

CLIMATIC DESIGN IN THE CITY  
A RESIDENTIAL BUILDING IN ATHENS

by  
PANAGIS A. PAPADIMITRIOU

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\_\_\_\_\_  
Panagis A. Papadimitriou  
Department of Architecture, May 17, 1985

Certified by

  
\_\_\_\_\_  
Timothy E. Johnson  
Principal Research Associate, Thesis Supervisor

Accepted by

  
\_\_\_\_\_  
Julian Beinart  
Chairman, Departmental Committee on Graduate Students

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After Le Corbusier

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*Submitted to the Department of Architecture on May 17, 1985,  
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**ABSTRACT**

The scope of this study is to examine the potential, limitations, and specific methods which can be used in applying climatic design principles in a densely populated urban environment. For illustrative purposes, a typical multi-storey residential building in downtown Athens, Greece, will be used as a case study. Its goal is to use the rich and ever increasing vocabulary of climatic design in order to enhance the dialogue between the urban building and the physical environment as perceived through our senses.

The first part analyzes the relationship between man, climate and architecture, and studies the basic principles of energy conscious design.

The second part examines issues related to the urban and climatic environment of Athens in order to give an overview of the general context of the case study. This is followed by the description of a building that will constitute the basis for the proposed redesign.

Finally, the third part discusses the application of climatic design principles on the proposed redesign, using techniques suitable to the specific climatic and environmental conditions, and provides a synthesis of the issues examined into a comprehensive design proposal. This part concludes with the author using the appraisal of specific improvements on the building to comment on the potential and limitations of this design approach to architecture and urban planning.

*Thesis Supervisor: Timothy E. Johnson*  
*Title: Principal Research Associate*

This Thesis was written largely because of Professor Tim Johnson to whom I am grateful for initiating my enthusiasm and greatly furthering my knowledge about climatic design.

Charette team:

Niloo Tashakori  
Gregory Beck  
M. Ali Tayar  
Nicos J. Koulis

*Dedicated to my parents, Andreas and Aiki; also, to Henri-Pierre Maillard, my Advisor at the Ecole des Beaux-Arts, who taught me to love Design (to which I shall return after the M.I.T. experience).*



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*FOREWORD*

## FOREWORD

The history of architecture throughout the centuries is a continuous response to the climatic conditions of the surrounding environment. From the swiss chalets to the flat roofed, sparkling white houses of the sunny mediterranean islands, the buildings have always been an expression of man's desire to cope with the natural elements, to alleviate the winter cold and the summer heat, but also to marry the nature around him to his own expression of beauty.

This dialectic relationship between architecture and the natural environment lasted for centuries throughout the recorded history of mankind only to be brought to a halt in the years following the first industrial revolution.

The introduction of new technologies in construction, the large scale urbanization and new city layouts lead to the development of high-rise multiple-family buildings, encompassing a large number of apartments shielded from the environment largely by mechanical means.

The application of mechanical systems and the associated divorcing of the building as a functioning organism from its surrounding environment increased throughout the twentieth century, assisted by the rapid development of new technologies, the heavy emphasis placed on economic growth and the availability of inexpensive energy.

It was the questioning of the limitless availability of cheap energy signaled by the 1973 oil crisis that triggered new trends in energy conscious design. In those times the main focus of solar architecture was to invent ways to reduce the sky-rocketing heating bills.

The use of solar energy as a substitute to other conventional forms forced the architects to take the environment and especially the climate much more seriously than at any other time during the twentieth century. This need for increased

climatic sensitivity lead the energy conscious designers back to an almost symbiotic relationship between the building and the environment. Climatic design is energy and environment conscious at the broadest sense, taking into account all the exchanges of energy between the indoor and the outdoor space. It leads to a harmony between the house and the environment which allows for a much more pleasant and livable home.

This played well into the "quality of life" consciousness of the 80's, and is the primary reason why climatic design survived the eclipse of the energy crisis of the 70's and the minimization of the economic incentives of solar architecture applications.

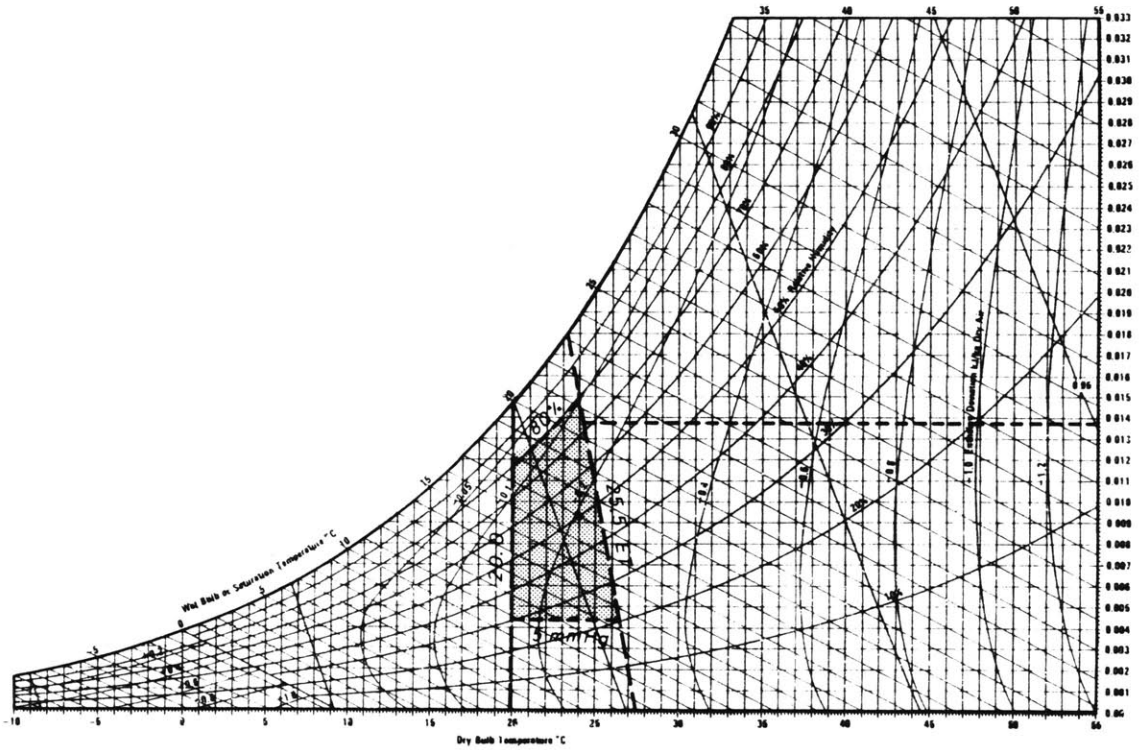
The most suitable environment for the application of climatic design principles is the low density suburban or the countryside. There the projects involve small detached houses lying in fairly large land lots, where the architect is unconstrained by fixed city layouts, strict building codes, and limited solar and ventilation access. It is primarily for this reason that few examples of climatic design applications in dense urban areas are known.

This Thesis attempts to fill this gap by examining the potential, the limitations and the specific methods that can be used in applying climatic design principles in a densely populated area. The writer hopes that he will show that climatic design will not only prove helpful in proposing a more rational employment of our natural resources, but will also make its own limited contribution in making our cities a better place to live in.



*PART I*

PRINCIPLES OF CLIMATIC DESIGN



TOTAL COMFORT	20.0 degrees C to 25.5 degrees ET 5 mmHg to 80 % RH (shading required)
TOTAL HEATING	under 20.0 degrees C
TOTAL COOLING	over 25.5 degrees ET
HUMIDIFICATION	under 5 mmHg
DEHUMIDIFICATION	over 17 mmHg or 80 % RH

(1) Thermal comfort zone and bioclimatic need analysis



*CHAPTER 1*

## THERMAL COMFORT

Thermal comfort can be defined as the state of mind which expresses satisfaction with the thermal environment.

Thermal comfort is achieved if the parameters of activity, clothing, physical condition and environment are in balance. Criteria for thermal comfort are subjective and vary from person to person or between different ethnic and geographic groups.

The major environmental variables affecting thermal comfort are the ambient air temperature, relative humidity, air speed and the surrounding radiant environment. There have been many studies of these variables in order to determine the range of specific climatic conditions of people living in temperate regions. The most commonly used set of comfort conditions, based on the responses of sedentary adults (activity level 1.0 to 1.2 met), wearing light office clothing (0.5 to 0.7 clo), extends from 20.0 degrees C to 25.5 degrees ET on the most recently developed Effective Temperature scale, and is bounded by a vapour pressure of 5 mmHg and a relative humidity limit of 80 %.

These conditions define a thermal comfort zone that can be illustrated by various graphic methods of weather data representation. Figure 1 delineates this zone on the psychrometric chart and describes the basic bioclimatic needs for restoring thermal comfort in the remaining regions; this will constitute the basic tool for weather analysis in the subsequent chapters.

The psychrometric chart, however, does not account for the effect of air movement and mean radiant temperature on human thermal comfort. The effect of these climatic parameters is capital, since the body loses 80 percent of its heat to the environment through convection and radiation.

### *Effect of air movement*

Air movement influences bodily heat balance and, therefore, thermal comfort, by affecting the rate of convective heat transfer between the skin and the air, and by affecting the rate of bodily cooling through evaporation of skin moisture. Increasing air speed increases the rate of heat transfer from the body to the air (or vice versa if the temperature of the latter is greater than skin temperature, i.e. 33 degrees). Similarly, increasing air speed also increases the rate of evaporation, hence the evaporative cooling effect, although at high vapour pressures the overall effect may be small.

Within certain conditions (and under constant activity and clothing levels), the effect of increased air movement is to extend the upper limit of the comfort zone to higher temperatures.

### *Effect of mean radiant temperature*

Heat is exchanged between the body and the environment by thermal radiation. The temperature of room surfaces vary, and may significantly differ from air temperature. MRT is defined as the uniform air temperature of an imaginary black body with which man exchanges the same heat by radiation as in the actual environment. In other words, MRT is the average of all room surfaces weighed according to the spherical angle their areas make with an occupant at a given space (since the emissivity of all building materials is almost equal, with the exception of shiny metals). The radiant heating or cooling ability of any surface must be evaluated in the context of its area in proportion to the area and temperature of other surfaces in a space. The angle of exposure of surface to body and the orientation of exposed parts of the body must also be considered.

Within certain conditions (and under constant activity and clothing levels), the effect of increased MRT is to extend the limits of the comfort zone to lower temperatures.

*CHAPTER 2*

## METHODS OF CLIMATE CONTROL

**2.1 Climatic Analysis**

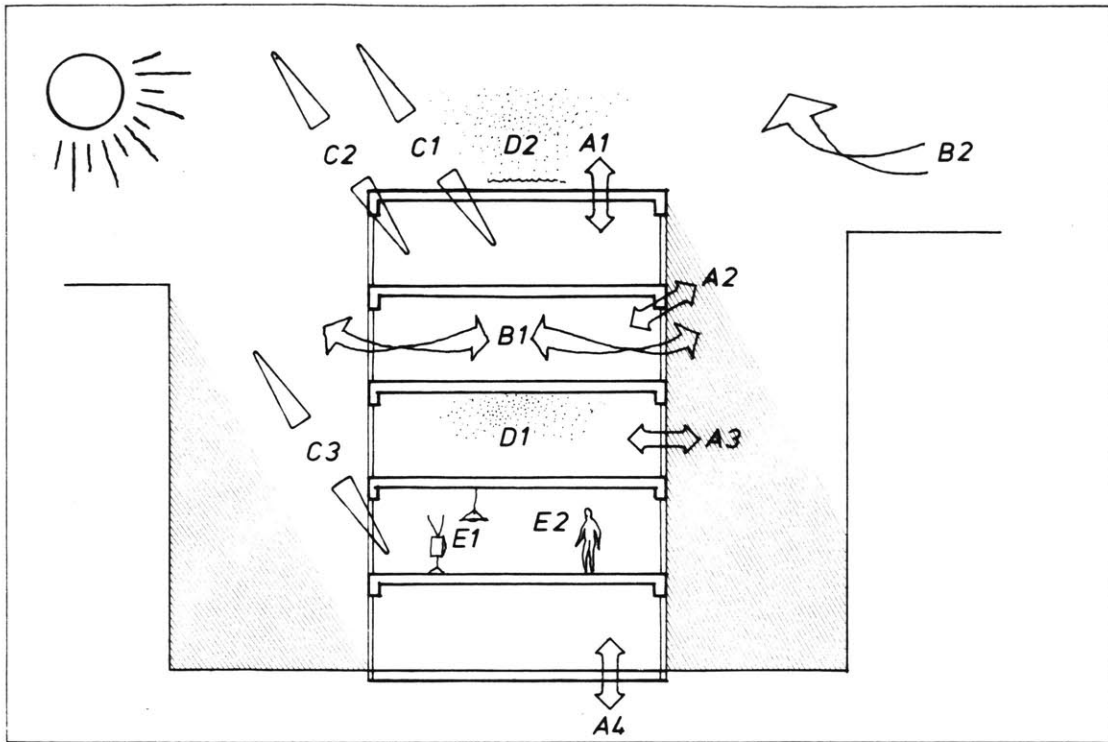
The appropriateness of any design decision on indoor climate control is determined, in addition to the requirements for thermal comfort, by the analysis of weather data.

Meteorological stations provide useful information on microclimate, that is, the overall climate of a region, depending partly on latitude, elevation and general terrain. Architectural regionalism usually offers a design type that is naturally suited only to a particular climate and would not be suited to another without selective modifications.

Site characteristics, however, can vary significantly from place to place, creating different microclimates within the same region. A thorough microclimate analysis enables the architect to adapt a building to its immediate environment by suggesting proper siting, orientation, form, materials, and other suitable aspects for each particular design issue.

Finally, the last level of climate is that within the building itself; the building envelope intercedes with the outdoor climate, bringing about a new indoor microclimate zone.

The scope of climatic design is to maximize the duration of the indoor microclimate within the comfort zone without recurring to the use of mechanical means.



*Heat exchanges with the environment*

<i>CONDUCTION</i>	A1, A2 through opaque building skin (walls and roof) A3 through glazed areas A4 with the ground
<i>CONVECTION</i>	B1 interior air flow B2 exterior air flow
<i>RADIATION</i>	C1, C2 through opaque building skin C3 through glazed areas
<i>EVAPORATION</i>	D1 indoor evaporation D2 outdoor evaporation

*Internal heat gains*

E1	occupants
E2	electric equipment

(2) Heat exchange and heat gain of buildings

## 2.2 Indoor Climate and the Environment

A building, like the human body, is constantly undergoing a heat exchange process with the outdoor environment: the building envelope is the device through which this process can be controlled. The ways buildings gain and lose heat must be examined, and methods of thermal comfort must be developed in order to assure a satisfactory performance, keeping in phase with the changing seasons.

The flow of heat by conduction through walls, floors, ceilings and windows may occur in either direction. Convective heat loss, particularly through glazed areas, accounts for a considerable part of the winter heating load in residential buildings.

Heat exchange by convection occurs by the movement of air between surfaces of different temperatures. Unintentional air infiltration is probably the most important component of residential heating loads. Ventilation, on the other hand, is a useful means of maintaining comfort conditions during overheated periods.

The sun can be a very significant source of radiative energy transmitted into an interior space primarily through windows or other transparent and translucent surfaces. Winter loads of solar heated buildings can be met by as much as 100 percent (and sometimes more); overheating, though, is mostly liable to occur in summer unless proper shading is provided. Conversely, thermal radiation from a warm surface to the environment will add to a building's heat loss.

The adiabatic phase change process of evaporation (ordinarily coupled with convection), although not a heat transfer process in itself, has a non negligible cooling potential.

Finally, internal heat gain sources include people, artificial lighting and electric appliances, and can provide approximately 25 percent of a conventional residential building's heating load; in a super-insulated solar heated building, heat gain sources can supply as much as 80 percent.

Indoor climate heat exchange mechanisms with the environment are represented schematically in figure 2.

	W I N T E R		S U M M E R	
	promote gain	resist loss	resist gain	promote loss
Conduction		<i>minimize conductive heat flow</i>	<i>minimize conductive heat flow</i>	<i>promote earth cooling</i>
Convection		<i>minimize ext. air flow and infiltr</i>	<i>minimize infiltration</i>	<i>promote ventilation</i>
Radiation	<i>promote solar gain</i>		<i>minimize solar gain</i>	<i>promote radiant cooling</i>
Evaporation				<i>promote evaporative cooling</i>

(3) Thermal comfort control methods

### 2.3 Indoor Thermal Comfort Control

The fundamental thermal comfort control options consist of: (a) admitting or (b) excluding heat gain from external energy sources, and (c) containing or (d) rejecting internal heat gain. Application of these four heat flow control options to the three mechanisms of heat transfer (conduction, convection, radiation) plus the adiabatic phase change process of evaporation generates a matrix of sixteen hypothetical strategies of climate control. Only eight of these can be productively exploited in design, the rest not availing themselves to use. The sun, for example, is the only global passive energy source; geothermal energy, when available, is not widely enough used to be considered in the scope of this thesis.

Each strategy can be implemented in a number of different ways. Its effectiveness, as well as the usefulness of the potential heat sinks, depend on locale and meteorological conditions.

The eight practicable strategies can be separated in those appropriate to underheated (winter) condition and those appropriate to overheated (summer) conditions. In predominantly underheated or overheated climates preference can usually be given to the more appropriate set, while the remaining strategies are used, if at all, in a secondary way. In the Athens area, as well as in most of Greece, both sets are applicable for significant fractions of the year. Failure to address both heating and cooling needs will result in sacrifices in overall annual comfort and energy performance.

The psychrometric limits of these strategies, the basic principles and the building characteristics necessary to effectively execute them are elaborated in the succeeding sections of this chapter.

## 2.4 Climatic Limits for Thermal Control Methods

*Each thermal control method has an effectiveness zone depending, in addition to the basic comfort requirements, on prevailing outdoor conditions. The climatic limits of thermal insulation and solar heating, shading, ventilation, and passive cooling strategies' effectiveness zones will be delineated in the following discussion.*

### *Restriction of conductive heat loss and infiltration, solar gain*

The need for passive solar heating --to the extent practicable within a regio- and the heat conservation strategies of minimizing conduction and infiltration heat loss is indicated whenever outdoor air temperature falls below the lower comfort zone limit of 20.0 degrees C.

### *Restriction of solar gain*

The need for solar gain control is indicated whenever outdoor air temperature exceeds the lower limits of comfort zone, the comfort conditions being defined under the assumption that MRT and air temperature are equal. Shading is the only strategy necessary when outdoor air temperature falls in the range of 20.0 degrees C to 25.5 degrees ET, and it is also required --although it is no longer sufficient-- for climate control when the outdoor temperature exceeds the upper limit of the comfort zone.

### *Ventilation*

The effectiveness of ventilation in producing body cooling in building interiors are based on the assumption that air temperature and vapour pressure are identical indoors and out, and that the mean radiant temperature of the building interior is approximately the same as that of the air. The upper limit is determined by the greatest wind speed that will not cause annoyance (about 1.5 m/sec), which results in a limit approximated by an air specific volume of .886 m<sup>3</sup>/kg when vapour pressure exceeds 17 mmHg. High rates of air movement become less desirable as the moisture content of the air decreases; a dry-bulb temperature of 32 degrees C is accepted as a limit for vapour pressure less than 17 mmHg.

### *Radiant cooling and thermal mass effectiveness*

The thermal mass approach to temperature control is limited by the assumption



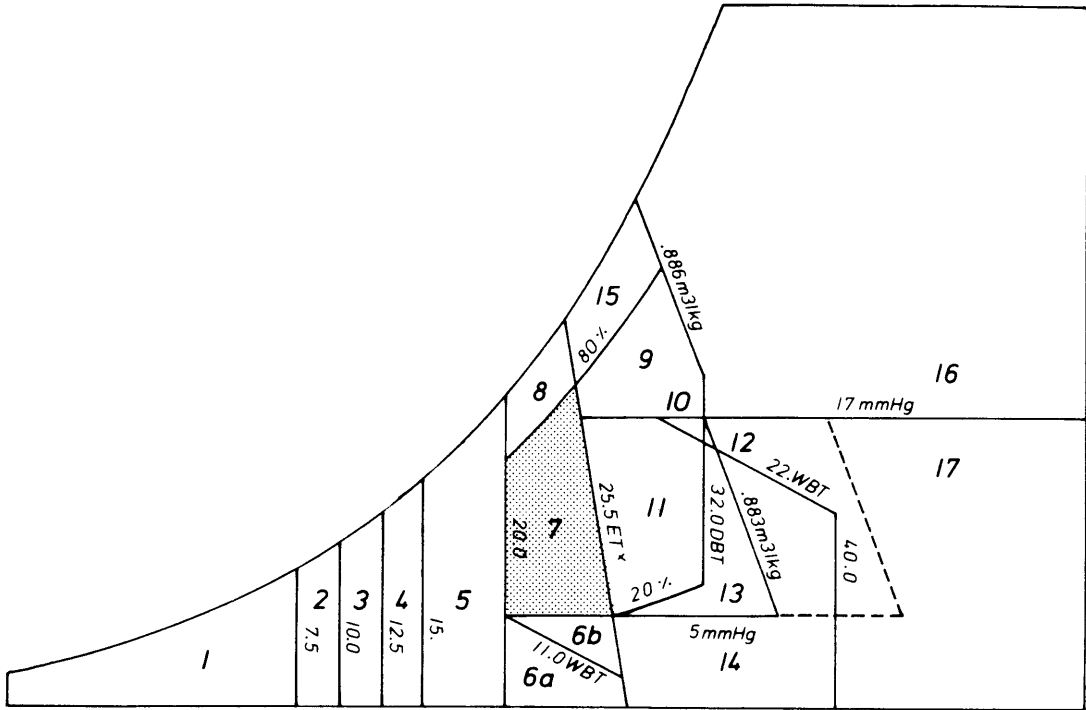
that the exterior shell is massive enough to damp out daily temperature fluctuations, and that the building is closed during daytime to minimize intrusion of heat. The second assumption necessitates an upper limit of vapour pressure of 17 mmHg, the maximum humidity at which one can feel comfortable in the absence of air movement; the upper temperature limit is satisfied by an air specific volume of .883 m<sup>3</sup>/kg.

The dry-bulb temperature limit is much greater under arid conditions because the body is comfortable at higher temperatures at low humidities, and because diurnal temperature range increases as absolute humidity decreases. A diurnal range of about 12 degrees C can be reasonably expected in climates where vapour pressure equals 17 mmHg (dew point of 20 degrees), and a range of 22 degrees C in climates where vapour pressure equals 5 mmHg (dew point of 2 degrees). Adding the corresponding half-ranges of these figures (to produce the expected daily minima) to the respective 25.5 ET degrees comfort zone limits of 24.5 and 26.5 degrees C at 17 and 5 mmHg, respectively, yields dry-bulb temperature limits of mass effectiveness strategy of 30.5 degrees at 17 mmHg and 37.5 degrees C at 5mmHg.

#### *Evaporative cooling*

The evaporative cooling process referred to here applies to direct evaporation of water into air drawn from the out-of-doors as it is admitted to the interior space. This adiabatic phase change is characterized by constant enthalpy (that is, the sum of sensible and latent heat remains the same). One limit of the evaporative cooling strategy, therefore, is the maximum wet-bulb temperature acceptable for comfort, set at 22 degrees; the dry-bulb boundary, which is a function of the temperature reductions that can be achieved at reasonable indoor air velocities, is taken as 40 degrees.

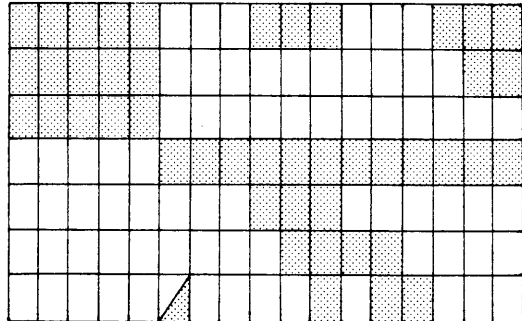
*The limits of appropriately developed executions of each thermal comfort control strategy identified in table 3, when plotted on a psychrometric chart, create an effectiveness zone that can be visualized as an extension of the comfort zone. The bioclimatic chart illustrated in figure 4 indicates that whenever ambient outdoor temperature and humidity conditions fall within the designated limits of a control strategy, then the interior of a building designed to implement that strategy will remain comfortable.*



*Zones of passive effectiveness*

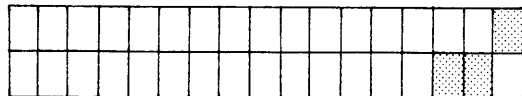
- Restriction of conductive loss
- Restriction of infiltration
- Solar gain
- Restriction of solar gain
- Ventilation
- Radiant cooling
- Evaporative cooling

1 2 3 4 5 6<sub>a</sub> 7 8 9 10 11 12 13 14 15 16 17



*Zones beyond passive effectiveness*

- Mechanical cooling
- Mech. cooling and dehumidification



(4) Limits of thermal comfort control methods

## 2.5 Restriction of Conductive Heat Flow

Thermal conduction is the process of heat transfer through solid building materials. The amount of energy transmitted through a composite building skin section is given by the relation :  $q = U * A * DT$ , where:

U is the overall coefficient of heat transfer,

A is the surface area, and

DT is the temperature difference between the two opposite faces

Within each of these three variables are numerous sub-strategies for reducing conductive heat losses or gains.

The use of high thermal resistance materials lowers the overall U-value of the building envelope and reduces the heat flow. This is particularly effective for the weaker elements, such as the windows, which account for the greatest part of conductive heat flow.

The same effect can be achieved by reducing the surface area: sub-strategies related to this approach include minimizing the surface-to-volume ratio (making the building more compact), and, possibly, reducing the relative area of the more conductive elements when this does not conflict with other major design criteria.

Finally, imposing restrictions on indoor ambient temperature may not be desirable; a decrease in temperature difference can be achieved by increasing the outdoor air temperature through selection of favourable building sites, building underground, or creating outdoor "sun traps" adjacent to the structure.

As in most systems, a multiplicity of control options is possible in the design of a building; for example, what may be inefficient in terms of excessive surface-to-volume ratio can be compensated by increasing the thermal resistance of the shell itself.

## 2.6 Restriction of Infiltration

Infiltration refers to the entry of cold air through joints, cracks and faulty seals in construction, and around doors and windows. Infiltration is considered the largest and most intractable cause of heat loss in a residence, once practical insulation measures have been taken. It is driven by the same two forces of wind pressure and thermal buoyancy as is ventilation. However, while ventilation of occupied spaces is always necessary, we seek to control this by making the building as airtight as possible and providing air change through devices in which it can be regulated. This approach allows further gains in energy efficiency when heat recovery systems are installed.

Controls on infiltration can be implemented at all stages of the design process, beginning with appropriate siting and ending with protective landscaping. The building itself can be shaped and oriented (including underground placement) to minimize its exposure to prevailing winds. Air tightness is attended to by detailing and care in construction of the building shell and in selection of window type and quality, as well as in securely closing dampers for other ventilating devices.

## 2.7 Solar Gain

The sun is the most significant natural source of energy available for passive heating of buildings. The feasibility of solar heating depends on the relationship between solar energy received and the winter temperatures which determine heating load.

The intensity and duration of solar energy received upon earth varies with latitude, local sky clearness and time of the year. Average daily total radiation throughout the heating season must be analyzed in relation to regional climatic conditions corrected for the site characteristics. *Direct (beam) radiation* availability can be determined by means of shaded sun path diagrams for the

specific location, which correlate surface azimuth, solar altitude and bearing, and time of the day. The importance of a thorough solar geometry study is obvious, especially for the implementation of a passive system in urban areas where the density and height of surrounding buildings restrict considerably solar access. *Diffuse radiation* sky component depends on the angle with which a particular point views the sky. *Reflected radiation*, finally, is a function of the overall surrounding surfaces' reflectance.

Average daily radiation on a horizontal and on a south facing vertical surface is recorded at local meteorological stations. Radiation incident on a surface of any orientation and tilt can be derived by tables and graphic methods, and calculated mathematically or through use of computer and calculator programs.

A solar heating system consists of the following parts : (a) a glazed aperture (collector) through which solar radiation is transmitted. Its area, orientation, tilt and glazing type determine the fraction of incident radiation that can be potentially collected. (b) an absorbing surface which intercepts the solar radiation and converts it into thermal energy, plus a medium for heat storage ; this can be either an integral part of the structure (concrete or brick masonry, etc), or an additional element (phase change material, containerized water), (c) a mechanism for solar gain control, and (d) the space to be heated.

In passive solar systems heat energy is transported from one component to the other through naturally driven mechanisms of heat transfer. It is often desirable, however, to assist the heat transfer --occurring primarily by natural processes-- through simple mechanical devices. Passive and hybrid system types are distinguished from one another by the physical relationship between apertures, absorbers, thermal storage media and conditioned spaces.

Passive solar heating issues discussed here are primarily based on the direct gain approach, which involves the simplest possible relations between a system's components. The space to be heated is directly coupled to the collector and contains the thermal mass in itself. Hence, the challenge for the concerned architect: the floor plan organization itself becomes the distributing system. Solar heating should be viewed as a process generating a set of criteria that have to be met throughout the design process, starting as early as during the conceptual stage, rather than as a device engineered and added to a building at some later stage.

Active systems, relying exclusively on the power of pumps or fans for the heat distribution, will not be discussed in this thesis.

Solar gain through a glazed surface is usually calculated on an average daily or average monthly basis. It is given by the equation:  $H_s = A * I_{tot} * TC$ , where:

A is the (unshaded) glass area.

$I_{tot}$  is the average daily (or monthly) total radiation incident on a unit area of the same orientation and tilt as the surface considered, and

TC is the transmission coefficient depending on the glazing material and on the angle of incidence of beam radiation.

Solar heating systems can increase radiation gain by increasing any of these variables. This involves increasing and carefully siting the collector's area in unshaded locations, optimizing its orientation and tilt, as well as selecting highly transmitting glazing materials. Each method can bring about undesirable side effects that must be studied in the context of every particular situation. For example, a high transmittance factor which usually characterizes single glazing materials can be counterbalanced by low solar heat gain to conductive-convective heat loss ratios.

In order to maintain ambient temperature within the comfort zone solar heated buildings make use of appropriate regulation devices. These may be static (roof overhang shading the collector's area during the summer months), or dynamic (movable night insulation or shading devices, operable vents). Control devices may also include electronic sensors, such as differential thermostats, that signal a fan or the auxiliary heating system to turn on and off.

The solar gain equation depends on orientation only in the sense this latter affects oncoming radiation. Solar heating can be achieved through windows of any orientation, although exposures that are problematic in shading, hence in regulating radiative gain in winter and preventing overheating in summer, are usually avoided (this involves easterly and --especially-- westerly exposures).

A considerable part of a building's heating load can be met by solar gain through *north* facing windows, especially in temperate climates where the average daily outdoor temperature is above the freezing mark. This approach exploits diffuse and reflected radiation by utilizing the new *selective transmitting glass*

generation, characterized by a high solar transmission to conductive-convective heat loss ratio. Low-E coated glass (heat mirror) accepts short wave radiation from the sky vault, while reflecting back into the space the longwave thermal radiation emitted by the storage mass or generated by the internal heat gain sources. However, total radiation being greatly reduced on a north exposure, a large glazed area is required to achieve significant solar gains; consequently, visual privacy and glare problems should be considered in order to reach an optimum solution.

## 2.8 Restriction of Solar Gain

When solar energy strikes an exposed material, some is absorbed, some is reflected, and a portion may be transmitted through it. The absorption of solar energy by an outdoor building surface raises its temperature above that of the air by some degree which depends on the surface colour and on the radiation intensity, as well as on the countervailing rate at which its temperature is reduced by convective and radiative loss to cooler surroundings.

Solar gain controls focus primarily on regulating the heat transmitted through glazing materials, whose transmittance is considerably greater than that of other translucent or opaque building materials. Control strategies can be grouped into three basic categories : (a) interception and (b) reflection of solar radiation, and (c) selection of glazing type, area and orientation.

Interception techniques are usually the most effective and desirable of all the control options, providing they do not interfere with acceptance of solar gain when it is necessary; the importance of a sun path analysis and the study of shading masks is therefore capital. Interception techniques range from use of double building envelope and roof overhangs to lightweight shading devices attached to walls and roof. These can be complemented by natural shading, achieved through appropriate use of vegetation and keeping in phase with the

seasons. Movable mechanical devices intercepting the sun --preferably at the outside of a window-- allow for the necessary adjustments to be made between seasons: on the other hand, fixed opaque louvers, set at an angle to admit winter sun while shading the window in the summer, produce a poor effect on natural daylighting.

The amount of heat transmitted as sunlight to the interior can be reduced through interception within the glazing system itself, by using tinted or heat absorbing glazing materials. Unless ventilated internally, however, the temperature of the glazing is significantly raised in the process, and much of this heat is released to the interior.

Finally, *double glazing containing very thin, movable, reflectorized louvers* can be a satisfactory shading solution: summer sun is reflected back to the outside when the louvers are rotated to the proper angle, while the inner glazing helps to contain the heat built-up occurring in the air gap. Louvered glass is also compatible with optimizing natural daylighting and achieving ceiling storage of solar heat during the heating season.

In regions like Greece, where summer air temperatures frequently exceed comfort limits, reflection of sunlight is an important complement to shading, as well as a climatic response extensively used in the vernacular architecture of the islands. Light colour masonry and a white pebble bed or white tile roof can significantly reduce radiative gains, especially for a building shell that is not well insulated, and therefore unable to resist inward conduction of heat absorbed at the surface.

The area of fenestration --and tilt, if different than vertical-- is of a major significance, particularly for westerly exposures that cannot be shaded easily. The shape and orientation of the building shell itself is important in overheated areas, but its significance diminishes as its thermal resistance increases.

It becomes apparent that the most desirable solutions for regulating solar heat gain make use of appropriate combinations of the different sub-strategies.



## 2.9 Ventilation

Ventilation is defined as the process of supplying or removing air by natural or mechanical means to or from a space. It serves three ends in the environmental control of buildings: it is used to satisfy the fresh air requirements of the occupants (health ventilation), to increase the rate of evaporation and sensible heat loss from the body (comfort ventilation), and to cool the building interior by exchanging warm indoor air for cooler outdoor air (structural ventilation).

Air is made to move by differences in pressure (forced convection) and differences in density (free convection). Natural ventilation applies to air flow which is driven by pressures or thermal forces created by or converted from meteorological events, as opposed to those generated by mechanical means. This includes cross-ventilation and ventilation by stack effect.

Continual ventilation and nighttime ventilation are the two primary convective heat flow strategies for comfort control. In both cases the cooling sink is the air, and the index of the cooling potential is the dry-bulb air temperature. The suitability of either method depends, in essence, on whether air movement at acceptable velocity is capable of maintaining comfort during typical daytime conditions, and, if not, whether nighttime temperatures are low enough to counterbalance the overheatedness of the day.

In general, arid region conditions exceed comfort zone so greatly during the daytime that ventilation is undesirable from both the standpoint of bodily water balance as well as that of thermal comfort. The clarity of the atmosphere allows temperatures to fall enough at night, so buildings constructed with massive walls and roofs can maintain relatively moderate temperatures through daytime. The ventilation strategy for such climates is to vent the interior at night and to close the building during the day. If prevailing night winds are difficult to capture, or simply too weak, night ventilation can be assisted by fans, and possibly exploit evaporative cooling techniques.

Thermal comfort is attained by natural means in more humid overheated regions only with a constant movement of air across the skin. Daytime temperature control is maintained by ventilating as efficiently as possible, both for dissipation of solar heat absorbed by the building shell as well as for body cooling.

## 2.10 Radiant Cooling

Thermal radiation is the transfer of heat energy through space by electromagnetic waves. Unlike conduction and convection, radiation is impeded, rather than conveyed, by a medium interposed between the regions of heat exchange.

The sky is the sink for radiant emissions from earth. Much of the outgoing longwave radiation, however, is absorbed by the carbon dioxide and water vapour present in the atmosphere, and then re-radiated back to earth. The difference between sky and ambient air temperature is related to the moisture content of the atmosphere (and to the level of pollution), and is smaller in humid regions than in arid regions, under clear skies. Cloud cover severely reduces the sky cooling rate, and a heavy overcast can effectively shut off the thermal "view" of the sky altogether. Even at maximum clear conditions cooling potential, however, the sky is not a powerful sink: except under very arid conditions, its temperature rarely drops more than 10 degrees below ambient air temperature.

Furthermore, convective heat gains can minimize the radiator's temperature depression: a 1.5 m/sec breeze is sufficient to halve the maximum clear sky flux loss. It can therefore be said that the greatest radiant cooling potential is found in relatively dry zones where summer skies are clear and night sky temperatures are low. Radiant cooling, generally, is not well suited to warm humid climates in which nighttime breezes prevail.

Architectural constraints in radiant cooling revolve around the difficulty of coupling the interior to the night sky without subjecting it to the solar load of the day. The basic design approach consists of a low mass radiator placed on top of an insulated roof and coupled to the interior by means of a heat transfer fluid (usually air or water); heat is dissipated from the fluid as it passes over or behind the radiator. Because the fluid becomes denser as it is chilled, it can drain by natural convection directly into the space beneath (or to an underfloor storage plenum). A conductive low mass construction enables the roof to respond quickly to ambient sky and outdoor air conditions. It offers the greatest radiant cooling potential at night, but performs very poorly during daytime, and is most adversely affected by convective heat gains.

High mass is a second approach to radiant cooling, and another typical climatic response of greek vernacular architecture. In contrast to low mass roofs, high mass construction sacrifices lower nighttime temperatures for more comfortable daytime conditions. It is most suitable for predominantly overheated arid regions where there is no significant winter heating load, or where the heating load is easily met by solar design.

### 2.11 Evaporative Cooling

Evaporation is the process by which liquid water at its free surface (in contact with the air) is transformed into water vapour. An amount of heat is absorbed by water in its change of phase: the specific quantity required to effect the change from liquid at a given temperature to vapour at the same temperature is called the latent heat. Wet-bulb temperature is defined as the temperature at which water, by evaporating into air, can bring the air to saturation adiabatically: wet-bulb temperature depression, defined as the difference between ambient air dry-bulb and wet-bulb temperatures, is an index of the evaporative cooling potential.

The heat dissipation value of evaporative cooling depends on what other mechanisms of resisting heat gain are provided in the design. Among these are maximizing the solar reflectivity of a surface, ventilating the underside of the roof, and resisting the conductive intrusion of gain (although mass alone does little to reduce the accumulated daily heat load).

There are two different approaches to evaporative cooling. On one hand, surface spraying and roof ponds can be considered as a means of dissipating solar heat absorbed at the surface; that is, they provide a method of reducing the amount of heat conducted into the interior through the building envelope, and are thus compatible with the conduction control strategy. In general, roof sprays are well suited to warm humid regions, where small winter heat loads require little in the way of insulation, but where solar loads are always high. On the other hand, evaporative treatments can be used to extract heat from the interior: in this sense, outdoor air provides a heat sink which evaporative treatments serve to

exploit. In order to achieve this, the interior must be coupled with the evaporative surface through a highly conductive structure.

The problem inherent in using a surface for evaporative cooling in order to extract heat from the interior is identical to that of coupling the interior to the roof as a radiator. There are, however, additional alternative solutions, since it is neither necessary nor desirable for the wetted surface to see the sky; an evaporating roof, or sub-roof, can be shaded, and the devices utilized for shading could also serve to direct the air stream of natural breezes over the wetted surface.

Because of their similarities, heat extraction by evaporative cooling and by radiant losses to the sky are often combined, employing movable insulation or thermosiphoning circuits that link exterior surfaces with the interior.

## 2.12 Conductive Cooling

The earth is the only sink to which a building can continuously lose heat by means of conduction during overheated seasons. The potential of earth coupled cooling is indicated by the difference between ground temperature --at a depth exceeding 1.5 m-- and the average air temperature. Problems of heat exchange between the ground and buildings burried in it are more complex than those of heat exchange between a building interior and the out-of-doors. The main problem is how to dissipate heat to the low grade sink without incurring the penalty of large winter heating loads. Secondary problems involve the risk of condensation occurence, and the difficulty of taking advantage of natural ventilation.

The basic approach to earth cooling consists of a direct coupling to the ground, and reffers to the indoor space of underground buildings. On the other hand, indirect coupling can also be achieved by means of earth-air heat exchangers or heat-pump mechanical systems (although this approach works more effectively with ground water, and can exploit geothermal energy, when available, through the opposite process).

The thermal value of earth cover is closely related to the importance of radiant and evaporative cooling, both of which must be viewed in a regional context; the likelihood of condensation occurrence also varies from region to region. Trade-offs between optimum earth coupling and effective ventilation rest with the designer, but, like the foregoing, this issue is also of a regional nature.

In very broad terms, arid conditions favour earth coupling, whereas earth coupled cooling design for humid zones is likely to be accompanied by compromise between benefits and liabilities. The value of ground coupled cooling can be enhanced by ground temperature modification techniques.

### 2.13 Auxiliary Heat Sources

The high solar heat transmission-to-loss ratio of the new selective transmitters makes it possible to achieve 100 percent solar heating even in cloudy climates, or in dense urban areas with limited direct radiation access. This, of course, provided that the average outdoor temperature remains well above freezing point, and that the occupants can accept large areas of the coated glass. While the climate of Athens satisfies the first condition, large glazed areas are very likely to cause privacy problems in a densely built environment, as well as overheating in summer unless proper shading is provided.

Optimizing the glazing area by taking into account important non-climatic parameters can lower the efficiency of passive solar heating in an urban residential building; an auxiliary heating system will be required in order to complement passive gain and thermal insulation features, and thus maintain indoor thermal control under extreme outdoor conditions.

Correctly sizing and coupling the auxiliary heating system with a solar heating concept is very important. It can bring about a total system cost (auxiliary heat plus solar) that is less than or equal to that of a conventional heating system. Further, the storage capabilities of a direct-gain system can be utilized to regulate the auxiliary heating system and optimize its cost-efficiency and overall performance.

*Off-peak electricity* may be a successful alternative to centralized oil-burning systems, currently used in the majority of residential buildings in Athens. Rather than utilizing isolated heat accumulators, the structural thermal mass (or the additional phase-change materials) can be exploited. For example, heat may be stored into a ceiling mass through use of ribbons of electrical resistance material: the process is regulated by a thermostat that turns off when the mass is charged enough to maintain thermal comfort throughout the day.

*Heat pumps* are another decentralized auxiliary means of maintaining comfort. Air-to-air heat pumps, or water-to-air when ground water access is easy, can be very efficient even under the most severe conditions of a temperate climatic zone (like that of all of southern Greece). High efficiency means low electricity consumption, which can be reduced even further by using off-peak electricity to run the heat pumps, provided that the heat can be stored. Finally, reversibility seems to be an additional attractive feature of heat pumps, especially for the athenian climate where extreme climatic situations are as likely to occur during summer as during winter.

#### **2.14 Visual, Olfactory and Acoustic Comfort Control**

*Visual comfort* involves maximizing the duration of natural daylighting in building interiors, increasing the daylight factor, achieving an appropriate distribution of lighting levels (allowing sunlight to penetrate deeply into a space), and eliminating glare problems. Although a number of design solutions can be implemented exclusively toward that end, all these issues are naturally associated with promoting or resisting solar heat gains. Increasing the surface area-to-volume ratio, bilateral lighting, light shelves, high ceilings, light colour interiors, optimizing the windows' position and dimensions, carefully detailing the reveals and mullions, and making use of louvers or other operable shading devices are only a few methods for achieving visual comfort.

Health ventilation. the response to *olfactory comfort* involves satisfying the fresh air requirements of the occupants. Natural ventilation has to be assisted by mechanical means in spaces requiring more frequent air changes, like in kitchens and bathrooms. In recent years atmospheric pollution has become a major problem for olfactory comfort, especially in the most heavily affected areas of Athens.

*Acoustic comfort* is a twofold issue, regarding whether noise is generated within or without a building. External (street) noise attenuation is probably the most important aspect in dense urban areas, aggravated by the phenomenon of resonance occurring in the narrow canyon-like streets: in some streets of Athens traffic noise may well exceed 75 decibels over extended periods of the day.

The effects of increasing the acoustic insulation of the external building shell and making use of balconies as sound barriers are insignificant, while the use of more insulating double glazing for acoustic purposes can only bring seasonal relief. Both noise and atmospheric pollution are major problems of the greek capital that have to be met by appropriate large scale long term urban design solutions.

Floor plan organization is the most important means available to the architect for achieving the closest situation to total acoustic comfort, based on the different acoustic requirements for bedrooms and study rooms, living and dining spaces, and kitchens and bathrooms. Placing the bedrooms on the backyard side of a building can be an important move, when not in conflict with other major design criteria such as orientation and view. Grouping together spaces with similar requirements, and taking advantage of buffer zones (for example, a closet or a bathroom between a bedroom and a dining room, or an adjacent apartment, or an elevator shaft) can also bring about desirable results. Finally, carefully detailing the structure, joints, mechanical equipment, pipes and ventilation ducts, choosing sound absorbing finishing materials, and taking advantage of acceptable masking noise effects, can play an important role for achieving indoor acoustic comfort.





*PART II*

**SITE ANALYSIS**

## CHAPTER 3

## ATHENS THE BUILT ENVIRONMENT

## 3.1 The City

*When Greece won its freedom after 400 years under ottoman rule, a village of 5,000 inhabitants around the Acropolis was chosen to be its capital. The foundation of Athens as the capital of the new Hellenic state marks the nationalistic aspirations of broader hellenism and the romantic expectations of the bavarian government to restore the ancient civilization. The history of the modern city of Athens begins in 1833, while the country enters a transitory period between a feudal and a capitalistic production mode.*

Not carrying any long urban tradition, as did other european cities, the urban development of Athens begins with a series of master plans proposing new large avenues, monumental buildings, and the organization of the city into a neoclassical space suited to its new functions. The reaction of powerful land owners to these plans brought about successive compromises and eliminated the large scale implementation of a neoclassical fabric while, at the same time, new spontaneous forms were springing up and multiplying rapidly. Starting as a purely administrative centre, Athens soon became enriched by educational, financial, commercial, and, later, industrial activities.

The process of land parcelling lead to a quick integration of the house construction industry into the capitalistic system; acquisition of the rural land --switched to small urban lots-- at relatively low prices ensured a large part of the new population a piece of land and a house of their own. One, two, or three-storey detached houses, usually endowed with a garden or a backyard, materialized the ambitions of a large new middle class growing within the context of the athenian "belle epoque".

*The unplanned, uncontrolled city expansion and the prevalence of land speculation that occurred at the turn of the century are expressions of two important trends: the liberalization of the constitution, following a period of political instability, and the infusion of foreign capital to the economy. This, in turn, led to the development of an industrial basis, the establishment of transportation networks, and a resulting change in the socio-economic structure of the Athenian society. All these developments combined with an absence of any government imposed urban planning other than small scale improvements in selected locations --intended primarily to guarantee a certain level of coherence in the street network-- determined the appearance of the Athenian landscape during the period preceding the first world war.*

*The period between the first and the second world war represents a dramatic change in the history of the nation, and is marked by the influx of refugees from Asia Minor's Greek centres, and by the development of industrialization. The shape of the capital during this period was determined by the establishment of scattered refugee settlements in its periphery, the ad hoc growth pattern of the whole of the Athenian agglomeration, and the failure of active planning attempts to cope with the rapid demographic and urban explosion.*

The centripetal and static space of neoclassicism was gradually replaced by a new fabric that spread vigorously in all directions to express the glutinous attitudes of the people and the explosive potential of the city. Greater Athens was characterized by two centres of intensified density --the downtown area and the port of Piraeus-- and a loose periphery constituted by the refugee settlements and the scattered speculative and industrial development. Previous planning attempts, based on various master plans for the neoclassical city --which by this time occupied only the central part of the agglomeration-- gradually gave way to a spontaneous and anarchic growth; the resultant mixed land use was a function of the new small scale urban centres developing within the city itself.

The population of greater Athens grew from 450,000 in 1920 to 1,100,000 in the eve of world war II. While migration to the capital became a national policy, the accomodation of the newcomers was disassociated from any social measure and became an individual affair. The continual and the sudden population increases that ocured during this period were obviously making changes inevitable; but the way in which these changes took place is a manifestation of the emerging power of the housing industry, the state's inability to respond to the demands for rapid growth, and the eagerness of the people to exploit their property without respect to their actions' side effects. During that period the state itself encouraged these developments by tolerating illegal lot trade. This was only a precursor of the post-war period, when land exploitation became a major form of city expansion.

Parallel to the uncoordinated, incremental process of urban growth, and the fragmented urban landscape that ocured as a result, was the development of the private building sector and the appearance of the condominium apartment building. In 1919, a set of building regulations involving mainly building heights as a function of street width, and horizontal elements protruding over the public street space, was soon to be revised, permitting more favourable (and profitable) conditions. Ten years later, the appearance of a new general building code ruling floor-to-area ratios, view, natural lighting and ventilation, insulation, and fire safety issues caused, again, such reactions that more flexible regulations were finally approved. All this resulted in the gradual replacement of the traditional backyards by minimal light wells, with all the long term consequences for both the architectural scale and the urban landscape.

The same year saw the implementation of the formula of horizontal occupancy (condominium), permitting for the first time ownership of a single floor, or even part of it. In such a supportive milieu, with all the legal conflicts of the previous time resolved, and with the importation of the necessary technology (elevators, high water pressure), the multi-storey urban apartment building started invading the capital. The catastrophic potential of this period's laws would be fully realized during the post-world war II era, when this new building type would become an unlimited source for speculation. The architects of the time either applauded its social necessity as a relief to the demographic problem, or involved themselves in a polemic focusing only on aesthetics.

In the years before the war, Athens already had a considerable number of row-buildings six and seven storey high, that were being suffocatingly squeezed into urban lots originally suited to accomodate single or double-family houses. These buildings dominated the city centre and imposed a random intensification of the urban tissue, thus destroying permanently the coherence of the pre-existing fabric.

*Following the economic downturn and the damages caused by the war and the subsequent turmoil, and up to the early 80's, the development of Athens has been defined within a context of conservative political rule, professional and social restructuring, and continual economic growth. During the 60's and the 70's, Athens was transformed into a permanent construction site (central areas in the 60's, and north, northeast and southeast suburbs in the 70's following the saturation of the centre).*

The demographic explosion and the resultant urban growth of Athens during the latter part of the 20th century, unequaled by any other european city, lead Greece to a state of hydrocephalitis (population of the greater Athens area: 1,400,000 in 1951, 1,900,000 in 1961, 2,500,000 in 1971, 3,000,000 in 1981, or 18, 22, 29 and 31 percent of the total greek population, respectively). At the present day the capital city attracts the majority of private investments, administrative functions and cultural activities, thus exercising an impressive dominance over the rest of the country.

The urban development of Athens during this period is characterized by the absence of planning --which has been reduced to a theoretical exercise detached from the city's reality--, the multiplication of illegal settlements (always subsequently legalized), and, most significantly, the residential building boom associated with the decisive role of the private building sector in the city's economy.

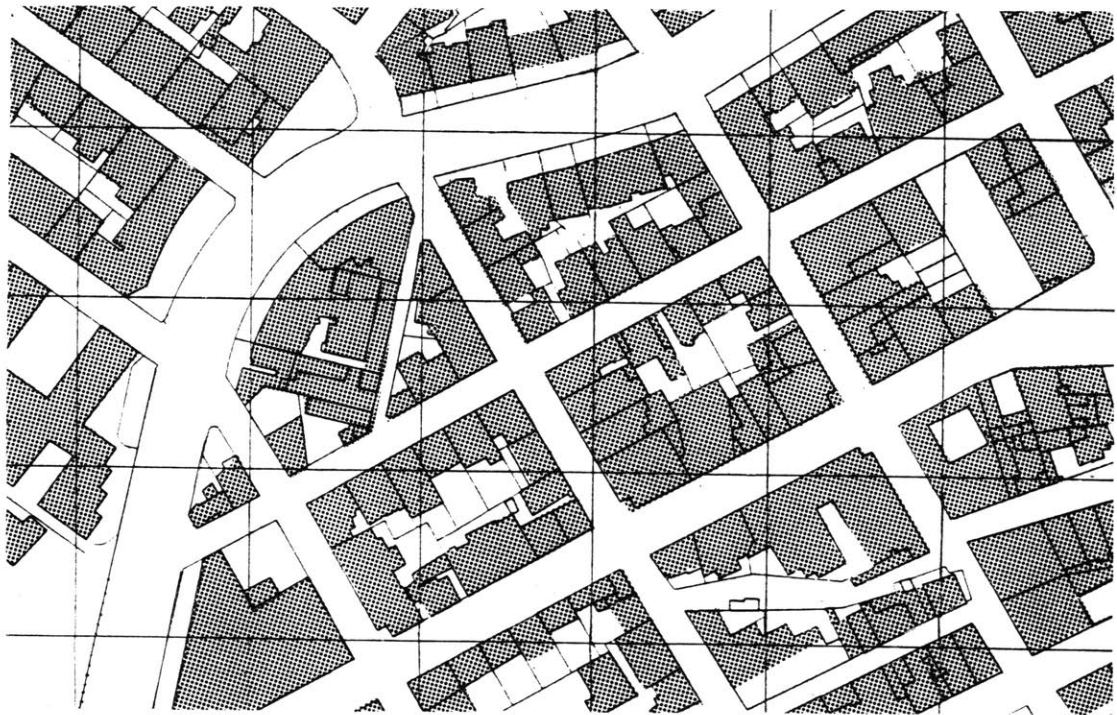
State authorities have been facilitating private building enterprises as much as possible, by influencing both the supply and the demand, or even by reducing construction undertaken by the public sector. While the legal framework had been set by the floor ownership law and the general building regulations of 1929, the decisive incentive for the proliferation of urban residential buildings came after

1955. New building regulations reduced even more the minimum distances for views, sunlight and ventilation access; later decrees increased considerably the floor-to-area ratio and the maximum building heights. In addition, the obstacle presented by the increased cost of land was overcome by a legislative formula establishing "building partnerships". According to this, a developer could form a partnership with the landowner, the latter contributing the land in exchange for ownership of a percentage of the total building floor area, the specific percentage being a function of the land's market value. These partnerships, which essentially eliminated the upfront cost for the purchase of land, coupled with continuously growing demand for urban housing, accelerated the already rapid growth of residential building in Athens.

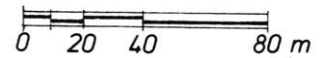
The urban context of Athens in 1985 is characterized by previous anarchic growth patterns, mixed land use, high density, and an unorthodox housing situation; the social functions are insufficient, the transportation is problematic, the aesthetic perception is poor, and the environmental pollution is alarmingly high. Three decades of uninterrupted building activity have saturated most of the central areas as well as the smaller urban centres of greater Athens. Continual rows of multi-storey residential buildings define narrow canyon-like streets and marginal free spaces, obstruct the view and provide inadequate natural lighting and poor ventilation. Such a physical environment prevails at a moment when improved socio-economic conditions allow the Athenians to question the quality of their life.



(5) Athens, 1985



(6) Athens; a typical residential area





### 3.2 The Urban Residential Building

Figure 6 shows an aerial plan of a representative, average income, residential part of Athens.

The secondary street network (excluding the major circulation arteries) is constituted by --mainly-- orthogonal axes of widths ranging from 10 to 14 metres.

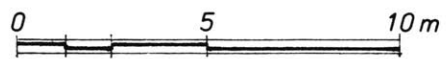
The typical bloc is subject to the primarily rectangular order of its urban context. Its dimensions range from 60 to 80 metres long and from 40 to 50 metres large.

The parcelling of the bloc is a direct consequence of the first urbanization of this part of the city. The modern residential buildings stand on the same lots, or associations of those occupied by the smaller detached houses built around the turn of the century. The result is twofold: on the first hand, the ratio of built versus free space is very high; on the other hand, the majority of the buildings are small, their footprint area being equal to or less than 250 square metres

The whole area is a typical example of the post-war multi-storey residential construction boom; more than 80 percent of buildings inside this zone were constructed after 1955. These are mostly six and seven-storey high (not including ground level), with the last one or two in set-back. The dense, continual building is regulated by a coverage ratio ranging from 60 to 80 percent.

In this mixed land use zone, characteristic of the greatest part of Athens, a strongly residential character coexists harmonically with commercial and other professional activities. Commercial spaces usually occupy large parts of the ground level of many apartment buildings along the front facade; similarly, the lower floors may house doctors' offices, architectural firms and other professionals.

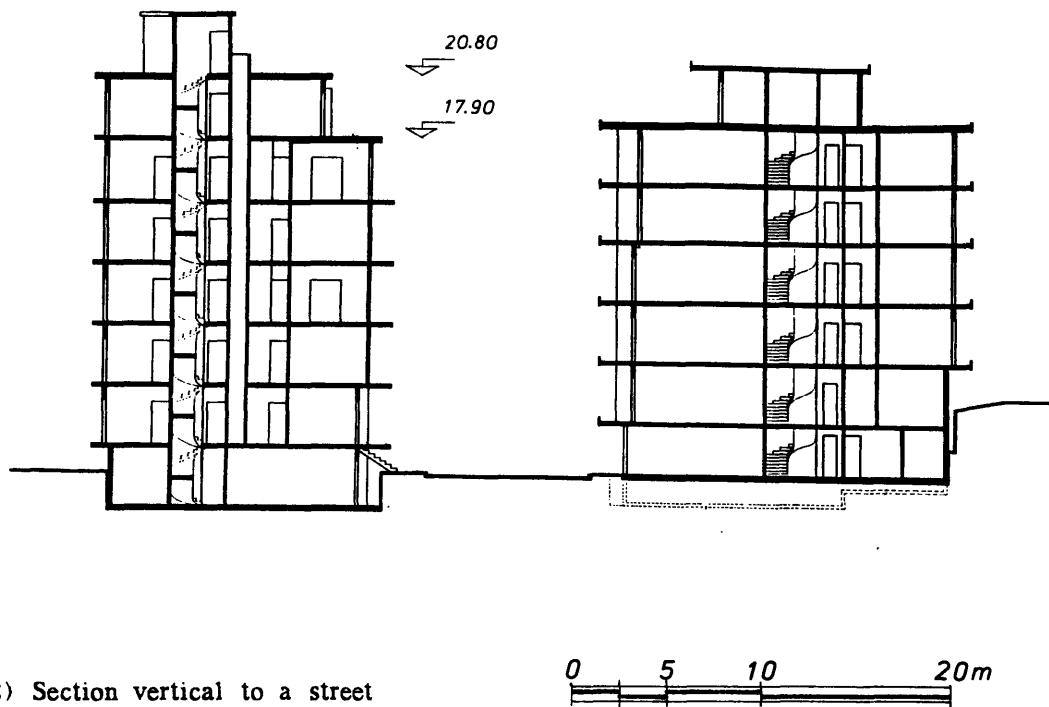
Since very recently, residential buildings are required to provide underground parking facilities in function of the number of apartments, as a response to large scale circulation and parking problems.



(7) Residential building floor plans

1 entrance, 2 living room, 3 dining room, 4 kitchen

5 bathroom / w.c., 6 bedroom, 7 storage (formerly maid room)

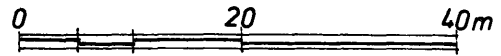


The residential building organization is based on a central vertical circulation core giving access to apartments --developed only horizontally-- through a landing hall or corridor. Each floor is usually subdivided into two or three apartments, with the exception of very large building (four or five apartments) and very small buildings, where a single unit can occupy a whole floor. Unit size varies, usually ranging from one to three-bedroom apartments.

Only the principal living spaces (bedroom, living and dining room) have visual access to the exterior; bathrooms and kitchens are positioned around minimal vertical light wells. This is particularly true since the floor is always subdivided along an axis parallel to the street, thus excluding flow through schemes (with the exception of end units of large buildings). Bathrooms and kitchens are organized along minimal vertical light wells. Finally, entrance and interior circulation always refers to closed, windowless halls and corridors.



(9) Front street elevation



The load bearing structure is monolithic and invariably utilizes reinforced concrete, while the infill exterior and interior walls are constituted by different thicknesses of brick.

Finishing materials include wood, marble, and ceramic tiles; wall-to-wall carpets are rarely used. Building materials are not exposed, being usually covered by a layer of plaster. False ceilings are not widely used, either.

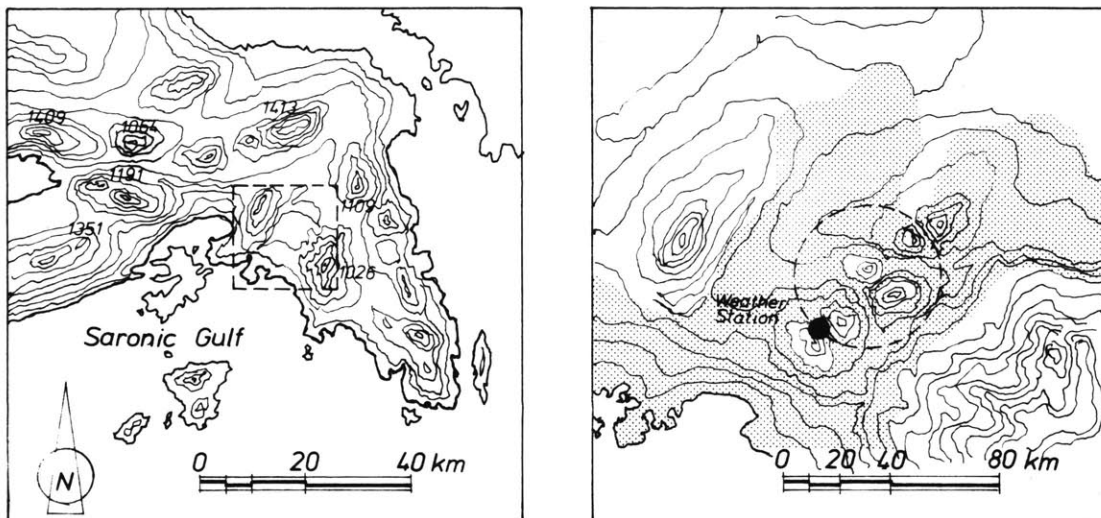
Windows are almost always single-glazed. Access to the balconies is assured by sliding balcony-doors no less than 1.2 metres wide. Balconies are an ever present feature of both free facades, especially on the front where building regulations allow for horizontal elements to protrude by 90 centimetres over the public street space. Making the most of this issue, residential building design is associated with narrow strips of balconies running along the full length of the facade, at the expense of daylighting.

An indoor air temperature of 18 degrees is guaranteed by a centralized oil-burning system. Ventilation is assisted by isolated mechanical devices only in kitchens. Finally, domestic hot water is supplied on an individual basis by electric water-heaters.

## CHAPTER 4

## ATHENS THE PHYSICAL ENVIRONMENT

The region of Attica is characterized by a very diversified terrain. Mountains reaching as high as 1,400 m define narrow serpentine valleys, and encircle the athenian basin from three sides. The city, whose profile is animated by a series of hills, extends to the south sloping smoothly towards the sea. The city of Athens lies at a latitude of 37. 58 degrees and a longitude of 23. 24 degrees.



(10) Topographic map of Attica and of the Athens metropolitan area

The main weather station is located on top of a hill (altitude 107 m), very close to the centre of the city. The data on air temperature, humidity, wind, and solar radiation, analyzed in the subsequent sections of this chapter, are based on the most recent climatological bulletin (1981) published by the Meteorological Institute of the National Observatory of Athens.

## AIR TEMPERATURE




	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AM 0-3	5.9	7.8	11.4	13.0	15.8	22.5	23.5	23.6	21.1	19.2	11.1	12.4
3-6	5.7	7.3	10.8	12.4	15.4	21.9	22.9	23.1	20.4	18.7	10.8	11.9
6-9	5.8	7.4	11.3	14.0	18.0	24.7	25.2	24.8	20.8	19.5	11.2	11.9
9-12	7.7	9.9	14.9	17.9	21.5	28.3	28.9	28.9	26.2	22.4	14.0	14.1
PM 12-3	8.9	12.1	17.2	19.8	22.5	29.7	30.6	30.6	28.1	25.1	16.1	15.6
3-6	8.3	11.5	16.5	18.7	21.6	28.7	29.7	29.5	27.1	23.8	14.8	14.8
6-9	7.0	9.3	13.7	15.6	18.6	25.6	26.3	26.1	23.6	20.9	12.5	13.2
9-12	6.3	8.4	12.3	14.0	16.9	23.8	24.3	24.4	22.0	19.8	11.6	12.7
Average 1981	7.0	9.2	13.5	15.7	18.8	25.6	26.4	26.4	23.8	21.3	12.8	13.3
Average 1950-1980	9.0	9.5	11.5	15.2	19.7	24.1	27.2	27.0	23.4	19.0	14.6	11.0

## GROUND WATER TEMPERATURE

Average Daily	9.3	9.4	10.0	12.2	15.3	18.7	20.8	22.7	21.5	18.5	14.7	12.1
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## 18.0 C HEATING DEGREE DAYS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	340	246	139	76	17	0	0	0	0	4	159	145
Average 1950-1981	264	224	196	85	10	0	0	0	0	29	96	206

	Air Temperature	% Annual Hours
	below 20 degrees	51.0
	20.0 - 25.5 degrees	32.2
	above 25.5 degrees	16.7

(11) Air temperature and heating degree days

#### 4.1 Air Temperature

The greater Athens region is characterized by a monthly air temperature variation of 20 degrees throughout the year. The daily temperature variation is about 5 degrees in winter and about 8 degrees in summer; peak temperatures occur around 4 a.m. and 4 p.m.

Winter temperature never remains below freezing point throughout a day. The heating season begins in November and ends in mid April (average temperature 11.2 degrees). The summer is very warm, with daytime temperatures exceeding comfort limits during June through September (average 1981 temperature 28.3 degrees versus 23.1 degrees during nighttime).

1981 air temperatures are quite representative of the athenian climate, with the exception of a cold January, a warm March and an unusually mild December.

Ground water temperatures --at a depth of 1.5m-- range between 9 and 23 degrees, with an average of 21 degrees during the four months of the overheated season.




## PRECIPITATION

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Total Monthly	86.0	30.9	24.0	36.7	2.5	0.0	1.9	0.4	0.0	17.0	22.9	48.8
Days	17	8	3	10	5	0	1	1	0	6	5	11
Duration	133.5	38.7	9.1	29.4	8.5	0.0	2.5	1.5	0.0	17.0	22.9	48.8

## RELATIVE HUMIDITY

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AM 0-3	79	75	75	69	63	63	55	56	64	72	72	77
3-6	79	77	77	71	66	64	57	57	65	73	73	77
6-9	77	76	74	64	56	54	50	54	61	70	72	76
9-12	69	66	59	49	47	44	41	42	44	52	58	66
PM 12-3	64	59	52	46	45	38	37	37	42	48	49	62
3-6	67	62	55	50	48	40	40	40	46	56	57	65
6-9	73	72	61	60	54	52	48	49	58	66	65	75
9-12	76	76	72	65	60	60	54	54	62	69	69	72
Average 1981	73	70	66	59	55	52	48	49	55	63	64	72
Average 1950-1980	73	71	67	62	58	53	46	47	54	66	72	75

*Relative Humidity*

	35 - 50%
	50 - 70%
	70 - 85%

(12) Precipitation and relative humidity



## 4.2 Humidity

The total yearly precipitation (324 mm in 1981) comes principally in the heating season months, extending to April and October; it is negligible during the period from late May through mid September, when it is reasonable not to expect anything more than one short shower per month.

In general, precipitation in 1981 was slightly lower than in other years, especially during spring and autumn. Rainfall level during January and December was particularly high and particularly low, respectively; this accounts --in part-- for the corresponding unusually cold and mild air temperature conditions.





Snow can occur several times per year, usually in January and in February; snowfall cover, however, never lasts more than a day, or two in the northern suburbs.

The yearly average relative humidity lies between 45 and 75 percent. In 1981, the daily range was 64 to 79 percent in winter and 37 to 57 percent in summer. Relative humidity peaks occur around 4 a.m. and 4 p.m., keeping in phase with air temperatures.

## WIND DIRECTION: FREQUENCY AND SPEED

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
N-NE(%)	28.4	31.2	22.4	22.5	27.2	18.0	38.4	47.7	33.0	24.2	30.2	8.6
Mean	3.8	2.7	2.6	2.4	2.9	3.5	3.2	4.7	2.5	2.1	2.0	1.7
Max	12	11	10	7.5	8	12	7.5	13.5	7	7	6.5	3.5
ENE-SSE(%)	3.6	3.9	4.7	6.2	4.1	3.0	2.9	1.1	3.2	5.3	5.0	7.2
Mean	1.2	1.8	0.9	1.6	1.1	1.2	1.0	0.7	1.0	1.5	1.4	2.1
Max	5	7.5	6	5	5	6	5	2	5	5.5	10	
S-SW(%)	13.2	23.2	24.6	31.7	26.5	37.9	19.7	19.9	21.3	25.1	14.7	39.7
Mean	2.8	1.8	1.7	1.8	2.3	1.7	1.8	1.8	1.7	1.8	1.5	2.8
Max	8.5	7	9	9	7.5	6	5	4.5	4.5	5.5	10	10
WSW-NNW	34.5	14.1	17.6	18.3	17.7	8.0	16.5	5.2	11.8	14.3	22.0	25.1
Mean	2.4	1.9	2.0	2.0	1.8	1.0	1.9	1.2	1.7	1.1	2.2	1.9
Max	10	7	9	8	7	3.5	6.5	5	7.5	4	8	8.5
Calm(%)	20.3	22.6	31.7	20.3	24.5	33.1	22.5	26.1	30.7	31.1	28.1	23.4

## Monthly Percentage Frequency

	00 - 10%
	10 - 20%
	20 - 30%
	more than 30%

(13) Frequency and speed of wind directions (in m/sec)

### 4.3 Wind

The wind axis in the Athens basin lies in the NNE-SSW direction. Wind speeds are generally stable throughout the year, ranging from 2.0 to 3.0 m/sec; high velocities are infrequent but probable in any month. The following analysis is based on 1981 data.

Prevailing N-NE winds, with a mean speed of 2.8 m/sec, account for 27 % of the total yearly hours. They are particularly significant during the overheated season (34 % from June to September), when their mean speed is increased to 3.5 m/sec; in August, occasional gusts can reach as high as 13.5 m/sec.

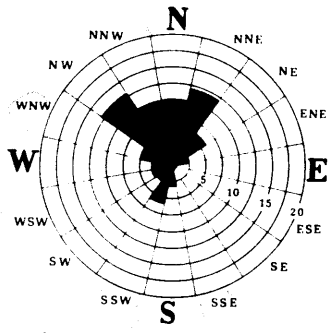
The second more frequent wind direction is S-SW, accounting for 25 % of the total yearly hours. Southerly winds are more predominant in spring (29 % from February through June). Their mean speed is 2.0 m/sec, with a maximum of 9.0 m/sec occurring in February and March. Unusual warm south winds provide another possible explanation for the mild conditions of December 1981.

There are some seasonal westerly winds peaking in December and in January, with a mean speed of 2.2 m/sec and a maximum of 10.0 m/sec.

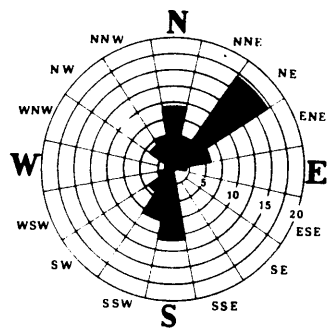
There is hardly any wind coming from the east.

Calm conditions are evenly distributed, and account for 26 % of the total yearly hours.

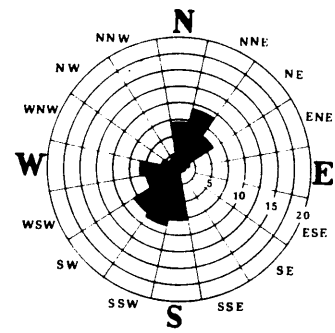
The wind roses, illustrated in figure 14, provide a more detailed understanding of the wind behaviour.



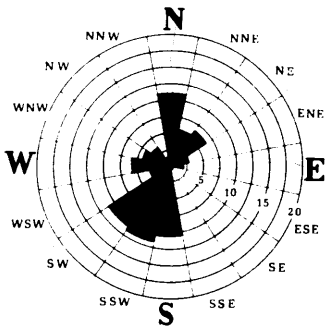
Jan



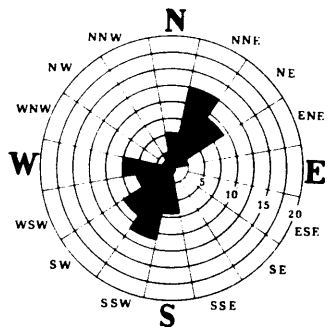
Feb



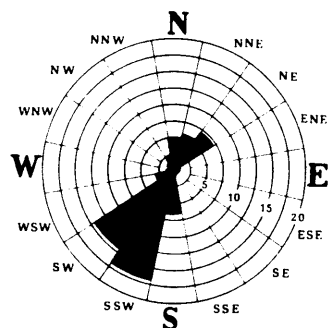
Mar



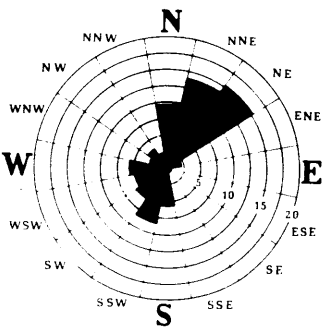
Apr



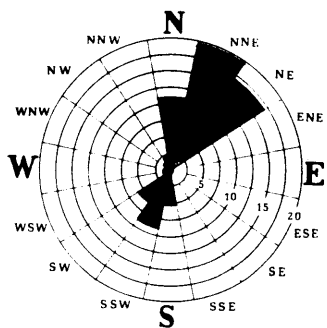
May



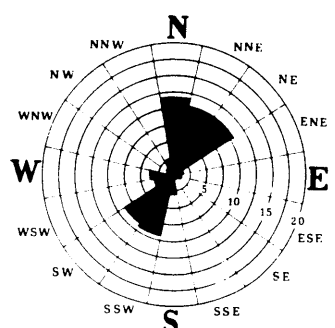
Jun



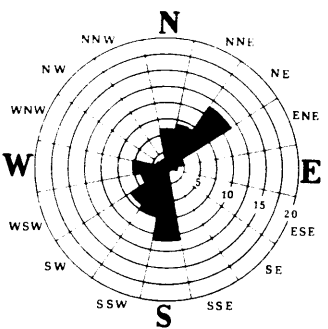
Jul



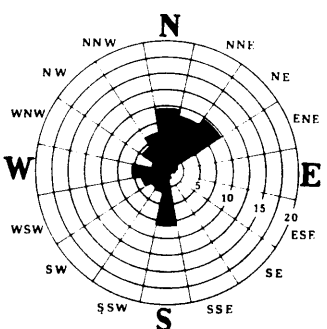
Aug



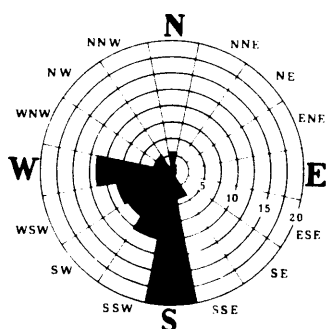
Sep



Oct



Nov



Dec

(14) Wind roses

	JUNE			JULY			AUGUST			SEPTEMBER		
	N-NE	S-SW	CALM	N-NE	S-SW	CALM	N-NE	S-SW	CALM	N-NE	S-SW	CALM
AM 0-3	17	3	62	28	3	48	37	1	47	33	0	50
3-6	15	0	62	26	1	46	39	0	49	27	3	57
6-9	17	18	42	27	6	38	42	2	43	31	4	47
9-12	20	68	1	39	30	3	42	31	12	32	28	12
PM 12-3	18	67	0	38	34	1	48	45	0	20	54	1
3-6	11	62	1	40	36	1	51	35	0	32	38	2
6-9	16	41	23	45	26	5	49	25	11	34	21	10
9-12	16	14	47	43	10	25	41	9	32	28	4	42
9AM-9PM (%)	18	66	7	44	34	3	51	37	6	33	39	7
9PM-9AM (%)	18	10	60	33	6	42	43	3	50	33	3	55

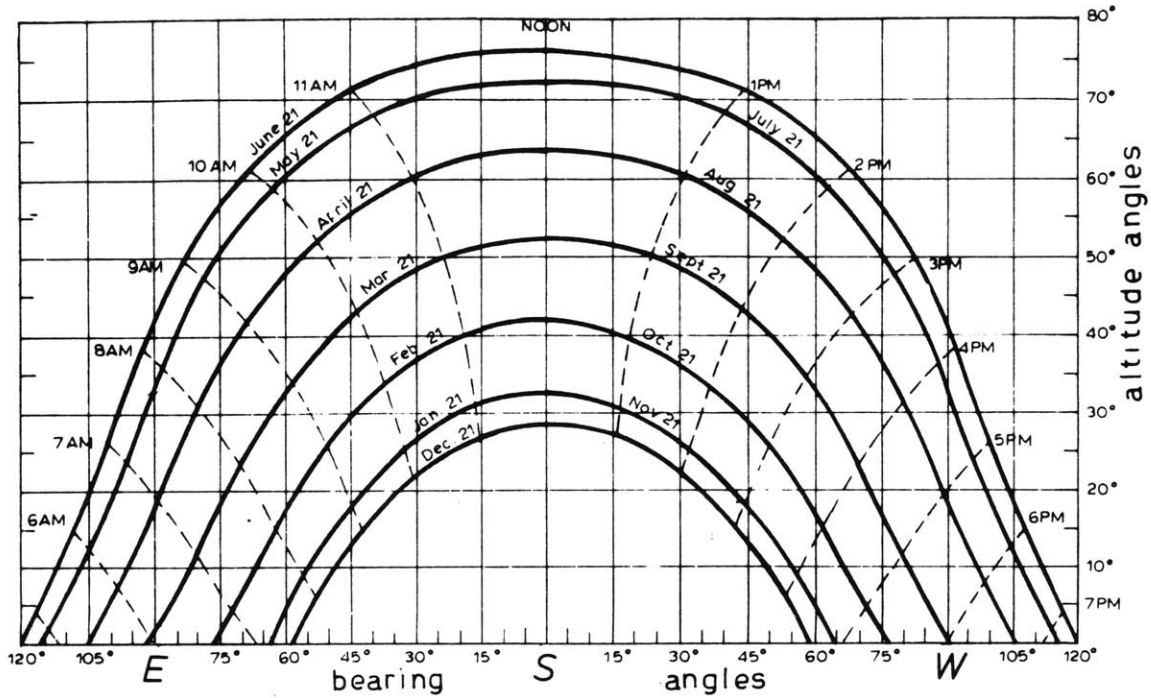
00 - 20%
  20 - 40%
  more than 40%
  Overheated Period

(15) Duration of prevailing wind directions in the overheated season (in hrs)

A more thorough wind study is required for the summer season, air movement being a means to extend comfort conditions in overheated periods.

Overheating occurs in Athens from 9 a.m. to 9 p.m. during June through September, when the average air temperature exceeds 28.0 degrees. Breezes are frequent during the daytime, with prevailing N-NE directions in July and August, and S-SW directions in June and September. On the other hand, nighttime conditions are consistently calm (50 % of the total hours); the only considerable winds come in July and August from the N-NE direction.

Wind data are recorded at an exposed location at an altitude of 107 metres. Although the altitude of the city itself varies greatly (up to 300 m in the northern suburbs), the city scape can play an important role in re-shaping wind flow pattern and velocity at pedestrian level.



(16) Sun path diagram

DURATION OF SUNSHINE (HRS)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Avg. Daily 1981	3.8	5.2	7.2	8.2	9.7	11.5	11.9	11.4	9.7	8.0	6.7	4.8
Avg. Daily 1966-1975	4.0	4.9	6.5	8.0	9.8	10.9	11.6	11.0	9.4	7.3	6.2	4.1
Duration of Day	9.7	10.6	11.8	13.0	14.1	14.6	14.3	13.5	12.3	11.1	10.0	9.4

SOLAR RADIATION (kWh/m<sup>2</sup>)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981 (A)	1.75	2.80	4.40	5.39	6.35	7.30	7.22	6.60	5.27	3.83	2.78	2.07
Avg. (A) 1966-75	1.85	2.62	3.82	5.15	6.41	6.84	6.88	6.78	4.86	3.38	2.33	1.69
Avg. (B) 1966-75	0.79	1.28	2.01	2.93	4.06	4.65	4.66	4.26	3.19	2.03	1.30	0.87
Avg. (C) 1966-75	2.42	2.95	3.18	3.09	2.84	2.52	2.75	3.33	3.79	3.75	3.39	2.75

(A) Average daily total radiation on a horizontal surface  
 (B) Average daily direct radiation on a horizontal surface  
 (C) Average daily total radiation on a vertical surface

 Underheated season

(17) Sunshine and solar radiation

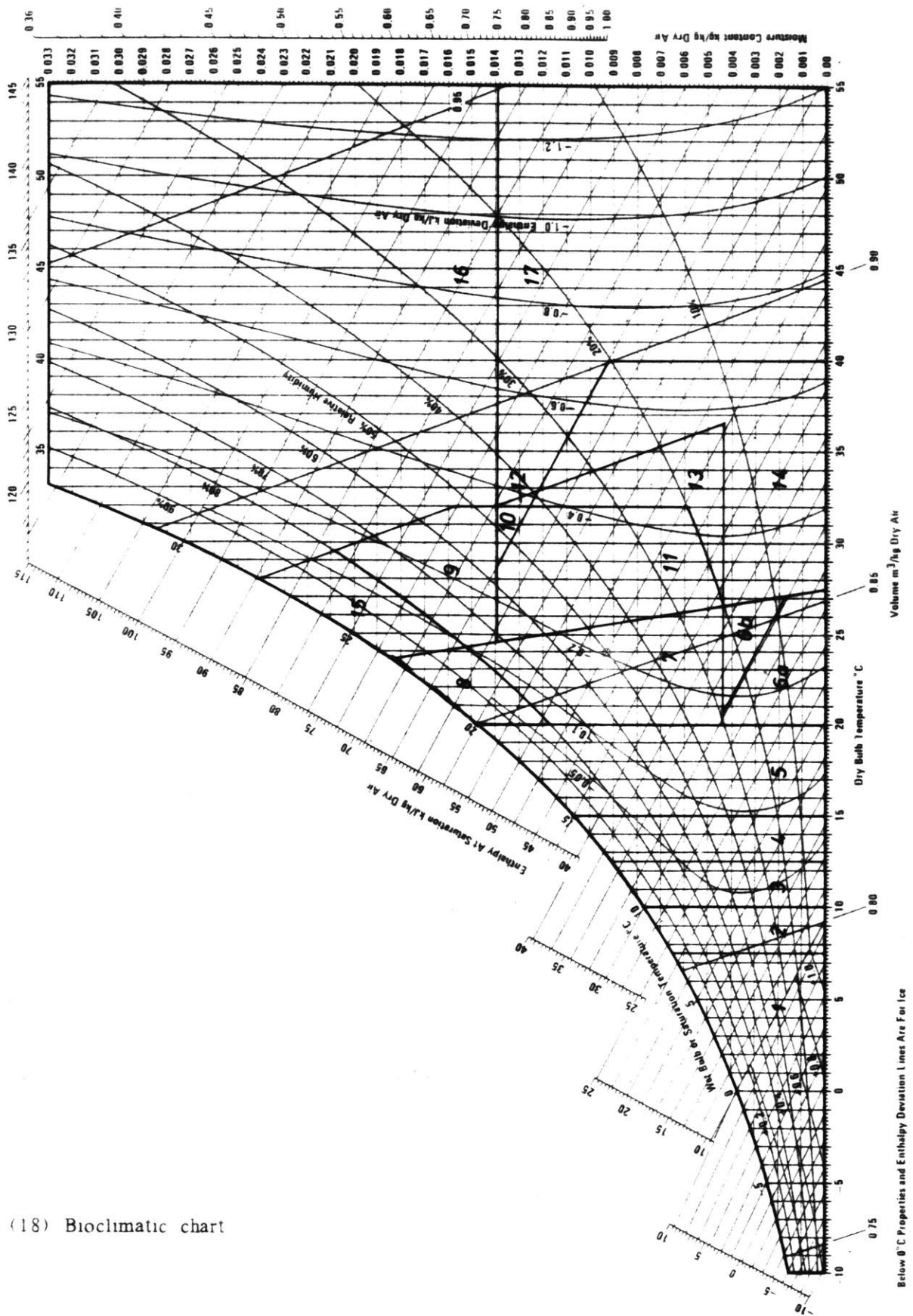
#### 4.4 Solar Radiaton

The duration of sunshine in Attica accounts for 68 % of the possible hours in the yearly average. During the underheated season (November to April) the average duration of sunshine is 6.0 hours per day. Minimum amount of possible sunshine occurs in December and January (45 %); January 1981, which, as already seen, was particularly cold, enjoyed only 3.8 hours of average daily sunshine.

During the overheated season (June to September) sunshine lasts an average of 11.1 hours per day, peaking in July to 11.9 hours per day. Very clear summer skies—during both daytime and nighttime— provide favourable conditions for the intrusion of solar radiation through the atmosphere; re-radiation of the earth back to the sky is impeded by the fairly humid nighttime conditions (52 percent average 9 p.m. to 9 a.m. relative humidity during the overheated period).

The information supplied by the Meteorological Institute on solar radiation is insufficient, and does not include data on direct radiation or total radiation on a vertical surface. Illustratively, average daily total radiation on a south facing vertical surface was 2.95 kWh per day during the underheated season for the period 1966 to 1975 (this figure takes into account the reduction of the radiation level due to the high atmospheric pollution of the city).

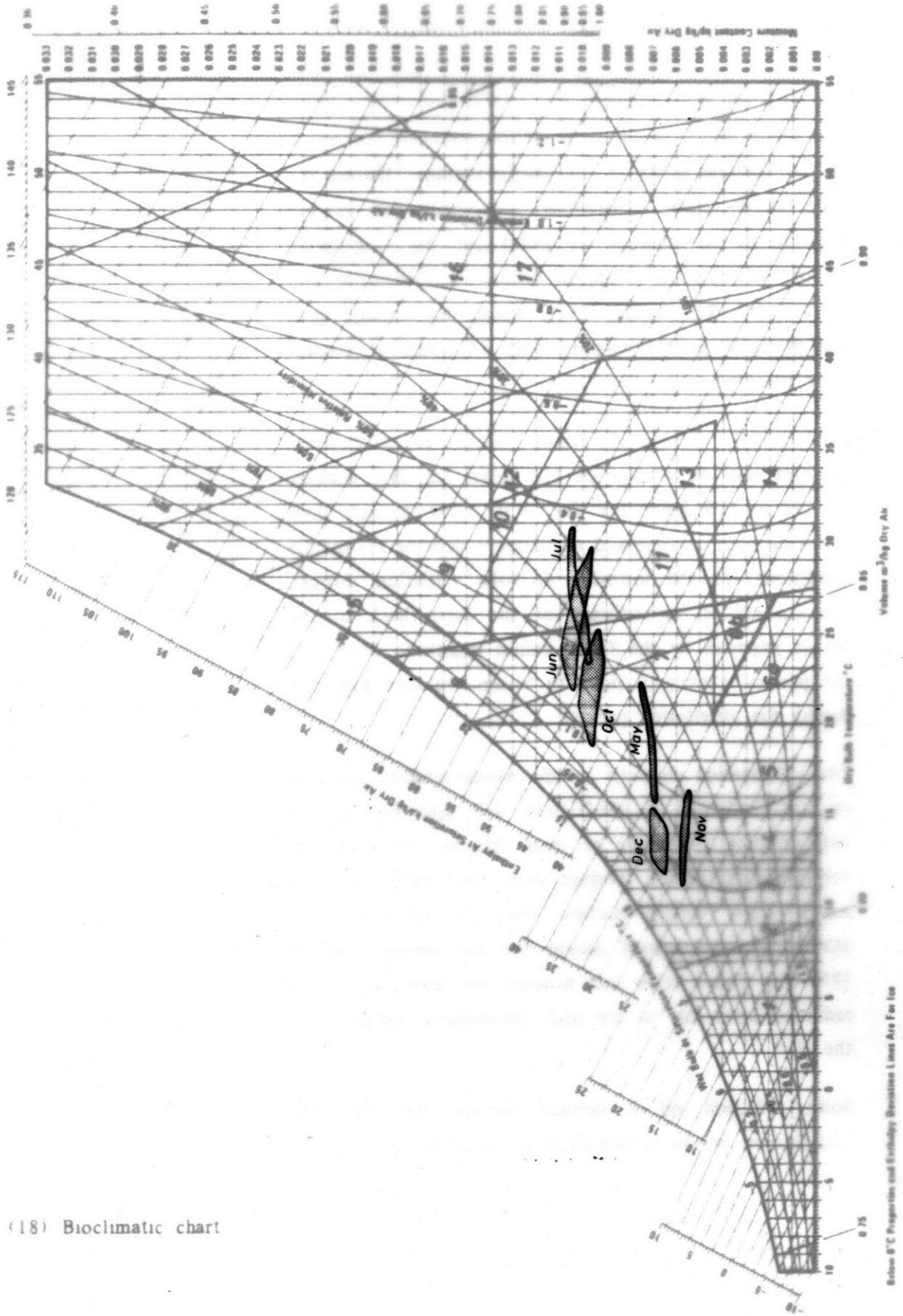
Solar radiation on a vertical surface for the 1981 underheated period is calculated in Appendix B.



(18) Bioclimatic chart

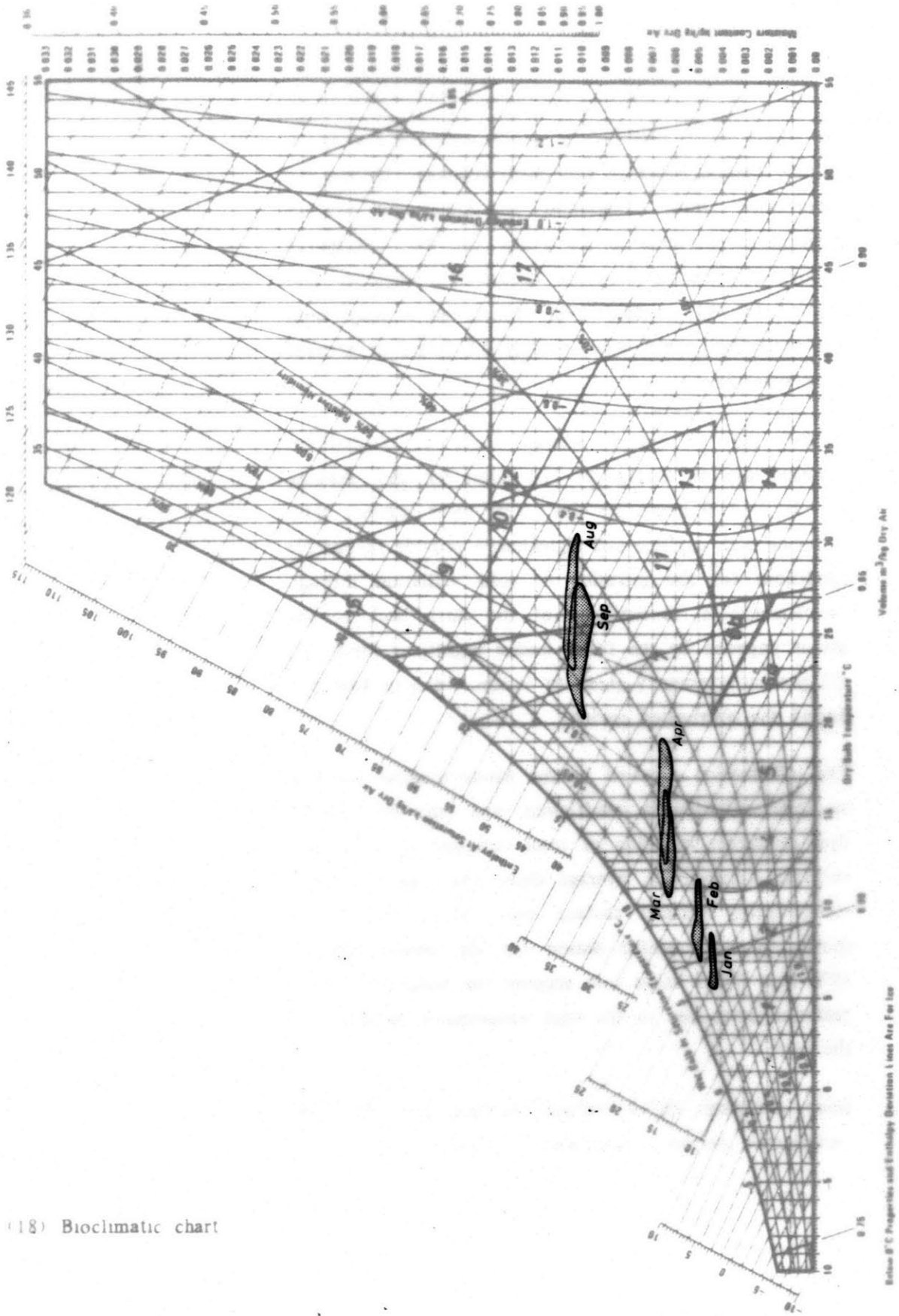
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice





(18) Bioclimatic chart

Below 0°C Properties and Enthalpy Constant Lines Are For Ice



(18) Bioclimatic chart

Below 8°C Properties and Enthalpy Deviation Lines Are For Ice

## 4.5 Conclusion

The limited range of atmospheric conditions in the Athens area is typical of a temperate climatic zone.

Air temperature comfort conditions prevail during daytime in May and October, and during nighttime in June through September. Solar radiation can extend the comfort zone to a significant part of the day in the spring and autumn months. Conversely, air movement can extend it into the overheated season if proper shading is provided.

As demonstrated in figure 4 --limits of thermal comfort control methods-- indoor thermal comfort can be restored during the underheated period by increasing the building shell insulation and promoting solar heat gain. During the overheated period, the same objective can be achieved by restricting conductive and radiative gain, proper ventilation, and implementation of passive cooling techniques.



*PART III*

CASE STUDY AND DESIGN PROPOSAL

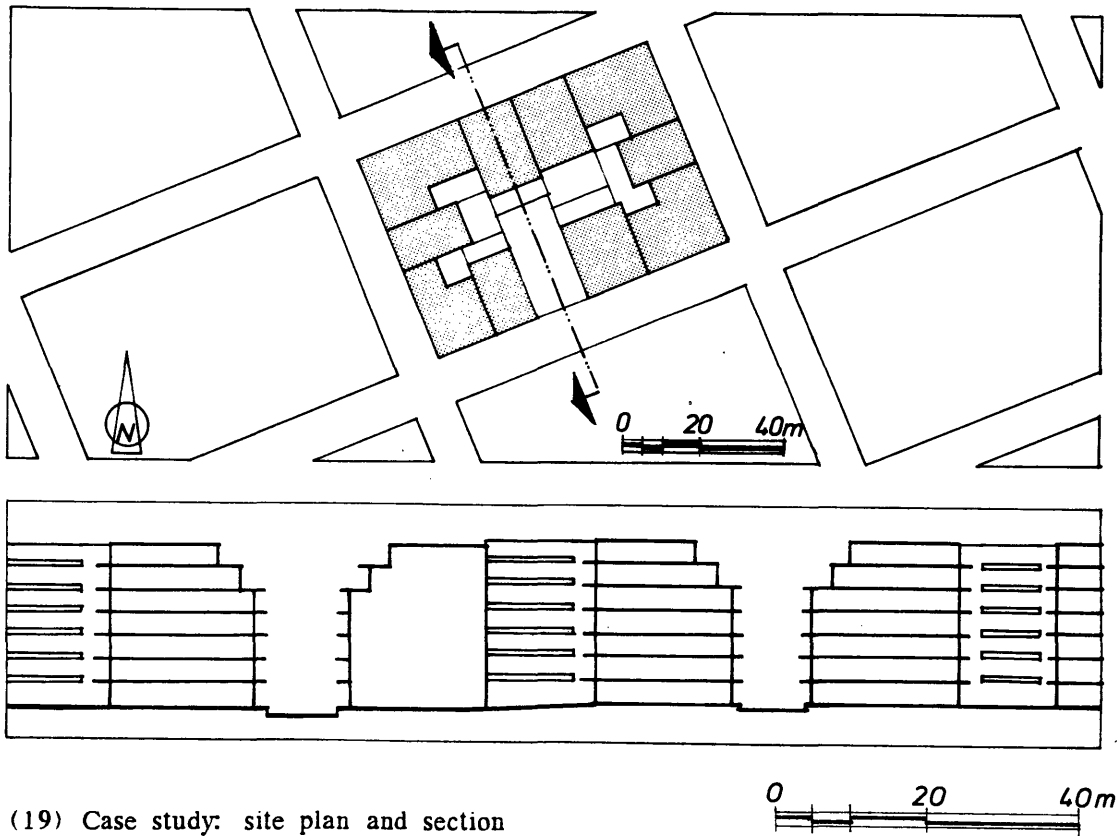
## CHAPTER 5

## IMPLEMENTATION OF CLIMATIC CONTROL METHODS

## CASE STUDY FOR AN URBAN RESIDENTIAL BUILDING

Figure 19 shows the urban context of the case study. The city block containing the lot is located in a densely built residential area. Its dimensions are 55 by 80 metres. The main streets are 12 m wide and lie on a WSW-ENE axis.

The dimensions of the lot itself are 14 m wide by 28 m long. It is contained between two other residential buildings, with its free sides facing SSE and NNW. The maximum coverage area is 75 percent.



(19) Case study: site plan and section

The following sections in this chapter deal with daylighting and natural ventilation issues, thermal insulation, solar heating, shading, and passive cooling techniques, implemented to respond to the specific urban and climatic conditions of the athenian context. These issues constitute the basis for the design proposal described in chapter 6.

## 5.1 Daylighting and Natural Ventilation

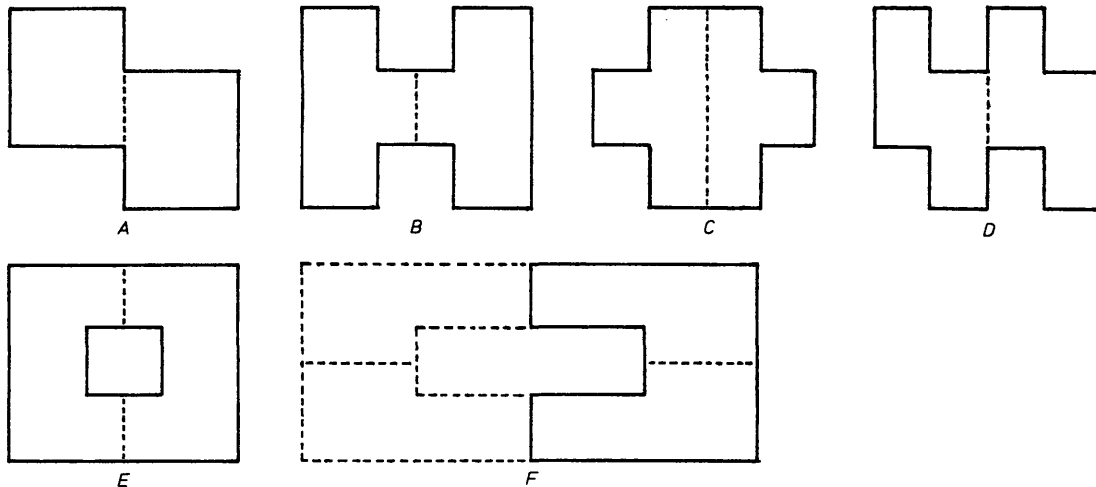
### *General Organization*

The limited solar and ventilation access, characteristic of a dense urban environment, can be a serious obstacle to fully exploiting the potential of climatic design in order to control indoor comfort. This becomes obvious in the case study situation, where the new building --approximately 20 m long-- will be contained between two blind lateral walls; the only contact of its 250 to 300 m<sup>2</sup> floor area with the out-of-doors would be through the 14 m long SSE and NNW facade. Minimal light wells would be conventionally provided to ameliorate the otherwise unacceptable daylighting and ventilation conditions of the central spaces.

The opportunity for both natural lighting and natural ventilation, occurring at the building perimeter, suggests a *large surface area-to-volume ratio*. Making a building less compact can be an appropriate response to the city's density, bringing about a twofold result: (a) the total surface in contact with the environment is increased; hence, the possibility of taking advantage of the conductive, convective, and radiative heat transfer control methods is also increased, and, (b) the distance between a central space and the building shell is reduced, thus facilitating the sunlight distribution and interior air flow.

Further, in order to improve cross-ventilation, a *flow through apartment scheme* coupled with an appropriate *open floor plan organization* is a second fundamental concept. It provides an inlet, an outlet, and an unobstructed course for air movement, while enhancing sunlight penetration and distribution to all interior spaces.

Integration of those three criteria into the early design process can suggest the most appropriate solution for each particular situation. Figure 20 illustrates several high surface-to-volume ratio schemes, based on different protrusion and recession patterns, or on the organization of the building around an atrium space.



(20) High surface area-to-volume ratio schemes

The first four schemes of figure 20 can compose a facade that is interesting both formally and functionally. The animated relief and resulting game of shadows, generated by the alternating protrusions and recessions, can be an alternative for the repetitious rhythm of the facade elements --like, for example, the balconies--, usually stacked one on top of another. In addition, it can provide a response to the specific daylighting, shading, and solar heating requirements of each particular space.

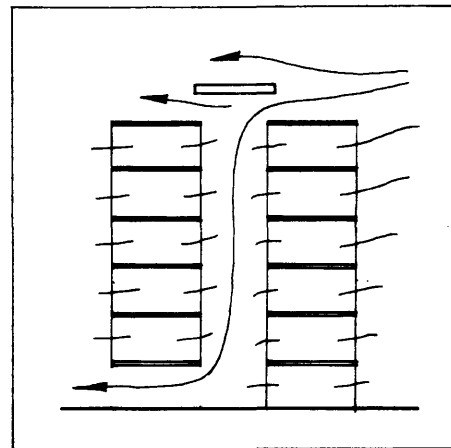
The organization of the --not necessarily symmetrical-- floor plan around an atrium can also offer various possibilities. Two separate buildings can be designed to share a large common atrium; this may have important implications for the structure of the city fabric, similar to the fabric of other european cities such as Paris and Berlin, where large buildings are built around a central courtyard. On the other hand, in the case of single buildings, a central atrium can be an appropriate solution allowing multi-directional daylighting and flow through units developed on either side; this solution obviously requires a sufficiently large footprint area.



The dimensions of the atrium are restricted by the coverage ratio regulations. This is because the space occupied by the atrium is not considered to be "free space" as defined for the purposes of the ratio. The architect has to choose between this functionally correct and aesthetically appealing feature on the one hand, and what the pure economics of the building dictate on the other. Will the prospective buyers consider the incremental utility to be derived by the existence of the atrium high enough to induce them to pay a higher price per square metre, and, therefore, compensate for the resulting reduction in the total available floor area? This is highly probable, especially considering the subsequent elimination of the conventional light wells, and the possible integration of the circulation core to the atrium; the latter can thus acquire dimensions that allow for visual privacy, as well as for adequate ventilation and daylighting --qualities in high demand in residences-- at all levels at the minimum expense of floor space.

If the building's interior circulation is open to the atrium space then an operable glazed roof system will have to be devised in order to keep it weatherproof during the heating season, and protect it from the rain during autumn and spring late. This system must be designed in such a way as to capture prevailing NNE and SSW summer winds, and help direct them down to the atrium space; in addition, it should be easy and safe to operate by an unskilled person.

If the ground floor is occupied by a large commercial surface, the atrium can begin at some higher level. It should preferably, however, begin at ground level and extend, through the lobby, to the entrance of the building. This creates a more coherent space, and provides a major outlet for the interior air flow.



(21) Interior air flow

### *Balconies*

The actual, institutionalized situation consists of narrow strips of balconies on each floor, along the full length of both facades --at the expense of daylighting; a translucent screen separates the balcony in as many sections as the number of apartments having access to it. The repetition of the same balcony and railing on each floor leaves a distinct mark on the appearance of the urban building.

Balconies are an important architectural feature of the athenian residential building. Optimizing the existing situation involves:

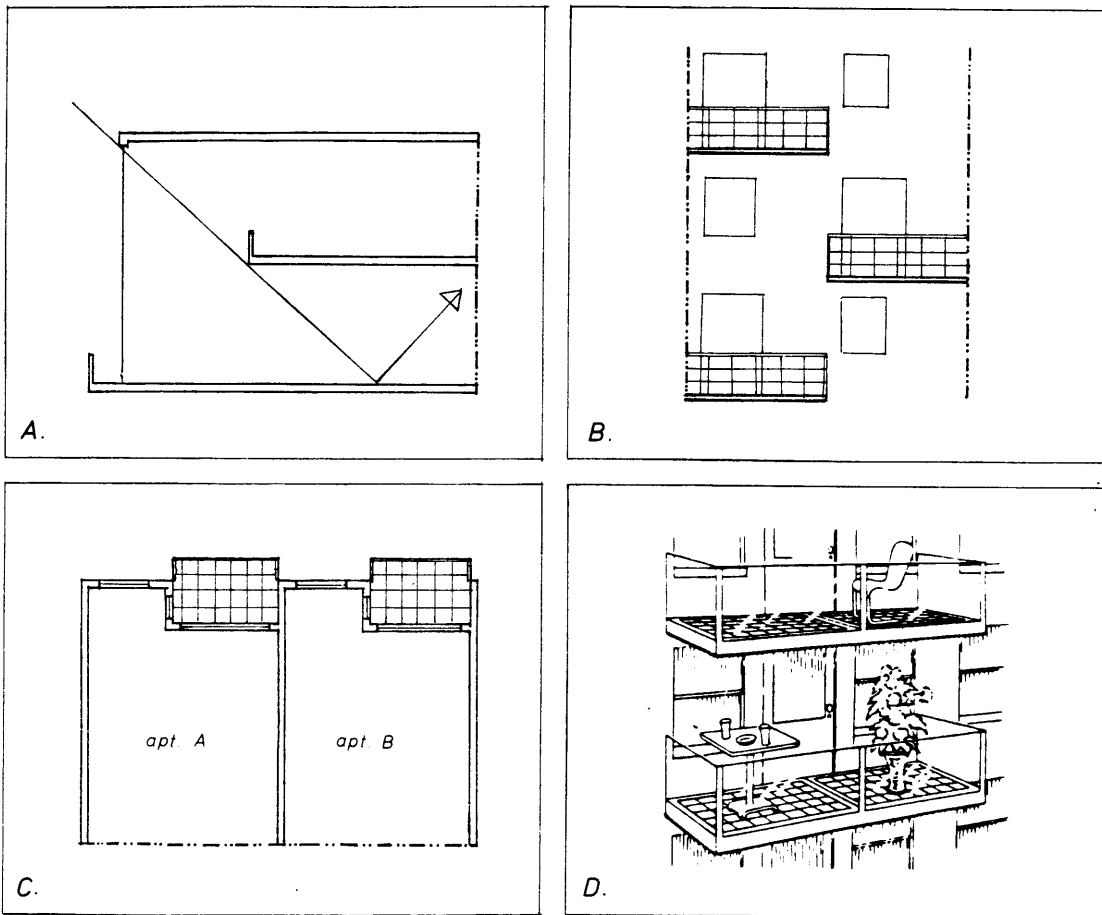
(a) eliminating the balconies in the lower floors, especially on the street side, where the high atmospheric and acoustic pollution prohibit their use. In these apartments, exterior balconies can be replaced by interior mezzanines in two-storey high spaces; double-height spaces are also desirable in order to achieve a deeper sunlight penetration (figure 22a). Two --or more-- level apartments, usually reserved for the top two floors, should be therefore organized primarily in the lower floors.

(b) Staggering the balconies in every other floor so that two balconies are not stacked one on top of another in two consecutive floors (figure 22b). This can significantly increase the angle of exposure of the surface directly below to the sky vault, and therefore improve its daylighting conditions.

(c) Placing the balconies in recessions --so that only a part protrudes over the street, or the backyard-- in order to enhance visual privacy, and to minimize the shading effect on the apartment below (figure 22c).

The protruding part of the balconies on the north side of the building can be made of translucent glass blocs --supported by a two-way reinforced concrete grid-- in order to maximize the sky component of the diffuse daylight (figure 22d). The same technique can be used for the staircase and the landings in the atrium in order to increase the daylight level and to enhance the perception of spaceousness.

Other daylighting issues involve high ceilings --restricted by the maximum building height regulations versus the desired number of floors--, splayed window reveal to increase daylight and reduce contrast and glare, light shelves to maximize sunlight penetration into spaces (especially on the south side), and use of louvered double glazing.



(22) Issues related to the balconies

## 5.2 Thermal Insulation

Building regulations for the climatic zone of Athens specify a maximum weather wall U-value of  $0.7 \text{ W/m}^2 \text{ C}$ , and a U-value equal to or less than  $1.9 \text{ W/m}^2 \text{ C}$  for the overall building shell. Other performance criteria regulate the ambient indoor air temperature to 20 degrees for bedrooms and living rooms, and less for other spaces according to each one's specific function.

High thermal insulation and low infiltration of the building shell is a fundamental method for reducing conductive and convective heat transfer; its efficiency lies greatly in the choice of appropriate materials, as well as in detailing and care in

construction. A weather wall U-value of 0.25 is easily attainable by utilizing 10 to 12 cm thickness of insulating materials (for example, glass fiber); this, however, prohibits the use of slots for the sliding balcony-doors. A reasonable 0.6 indoor-outdoor air change per volume of air per hour can lower significantly heat loss through infiltration.

Double glazing can be utilized in order to increase the radiative gain to conductive-convective heat loss ratio, as well as to assure thermal comfort in the space near the windows. The use of double glazing is imperative for the implementation of direct gain passive solar heating methods.

The thermal performance of other parts of the building must be studied in the context of the thermal behaviour desirable for each particular situation. For example, the atrium walls should *not* be as insulating as the weather walls, since some amount of heat energy *should* be transmitted to the atrium from each apartment, in order to maintain a comfortable temperature. In Appendix A it is demonstrated that a wall U-value of 0.4 W/m<sup>2</sup> C and the use of single glazing maintain the average air temperature inside the atrium within a range of 16 to 19 degrees throughout the heating season.

### 5.3 Solar Heating

The preliminary approach consists of sizing the collector's area. Only the glazing of the exposed weather wall can be used for collecting solar heat, the radiative gain from windows opening to the atrium being negligible.

#### *HEAT LOSS*

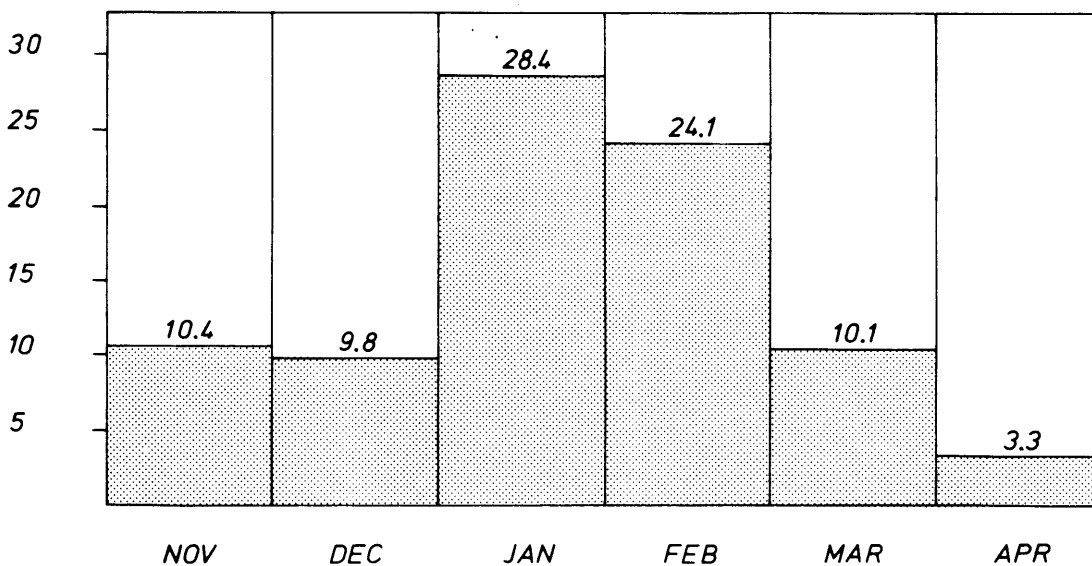
The first step is to identify a typical apartment unit and to determine its average daily heat loss during the heating season. This unit consists of half of one floor area, and is approximately equal to 110 m<sup>2</sup> (excluding the partition walls). It undergoes conductive and convective heat losses to the atrium space, through a 36 m<sup>2</sup> wall, and to the out-of-doors, through a weather wall of 42 m<sup>2</sup>.

During the heating season, the roof is closed so that atrium space acts as a buffer zone between the indoors and the outdoor environment. Its major heat gain source includes the building's fourteen apartment units (each floor is sub-divided into two units for the purposes of this preliminary study). The important radiative gain through the glazed roof system cannot be fully exploited --without recurring to mechanical means-- because of the air stratification occurring in the upper part of the atrium space. The heat flow pattern through the atrium walls --and, consequently, the atrium ambient temperature-- can be fine tuned through modification of the thermal insulation, and by taking into account the solar heat gain through the roof glazing.

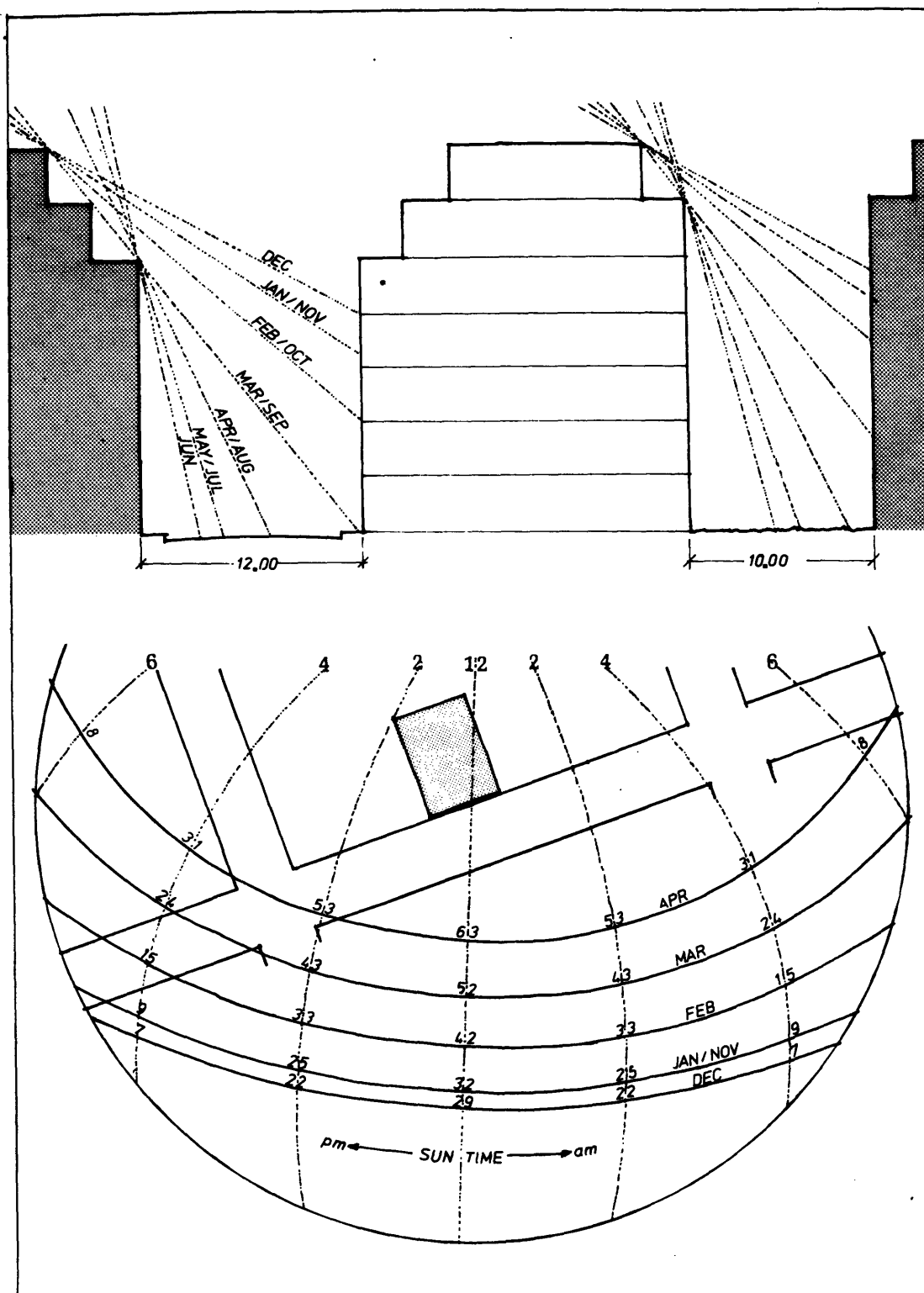
The apartment unit heat loss through conduction and infiltration is based on the thermal performances described in the previous section of this chapter. This heat loss is reduced by the internal heat gains (generated by the occupants, the artificial lighting, and the electric equipment). The resulting average daily real heating load required to maintain indoor temperature at 20 degrees is shown in table 23.

Heat loss and heat gain calculations are contained in Appendix A.

*kWh/day*



(23) Daily average real heating load for an apartment unit



(24) Solar path and altitude during the heating season

### HEAT GAIN

The next step is to determine the amount of solar radiation incident on a unit area of the two weather walls, at each different floor of the case study building. The *Average Daily Radiation III* program was used to calculate the average daily insolation striking a vertical surface of a SSE and a NNW orientation.<sup>1</sup> The total radiation was broken down into its direct, diffuse, and reflected components in order to facilitate determining the amounts available at each different floor. The input average daily total solar radiation on a horizontal surface values were those given for 1981 in chapter 4.4.

The *direct radiation* available at each different floor on the two sides of the building is a fraction of the total direct insolation striking a vertical surface of a SSE or a NNW orientation, depending on the shading effect of the cityscape. A sun path study is required in order to determine the hours each floor is exposed to beam radiation throughout the average day of every month of the heating season. In order to take into account the *intensity* of the sun's radiation --varying throughout the day-- the Solar Heat Gain Factor tables can be used to determine the hourly gain as a percentage of the total daily load for the given orientation.<sup>2</sup> This percentage is then applied to the beam component calculated by the Average Daily Radiation III program.

The sky is "viewed" with a different angle by each floor; *diffuse radiation* is a function of the angle of exposure to the sky zenith. Its correction factor can be determined by utilizing the British Research Station *Sky Component Protractor* (as explained in Appendix B). In the case study the front street width is 12 m. while the combined length of the two backyards on the north side is 10 m.

The calculator program determined the amount of *reflected radiation* based on reflectances describing as closely as possible the situation on the two sides of the case study building: an overall reflectance equal to 0.2 on the street side, and to 0.4 on the north side, where the building across the backyard is bathed in sunlight.

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<sup>1</sup> Texas Instrument TI-59 program by J. Rosen, contained in *Solar Architecture: the Direct Gain Approach*, by T. Johnson.

<sup>2</sup> Contained in the ASHRAE *Book of Fundamentals*

### COLLECTOR AREA SIZING

Once the average daily total radiation incident on the exposed weather wall of each floor is known, the glazing area can be determined as a function of the heating load to be met. The average daily solar intake is given by:  $H_s = A \cdot I_{tot} \cdot T.C.$ , where: A is the (unshaded) glass area,

$I_{tot}$  is the average daily total solar radiation, and

T.C. is the glass transmission coefficient.

Table 25 shows the solar heat gain --as a percentage of the daily heating load-- through a glazing area ranging from 13 to 25 square metres, depending on the orientation and on the floor. These figures correspond to 30 % and 60 %, respectively, of the total apartment unit weather wall area; heat loss calculations were based on a glazed area equal to 40 % of the total area.

Radiative gain calculations are contained in Appendix B.

Floor level	SSE							NNW						
	Gr	1	2	3	4	5	6	Gr	1	2	3	4	5	6
Glass area	25	25	25	16	13	13	13	25	25	21	21	21	21	21
NOV	80	83	93	100	100	100	100	100	100	100	100	100	100	100
DEC	75	76	83	100	100	100	100	96	100	91	95	100	100	100
JAN	26	27	29	43	48	62	65	30	33	30	32	34	32	38
FEB	42	51	100	84	93	100	100	54	57	51	55	58	62	64
MAR	100	100	100	100	100	100	100	100	100	100	100	100	100	100
APR	100	100	100	100	100	100	100	100	100	100	100	100	100	100

#### Solar Heating

 25 - 59 %

 60 - 99 %

 100 %

(25) Solar gain as a percentage of the daily heating load

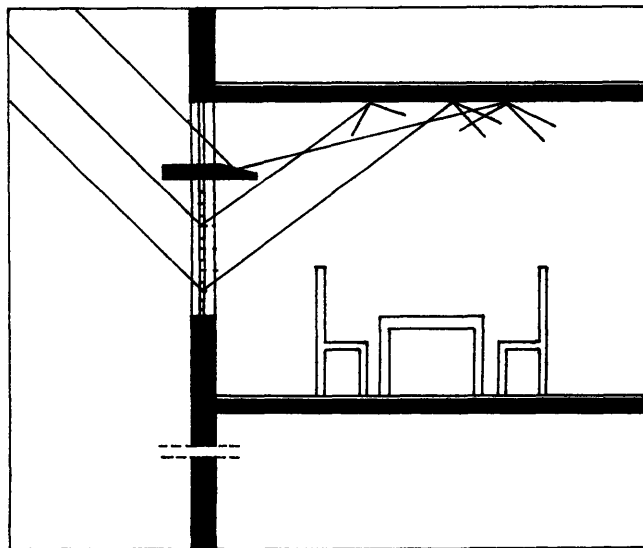


The performances described in table 25 are based on criteria aiming at promoting solar heat gain. The glazing area suggested for each floor may be subject to modifications in response to other design criteria, such as balcony access, view, visual privacy, elimination of glare, aesthetics, etc.

The limited direct solar access on the north side, as well as on the lower floors of the south side of the building, permit only moderate radiative gains. Low-E coated glass --reflecting outgoing long-wave thermal radiation back to the space-- can be used to transform these spaces into heat traps and, thus, to assist solar heating.

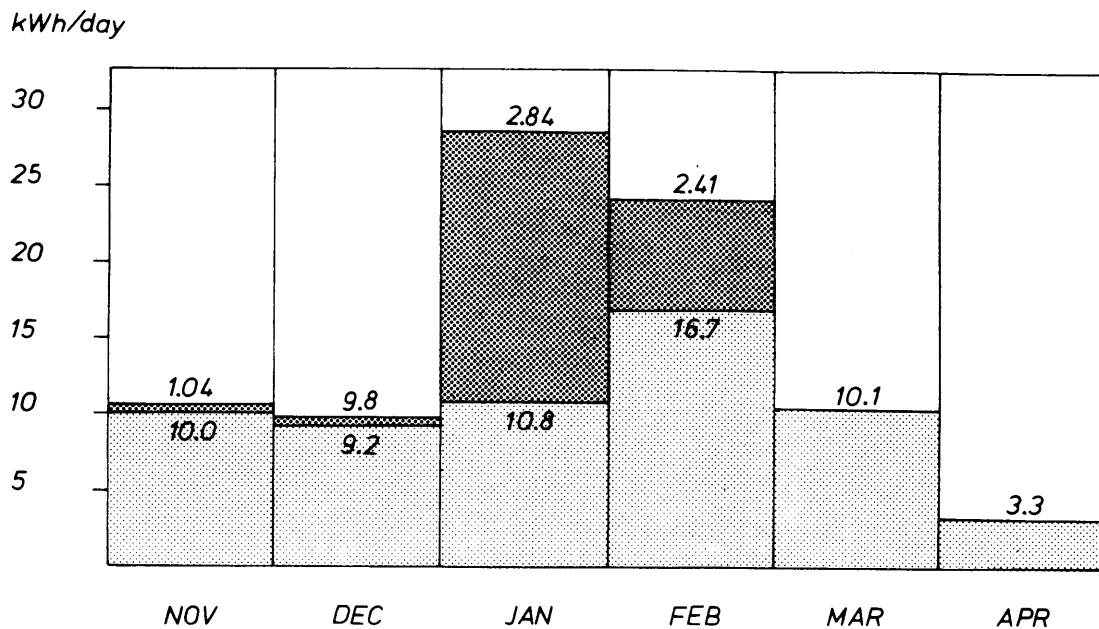
### *THERMAL STORAGE*

The incoming short wave solar radiation is diffused at the window plane by reflectorized louvers and light shelves. Inside, sunlight is further scattered by reflections off the light coloured ceiling and walls. Thermal storage is assured by the structure of the building itself: with each reflection of sunlight off the exposed concrete slab ceiling, part of the energy is absorbed and stored. It is re-radiated later as long-wave thermal radiation, and slowly builds up to counterbalance the low night temperatures. Ample, unobstructed thermal mass prevents overheating and minimizes the temperature swing range.



(26) Ceiling thermal storage

Ceiling thermal storage presents a number of advantages over conventional direct gain storage methods: it cannot be impeded by the presence of carpets and furniture (which, in turn, are protected from deterioration caused by the direct infrared radiation), it eliminates high contrast areas on the floor (and therefore reduces the possibility of glare problems), and, furthermore, allows for any type of floor finishing materials to be used.



(27) Daily average solar heat gain as a fraction of the total building daily average real heating load during 1981

Figure 27 shows the fraction of the total building heating load that can be met by passive solar gain (utilizing the glazing area suggested in figure 25 for each floor). Energy consumption can be more than halved during the coldest period (January and February), while auxiliary heating is hardly necessary whenever the outdoor air temperature exceeds 13 degrees. Annual energy savings can reach as high as 70 percent.

## 5.4 Shading

As seen in the previous section of this chapter, the warming effect of the sun is desirable during the underheated season. However, whenever the outdoor air temperature exceeds or falls within the limits of the comfort zone --as defined in chapter 2.4--, shade is needed in order to achieve or approach thermal comfort conditions. The following shading need analysis is based on the assumption of no wind movement, in order to respond to extreme summertime climatic conditions; however, daytime breezes can further alleviate excessive heat.

Figure 28 shows the comfort zone and the overheated period in the region of Athens, outlined on a yearly air temperature chart. Shading is required all day long during June through late September, as well as during a significant part of the day in May and in October.

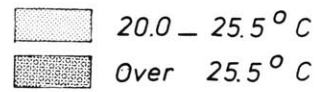
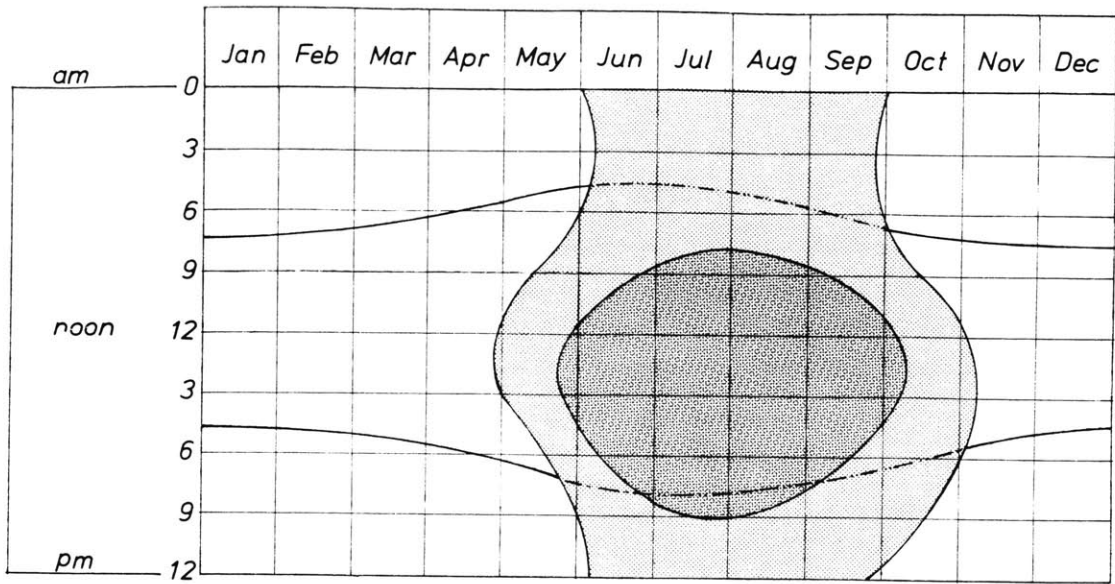
This period is transferred to the sun path diagram --showing the sky vault projected on to a horizontal plane-- for the latitude nearest to that of Athens. The new diagram shows not only the position of the sun, but also indicates whether shading is desirable or not at a given time; the needed *shading mask* can be determined by overlaying the *Shading Protractor* in the proper orientation.<sup>1</sup>

The shading protractor delineates on one side segmental curves --to plot lines parallel and normal to an observed wall-- and on the other side bearing and altitude angles. It serves to suggest the basic geometry of appropriate shading devices, or, vice-versa, to plot the shading mask for any shading device or object.

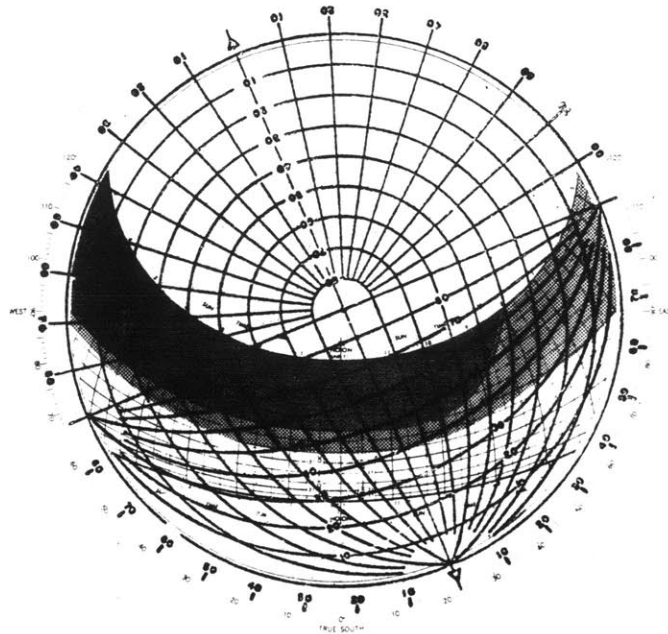
The efficiency of a shading device depends on the relative success with which it covers the total yearly period in which shading is required, without covering the underheated area. In practice, the most appropriate shading device is the one that makes the best compromise between total shading in the overheated season, on one hand, and allowing the maximum solar heat gain and sunlight penetration in the underheated season, on the other.

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<sup>1</sup> As described by Olgyay and Olgyay in *Solar Control and Shading Devices*



(28) Period when shading is needed



(29) "Shaded" sun chart with the protractor overlaid at 22.5 degrees East of South

Figure 29 shows the protractor overlaid on the shaded sun chart in the orientation of the windows of the case study building (SSE, NNW). It becomes obvious that, on the south side of the building, suitable shading can only be achieved by a combination of both horizontal and vertical elements. A horizontal overhang alone seems inappropriate since, in order to intercept the intense summer afternoon sunlight, its angle would have to be too wide (close to 40 degrees, measured from the wall); this, however, would be inefficient in terms of solar heating and daylight penetration during the rest of the year. On the north side, shade is needed during afternoon hours (after 2 p.m. in July). Here, too, a combination of small horizontal overhangs and --more important-- vertical fins seems to be the most appropriate solution.

The typical athenian residential building makes use of the balconies as shading devices; the balconies, occupying the greatest part of the length of both facades, and stacked one on top of another, can produce acceptable shading during the summer months. On the other hand, the 1.20 to 1.80 metre overhang plays a negative role for sunlight access when this is needed.

Balconies are an important architectural feature responding to the Athenians' lifestyle. The concepts presented on the first section of this chapter --aiming at maximizing daylight-- must be complemented by a design that makes the most efficient use of balconies as horizontal elements of the summer shading scheme. The length of the overhang must be determined through a thorough examination of the shading mask and in relation to the height of the specific surface area to be shaded by each balcony.

On the north side of the building, daylighting and solar heating depend largely on diffuse radiation, hence on the angle of exposure to the sky vault. Balconies, therefore, can be critical since only a minimal overhang is required for shading purposes. Translucent glass blocs can be a successful solution, as seen in the first section of this chapter: a 1.2 m translucent overhang with a transmission coefficient of 0.6 can produce the same overall shading effect as a 50 cm opaque overhang.

On both sides of the building, the recessions and protrusions of the facade can provide the necessary --built-in-- vertical shading elements; the relief of the

facade itself is the most elegant way to assist balconies in achieving appropriate summer shading.

For south facing surfaces that are not located directly under a balcony, direct sunlight must be intercepted --at the exterior of the glazed area-- by other shading devices. These devices may include operable lightweight metal structures, light shelves (protruding in the out-of-doors), translucent canopies, or opaque shutters (in the form of venetian blinds, persian blinds, or sliding balcony-doors).

Some of these devices can be also used on the north side: for example, persian blinds, at the 90 degree position (vertical to the wall), can provide appropriate shading for the window area during summer afternoons, without obstructing the view of the sky. Persian blinds are also compatible with (a) promoting ventilation, by helping capture and direct prevailing winds into the building, (b) restricting heat loss, by providing additional night insulation to assist the low-E glazing, and (c) assuring privacy in the bedrooms (although this can be taken care of through use of louvered glazing systems).

The use of louvered double glazing is appropriate for an overheated period with important solar gains. The transmission coefficient of the glass decreases significantly as the solar altitude increases, while the louvers help reject most of the oncoming insolation.

Reflection of sunlight can be an important complement to shading. Light colour finishing materials are very helpful in rejecting part of the solar radiation, especially in the roof, where the total daily load can exceed 7 kWh/m<sup>2</sup> during the summer months. Light colour tiles seem appropriate for the latter, which must be accessible --at least to the person operating the glazing system.

Finally, vegetation (deciduous trees, ivy growing on lightweight treillis, etc.), can provide natural shading keeping in phase with the changing seasons, while being a very appealing feature in an urban environment.

## 5.5 Passive Cooling

The need for cooling occurs between 9 a.m. and 9 p.m. in the summer months, and during the greater part of the day in September. Once shading and appropriate thermal insulation measures have been taken, air movement is the most efficient way to extend the comfort zone into overheated conditions. Chapter 5.1 deals with ventilation as a criterion to bring forth various concepts about the general building design. Open floor plans and flow-through organization schemes maximize the potential of achieving desirable air flow patterns within the building shell; the large number and variety of inlets and outlets promote cross-ventilation through the atrium, through each different apartment, and, in many cases, through single spaces.

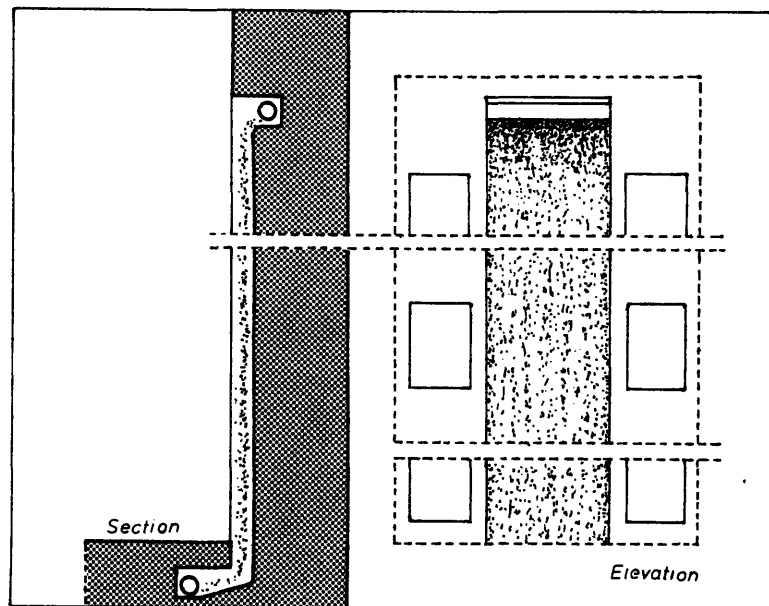
*Ventilation* as a strategy to produce bodily comfort and to cool the building interior has to be examined in a closer relation to the specific climatic environment of Athens. Thermal comfort during the overheated season can only be attained with a constant movement of air across the building skin, by exploiting prevailing N-NE and S-SW daytime breezes. Nighttime ventilation may also be desirable, although the humidity of the atmosphere (58 % average relative humidity), the small temperature range (average air temperature: 28.0 degrees between 9 a.m. and 9 p.m. and 23.1 degrees between 9 p.m. and 9 a.m.), and the consistently calm nighttime conditions make it inapplicable as a method for maintaining moderate air temperatures through daytime.

*Radiant Cooling* is favoured by clear skies and prevailing calm conditions during nighttime, but is impeded by the humidity and the pollution of the atmosphere: pollution can reach high levels --especially in the summer-- following a frequent high pressure meteorological phenomenon. High mass seems to be the most suitable approach to radiant cooling, since the main problem is not how to achieve lower nighttime temperatures, but to maintain more comfortable conditions during daytime. The roof, more particularly, should be massive enough to withstand and slow down the intrusion of a radiative load exceeding 7 kWh/m<sup>2</sup> per day during the summer months, while exploiting nighttime conditions to reject a part of the accumulated heat.

An examination of the climatic conditions indicates a reasonable potential of *evaporative cooling* techniques. Summer wet-bulb temperatures remain below 20.5 degrees, while the wet-bulb temperature depression during the day falls within a range of 7 to 10 degrees.

Roof sprays can be used to dissipate solar heat absorbed at the surface, which can be very helpful in the case of a high mass construction exposed on the underside to an inhabited space. In addition, the daytime summer breezes --regardless of the wind direction-- can significantly increase the rate of evaporation, and, therefore, the cooling potential of this technique.

Spray-pipes on the upper part of the atrium walls can be another effective way to implement evaporative cooling. A relatively inexpensive system consists of a thermostat controlled timer that signals for the pipe to spray the wall with water for a few seconds at a given interval, whenever the air temperature exceeds 25 degrees. The surface tension keeps the water flowing downhill along a 2 cm recession on the atrium walls (the waterproof finishing material should be chosen appropriately). Collection of the return water should be provided, although a small quantity of water sprayed each time may have time to evaporate before reaching the ground level of the atrium).

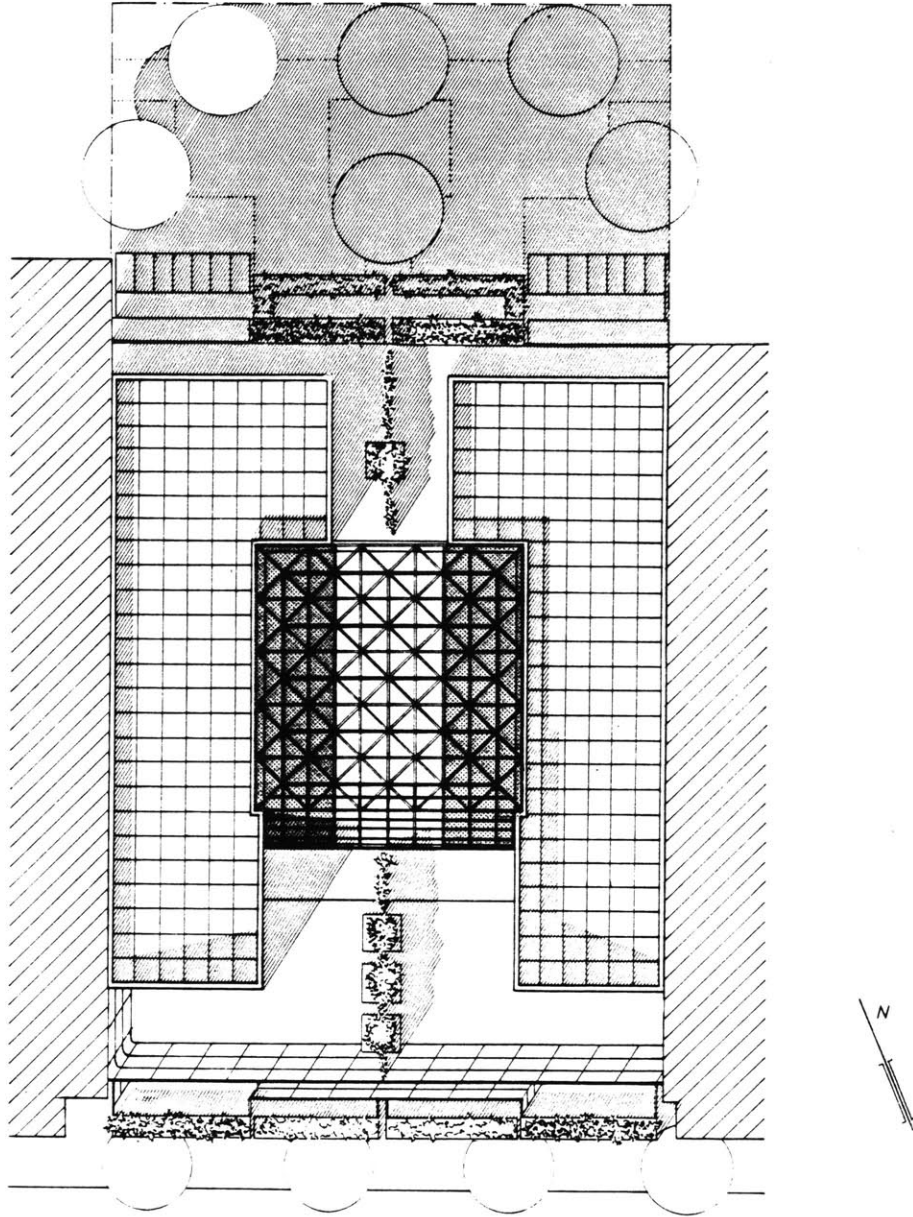


(30) Wall spraying



The evaporative process cools the wall surface as well as the air, thereby reducing both ambient and mean radiant temperature. This reduces the intrusion of heat into the apartments through the atrium wall, and makes natural ventilation more desirable and effective; the natural ventilation can be enhanced by a roof system design capturing the daytime breezes and directing them into the atrium. As the air flow sweeps the wetted surface, it forms a cool, dense air curtain, that flows downwards, enters the apartments through the atrium windows and clerestories, and transforms the lower part of the atrium space into a cool air sink.

A difference of 4.5 degrees between ground water temperature --at a depth of 1.5 m-- and the average air temperature during the overheated season indicates a moderate potential of *conductive cooling*. Detached earth coupling --using air or water as a heat transfer fluid-- can cool the structural mass, and thus reduce significantly the sensible load of an average single-family detached house. On the other hand, the high density of urban multi-storey residential buildings makes conductive cooling techniques inefficient, and, therefore, inapplicable for this type of construction in the climatic environment of Athens.



(31) Roof plan  
scale 1/200

*CHAPTER 6*

## DESIGN PROPOSAL

The building occupies the maximum footprint area permitted by the coverage ratio regulations, leaving a backyard on the north side for the use of the occupants of the ground floor. It is organized around a central atrium, whose dimensions are a compromise between the need for an open interior space and the concern of providing the maximum total floor area. The atrium almost doubles the building's weather wall that can be used to enhance the interplay between the indoor and the outdoor environment.

The vertical atrium space is prolonged through the lobby to the building entrance, thus creating a coherent indoor space and providing a main artery for the interior air flow.

During the underheated season the atrium is covered by an operable glazed roof --supported by a lightweight spatial structure-- allowing for maximum sunlight penetration. The vertical NNE and slightly slanted SSW lateral sides of the roof system can be opened during the spring and autumn months in order to capture the prevailing breezes --coming from the same two directions--, and achieve the desirable air flow while protecting the interior circulation from the rain. The top is also operable, with the two central rows of glass pans sliding downwards to cover the fixed pans on the lower sides of the slightly pitched roof. During the summer the central part of the roof is open to maximize the air inlet area, while the two superimposed glass layers reduce the intrusion of direct sunlight into the atrium along the two sides.

The atrium space is a buffer zone between the apartments and the out-of-doors. It enhances the natural air movement in the flow-through apartments, while enabling the cross-ventilation in those apartments --mainly small one-bedroom

units-- that do not have access to both sides of the building. The atrium also increases the daylight level in the central spaces and offers the possibility to achieve bilateral lighting in the rooms along the periphery of the building.

The potential privacy problems that may occur as a result of the limited dimensions of the atrium can be minimized by properly siting, staggering, and sizing the interior windows and clerestories (so that, for instance, no opening faces directly another one on the same floor). In addition, a fountain on the ground level can assist the wall-spraying technique --described in chapter 5.5--, while creating a suitable masking noise to attenuate the acoustic problems that may occur during summertime, when the atrium windows are open.

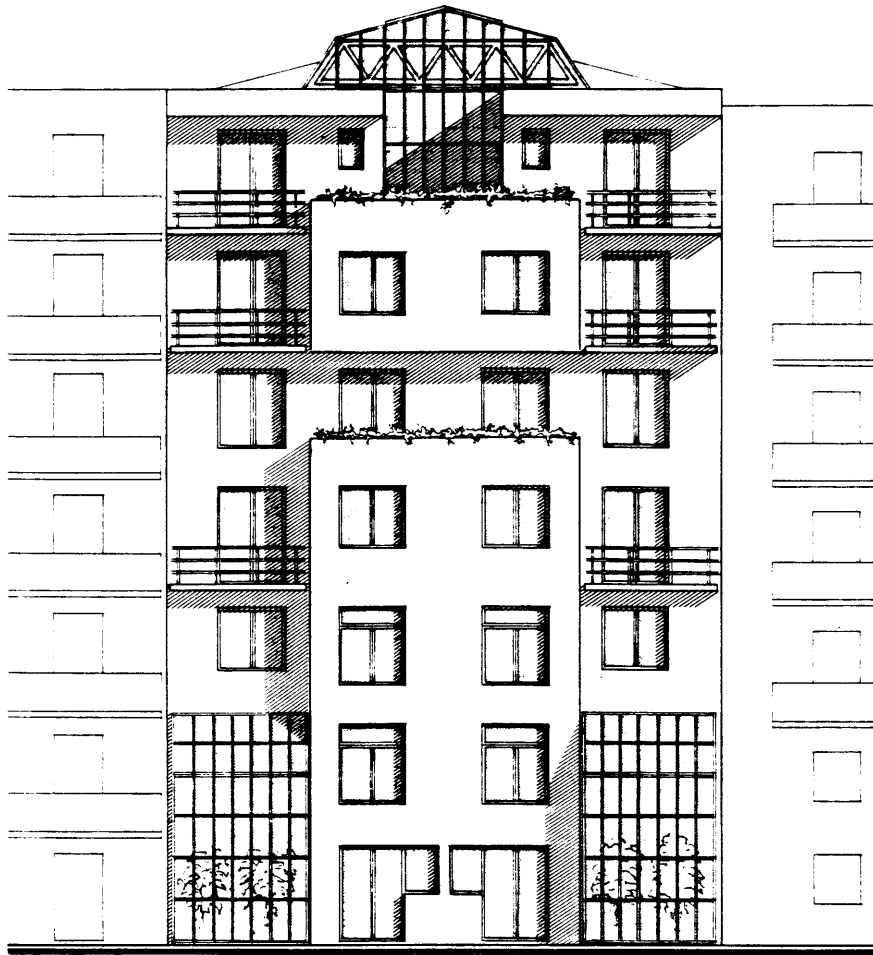
The basic apartment organization consists of an elongated floor plan, with a central circulation space along the atrium. The bedrooms are located on the more quiet and more private backyard side, while the larger living and dining spaces --requiring larger quantities of sunlight in order to be heated with passive means-- are located on the SSE facing front street side. The kitchens are open to the dining areas and are situated, together with the bathrooms and the storage spaces, along the central part of the lateral blind walls.

The windows of the building are dimensioned according to each room's function and position in the building. Appendix B shows the preliminary window area sizing from a purely solar heating perspective. Naturally, a number of other considerations have to be taken into account in determining the appropriate window size: the residents' preference for large windows, ease of access to the balconies, or even purely subjective aesthetic considerations. As a result, the windows on the top floors are quite larger than what Appendix B would suggest. In these floors, the south windows are shaded by horizontal overhangs and the animated relief of the facade.



(32) Front street elevation  
*scale 1/200*

The building's SSE facade shows the actual shading in mid-day March. Shading, which is one of solar architecture's primary tools, is instrumental in reducing the solar heat accumulation on the SSE side throughout the year. This is accomplished by the interplay of horizontal overhangs and the succession of recessions and protrusions on the building's facade. Windows on walls perpendicular to each other are helpful in evenly distributing the lighting level within a space, as well as in washing in sunlight wall surfaces adjacent to bright south facing windows to minimize contrast, and thus to reduce glare.



(33) Backyard elevation  
scale 1/200

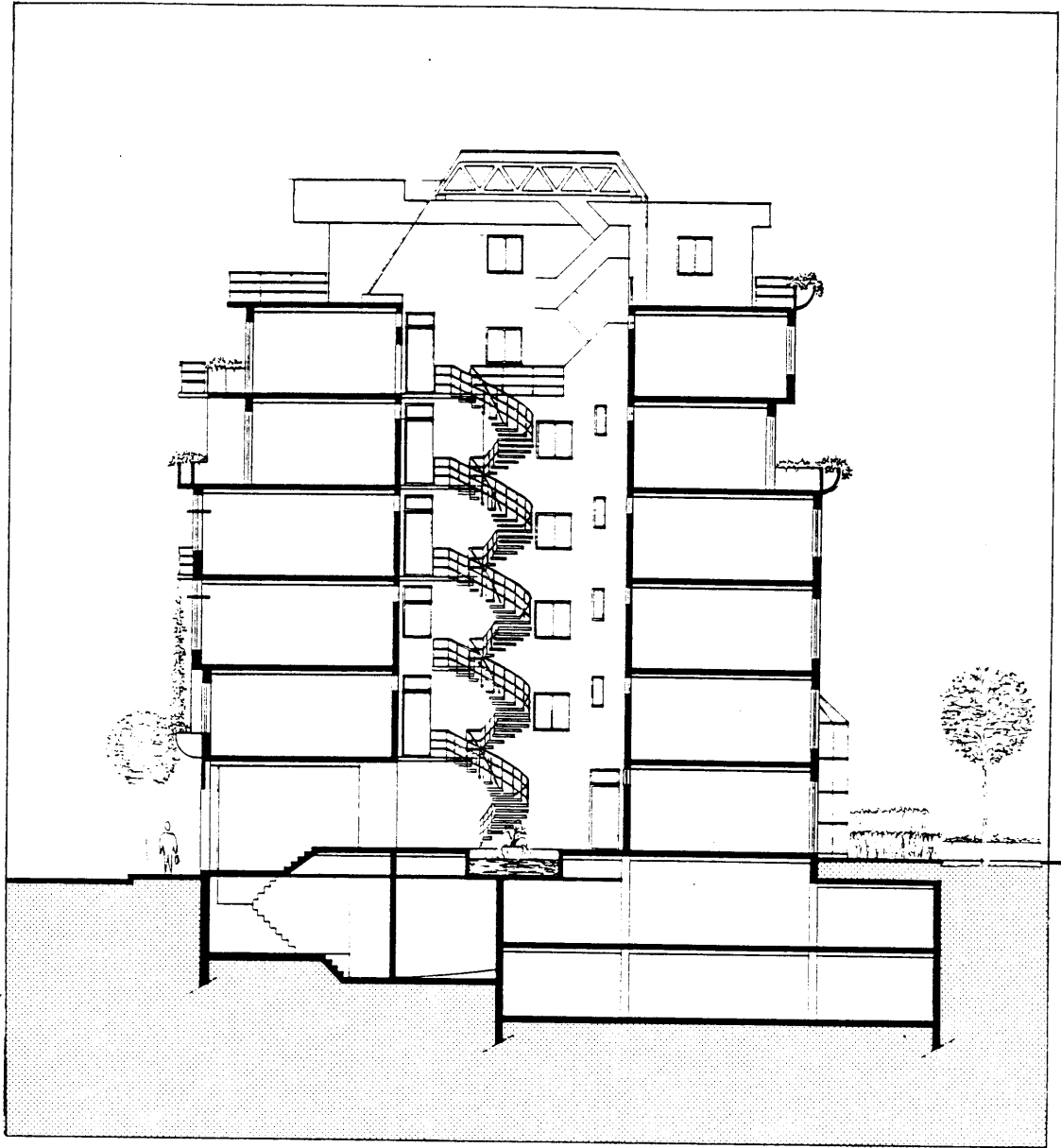
The NNW side of the building is exposed to direct sunlight only during the three summer months in mid-afternoon. Since fixed vertical fins would reduce the limited solar radiation throughout the year, a compromise solution was chosen for summer months shading. During these months, the northern rooms will be protected by the protruding parts of the building as well as by the louvers contained within the glazing system, or by persian blinds.

The center of the building is dominated by the atrium area. The integration of the central circulation core in this area leaves more space to be occupied by the atrium, which appears to be even larger because of the translucent glass blocks utilized for the steps and the landings. The detached spiral staircase, although occupying a large footprint area, does not really interrupt the visual continuity of the interior space.

On the building's periphery the balconies are designed in such a way as to meet the specific needs for outdoor space and solar access of each room. The balconies are partially recessed and partially protruding, with no one completely superceded by the next floor's overhang. The balconies are narrower on the north side, where their protruding parts are made of the same translucent glass blocks as the staircase so as to compensate for the limited sunlight exposure of the bedrooms.

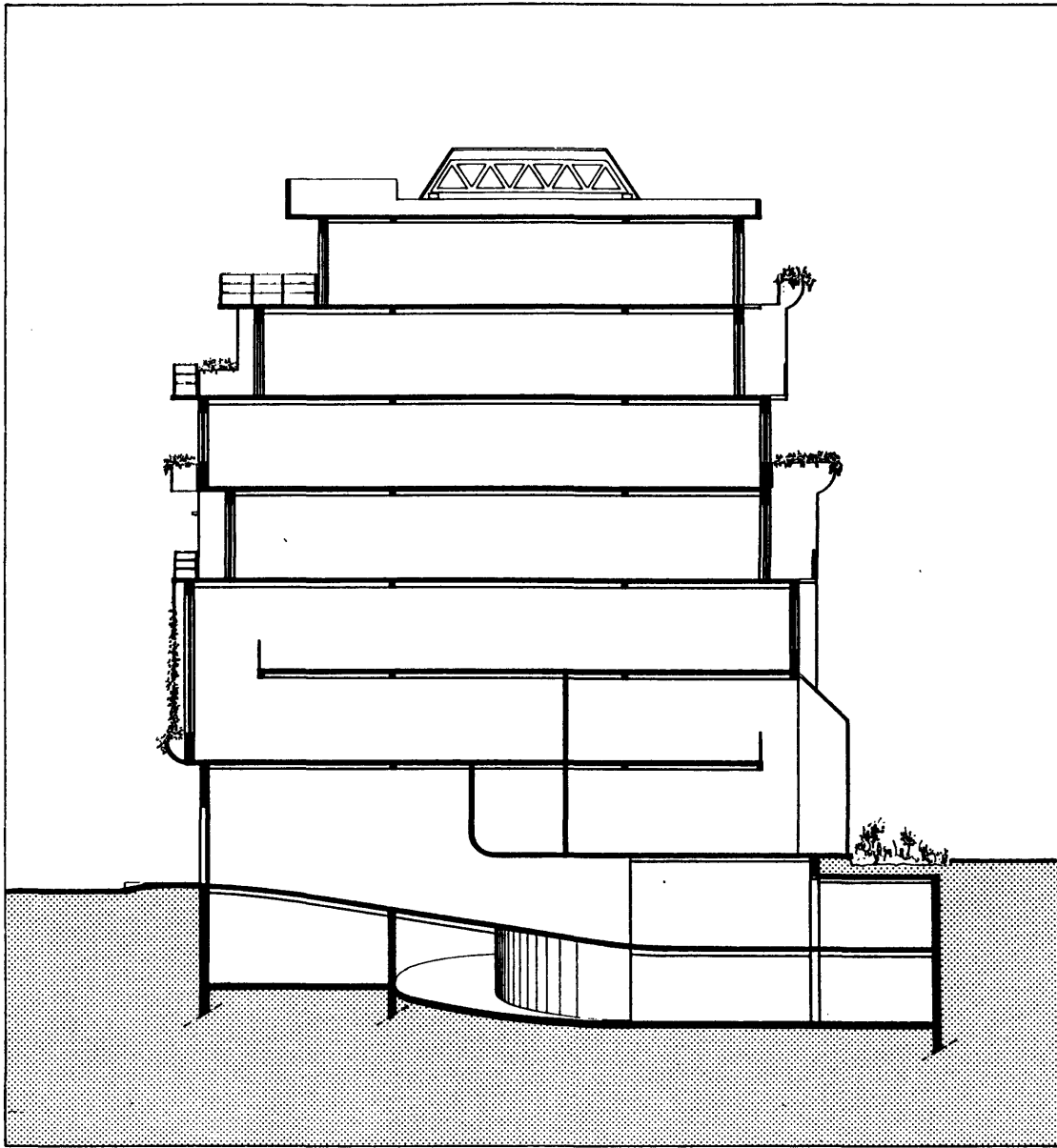
In Athens one can find duplex apartments on the top floors of large buildings. The lower floor apartments in most buildings, though, frequently suffer from lack of adequate solar access. Their balconies, mostly unusable because of the street noise and city pollution, further aggravate those apartments' solar access problem. This complication is dealt with in this building by creating duplex apartments on the lower two floor. The balconies are replaced by a large glazed surface shielding an indoor mezzanine. This, in essence, creates an indoor balcony open to a double height space, which allows for much deeper penetration of sunlight. The large glazed surface in the south is protected from direct sunlight by ivy, conveniently sprouting during the overheated period around the attached treillis. On the north side the same is served by the shadow of the trees growing on the building's backyard.

Duplex apartments also occupy the 5th and 6th floor. Their entrance is located on the lower level so as to avoid the enlarged, upper part of the atrium space --rendered uncomfortable by the warm air stratification-- and to reduce the elevator course.

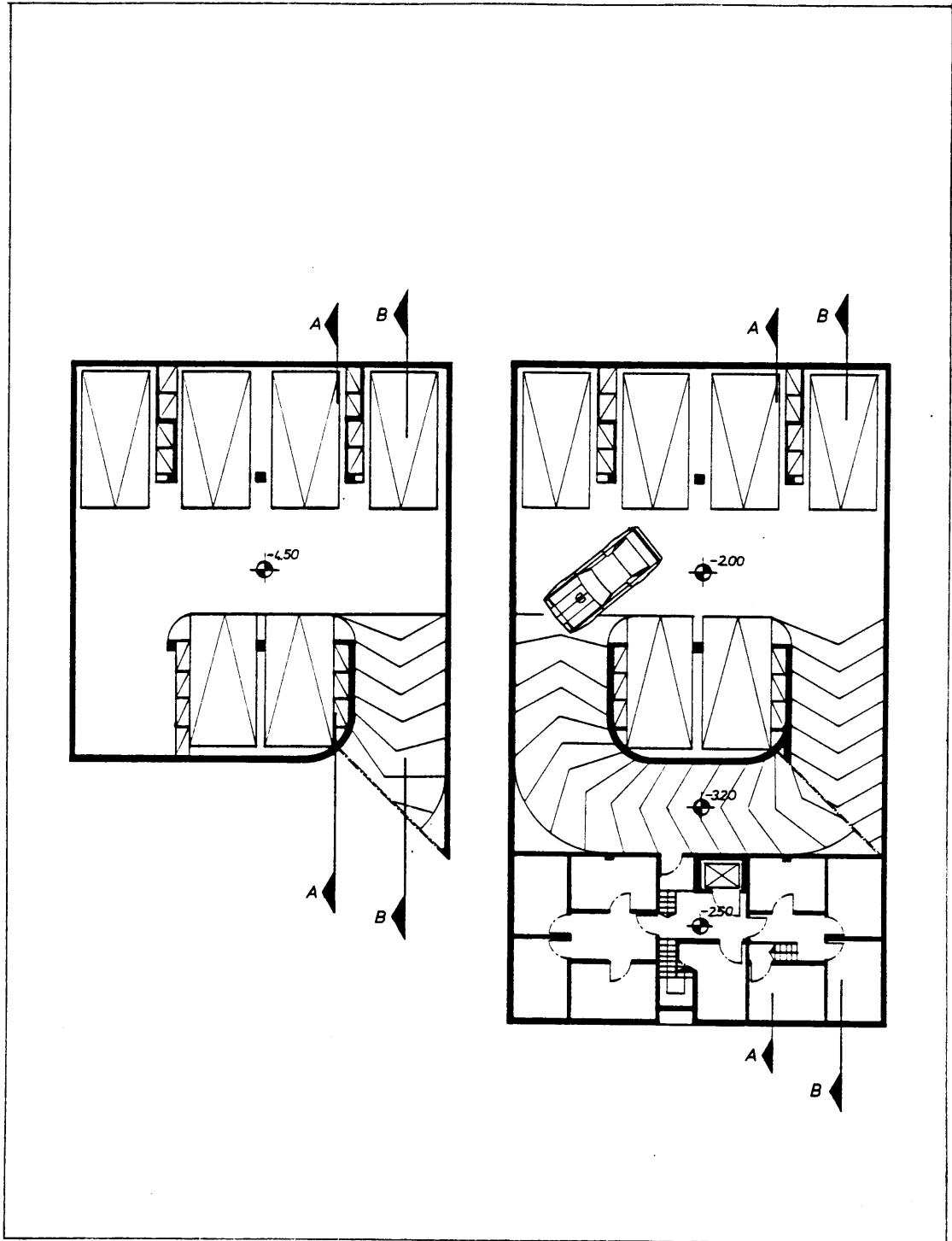


(34) Section AA  
scale 1/250

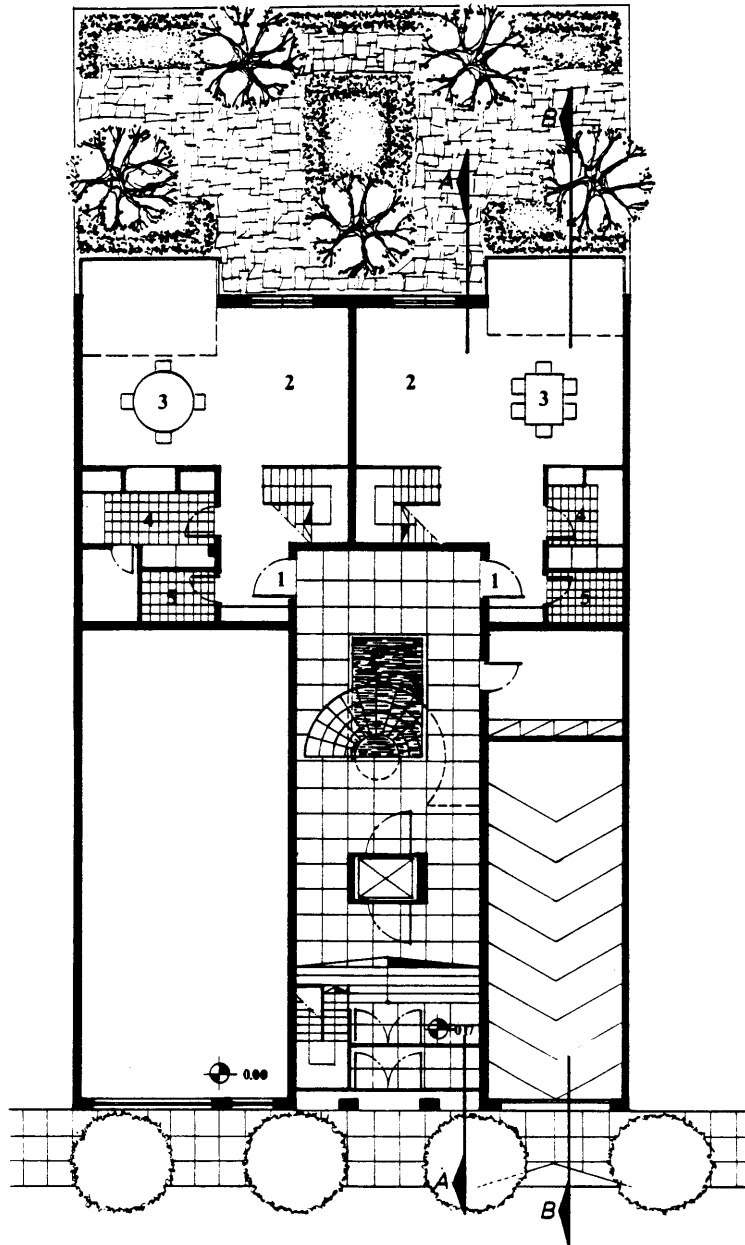




(35) Section BB  
scale 1/250

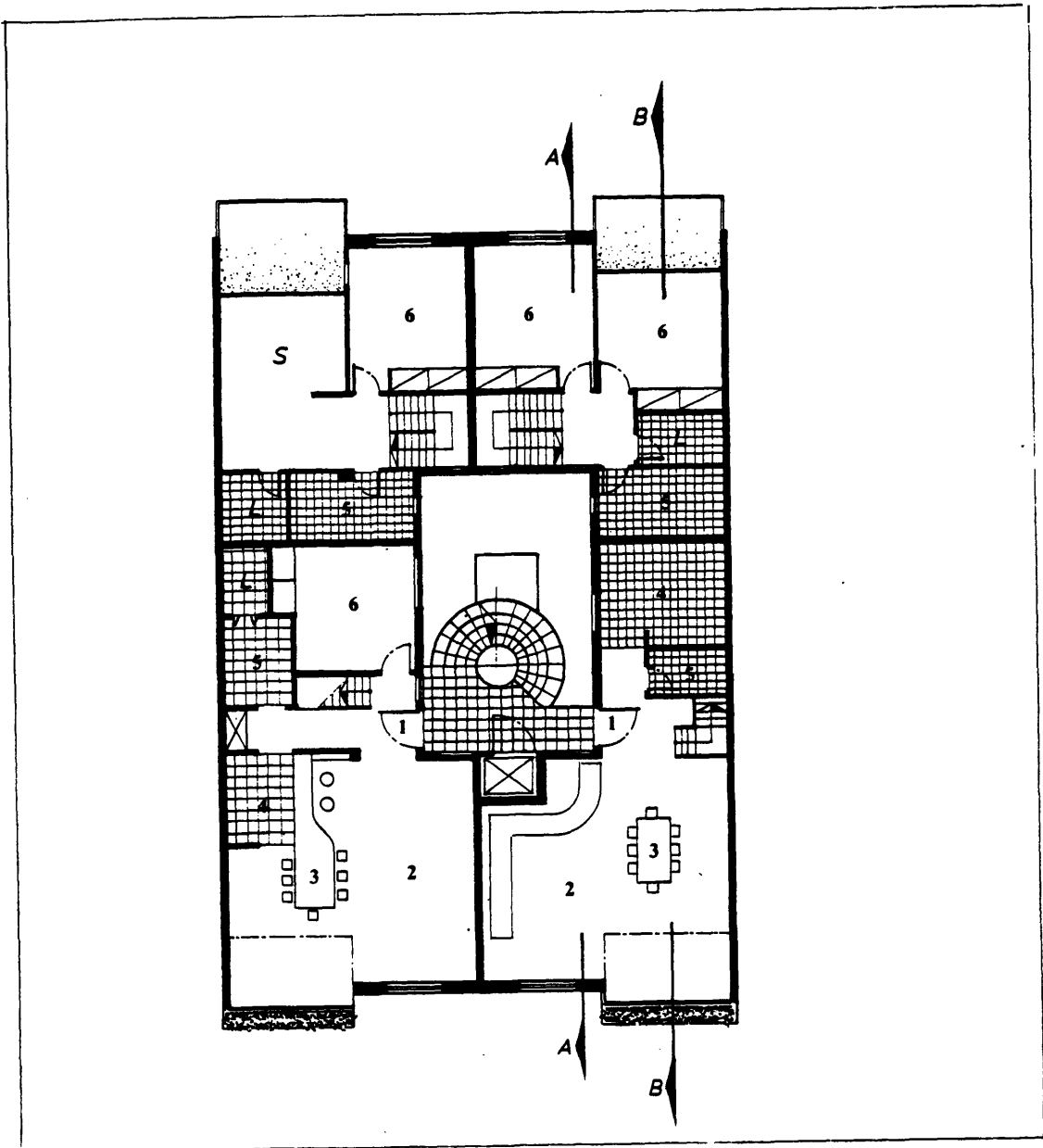


(36) Basements  
scale 1/250



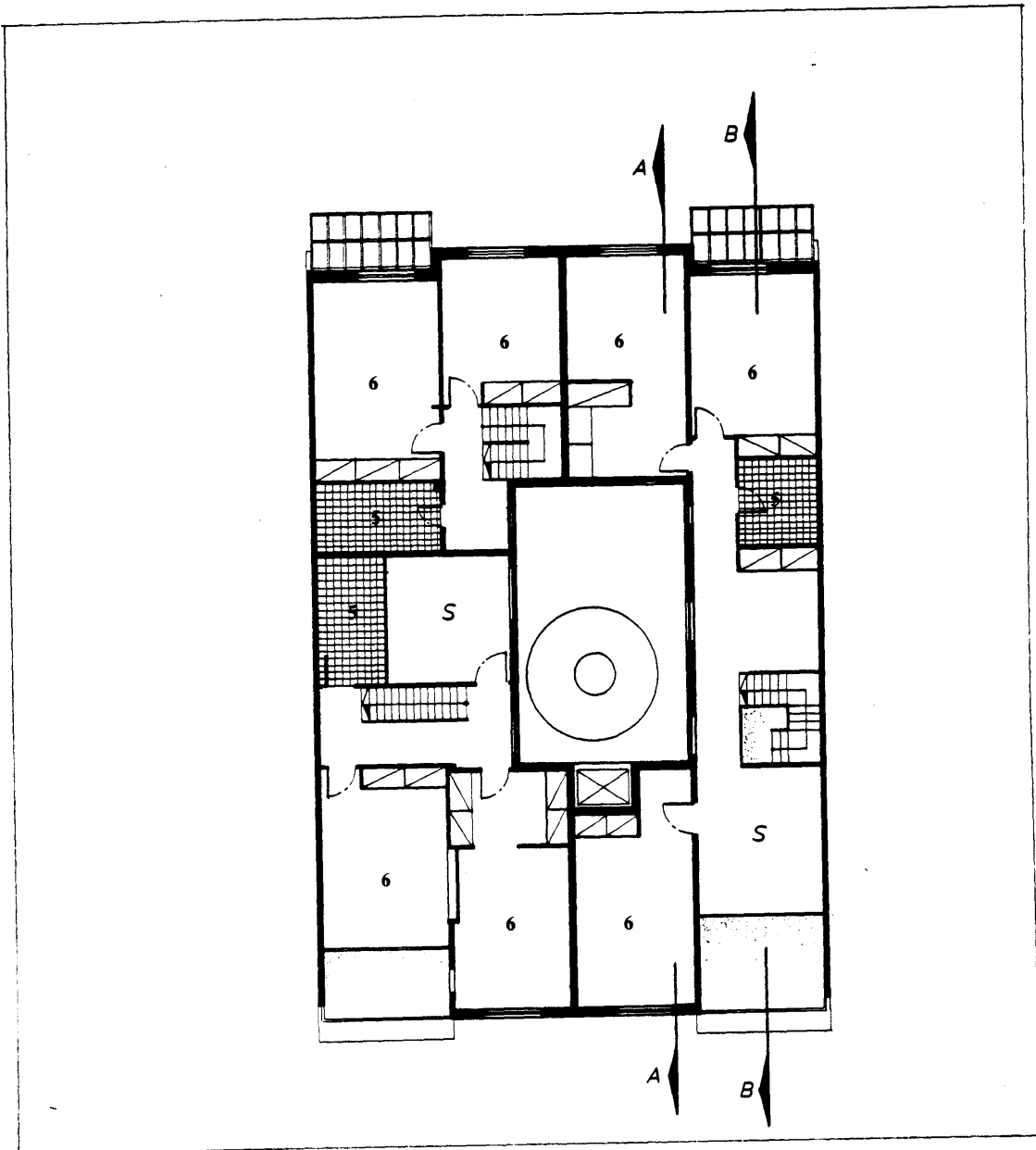
(37) Ground floor  
scale 1/200

- 1 entrance
- 2 living room
- 3 dining area
- 4 kitchen
- 5 w.c.



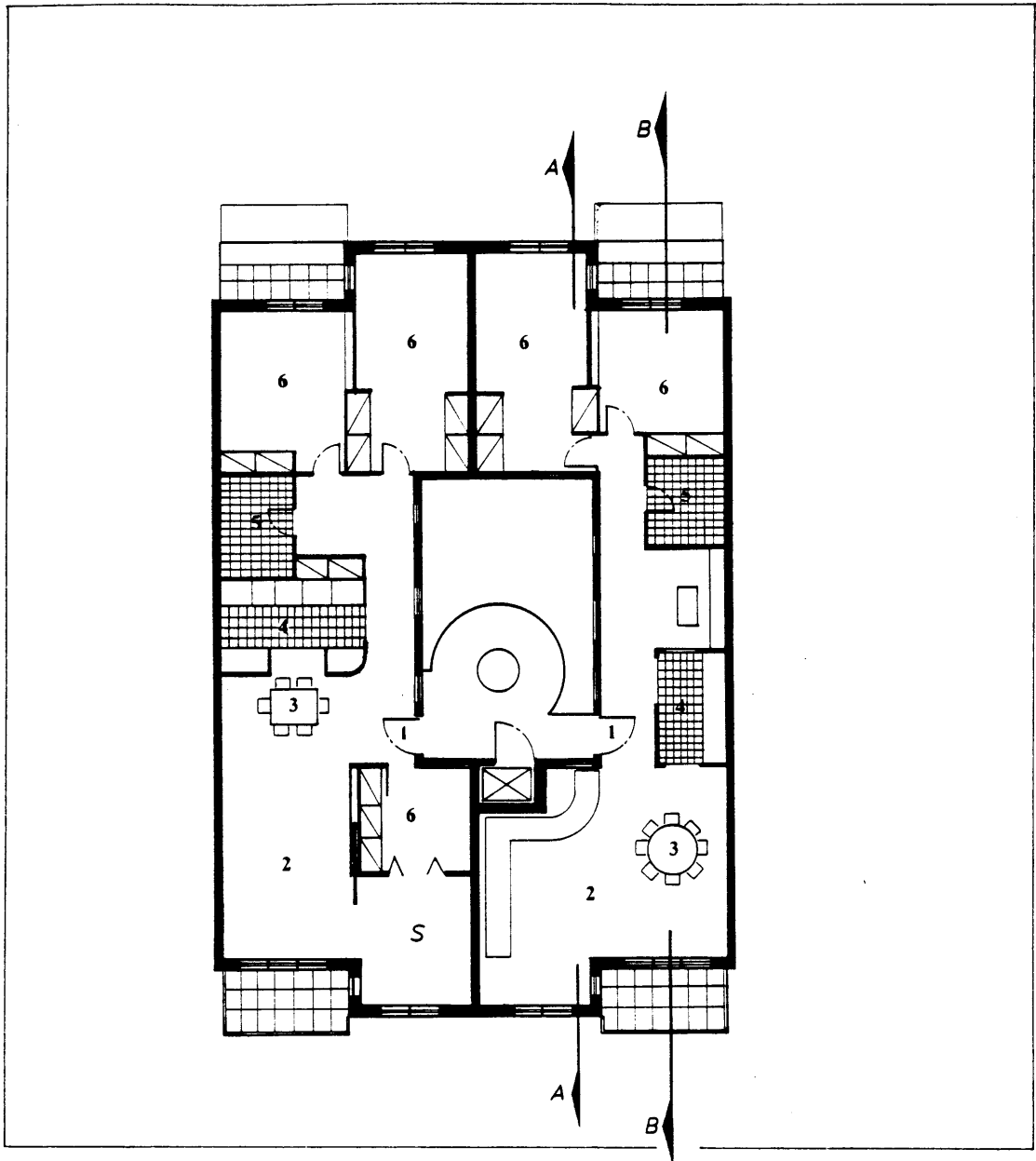
(38) First floor  
scale 1/200

- 1 entrance
- 2 living room
- 3 dining area
- 4 kitchen
- 5 bathroom/w.c.
- 6 bedroom
- 7 storage



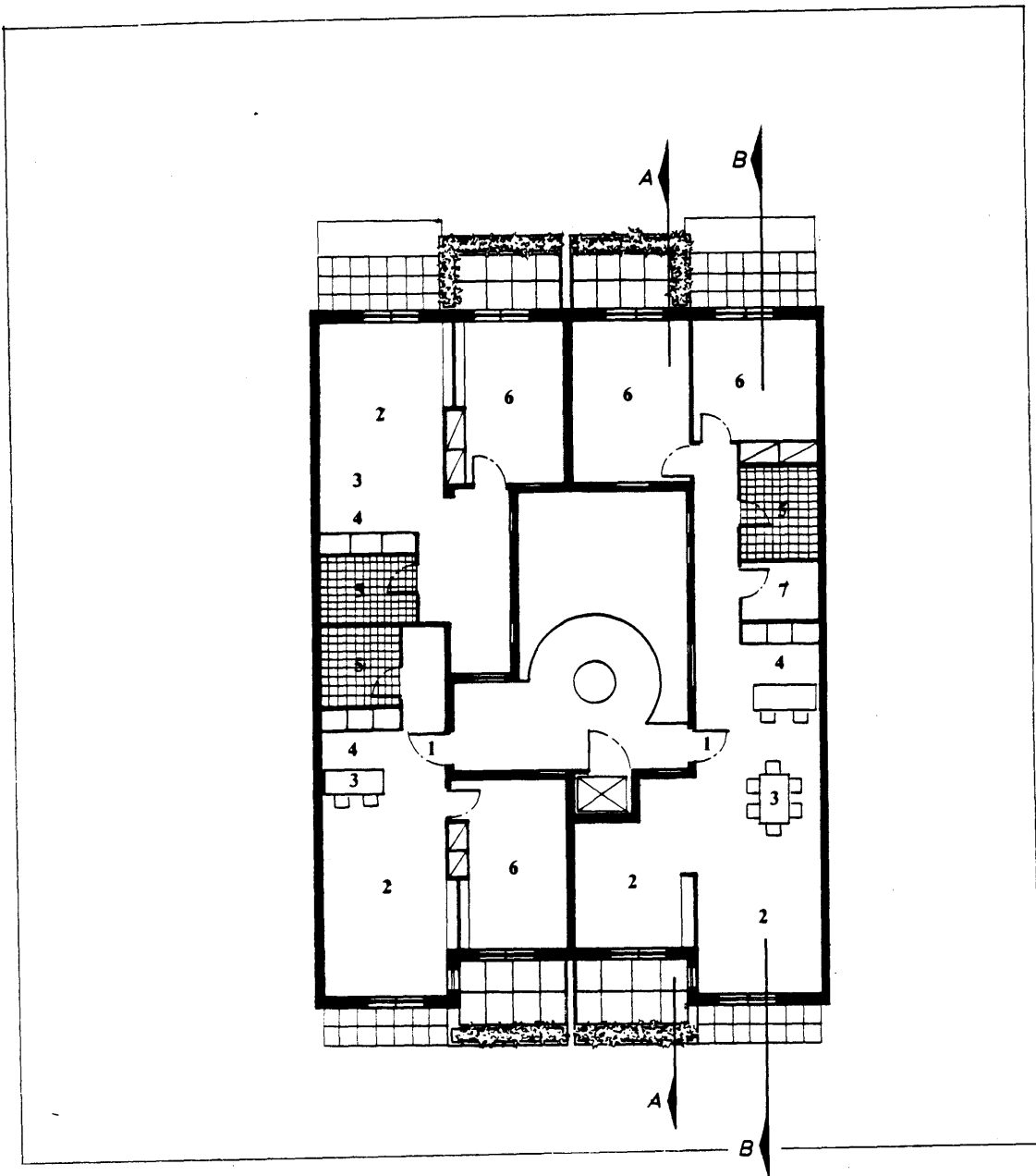
(39) Second floor  
scale 1/200

- 1 entrance
- 2 living room
- 3 dining area
- 4 kitchen
- 5 bathroom/w.c.
- 6 bedroom
- 7 storage



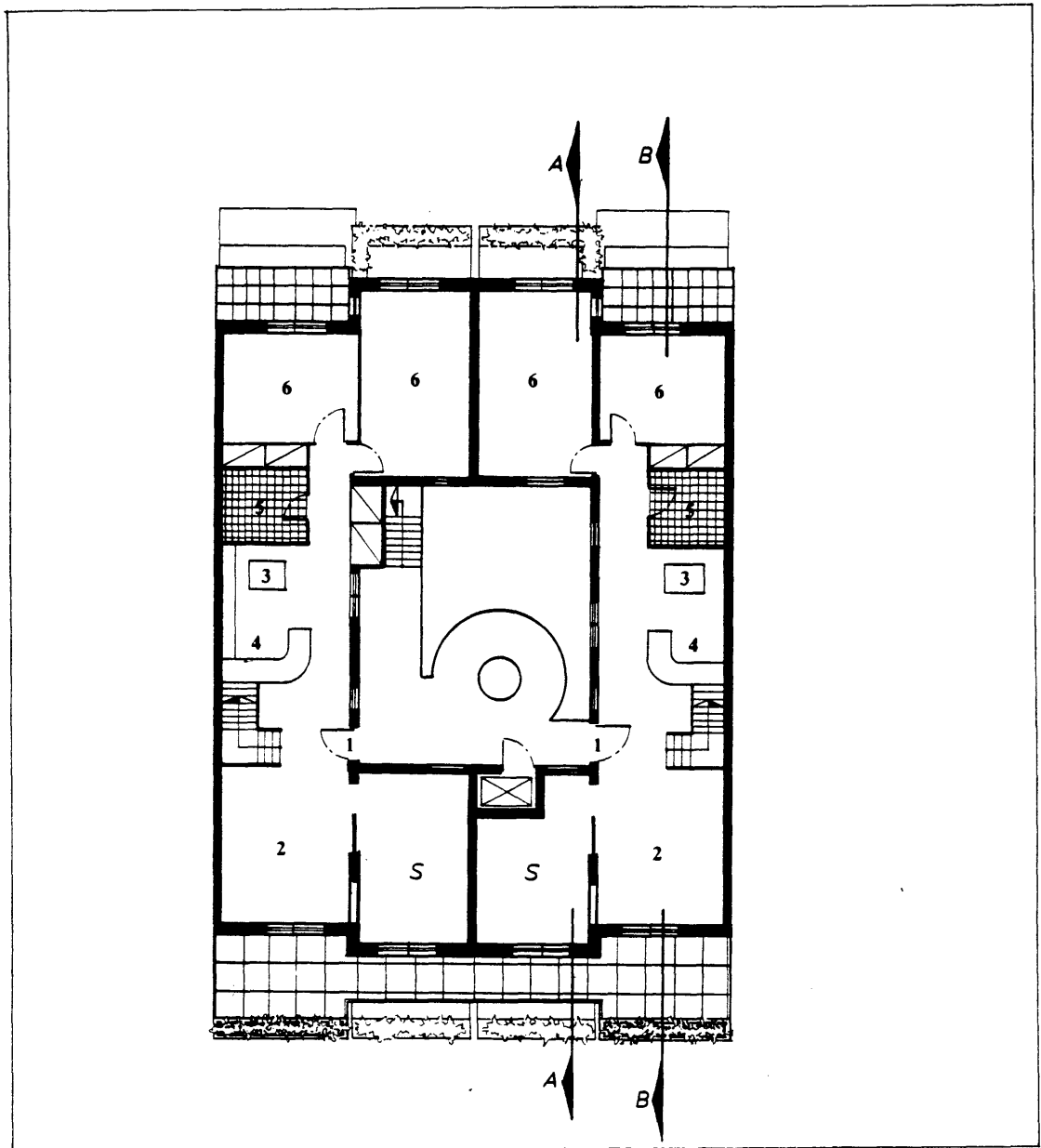
(40) Third floor  
scale 1/200

- 1 entrance
- 2 living room
- 3 dining area
- 4 kitchen
- 5 bathroom/w.c.
- 6 bedroom
- 7 storage



(41) Fourth floor  
scale 1/200

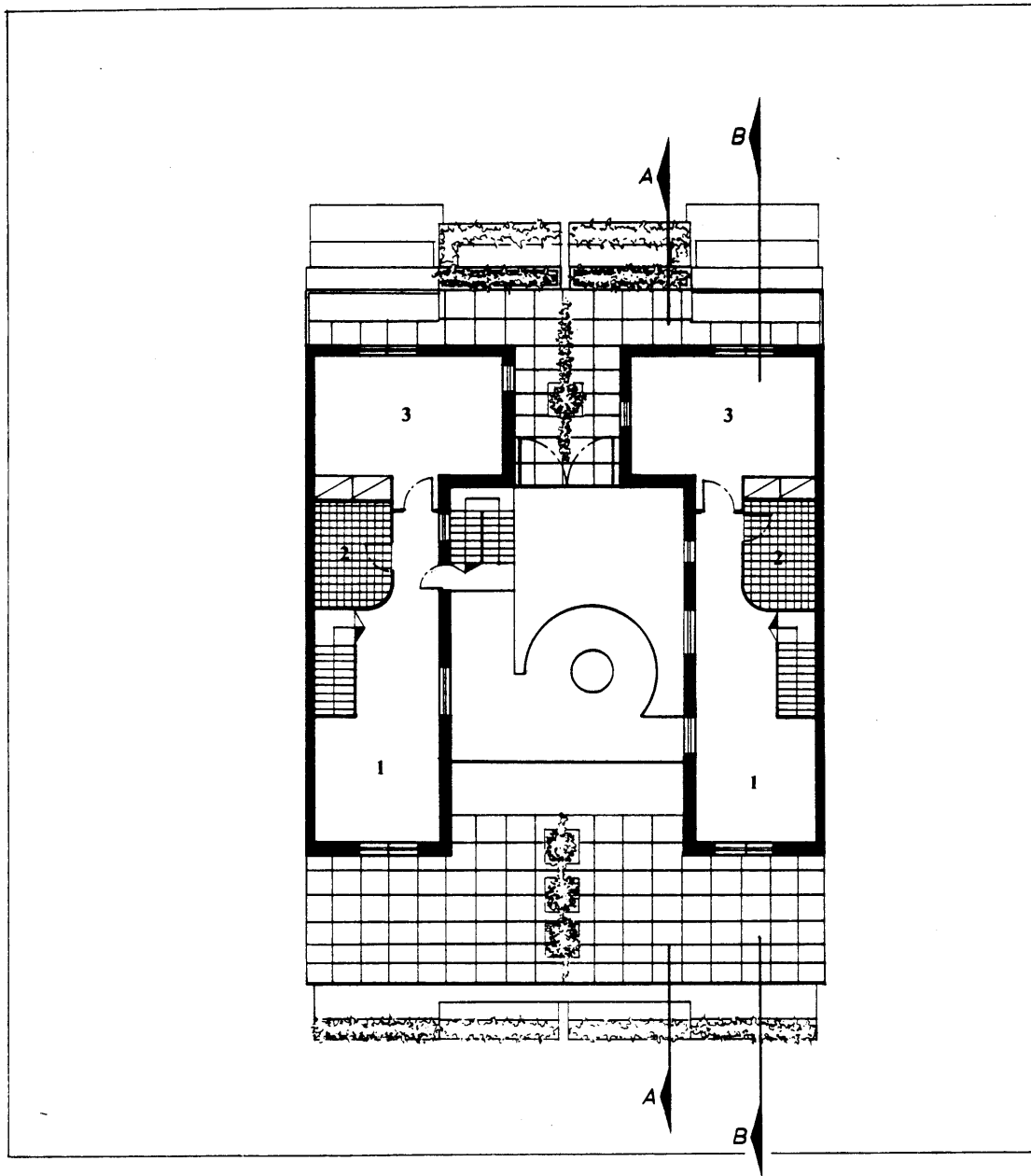
- 1 entrance
- 2 living room
- 3 dining area
- 4 kitchen
- 5 bathroom/w.c.
- 6 bedroom
- 7 storage



(42) Fifth floor  
scale 1/200

- 1 entrance
- 2 living room
- 3 dining area
- 4 kitchen
- 5 bathroom/w.c.
- 6 bedroom
- 7 storage





(43) Sixth floor  
scale 1/200

- 1 drawing room
- 2 bathroom
- 3 bedroom

## Conclusion

The city of Athens enjoys a temperate climate. The outdoor conditions lie within, or close to the thermal comfort zone during the greatest part of the year. The underheated season is fairly mild, with air temperatures rarely remaining below the freezing mark for more than one day even during the peak January and February months. The abundant sunshine can alleviate the winter cold, but can be a potential problem during the overheated summer months. In turn, the prevailing NNE and SSW breezes can partially compensate for the overheatedness of the day. The amount of precipitation is moderate, and the air gets neither too humid, nor excessively dry throughout the year.

In such a supportive climatic milieu, the density of the urban environment plays a negative role for any passive approach to achieve comfort conditions within the compact residential buildings.

The concepts discussed in the first chapter of part III set the framework for a design proposal which attempts to make the most of the environmental resources of the athenian context.

Increasing the surface-to-volume ratio --that is, the total weather wall area, achieved mainly through the atrium design--, allow for the openings necessary to optimize the interplay between the indoors and the outdoor environment. The appropriate use of the balconies, in relation to the window siting, sizing, shading, and choice of materials serve to regulate the reception of the natural energies in a way keeping in phase with the changing seasons. Open floor plans and the flow-through organization of the individual apartments enhances the distribution of solar energy in winter --to assist the high thermal insulation of the building shell--, as well as the unobstructed air flow whenever natural ventilation is desirable. Finally, radiative and evaporative cooling techniques -- introduced in chapter 5-- further alleviate the overheatedness of the summer.

This concludes the description of the building re-design. The result is a residential building better fit in the athenian environment, better equipped to deal with the athenian winter and the summer heat, and, therefore, offering better living conditions to its residents. The appearance of the building, in contrast to the established construction type, generates --through a natural process-- a new aesthetic conception brought forth by the direct application of climatic design principles.

The design proposal is by no means the "correct one". There are innumerable good ways to redesign a building taking climatic considerations into account; furthermore, the proposal could easily use some fine tuning and improvements (the atrium space, whose temperature is maintained within a range of 16 to 19 degrees throughout the heating season --at the expense of the apartments' heating efficiency-- immediately comes to mind). Nevertheless, the author feels satisfied that, having chosen an inner city building which is not ideal for climatic design applications, he presented a proposal that is efficient, and consistent with the principles discussed in the previous parts of this Thesis.



*AFTERWORD*

## AFTERWORD

In Part III of this Thesis we examined a typical residential building located in a dense urban area. Being typical, the building is neither perfectly suitable, nor unsuitable for climatic design applications. Its importance lies precisely with the fact that it is similar to the tens of thousands of buildings concentrated in large urban areas today. Part III demonstrated that climatic design applications can offer a viable alternative to the established design and construction processes of multi-storey buildings in Athens, Greece. This alternative, without being any revolutionary idea, presents a more efficient use of what our environment offers and can lead to an aesthetically more attractive, and functionally more livable residence.

The extent of climatic design improvements depends on the specific site's microclimate. This microclimate, in turn, is heavily influenced by the urban layout and cityscape. A highrise designed without taking consideration of the surrounding buildings, for instance, can modify the prevailing wind flow patterns and block the buildings' solar access thus limiting the opportunities for climatic design applications on the surrounding buildings.

These applications, therefore, can be more successful in the presence of a supportive city layout resulting from an urban planning conscious of climatic design considerations. As an example of such a layout one can use the Back Bay area in Boston, Massachusetts. Back Bay's fabric is subject to a rectangular grid with the elongated side of the urban blocks exposed to a North-South orientation. The buildings occupy the periphery of the blocks, leaving space for front yards --thus further reducing the building height to street width ratio--, and larger tree planted back yards and alleys. The three and four-storey buildings allow for one flow through apartment per floor, having excellent sunlight and ventilation access due to the large bay-windows on both sides and their appropriate depth to width ratio. All these make Back Bay an excellent illustration of a neighborhood whose

buildings are harmonically tied to the environment and offer more pleasant living conditions to its residents.

The importance of city planning poses a creative challenge to the energy conscious architect. The crystallization of the urban tissue in high density areas such as the one used as a case study in this Thesis, prohibits large scale applications of climatic design. Such applications are more suitable for urban areas designated for intensive regional development, where new city planning can create a framework conducive to energy conscious design in the micro-level. Another area suitable for such applications, although sometimes economically prohibitive, is the large scale urban restructurings where whole parts of cities are torn down and rebuilt around contemporary and, hopefully, more climatic conscious city plans.

However, as demonstrated in Part III, even in the dense urban areas one can offer significant improvements to the existing conventional design, making inner city structures more compatible with their environment and turning the residences into more livable homes. Climatic Design at its best can create a synthesis of our environment, the human needs, and the existing technology, making once more the human residence an integral part of nature, and elevating human well being as its pivotal objective.



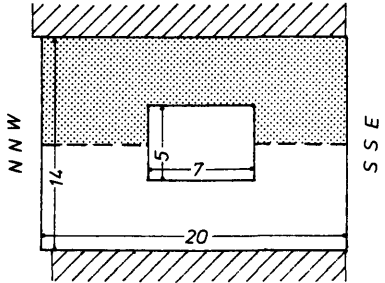


*APPENDICES*



## APPENDIX A

## TYPICAL APARTMENT UNIT



Total floor area:  $14 \times 20 - 5 \times 7 = 245 \text{ m}^2$   
 Apartment unit floor area  
 (minus 12 % for partition walls) =  $110 \text{ m}^2$

Exposed weather wall area:  $14 \times 3 = 42 \text{ m}^2$   
 Atrium wall area:  $(5+7) \times 3 = 36 \text{ m}^2$   
 No heat losses to adjacent buildings

Ceiling height: 2.75 m  
 Volume : approx.  $300 \text{ m}^3$

## APARTMENT UNIT AVERAGE DAILY HEAT LOSS CALCULATION

1. Through conduction ( $H_c = U \cdot A \cdot DT \cdot 24 \text{ hrs}$ )

(a) Weather wall:

$U_{\text{wall}}: .25 \text{ W/m}^2 \text{ C}$   
 $U_{\text{glass}}: 3.40 \text{ W/m}^2 \text{ C}$   
 Glass area is 40 % of the total weather wall area  
 $U_{\text{tot}}: .4 \times 3.40 + .6 \times .25 = 1.51 \text{ W/m}^2 \text{ C}$   
 $U_{\text{tot}} \cdot A: 1.51 \times 42 = 63.4 \text{ W/ C}$

(b) Atrium wall:

$U_{\text{wall}}: .40 \text{ W/m}^2 \text{ C}$   
 $U_{\text{glass}}: 6.00 \text{ W/m}^2 \text{ C}$   
 Glass area is 20 % of the total atrium wall area  
 $U_{\text{tot}}: .2 \times 6.00 + .8 \times .4 = 1.52 \text{ W/m}^2 \text{ C}$   
 $U_{\text{tot}} \cdot A: 1.52 \times 36 = 54.7 \text{ W/ C}$

2. Through infiltration ( $H_i = V \cdot \text{air ch.} \cdot q \cdot DT \cdot 24 \text{ hrs}$ )

.6 air changes per hour  
 $q = .335 \text{ W/m}^3 \text{ C}$   
 $300 \times .6 \times .335 = 60.4 \text{ W/ C}$   
 25 % of total infiltration loss to the atrium

Total heat loss:

to the out-of-doors:  $63.4 + 45.3 = 108.7 \text{ W/ C}$   
 to the atrium:  $54.7 + 15.1 = 69.8 \text{ W/ C}$

$H_{\text{tot}} = H \cdot DT \cdot 24 \text{ hrs}$

## APARTMENT UNIT AVERAGE DAILY INTERNAL HEAT GAIN CALCULATION

### 1. Occupants:

Two adults (1) and one child (.7)  
 Occupancy: 14 hrs/day  
 Sensible heat: 80 W (60 W while sleeping)  
 $Q_o: [(.08*7)+(.06*7)]*(2+.7) = 2.6 \text{ kWh}$

### 2. Artificial lighting:

35 % of the total floor area during 6 hrs  
 Illumination level: 12 W/m<sup>2</sup>  
 $Q_l: 12*(110*.35)*6 = 2.8 \text{ kWh}$

### 3. Electric Equipment:

Refrigerator: 4.0 kWh  
 T.V..stereo. washing machine, etc.: 1.0 kWh  
 Cooking: 2.0 kWh  
 $Q_e = 7.0 \text{ kWh}$

### TOTAL HEAT GAIN

$$Q_{tot} = Q_o + Q_l + Q_e = 12.4 \text{ kWh}$$

AVERAGE DAILY REAL HEATING LOAD :  $H = H_{tot} - Q_{tot}$

	T outside	T atrium	H outside	H atrium	$H_{Total}$	$\frac{H}{\text{kWh/Day}}$
NOV	12.8	17.6	18.78	4.02	22.80	10.4
DEC	13.3	17.8	17.48	3.68	21.16	9.8
JAN	7.0	15.9	33.91	6.87	40.78	28.4
FEB	9.2	16.6	30.78	5.70	36.48	24.1
MAR	13.5	17.9	16.96	3.52	20.48	10.1
APR	15.7	18.5	1.22	2.51	13.73	3.3
Average heating season	11.6	17.3	21.91	4.52	26.43	

## ATRIUM

### AVERAGE DAILY HEAT LOSS

#### 1. Through conduction

##### (a) Roof:

Footprint area:  $5 \times 7 = 35 \text{ m}^2$   
 Pitched glass roof total area:  $50 \text{ m}^2$   
 $U_{\text{glass}}: 6.00 \text{ W/m}^2 \text{ C}$   
 $U \cdot A: 6.00 \times 50 = 300 \text{ W/ C}$

##### (b) Entrance:

Glass area:  $15 \text{ m}^2$   
 Single glazing double doors  
 Overall  $U_{\text{glass}}: 3.40 \text{ W/m}^2 \text{ C}$   
 $U \cdot A: 3.40 \times 15 = 50.0 \text{ W/ C}$

#### 2. Through infiltration

Atrium space:  $35 \times 3 \times 7 = 735 \text{ m}^3$   
 Entrance and lobby:  $4 \times 6 \times 3 = 72 \text{ m}^3$   
 Total interior space: approx.  $800 \text{ m}^3$   
 .3 air changes per hour  
 $800 \times .3 \times .335 = 80 \text{ W/ C}$

#### TOTAL HEAT LOSS:

$H_{\text{tot}}: 300 + 50 + 80 = 430 \text{ W/ C}$

### AVERAGE DAILY HEAT GAIN

Heat is supplied to the atrium by the 14 apartment units; no solar heat gain through the glazed roof system is considered here (effect of air stratification in the upper part, etc)

#### 1. Through conduction

$Q_c = 54.7 \text{ W/ C}$

#### 2. Through infiltration

25 % of the total loss of each apartment unit  
 $Q_i = 15.1 \text{ W/ C}$

#### TOTAL HEAT GAIN

$(54.7 + 15.1) \times 14 = 977 \text{ W/ C}$   
 $Q_{\text{tot}} = .98 \text{ kW/ C} \times (T_{\text{apt}} - T_{\text{ar}}) \times 24 \text{ hrs}$

If the heat loss equals the heat gain, and with  $T_{\text{apt}} = 20.0$  degrees, then solving  $H_{\text{tot}} = Q_{\text{ot}}$  gives an average air temperature:

$T_{\text{atr}} = 13.8 + (.3 \times T_{\text{outside}})$  degrees

## APPENDIX B

The *Average Daily Radiation III* program was used to calculate the average daily nsolation striking a vertical surface of a SSE and a NNW orientation.

Input data base:

- (A) TILT = 90 degrees (vertical)
- (B) AZIMUTH = 22.5 (SSE) / 156.5 (NNW)
- (C) REFLECTANCE = .2 (SSE) / .4 (NNW)
- (D) LATITUDE = 38 degrees
- (E) MONTH = { 1 to 12 }
- (F) AVRG DAILY TOTAL RADIATION ON A HOR. SURFACE <sup>1</sup>

## AVERAGE DAILY RADIATION ON A VERTICAL SURFACE

	Horiz.	SSE				NNW			
		Beam	Diff	Refl	Total	Beam	Diff	Refl	Total
JAN	1.75	1.66	.46	.18	2.30	.0	.46	.35	.81
FEB	2.80	2.25	.59	.28	3.12	.0	.59	.56	1.15
MAR	4.40	2.58	.70	.44	3.72	.10	.70	.88	1.68
APR	5.39	1.82	.88	.54	3.24	.24	.88	1.08	2.20
MAY	6.35	1.30	.94	.64	2.88	.30	.94	1.27	2.51
JUN	7.30	1.20	.82	.73	2.75	.74	.82	1.46	3.02
JUL	7.22	1.41	.78	.72	2.91	.52	.78	1.44	2.74
AUG	6.60	2.15	.69	.66	3.50	.42	.69	1.32	2.43
SEP	5.27	2.87	.64	.53	4.04	.20	.64	1.06	1.90
OCT	3.83	3.28	.54	.38	4.20	.0	.54	.77	1.31
NOV	2.78	3.50	.42	.28	4.20	.0	.42	.56	.98
DEC	2.07	2.82	.40	.21	3.43	.0	.40	.41	.81

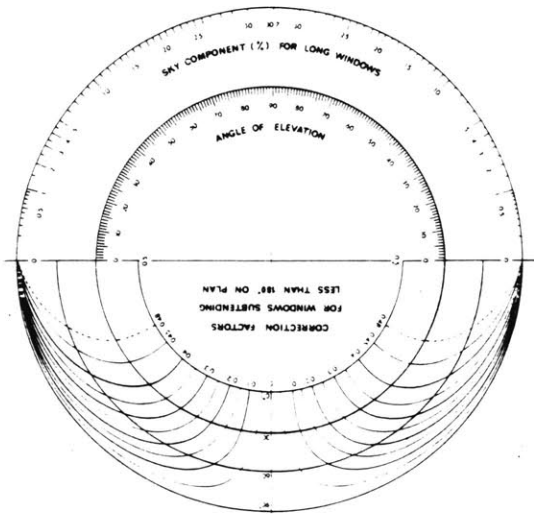
<sup>1</sup> 1981 data contained in chapter 4.4

The direct and diffuse components of the total radiation have to be corrected by taking into account the solar geometry with respect to each different floor.

The beam radiation depends on the shading effects of the cityscape along the solar path.

CORRECTION FACTOR FOR DIRECT RADIATION								
	SSE						NNW	
	NOV	DEC	JAN	FEB	MAR	APR	MAR	APR
Gr	.0	.0	.0	.0	.4	.5	.0	.0
1st	.0	.0	.0	.05	.55	.6	.0	.0
2nd	.0	.0	.0	.35	.65	.7	.0	.2
3rd	.35	.15	.35	.55	.8	.7	.3	.5
4th	.6	.5	.6	.85	.8	.7	.6	.7
5th	.85	.9	.85	.90	.85	.75	.85	.85
6th	.95	.95	.95	.95	.85	.75	.8	.9

The percentage of diffuse radiation can be determined by superimposing the protractor over the angle formed by a line drawn from the window sill to the roof of the building across, and a line clearing the window header (or overhang).



SKY COMPONENT FACTOR FOR DIFFUSE RADIATION		
	SSE	NNW
Gr	.58	.40
1st	.63	.49
2nd	.74	.60
3rd	.82	.70
4th	.89	.8
5th	.96	.91
6th	.99	.98

The average daily direct, diffuse, reflected, and total radiation striking the exposed weather walls of each floor is given in the following tables.

AVRG TOTAL INCIDENT DAILY RAD. ON A HORIZ. SURFACE		AVRG DAILY INCIDENT DAILY RAD. ON A VERT. SURFACE		AVERAGE DAILY INCIDENT RADIATION ON THE SOUTH-SOUTHEAST SURFACE OF THE BUILDING (KWH/M)						
				GR	# 1	# 2	# 3	# 4	# 5	# 6
NOV.	2.78	BEAM	3.50	.0	.0	.0	.0	1.23	2.10	3.33
		DIFF	.42	.24	.26	.31	.34	.37	.40	.42
		REFL	.28	.28	.28	.28	.28	.28	.28	.28
		TOTL	4.20	.52	.54	.59	1.85	2.75	3.66	4.03
DEC.	2.07	BEAM	2.82	.0	.0	.0	.42	1.44	2.54	2.68
		DIFF	.40	.23	.25	.30	.33	.36	.38	.40
		REFL	.21	.21	.21	.21	.21	.21	.21	.21
		TOTL	3.43	.44	.46	.51	.96	1.98	3.133	3.29
JAN.	1.75	BEAM	1.66	.00	.00	.00	.61	1.05	1.49	1.58
		DIFF	.46	.27	.29	.34	.38	.41	.44	.46
		REFL	.18	.18	.18	.18	.18	.18	.18	.18
		TOTL	2.30	.45	.47	.51	1.17	1.64	3.11	2.22
FEB	2.80	BEAM	2.25	.00	.11	.79	1.24	1.91	2.10	2.14
		DIFF	.59	.32	.37	.44	.48	.53	.57	.58
		REFL	.28	.28	.28	.28	.28	.28	.28	.28
		TOTL	3.12	.62	.76	1.51	2.00	2.72	2.95	3.00
MAR	4.40	BEAM	2.58	1.03	1.42	1.68	2.06	2.06	2.19	2.19
		DIFF	.70	.41	.44	.52	.57	.62	.67	.69
		REFL	.44	.44	.44	.44	.44	.44	.44	.44
		TOTL	3.72	1.88	2.30	2.64	3.07	3.12	3.30	3.32
APR	5.39	BEAM	1.82	1.09	1.09	1.27	1.27	1.27	1.37	1.37
		DIFF	.88	.51	.55	.65	.72	.78	.84	.87
		DEFL	.54	.54	.54	.54	.54	.54	.54	.54
		TOTL	3.24	2.14	2.18	2.46	2.53	2.59	2.75	2.78

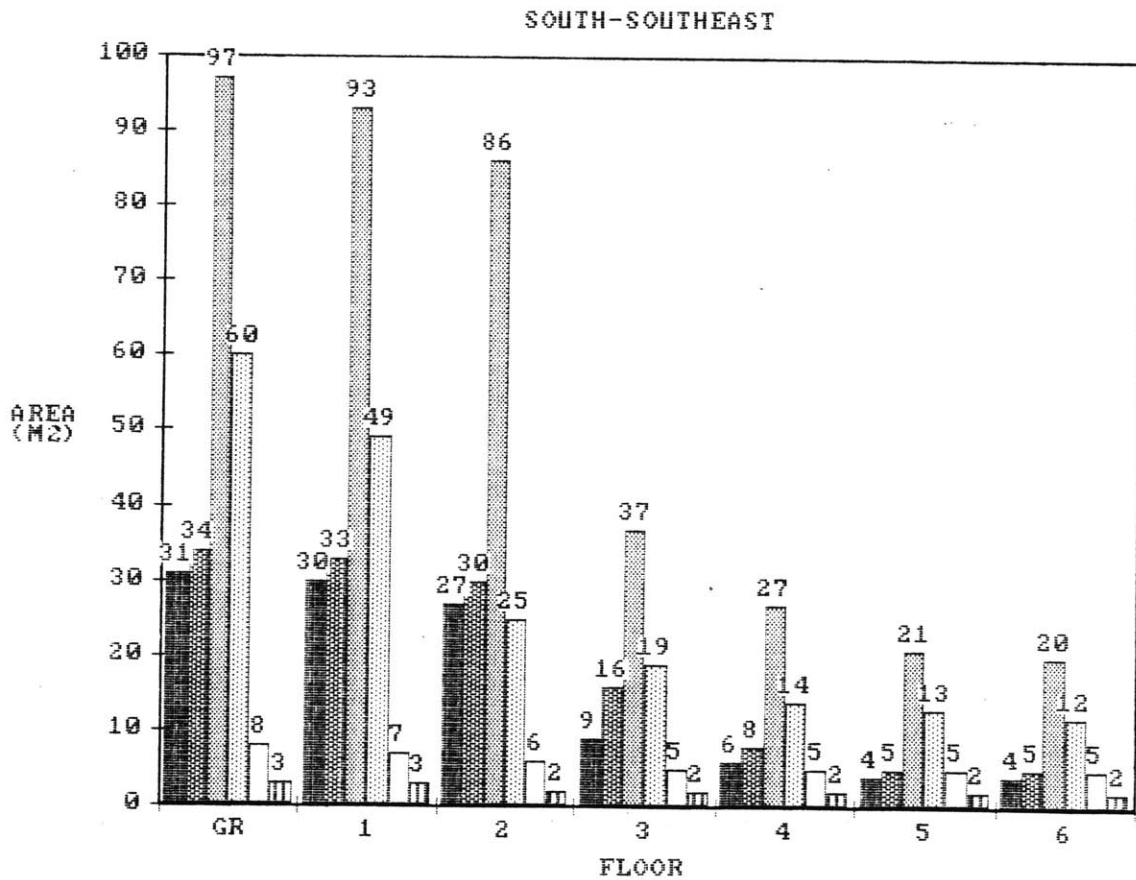


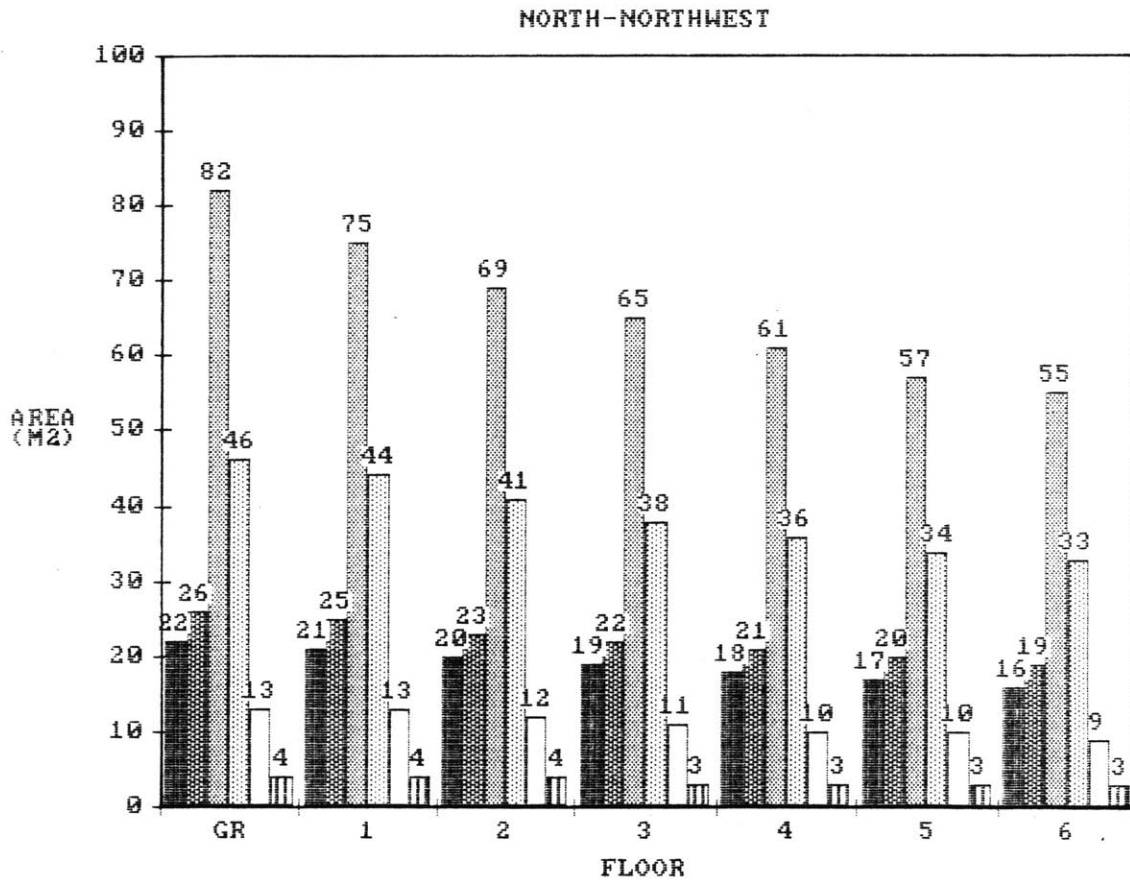
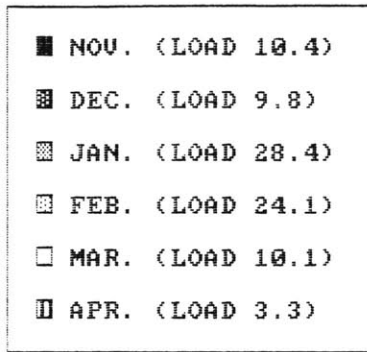
AVRG TOTAL INCIDENT DAILY RAD. ON A HORIZ. SURFACE		AVRG DAILY INCIDENT DAILY RAD. ON A VERT. SURFACE		AVERAGE DAILY INCIDENT RADIATION ON THE NORTH-NORTHWEST SURFACE OF THE BUILDING (KWH/M)						
				GR	# 1	# 2	# 3	# 4	# 5	# 6
NOV.	2.78	BEAM	.00	.00	.00	.00	.00	.00	.00	.00
		DIFF	.42	.17	.21	.25	.29	.34	.38	.31
		REFL	.56	.56	.56	.56	.56	.56	.56	.56
		TOTL	.98	.73	.77	.81	.85	.90	.94	.97
DEC.	2.07	BEAM	.00	.00	.00	.00	.00	.00	.00	.00
		DIFF	.40	.16	.20	.24	.28	.32	.36	.39
		REFL	.41	.41	.41	.41	.41	.41	.41	.41
		TOTL	.81	.57	.61	.65	.69	.73	.77	.80
JAN.	1.75	BEAM	.00	.00	.00	.00	.00	.00	.00	.00
		DIFF	.46	.18	.23	.28	.32	.37	.42	.45
		REFL	.35	.35	.35	.35	.35	.35	.35	.35
		TOTL	.81	.53	.58	.63	.67	.72	.77	.80
FEB	2.80	BEAM	.00	.00	.00	.00	.00	.00	.00	.00
		DIFF	.59	.24	.29	.35	.41	.48	.54	.58
		REFL	.56	.56	.56	.56	.56	.56	.56	.56
		TOTL	1.15	.80	.85	.91	.97	1.04	1.10	1.14
MAR	4.40	BEAM	.10	.00	.00	.00	.03	.06	.08	.08
		DIFF	.70	.28	.34	.42	.49	.57	.64	.69
		REFL	.88	.88	.88	.88	.88	.88	.88	.88
		TOTL	1.68	1.16	1.22	1.30	1.40	1.51	1.60	1.65
APR	5.39	BEAM	.24	.00	.00	.05	.12	.17	.20	.22
		DIFF	.88	.35	.43	.53	.62	.71	.80	.86
		DEFL	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
		TOTL	2.20	1.43	1.51	1.66	1.82	1.96	2.08	2.16

In order to achieve total solar heating, the total radiative gain should equal the real heating load for the average day of each heating season month. The glass area is then given by:  $A = I_{tot} / H_{tot} * T.C.$ , where:

$I_{tot}$  is the average daily total radiation,  $H_{tot}$  is the average daily real heating load, and T.C. is the transmission coefficient, equal to .65 for angles of incidence ranging between 29 and 63 degrees (corresponding to the maximum solar altitude in December and in April, respectively).

The following table shows the glass area required in order to achieve 100 percent solar heating on every floor of the case study building throughout the heating season.







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