across the other side of the heat exchanger and is cooled without receiving moisture directly



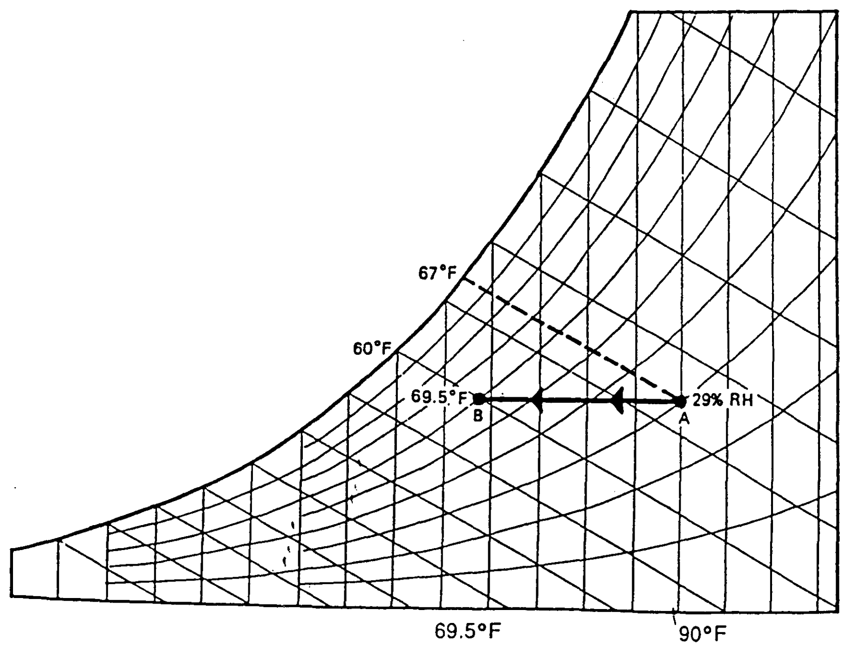


Fig.12.

Indirect Evaporative Cooler Schematic

Indirect Evaporative Cooling Process

Dry surface Indirect evaporative cooler:

In operation, cooled water from the cooling tower is circulated through the heat exchanger by a small pump (Fig.13 a&b). A fan circulates interior air through the heat exchanger and supplies it to the building [Abrams '86].

These systems are quite effective in dry climates. They often reduce indoor temperatures by 20° to 30°F on a hot afternoon*. Also, in the air provided to the building, sensible cooling is achieved without an increase in latent heat. Of course the air on the other side of the heat exchanger undergoes a direct evaporative cooling process with an increase in moisture content and latent heat, but it serves only to cool the heat exchanger and is not used inside the building.

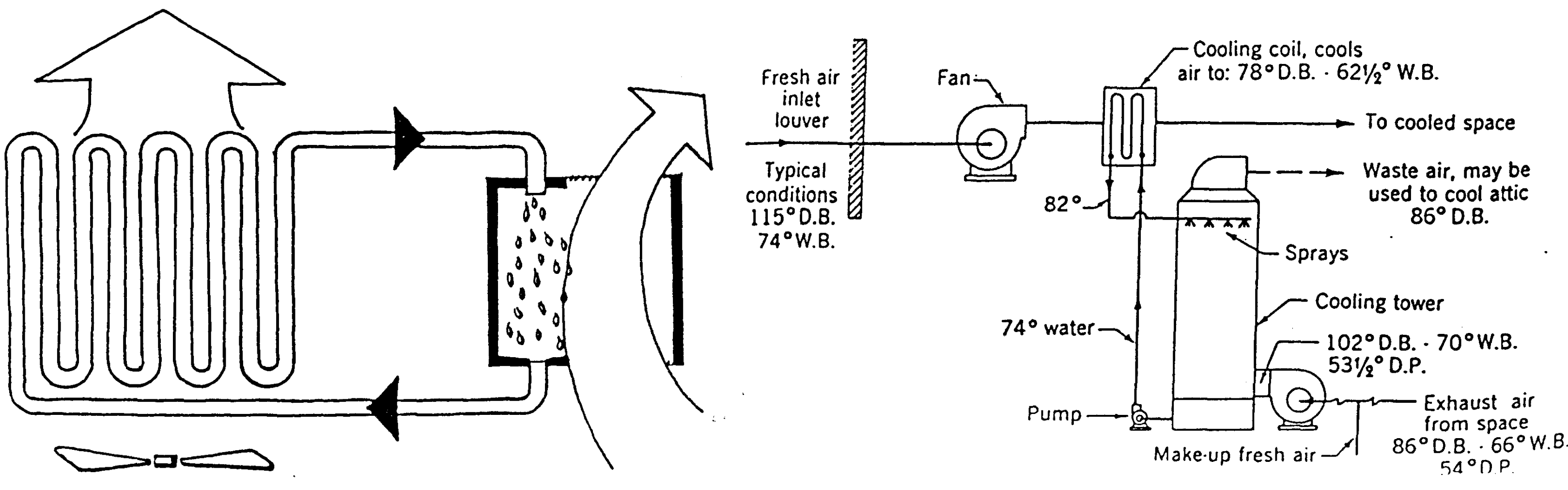
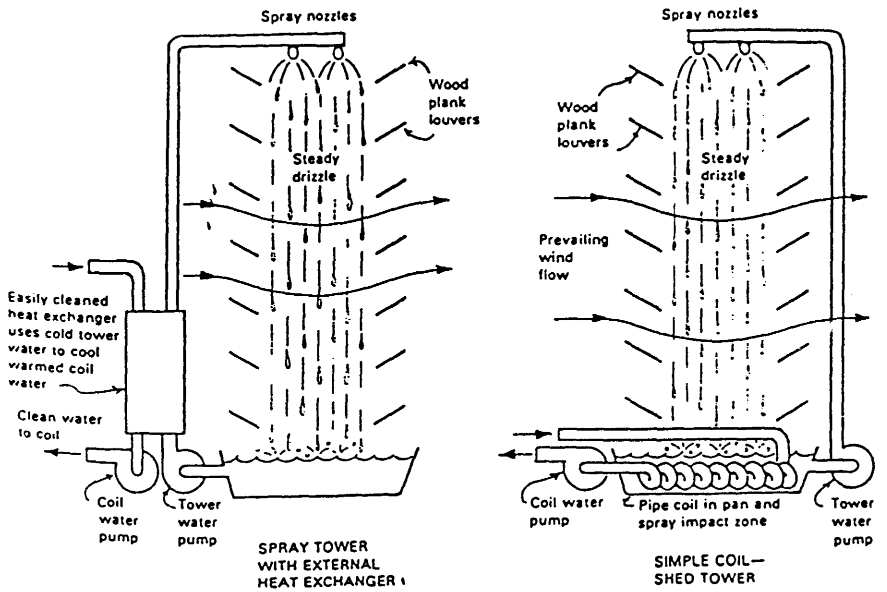
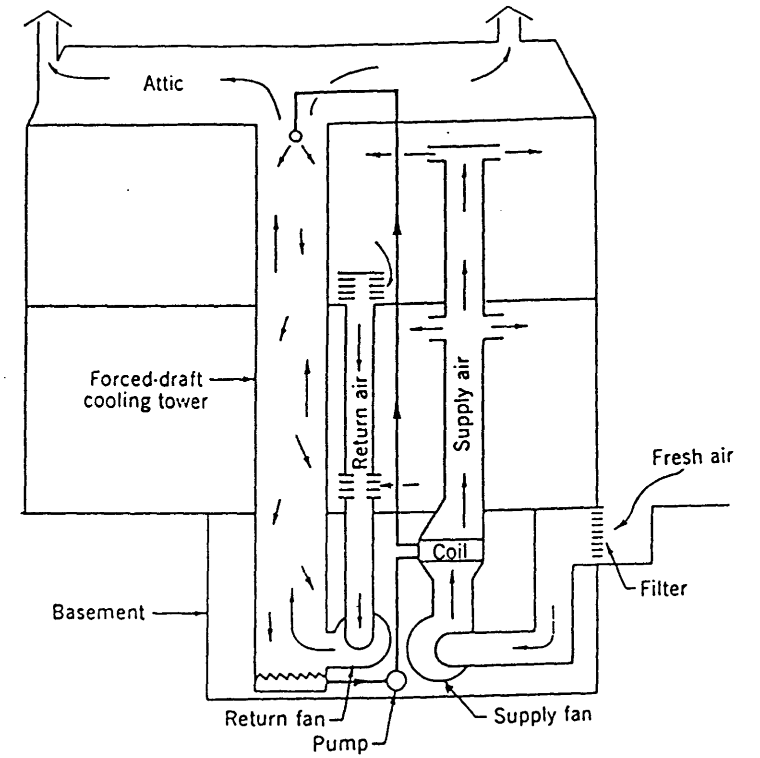


Fig.13a. Dry Surface Evaporative Cooling System Schemes

**a simple indirect cooling process is shown on the psychrometric chart : fig.12.*



Schematic view of "closed-system" cooling towers best for tower-and-coil indirect cooling. Here the cool mineral-laden tower water and the circulating, clean coil water are kept separate by two types of heat exchanger. They protect the indoor coils but require an extra heat exchange and pump, and deliver warmer water than do the simpler "open" systems,



Schematic view of University of Arizona Administration Building regenerative dry-surface system, 1936–1952, designed by Arthur Hess.

Fig. 13b. Schematic Design of dry surface evaporative Cooler

Plate-Type Indirect evaporative Coolers

They consist of a series of parallel plates that form two sets of air channels. Outdoor air is circulated through one set of the passages and indoor air in the other set. When water evaporates into the outdoor air, it absorbs heat through the plates from the indoor air.

C.1.3. Two-Stage Evaporative Coolers

Two-Stage evaporative cooling offers significant performance improvements over indirect evaporative cooling system. The two-stage evaporative cooling system combines ***Indirect** evaporative cooling* in the first stage which supplies precooled air to the ***Direct** evaporative cooling* system in the second stage [Sharag Al-din '88].

First stage: Pre-cooling Unit (A-D-E-F)

Outside air flows between dry plates or through plastic tubes surrounded by a wet pad or cloth. The surrounding wet pad is cooled by evaporation, when air is blown over them (by means of wind, electric fan, or solar chimney). The outside air between the plates is then cooled by conduction without increasing its moisture content [fig.14].

Second Stage: Direct Evaporative Cooler (F-I-J)

(F-I) This stage can bring the indoor conditions to the thermal comfort zone.

(I-J) As the supply of air draws heat from the space, it will increase its temperature.

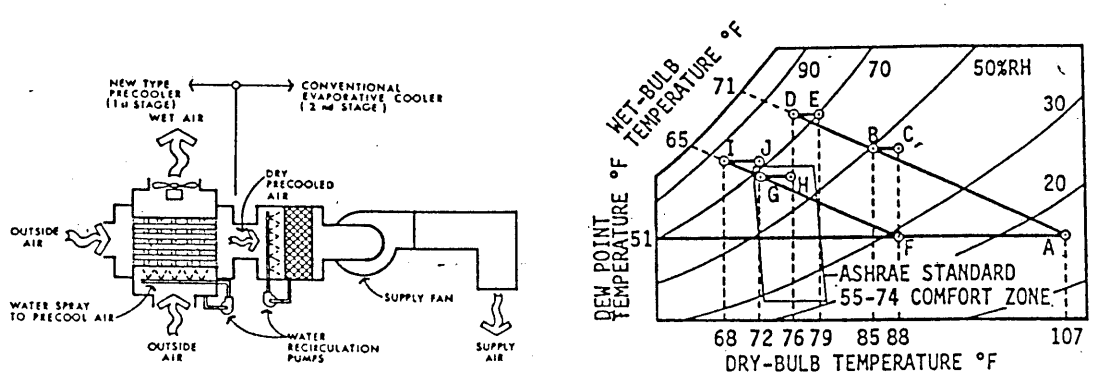


Fig.14. Two-Stage Evaporative Cooler

C.2. HIGH MASS COOLING WITH NIGHT VENTILATION

This hot-dry climate strategy must use the air at comfortable night-time temperatures to flush away the heat stored in daytime. The fewer the comfortable night hours, the more thermally massive surfaces must be provided to store the day's heat. Also, ventilation must occur more quickly and thoroughly, perhaps with fans. The building switches from a closed condition by day (to exclude sun and hot air), to an open one at night (to allow ventilation to cool the mass)*.

The following procedures go beyond the quicker rules of thumb, they allow the designer to better adjust preliminary architectural design to the local climate [McGuiness & Stein '86].

Night Ventilation of Thermal Mass

Calculation Procedure Using the following chart according to the subsequent steps: (1-14)

(column i) hour	(step 1) (column ii) outside air temperature (F)	(step 4) (column iii) cooling (Btu)	(step 5) (column iv) mass surface temperature (F)
8 pm	______	______	______
9 pm	______	______	______
10 pm	______	______	______
11 pm	______	______	______
midnight	______	______	______
1 am	______	______	______
2 am	______	______	______
3 am	______	______	______
4 am	______	______	______
5 am	______	______	______
6 am	______	______	______
7 am	______	______	______
8 am	______	______	______
9 am	______	______	______

End of cooling procedure: step 6 [Crowther '80]

**Night time outdoor temperature should be cooler than the comfort zone if this strategy is to be effective.*

A.	Mass surface area (step 2) surface area of mass in contact with the cool air (e.g: air ducts embedded in the ceiling's mass)			______ sq.ft
B.	Mass heat capacity (step 3)			______ Btu/F
C.	Total mass cooling (step 7)	______ Btu		
D.	Final mass temperature (step 8)			______ F
E.	Floor area (to be used in supplementary cooling):	______ sq.ft		
F.	Supplementary cooling (step 9)	______ Btu		
G.	Total cooling (C+F) (step 10)	______ Btu		
H.	24-h heat gain (step 11)	______ Btu		
I.	Total building volume:	______ cu.ft		
J.	Flow rate required for night ventilation (step 12)	______ cfm	**or**	______ ACH

Step.1 In column ii list the **hourly out-door temperatures** for the design conditions (these may be approximated from the summer DB temperatures and mean daily range provided in the climatic data). This will give the worst-day performance. (to get average-day performance, list average hourly temperatures). You need not list temperatures above 80°F *.

Step.2 Find the total **Area of the thermal mass surface** that is exposed both to the space to be cooled and to the moving night air during ventilation "open" cycles. Or it is only the area that is exposed to the moving night air during ventilation ***open*** cycles in the case of the cored concrete ceiling slab**. Also keep direct sun off the mass, and out of the building, during the cooling season.

Step.3 Find the **mass heat capacity for the entire thermal mass to be cooled**

= (thermal mass volume) x (density) x (specific heat).

Enter this total mass heat capacity on line B. The thermal mass can be in the form of concrete ceiling, masonry walls or floors, and free-standing water containers, etc.

**For Egypt, people will still be comfortable at air temperature of 83 °F-86 °F. So when listing the outside temperature for this cooling method we will not list air temperatures above 83 °F.*

***Note that the larger mass area exposed the better the performance (this is why direct-gain solar heated buildings often make such good candidates for night ventilation cooling).*

Step.4 Complete column iii *hour by hour*, after determining the mass temperature (column iv for the preceding hour);

Cooling Btu = (previous hour mass temp.) - (outside temp.) x (mass surface area)
col. (iv) col. (ii) line A

Step.5 Complete column iv <u>hour by hour</u>, after calculating the (cooling Btu) - (column iii). Therefore,

mass surface temperature = (previous hour mass temp.) - <u>(cooling Btu (col. iii))</u>
col. (iv) (mass heat capacity (line B))

Step.6 Continue this hourly process using cooling columns iii & iv *until the falling temperature of the mass equals the rising temperature of the outdoor air*. At that point, continuing with plentiful ventilation will only rob the mass of its "coolth". The building, therefore, switches to *closed* mode with minimal ventilation.

Step.7 Add all the hourly cooling Btu values (column iii) to obtain the total mass cooling.

Step.8 Note that the final mass temperature, from column (iv) could very likely be at least 5°F above the lowest air temperature of the night (col. ii). If the mass temperature is significantly higher, consider redesigning for more exposed mass surface area.

Step.9 For supplementary cooling (by night ventilation of thermal mass), **list other surface areas** that are exposed both to the space to be cooled and to the moving night air during ventilation. *This step should only be taken for spaces with a significant amount of roof, wall, or floor area, in addition to the thermal mass area counted before.*
If supplementary cooling is appropriate, calculate the floor area (line F) as follows:
If all your thermal mass is in the form of free-standing water containers, enter the entire floor area .
If the entire ceiling is a thermal mass, but the walls or the floors are not, enter half of the floor area.
If the entire ceiling is a thermal mass, but the floor is not, and there is few or no walls, enter one third to one-forth of the floor area.

**For Egypt, when calculating the supplementary cooling in step.9, use 83°F instead of 80°F .*

Supplementary cooling Btu = [80°F - (final mass temperature: line D)] x 2.25 x (floor area)

The (2.25) factor assumes a modest role for the other, less thermally, massive surfaces. Enter the supplementary cooling on line F.

Step.10 Obtain total cooling by adding lines C& F. Enter total on line G.

Step.11 Calculate the **24-h heat gain** for the building in Btu. Find the sum of all the hourly heat gains through the envelope, the minimum ventilation (while closed), and the internal gains (while operating). Enter the 24-h heat gain for the building on line H. Compare this cooling Btu needed to the total provided (line G). If you have not provided enough cooling, and the final mass temperature is more than 7°F above the lowest night-time outdoor temperature, consider redistributing the building mass over a wider surface (ex: 3000 sq.ft of 4" slab rather than 2000 sq.ft of 6" slab), and try it again. If you don't have enough cooling (the final mass temperature is 5°F to 7°F above the lowest night-time outdoor temperature) consider providing both more mass and more surface area (ex: 3000 sq.ft of 4" slab rather than 2000 sq.ft of 4" slab), and try it again.

Step.12 Determine and enter on line I the approximate flow required for night ventilating air. Use the formula:

cfh = (Btu/h) / 0.018 x Δt

where **cfh** is the minimum required flow rate of night air; **Btu/h** is the cooling Btu for the hour of maximum cooling during the night (col.iii); and **Δt** is the temperature difference between the final mass temperature (col. iv) and the outdoor air (col. ii) for that same hour of maximum cooling.

It is often useful to express this night ventilation flow rate in terms of air changes per hour (ACH).

$$\text{ACH} = \frac{\text{cfh required}}{\text{building volume (cu.ft)}}$$

C.3.NATURAL VENTILATION *(PROMOTING AIR MOVEMENT WITHIN THE BUILDING)*

C.3.1. Motive Force Caused by Wind Blowing onto the Facade

The wind gives rise to positive pressure on the wind-ward side of the building and negative pressure on the lee-ward side. Pressure conditions are complicated and depends on the shape of the building, the surrounding vegetation, proximity to other buildings, etc. P. O. Nylund has shown that wind blowing onto the facade has very little effect on the flow of ventilating air, provided that the building is in *closed mode* at day time, and that it is reasonably air-tight [Erickson '86]. Wind blowing onto the facade has only marginal significance in this respect and is, therefore, of no further interest.

C.3.2. Thermal Motive Force*

Stack-Effect Ventilation

As air is heated it expands, becoming less dense and tending to rise above nearby cooler air. Warmer air is more buoyant; it *floats* on top of the denser cool air. The greater the difference in temperature, the greater the force associated with the upward flow.

The stack-effect principle may be used to create flow through the building when there is little wind. The basic elements required for stack-effect flow are the warm column of air, a cool column, and a path for flow between them. The area of the stack opening has a greater effect on the air flow than both the *temperature difference* and the *height between the openings*. Air flow is directly proportional to the area of the stack and by square root of the temperature difference and height.

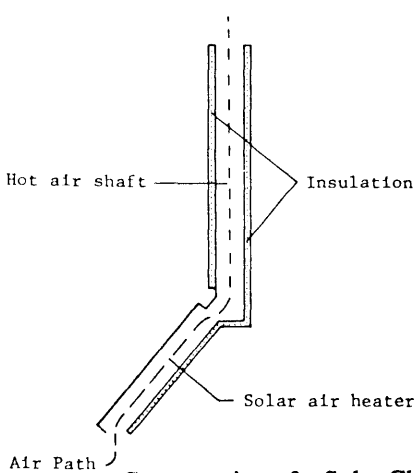
**In a natural ventilation system, the motive force is made up by difference in temperatures between the outside and inside environments in combination with the stack effect.*

Solar Chimney

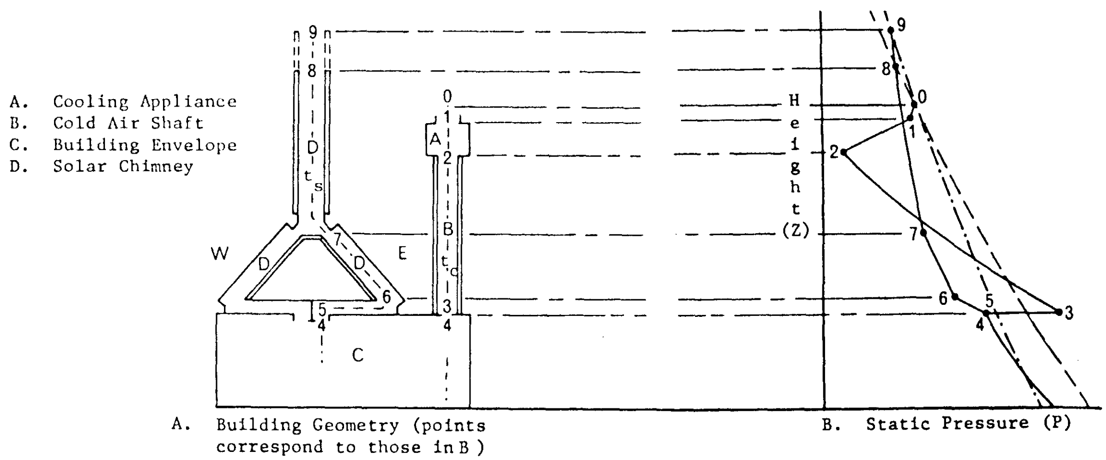
To ventilate the building by the use of solar energy (only at day time), a solar chimney is employed. The solar chimney is used to heat the exhaust air from the building to a temperature higher than that of the outside air, thus creating a pressure differential which pulls fresh air into and through the building. The interior spaces are air-conditioned as the incoming air is treated by either active, or passive conditioning equipment.

Solar Chimney System

Discused below is a solar chimney developed by Robert J. Haisley [Haisley '81]. The solar chimney consists of two integral parts [fig.15]: ***A solar air heater*** and ***a hot air shaft.*** The solar air heater forms a conduit for air transmission, for absorption of heat from the sun and for the dissipitation of that heat to the body of air within the heater. For solar chimney applications, the solar air heater heats the incoming air above the outside air temperature for the purpose of making a difference in air densities between the contained air and outside air, which in turn causes the, air being heated, to rise.



Cross section of a Solar Chimney;



Pressure changes in the solar chimney system at moderate and high ambient temperature

Fig.15. Solar Chimney System Developed by Robert Haisely

The hot air shaft, the second integral part of the chimney, is an insulated open-ended vertical duct, and that is in order to encroach the height of the column of hot air in the solar air heater.The purpose of this hot air column formed in the solar chimney is to create an air flow, known as ***theoretical draft***. It is comparable to the motive pressure created in a gas passage of a heat generating unit; such as a chimney.

Theoretical draft is defined as a static pressure resulting from the difference in weight between two columns of air of equal heights and at different temperatures.These columns are a column of hot air in the solar chimney and an equal column of colder, heavier, ambient air. A column of cold air is formed and sustained as the conditioned air falls from the cooling appliance through the long insulated shaft to the enclosure below.The cool air shaft is an insulated, open-ended, duct. A pressure differential is created by the difference in weight between the column of cold air and an equivalent column of ambient air of higher temperature. For the *solar chimney system,* the term "stack effect" implies the combined theoretical draft of the two connecting unbalanced columns in the solar chimney and the cold air shafts which are both under the same atmospheric pressure.

Motive Force due to the Entrainment Effect of Wind at the Top of the S. Chimney

Pressure conditions in the chimney are modified by wind velocity at the top of the chimney [Erickson '86]. The usual consequence is negative pressure which encroaches the airflow rate. This motive force is difficult to calculate. However, it has been imperically assessed that according to a wind velocity of about 10 m/s, the air change rate in natural ventilation system can increase by a factor of three or two [Carlson '85].

Advantages

- The system is quiet in operation since there are no fans.
- Operation is not affected by power failure.

CHAPTER THREE

APPLICATION OF COOLING SYSTEMS

A MULTI-STORY RESIDENTIAL BUILDING IN AN URBAN CITY: CAIRO-EGYPT

A

COOLING LOAD CALCULATIONS (Based on ASHRAE Handbook of Fundamentals)

In this chapter, we shall be examining an application of cooling systems acquired in a residential building (in a hot arid climatic zone). We shall be making comparisons between *peak heat gains* of an *existing building* and the *solution after redesigning* some of the building elements. But first, we have to introduce some of the terminology, often mentioned in this chapter, and its definitions.

A.1. Definitions and Symbols (of terminology used in this chapter)

A **Area** (sq.ft)

U **Overall coefficient of heat transmission.**

The overall rate of heat flow through any combination of materials, air, layers, and air spaces. It equals the reciprocal of the sum of all resistances "**R**" that are involved in the combination:

Btu/h sq.ft °F
w/sq.m K
w/sq.m °C

where: one Btu/h sq.ft °F = 5.6 w/sq.m K *and* one w/sq.m K= 0.176 Btu/h sq.ft °F

R **Resistance.** A measure of resistance to the passage of heat. The reciprocal of conductance.

h sq.ft °F/Btu
sq.m K/w
sq.m °C/w

CLTDCooling Load Temperature Difference.

CLTD has been developed to account for sol-air-temperature and weights of construction. It was computed for the following standard conditions:

indoor temperature 78°F	(25.5 °C)	
outdoor air max 95°F	(35 °C)	
outdoor mean temp. 85°F	(29.4 °C)	
outdoor daily range 21°F	(11.6 °C)	solar radiation for 40° N & latitude on July 21.

$CLTD_{corrected}$

Cooling load temperature difference at the following conditions:

indoor temperature 83°F	
outdoor air max 97°F	
outdoor mean temp. 84°F	
outdoor daily range 27°F	solar radiation for 32° N & latitude on July 21.

A.2. Overall Coefficient of Heat Transmission for Roofs

To calculate heat gain through the roof we need to know its Overall Coefficient of heat transmission.

A.2.1. Overall Coefficient of Heat Transmission *U value* for EXISTING ROOF [fig.16]:

No.	Description	R	U
1	air film: moving air any position 7.5 mph wind for summer	0.25	
2	cement sand tiles	0.05	
3	2" sand	0.15	
4	1.75" cement sand leveling screed	0.35	
5	2" expanded polystyrene	10.00	
6	3 layers bituminous felt	0.154	
7	4" reinforced concrete slab	0.333	
8	3/4" cement sand plaster	0.15	
9	airfilm still	0.68	
	Total R	**11.817**	
	U value = 1/ (total R)		**0.084**

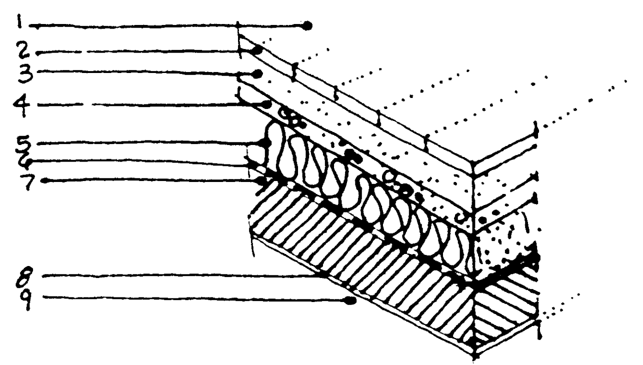


Fig.16. Details of the Existing Roof

A.2.2. **Overall Coefficient of Heat Transmission for REDESIGNED ROOF** [fig.17]:

No.	Description	R	U
1	air film: moving air any position (7.5 mph wind for summer)	0.25	
2	cement sand tiles.	0.05	
3	2" sand	0.15	
4	1.75" cement sand leveling screed	0.35	
5	2" expanded polystyrene	10.00	
6	3 layers bituminous felt	0.154	
7	4" reinforced concrete slab	0.333	
8	3/4" cement sand plaster	0.15	
9	airfilm still	0.68	
10	*2" still air core (horizontal)*	*2.5*	
	Total R	**14.27**	
	U value= 1/ (total R)		**0.07**

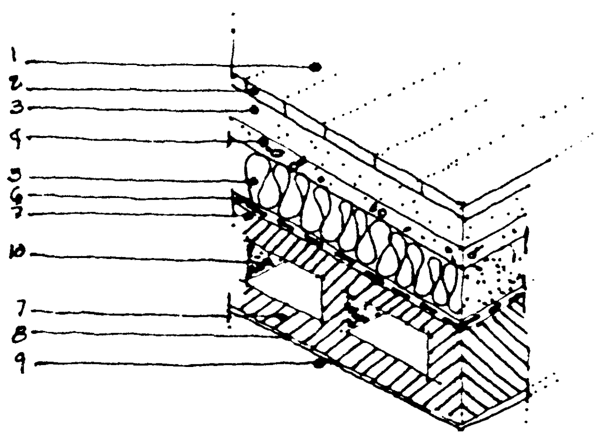


Fig.17. Detail of the Redesigned Roof

DETAILED HOURLY HEAT GAIN CALCULATIONS (CLTD)

LOAD SOURCE	EQUATION	REMARKS
External Roof	$q = U x A x CLTD$	U = Design heat transfer coefficients A = Area calculated from architectural plans CLTD = Cooling load temperature difference at base conditions for roofs Note : Correction for color of exterior surfaces Correction for outside dry-bulb temperature and daily range Correction for inside dry-bulb temperature Application for latitutde and month
Walls	$q = U x A x CLTD$	U = Design heat transfer coefficients A = Area calculated from architectural plans (wall construction description) CLTD = Cooling load temperature difference at base conditions for walls Note : Convection for color of exterior surfaces Correction for outside dry-bulb temperature and daily range Correction for inside dry-bulb temperature Application for latitutde and month
Glass Conduction	$q = U x A x CLTD$	U for type of glass and interior shading if used Area, Net glass area calculated from architectural plans CLTD, Cooling load temperature difference for conduction load thru glass Note : Correction for outside dry-bulb temperature and daily range Correction for inside dry-bulb temperature
Solar	$q = A x SC x SHGF x CLF$	A = Net glass area calculated from plans SC = Shading coefficients for combination of type of glass and type of shading SHGF = Maximum solar heat gain factor for specific orientation of surface, latitude, and month CLF = Cooling load factor with/ without interior shading

Space Cooling Loads Using the CLTD and CLF Method *(From ASHRAE 1981 Handbook of Fundamentals).*

Table.1. Summary of Cooling Loads using CLTD and CLF methods

Partitions, Ceilings, Floors	$q = U \times A \times TD$	U = Design heat transmission coefficients A = Area calculated from architectural plans TD = Design temperature difference
Internal Lights	$q = Input \times CLF$	Input rating from electrical plans or lighting fixture data CLF = Cooling load factor based on total hours of operation and time Note : Correction for schedule of operation of cooling system
People Sensible Latent	$qs = No. \times Sens.\ H.\ G. \times CLF$ $ql = No. \times Lat.\ H.\ G.$	No. = Number of people in space Sens. H. G. = Sensible heat gain from occupants CLF = Cooling load factor for people, based on duration of occupancy and time from entry Note : Correction for density of occupants and/ or space temperature Lat. H. G. = Latent heat gain from occupants
Appliances Sensible Latent	$qs = Heat\ Gain \times CLF$ $ql = Heat\ Gain$	Heat gain = recommended rate of sensible heat gain CLF, for use with hood Latent Heat Gain = is recommended rate of heat gain
Power	$q = Heat\ Gain \times CLF$	Heat Gain provided from the manufacturer's data CLF = 1.0 if cooling system is not operated continuously
Ventilation and infiltration Sensible Latent Total	$qs = 1.08 \times cfm \times \Delta T$ $ql = 4840 \times cfm \times \Delta W$ $qs = 4.5 \times cfm \times \Delta H$	Cfm = Ventilation and infiltration air standards ΔT = Inside-outside air temperature difference ΔW = Inside-outside air humidity ratio difference ΔH = Inside-outside air enthalpy difference

Cooling Loads Using the CLTD and CLF Method.

A.2.3. Peak Heat Gain for the EXISTING BUILDING

External Roof (ONE floor per ONE hour) $Q = A \times U \times CLTD_{corrected}$

A	U	CLTD	correction					CLTDcort'd	Q
			LM	K	Tin	Tout	F		
2800	0.084	53	1	0.5	-5	-1	1	21	**4,939.2**

A Floor area (4 apartments) sq.ft

U Overall coefficient of heat transmission Btu/sq.ft °F h.

$CLTD_{max}$ Cooling load temperature difference (40° N). °F roof no. 9:

4" heavy weight concrete

2" insulation [McGuiness & Stein table5-28] CLTD for flat roofs.

$CLTD_{correct'n}$ Max. cooling load temperature difference in existing building (Cairo 30° latitude in the month of July).

LM: Latitude-month correction for lat. 32°N in July (nearest latitude to Cairo) [McGuiness & Stein'86].

K: is the color adjustment factor and is applied after making latitude-month adjustments.

T_{in}: (78-TR) indoor design temperature correction, where TR=indoor temperature (TR=83°F).

T_{out}: (To-85) outdoor design temperature correction;To=average outside temperature on design day.

To=97°F - (daily range (26°F))/2.

To=84 and Tout-(84-85)=-1.

F: factor for attic and/or ducts above ceiling applied after all other adjustments have been made

F=1.0 (no attic ducts).

F=0.75 (positive ventilation) [McGuiness & Stein table 5-2].

Therefore, **$CLTD_{cort'd}$** = (CLTD+LM) x K + (78-TR) + (To-85) x F
= (53+1) x 0.5 + (-5) + (-1) x 1 = **21°F.**

A.2.4. Peak Heat Gains after REDESIGNING the Building

External Roof (ONE floor / ONE hour) $Q = A \times U \times CLTD_{corrected}$

A	U	CLTD			correction			CLTDcort'd	Q
			LM	K	Tin	Tout	F		
2800	*0.0 7**	53	1	0.5	-5	-1	1	21	4116

* Factors that have changed due to redesign of building elements will be indicated in ***italics***.

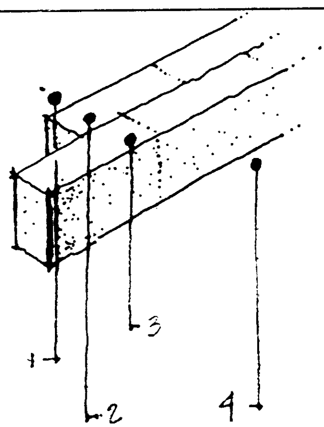
A.3. Overall Coefficient of Heat Transmission for WALLS [fig.18]

WALL NO. ONE: EXISTING WALLS

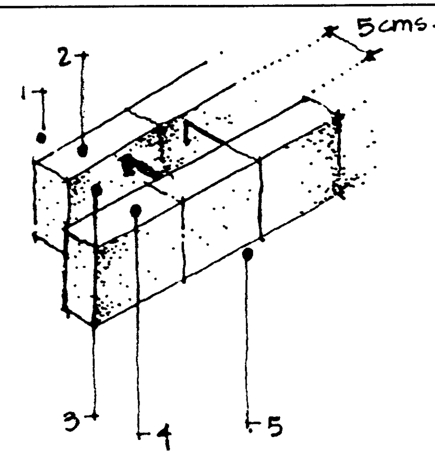
	U	R
1. moving air (7.5 mph)		o.25
2. 4" common brick		0.80
3. 4" common brick		0.80
4. still air film		0.68
Total R and U values	**0.36**	**2.53**

WALL NO. TWO: RE-DESIGNED WALL

	U	R
1. moving air (7.5 mph)		0.25
2. 4" common brick		0.80
3. 2" still air (vertical)		2.50
4. 4" common brick		0.80
5. still air		0.68
Total R and U values	**0.19**	**5.03**



Wall no.One



Wall no.Two

Fig.18. Alternative Wall Design (and the selected one)

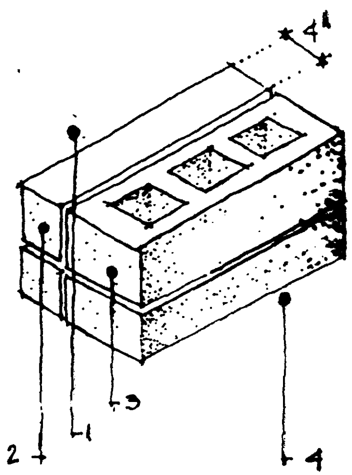
COMPARISON BETWEEN THE *U VALUES* OF OTHER WALL TYPES

WALL NO. THREE:

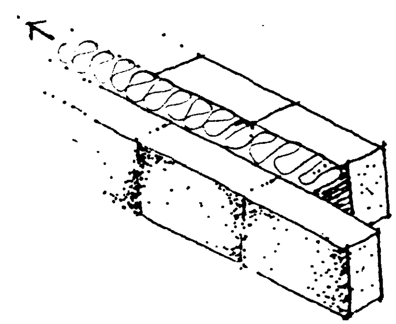
	U	R
1. moving air (7.5 mph)		0.25
2. 4" common brick		0.80
3. 4" cored cinder-block (3 holes)		1.10
4. still air		0.68
Total R and U values	**0.35**	**2.83**

WALL NO. FOUR:

	U	R
1. moving air (7.5 mph)		0.25
2. 4" common brick		0.80
3. 2" expanded polystyrene		10.53
4. 4"common brick		0.80
5. still air		0.68
Total R and U values	**0.076**	**13.06**



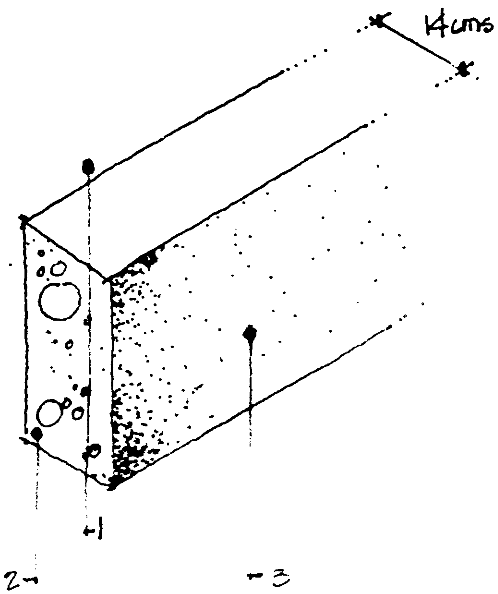
Wall no. Three



Wall no.Four

WALL NO. FIVE:

	U	R
1. moving air (7.5 mph)		0.25
2. 14 cm(5.4x0.08) o. concrete		4.48
3. still air		0.68
Total R and U value	**0.18**	**5.41**



Wall no.Five

WALL NO. SIX:

	U	R
1. moving air (7.5 mph)		0.25
2. Clay tile: hollow 3 cells deep 12"		2.50
3. still air		0.68
Total R and U values	**0.29**	**3.43**

In the proposed design, wall no. two was selected (two 4" brick walls and 2.5 " of air in between them .) because of its low coefficient of transmission, besides no new materials will be additionally used .

A.3. Heat Gain through Glass

A.3.1. Peak Heat Gain through Glass by *Solar Radiation* in EXISTING Building*

For ONE floor / ONE hour **$Q = A \times SHGF \times SC \times CLF$**

Orien.	A	SHGF	SC	CLF	Q
Northern edge of the building					
NW	110	167	1	0.3	5511
SW	22	150	1	0.75	6187.5
SE	55	150	1	0.28	2310
NE	-	-	-	-	-
Southern edge of the building					
NW	55	167	1	0.3	2755.5
SW	22	150	1	0.75	2475
SE	110	150	1	0.28	4620
NE	-	-	-	-	-
Heat Gain From Glass by Solar Radiation					**23,859** Btu/hr
Total Heat Gain From Glass (Rad. & conduction.)					**27113.4** Btu/h

A Net glass area calculated from plans (sq.ft).

SHGF Solar Heat gain factor due to solar radiation (Btu/h sq.ft) for sun lit glass -north latitude [McGuiness & Stein tables 5.34/5.36 for maximum hour of radiation].

SC Shading Coefficient = $\frac{\text{(solar heat gain from fenestration)}}{\text{(Solar heat gain of double strength glass)}}$

CLF Cooling Load Factor.

This factor must be used along with SHGF to account for the delay in the impact of incoming solar radiation on the air temperature of a cooled space [McGuiness & Stein tables 5.43/5.44 calculated at 14:00 solar time, with interior shading).

Detailed calculations for peak heat gain form **walls, and from **glass by conduction** before and after redesigning is in appendix A.. Also, calculations for the existing solution is based on a window with no external shading devices.*

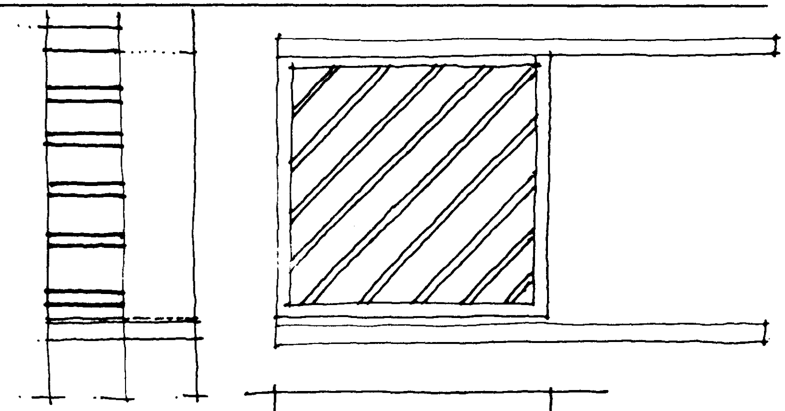
A.3.2. Peak Heat Gain through Glass by *Solar Radiation* after REDESIGN

For ONE floor per ONE hour [fig.19] **Q = A x SHGF x SC x CLF**

Orien.	A	SHGF	SC	CLF	Q
Northern edge of the building					
NW	110	167	*0.25*	0.3	1377.75
SW	22	150	*0.25*	0.75	618.75
SE	55	40	*0.25*	0.28	154
NE	*11*	*167*	*0.25*	*0.24*	*110*
Southern edge of the building					
NW	55	40	*0.25*	0.3	165
SW	22	150	*0.25*	0.75	618.7
SE	110	150	*0.25*	0.28	1155
*NE**	*11*	*167*	*0.25*	*0.24*	*110*
Heat Gain From Glass by Solar Radiation					**4,309.2** Btu/hr
Total Heat Gain From Glass (Rad. & cond.)					**7,746.4** Btu/hr

Diagonal Shading Device is Selected for the Design

(Refer to appendix for details)



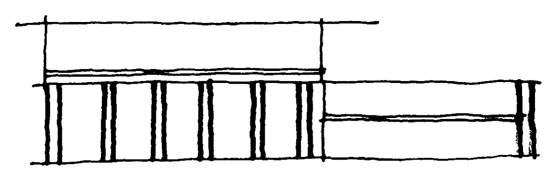


Fig.19a. SOUTH EAST AND NORTH WEST ORIENTATION

**Windows are added in the north east (NE) side of the facade in the northern and southern edge of the building.*

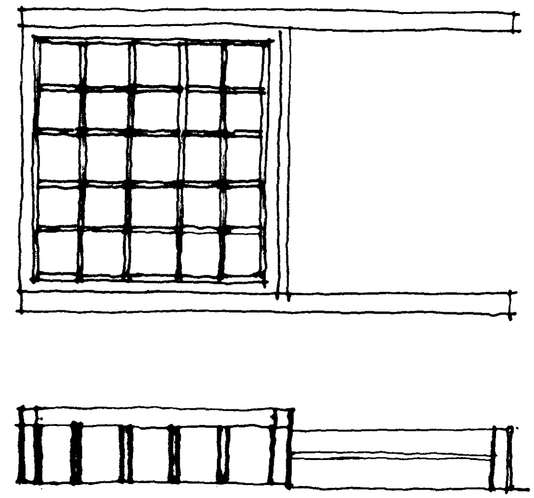


Fig.19b. SOUTH AND SOUTH WEST ORIENTATION

Egg-Crate with Window Depth Equals to 1/3- 2/3 Dimension of the Window is the Best Shading Device for this Orientation

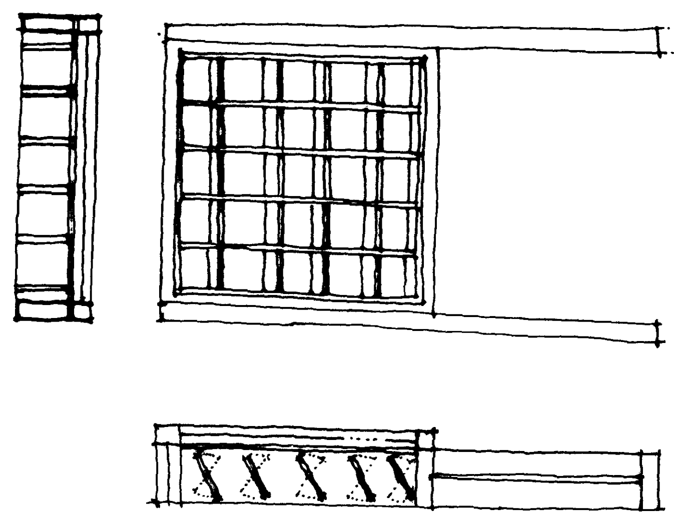


Fig.19c. WEST AND EAST ORIENTATION

Horizontal and vertical fins tilted 45 degrees to the south is the best shading device for this orientation

A.4. Peak Sensible Heat Gain from people

Q = number of people/one floor x heat gain x CLF

	no. of people	CLF	heat gain/person	Q
Sensible Heat	20	0.92	225	4,140
Total SENSIBLE Heat Gain from people				4,140

A.5. Peak Heat Gain from INTERNAL Light

For one floor per one hour [Johnson '81] **Q = Input x CLF** (Btu/Kwh = kw x 3400)

	INPUT	CLF	Q
input/day (8 hours) / one family (Kw)	5.5		
input/day (8 hours) / one family (Btu/Kwh)	18700		
input/day (8 hours) / 4 families (Btu/Kwh)	74800		
input / one hour / 4 families (Btu/Kwh)	9350	0.56	5,236

CLF **Cooling load factor.**

We assume that energy supplied to lights becomes immediate heat gain. However, this is often untrue. Light component raises air temperature only after it has been absorbed and released by the materials in the space. Thus cooling load factors are necessary to account for this lag. Given information about the type of furnishing, the air supply and return, the type of electrical lights [McGuiness & Stein table 5.45] , the type of room envelope, and the air circulation; the actual CLF can be computed. Note that Peak heat gain from electric lights is reached after 2 hours of usage.

A.6. Summary of PEAK HEAT GAIN

Comparison between the existing & recommended solutions after redesigning certain elements

	EXISTING BUILDING	AFTER REDESIGNING
Roof	4,939.2	4,116
Wall*	20,652	10,917.5
Glass conduction*	3,254.4	3,437.2
Glass solar radiation	23,859	4,309.2
People	4,140	4,140
Electric Lights	5,236	5,236
Total heat gain per hour	**62,080.6**	**28,285.4 (45.5% red. in cooling loads)**

A.8. SUMMARY OF HEAT GAINS (For one floor: 4 apartments)

	HEAT GAIN for one hour Based on PEAK calc.	**HEAT GAIN**** for one hour Based on AVERAGE calc.	**HEAT GAIN** for 12 h DAY-TIME based on AVERAGE calc.	**HEAT GAIN** for 12 h DAY-TIME based on PEAK calc	**HEAT GAIN** for 12 h NIGHT TIME based on AVERAGE calc.	**HEAT GAIN** for 24 h NIGHT & DAY TIME based on AVERAGE calc.
Roof	4,116	3,822	45,864	49,392		45,864
Wall	10,917	7,495	89,940	131,004		89,940
Glass conduction	3,437.2	-164.724	-1,976.6	41,246		-1,976.6
Glass solar radiation	4,309	7,385	88,624	51,708		88,624
People	4,140	4,140	49,680	49,680	49,680	99,360
Electric Lights	5,236	5,236	10,472	10,472	31,408	41,880
Total	**28,285.4**	**27,913.3**	**282,603**	**28,285.4**	**81,088**	**363,691**
latent heat gain (299/person/h)	5,980	5,980	71,760	71,760	71,760	143,520
Total heat gain (sensible&latent: 4 apts)	**34,265.4**	**33,893.3**	**354,363**	**405,262**	**152,848**	**507,211**

* *Refer to appendix for detailed calculations*

***Refer to the appendices for average heat gain calculation*

B

SELECTING COOLING SYSTEMS

By Applying Cairo's Summer Design Data on the Bioclimatic Chart

When plotting the climatic conditions of Cairo /Egypt on the Bio-climatic chart [fig.20], we find that the temperature-humidity combination lies above the shading line*, and these conditions can be made comfortable by ***Evaporative coolers***, ***natural ventilation*** and ***High mass cooling with night ventilation*** (explained in chapter two). Each of these cooling system, and a combination of them will be examined later in the section to follow [Nicholson '76].

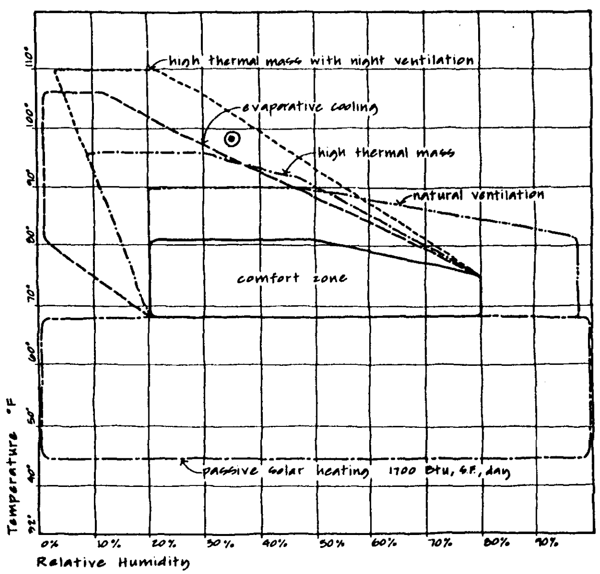


Fig.20. Plotting Cairo's Summer Time Design Conditions on the Bioclimatic Chart to Determine the Cooling System that Will Be Used

**summer design data: DBT 1%-2.5% = 97°F; WBT 2.5% =75°F; RH = 35% at day time (from the psychrometric chart).*

C

COOLING SYSTEMS AND SCHEMES

High mass cooling with night ventilation, Evaporative coolers, and **Natural Stack Ventilation,** are the used cooling systems for such a context. Each of these cooling systems, and a combination of them will be examined and sized. Several cooling schemes can be used for cooling the building passively, or perhaps with minimum energy [fig.21]. The research procedure is described as follows:

C.1. SCHEME ONE*

Examining whether the use of a thermal mass (cored concrete slab) flushed with night ventilation will remove the 24-hour heat gain or not.

*First we shall estimate the size of the thermal mass and the air ducts embedded in it . And by following the step-by-step method for cooling with forced night ventilation through the thermal mass (described in chapter one), we can calculate the total heat removed form each apartment, and the duration of operating this cooling system. In addition, we can also compute the volume rate of air "**cfm**" needed to achieve this cooling load.*

If this scheme did not succeed to remove the 24-hour average heat gain, it may succeed to remove the average heat gain generated during the closed mode at day time. If that was not fulfilled either, change the size of the thermal mass, or switch to another cooling scheme

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**The average heat gain for 24 hour (of the building envelope, people, and artificial lighting) is the heat gain used in this cooling scheme. Refer to chapter two for details*

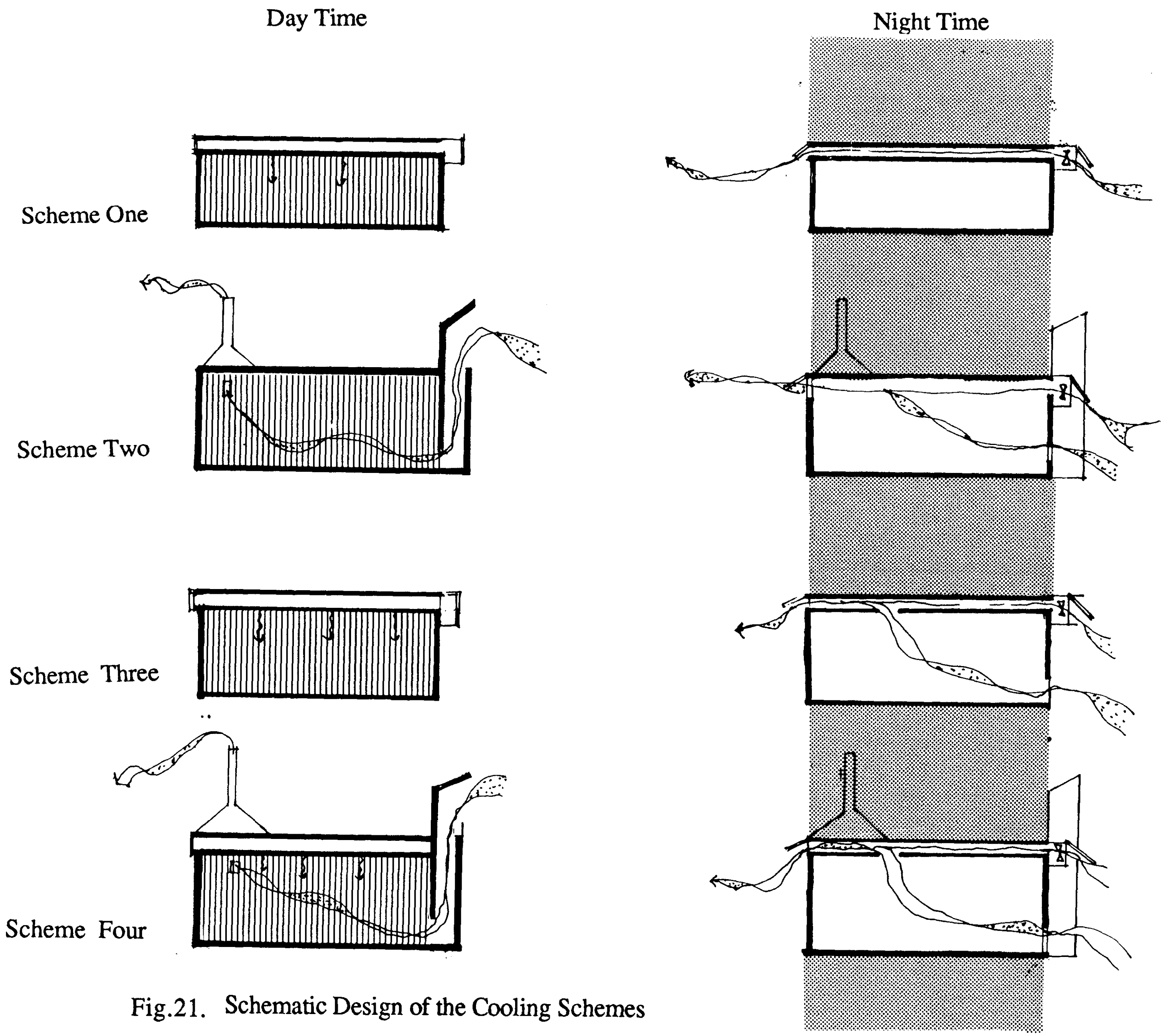


Fig.21. Schematic Design of the Cooling Schemes

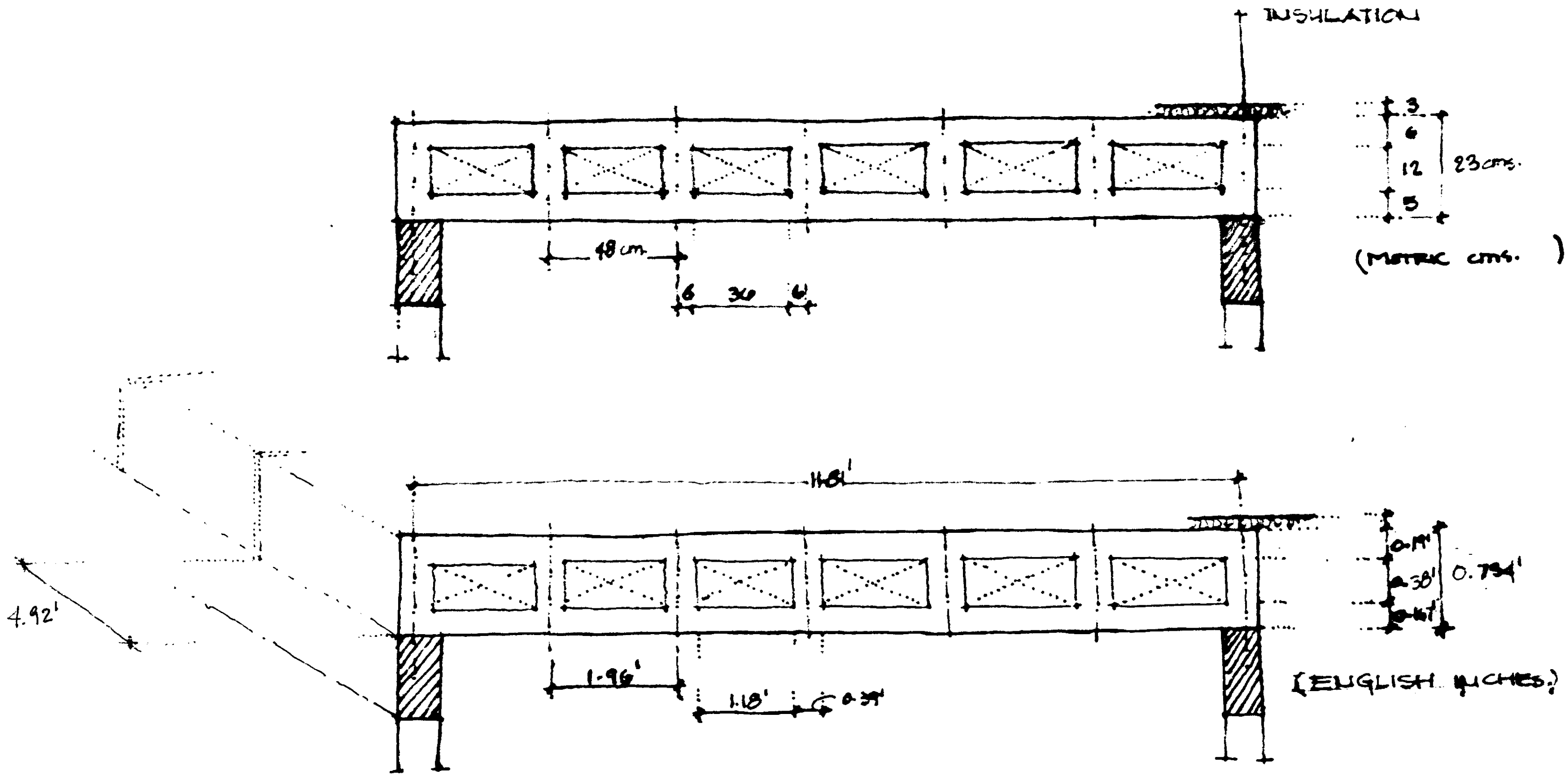


Fig.22. Dimension of the Proposed Cored Slab

C.1.1. By iterated use of the *high mass cooling with night ventilation* method (discussed in chapter.2), a design of the thermal mass of the ceiling was generated, and was similar to the design of the ceiling slab in the cooling scheme reported by *O.A Barra* [Jesch '85].

Using the above method iteratively [fig.22]

#1*	Concrete slab thickness	= 0.734 ft.
#2	Concrete slab length	= 11.81 ft.
#3	Concrete slab width	= 4.92 ft.
#4	No. of concrete slab units in a building	= 60 (12 X 5)
#5	No. of air cores in one slab unit	=6 cores
#6	Air-core's thickness	= 0.38 ft.
#7	Air-core's width	= 1.18 ft.
#8	Air-core's length in one slab unit	= 4.92 ft.

Volume of concrete	= #1 x #2 x #3 x # 4	
	= 0.734 x 11.81 x 4.92 x (12 X 5)	
	= **2556 cu.ft**	(1)
Volume of air ducts	= # 6 x # 7 x #5 x # 8 x # 4	
	= 0.38 x 1.18 x 6 x 4.92 x (12 X 5)	
	= **792 cu.ft**	(2)
Mass heat capacity	= (1) - (2) x [concrete heat capacity = (22.5)]	
	= **39640 BTU/F**	
Mass Surface Area	= (# 6 + # 7) x # 8 x # 5 x 2(sides/duct) x #4	
	= (0.38+1.18) x 4.92 x 6 x 2 x (12 x 5)	
	= **5,522.112 sq.ft**	

Cooling Btu/h: In case of cored slab ceiling, multiply the cooling (Btu/h) by the convection coefficient: 4 Btu F/sq.ft h

C.1.2. Supplementary Cooling = **[(mass temperature at beginning of the cooling process) - (final mass temperature of the thermal mass)] x 2.25 x (Floor area /2)**

"#" is a row label. Also refer to fig.22 for further explanations.

C.1.3. Forced Night Ventilation Of Thermal Mass (Cored Concrete Ceiling Slab)

Hour	T(out) °F	Cooling Btu / hour	Mass Temperature (F)
20	84.9	none	
21	83.55	none	83.55
22	82.2	4 x (83.50-82.20) x 5522 = **28,714.4**	83.55 - (28,714.4/39,646) = 82.82
23	80.85	4 x (82.82-80.85) x 5522 = **43,513.36**	82.82 - (43,513.3/39,646) = 81.73
24	79.5	4 x (81.73-79.50) x 5522 = **49,256.2**	81.73 - (49,256.0/39,646) = 80.48
1	78.15	4 x (80.48-78.15) x 5522 = **51,465.04**	80.48 - (51,465.0/39,646) = 79.18
2	76.8	4 x (79.18-76.80) x 5522 = **52,606.7**	79.18 - (52,606.7/39,646) = 77.85
3	75.4	4 x (77.85-75.40) x 5522 = **54,179.36**	77.85 - (54,179.3 /39,646) = 76.48
4	76.0	4 x (76.48-76.00) x 5522 = **10,602.24**	76.48 - (10,602.2/39,646) = 76.20
5	78.4	STOP	

Total mass cooling = **290,000 Btu**
Final mass temperature = **76.20 °F**

Therefore, supplementary cooling becomes = (83.55 -76.2) x (2.25)x floor area (2800/2)
= 23,152.5 Btu

Total cooling =23,152.5 + 290,000
=313,152 Btu

24-hour heat gain(sensible heat gain only) =363,691 Btu
12-hour heat gain =282,603 Btu

Approximate flow required for night ventilating air equals ***cfm*** = $\frac{\text{54179 maximum cooling Btu/h}}{\text{60 X 0.018 }(\Delta t)(76.4-75.4)}$

CFM =50,165 sq.ft/ min/ 4 apartments
=12,541 f/ min/ one apartments

ACM =12,541/5600
=2.2 air change per minute

This scheme ONE failed, theoretically, to remove the 24-hour heat gain (closed and open modes). But it can remove the heat gain at day time during when the building is closed to the outside environment. This method is used later in scheme three.

C.2. SCHEME TWO

C.2. SCHEME TWO

Examining whether the use of the Evaporative Cooling (2-Stage Evaporative Cooling, or Indirect Evaporative Cooling) during the day remove the instantaneous heat accumulation with the night time forced ventilation, in order to flush the night time heat gain from the ordinary uncored ceiling slab, is a valid scheme or not.*

After following the step-by-step method for cooling with forced night ventilation of the thermal mass, described in chapter one, we are now able to calculate the total heat removed form each apartment, and the duration of operating this cooling system, in addition to the volume rate of air "cfm" needed to achieve this cooling load. Now we shall decide whether this cooling system will succeed to remove the 12-hour average heat gain during night-time or not. If it did succeed, start sizing the evaporative cooler (2-stage evaporative cooler, and the indirect evaporative cooler), by calculating the volume of air flow rate "**cfm**" needed to remove the heat gain, the Air Change per minute, and the size of the supply register's "Free face"area.

C.2.1. Night-time Forced Ventilation

Total average heat gain at night becomes	= 81,088 Btu/night.
Total cooling at night**	= 123,767 Btu/night

Approximate flow required for night ventilating air equals ***cfm***

cfm	= 338.1 cu.ft/min./ 4 apartments
	= 864 cu.ft/ min./ one apartment
ACM	= 846/5600
	= 0.1 air change per minute.

Cooling the ordinary slab by ***Forced night ventilation*** succeeded in removing the heat gain at night .

**In sizing the evaporative cooler , use peak hourly heat gain(sensible & latent)*
In case of flat slab cooling by forced night ventilation, heat gain removed each hour (Btu/h) is multiplied by convection coefficient =1 Btu F/sq.ft h), which is 1/4 the convection coefficient in the case of embedded air ducts in the cored ceiling slab.
***Refer to appendix C for detailed calculations.*

C.2.2. Day-time Use of Evaporative Coolers

Two stage evaporative coolers* will supply dwellings with air characterized by low temperatures (TDB = 83°F), but rather with relatively a high relative humidity (RH=65%). However, if we use the indirect evaporative cooler, we can achieve another level of comfort with higher temperatures (TDB = 87°F), and reasonable relative humidity (RH=50%).

Using 2-stage Evaporative Cooling [fig.23]

Peak heat gain per apartment = 8,566.35 Btu. (Summer; June 21).

First-Stage Indirect cooling:

$$T_{supply}\ TDB = TDB_{out} - (TDB_{out} - TWB_{out}) \times Es^{**}$$
$$= 97 - (97 - 75) \times 0.82$$
$$= 78.96°F$$

As the supply of air draws heat from the space, it will increase its temperature by 4°F, and it becomes 82.96°F. And when the supply of air passes through the heat exchanger, it will increase its temperature by an additional 4°F. Therefore, the final air supply temperature becomes = 78.96 + 8

=86.96°F

When plotting [$T_{supply\ (final)}$] on the psychrometric chart, 86.96°F dry bulb temperature corresponds to 50 % relative humidity. Also, we can have almost the same temperature of supply air when using the psychrometric chart .

		BDT	RH%	WBT
A	outside conditions (day time)	97	35	75
D	after the cooling process through the heat exchange of the first stage	87	50	72
E	Second-stage supply	79	76	72
F	second-stage exhaust	83	65	73.5

*use the peak hourly heat gain when sizing cooling equipments.
**Es = saturation efficiency %. Refer to Chapter two for theory .

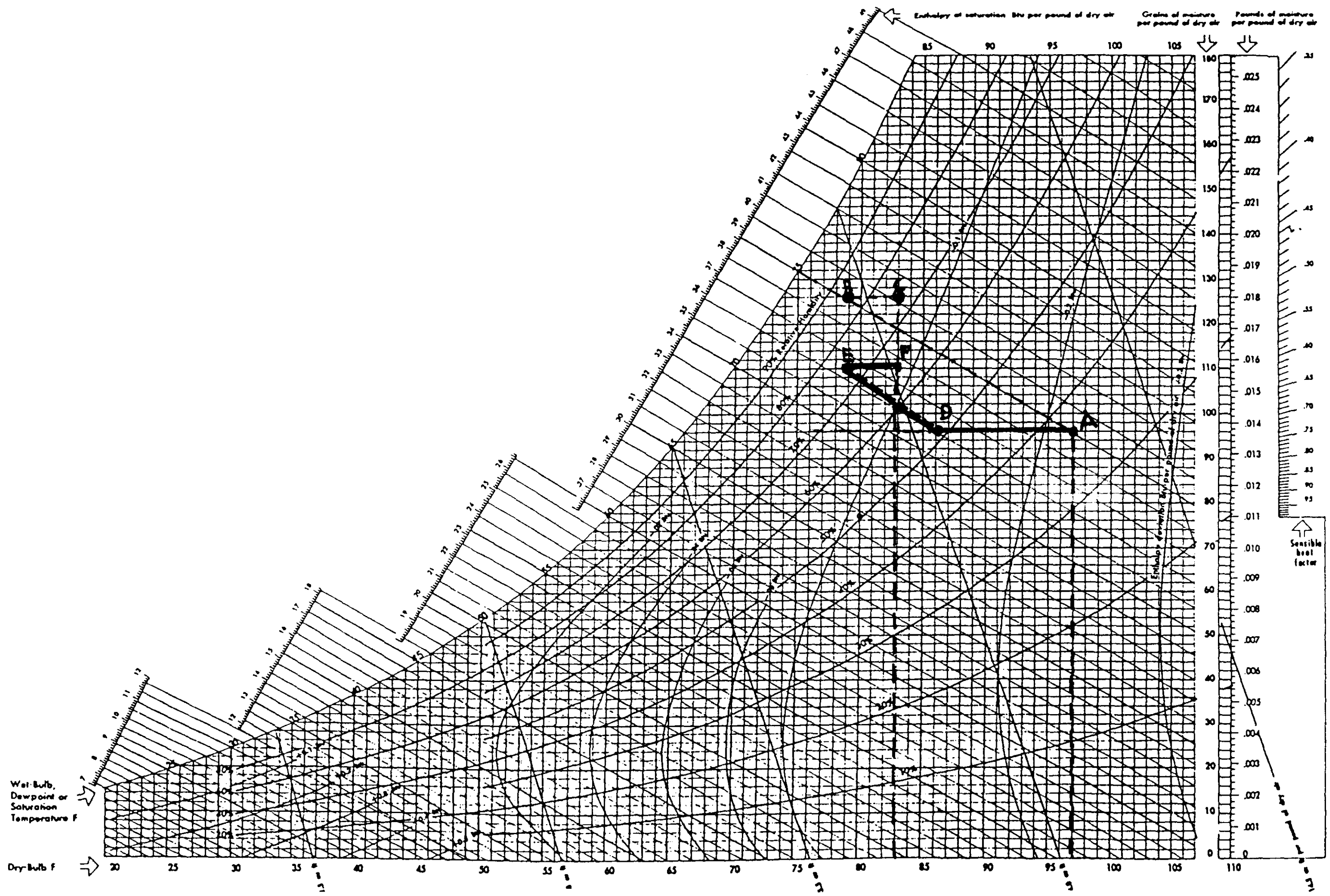


Fig.23. Plotting Two Stage Evaporative Cooling Process on Psychrometric Chart

where:

WBT **Wet Bulb Temperature.**

The temperature shown by a thermometer with a wetted bulb, rotated rapidly in the air to cause evaporation of its moisture. In dry air, the moisture evaporates and draws heat out of the thermometer to produce large wet bulb depression (difference between dry and wet bulb temperatures). This is an index of low relative humidity.

DBT **Dry Bulb Temperature.**

The temperature of the ambient mixture of air and water vapor measured in the normal way with a simple thermometer.

C.2.3. Sizing the Evaporative Cooler

C.2.3.1. Using 2-stage Evaporative Cooling System

Final air temperature and relative humidity = DBT=83°F, and RH= 65%

Q = peak heat gain for one hour (latent & sensible)

= 34,265.4 Btu/hr/4 apt.

Therefore,

Q = peak heat gain for one hour for one apartment (latent and sensible)

= 8,566.35 Btu/hr.

This constitutes the amount of heat that will be absorbed from each apartment by evaporation. When sizing the evaporative cooler, we need to know the outside air flow rate: **cfm** *(cubic foot of air per minute),* which can be found by the familiar ventilation formula [McGuiness & Stein '86]:

Q = cfm x 1.08 x Δ**t**

cfm Rate of heat flow needed to remove the heat from the room.

Q Sensible cooling provided by evaporative cooler.

Δt The difference between supply and exhaust air temperatures within the space. As the supply of air draws heat from the space, it will increase its temperature by 4°F.

1.08 A constant derived from the density of air at 0.075 lb/cu.ft under *average* conditions, multiplied by the specific heat of air (heat required to raise 1 lb of air 1°F); 0.24 Btu /lb °F, and by 60 min/h. The units of this constant are Btu min/cu.ft °F h.

Q = 8,566.35 Btu/hr

Δt = 4°F

[1] **Therefore, Rate of air flow (cfm) per one apartment when operating the cooler one hour:**

CFM = **1982** (equals the rate of air flow of one manufactured evaporative cooler)

[2] **Air change per hour**

By passing the cooled air directly to the space, the air change/min becomes:

ACM = 1982/ (5600 cu.ft/apt.)

= 0.353

ACH = ACM x 60

= **21.2** (air change per hour)*

[3] **The Supply Register's "Face Area" size for each unit:**

The supply register's "face area" = cfm / maximum face velocity

= 1982/ 750

= **2.6 sq.ft**

**With such flow rate, supply openings should be sized to avoid excessive air velocity (assuming maximum face velocity of 750 fpm).*

C.2.3.2. Using Indirect Evaporative Cooler only [fig.24]

Final temperature and relative humidity = DBT= 87°F, and RH50%

	BDT	RH%	WBT
A Outside conditions (day time)	97	35	75
D After the cooling process through the heat exchange of the first stage	87	50	72

since **Q = CFM x 1.08 x Δt**

where **Q** = 8,566.35 Btu/hr

Δt = 8°F (explained in indirect cooling in 2-stage evaporative coolers)

[1] Therefore, Rate of air flow (cfm) per one apartment when operating the cooler one hour:

cfm = 991.4

[2] Air change per hour

If evaporative cooled air flows directly to the space,
the air change/minute becomes:

ACM = 991.4/(700x8 =5600 cu.ft per apt.)
= 0.177
ACH =**10.62**

[3] **The supply register's face area size for each unit:**

= 991.4/ 750
= **1.32 sq.ft**

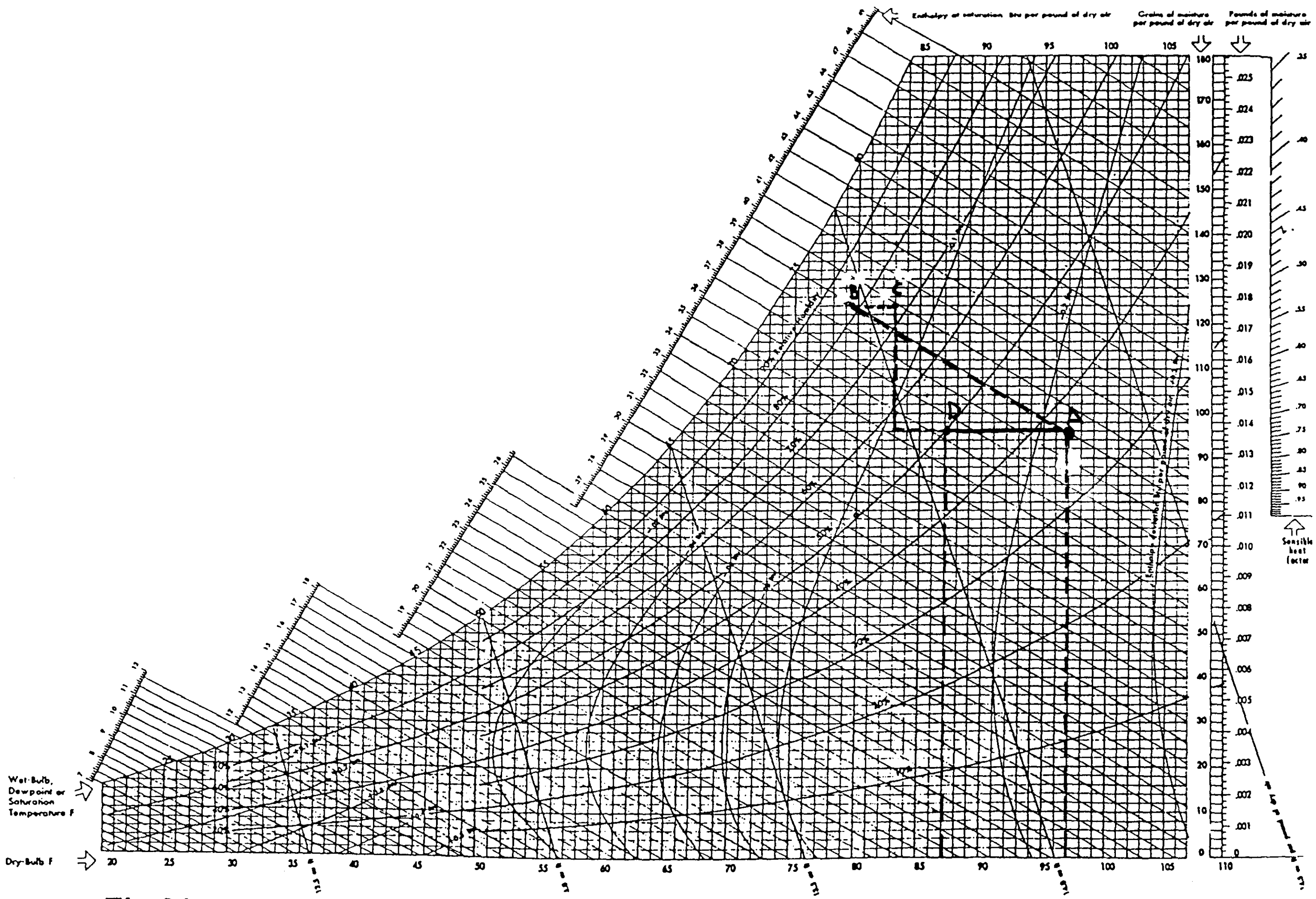


Fig.24. Plotting Indirect Evaporative Cooling Process on Psychrometric Chart

C.2.4. Stack-Effect Ventilation by Means of the Solar Chimney System*

The evaporation process could be accomplished by the use of a fan's or a solar chimney's power of suction (stack effect ventilation). Earlier in this chapter, we calculated how many evaporative coolers are needed for each apartment in order to achieve a reasonable/comfortable temperatures and relative humidity inside the dwelling (RH 50%; T DB87°F in case of indirect evaporative cooling, and RH 65%; TDB = 83°F in case of two stage evaporative coolers).

From these results, we have concluded that only one evaporative cooler for each apartment (with 1982 cfm) can cool the dwellings . At night time the buildings' windows are opened to cross ventilation. Fans or solar chimney can be used if there is no wind. However, the question remains whether we can use the solar chimney instead of the fan, and what would be the suction power of either one. Will the sun bless us with this free power of cooling and moving air into the dwellings? Is it feasible to operate the solar chimney at night to act as a fan and work by the laws of stack-effect ventilation?

C.2.4.1. Design Decisions with Respect to Building Materials of the Solar Chimney

As explained before in chapter.1, the solar chimney is basically a solar radiation trap, it acts like a solar heat collector. Careful choice of surface material for this solar chimney is of prime importance, and that is in order to ensure best heat absorption. Air (inside the solar chimney) is heated by convection, and indirectly by the emitted long wave solar radiation from surrounding surfaces. Sol-air temperature** is a good indicator for heat absorption. Absorption of different materials will be examined in the following section:

**Refer to chapter one for stack effect ventilation with solar chimney*

** *Sol-air temperature measures the combined effect of solar radiation and ambient air conditions of surfaces.*

$$\text{Sol-Air Temperature} = \textit{outside temp.} + \frac{\textit{absorption of surface} \times SHGF^{*}(\textit{transmission}.88)}{\textit{wind coefficient of convection} = 3.0\ BTU/h\ sq.ft}$$

$$- \frac{\textit{back radiation loses to the sky vault} \times \textit{Emissivity of surface}}{\textit{wind coefficient of convection} = 3.0\ BTU/h\ sq.ft}$$

Concrete **has heat capacity of 29.4 BTU/cu.ft. When coated with a matt black paint its absorbance will be equal to 0.90 with high emissivity***; typically 90% [Johnson '81]..

Sol-air temperature For ***Black painted concrete surfaces*** $= 97 + \frac{0.90\times(280/0.88)}{3} - \frac{15\times0.90}{3} = \mathbf{187.95°F}$

Shiny metals have low emissivity (absorption in the infra red); typically 10-15 % [Johnson '81].

Sol-air temperature For ***Galvanized steel*** $= 97 + \frac{0.25\times(280/0.88)}{3} - \frac{15\times0.25}{3} = \mathbf{121.75°F}$

Selective surfaces are highly reflective surfaces treated chemically to combine low emissivity with their high absorptivity. This treatment is based on the deposition of a very thin layer of a black metallic oxide over highly reflective surfaces, or the deposition of successive very thin layers of reflecting and transparent materials. In this way, the interference effect, which occurs between two reflective layers separated by a transparent layer of the proper thickness, is utilized to reduce the emission of long-wave radiation without big reduction in solar absorption [Givoni '76]

**SHGF : is the solar heat gain factor. [Ref. McGuiness / appendix]*

***Black painted concrete surfaces is the best affordable surface that can be selected to insure high air temperature inside the solar chimney. Air temperature inside the solar collector ±5 °F = 182 °F. In Egypt (April 1989) 1 m 3 of ordinary concrete costs 70 Egyptian pounds.*

****Absorption into the far infra-red. It is a measure of how easily radiation can escape from a surface [Johnson '81].*

Sol-air temperature for Selective ***surfaces*** $= 97 + \dfrac{0.90 \times (280/0.88)}{3} - \dfrac{15 \times 0.25}{3} = \mathbf{191.2°F}$

Sol-air temperature for tinted ***gray glass**** $= 97 + \dfrac{0.30 \times (280/0.88)}{3} - \dfrac{15 \times 0.90}{3} = \mathbf{124°F}$

Black painted Building Material (such as concrete ,or any other building material) are the best affordable surfaces that can be selected to insure high air temperature inside the solar chimney. Air temperature inside the solar collector is no greater than 182°F, and actually somewhat less due to the slight air movement through the voluminous sections of the glass solar chimney.

C.2.4.2. Velocity of Air Inside the Duct Due to the Stack Effect (for fifth floor)

The air velocity (inside the duct) that is induced in a chimney due to the buoyancy forces is a function of its height and difference in temperature of the outlet (where a solar collector can be used to elevate the air temperature), and the inlet (the inside temperature of the house during day-time after the 2-stage evaporative cooler effect has taken place).

V	=	$9.4 \sqrt{(h \times \Delta t)}$ = feet per minute
h	=	35 .5 feet high for the fifth floor.
Δt	=	(182 - 83) = 99°F
V	=	$9.4 \sqrt{(35.5 \times 99)}$
	=	**557.26 ft/min.**

C.2.4.3. The Duct Size of the Solar Chimney

Peak heat gain for one apartment equals 8566.35 Btu, and accordingly, the duct size could be determined by according to the following formula:

Peak heat gain	=	velocity of air in duct x area of duct x 1.08 x Δt [Johnson '88].
8566.35	=	557.26 x area of duct x 1.08 x 4
Area of duct	=	**3.6 sq.ft** For each apt.

**In Egypt (April 1989) 1 sq.m of 6mm tinted glass costs 50 Egyptian pounds.*

C.2.4.4. Volume of Air Flow into the Solar Chimney for One Apartment (fifth floor)

Volume of air flow = velocity of air in duct x area of duct
= 557.26 x 3.6
= **2006 cfm**

The evaporative cooler needed for cooling one apartment needs volume of air flow equals to1982 cfm/apartment, so that the solar chimney can act like a fan needed for the evaporation process (only during the day).
At day-time Stack-effect ventilation is feasible. And hence, the question becomes how does the solar chimney operate, and how can we heat the air inside the chimney at night.

The following is a summary of my previous trial calculations to store the heat from the sun at day time and release it at night time. The storage of heat in water (for a 5-storey building) needs thousands of cubic feet of water to absorb enough solar heat for the day. This is obviously not feasible in this application for the limitation of space availability on the roof of the building. Storage of the solar heat in the thermal mass of the solar chimney, made with walls one foot thick, will only operate for seven hours after sunset. However, if we can provide a heat source (low cost energy source); such a common gas-Furnace appliance (which is relatively cheap in Egypt), we can supply this solar chimney with the amount of heat that is equivalent to 1800 Btu/day, keeping its stack effect working during night time.

Average sensible heat gain at night = 81,088 Btu
Average sensible heat gain at night per hour for one apartment =1,689.25 Btu/h

The following procedure examines the capability of the gas-furnace (used to heat the air inside the solar chimney)to remove average heat gain at night

Q = A x V (velocity of air in Solar chimney) x Δt_2 x 1.08
where **V** = 9.4 $\sqrt{(h \times \Delta t_1)}$
h = height of solar chimney = 3 5.5 ft. for the fifth floor

Assume that the gas furnace will produce heat that elevates the air temperature to 187°F ,while the air inside the house, at night time, will have temperature of 87°F.

Δt_1 = difference in temp. inside the solar chimney and inside the house = (187-87)°F
V = 560 ft / min
Δt_2 = difference in temp. inside and outside the house = (87-83)°F
A = area of the solar chimney duct = 3.6 sq.ft
Q = $3.6 \times (9.4 \times \sqrt{(35.5 \times \Delta t_1)}) \times \Delta t_2$
= 8,468.25 Btu /h

The gas furnace succeeded in removing night heat gain from the dwelling.The second step is trying to use the *gas-furnace* to assist the fans in further reduction to the air temperature.

Assume that the gas furnace will produce heat that elevates the air temperature (inside the solar chimney) to 400°F, while the air inside the house, at night time, will have temperature of 87°F.

Q = A x V (velocity of air in Solar chimney) x Δt_2 x 1.08
Δt_1 = 400-87 =313
V = $9.4 \sqrt{(h \times \Delta t_1)}$
V = 990.86 ft / min

Removed heat gain:

Q = 15,409 Btu/h

This gas furnace will remove night time heat gain, and will reduce the air temperature by 3.4°F and that will reduce the ***cfm*** needed for the fans which in turn reduce the electricity consumption of the fans.

C.3 .SCHEME THREE

Examining whether the use of a thermal mass (cored concrete slab) flushed with night ventilation can remove the average 12-hour heat gain at day time or not. Also, examining whether in case there is no wind at night time, together with the use a night time forced ventilation method, in order to flush the night time heat gain from the interior ceiling slab facing the space, or not.

In my observations; we can notice that ***scheme one*** failed to remove the twenty-four hour heat gain (closed and open modes)*. However, we notice that this *scheme one* can easily remove the average heat gain at day time during when the building is closed to the outside environment. At night, the building is open, **and the night-time heat gain is flushed away by forced ventilation** (calculated in scheme two).

when the column of air (inside the solar chimney) is heated by the sun, it rises to the outside of the chimney, and another column of cooler air replaces it. This air motion creates air flow inside the space.

C.4. SCHEME FOUR

Examining whether the use of a thermal mass (cored concrete slab) flushed with night ventilation will remove the 12-hour heat gain at day time or not.

We use the night time forced ventilation method in order to flush the night time heat gain from the interior ceiling of the slab facing the space (in case there is no wind at night time). We also use of the minimum power evaporative cooling (2-stage & indirect evaporative coolers) during the day to remove the instantaneous peak heat accumulation.

C.4.1. Designing Decisions with Respect to Building Materials of the Solar Chimney

Concrete has heat capacity of 29.4 BTU/cu.ft, when coated with a matt black paint. Its absorbance will be equal to 0.90 with high emissivity (typically 90%).

Sol-air temperature for black ***painted concrete surfaces*** $= 97 + \frac{0.90 \times (280/0.88)}{3} - \frac{15 \times 0.90}{3} = \mathbf{187.95°F}$

C.4.2. Velocity of Air inside the Duct Due to the Stack Effect (for fifth floor)

$V = 9.4\sqrt{(h \times \Delta t)}$ = feet per minute

h = 18 feet high for the fifth floor.

$\Delta t = (182 - 83) = 99°F$

$\mathbf{V} = 9.4\sqrt{(18 \times 99)}$

$= \mathbf{396.8}$ **ft/min.**

C.4.3. The Duct Size of the Solar Chimney

Since the night ventilation of the cored slab removes the average (sensible) heat gain at day-time, we need to remove the instantaneous peak heat gain (sensible and latent).

The **peak heat gain** for one apartment = 8,566.35 Btu/h (1)

and the **average heat gain** removed by night forced ventilation = 6,978.325 Btu/h (2)

Therefore, the peak heat that should be removed each hour = (1) - (2) =1,588 Btu/h

Hence, the duct size would be determined according to the following formula:

Hence, the duct size would be determined according to the following formula:

Peak heat gain to be removed	=	velocity of air in duct	x area of duct x 1.08 x Δt
1,588	=	396.8	x area of duct x 1.08 X 4
Area of duct	=	**0.9 sq.ft** (for one apt.)	

C.4.4. Volume of Air Flow into the Solar Chimney for One Apartment (fifth floor)

	=	velocity of air in duct x area of duct
	=	396.8 x 0.9
Volume of Air flow	=	**357 cfm**

By passing the cooled air directly to space:

Air change/ min.	=	357 / (5600 cu.ft/apt.)	= 0.06
Air change per hour	=	3.9	

C.5. Summary for Designing the System

C.5.1. SOLAR CHIMNEY

For Scheme-two:

- Duct size for each apartment = 3.6 sq.ft
- Velocity = 557.26 ft/min.
- Rate of air flow/unit (5th floor) = 2006 (cfm: cubic feet of air per minute)
- Height of solar chimney's =35.5 ft

C.5.2. EVAPORATIVE COOLER

- rate of air flow in evap. cooler (in one tower at 5th floor) needed for cooling = 1854 cfm/apt.
- When using the in-direct evaporative cooler duct size for the cooling tower = 1.3 sq.ft/one apt.
- When using the 2-stage evaporative cooler duct size for the cooling tower = 2.6 sq.ft/one apt.

C.5.3. SOLAR CHIMNEY For Scheme-four:

- Duct size for each apartment	= 0.9 sq.ft
- Velocity	= 398 ft/min.
- Rate of air flow per unit (5th floor)	= 367 (cfm: cubic feet of air per minute)
- Height of solar chimney	=18 ft

C.6. Evaluation of the Four Cooling Schemes

Scheme one

Did not succeed in removing the average 24- hour heat gain

Scheme three

Succeeded in removing the average 12-hour average heat gain at day time, but could not remove the heat in peak gain conditions.

Scheme two

Ideal for retrofit (redesigning the existing apartment to be cooled passively and/or by low energy cooling). The scheme relies on two sources of energy (electricity* at night and the power of the sun (at day time) that will drive the stack-effect ventilation in the solar chimney). This scheme removes not only the average heat gain, but also peak heat gain.

Some of the drawbacks of this scheme are the relatively big area of ducts that are used for the solar chimney system and the cooling tower, as well as the big height of the solar chimney which rises two floors above the roof.

**These are fans that produce volumetric heat flow rate of 1000 cfm (cubic foot per minute); 700 sq.ft for each apartment,to remove the night heat gain: In Egypt (April 1989) low energy fan (3000 cfm) costs about 40 Egyptian pounds, and one Kilo-watt per hour of electricity costs 0.05-0.07 Egyptian Pounds.*

Scheme four

Ideal when used as a cooling solution integrated in the Architectural design of a new building. Just like scheme-two, this scheme also relies on two sources of energy (electricity* at night and the power of the sun, at day time, that will drive the stack-effect ventilation in the solar chimney), in order to remove not only the average heat gain, but also the peak building heat gain. This scheme has many advantages:

The slab is relatively light in weight, and this in turn reduces the dead load that affects the size of the columns and foundation. The cored slab ceiling can take many configurations in term of fabrication; it can be a pre-fabricated cored slab; reinforced concrete slab with embedded air ducts; or hollow-block** ceiling with custom made blocks that have the desired dimensions that corresponds to the slab cores calculated previously.

The biggest advantage of this scheme is the relatively small size ducts used for the solar chimney and the cooling tower, as well as the small height of the solar chimney (rises only one floor above the roof) .The only drawback, from my point of view, is the negative aesthetical effect this cooling scheme casts on the facade, especially the cored slab that should have an opening to the outside environment.

**Fans that produces volumetric heat flow rate of 12,000 cfm (cubic foot per minute) 700 sq.ft for each apartment, to remove the night heat gain, and another 1000 cfm [forced night time ventilation through the cored ceiling slab] to remove the day time average heat gain from each apartment.*

***In Egypt (April '89) the price of 1 cu.mt of R.C. slab is 220-230 Egyptian Pounds, and 1 cu.mt of hollow blocks is 90 Egyptian Pounds*

CHAPTER FOUR
DESIGN SYNTHESIS
A MULTI-STOREY BUILDING IN CAIRO/EGYPT

THE CONTEXT

Egypt is a highly over-urbanized country, where its entire population (54 million inhabitants) live on only 4% of the land's area. The rest of the country is a barren arid desert. This over urbanization situation resulted in a severe housing crisis formulated in two major dimensions [Beshara '81]: *An enormous housing deficit;* where 3.6 million household units should be built between 1981 and 2000 [Molt '80]. *Affordability;* where the enormous gap between the cost of housing supplied and the ability of the majority of housing demand group to pay is growing.

To face this sharp, political and economical, problem the government started adopting Industrialized building systems techniques as a means of providing mass numbers of housing units. While modular coordination and standardization were practically the major guiding lines for designing those "industrialized" building, unfortunately, environmental considerations were never accounted for. Accordingly, this thesis stresses the effects and impacts of those environmental issues. In this chapter, the technical analysis for the two previously selected schemes is formulated as *architectural design sketches*.

The chosen housing type for both schemes [found out to be widely used in and around Cairo [Cairo University & MIT '79], is a traditional 5-storey walk-up building with a core stair case that serves four apartments per floor. Both schemes are designed to operate independently, regardless of orientation.

For the redesign of this building type, ***Internal Flexibility*** shall be stressed upon for the given architectural plan: The possibility of having different configurations for a floor plan, where areas of each unit may vary, will be a guiding theme, together with the quantitative criteria for passive cooling system design. This particular criteria has an impact on the interior, as well as, the exterior of the building (as we shall see in the provided drawings). It can always result in a continuous FORM change and generation processes.

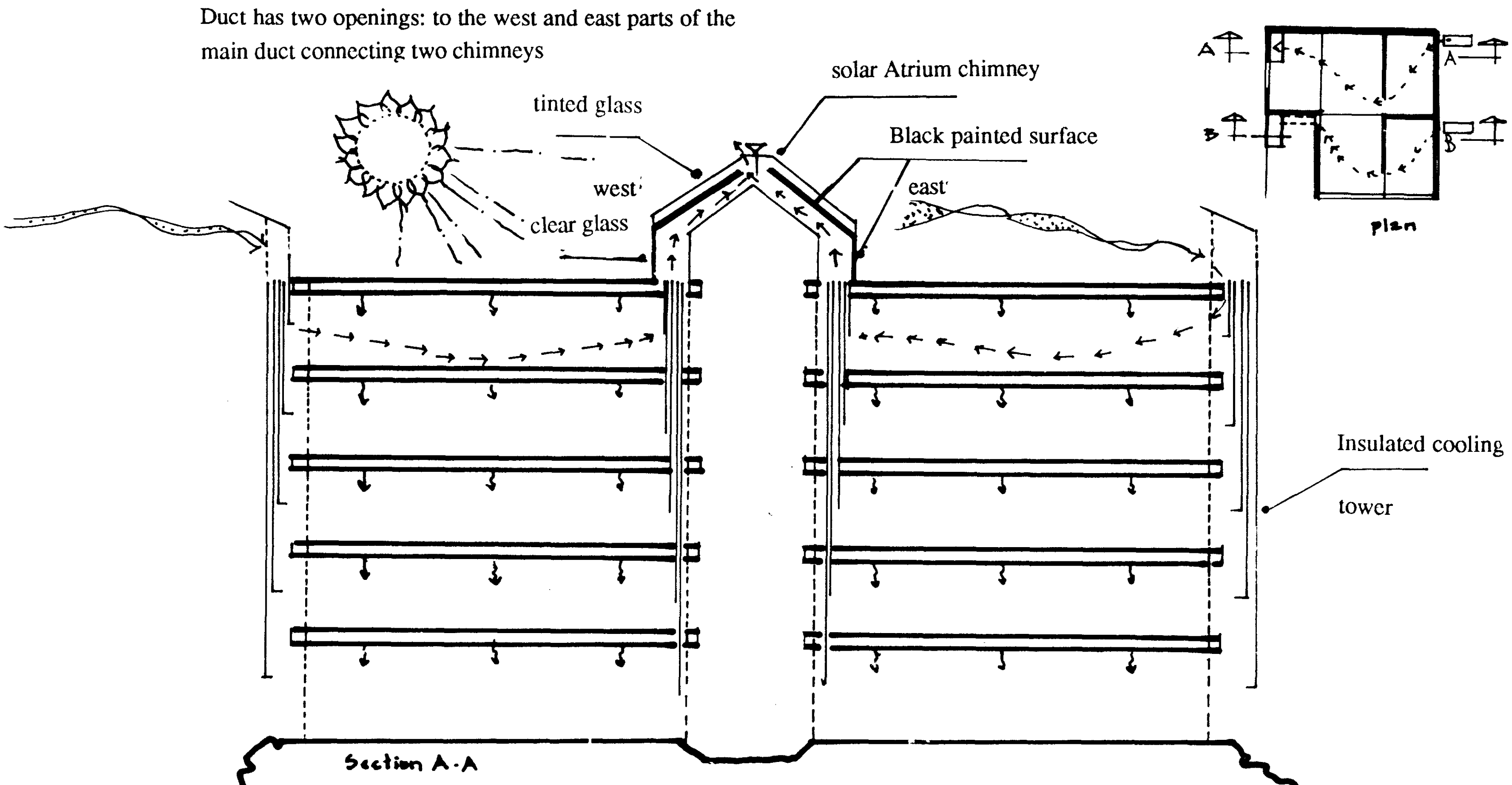
Note that the forth-coming illustrations and sketches for ***scheme four*** (application of this cooling system to new building) are in figures 25 to 43. Figures 44 to 45 are for ***scheme two*** (application of cooling system to redesigned existing building).

Scheme Four (for new building)

This is characterized by a general internal flow configuration of a building ventilated and cooled at day time by means of the solar atrium chimney system. Illustrated are the cooling tower, the insulated cold air shaft, the conditioned interior space, and the solar atrium chimney.

The solar chimney comprises an east and west facing solar air heaters and insulated hot air shaft. The solar air heaters are rectangular in plan with their long sides facing east and west. The cooling appliance (evaporative coolers) cools the incoming air below the outside air temperature, which in turn causes the air being cooled to fall. The pressure differential created in the cold shaft is called ***"theoretical draft"*** [Haisley '81], as in the case of the solar chimney. At night time, forced ventilation is used through cored concrete slabs.

Scheme Four



Day and night operation are completely separated; which means that the ventilation of cored slab at night time will not play any role in the cooling system at day time. This decision of separating the two operations was made because of the unpredicted level of relative humidity that could damage the plastering, and could also be responsible of Mildew or wet spots on the ceiling if it exceeds the average percentage (refer to chapter three for description of this scheme).

Fig.25. Scheme Four achieved by the solar Atrium chimney which pulls the air by suction forces

in order to achieve the best cross ventilation throughout the whole apartment, air can be pulled through the duct to the solar chimney.

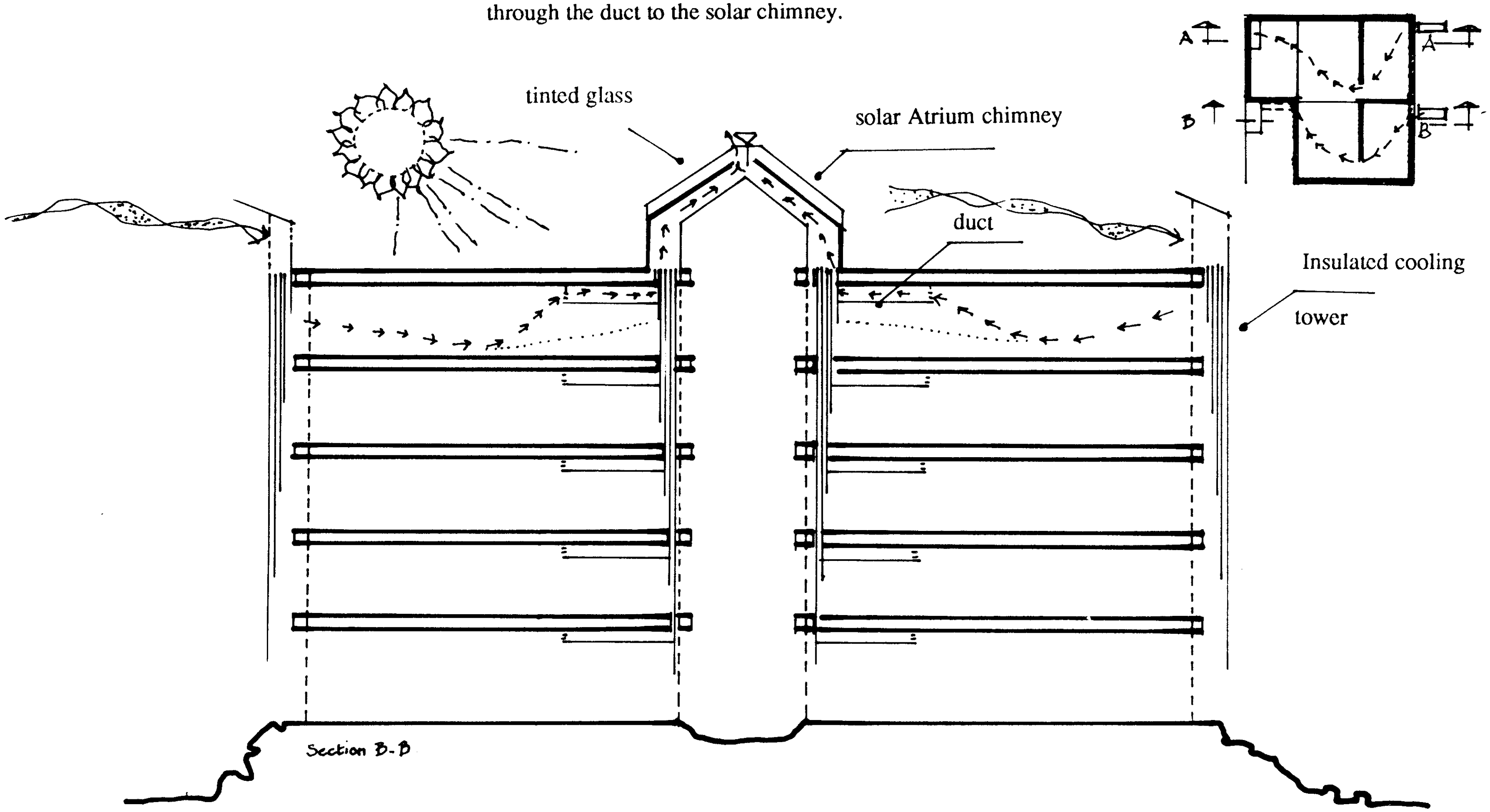


Fig.26. Day-time Operation (for better cross ventilation)

Scheme Four

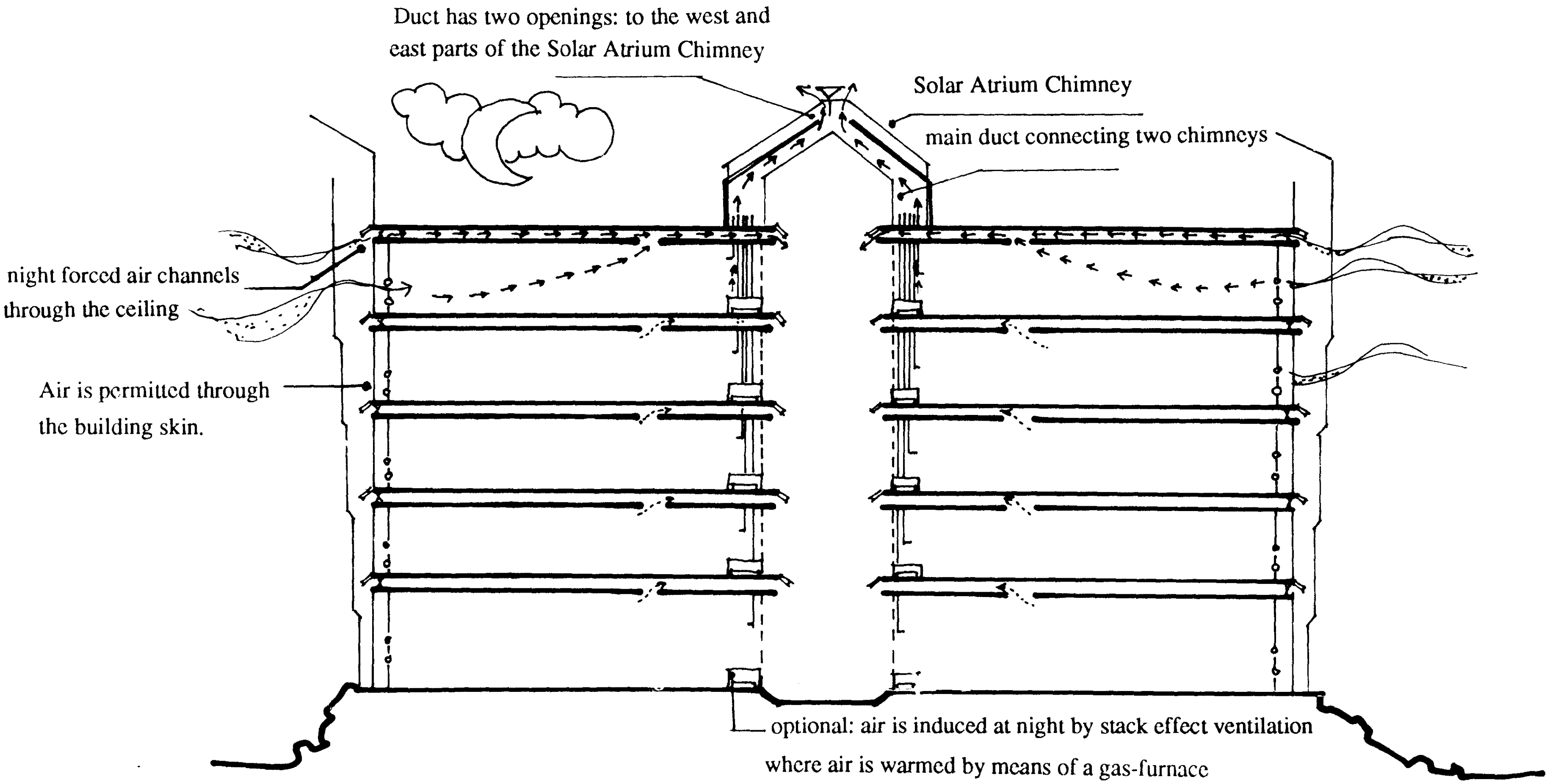


Fig.27. Night-time Operation (opened mode)
showing optional solution

Design building's elements that act like cooling devices such as:
Cored concrete slab
wall openings
Cooling tower
Solar chimney

Design of building's elements

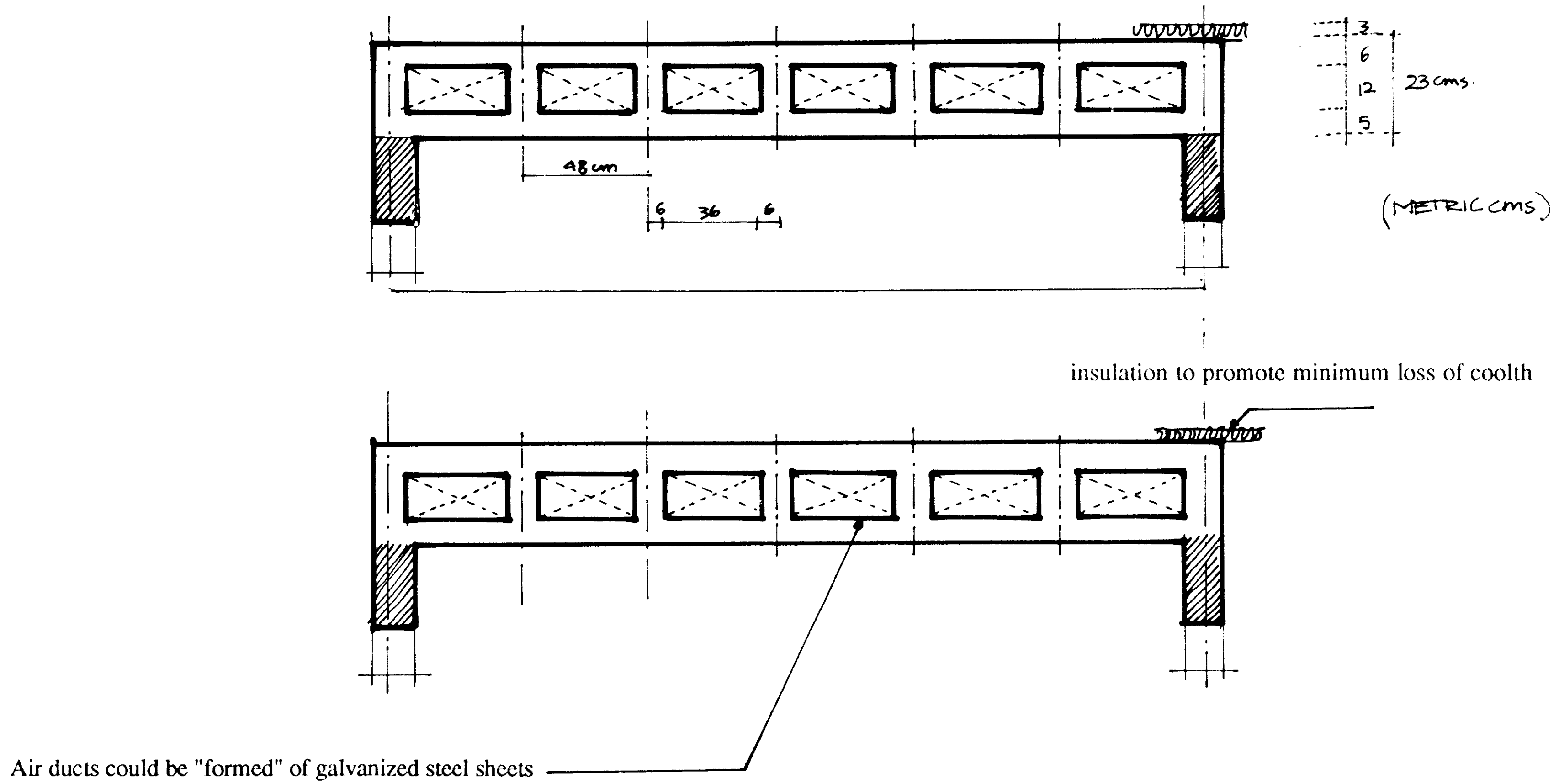


Fig.28. Cored Concrete Slab (used as one of the cooling devices)

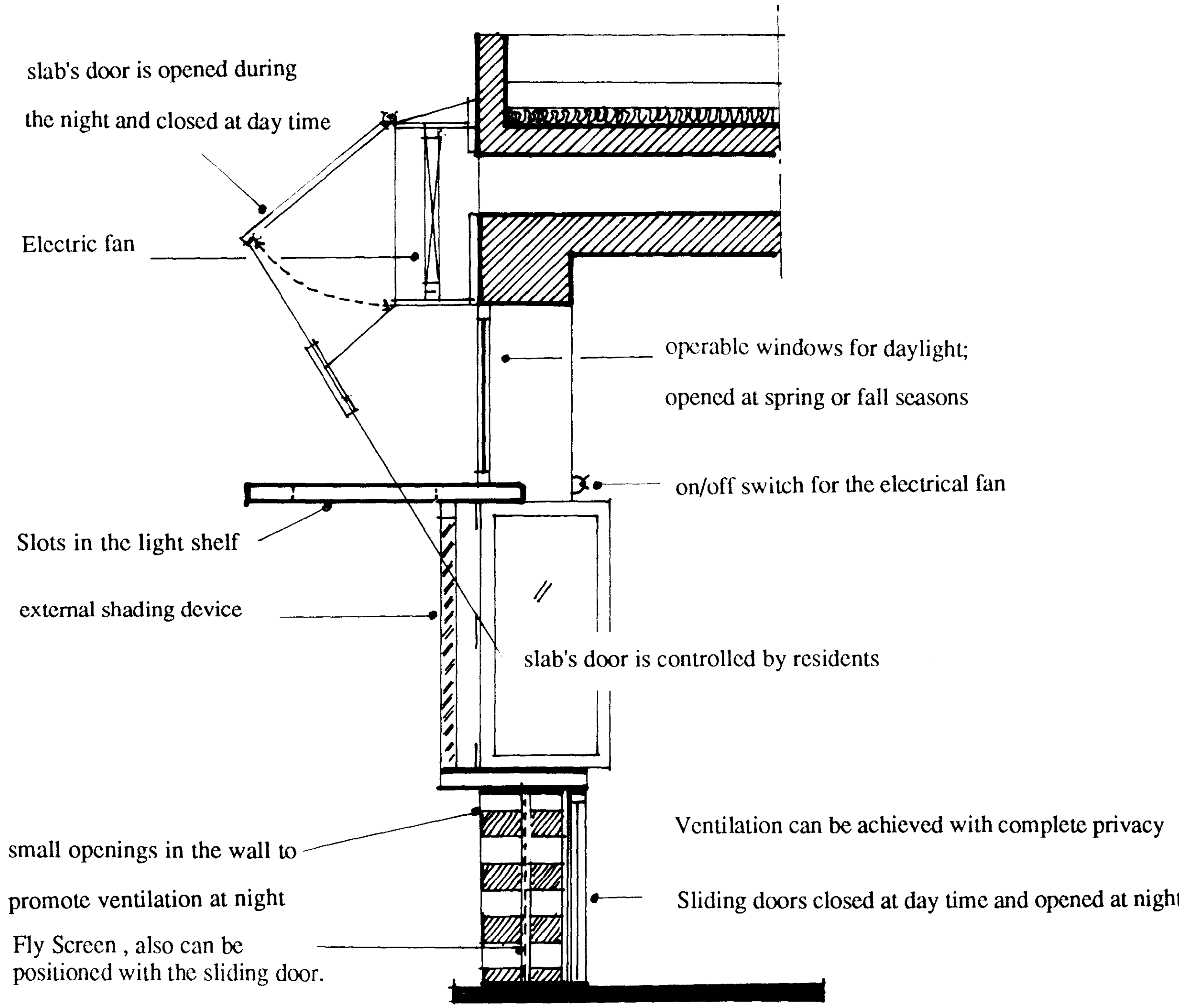


Fig.29. Section through External Wall (showing operation of its openings)

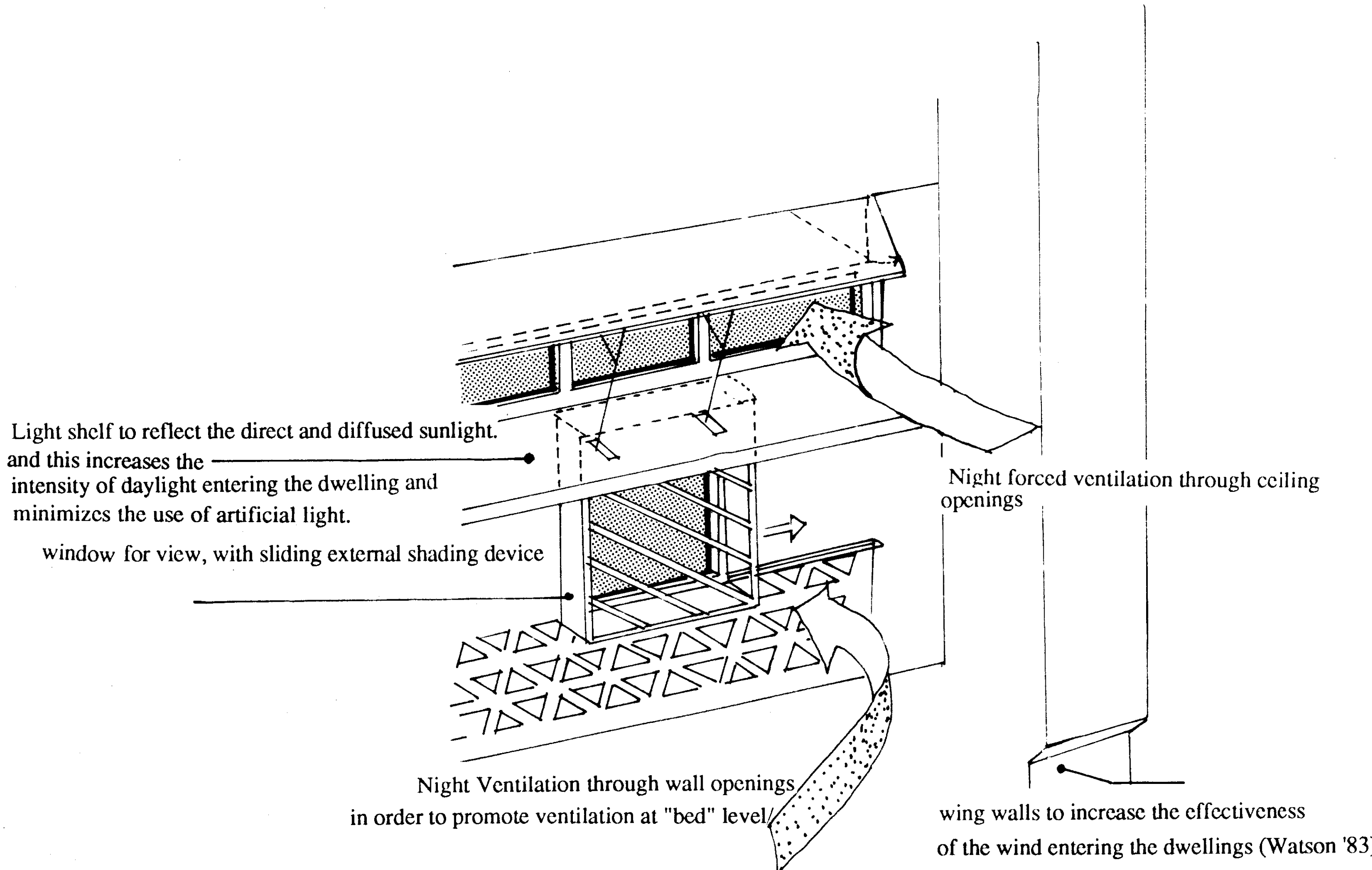


Fig .30 . Window Design

Windows' function is to promote daylight, view, and ventilation. Here, for these three functions of the window, there are three different openings

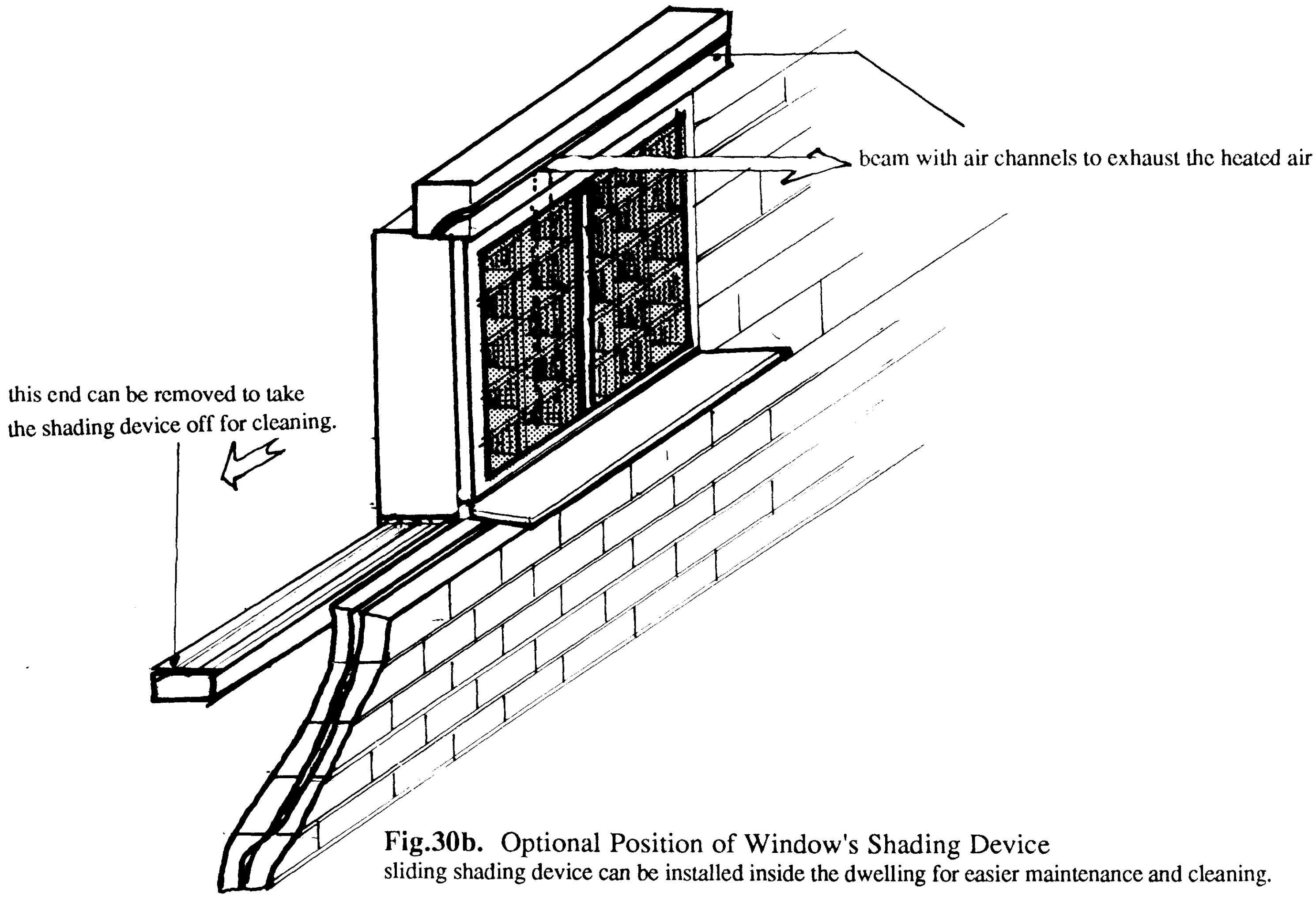


Fig.30b. Optional Position of Window's Shading Device
sliding shading device can be installed inside the dwelling for easier maintenance and cleaning.

Designing the cooling tower :
As an introduction the two - stage evaporative cooling process, and different types of heat exchangers will be explained .

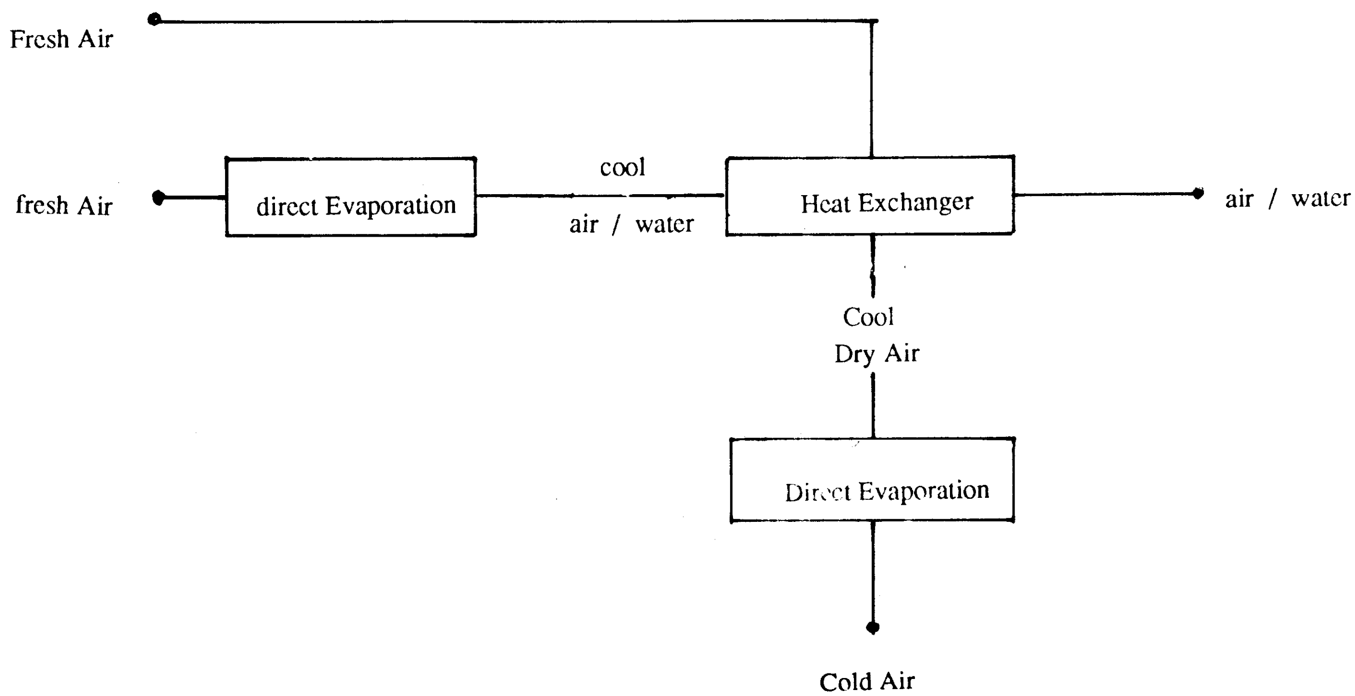
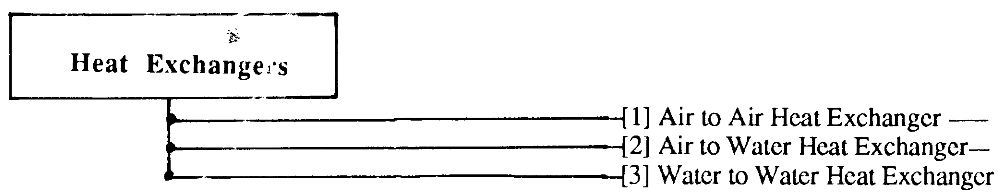


Fig . 31. Diagrams of Two-Stage Evaporative Cooler



Air to Air Heat Exchangers

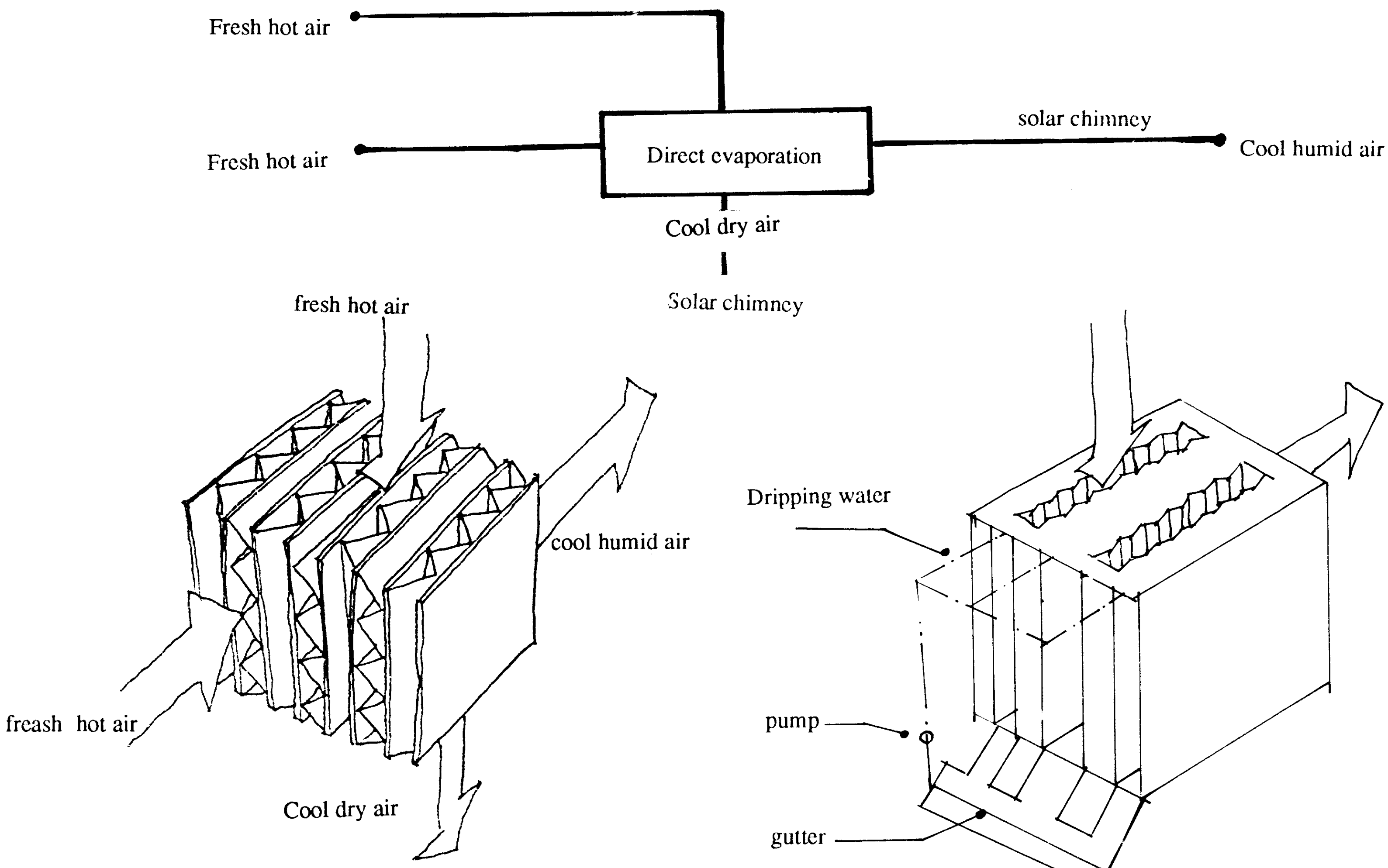


Fig . 32 . Air to Air Heat Exchanger

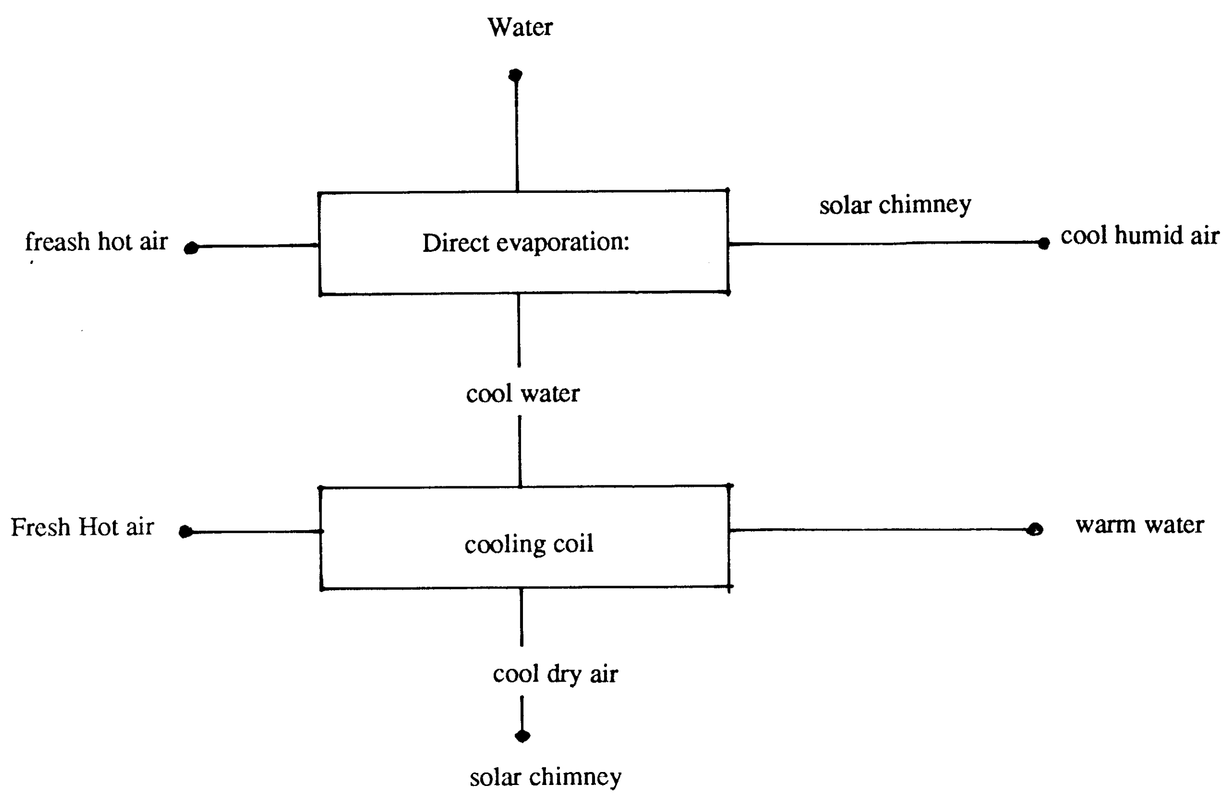


Fig .33 . Water to Air Heat Exchangers

Final design of the cooling tower using two types of " Heat Exchangers".

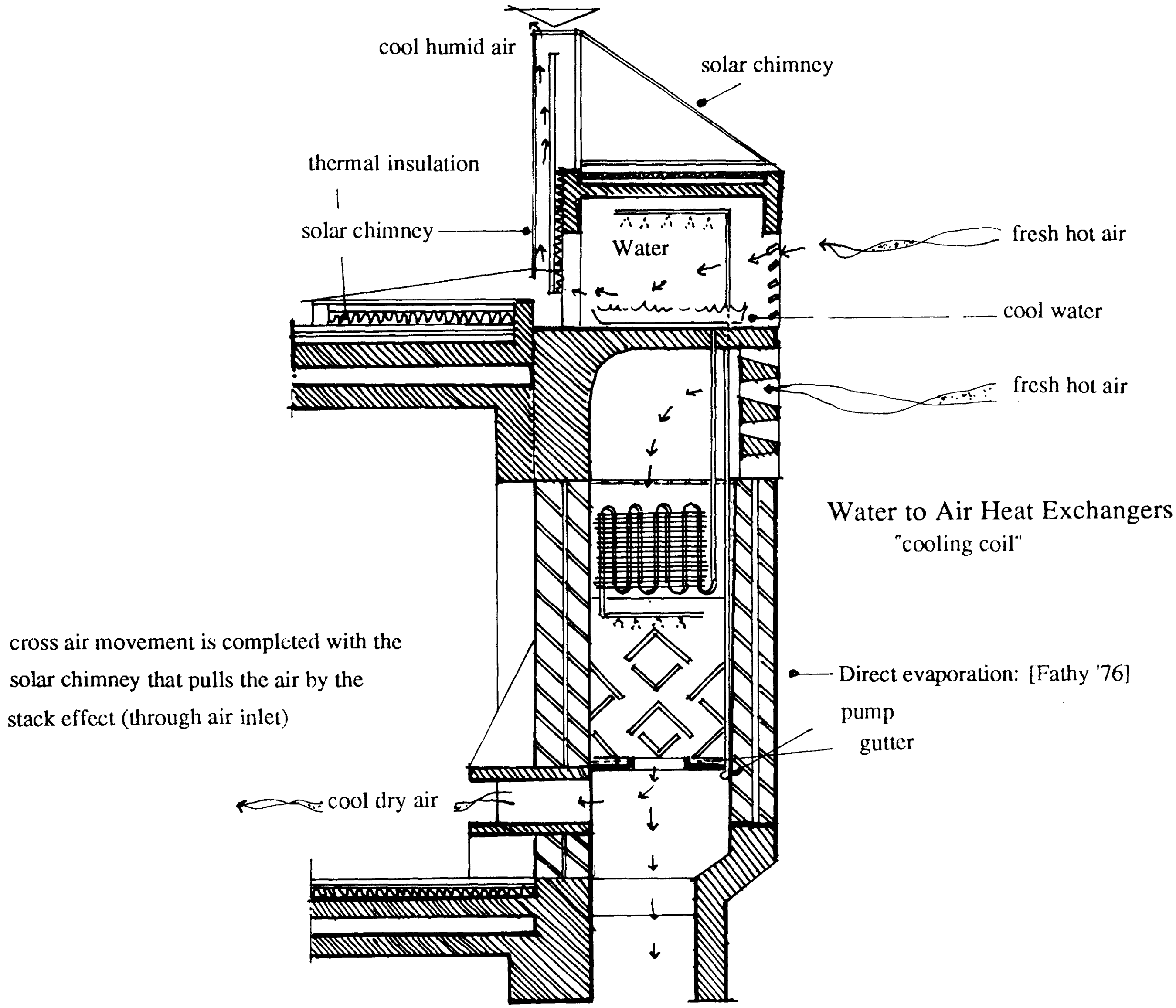


Fig .34 . Schematic Design of the Cooling Tower Using Air to Water Heat Exchanger

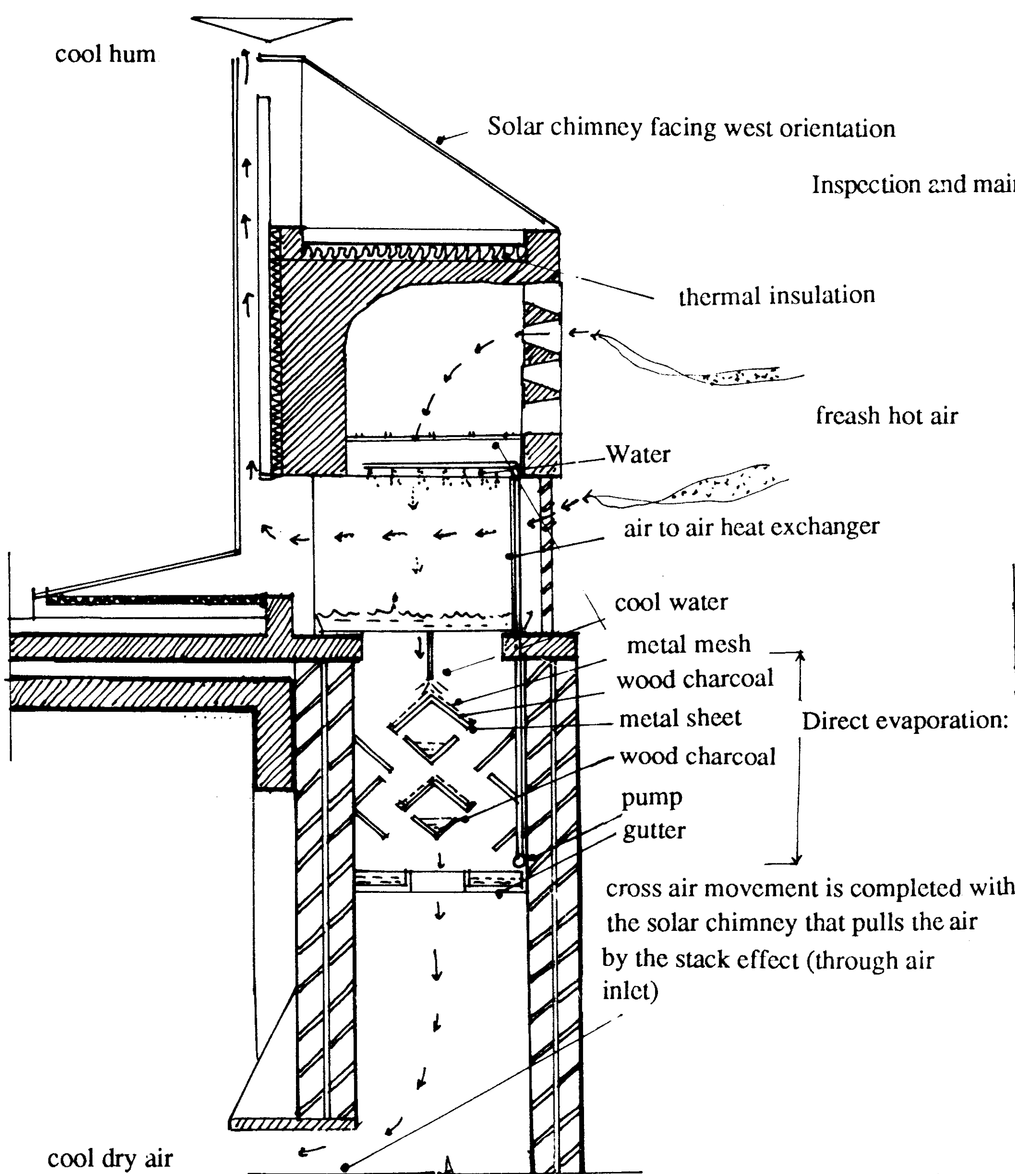


Fig.35a. Schematic Design of the Cooling Tower Using Air to Air Heat Exchanger

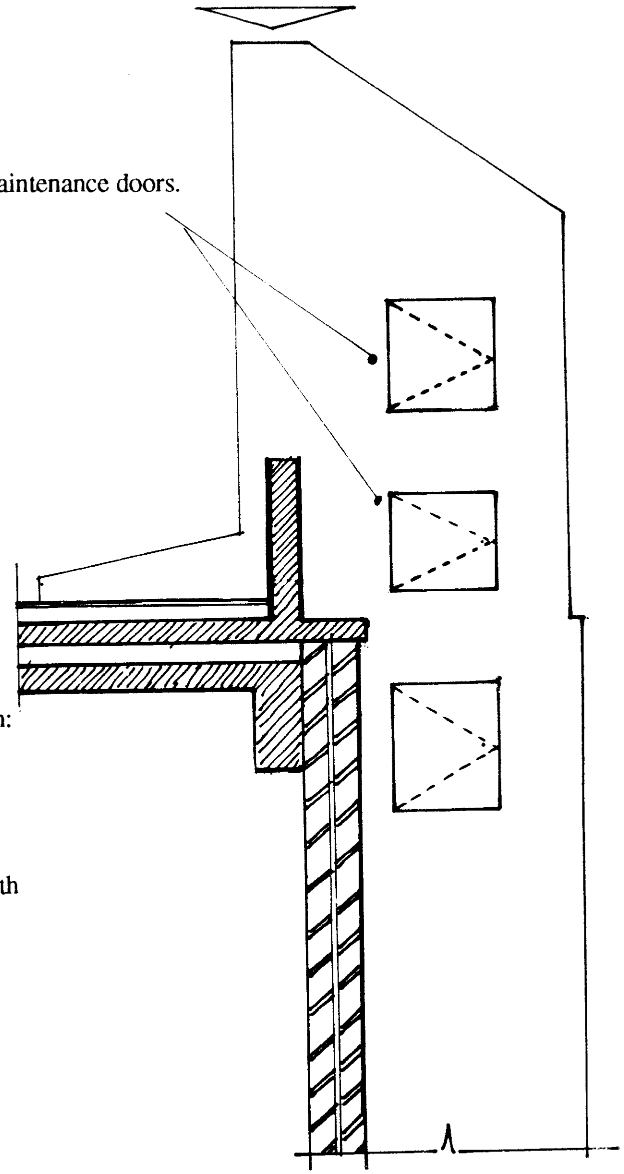
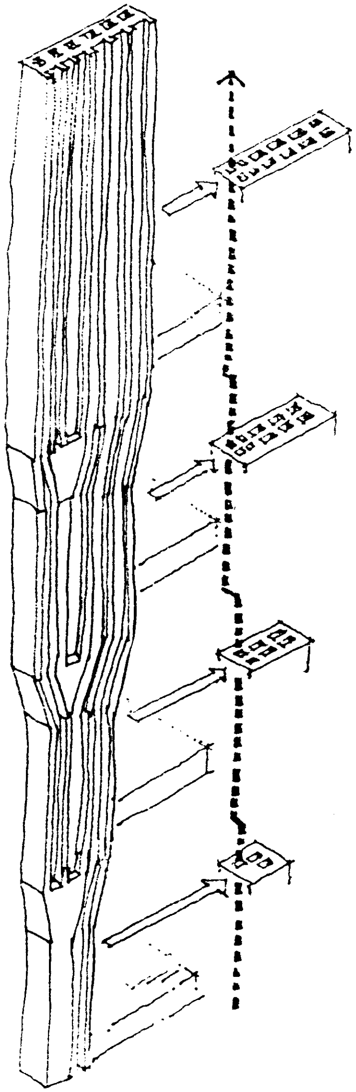


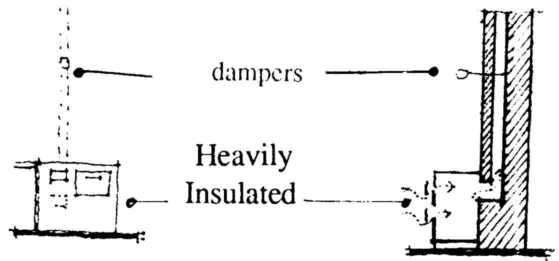
Fig . 35 b . Side-view of the Cooling Tower

Design of solar chimney risers for the atrium court.

Construction of a natural Ventilation system



Natural ventilation system using the kitchen range



Normal flow conditions; wood fired kitchen range (Erikson '86)

A natural ventilation system that can be used for night ventilation in the absence of the sun .
Refer to chapter three for details of ventilation using the gas furnace.

schematic of
Multi-story residential building with natural ventilation

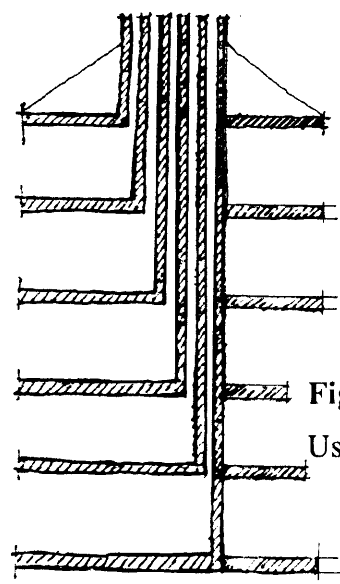


Fig.36. Natural Air Movement Using Chimney [Erikson '86]

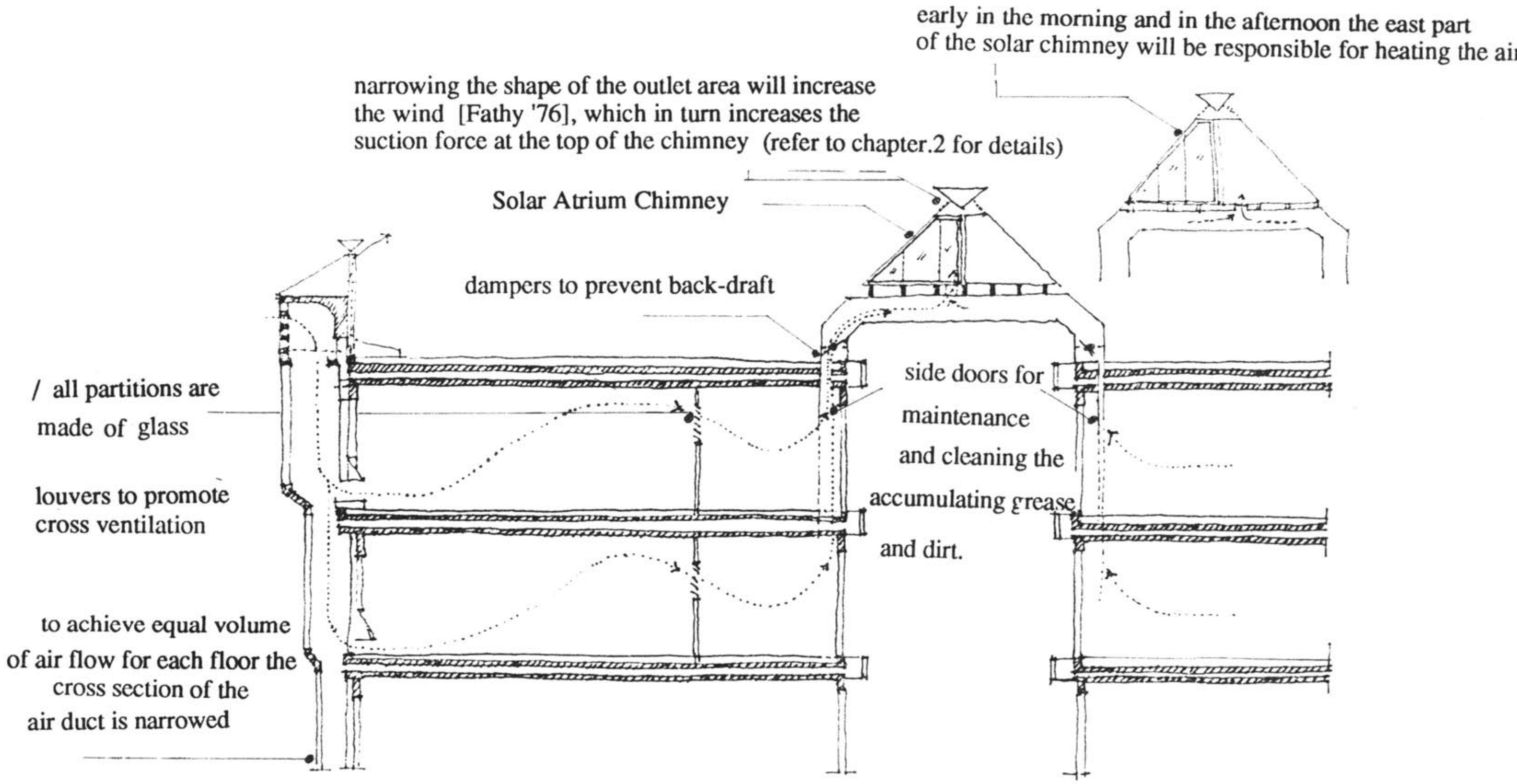


Fig.37. Operation of the Cooling Scheme
Late afternoon: where the west part of the solar
atrium is responsible for heating the air.

Fig.38. Original Plan of the Selected Multi-Story Building

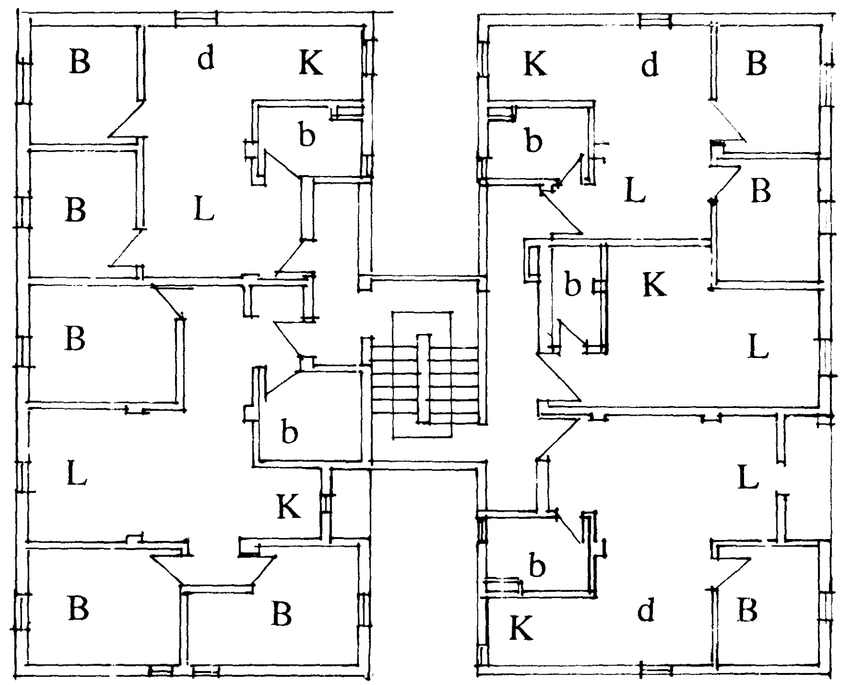


Fig .39 . Plan Alternative Design after Applying "SAR Method"
(Cairo University & MIT, 1978)

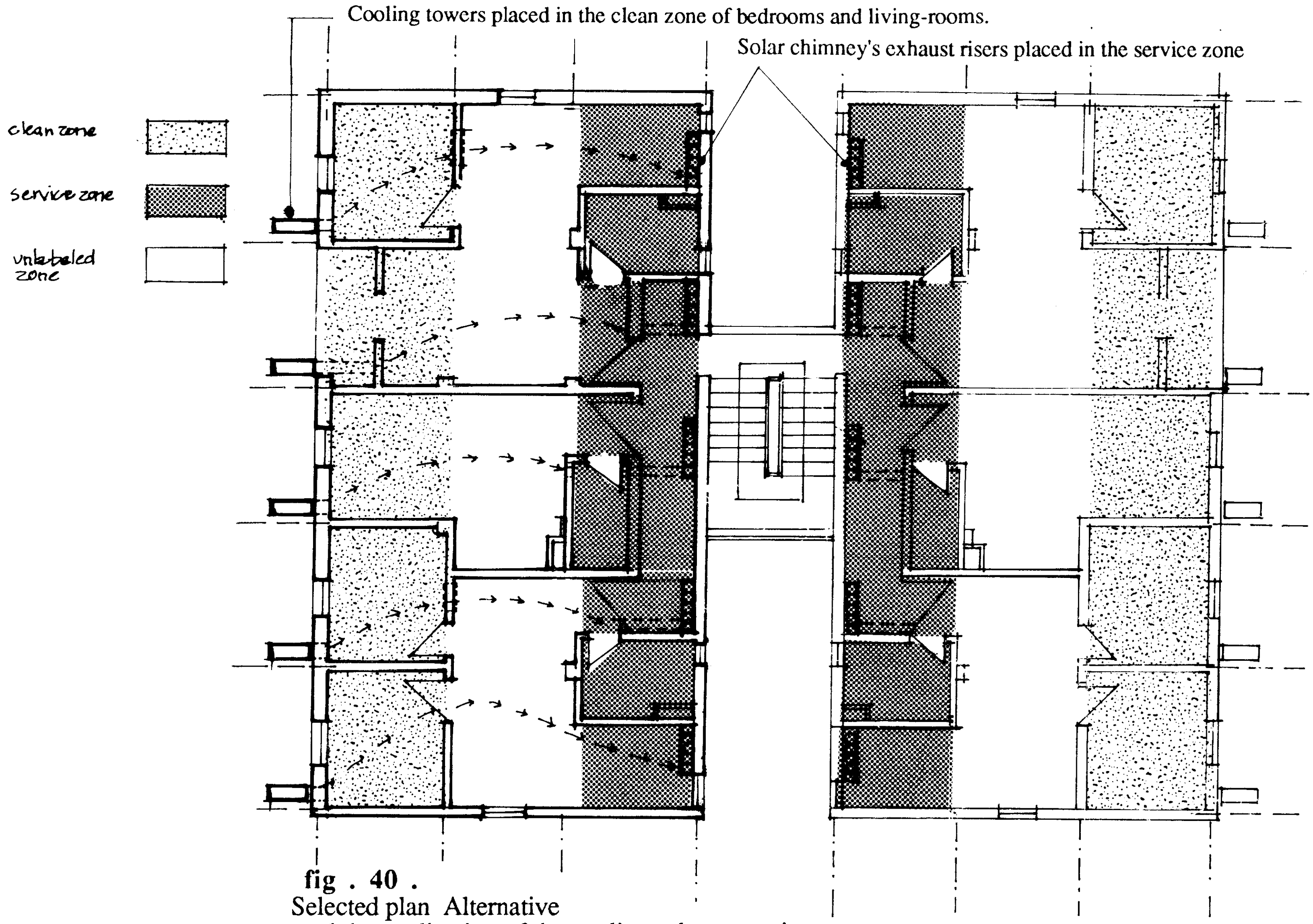


fig . 40 .
Selected plan Alternative
and the application of the cooling scheme on it

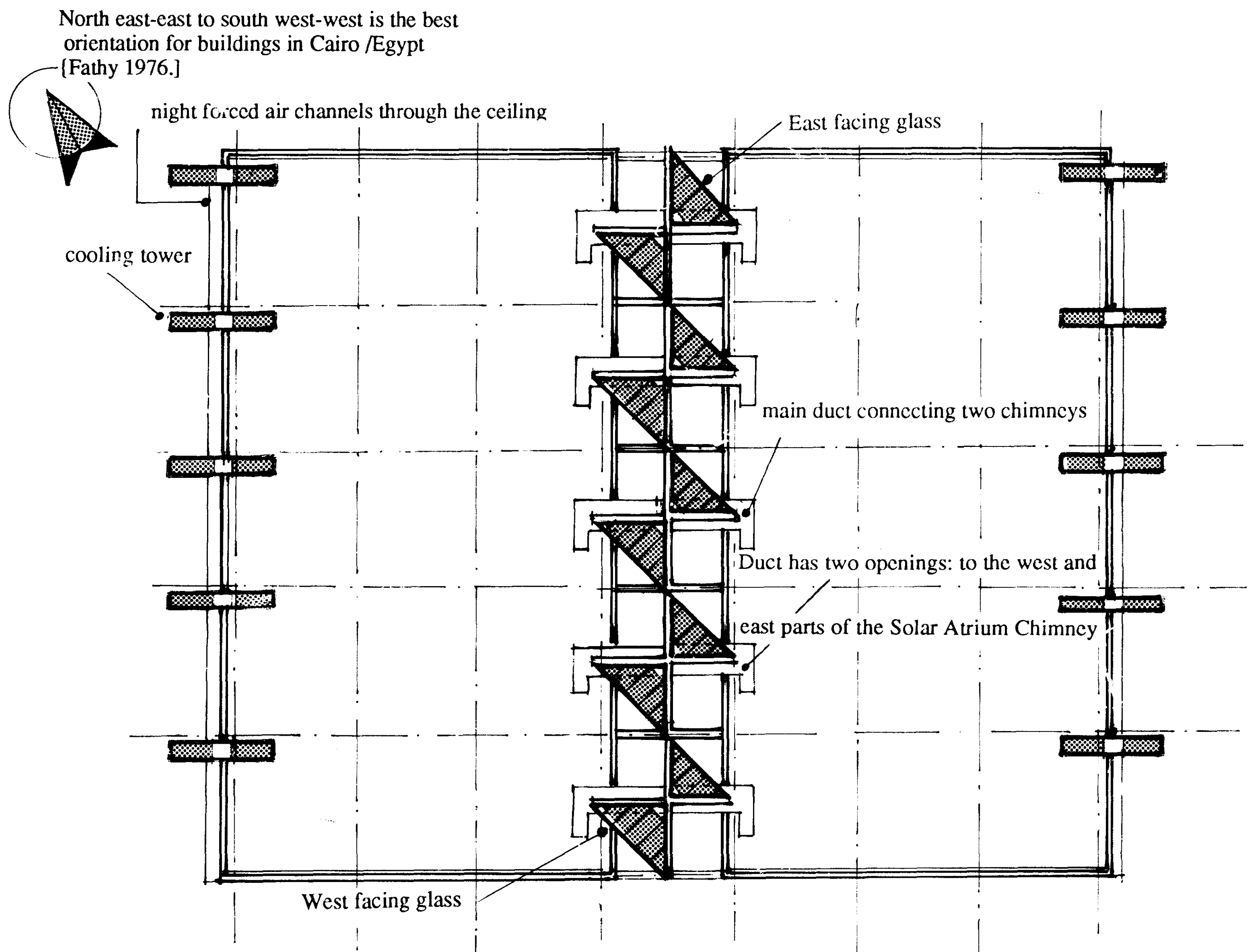


Fig.41. The Roof Layout

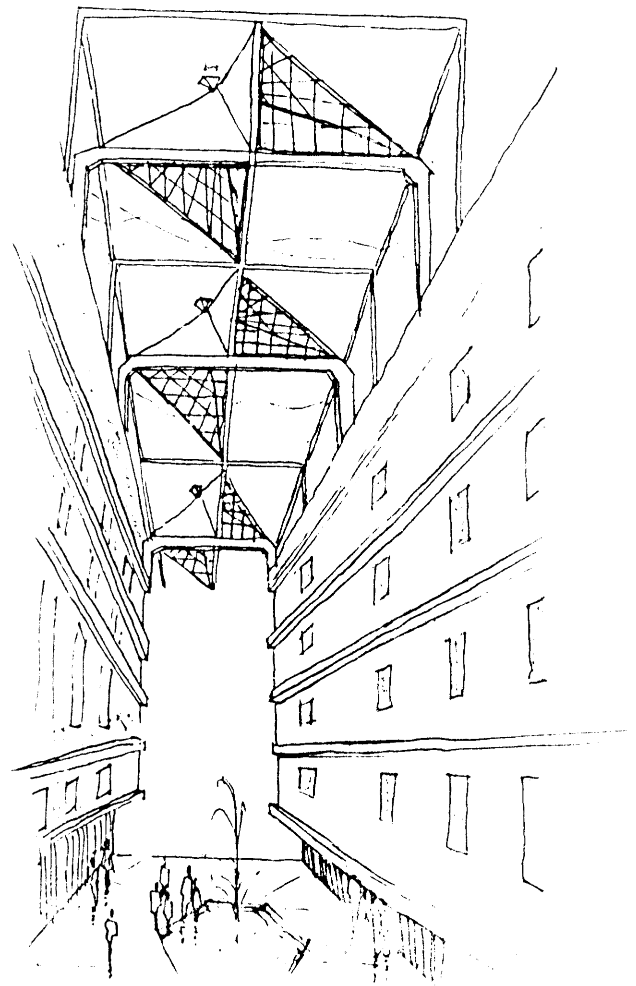


Fig.42. Schematic Showing Atrium Solar Chimney

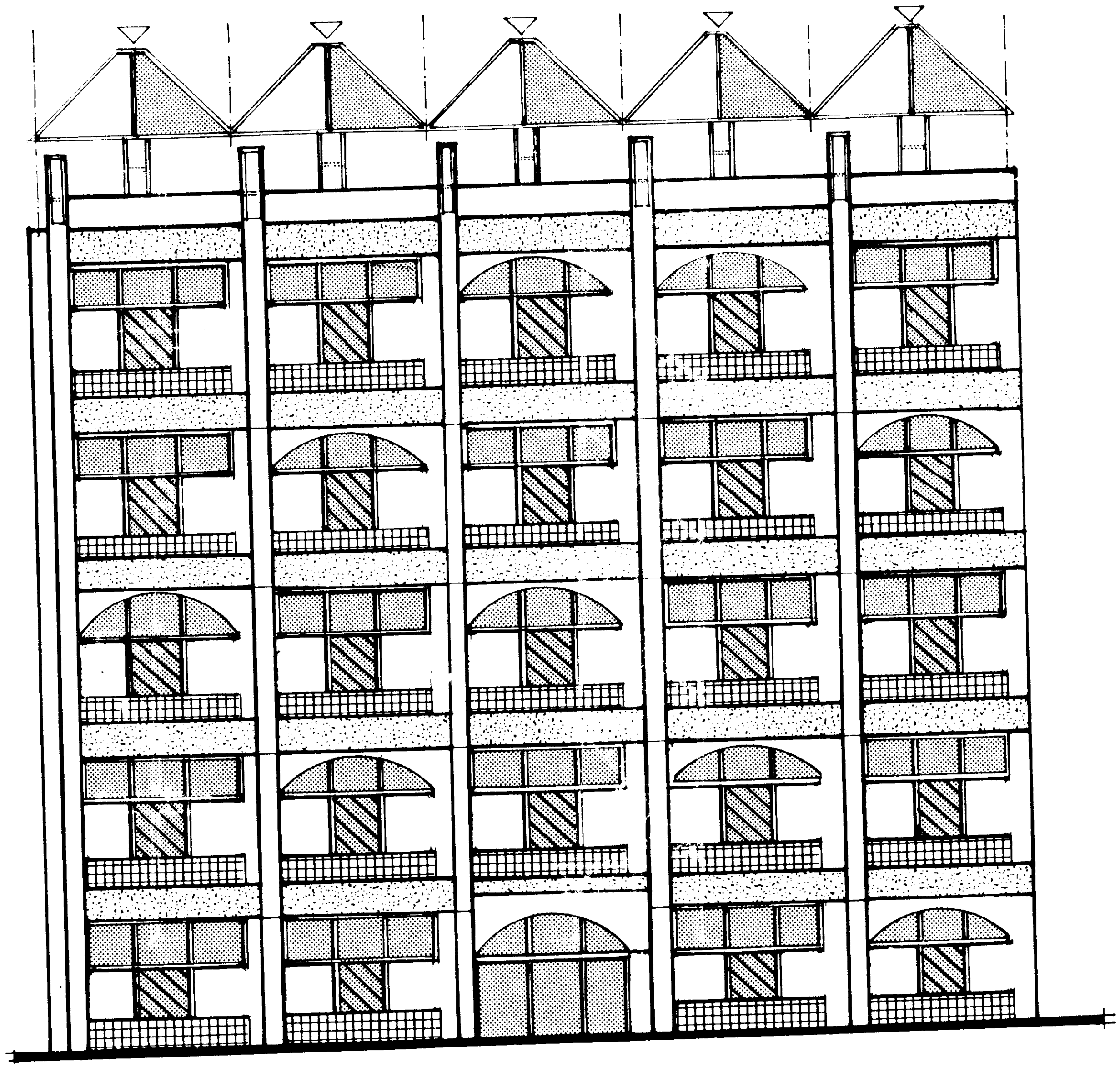


Fig.43 a.
Elevation of scheme 4

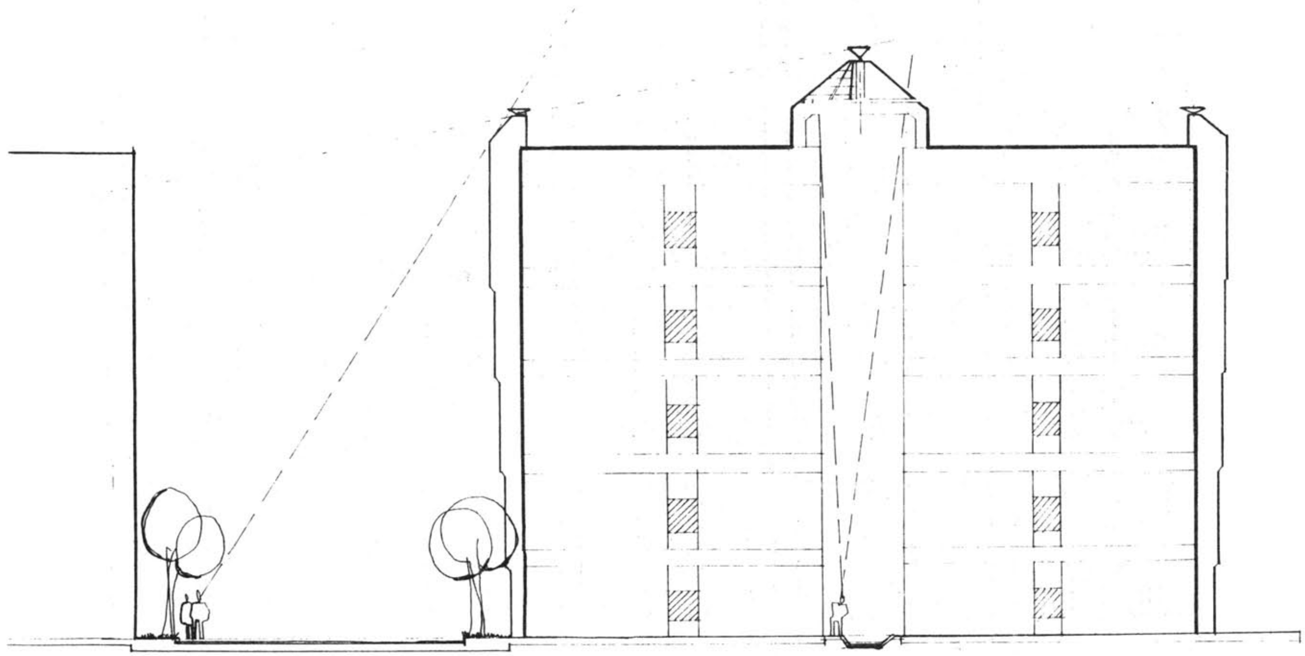


Fig.43 b.
Sky line of scheme 4

Architectural Design

Scheme Two

This is characterized by a general internal flow configuration of a building ventilated and cooled at day time by means of the solar chimney system. Illustrated are the cooling appliance, the insulated air shaft, the conditioned air space and the solar chimney.

The solar chimney comprises an east and west facing solar air heaters and insulated hot air shaft. The solar air heaters are rectangular in plan with their long sides facing east and west. The cooling appliance (evaporative coolers) cools the incoming air below the outside air temperature, which in turn causes the air being cooled to fall. The pressure differential created in the cold shaft is called ***"theoretical draft"*** [Haisley '81], as in the case of the solar chimney. At night time, forced ventilation is used for ordinary concrete slabs.

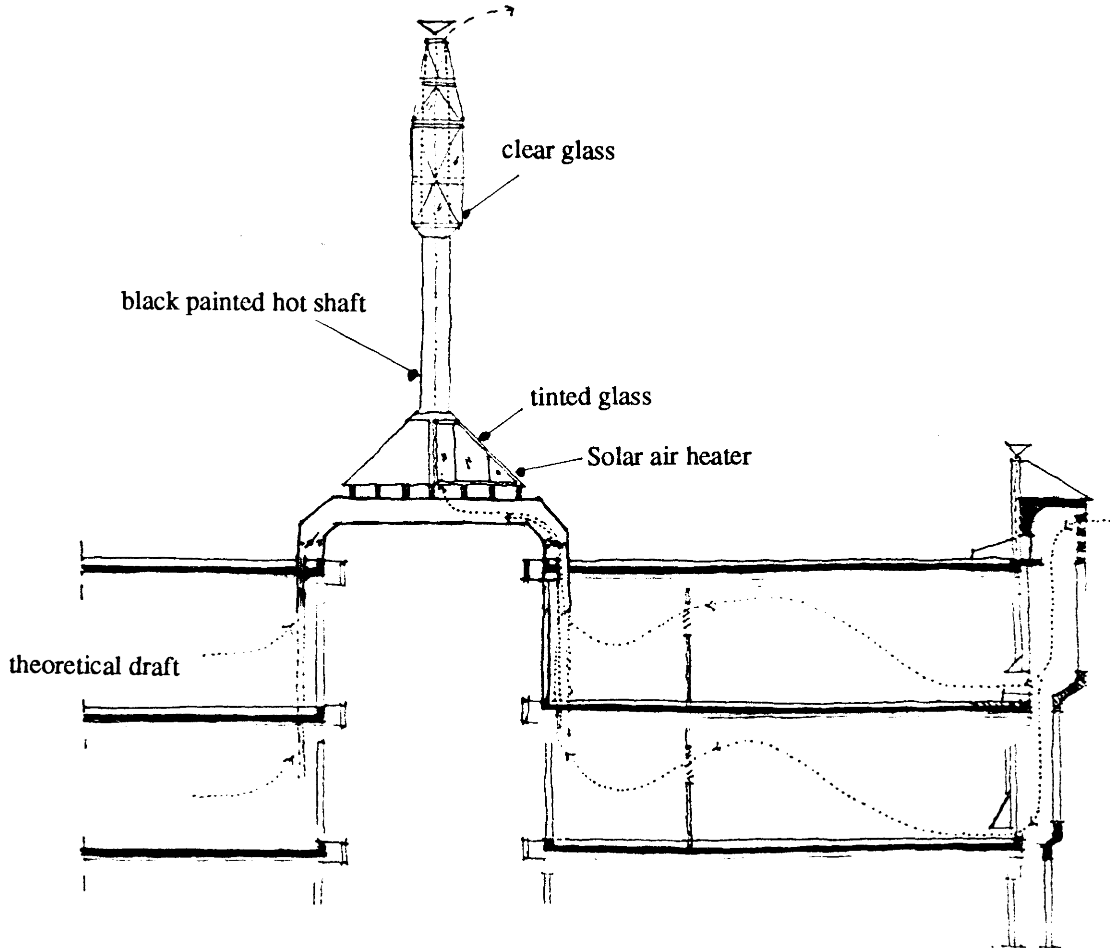


Fig.44a. Day-time Operation
(refer to chpter.3 for description of operation)

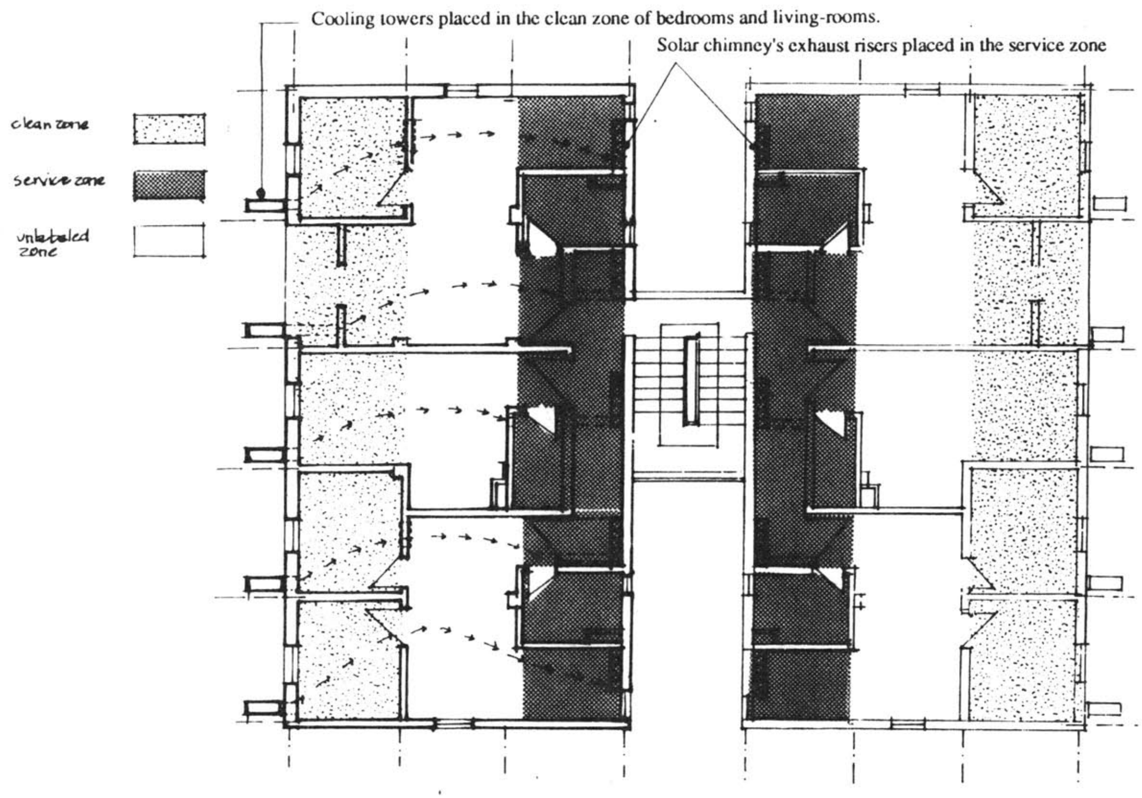


Fig.44 b.
Retrofitting the original plan
and positioning the cooling system.

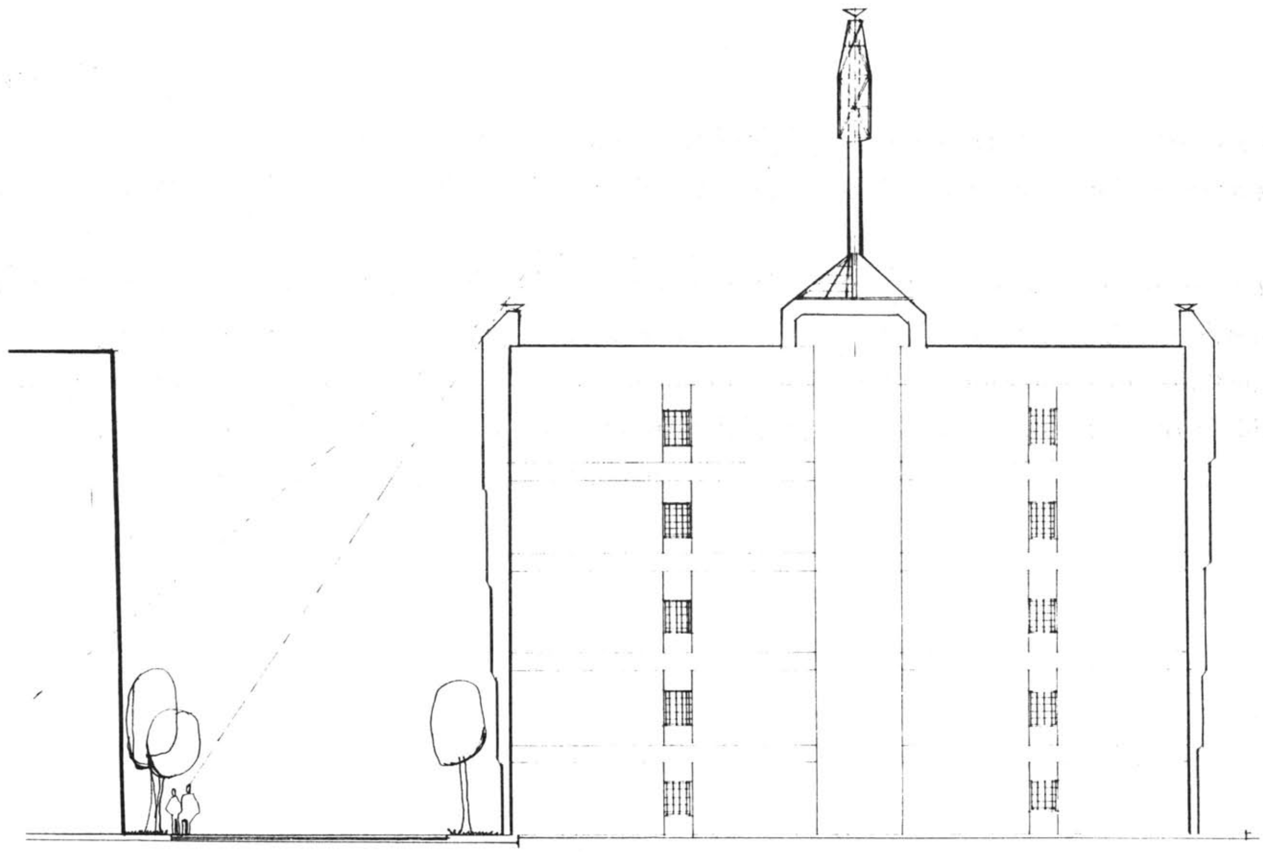


Fig.45. Skyline of Scheme 2

CONCLUSION

This research analytically concludes that: ***scheme one*** which uses the thermal mass -cored concrete slab-flushed with night ventilation, failed to remove the average twenty-four hour heat gain . ***Scheme three,*** which uses the thermal mass -cored concrete slab flushed with forced night ventilation, succeeded in removing average twelve-hour heat gain at day time, and natural night time ventilation through the windows to remove night time heat gain. The third scheme, however, failed to remove the hourly peak heat gain at day time. On the other hand, ***scheme two,*** which uses evaporative cooling by means of a solar chimney system at day time, and forced night ventilation for the ordinary slab at night time, together with ***scheme four*** which uses the night time forced ventilation of the cored concrete slab and minimum use of evaporative cooling by means of a solar chimney system at day time, both succeeded in removing the peak heat gains.

In the qualitative Architectural study, ***schemes two*** and ***four*** (and their cooling systems) are expressed as physical architectural elements: Cooling tower, Solar atrium chimney, ceiling ducts, and wall openings. Both schemes use the court space without blocking the wind or daylight into the rooms overlooking that court. Also, both schemes are orientation-free which means that they can be applied to any building with any design, independent of *orientation*, as long as the cooling tower and solar chimney are placed properly following the previously explained zones (clean and service zones -chapter.4).

Schemes four and two are designed for the middle-class Egyptian context with respect to its economical and social constrains. This design uses indigenous materials and local building systems. Also, this design gives preference to ventilation-cooling systems. that achieves privacy as a contextual social value.

In fact, both schemes (two and four) did not only attain desired reduction of the interior's dry bulb temperature, but also maintained comfortable levels of relative humidity. The schemes succeeded in; 1) promoting air movement inside the dwellings (by the use of solar chimney system), 2) reducing the consumption of artificial lighting (by the careful design of windows and shading devices), 3) and using only six hours of low energy fans at night time (12,000 cfm per 81 sq.m).

Scheme two is recommended for new buildings; because its cooling system elements integrate well with the buildings' architectural design. The solar Atrium chimney is an attractive architectural element that can create a pleasant interior court-yard for common activity and urban public use. On the other hand, scheme four is recommended for retrofitting existing building.

In the end, this research throws light on ways for adapting low energy cooling systems for buildings in hot arid climates. It certainly raises questions and and leaves the research door open for further development. It also confronts the architectural community with means of providing thermal comfort dwellings while remaining within the contextual domain of design and architecture.

APPENDIX .A.

This section is a continuation of **Peak** heat gain calculations (started in chapter three)

A.1. Peak Heat Gain for the EXISTING Building

External Walls (ONE floor per ONE hour) $Q = A \times U \times CLTD_{corrected}$

Orien-tation	A	U	CLTD	correction LM	K	Tin	Tout	$CLTD_{cort'd}$	Q
Northern edge of the building									
NE	297	0.36	21	1	1	-5	-1	15	1603.8
SW	286	0.36	28	-1	1	-5	-1	21	2162.16
SE	479	0.36	26	-1	1	-5	-1	19	3276.36
NW	506	0.36	23	1	1	-5	-1	18	3278.8
Southern edge of the building									
NE	297	0.36	21	1	1	-5	-1	15	1603.8
SW	286	0.36	28	-1	1	-5	-1	21	2162.16
SE	506	0.36	26	-1	1	-5	-1	19	3461.04
NW	479	0.36	23	1	1	-5	-1	18	3103.92
Total Heat Gain									**20,652 Btu/hr**

A Floor area (4 apartments) sq.ft
U Overall coefficient of heat transmission Btu/sq.ft °F h.
CLTD Maximum Cooling load temperature difference for sun lit walls (conventional units) [McGuiness & Stein '86].
For *group wall B: 8" common brick (weight 130 lbs/sq.ft)*
$CLTD_{correction}$: cooling load temperatures' difference in existing building (Cairo 32°N latitude in July).
LM: The latitude-month correction for latitude 32°N in July at 14:00 hours.
K: is the color adjustment factor and is applied after making latitude-month adjustments.
T_{in}: (78-TR) indoor design temperature correction, where TR=indoor temperature (TR=83).
T_{out}: (To-85) outdoor design temperature correction, where To=average outside temperature on design day.
To=97°F - (daily range (26°F))/2. Therefore, To=84 and T_{out}-(84-85)= -1

A.2. Peak Heat Gain after REDESIGNING the Building

External Walls (ONE floor per ONE hour) **Q = A x U x CLTDcorrected**

Orien-tation	A	U	CLTD	correction LM	K	Tin	Tout	CLTDcorr'd	Q
Northern edge of the building									
NE	297	*0.19*	21	1	1	-5	-1	15	846.45
SW	286	*0.19*	28	-1	1	-5	-1	21	1141.1
SE	479	*0.19*	26	-1	1	-5	-1	19	729.1
NW	506	*0.19*	23	1	1	-5	-1	18	1730.52
Southern edge of the building									
NE	297	*0.19*	21	1	1	-5	-1	15	846.45
SW	286	*0.19*	28	-1	1	-5	-1	21	1141.1
SE	506	*0.19*	26	-1	1	-5	-1	19	1826.6
NW	479	*0.19*	23	1	1	-5	-1	18	1638.18
Total Heat Gain									10,917.5Btu/hr

A.3.Peak Heat Gain through Glass by Conduction in EXISTING Building

For ONE floor per ONE hour $Q = A \times U \times CLTD_{corrected}$

Orien.	A	U	CLTD	correction Tin	Tout	CLTDcorr'd	Q
Northern edge of the building							
NW	110	1.04	14	-5	-1	8	923.6
SW	22	1.04	14	-5	-1	8	246.0
SE	55	1.04	14	-5	-1	8	457.6
NE	-	-	-	-	-	-	-
Southern edge of the building							
NW	55	1.04	14	-5	-1	8	457.6
SW	22	1.04	14	-5	-1	8	246.0
SE	110	1.04	14	-5	-1	8	923.6
NE	-	-	-	-	-	-	

Total Heat Gain through Glass by Conduction **3,254.4 Btu/hr.**

A Net glass area calculated from plans.

U Type of glass and interior shading [McGuiness & Stein table 4.17]. Single glazed 3 mm.for summer heat gain at 7.5 mph wind velocity.

CLTD Maximum Cooling load difference from conductor load through glass [McGuiness & Stein table 5.33]. Inside and outside temperatures are the only factors corrected in the CLTD.

CLTDcorrected = CLTD + ((78-TR)=Tin) + ((97 max outside temp - (daily temp range)/2) -85 = Tout
= CLTD + ((78-83)=-5) + (((97 - (26/2)) - 85 = -1)
= 14 - 5 - 1
= 8 °F

A.4. Peak Heat Gain through Glass by Conduction after REDESIGNING the Building

For ONE floor per ONE hour **Q = A x U x CLTDcorrected**

Orien.	A	U	CLTD	correction Tin	correction Tout	CLTDcorr'd	Q
Northern Edge of the building							
NW	110	1.04	14	-5	-1	8	923.6
SW	22	1.04	14	-5	-1	8	246.0
SE	55	1.04	14	-5	-1	8	457.6
NE	*11*	*1.04*	*14*	-	-	*8*	*91.4*
Southern edge of the building							
NW	55	1.04	14	-5	-1	8	457.6
SW	22	1.04	14	-5	-1	8	246.0
SE	110	1.04	14	-5	-1	8	923.6
NE	*11*	*1.04*	*14*	-	-	*8*	*91.4*
Total Heat Gain Through Glass by Conduction							**3437.2 Btu/hr.**

APPENDIX .B.

In this section, Average heat gains will be calculated to be used later when applying cooling systems.

B.1. Heat Gains per Hour after REDESIGNING the Building

External Roof (One Floor per ONE Hour) **Q = AxUxCLTD(average corrected)**

A	U	CLTD	correction LM	K	Tin	Tout	F	CLTDcort'd	Q
2800	0.0 7	49	1	0.5	-5	-1	1	19,5	**3,822**

heat gain for roof /24 h =U x A x CLTDaverage x 24 = 91,728 BTU/day
heat gain for roof /12 h =U x A x CLTDaverage x 12 = 45,864 BTU/12h

B.2. Average Heat Gain after REDESIGNING the Building

External Walls for One floor per One hour **Q = AxUxCLTDaverage corrected**

Orien.	A	U	CLTD	correction LM	K	Tin	Tout	CLTDcort'd	Q
Northern edge of the building									
NE	297	0.19	17	1	1	-5	-1	12	672
SW	286	0.19	21	-1	1	-5	-1	14	720
SE	479	0.19	20	-1	1	-5	-1	13	1175.23
NW	506	0.19	17	1	1	-5	-1	12	1160.5
Southern edge of the building									
NE	297	0.19	17	1	1	-5	-1	12	672.54
SW	286	0.19	21	-1	1	-5	-1	14	760.76
SE	506	0.19	20	-1	1	-5	-1	13	1241.9
NW	479	0.19	17	1	1	-5	-1	12	1092.12

Total Heat Gain/hour	7,495.02 Btu/hr.
heat gain for walls /24 h	179,880.48 BTU/h
heat gain for walls / 12 h	89,940 Btu/12 h

B.3. Average Heat Gain from Glass Conduction after REDESIGNING the Building
For One floor per One hour $Q = A \times U \times CLTD_{\text{average corrected}}$

Orien.	A	U	CLTD	correction Tin	correction Tout	$CLTD_{\text{cort'd}}$	Q
Northern edge of the building							
NW	110	1.04	5.6	-5	-1	-0.4	-45.76
SW	22	1.04	5.6	-5	-1	-0.4	-9.152
SE	55	1.04	5.6	-5	-1	-0.4	-22.88
NE	11	1.04	5.6	-	-	-0.4	-4.57
Southern edge of the building							
NW	55	1.04	5.6	-5	-1	-0.4	-22.88
SW	22	1.04	5.6	-5	-1	-0.4	-9.152
SE	110	1.04	5.6	-5	-1	-0.4	-45.76
NE	11	1.04	5.6	-	-	-0.4	-4.57

Total Heat Gain Through Glass by Conduction	-164.724 Btu/hr
average heat gain from glass/24	-3953.3376 Btu/day
average heat gain from glass/12	-1,976.688 Btu/day

B.4. Average Heat Gain through Glass by Solar Radiation after the REDESIGN

For One floor all day **$Q = A \times SHGF_{average/all\ day} \times SC$**

Orien.	A	SHGF	SC	Q
Northern edge of the building				
NW	110	945	0.25	25,987.5
SW	22	865	0.25	4,757.5
SE	55	855	0.25	1,756.25
NE	11	884	0.25	2,431.00
Southern edge of the building				
NW	55	945	0.25	12,993.75
SW	22	865	0.25	4,757.5
SE	110	855	0.25	23,512.5
NE	11	884	0.25	2,431.0
Heat Gain through Glass by Solar Radiation				88,627.0 Btu/hr.
Total Heat Gain through Glass (Rad. & cond.)				86,651.0 Btu/hr

B.5. Average Heat Gain from PEOPLE (sensible) **Q = number of people/one floor x heat gain x CLF**

	no. of people	CLF	heat gain/person	Q
Sensible Heat	20	0.92	225	4,140
Total Heat Gain from people/h				4,140

B.6 Average Heat Gain from INTERNAL LIGHT

For ONE floor per ONE hour

Q = Input x CLF (Btu/Kwh = kw x 3400)

	INPUT	CLF	Q
input/day (8 hours) / one family (Kw)	5.5		
input/day (8 hours) / one family (Btu/Kwh)	18700		
input / one hour / 4 families (Btu/Kwh)	9350	0.56	5,236
input/day (8 hours) / 4 families (Btu/Kwh)	74800	0.56	41,888
Total average heat gain at night becomes			81,088 Btu/night

SCHEME TWO

Using the Night-time forced Ventilation; to flush the night time heat gain from the ordinary uncored ceiling slab with the Evaporative Cooling* during the day (in order to remove instantaneous heat accumulation).

Mass surface area	= 2800 sq.ft
Mass heat capacity = vol. of concrete x 22.5	= 188, 900 Btu/°F

Hour	T°	Cooling	Mass Temperature
21	83.55	none	= 83.55
22	82.2	1x(83.55-82.20) x 2800 = 3780	83.55 -(3780/188900) = 83.35
23	80.85	1x(83.35-80.85) x 2800 = 7000	83.35 -(7000/188900) = 82.97
24	79.50	1x(82.97-79.50) x 2800 = 9716	82.97 -(9716/188900) = 82.45
1	78.15	1x(82.45-78.15) x 2800 = 12056.59	= 82.33
2	76.80	1x(82.33-76.80) x 2800 = 15489.84	= 81.50
3	75.40	1x(81.50-75.40) x 2800 = 17109.2	= 80.59
4	76.00	1x(80.59-76.00) x 2800 = 12865.3	= 79.90
5	78.40	1x(79.90-78.40) x 2800 = 4226	= 79.67
Cooling Btu		= 114,714.9	

Supplementary cooling = (83.55-79.67)X (2.25)X floor area (2800/2.7)
= 9,053.01 Btu/night
Total Cooling at Night = 123,767 Btu/night
Approximate flow required for night ventilating air = cfm

CFM =12,541 cu.ft/ min/ one apartments
ACM =12,541/ 5600

Cooling the ordinary slab by *Forced night ventilation* succeeded in removing the heat gain at night.

APPENDIX .D.

Thermal Effect of Windows and Efficiency of Shading Devices

The thermal effect of windows is dependent on the shading provided and the properties of its glass*. The thermal effect of the glass can be, furthermore, considered from two aspects: First, the actual heat gain (from the glass) of the interior, which is important for calculating the cooling loads; and second, the resulting rise in the indoor temperature which have a great effect on indoor thermal comfort.

Shading this glass affects the quantity of incident radiation and accordingly modifies both the heat flow to the interior. Also, the quantitative modification of this incident radiation depends on the location of the shading with respect to the glass (whether internal or external), the orientation of the window, the shape, color, and depth of the shading device.

From a study done by Givoni [Givoni 76]; it was concluded that for latitude 32°N** the adequate shading for ***east and west orientations*** can be provided with an *egg-crate shading, especially if the vertical members are oblique at a 45° angle to the south* (with the shades projecting over the window 2/3 of its length). Horizontal shading, however, is more effective than vertical shading, even with infinite height. That's because it provides very poor shading in the summer, while cutting off almost all radiations in winter. ***For southern, southwest orientations*** *horizontal shadings* (with the shades projecting over the window 1/3 of its length) are more effective than vertical ones, while the egg-crate frame shape is the most effective.

In another study done by Shaviv [Shaviv 88]; he continued exploring the optimum external shading device with the use of a computer program "SUNSHADES" (developed by Shaviv). According to the method suggested, a shading nomogram, with ***all the possible solutions*** for external sunshades, is first generated by the computer, and then the design of sunshades can be carried out by the architect following this nomogram ***.

The "ENERGY" simulation model was used to evaluate four different types of geometric forms for the external shading devices. For each geometric solution different depth of shading devices were examined. For the ***southeast orientation***, the study concluded that the *diagonal external shading device* was the best. A comparison between different shading devices **** was also conducted for the *south-east* and the *north-west* orientations. It was found that the best shading device (with lowest energy consumption for cooling, heating, and for lighting) was the external shading device for the ***south east orientation***. Also, *venetian blinds and white curtains* were found to be the best shading devices for the ***northwest orientation***.

**In Egypt the cost of tinted "Low E" or "reflecting" glass is too high, therefore, single glass 3mm. will be used, and a better external shading device with high percentage of shading coefficient will be examined and then applied in the design.*

***Very close to Cairo Latitude 30°N*

**** The nomogram gives the minimum length of the pole in each grid point of the given window that will cast a shadow long enough to reach the bottom of the window or its sides. The test is carried over the whole period during which the window should be protected (months and hours). The needed protection period and hours are determined according to the amount of short wave radiation (direct and defuse) incident on a particular window, and the hours the building is in use. The nomogram can be used to determine the kind of external shading devices solution that is needed [Givoni 1978].*

*****This comparison was held between Venetian blinds, white curtains, and external shading devices.*

SCHEME FOUR

Using the Gas-Furnace to Remove the Heat Gain (optional)

- Average sensible heat gain at night for one floor = 81,088 Btu
- Average sensible heat gain at night per hour for one apartment = 1689.3 Btu /h

The following procedures examine the capability of the gas-furnace (to heat the air inside the solar chimney) to remove average heat gain at night: **Q** = A x V (velocity of air in Solar chimney) x $\Delta t_{(2)}$ x 1.08

where: **V** = $9.4 \sqrt{(h \times \Delta t1)}$

h = height of solar chimney = 18 ft. for the fifth floor

Assume that the gas furnace will produce heat that will elevate the air temperature to 220°F, while the air inside the house, at night time, will have temperature of 87°F.

$\Delta t_{(1)}$	=	difference in temp. inside the solar chimney and inside the house = (187-87)°F	
V	=	390 ft/min	
$\Delta t_{(2)}$	=	difference in temp. inside and outside the house	= (87-83)°F
A	=	area of the solar chimney's outlet for one apartment	= 0.9 sq.ft.
Q	=	$0.9 \times (9.4 \times \sqrt{(18 \times \Delta t_1)}) \times \Delta t_2 \times 1.08$	= 2299.8 Btu /h

The gas furnace succeeded in removing night heat gain from the dwelling. The second step is trying to use the *gas-furnace* to assist the fans in further reduction of the air temperature.

AFRICA

CAIRO IAP UNITED ARAB REPUBLIC/EGYPT

LAT 30 08N LONG 31 24E ELEV 367 FT

APPENDIX .F.

MEAN FREQUENCY OF OCCURRENCE OF DRY BULB TEMPERATURE (DEGREES F) WITH MEAN COINCIDENT WET BULB TEMPERATURE (DEGREES F) FOR EACH DRY BULB TEMPERATURE RANGE

Tempera-ture Range	MAY					JUNE					JULY				
	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB
110/114							1		1	69					
105/109		1	0	1	65		3	0	3	68		0		0	79
100/104		5	1	6	67	0	15	5	20	68		4	1	5	73
95/99		19	6	25	65	0	29	13	42	68		20	9	29	71
90/94	1	33	16	50	64	2	59	34	95	68	0	64	37	101	71
85/89	3	50	27	80	63	4	62	48	114	67	1	84	52	137	70
80/84	6	56	45	107	62	13	40	48	101	67	7	53	59	119	70
75/79	13	55	57	125	62	38	27	62	127	67	79	23	70	172	70
70/74	43	22	52	117	61	110	3	26	139	66	134	0	19	153	68
65/69	92	7	37	136	61	68	0	3	71	63	25		1	26	65
60/64	81		7	88	58	4			4	59					
55/59	9			9	55	0			0	59					

Tempera-ture Range	AUGUST					SEPTEMBER					OCTOBER				
	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB
110/114															
105/109		0	0	0	75										
100/104		2	0	2	73		2	1	3	68					
95/99		18	5	23	72		13	1	14	69		4	0	4	66
90/94	0	78	35	113	71		59	21	80	70	0	20	3	23	66
85/89	1	78	55	134	71	1	74	41	116	69		39	11	50	67
80/84	5	52	65	122	71	4	57	52	113	69	1	64	29	94	66
75/79	92	19	70	181	71	44	31	88	163	69	9	85	66	160	64
70/74	139	1	17	157	69	138	3	32	173	68	63	25	80	168	64
65/69	10		0	10	66	49	0	3	52	65	93	11	49	153	62
60/64		0		0	61	4		0	4	60	73	1	10	84	58
55/59	0		0	0	58	0			0	59	9		1	10	55

Tempera-ture Range	NOVEMBER					DECEMBER					JANUARY				
	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB
110/114															
105/109															
100/104															
95/99															
90/94		1	0	1	68										
85/89		1	1	2	65							1		1	61
80/84		9	1	10	63		3	0	3	60		2		2	59
75/79	1	61	13	75	62	1	9	1	11	57		6	1	7	58
70/74	5	92	41	138	61	1	29	6	36	57	1	22	5	28	55
65/69	18	49	81	148	59	3	82	22	107	55	3	57	18	78	53
60/64	96	22	73	191	57	11	72	69	152	53	11	82	56	149	52
55/59	91	4	30	125	53	72	43	102	217	51	36	57	99	192	50
50/54	27	0	1	28	49	117	9	42	168	48	131	19	62	212	47
45/49	2	0		2	46	35	2	6	43	44	55	2	7	64	43
40/44	0			0	43	8			8	40	9	0	1	10	40
35/39						0			0	36	1			1	34

Tempera-ture Range	FEBRUARY					MARCH					APRIL					ANNUAL TOTAL				
	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB	Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	MCWB
110/114																	1		1	69
105/109												1	0	1	66		5	0	5	68
100/104												4	2	6	65	0	32	10	42	68
95/99							2	0	2	62	0	7	2	9	64	0	112	36	148	68
90/94		0		0	61		10	2	12	59	1	14	6	21	62	4	338	154	496	69
85/89		2	1	3	57		12	5	17	58	2	20	10	32	61	12	423	251	686	68
80/84		6	2	8	57	2	17	9	28	57	4	31	18	53	60	42	390	328	760	66
75/79	2	16	6	24	55	7	36	19	62	56	11	53	36	100	58	297	421	489	1207	65
70/74	3	35	14	52	55	12	43	31	86	55	15	52	46	113	57	664	327	369	1360	63
65/69	4	60	32	96	53	18	62	44	124	54	27	40	49	116	56	410	368	339	1117	58
60/64	15	66	58	139	52	30	47	54	131	53	63	15	51	129	55	388	305	378	1071	55
55/59	47	33	76	156	50	80	16	62	158	51	95	2	19	116	53	439	155	389	983	51
50/54	115	5	35	155	47	83	2	20	105	48	19	0	1	20	49	492	35	161	688	47
45/49	36		1	37	44	16		0	16	43	1			1	45	145	4	14	163	44
40/44	2	0		2	41	1			1	41						20	0	1	21	40
35/39	0			0	38											1			1	35

Table.2. Engineering Weather Data for Cairo/EGYPT

AREA Country Station	LOCATION			WINTER DESIGN DATA HEATING Dry Bulb				DEGREE DAYS	SUMMER DESIGN DATA AIR CONDITIONING Dry Bulb								Wet Bulb			SUMMER CRITERIA DATA AIR CONDITIONING Dry Bulb		Wet Bulb	
	Lat	Long	Elev	99%	97.5%	Pvlg Wind	Mean Speed	Heating	1%	MCWB	2.5%	MCWB	Mean Daily Range	Pvlg Wind	5%	MCWB	1%	2.5%	5%	93°F	80°F	73°F	67°F
			feet	°F	°F	dir	knots	annual	°F	°F	°F	°F	°F	dir	°F	°F	°F	°F	°F	hrs	hrs	hrs	hrs
UNITED ARAB REPUBLIC/EGYPT	N	E																					
Alexandria/Nouzha	31 10	29 57	-10	44	46	S	4	841	90	73	88	74	14	NNW	86	74	77	76	76	23	1217	872	2963
Cairo IAP	30 08	31 24	367	44	46	SSW	6	689	100	70	97	70	25	NNW	94	71	76	74	74	295	1892	308	2497

Table.2. Engineering Weather Data for Cairo/Egypt

ARAB REPUBLIC OF EGYPT

CAIRO Elevation 381

	Temperature: Daily Average Max.	Daily Average Min.	Monthly Extreme Max.	Monthly Extreme Min.	Rel. Hum. 2:00 p.m.	Precipitation (Inches) Average
J	65	47	88	35	40	0.2
F	69	48	92	35	33	0.2
M	75	52	101'	38	27	0.2
A	83	57	113	42	21	0.1
M	91	63	116	49	18	0.1
J	95	68	117	55	20	<0.1
J	96	70	109	61	24	0.0
A	95	71	109	63	28	0.0
S	90	68	108	58	31	<0.1
O	86	65	109	51	31	<0.1
N	78	58	100	42	38	0.1
D	68	50	87	34	41	0.2
	83	60	117	34	29	1.1

Table.3. Climatic Weather Data Cairo/Egypt

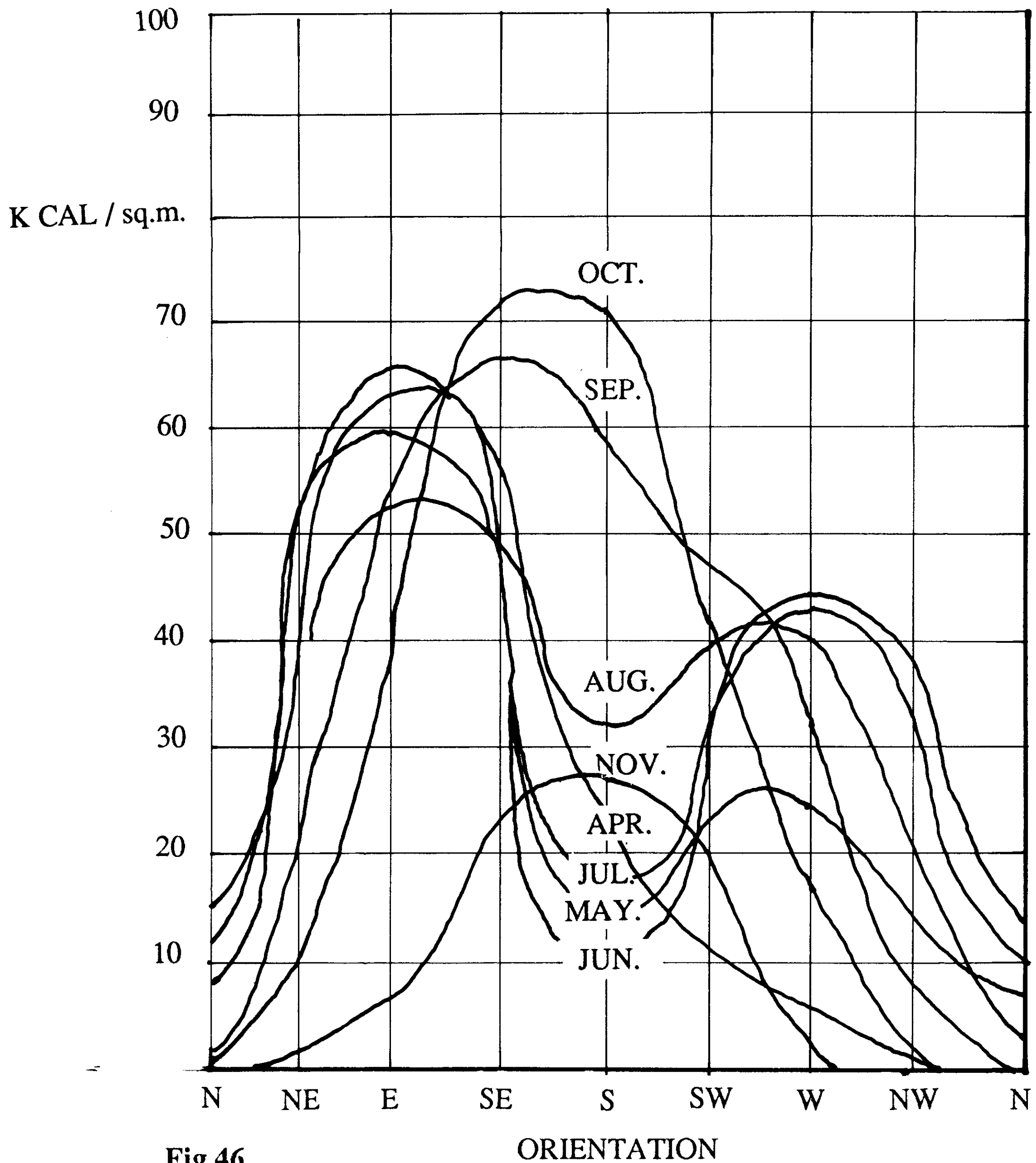


Fig.46.
Solar intensity on vertical and horizontal surfaces of Cairo Egypt

Table .4.
Daily Total Solar Radiation Received on Surfaces of Various Orientations (Cal / Cm2)

Surfaces	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NORMAL	720	752	756	830	833	828	790	714	790	714	672	660
HORIZONTAL	360	435	523	600	650	662	650	610	545	438	361	330
FACING SOUTH	485	440	350	226	150	115	130	150	253	385	452	456
FACING NORTH	44	49	56	65	106	130	116	60	59	51	45	42
FACING EAST	215	250	273	275	288	295	288	270	240	216	202	
FACING WEST	215	250	273	258	295	268	285	270	240	216	202	

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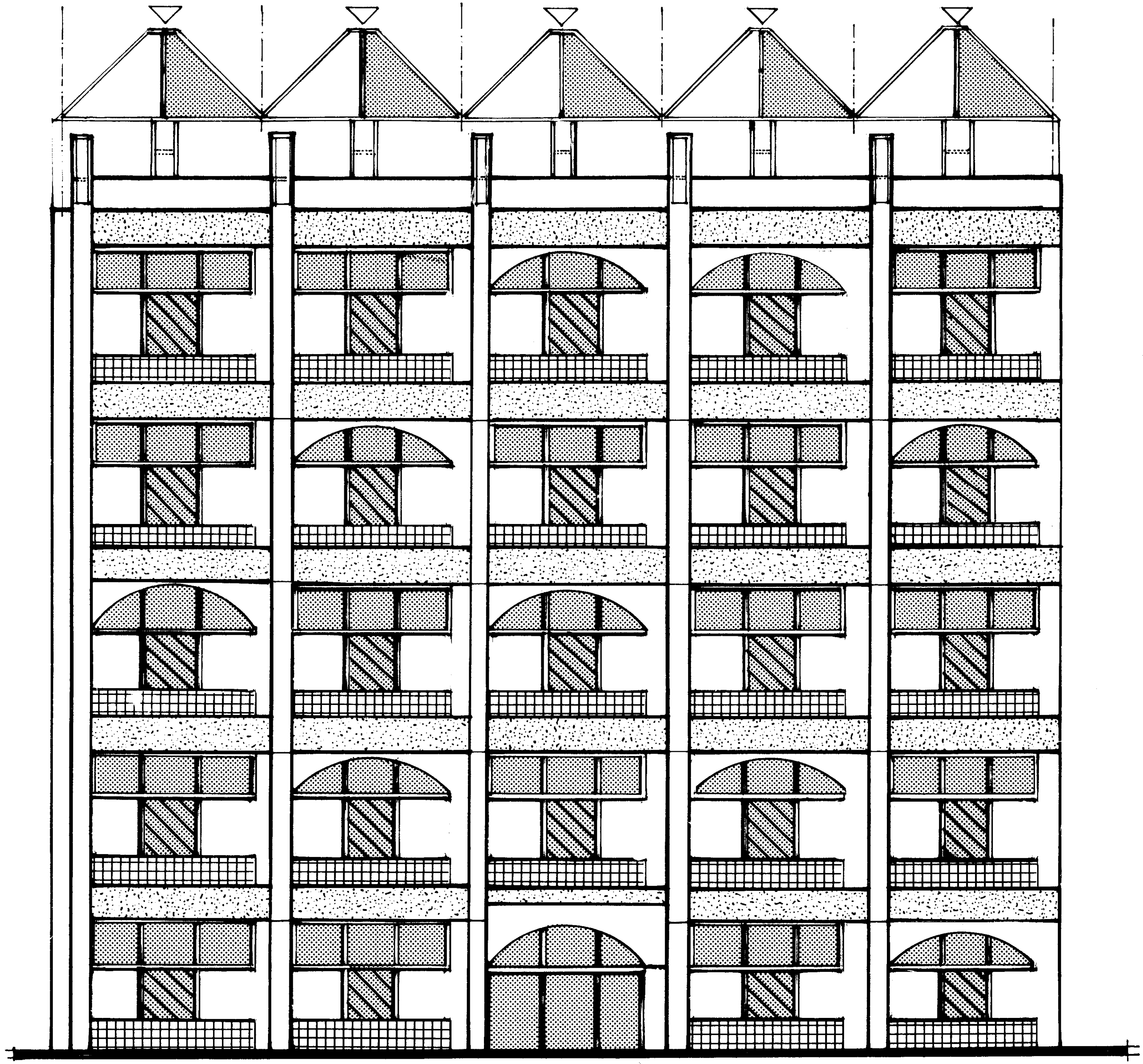

LOW ENERGY COOLING IN MULTI-STOREY BUILDINGS

APPLICATION IN THE HOT ARID CLIMATIC CONTEXT OF CAIRO/EGYPT