UNIVERSITY OF STRATHCLYDE

WINDOW OPTIMISATION FOR IRAQI HOUSES

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To my wife, Sabah Yehya Al-Mallah,

from whom I received so much encouragement.

The above design is composed of the following sentence, from the Holy Qur'an in Arabic script:

"Of knowledge it is only a little that is communicated to you. (O men!)"

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ABSTRACT

This work was carried out for latitude 33 deg. north longitude 45 deg. east (Baghdad region), but the procedure can be applied for any region in order to find optimum window sizes and proportions.

The study was concerned with the housing sector, and was chosen because most people are keen to search for lower energy expenditure in their own houses, but contribute little to energy efficiency in offices.

Although the study was for housing, it could be used to a limited extent to cover other types of building.

For this study a housing survey was carried out in Baghdad in a middle-income region. An estate model was designed, and experiments were carried out on the estate and on individual houses under an artificial sun to determine sun exposure times on the external walls for sixteen orientations. Small scale measurements were carried out for daylight under a Baghdad clear sky on a room model to be used in verifying the mathematical formulae and findings. A wind tunnel was used for natural ventilation and wind distribution studies.

For direct sunlight-control computer programs were written to compute room sun patch areas in summer and winter, sun patches

per unit window area and the yearly efficiency of seventy seven different windows for about two thousand cases of wall position, wall thickness, interhouse distance, wall orientation and obstruction height. The program produced the results in graphic and tabular forms.

For daylight, computer programs were written to compute the daylight level formed by forty four types of windows for one thousand two hundred and eighty cases of wall position, inter-house distance, wall orientation, and obstruction height, for two types of external wall reflection. Lighting level were computed at a fixed distance from the outer side of the fenestration.

Computed results were prepared in tabular form accompanied by British IES recommended daylight levels for various domestic activities in order to allow designers to make their own decisions on the degree to which they wished to fulfil the requirements.

For natural ventilation a limited number of windows was studied in the wind tunnel to generate a sample set of results on the effect of window dimensions on natural ventilation and wind distribution. The study was limited to forty four cases.

The results produced by the computer programs for direct sunlight control and daylight together with the experimental wind tunnel results were combined for optimization and selecting the best group of windows. Pareto optimisation techniques were used for selecting and recommending windows having the capability of providing good control of direct

sunlight, sufficient amount of daylighting, and the highest possible wind velocities for body cooling.
Although the study is incomplete in at least one aspect - the optimisation of natural ventilation for room and body cooling - it yields a significant set of results and demonstrate the potential of computation, experimental work and Pareto optimisation as a techniques which yield usable results.

The recommendations for the whole set of 1968 cases are presented in graphic and tabular forms in a way that gives a designer a clear picture of the capability of each of the recommended windows in fulfilling functional requirements.

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INTRODUCTION

INTRODUCTION

Through my work in the Iraqi Scientific Research Council in providing designers with useful information to help them to contribute in the programme of energy conservation, and through the negotiation with and visits to a large number of architects during the formation of research plans in the field of architecture during years '81-'85, it was found that designers were asking for work to be done on window dimensions for direct sunlight control, and natural lighting, and on the effect of window sizes and proportions for natural ventilation. They also sought optimum window sizes and proportions covering direct sunlight control, natural lighting, and natural ventilation.

Responding to these desires I took it as my job to provide answers to these questions, and to concentrate my efforts on trying to prepare useful data, in the expectation that I could produce something useful for designers and at the same time respond to the worldwide call for relying on natural and clean energy .

CHAPTER 1

C H A P T E R - 1 -

HOUSING AND HOUSE AND WINDOW DESIGN IN IRAQ

1.1 THE PAST

1.1.1 The founding of the cities

As the study is concerned with the city of Baghdad and the result generalized to cover most parts of Iraq, it has been decided to take Baghdad as the example especially since it is located almost in the centre of the urban area of Iraq. Baghdad was founded by the Kalief Abu Jafar Al-Mansour in 762 A.D. on the west side of the river Tigris [Ref.88] and its location was chosen after research was done to find the best fresh and unpolluted area near the river Tigris. It is said that the place was investigated by hanging several pieces of sheep's legs in different places in the area. The period of decomposition of these legs was watched and the result determined the place and the orientation of the Kalief's palace as well as of the city itself. Baghdad was constructed with a high level of defence in the form of walls and gates (see Figure 1.1). As is mentioned by Dr.Mustafa Jawad et.al. [Ref.88] the main roads were about 25m and the alleys about 8m. in width. The city was designed in a circular form by Abu Arttaa who was one of

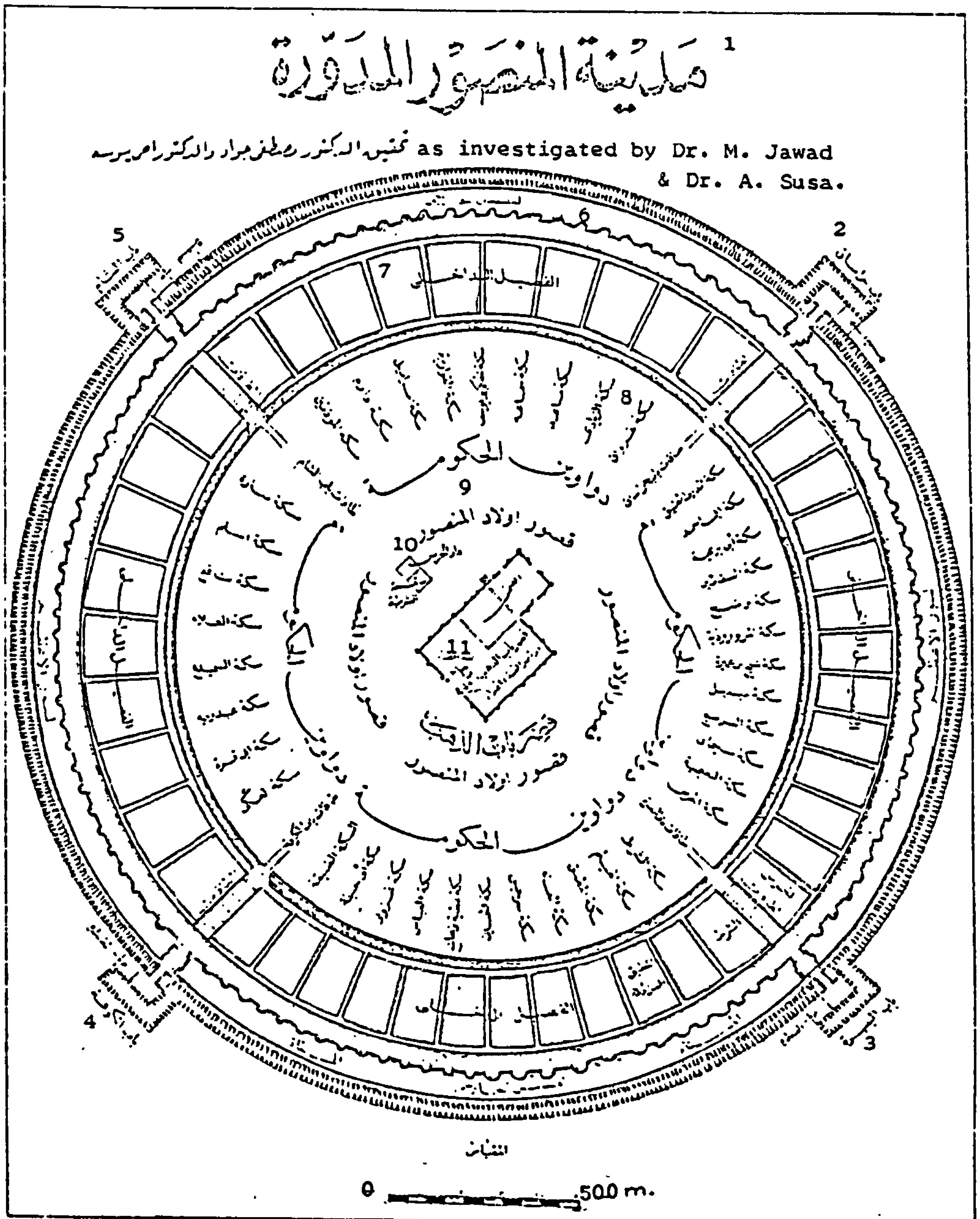


Figure 1.1 Baghdad as a circular fortified city.

No. 1 Circular Baghdad as investigated by Dr. M. Jawad & Dr. A. Susa.

No. 2 Kurassan Gate.

No. 3 Basrah Gate.

No. 4 Kufa Gate.

No. 5 Al-Sham Gate.

No. 6 The Walls of the City.

No. 7 The Estates.

No. 8 Alleyways.

No. 9 Government Administration Blocks.

No. 10 The Palaces of the Kalief's Sons.

No. 11 The Palace of the Kalief.

the most famous planners of the time, and some other engineers and builders.

Baghdad was expanded in 768 A.D. onto the left side of the river, though later Baghdad, like other cities, expanded more and more and many agricultural lands were divided and converted into residential areas by the agreement of the local Governor and sometimes even without the agreement of the higher authorities. It would seem that the city expanded in a way which, although it did not affect the inhabitants through the location of their houses or through the general expansion of the city, it did apparently change completely the original plan of Baghdad in that it no longer existed in the form of a circle nor is there now any indication of its original form. Although Professor Strange [Ref.88] has located the circular Baghdad on his map of present day Baghdad, the investigation of Dr. Susa shows that he is not correct and that the Circular Baghdad has to be located further north of the location given by him (see Figure 1.2).

1.1.1.1 Baghdad : The Old City

When one looks at an old Baghdad plan one can see that the lanes and alleys are mostly narrow (mainly between 1 to 4m wide), and winding in shape (see Figure 1.3). Many of these little lanes are cul-de-sacs, which run off the main thoroughfares.

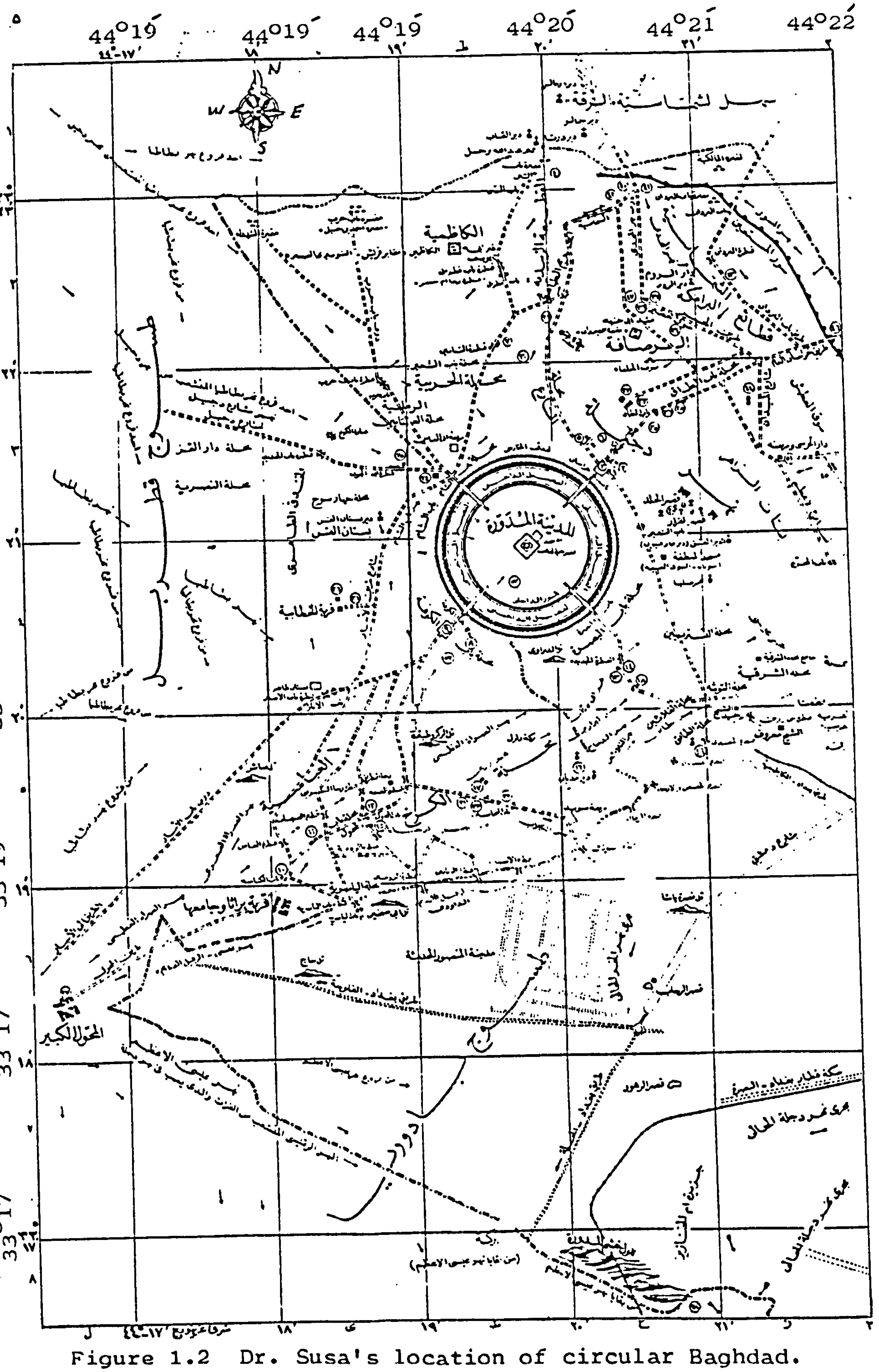


Figure 1.2 Dr. Susa's location of circular Baghdad.

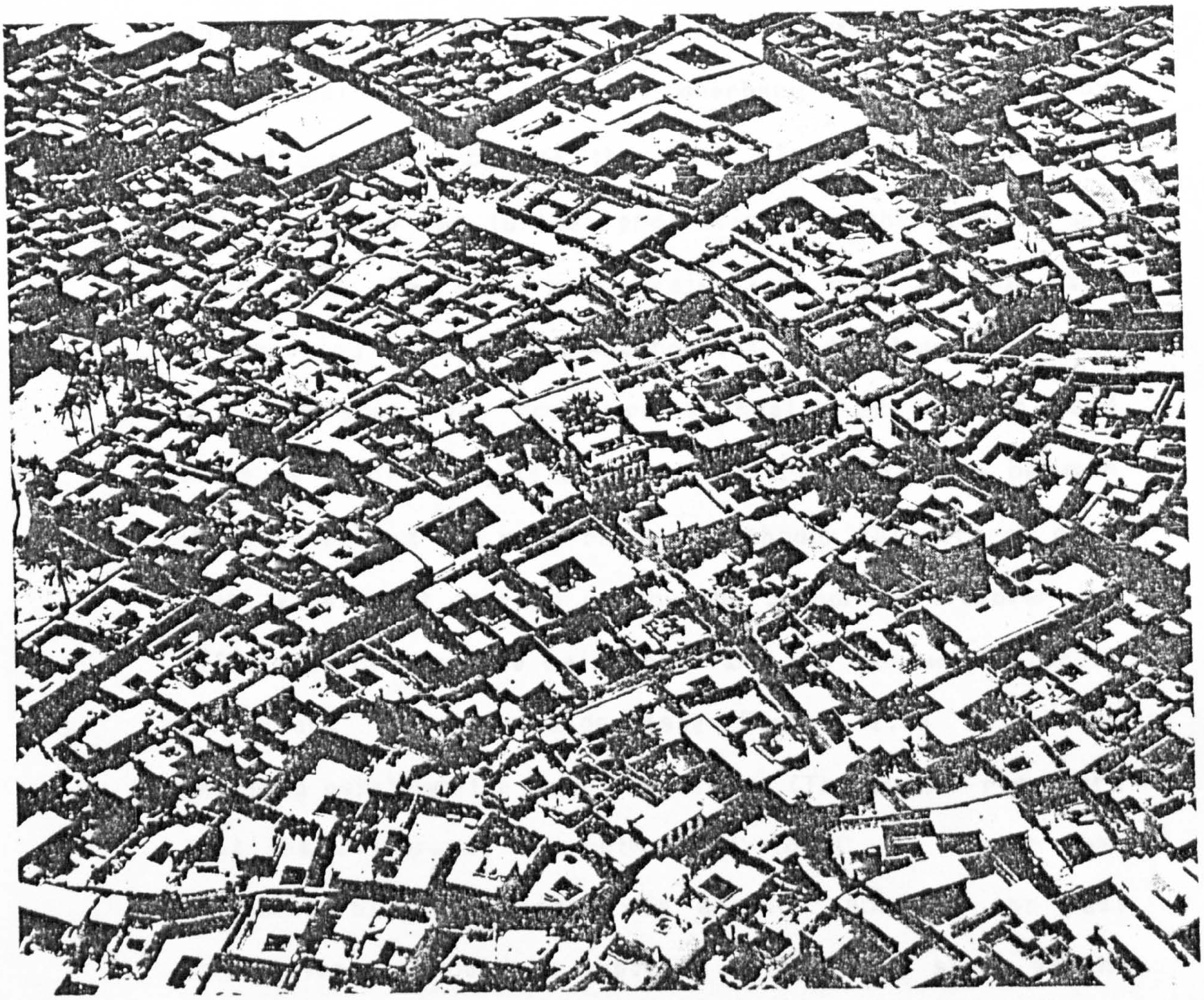


Figure 1.3   An ariel view of old Baghdad.

It was considered that the winding lanes were more secure from a defence point of view. Moreover these curves and bends increase the general shading of the lane, thus achieving a layer of cooler air at the lower level of the lanes. Most of the lanes are overhung to about 0.7m by projections from most of the first floors of the houses, not to mention the further projections by the roofs (see Figure 1.4). Therefore both projections play a major part in improving the internal environment of the houses on both sides. Moreover the courtyard is heated by the sun, and there is a quite significant temperature difference between these lanes and the main roads - although the records of a small experiment carried out by the author to discover the difference between the main roads and the narrow and curved lanes and the courtyards (see Figure 1.5) using the whirling psychrometer have been lost. (The author remembers that the difference was between 4°C to 5°C in summer when the meteorological record was around 45°C; in the past the difference would be expected to be more, since at the time when the author was carrying out the experiment, most of the houses were occupied by poor people who did not wash the lanes and keep them as clean as people used to do. When these houses were first built, each householder used to wash the front of his house daily in summer, which reduced the temperature of the lane further . As the lane was expected to supply the houses with cold air, the householders would leave their main doors and lower

Figure 1.4 Typical lane in Baghdad.

Figure 1.5 Measurements taken by the Author in a courtyard.

windows, which looked onto the lane, open at noon in order to obtain the benefit of the breeze and allow the cool air to enter the courtyards as a result of the 'stack' effect.

1.1.2 Types of Houses

Now, if one looks at any of the areas in old Baghdad one will see that, the traditional courtyard houses are the only type that exist there and they vary, from luxury to simple types. Moreover when one considers them more closely, one can see a distinct likeness between some of them and the houses found in Ur in the south of Iraq, which which built during the period 2025-1763B.C.[Ref. 54].In other words the plan form is very ancient.
Small courtyard houses are mainly built on plots between 40-100m2 whereas the larger houses are built on plots of an area greater than 150m2

1.1.2.1 High Income Houses (The Typical Baghdady Houses)

Most of the high income houses are built on plots of over 150m2 in size, and usually consist of two stories. The rooms are generally built around three sides of the courtyard. This type of house has a verandah running around the courtyard, contributing to the shading of the courtyard, decorating the house and protecting walls and windows from winter rain (see Figure 1.6). The house usually consists of two reception rooms, one for males and one for females, several bedrooms, a large kitchen, toilets

Figure 1.6 Courtyard Verandah.

and bathrooms. The courtyard is paved with light yellow brick tiles, and as no waterproof substances are used under the brick, the heat created by the sun patches formed in the courtyard is either absorbed by the ground or causes evaporation through the bricks which are always wet either from the earth underneath or from the daily washing of the courtyard. These houses usually have basements, one or more terraces, galleries (see Figure 1.7) and a small garden (see Figure 1.8). Wind catchers are one of the dominant characteristics of the Baghdady courtyard houses. Wind catchers (as seen in Figures 1.9 and 1.10) trap the prevailing wind coming over the roof and push it down through a vertical tunnel (see Figure 1.11), so that the air is cooled by the time it reaches the lowest part of the house. This type of wind catcher works on three principles. First, the wind pressure forces the air downwards. Second, the cool room air moves to the warm courtyard and rises, thus creating a downward air movement from the wind catcher. Third, the presence of moisture in the walls and floors causes evaporative cooling (see Figure 1.12). If waterproofing materials are used to stop ground water from moistening the walls and floor neither the wind catcher nor the Baghdady courtyard house would function.

In the courtyard house one can also find many architectural treatments for climatic adaptation and energy conservation. Roofs, for example, are cavity constructions made of large tree trunks, covered from inside with wood or

Figure 1.7   Courtyard Gallery.

Figure 1.8 Courtyard Garden.

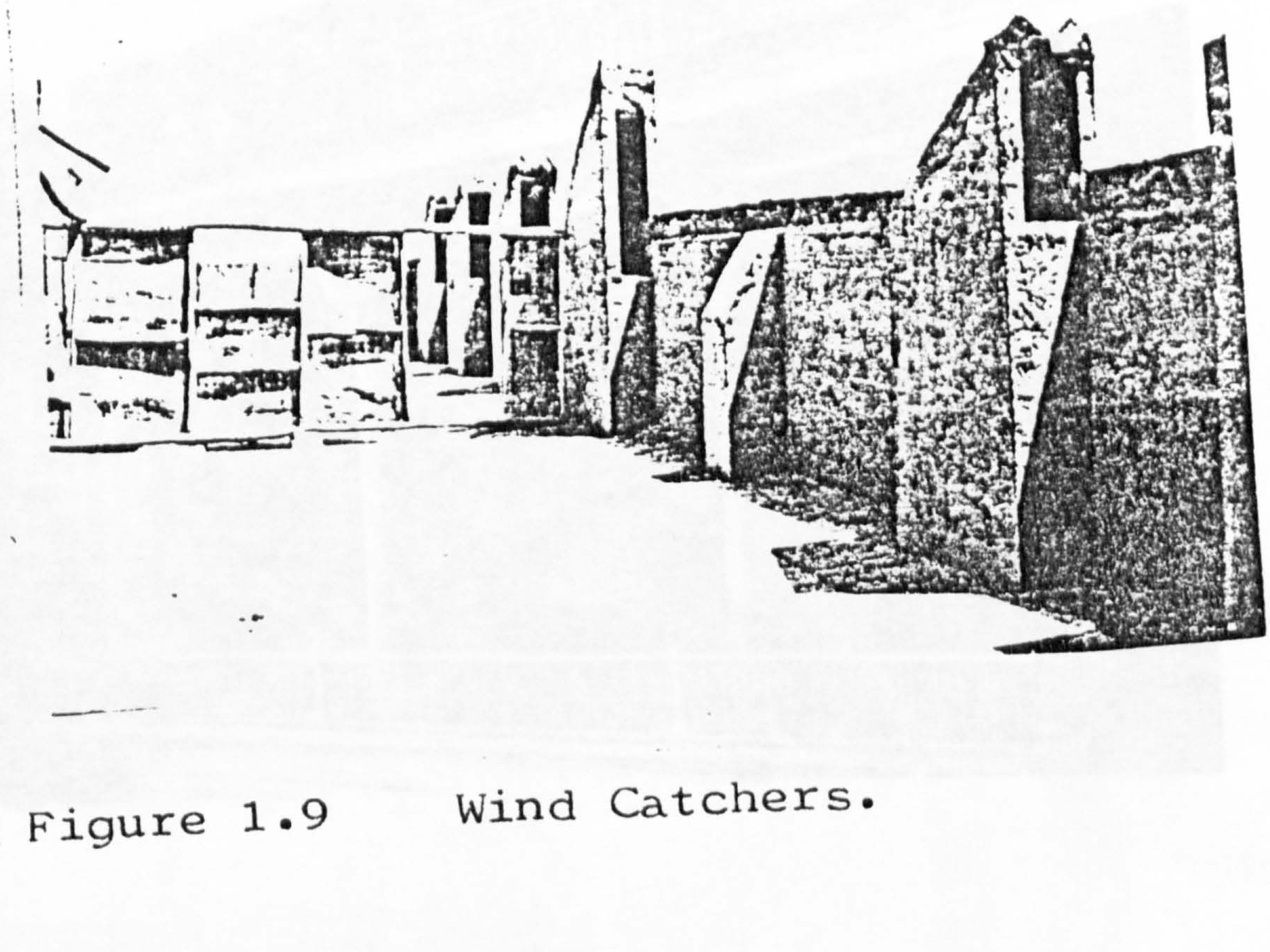


Figure 1.9 Wind Catchers.

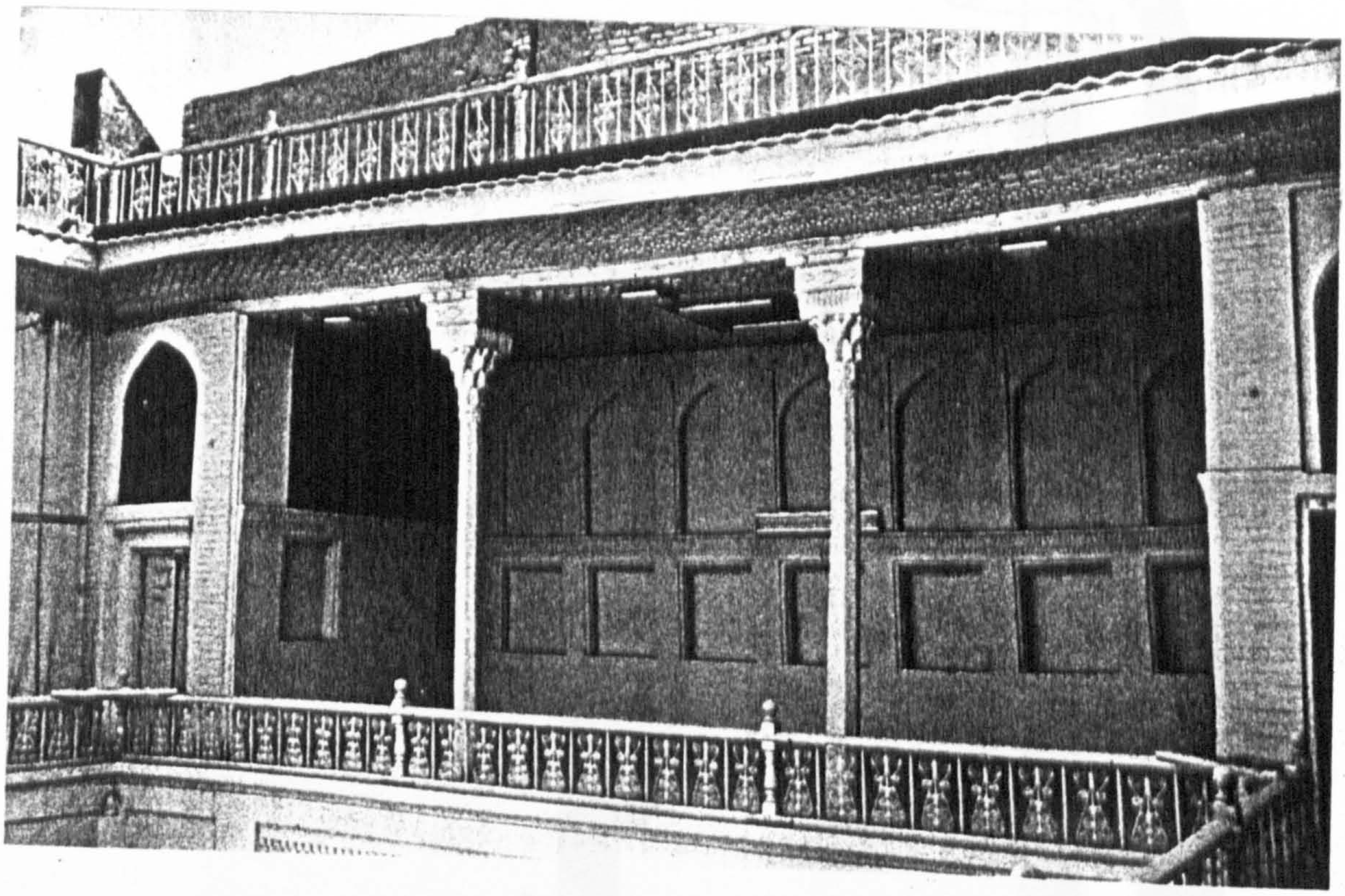


Figure 1.10 Wind Catchers.

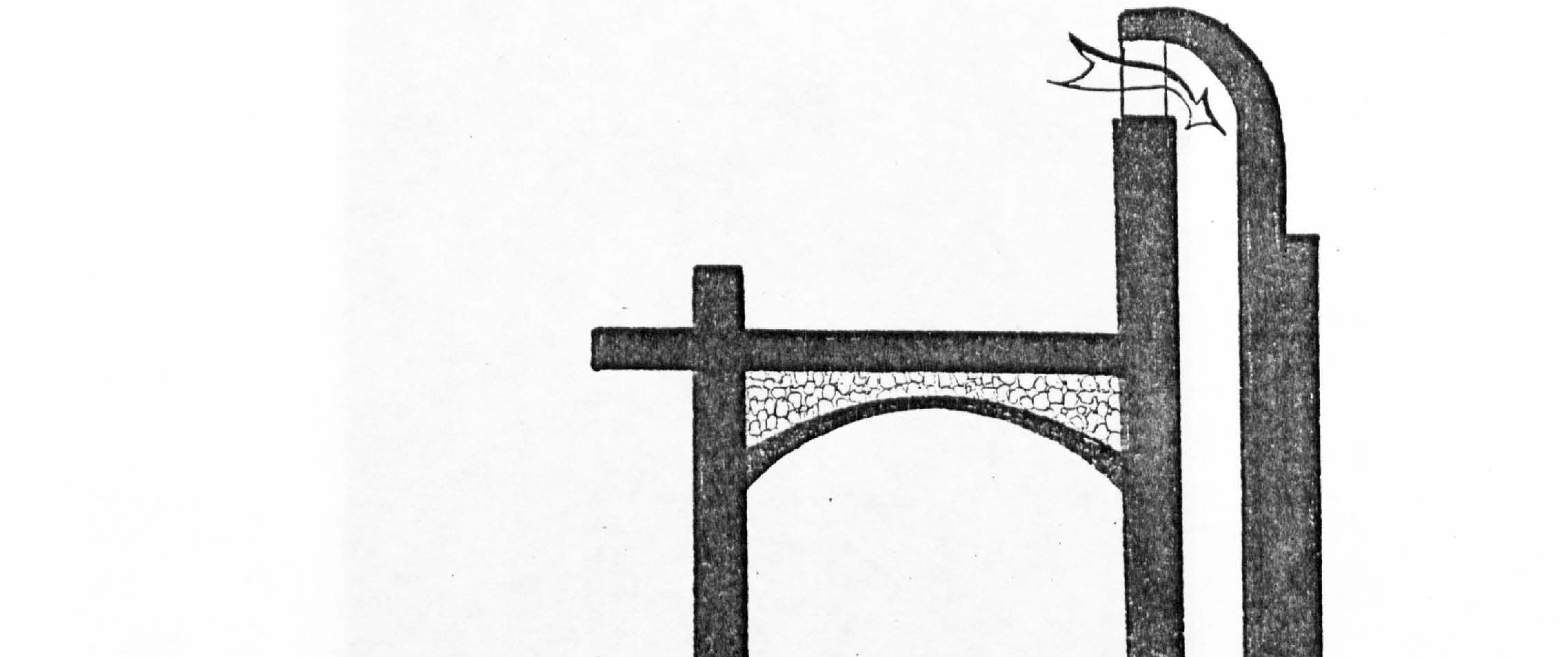


Figure 1.11 Wind Catchers.

Figure 1.12 Efflorescent salts deposited by moisture evaporation on brick walls and vaults.

metal sheets and from outside with reed carpets paved with mud and brick tiles (see Figure 1.13); the total roof thickness is about 500mm . The first floor wall is usually constructed of a timber framework, (see Figure 1.14) to reduce the load on the foundation and to give good thermal insulation in winter, as well as to help project the wooden-walled trellises (see Figure 1.15), in order to increase the first floor area, to shade the alley from the summer sun and to protect any pedestrians, as well as the windows and walls at ground floor level from the winter rain.

Windows on most of the first floors and some of those on the ground floors are designed to be multifunctional to control direct sunlight, provide the room with suitable daylight and natural ventilation and to maintain a high level of privacy (see 1.1.3 for details). In some houses natural lighting is increased by using mirrors on the roof to maintain the lighting levels inside the rooms (see Figures 1.16 and 1.17).

Decorative mirror panels were used in some houses to increase the lighting levels on the opposite walls or galleries located in the shade (see Figure 1.18).

In summer some householders cover the courtyard with heavy and light coloured hangings to prevent excessive direct sunlight penetration, especially in large courtyards such as those used as an assembly area for daily visitors (see Figures 1.19 and 1.20) .

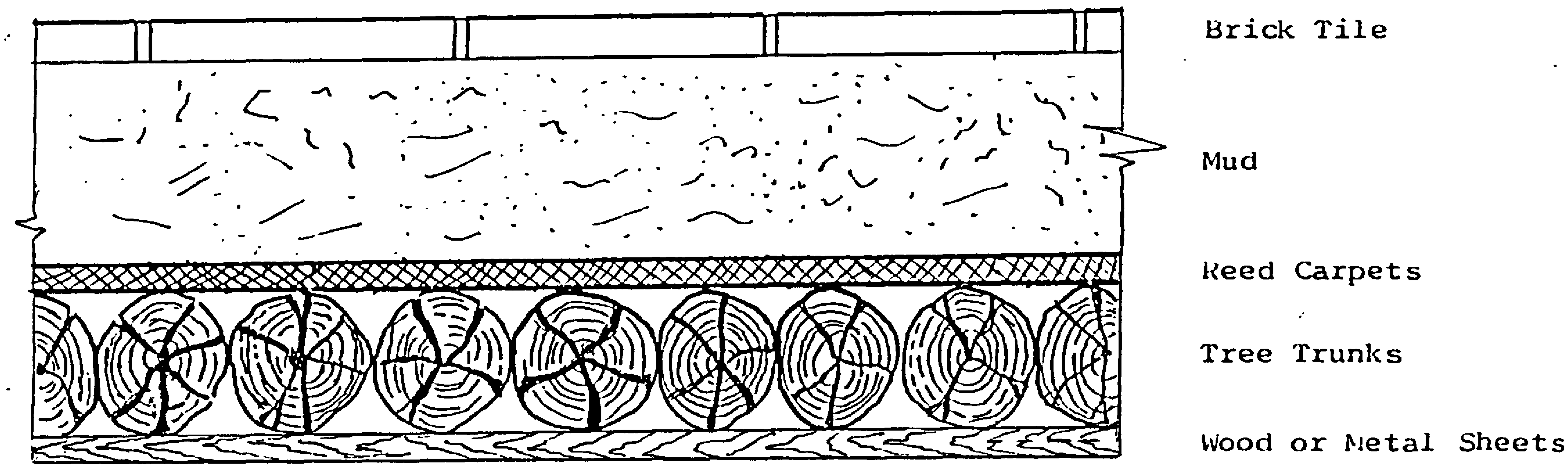


Figure 1.13 Section through roof.

Figure 1.14   Timber first floor wall.

Figure 1.15 Timber Trellis.

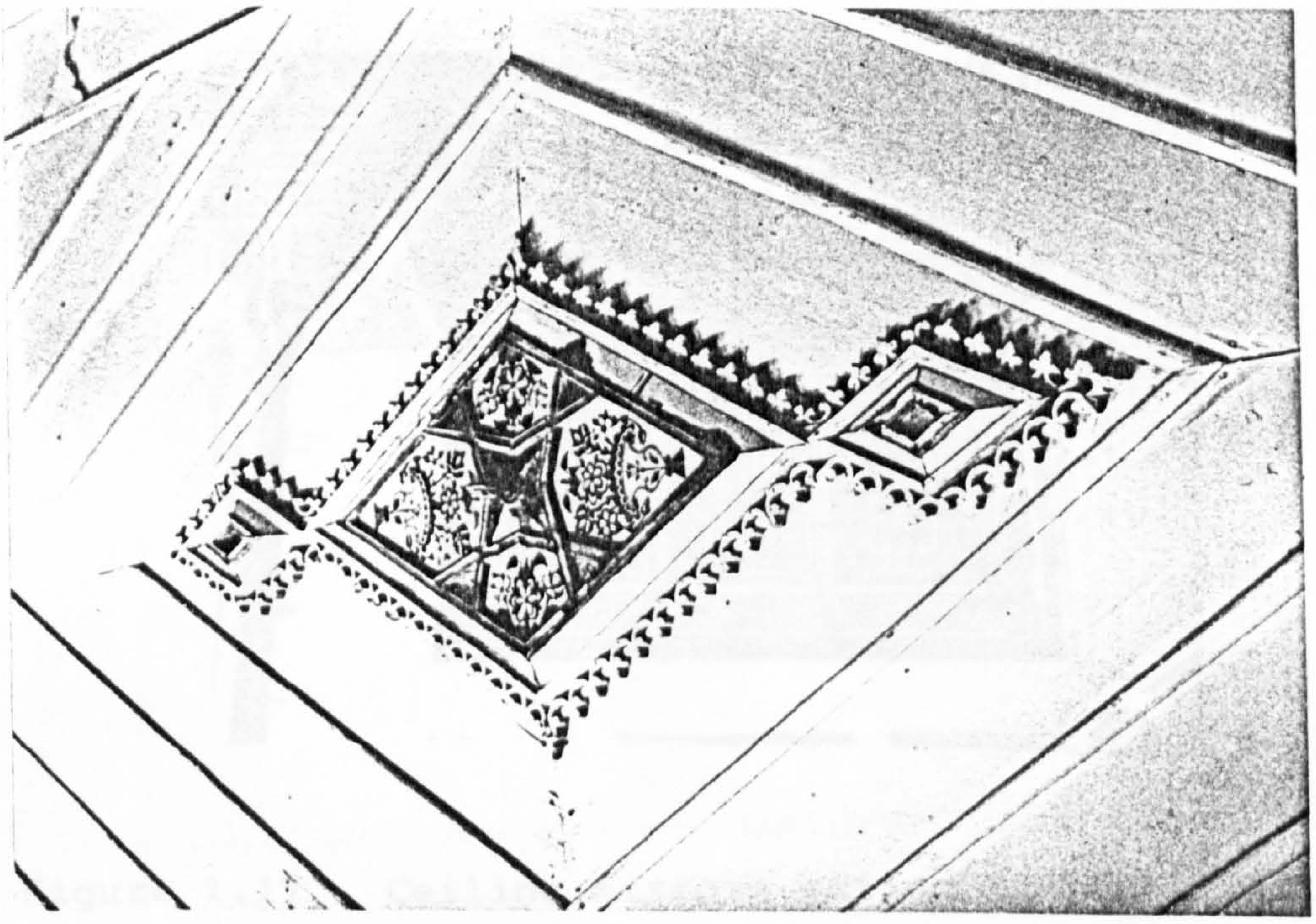


Figure 1.16   Ceiling mirrors acting as light reflectors.

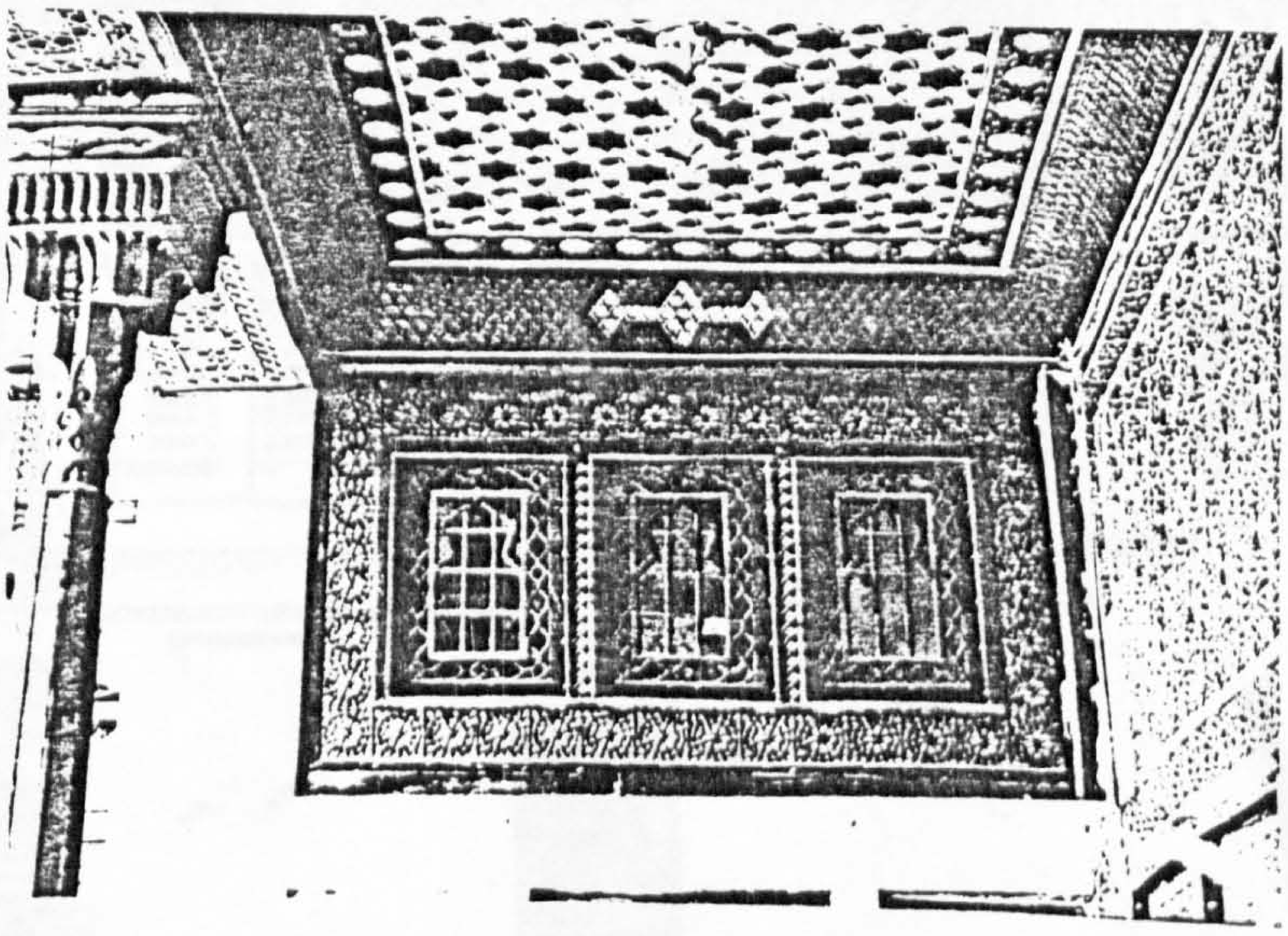


Figure 1.17 Ceiling mirrors acting as light reflectors.

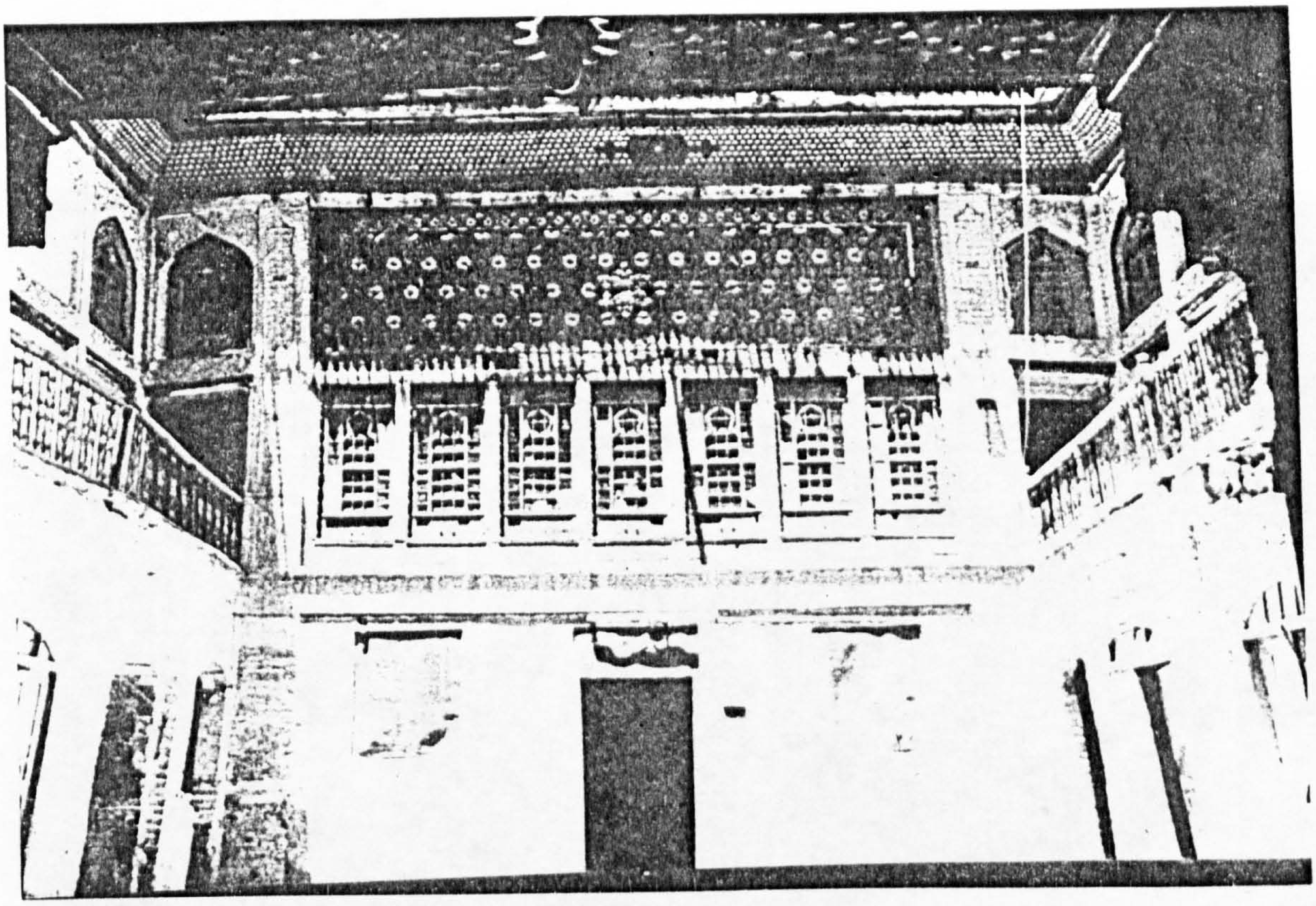


Figure 1.18 Wall mirrors acting as light reflectors.

Figure 1.19 Fabric shading devices.

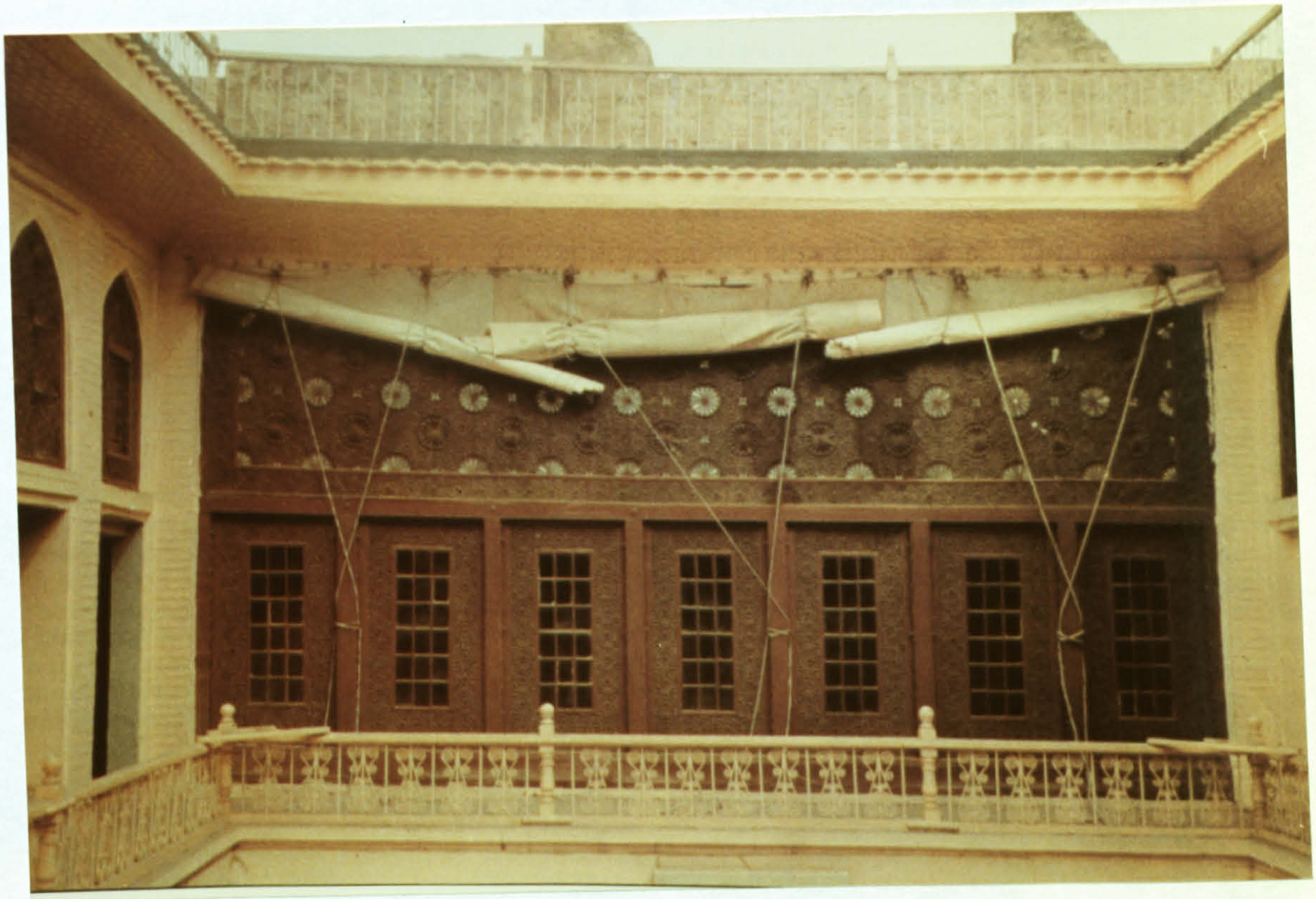


Figure 1.20 Fabric shading devices.

1.1.2.2 Middle Income Houses

In this category houses are built on land between 100 to 150m2 and each house has several rooms, a kitchen, toilets and a small bathroom. Such houses have wooden facades for use especially on the first floor (see Figure 1.21). The walls of ground floors are usually made of bricks with ordinary or simple multifunctional windows .

A basement might exist but with most of these houses the basement often becomes damp because of the ineffective treatments used to stop underground water. Very often therefore most of the basements were filled with broken bricks and earth and closed up completely. Wind catchers also exist in these houses which can be considered as typical Baghdady houses since they possess most of the climatic, social and security needs required by their occupants.

1.1.2.3 Low Income Houses

Houses in this category (the 40-100m2) tend to be very simple in style with one to three rooms and a small courtyard and no friezes, wooden facades or multifunctional windows. The thermal environment cannot be controlled adequately in such types of houses and the only benefit of the design is the reduction of exposed walls (see Figure 1.22).

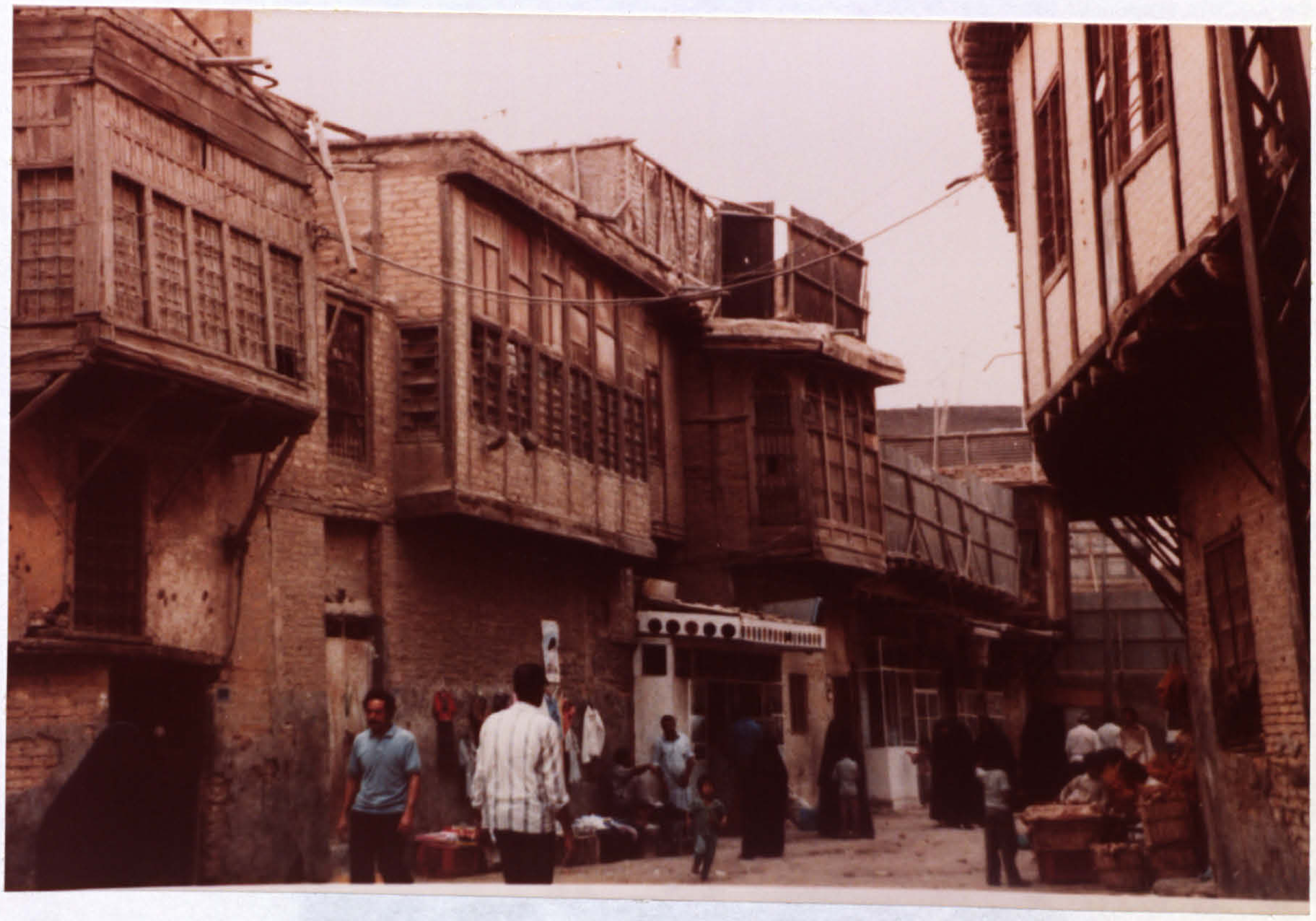


Figure 1.21   First floor wooden facades.

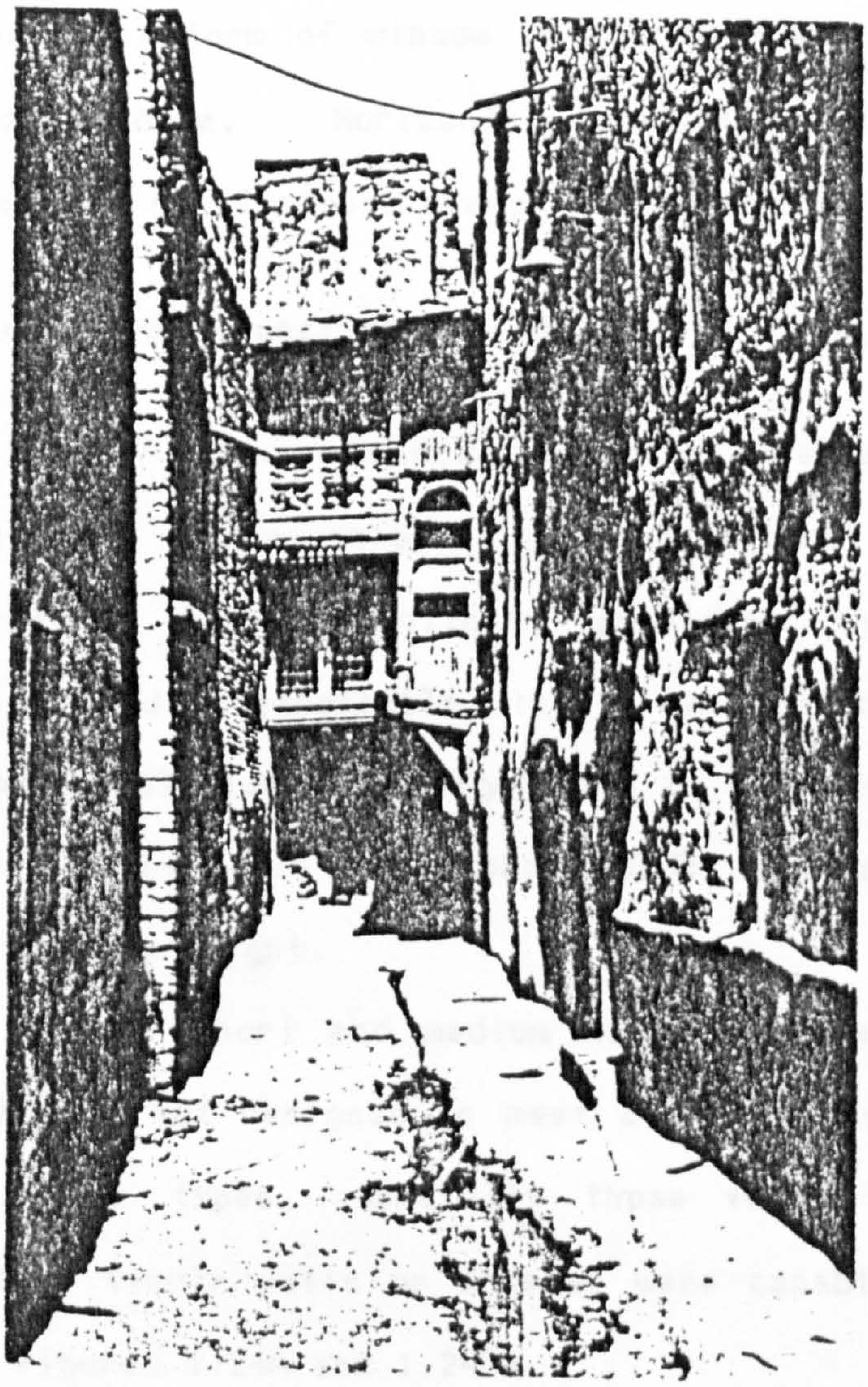


Figure 1.22

1.1.3 Window Types

The traditional design of windows varied from the very simple type mainly for ventilation purposes to the complex multifunctional type .

The vertical form of window is the dominant shape in the Baghdady house. Horizontal, circular, and hexagonal windows are rarely found except in the form of ventilators.

1.1.3.2 The Luxury Multifunctional Window

This type of window was designed to be capable of providing rooms with an acceptable level of natural ventilation, controlling direct sunlight, providing the room with varying and controllable levels of natural lighting, thermal insulation and a high level of privacy.

Usually it is of an arched shape, 0.5m to 1.0m in width and 1.0m to 2.5m height.

Most of the short and medium height windows (see Figure 1.23) were not designed to meet all these functions, only the taller types, especially those found as a part of complete timber walls or oriels, were capable of doing so (see Figures 1.24A and 1.24B).

The multifunctional window consists of three parts (see Figure 1.25):

A - The lower part of the window consists of a hollow space covered from the outside with a wooden panel and from the inside with either a timber shutter or brick wall. This

Figure 1.23 Short Windows.

Figure 1.24a

Sketch of the multifunctional bay window.

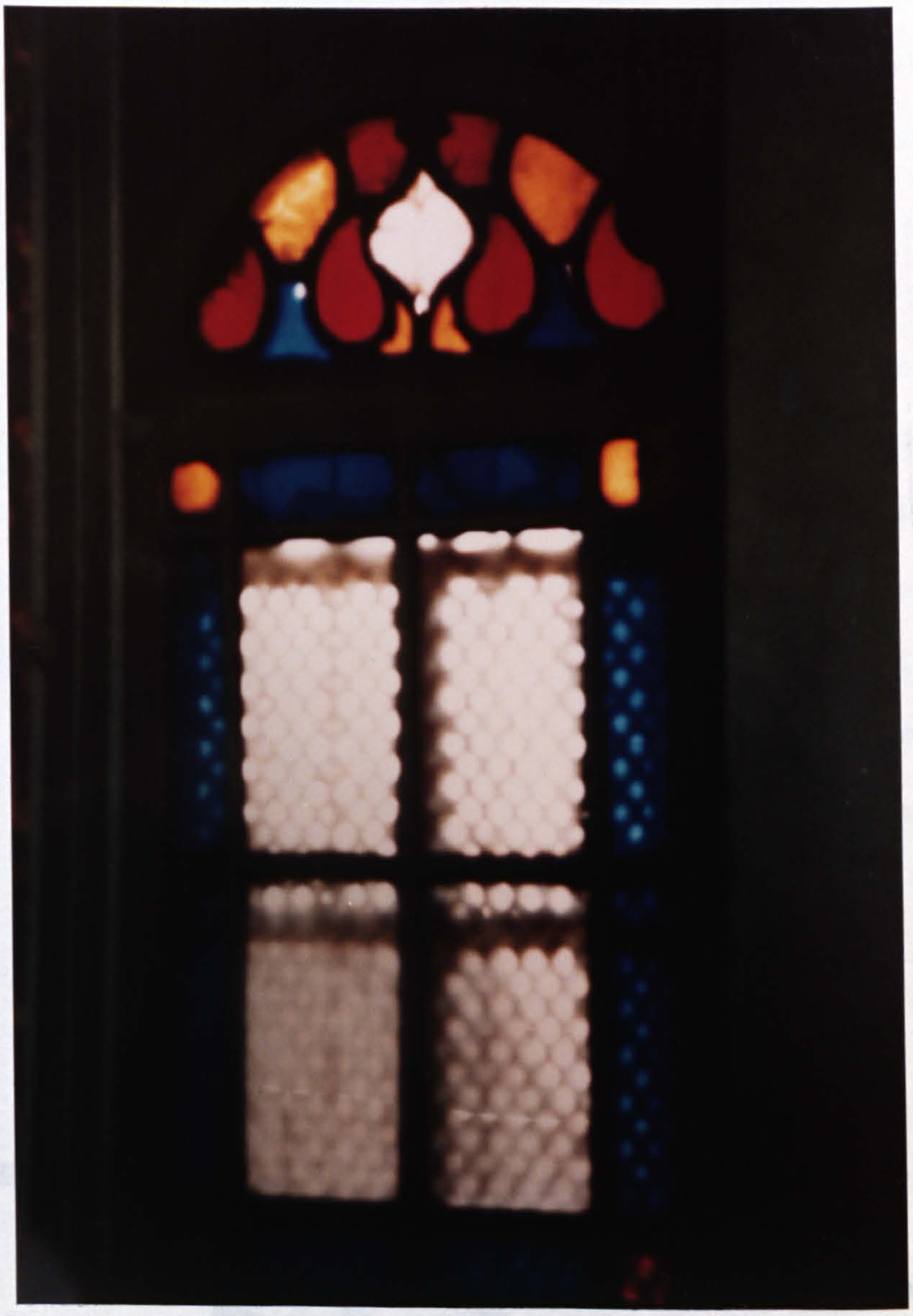


Figure 1.24b   Tall Windows

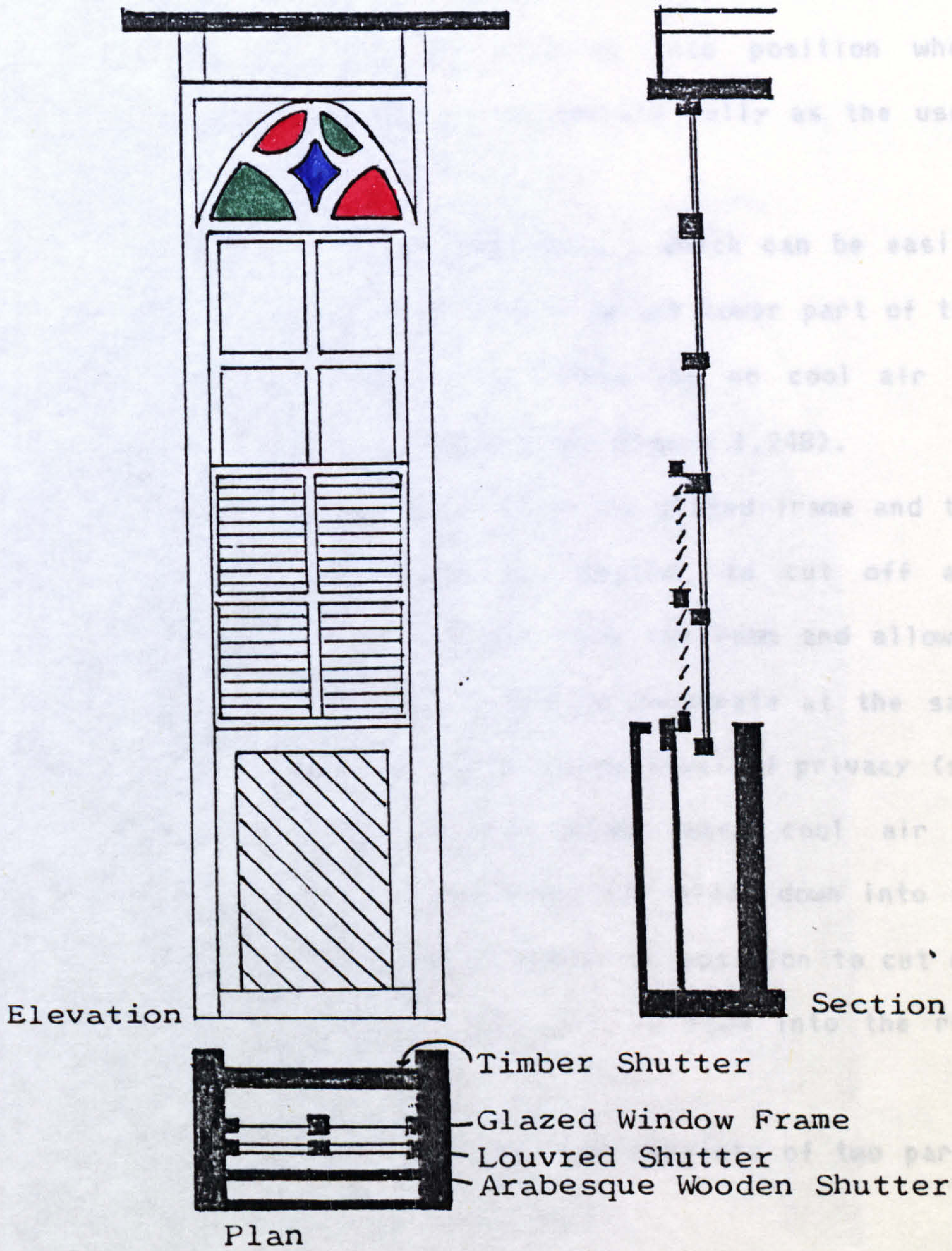


Figure 1.25 shows the structure of the multifunctional window.

space is designed to store glazed window frames, wooden shutters and a louvered or arabesque wooden shutter. Each of these shutters can be slid up into position when required, either half-way or to operate fully as the user desires.

B - The middle part is an open area , which can be easily glazed by sliding a glazed frame from the lower part of the window up when insolation is needed and no cool air is required to flow into the room (see Figure 1.24B).

In summer the glazed frame or both the glazed frame and the louvered shutter can slide up together to cut off any direct sunlight,exclude hot air from the room and allow a certain amount of diffused light to penetrate at the same time providing the room with a high level of privacy (see Figure 1.24). In spring and autumn when cool air is preferred, the glazed window frame can slide down into the cavity, Keeping the louvered shutter in position to cut out direct sunlight and allow cool air to flow into the room (see Figure 1.26).

C - The upper section of the window consists of two parts, the arched part and the oblong part.

The oblong part is a colourless , glazed area which receives direct sunlight in winter because of the low sun angles during that season and is almost shaded in summer either by the frieze, verandah or trellises .

The arched part is usually glazed with coloured glass. Since this part is very near to the ceiling, it is usually shaded in summer, and this allows diffused light to

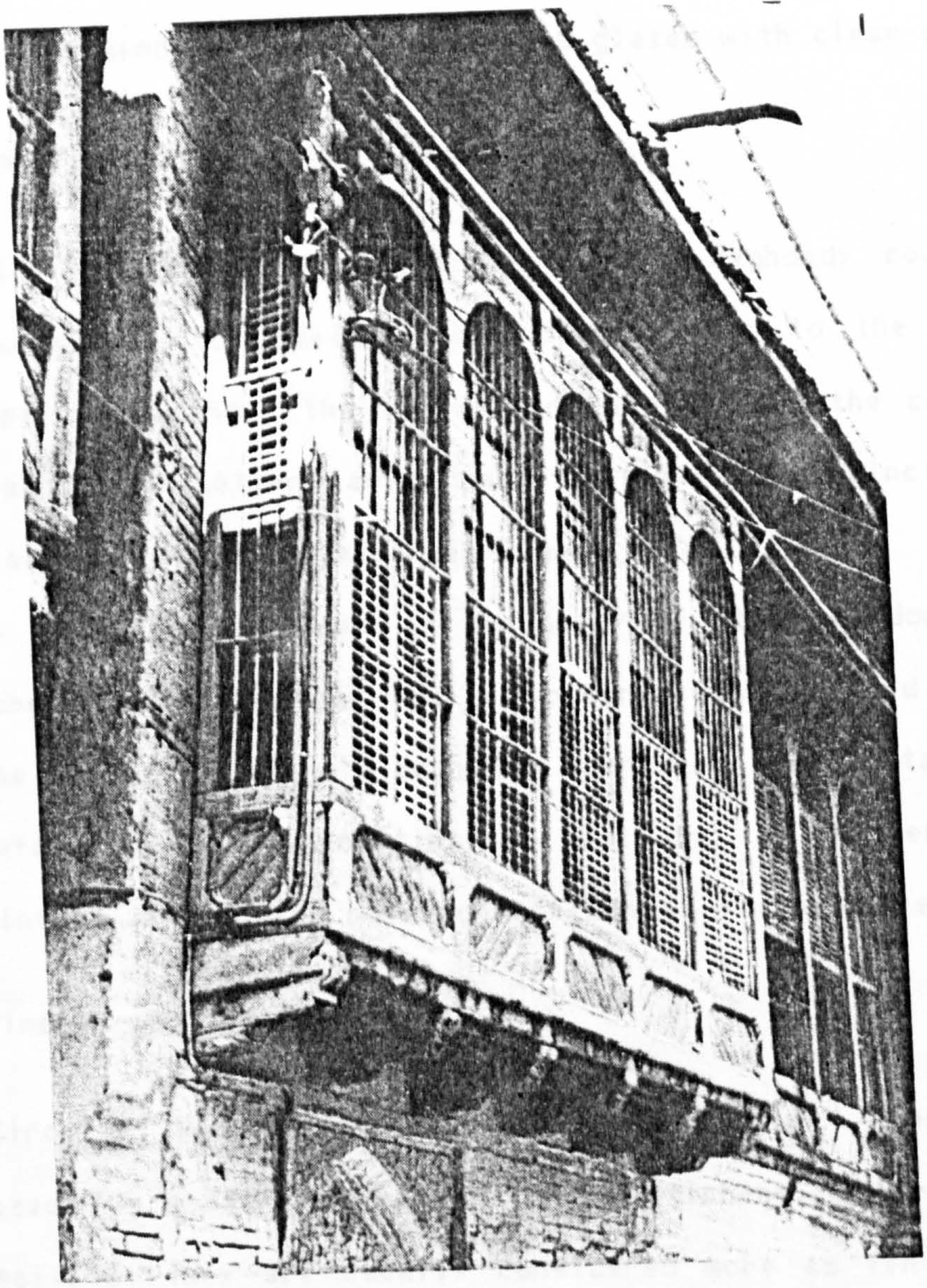


Figure 1.26 Window Louvre.

penetrate and relieve the dark when the wooden shutters block the clear glass areas, as well as providing the house with a pleasent decorative feature.

In some windows the arched part is glazed with clear glass.

1.1.3.2 Simple Multifunctional Windows

This type of window is widely used in Baghdady courtyard houses and it sometimes has similarities to the arched type, but without the arched part and without the coloured glass. The shutter cavity part is similar in principle to that of the arched type (see Figure 1.26).

As has been mentioned the majority of these windows, are longitudinal. Moreover during observations carried out by the author in the old Baghdady courtyard areas established before the implimentation of the the (I) steel beam lintols in building no large horizontal windows were found.

1.1.3.1 Windows for ventilation

Circular, hexagonal and sometimes horizontal windows are used for ventilation and lighting kitchens, bathrooms and toilets; they are usually considered more as fenestration rather than as windows because most of them are not even glazed and those that are glazed are not designed to open . Circular and hexagonal unglazed windows are often used over the main door of the houses to allow the breeze and cold wind to move in summer from the alleyway into the courtyard when the main door of the house is closed .

1.2 THE PRESENT

1.2.1 The Establishment of Cities and Estates

In modern Iraq, cities and estates developed under a state law and any expansion or change which requires any land from agricultural areas being used for residential purposes has to be acquired under an explicit law and certain regulations have to be obeyed .

1.2.1.1 Baghdad City Plan and Plot Sizes

After the first World War, the invasion of Iraq and the import of cars in to Baghdad resulted in an expansion different from any carried out before. The land distributed to the middle income group was in plots greater than 200m2, narrow alleys disappeared in the new areas and were replaced with wider roads. This first happened under the British Governor and the pattern was followed by Iraqi and other foreign experts. Todays the master plan for Greater Baghdad is carried out by the Municipality of Baghdad and a Japanese consulting firm.

From the 'fifties to the 'seventies the Government distributed residential land in plots mainly between 300m2 to 800m2. During the last ten years however the Government decided not to distribute any plots of greater than 400m2. The Government policy of reducing plots was the result of the rapid and extensive horizontal expansion of Baghdad, since it was known that Iraqi people do not like living in flats (see Figure 3.29).

1.2.1.2 Factors Affecting Road Widths

One of the most important factors in modern society is the presence of the motor car which affected urban planning in hot tropical countries as it did in cold European ones. It is difficult in modern cities to continue to use curved and narrow lanes and alleys in the same way as was the case in the old cities, because the minimum width required for cars and the need for pedestrian walkways. Therefore the minimum road width is now be defined as that required for safe and efficient driving and for pedestrians safety. Following these changes, people have to accept change, live with the new types of road, search for suitable landscape and architectural treatments and adapt to life in a modern, car-using society.

1.2.1.3 The Breakaway from the Traditional Courtyard House

The effect of road widths and the import of modern building materials, the influence of modern architecture and the desire for change had a significant influence on the people of Baghdad. Many enjoyed being "modernized", desired to own cars and built houses which had a shelter for their vehicles. All these factors, along with tradition related culture and religion, were reflected in the new designs, which however for the most part, retained some of the older principles in the design of the <u>interior</u> layout but with some modifications .

Most of these houses were constructed in the south of the old city (Battawiyien and Al-Sadoon place), in the north of Baghdad in Adhamiyah place and in the west of Baghdad in Al-Salihiyah (see Figure 1.27).

This type of house is a new version of the traditional courtyard house, in which the courtyard has been replaced with a covered central hall, mainly used as a living area as well as the main circulation area for all the rooms located around it. An open area similar to the courtyard is found at the back, where the kitchen and servants quarters are located. This space in some houses is a garden surrounded with high walls or servants' accommodation. Roofs were built with jack arching techniques to allow a brick balcony wall to be constructed (see Figure 1.28). This type was considered as the first departure from the traditional courtyard house. However when detached houses were constructed, although basements were often still included, wind-catchers disappeared completely.

When this type of house first appeared it was owned by high income groups. Now these houses are under multihousehold occupation by low income groups. The original householders, who built the detached houses in the new suburbs of Baghdad have either sold or rented the houses, while others have

Figure 1.27   Non-traditional home in Al-Salihiyah

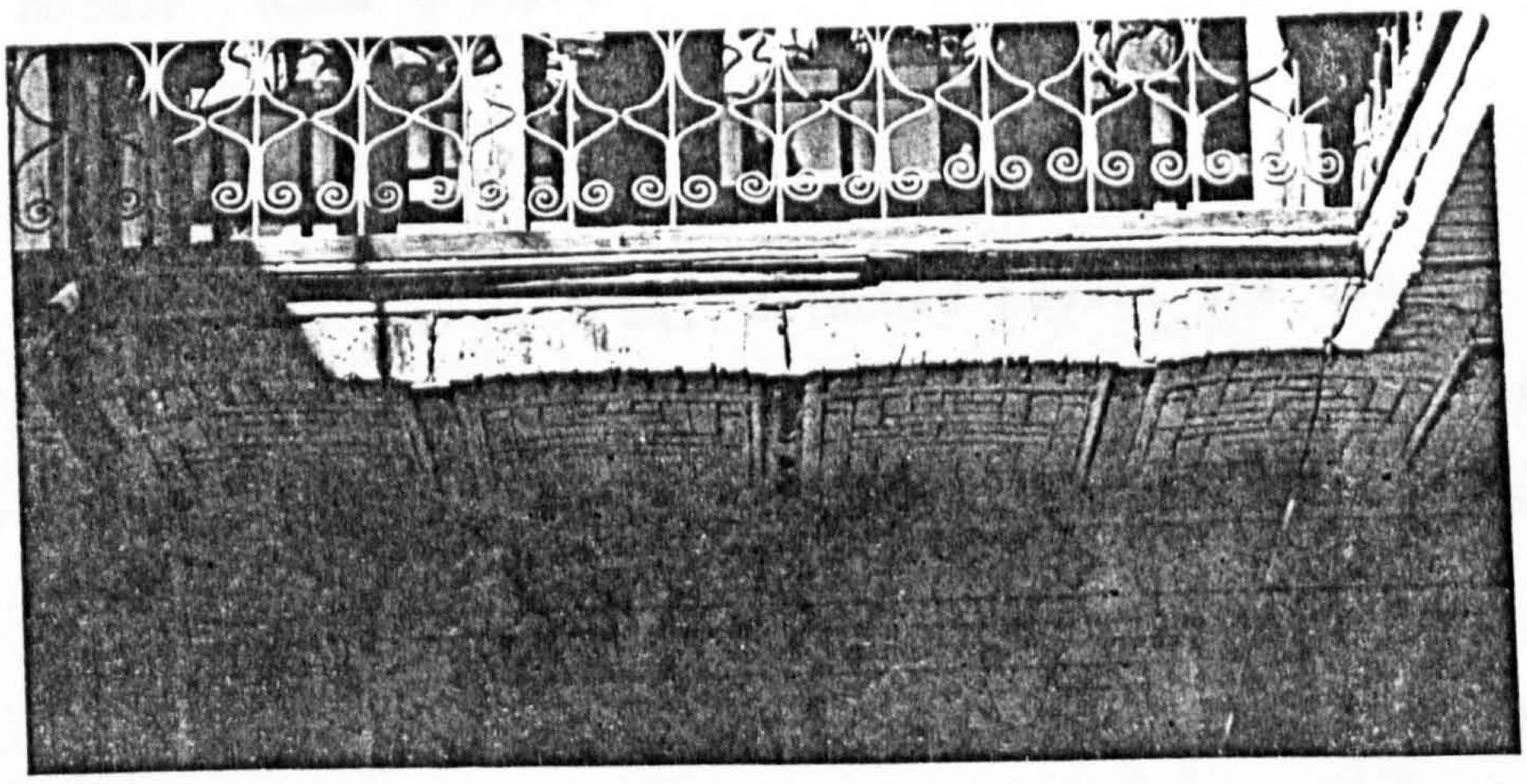


Figure 1.28

been converted into printing presses or small factories for light industry .

1.2.2 Actual and Most Common House Types in Urban Area

Apart from the courtyard houses found in the low income areas, semi-detached and detached houses are the most common types in the areas occupied by the middle and upper middle income groups.

1.2.2.1 Detached Houses

In urban areas in Iraq, detached houses are usually built on plot areas larger than 400m2, and it was found from the large number of plans collected by the author [Ref.15] from the municipal offices and other sources that people with 600m2 plot areas cover an average built ground area of 170m2 and those having 500m2 plot areas cover an average built ground area of 164m2, the rest being left as garden, walkways and garage. This gives a clear indication that the ratio of built:unbuilt area is about 1:3.

The Iraqi building regulations and some municipal rules allowed builders in these areas to have one side of the house built on one edge of the plot, two sides to be at least one metre distant from the edge of the plot and the facade had to be at least four meters in from the front edge (see figure 1.29).

Most people do not attach their houses to their neighbour's, although they know that the regulations would

Figure 1.29

allow them to do so. In some places one also finds that, although the houses are detached, people sometimes form a direct attachment by linking kitchens and garages across the two adjacent plots, which is not considered as affecting the "detached" status of the two houses.

Figure 1.30 show some shapes and layouts representing the built area in proportion to the total plot area and block plans of different types of houses on the plot and the types of attachment and detachment usually found.

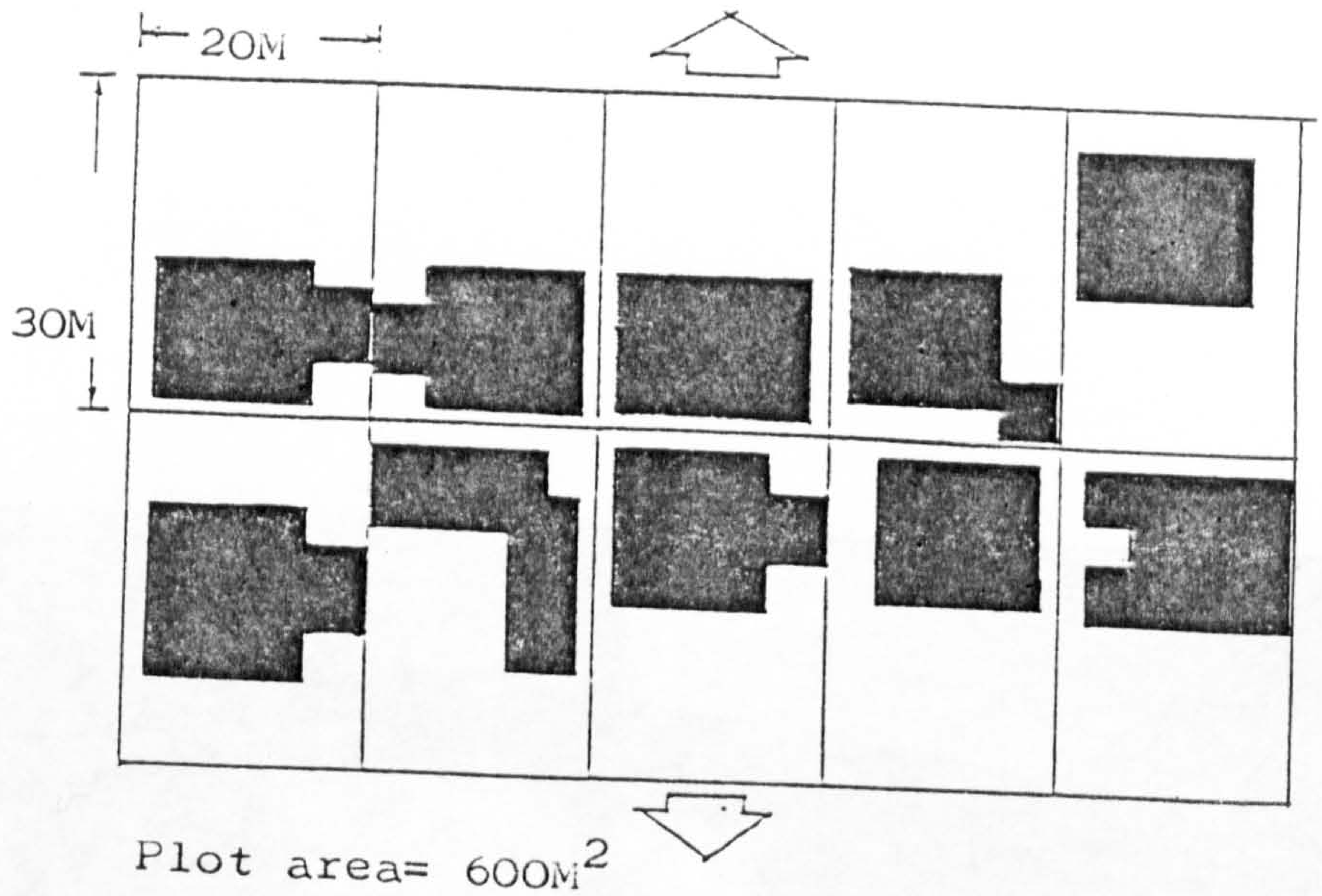
1.2.2.2 Semi-detached Houses

These houses are usually found in the middle and lower middle income categories, and the plot sizes vary between 200m2 to 400m2.

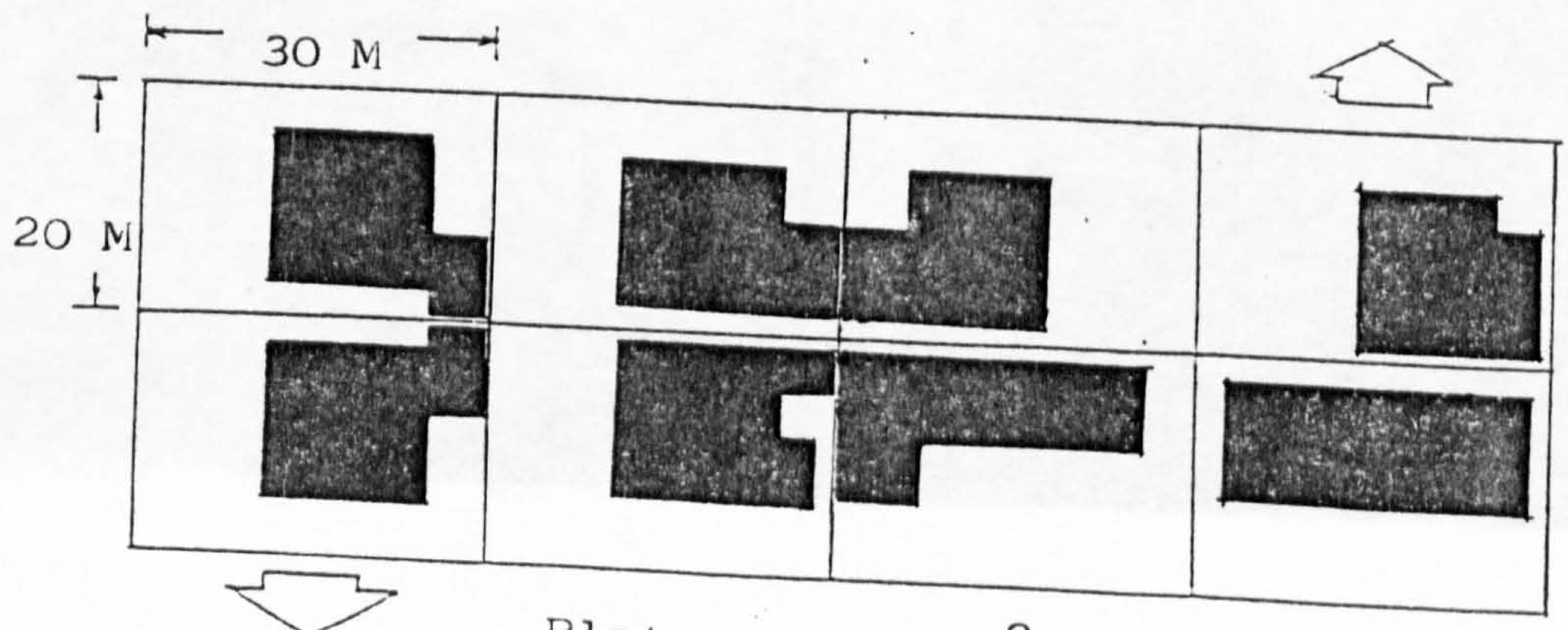
In such areas it is usual for one or two rooms of the houses to be attached to the neighbour's walls, leaving at least one metre from the back boundary as a walkway and four metres from the front as a garden (see Figure 1.31) .

1.2.2.3 Terraced Houses

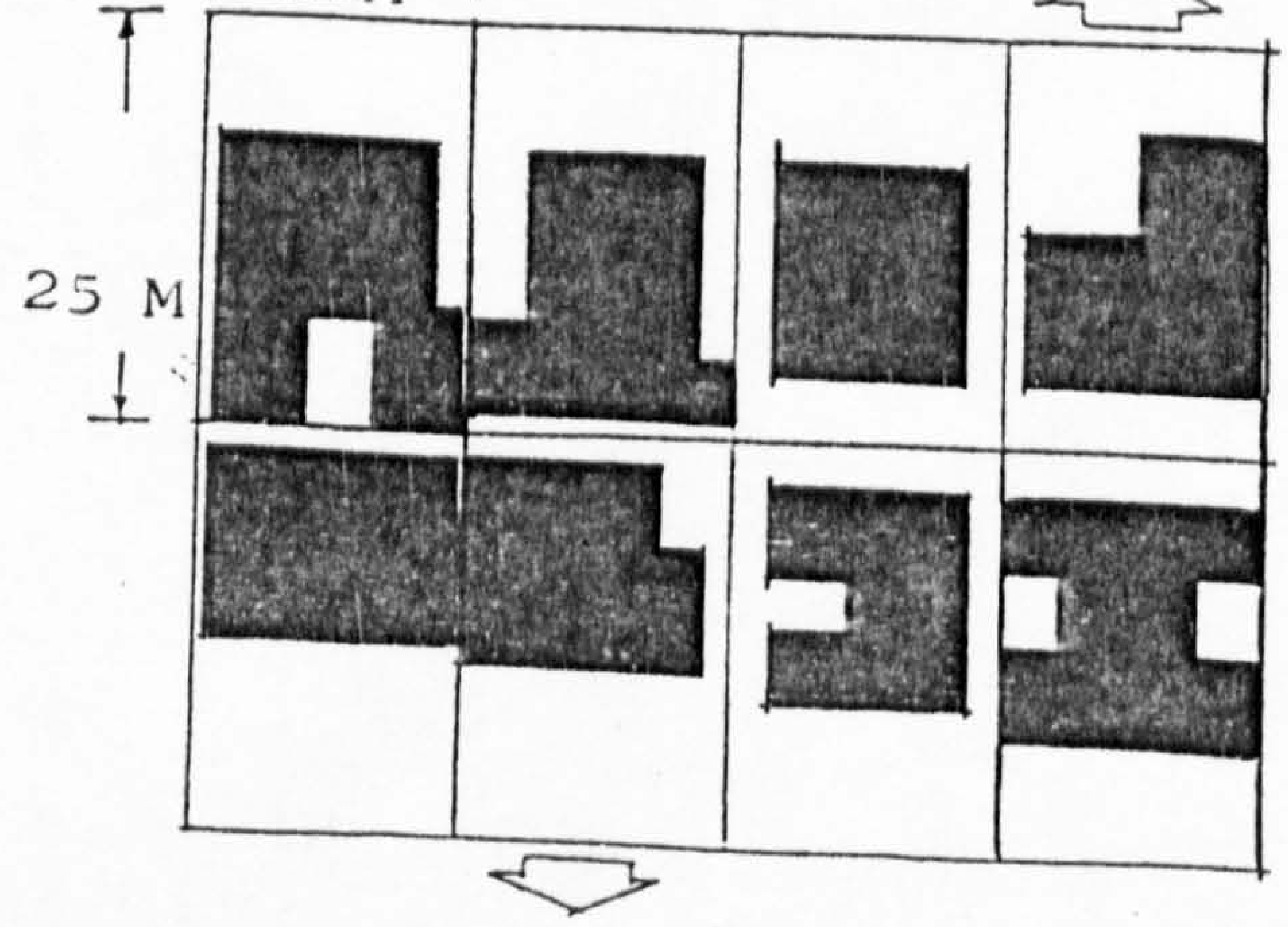
This type of house is normally found in the low income areas (see Figure 1.32), where plot areas are between 120m2 and 200m2. In such places most houses are attached on two or three sides leaving a small area in one or two places near the side or the middle for ventilation, lighting and



Plot area= $600M^2$



Plot area= $600M^2$



Plot area $400M^2$

Figure 1.30

Figure 1.31   4m front set-back.

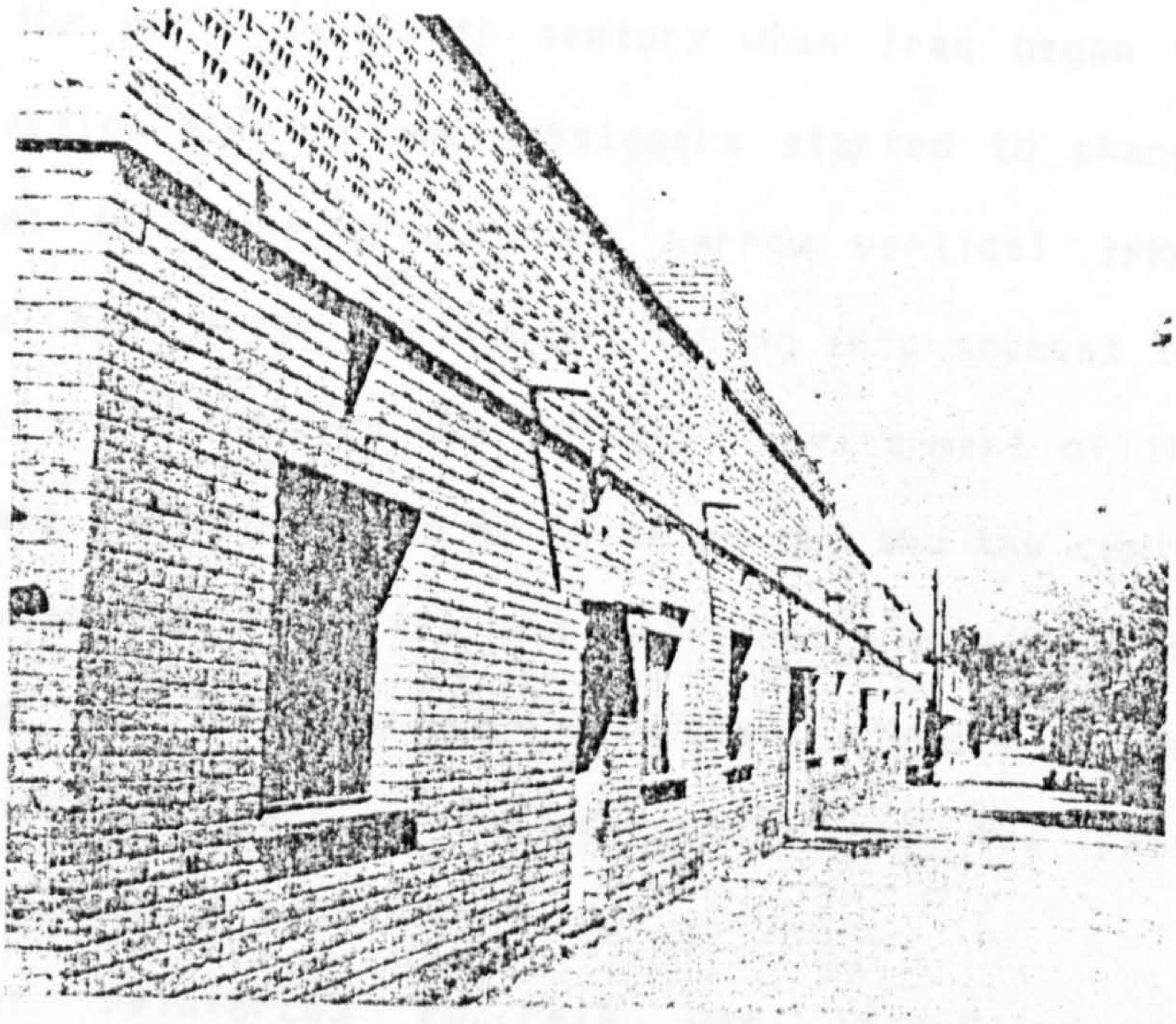


Figure 1.32 Terrace House Facade

for installing water heaters, gas cylinders and sometimes air coolers (see Figure 1.5).

1.2.3 Modern Types of Windows in Iraq

1.2.3.1 General View

In the early twentieth century when Iraq began to import I-section steel beams, designers started to change window types from the traditional narrow vertical type to the wide, horizontal one without taking into account the effect this would have on the internal environment of the house. Figure 1.33 shows one of these houses and the contradiction between the beautiful and efficient windows on the first floor and the ugly and inefficient windows on the ground floor which are a failure both from the privacy and environmental points of view.

After reinforced concrete was introduced to Iraq, architects qualified in Europe started to transfer European styles, to hot, dry countries such as Iraq. Some architects attempted to compromise between function, tradition and modern architecture (see Figure 1.34).

The majority, however, just introduced a touch of the old traditional style into their designs, leaving other factors out of consideration . The author suggests that this problem arose partly as a result of lack of adequate information and data.

Figure 1.33 Conflict between traditional first floor and modern ground floor windows.

Figure 1.34   Modern interpretation of traditional window.

1.2.3.2 Existing Window Types

Wooden windows were the only type used in Iraqi buildings until the year 1935 [Ref 195]. In that year and for the first time steel windows were imported from the United Kingdom and used in the building of the Royal Hospital (now The Republic Hospital). Since that time the use of steel windows has increased to such an extent that today wooden windows have almost completely disappeared . Glazed areas have also increased, horizontal windows have grown in usage and the use of the wall thickness for shading was discarded.

Figure 1.35 shows common types of windows in houses built after the sixties, while Figure 1.36 shows the window types in existence and widely used before 1960.

In general, windows currently used in Iraq can be classified as follows.

A - Horizontal oblong windows(the most popular type) .

B - Vertical oblong windows (less popular) .

C - The arched type

1.2.3.2.1 Horizontal Oblong Windows

This type of window is found in most housing and is 0.60m to 3.0m in width and 0.30m to 2.10m in height .

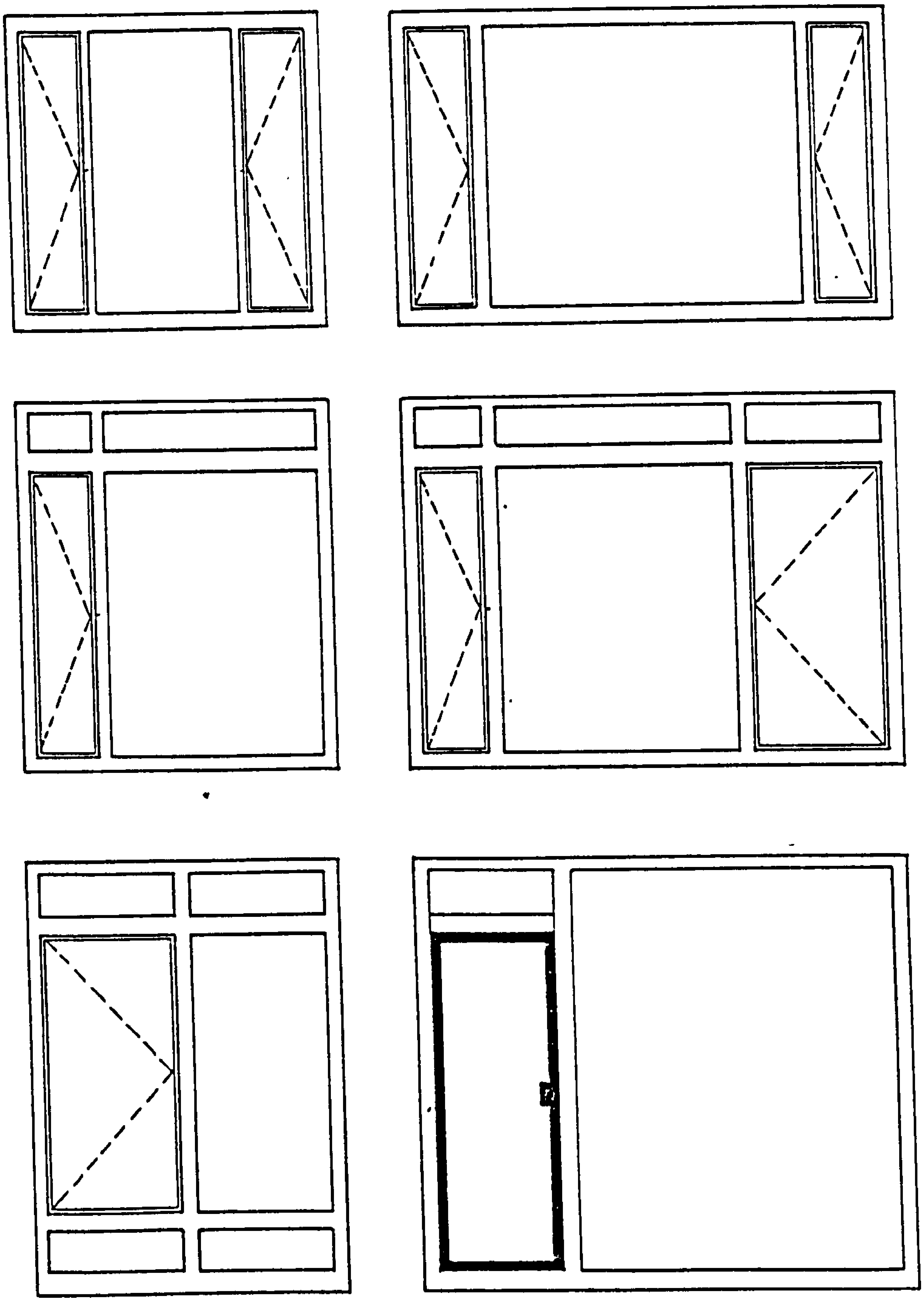
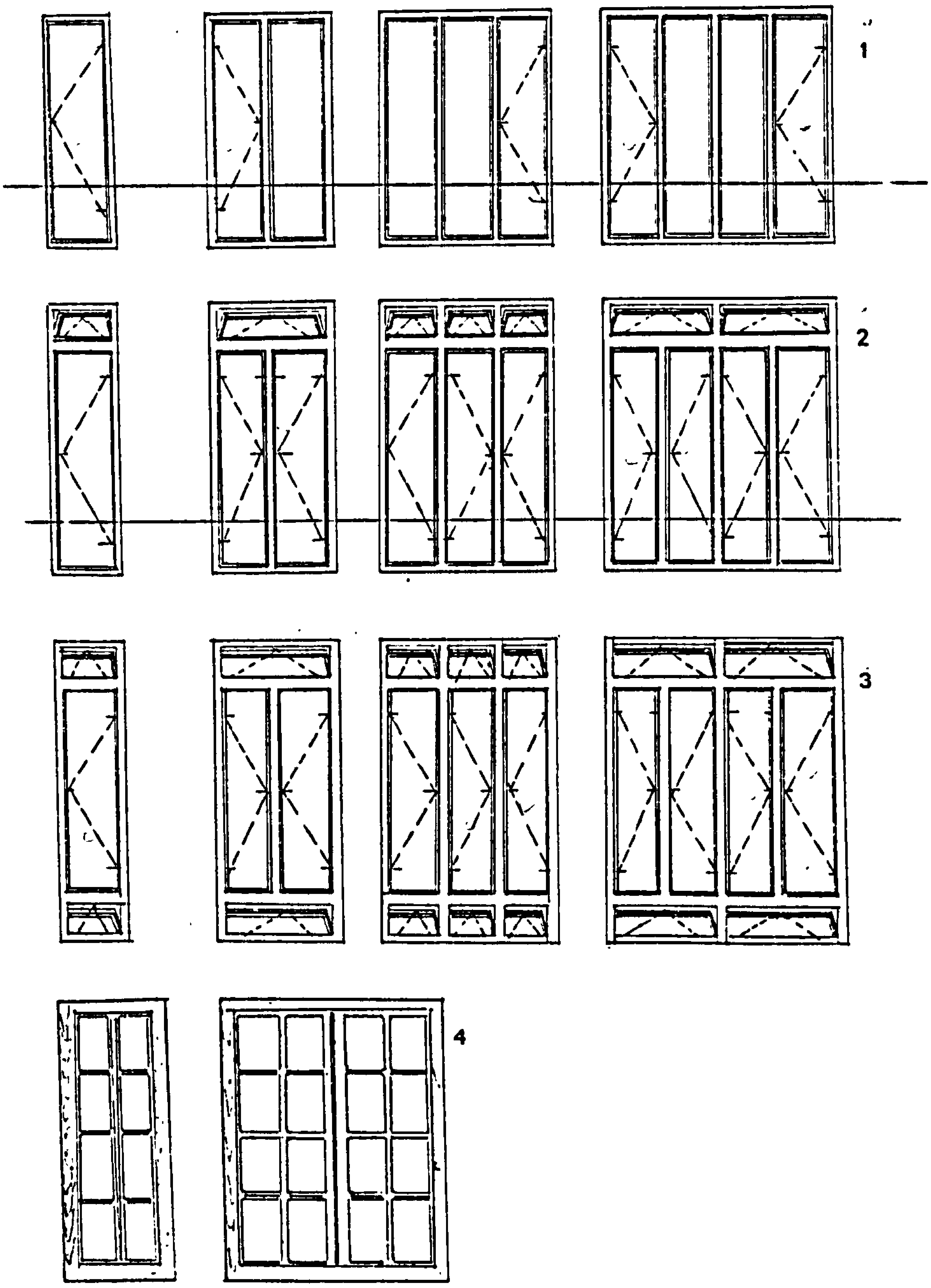


Figure 1.35 Post-1960 window types.



Note:- 1,2,3,& 4 were used in houses built in the sixties.

a. Larger sizes were most popular especially in middle and higher income areas.

b. The line on 1&2 shows the possibility of other proportions.

Figure 1.36 Pre-1960 window types.

1.2.3.2.2 Vertical Oblong Windows

This type is less common and is normally of 0.30m to 1.50m in width and 0.60m to 2.10m in height

1.2.3.2.3 Arched Type of Windows

This type has reappeared in modern architecture in Iraq . When it was first used twenty years ago it seemed an obtrusive and ugly patch on the building .
In the last decade the government encouraged architects to add a touch of tradition to their designs and, in response, a few succeeded in demonstrating their ability to marry the old with the new in a harmonious way.

1.3 Requirements and Needs for New House Designs

1.3.1 Users' Needs

Householders require:

A - Houses suitable to their standard of living.

B - Better designs to cope with the climatic environment, their tradition and culture and to fulfil their psychological needs.

1.3.2 What Designers Need

Following from a Knowledge of the plot size, types and number of rooms, the approximate sizes of each room and the users' requirements in order of priority, the designer needs to have thorough knowledge of:

A - The climate

B - The extremes of climatic conditions

C - Ways of preventing buildings from admitting excessive direct sunlight in summer and how to enable them admit as much direct sunlight as possible in winter.

D - Ways of selecting windows and openings so as to achieve a balance between controlling direct sunlight, the need for ventilation, the need for daylight and psychological / aesthetic needs .

1.3.3 The Regulations

Constraints come from urban design regulations issued by the Ministry of Planning and the Building Regulations, drawn up by the municipalities, which have to be followed by the designer.

1.3.4 The Conservation of Energy

A concern about conservation of energy is not merely a question of reduction of energy costs, of immediate concern to most building owners and users, but also a concern for the worldwide shortage of fossil fuels and for the reduction of pollution. Therefore the designer has to take into consideration:

A -The reduction of energy costs and, at the same time the improvement of the internal house environment.

B -Reduced reliance on artificial mechanisms and means.

C -The possible contribution to the control of environmental pollution.

1.3.5 Psychological Needs

Although the importance of energy conservation and cost reduction in buildings is widely discussed, it must be stated here that, houses and shelters, and indeed all human activity, are aimed primarily at the enjoyment of life on this planet. Therefore people do not wish only to be provided with energy conservation or cost reduction, but in addition they seek a more comfortable and enjoyable existence.

Accordingly, the designer has to act sensibly and treat the psychological needs as having an equal priority to those for energy conservation and cost reduction.

Consequently the following factors should be catered for in any design and above all in houses:

A - The importance of a satisfactory relation between the occupant and the external environment.

B - The importance of privacy and family customs.

C - The importance of light and sunlight admission.

From the author's experience, arrived at through discussion with designers and with occupants during the housing survey (see chapter 3), it is evident that, although the intensity and penetration of solar radiation is the main factor in raising the internal house temperature it is the area of a room's surfaces which are insolated which is the <u>perceived</u> phenomenon, which correlates, subjectively, with people's experience of solar energy gain. Occupants have a widespread desire to minimise this insolated area ("sunpatch") in summer and maximise it in winter. Since total sunpatch area is, in any case a useful approximate measure of solar energy gain and since its psychological siqnificance seems so potent in terms of the <u>perceived</u> environment, this study makes the important assumption that the "sunpatch area" is the most relevant single measure for evaluating the shape and size of windows for direct sunlight control.

1.3.6 Ways of Achieving Users' and Designers' Needs

It is common knowledge that designers try their best to tackle energy conservation in design, but when they find that much of their time has to be spent on calculations, there is a tendency for them to transfer their efforts more to the aesthetic issues and to leave the environmental control side unresolved, especially when they believe that there are no firm standards laid down or any reliable information to which they may refer. On the other hand, it also appears that when designers find information which is quite clear, practical and easy to use this is implemented in the design.

Thus it is clear that the designer needs as much information as it is possible to provide for easy and ready use.

During discussions and interviews with architects on energy conservation in buildings in both the private and public sectors, when the possibility of contributing to this project was raised, the author found that the architects called for more research on various aspects and they expressed a desire to be provided with:

A - Data on the effect of building shapes and orientation on energy conservation.

B - Data on sunbreaker types and dimensions for different window sizes for different building orientations.

C - Data on window sizes and proportions for better direct sunlight control.

D - Data on window sizes and proportions for better natural lighting.

E - Data on window sizes and proportions and the positioning of windows for better ventilation and air distribution for cooling purposes.

F - Some methods for optimizing window sizes and proportions to obtain overall good performance in controlling direct sunlight, providing a sufficient amount of daylighting, and cooling ventilation.

1.4 The Author's Contribution

Responding to this call

A - Joint work was carried out between the author and an other researcher on plot and house proportions, and orientations for Iraq and for other countries lying between 30 to 36 degrees north and south. The paper was published twice by the International Association of Housing Science in the U.S.A. [Ref.15]. Nevertheless further work is needed,and the author hopes to make it a part of his future work.

B - Work has already been done by the author on the dimensions of sun-breakers for windows and fenestrations for buildings in Iraq and for other countries on latitudes 30 to 36 degrees north . (A handbook was published by the Iraqi Scientific Research Council 1982 [Ref.19]).

C - Within the present research the author has set out to produce useful data concerning the optimization of window design, which, it is hoped, will help to provide Iraqi designers with some of the window design guidance which they need..

1.4.1 An Effective Way of Tackling the Problem of Window Design for Housing

It is believed that the problem of window design for housing has to be studied and recommendations made whithin the following framework:

A - For real situations in housing areas and not only for scattered, individual houses.

B -For the most common windows found in design practice (square and oblong windows); these are the only shapes included in this study.

C - Recommendations on window sizes and proportions have to be made in such a manner that they allow the designer freedom to choose a suitable window according to his or her own evaluation between the recommendations set out and other, possibly conflicting, factors in the field of economics, aesthetics or psychology. Accordingly such a study has to present an optimization method which gives a clear and wide range of information on window efficiency covering each parameter separately as well as jointly.

D - For a hot country such as Iraq, direct sunlight is the principle and most important factor affecting internal environmental control. Therefore the first factor which has to be considered is the careful evaluation of windows so that they are capable of reducing or eliminating the penetration of summer sun, while allowing desirable winter sun to enter. Moreover the ratio of winter sun penetration to summer sun penetration adopted has to follow the ratio of the summer period to the winter period. The designer has to be provided with a set of results and recommendations regarding this aspect of the problem separately, to provide a clear picture concerning the capability of different window sizes and proportions, for control of direct sunlight for all wall orientations (16 orientations were chosen), for the most common housing shapes and layouts. Thus this important factor should be considered as number one priority.

E - As for daylight, the same group of windows studied for direct sunlight has to be studied to show their capabilities for providing certain levels of lighting, with the sky and the external surfaces as the light sources for the same 16 wall orientations for a range of interhouse distances. Internal room reflection should not be taken into account because of the wide variation of internal colours used in practice and the presence of furniture. The author has chosen, for practical reasons, to consider the internal colour as black and calculate the lighting level from the sky and the external obstructions at a point representing the centre of the room at a working level (0.75m height). Naturally designers know that, with walls having any actually used colour the lighting levels will be higher and allowing for this condition is a part of their design responsibility . However, designers will also be provided with the reflection factors of paints and material

surface colours and a general design aid concerning the effects of reflection from floor, ceiling and walls.
The designer has also to be provided with the international recommended levels of lighting for every type of room so that a rational choice of a window, or a number of windows which reach the required lighting levels, can be made.

F - As for ventilation, its main purpose in hot dry countries is for body cooling. Windows therefore have to be studied to give the designer information on the effects of size, proportions, numbers and positioning to give adequate air distribution in rooms of different orientations with regard to air distribution and velocity, for the various building shapes and layouts in common use.

G - It should be normal practice for the designer to know the window sizes and proportions which can serve criteria based on combinations of any two of the three criteria of sunlight control, daylight provision and ventilation and, further, a combination of all three.

Thus it is the aim of the study to provide the designer with optimal solutions for all the above requirements.

CHAPTER 2

CHAPTER - 2 -

CLIMATE

2.1 General View

Before an architect designs any kind of building he or she requires some information about the climate of the place where the building will be constructed. For the present study, climate has to be defined in a manner which allows the designer to be provided with clear information and can help to lay the foundation for recommendations on the optimization of window design.

Consequently the analysis of climate has to serve building design requirements.

2.2 The Climatic Elements

For building design requirements, the basic climatic elements are air temperature, humidity, wind speed, wind direction, solar radiation, sunshine duration, precipitation and sky condition.

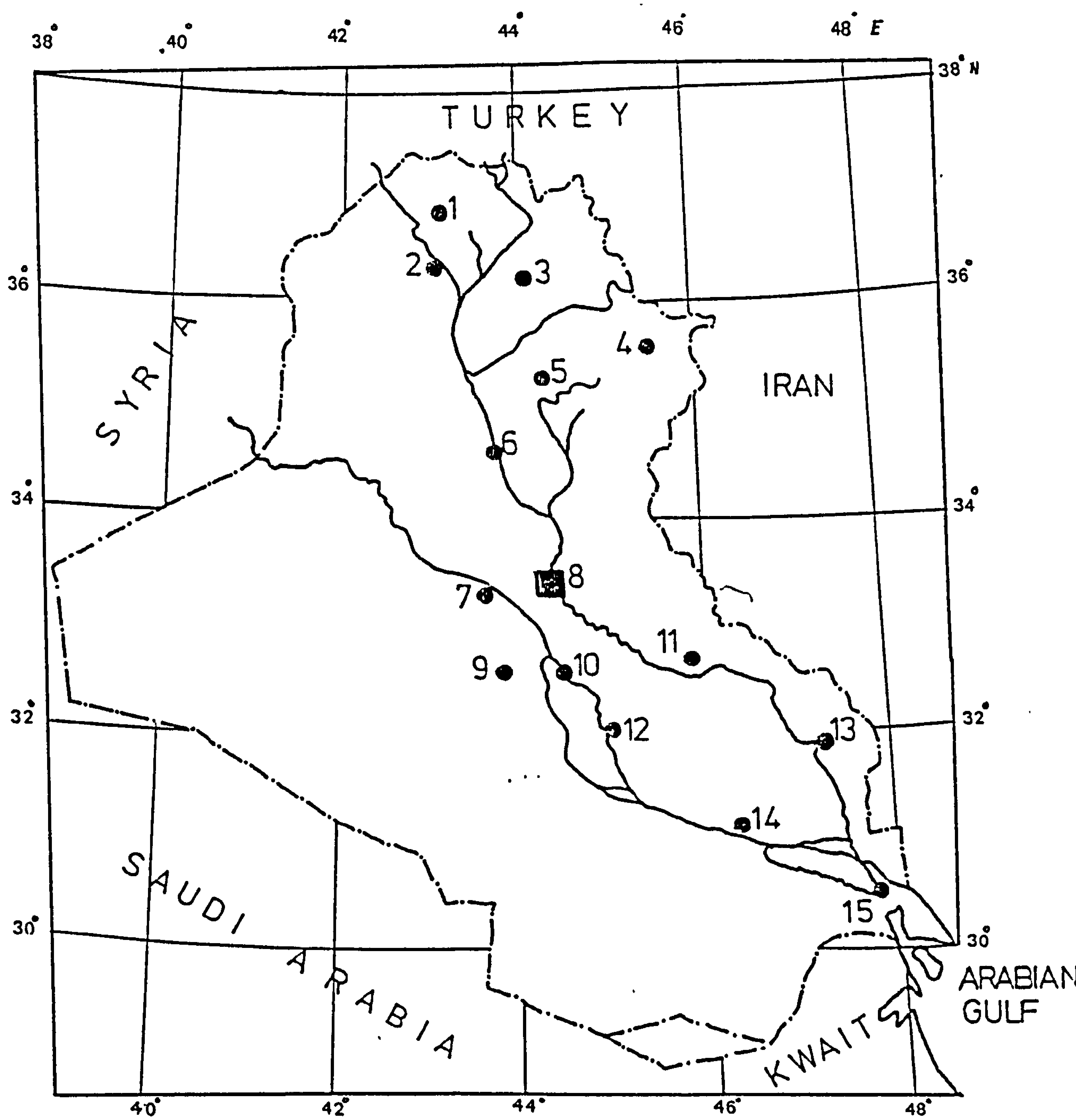
2.2.1 Air Temperature

Air temperature varies according to the latitude, the height above sea level, and the geographical character of the location.

Most of Iraq is located between latitudes of 29° and 37° north and the main cities are situated between 30° and 36° north. The south of Iraq is 2m above sea level. The middle area is 34m above the sea level, while in the mountain area the level varies between 200m to more than 1000m above sea level. The main cities do not exceed 350m above sea level. Since Iraq borders on all sides with other countries (see Figure 2.1) and has only a very small opening on to the Arabian Gulf, the sea does not make a major contribution to its climate, and consequently Iraq tends to be hot and dry, which means that the sky is mostly clear and the incoming solar radiation is minimally obstructed during day-time and the long wave radiation to the sky during night-time, as a result of which there are large diurnal and annual temperature differences . Figures 2.2 to 2.13 show the diurnal temperature variations in Baghdad in winter and summer.

2.2.2 Humidity

It is well known that water vapour exists in the atmosphere even if it is not raining. Relative humidity is the term used to express in practice the amount of water vapour in the air. It is defined as the ratio of the pressure of the water vapour actually present in the atmosphere to the pressure of the saturated atmosphere at the same temperature. Humidity is an important factor in the assessment of climatic stress (see Figure 2.14). The mean relative humidity records for thirty years for Baghdad are plotted and illustrated in Figures 2.2 to 2.13 . These Figures give a clear picture on how temperature and humidity behave in a hot-dry climate.



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3. ARBIL	8. BAGHDAD	13. AMARA
4. SULAYMANIYA	9. KARBALLA	14. NASIRIYA
5. KIRKUK	10. HILLA	15. BASRAH

Figure 2.1 Map of Iraq

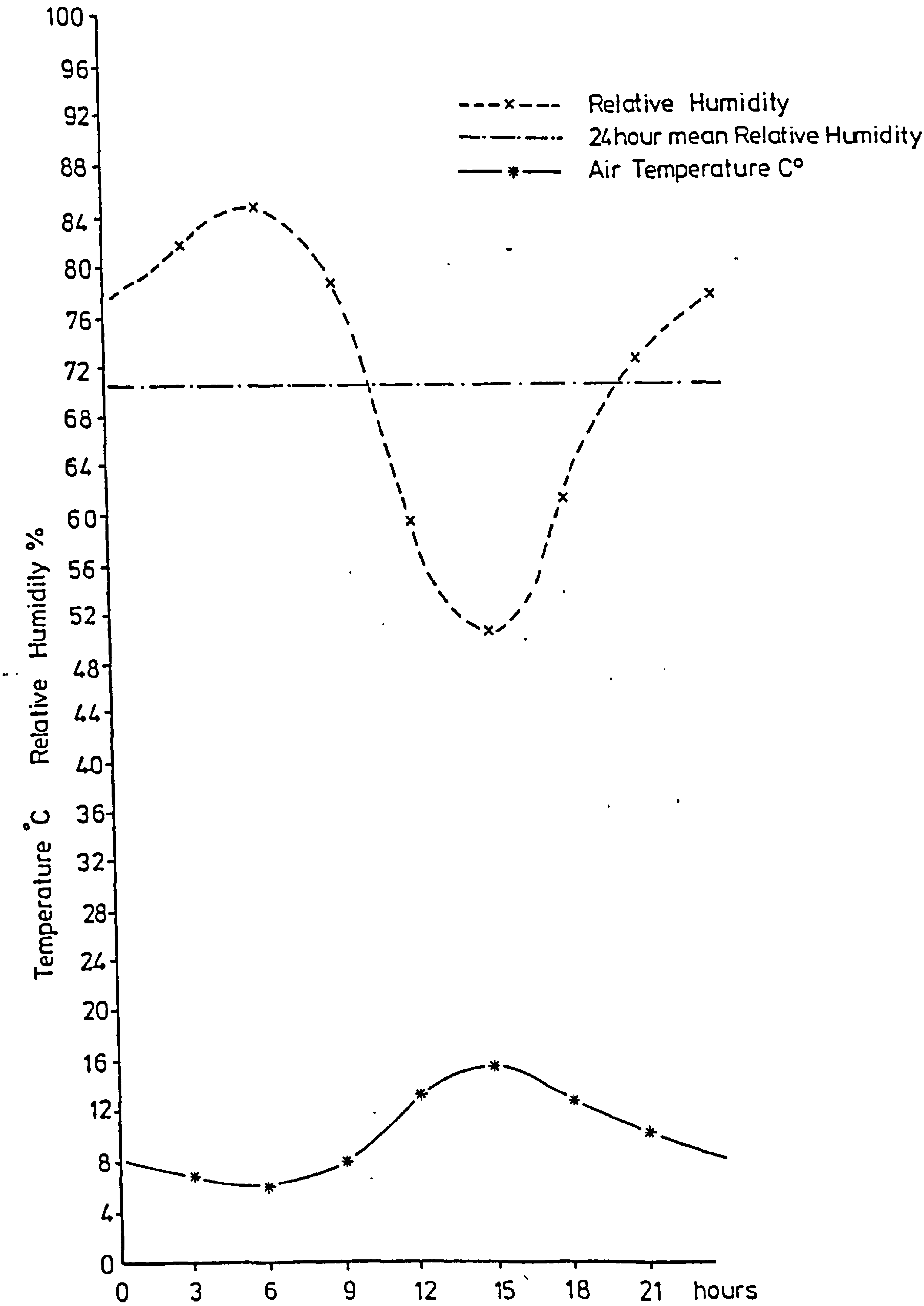


Figure 2.2 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD JANUARY 1941-1970

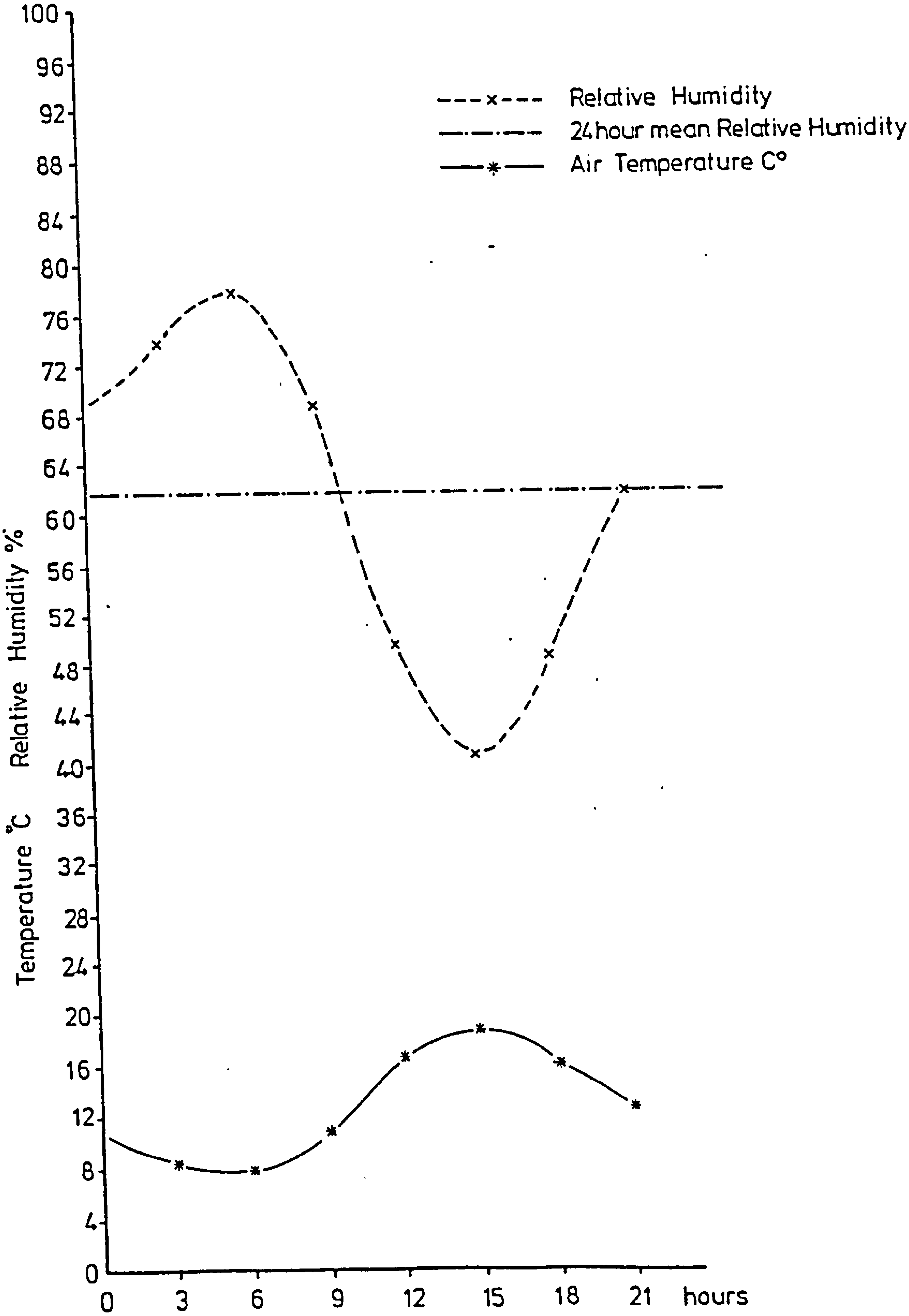


Figure 2.3 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY BAGHDAD FEBRUARY 1941-1970

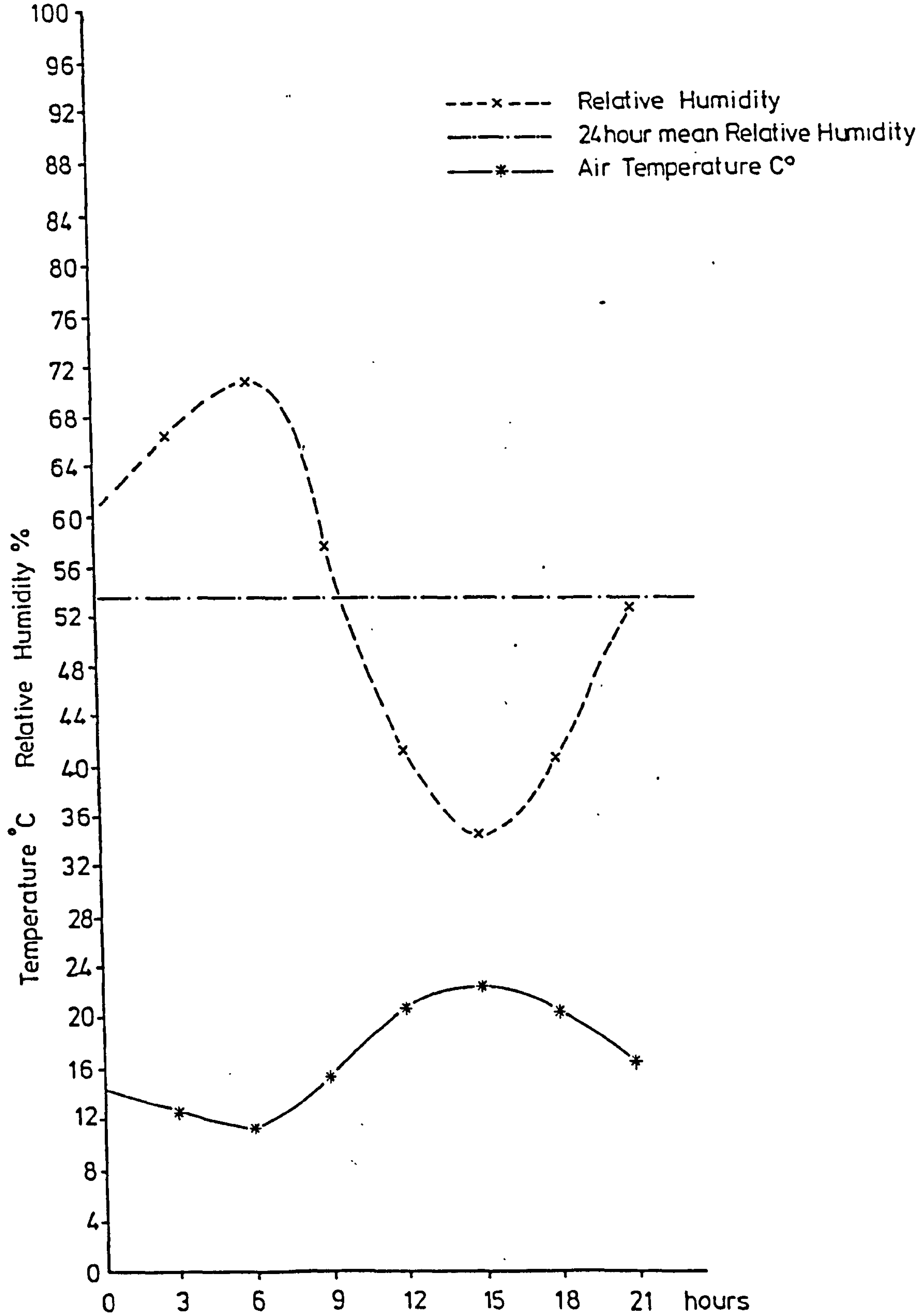


Figure 2.4 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD MARCH 1941-1970

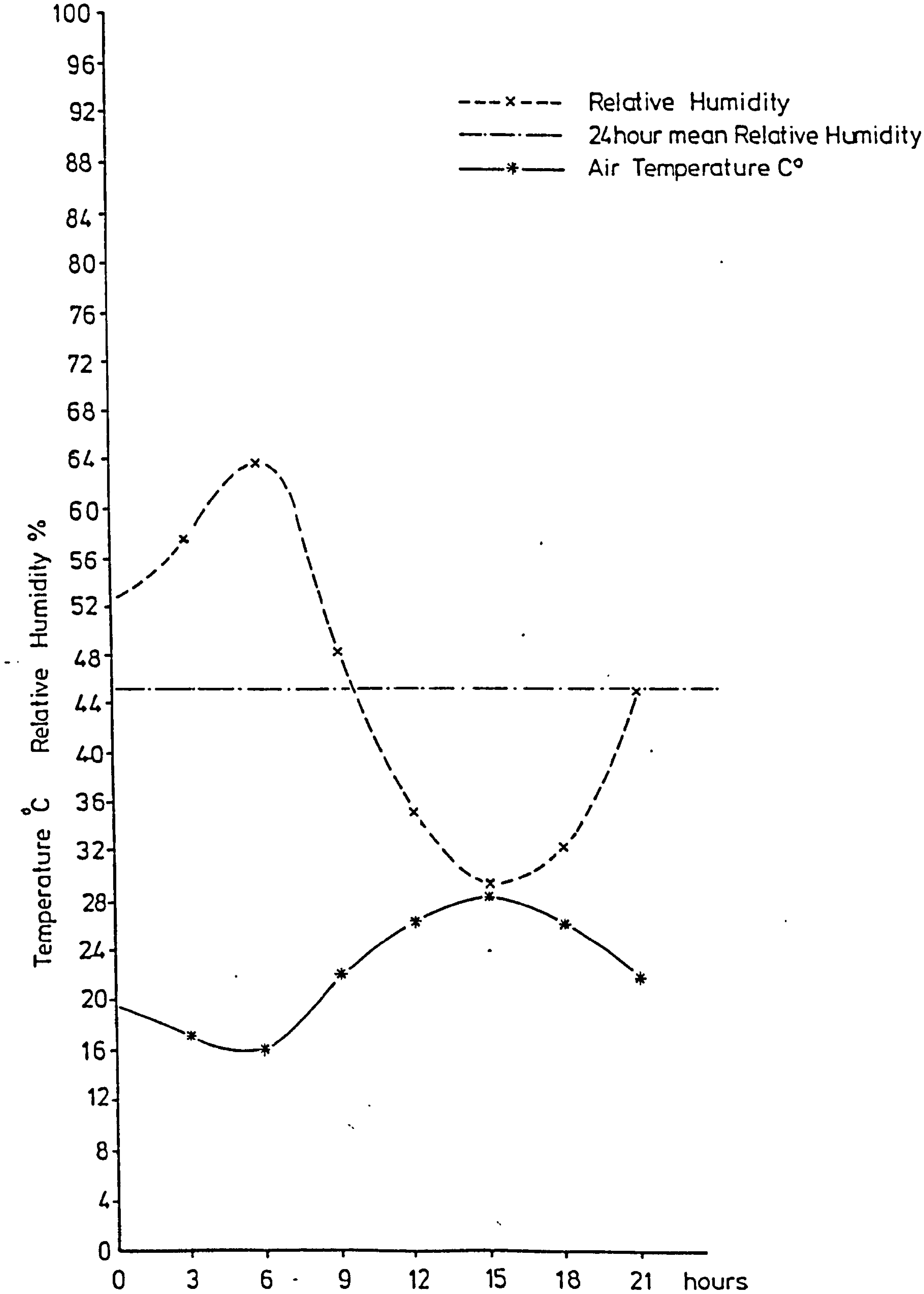


Figure 2.5 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD APRIL 1941-1970

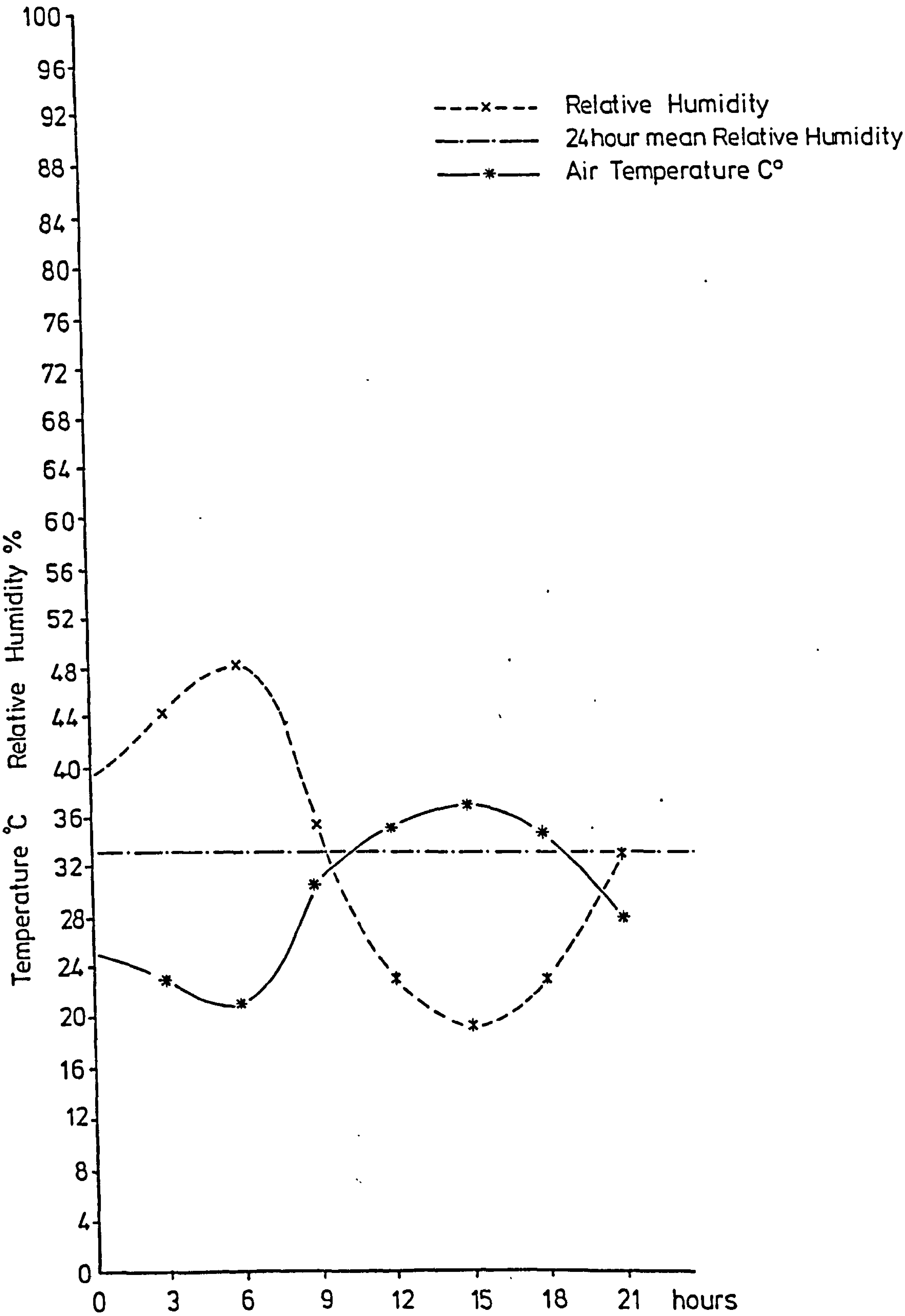


Figure 2.6 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD MAY 1941-1970

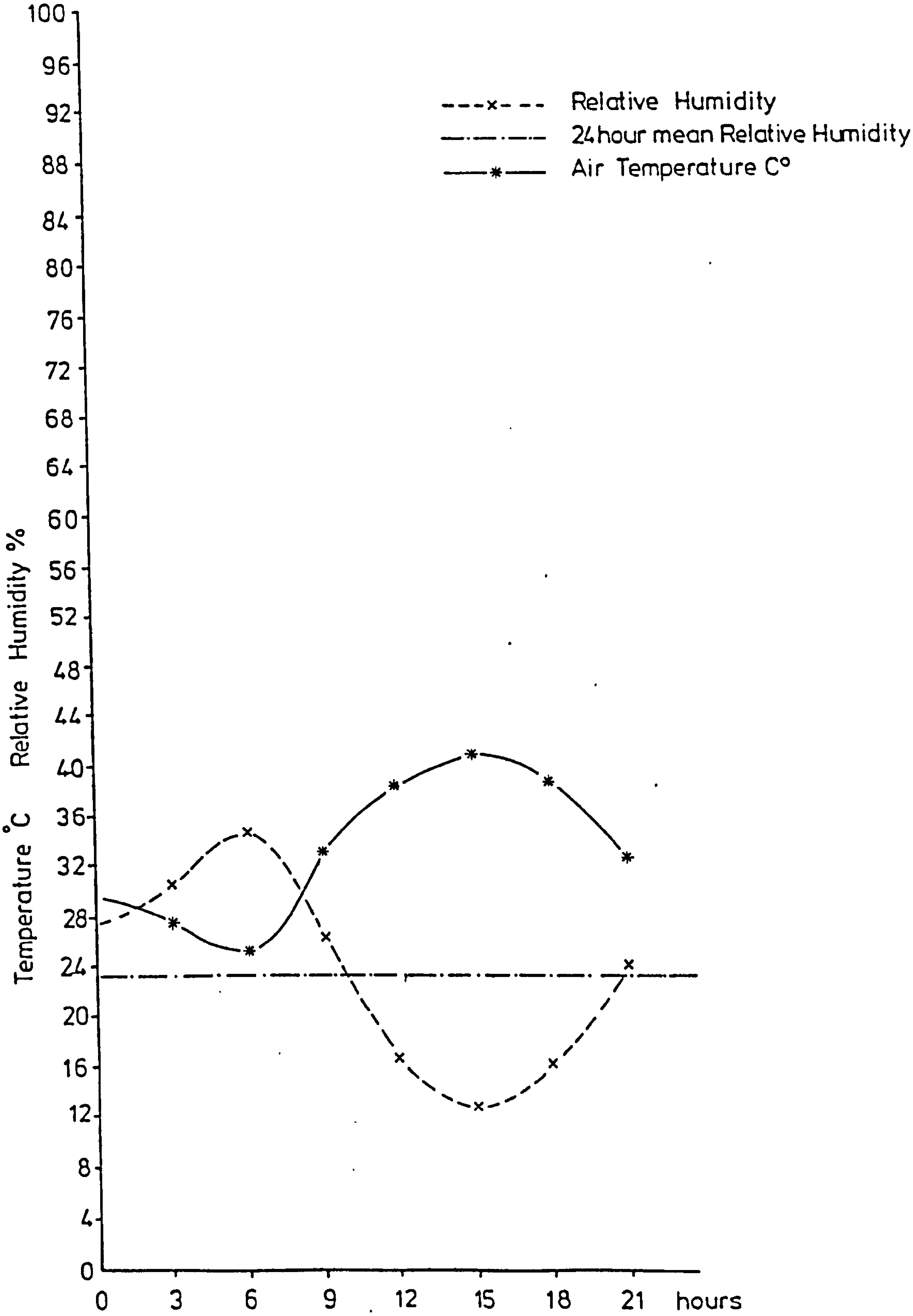


Figure 2.7 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD JUNE 1941-1970

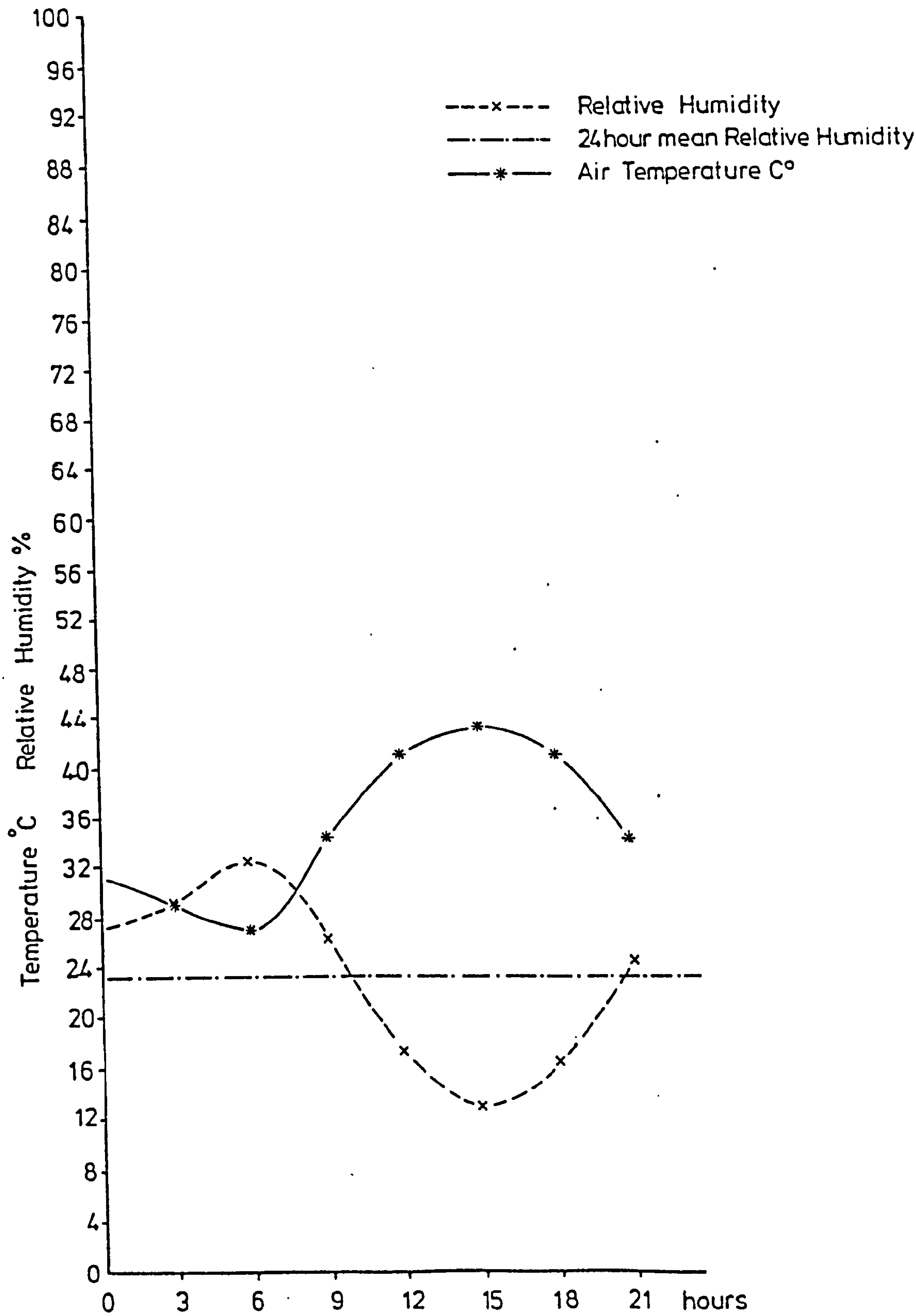


Figure 2.8 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD JULY 1941-1970

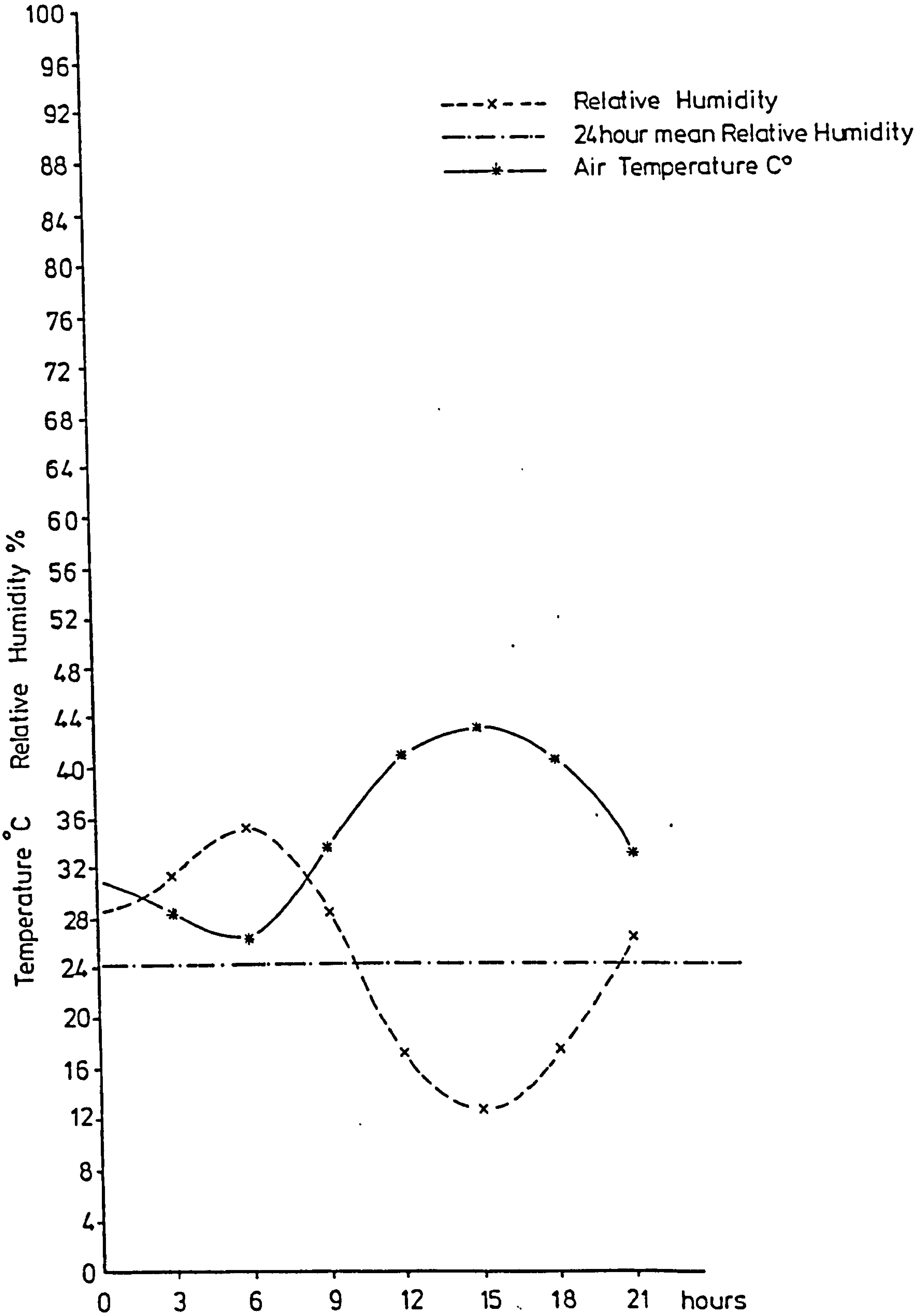


Figure 2.9 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD AUGUST 1941-1970

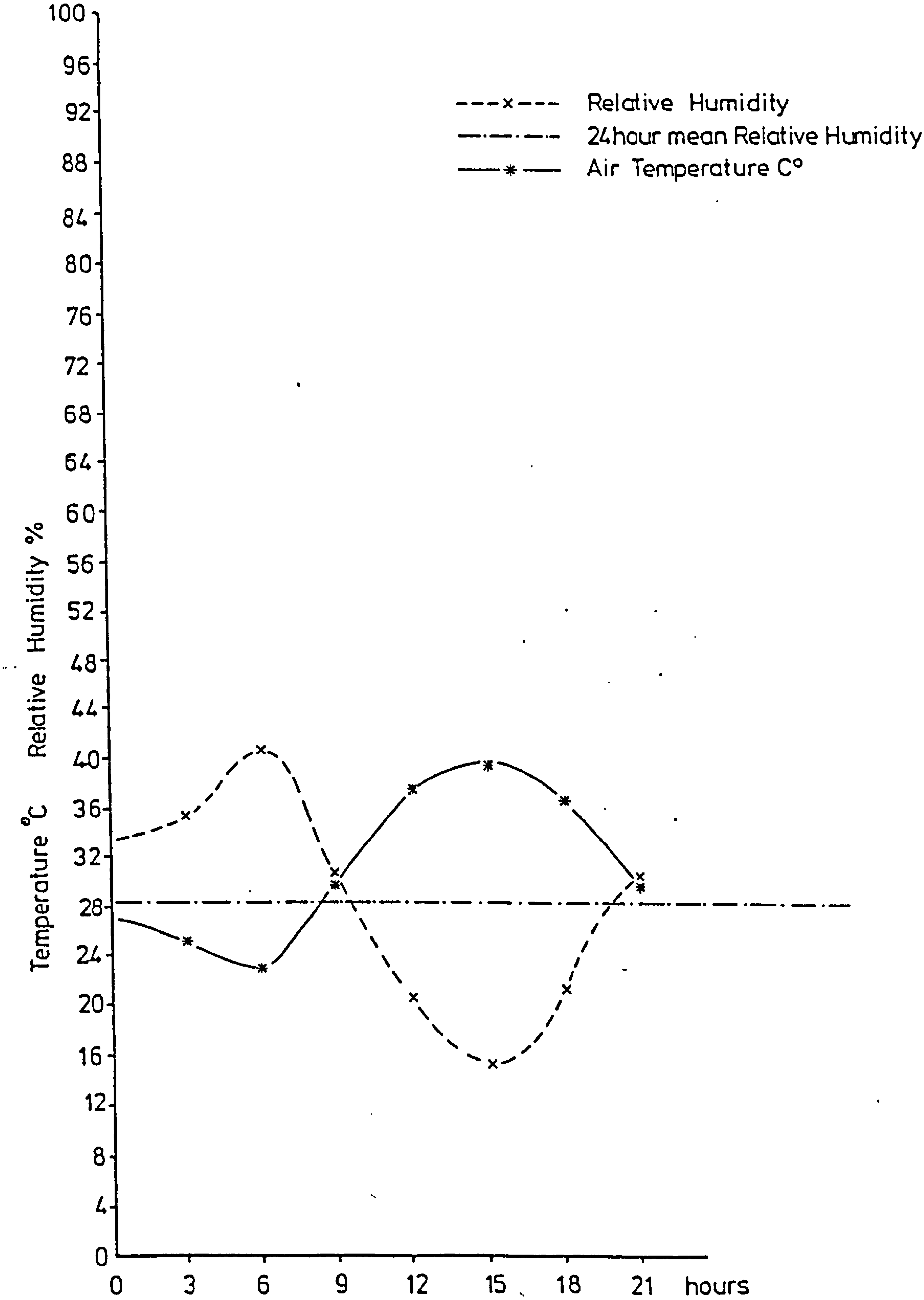


Figure 2.10 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD SEPTEMBER 1941-1970

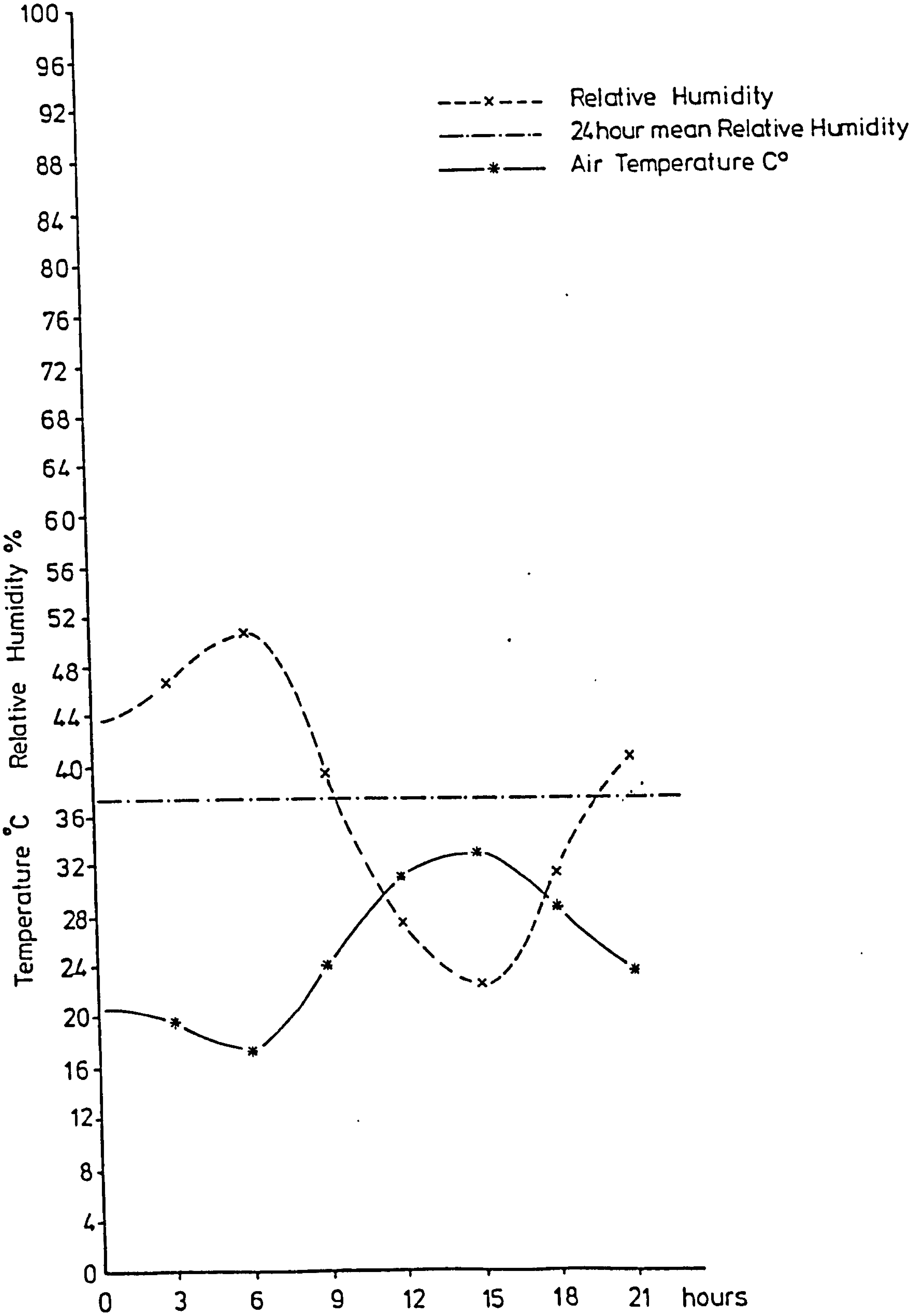


Figure 2.11 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD OCTOBER 1941-1970

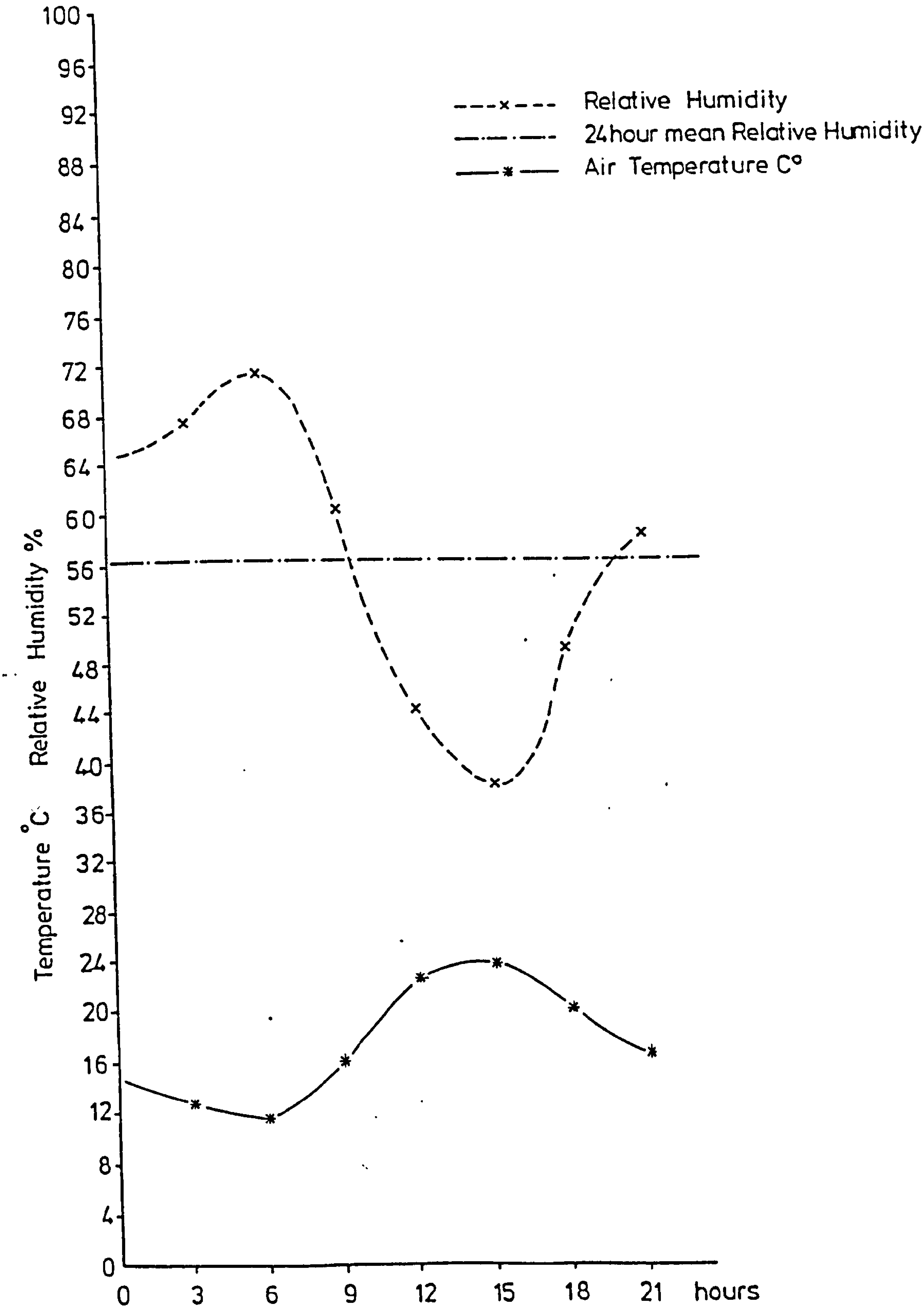


Figure 2.12 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD NOVEMBER 1941-1970

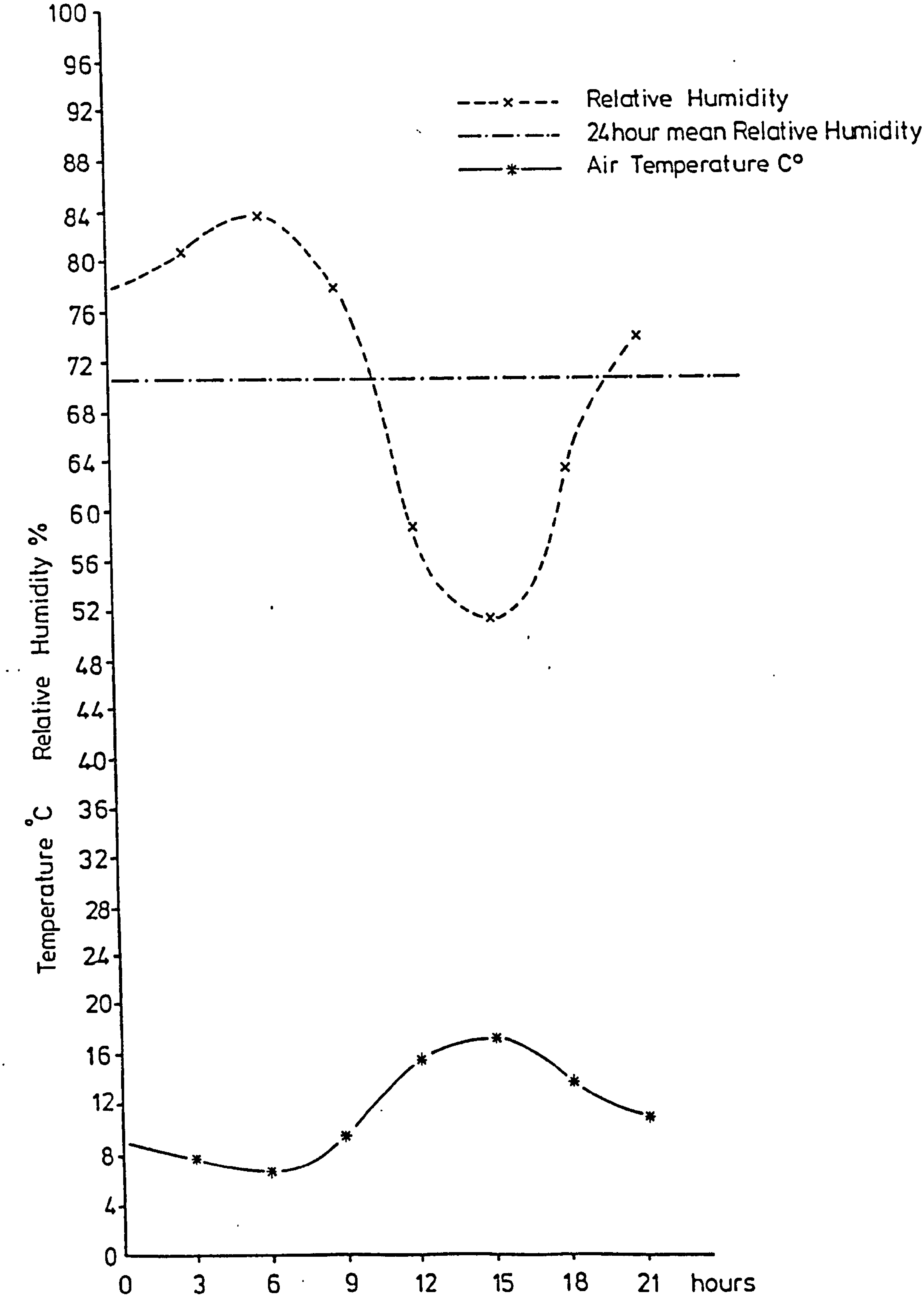
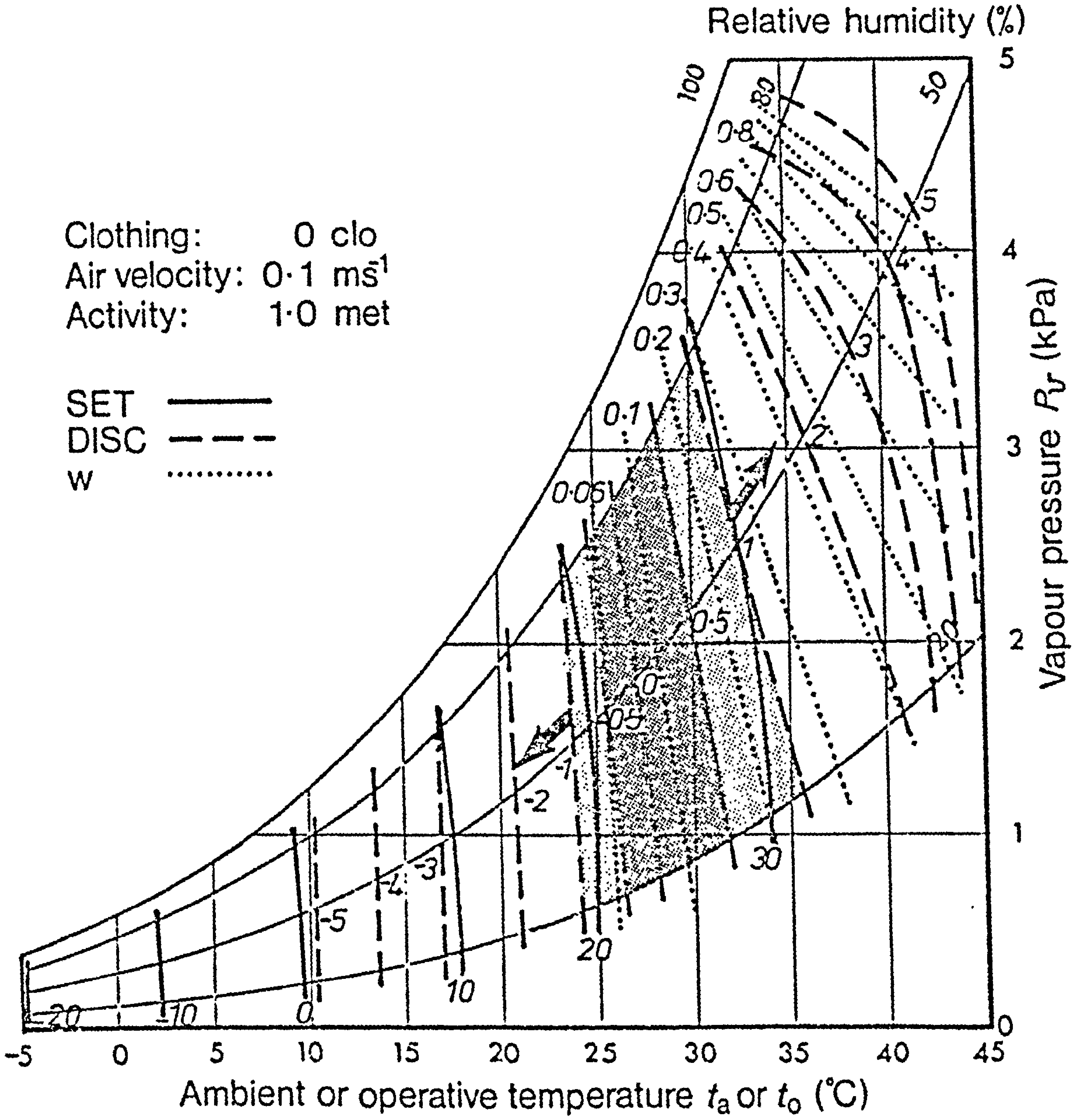


Figure 2.13 AVERAGE AIR TEMPERATURE AND RELATIVE HUMIDITY

BAGHDAD DECEMBER 1941-1970



Thermal comfort

Figure 2.14 (After Ref. 129)

2.2.3 Solar Radiation and Sunshine

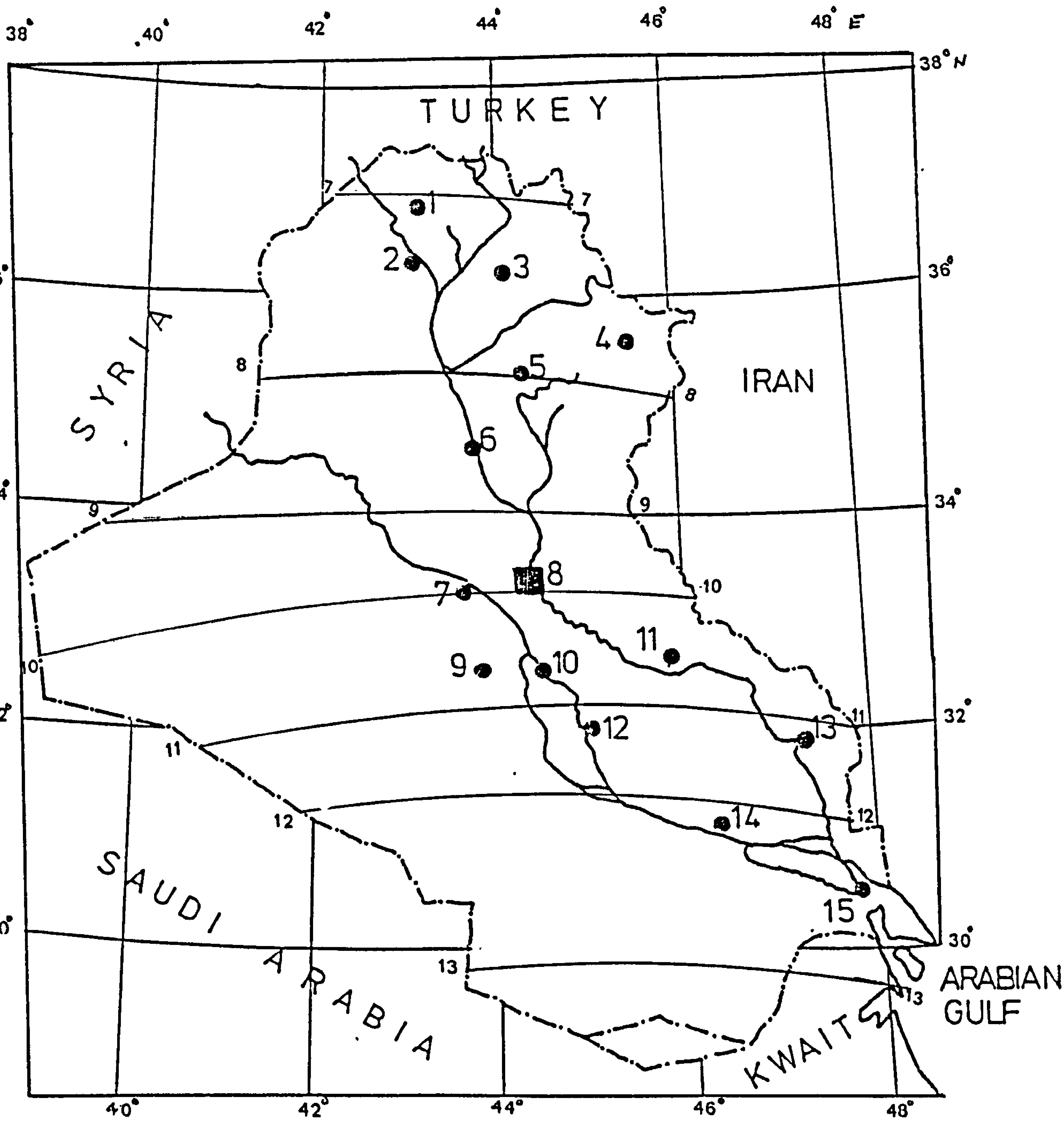
Solar radiation is the most important factor affecting and determining the climate at any location on the earth's surface. The amount of solar radiation received depends on the latitude, height above sea level, sky turbidity (dust, water vapour, smoke) and sunshine hours.

Due to the low relative humidity and the long sun duration, Iraq receives a large amount of direct solar irradiation. The average minimum total solar radiation on a horizontal surface is about 10 MJ/m2/day in winter and the average maximum of about 25 MJ/m2/day in summer. (see figures 2.15 and 2.16) [Ref 4].

The maximum sun altitude in Baghdad at noon in summer is 80° and the minimum at noon in winter is 34°, while the maximum sun altitude in the far north of Iraq at noon in summer is 77° and the minimum at noon in winter is 31°. In the far south the maximum sun altitude at noon in summer is 83° and the minimum at noon in winter is 37°.

2.2.4 Wind

Wind speed varies with location, topography and height. It is important to assess the direction and speed of the prevailing wind in the underheated and overheated periods and use this data to decide the correct orientation, size and proportion of window opening heights and ventilators.



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3. ARBIL	8. BAGHDAD	13. AMARA
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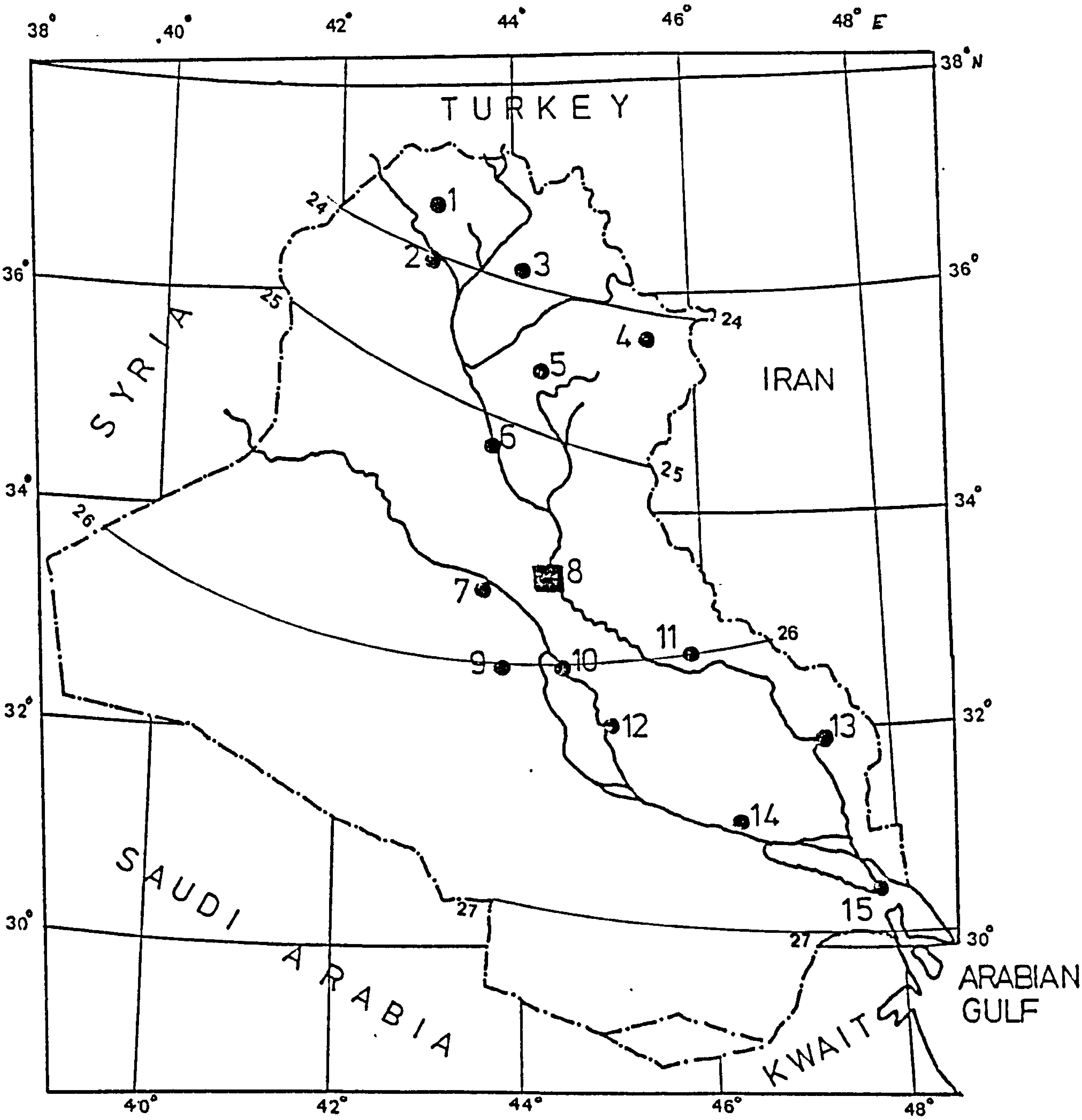
5. KIRKUK	10. HILLA	15. BASRAH

Figure 2.15

A map of Iraq showing isolines of total irradiation for December (MJ/M^2day)



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9. KARBALLA
10. HILLA
11. KUT
12. DIWANIYA
13. AMARA
14. NASIRIYA
15. BASRAH

Figure 2.16

A map of Iraq showing isolines of total irradiation for June ($MJ/M^2 day$)

Wind is most welcome in hot humid regions at all times in summer, spring and autumn to help infiltrate the building to produce cooling effects on both the building and the body, while in hot dry climates wind is preferred for cooling purposes both day and night during spring and autumn and only at night-time during summer, because in summer day-time the ambient temperature (Ta) is higher than the skin temperature (TsK) but it is lower than (Tsk) at night-time.

In hot, dry countries like Iraq the use of wind plays a major part in the control process of the outdoor and indoor climatic environment and on the degree of comfort that occurs due to the fact that wind movement increases body sweating which in turn causes cooling by a reduction of skin temperature. Air velocity affects both the convective heat transfer and the rate of evaporation from the body; if Ta > Tsk, whilst there will an increase of evaporation with velocity, there will also be an in convective heat gain. The body cooling will be a resultant of the convective heat gain and the heat loss by evaporation. If the ambient temperature is much higher than the skin temperature, the cooling caused by evaporation will be more than off set by the convective heat gain and no cooling benefit can be obtained from air movement. If Tsk > Ta increase in wind velocity affects positively both the convective heat loss and the rate of evaporative cooling of the body.

In Baghdad the prevailing wind direction is north west and the mean wind speed varies between 2.5 to 4.5 m/s . (see Table 2.1)

2.2.5 Rain

Rainfall in Baghdad is relatively low. The total mean annual rain fall is 148 mm, the maximum amount is in January and there is no rainfall at all during July and August.The heaviest rainfall occurs in April and tends to be sporadic heavy showers accompanied by thunder-storms (see Table 2.2) .

2.3 The Analysis of the Climate of Baghdad

For the purpose of this study the analysis of the climate of Baghdad has been carried out in a manner such that it serves the designer's needs and at the same time is orientated towards determining the factors affecting the internal building environment. Therefore, this section does not cover a wide analysis of the Baghdady climate but rather focuses on the factors related to the internal building environment .

As is well known, Baghdad is located in a hot dry region, with very short, cold winters and very long, hot summers. Thus, for our present study the analysis will be concerned with determining :

A- Day and night comfort.

Month	N	NE	E	SE	S	SW	W	NW	Calm
January	8.0	3.0	8.5	16.0	5.9	3.8	9.6	27.7	17.5
February	9.7	4.1	8.4	17.9	7.4	3.6	9.1	25.0	14.9
March	11.8	6.0	8.2	15.1	6.3	4.1	11.0	26.5	10.9
April	15.0	6.7	9.7	14.2	7.4	3.5	9.0	23.2	11.3
May	19.8	7.0	5.8	6.5	4.8	2.9	10.1	31.7	11.4
June	21.6	2.5	1.4	1.3	1.4	1.4	13.5	46.2	10.7
July	12.4	1.3	0.4	0.8	1.4	1.4	18.7	53.9	9.8
August	15.8	2.5	1.2	1.3	2.0	1.6	17.0	46.9	11.7
September	20.0	3.8	2.0	1.9	2.1	1.9	11.2	39.3	17.8
October	17.8	5.8	5.9	6.6	3.1	1.9	9.5	29.3	20.1
November	11.2	4.8	8.0	9.2	4.0	1.9	9.0	29.9	22.0
December	8.0	2.8	7.5	13.5	4.7	3.0	10.6	30.4	19.5
Annual	4.3	4.2	5.6	18.7	4.2	2.6	11.5	34.2	14.8

Table 2.1a Mean Surface-wind Direction % for Baghdad (1941-1970)

Month	Hours of Observation - Local Time 0.0	0300	0600	0900	1200	1500	1800	2100	Mean
January	2.4	2.3	2.3	2.7	4.2	4.3	2.6	2.4	2.9
February	2.7	2.7	2.8	3.3	4.5	4.9	3.1	2.7	3.4
March	3.3	3.0	2.9	3.6	4.7	5.0	3.7	2.9	3.6
April	2.8	2.9	2.9	3.8	4.6	4.6	3.9	2.3	3.4
May	3.0	2.9	2.7	3.8	4.8	4.8	4.0	2.8	3.6
June	3.1	3.2	3.2	4.8	5.7	5.8	4.6	2.7	4.2
July	3.1	3.5	3.7	3.7	6.3	6.2	4.9	2.8	4.5
August	2.9	3.1	3.3	4.9	5.7	5.9	4.1	2.5	4.0
September	2.7	3.0	2.7	3.7	5.0	5.0	3.0	2.2	3.4
October	2.4	2.5	2.4	3.0	4.2	4.2	2.1	2.2	2.9
November	2.1	2.0	2.1	2.5	3.7	3.5	2.0	2.1	2.5
December	2.1	2.3	2.1	2.6	3.8	3.9	2.1	2.2	2.6
Annual	2.5	2.8	2.8	3.5	4.8	4.8	3.3	2.5	3.4

Table 2.1b Mean Surface-wind Speed $^{m}/s$ for Baghdad (1941–1970)

Month	Mean Monthly	EXTREMES			
		Highest	Year	Lowest	Year
January	25.4	78.9	70	0.6	41
February	24.2	85.5	51	0.7	65
March	23.7	69.5	54	0.6	62
April	22.3	148.4	68	tr.	68
May	8.1	73.8	59	0.0	70
June	0.1	2.5	55	0.0	70
July	tr.	tr.	50	0.0	70
August	tr.	tr.	42	0.0	70
September	0.3	6.2	65	0.0	70
October	3.7	25.6	66	0.0	64
November	17.2	77.8	57	tr.	66
December	22.9	90.1	54	1.8	65
Total	147.9	336.0	57	72.9	52

Table 2.2 Precipitation (mm) Baghdad (1941-1970)

B- The period when direct sunlight is required and the period when it should be excluded.

C- Sun duration time

D- Wind direction and speed

E- General weather phenomena and sky condition

For the purpose of the analysis the latest climatic data released in 1979 by the Iraqi meteorological organization was used [Ref. 201]. The procedure was that carried out in a previous work by the author, which was published by the Iraqi Building Research Centre in 1973 [Ref 191]. At that time the recorded data used was published by the Iraqi meteorological organization and covered the period 1931-1960.

The present discussion can therefore be considered as an updating of the previous work

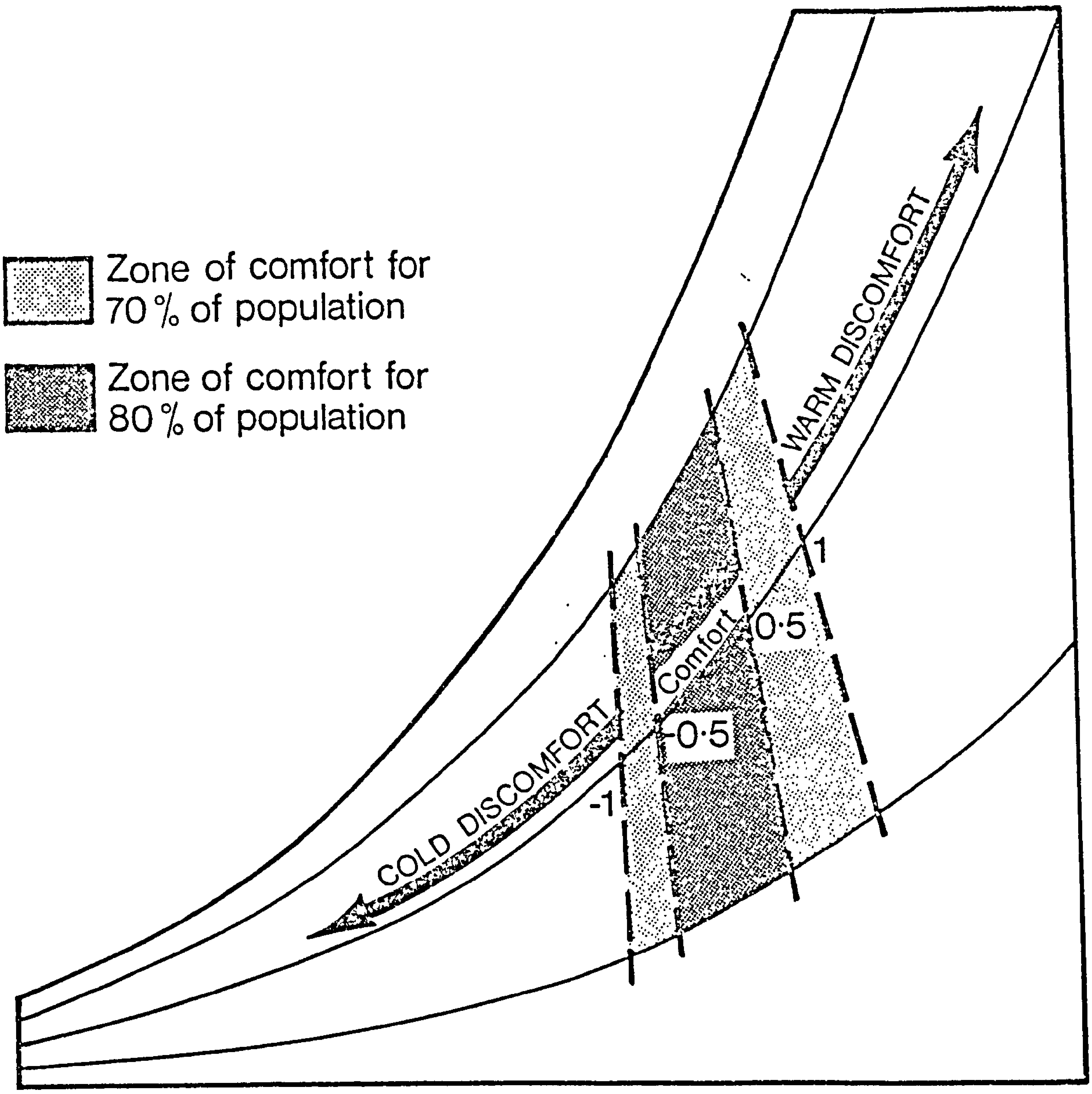
2.3.1 Day and Night Comfort

It is clear that people want direct sunlight for heating purposes when it is cold and no direct sunlight when it is moderate or hot. Therefore designers need to know the period when heating is needed, when neither heating nor cooling is required as well as those when cooling is esential.

To determine the comfort state in each month of the year and to determine the number of cold, moderate and hot months is one of the most important factors in environmental design as well as being one of the essential pieces of data required for this research. Initially thermal comfort has to be defined .

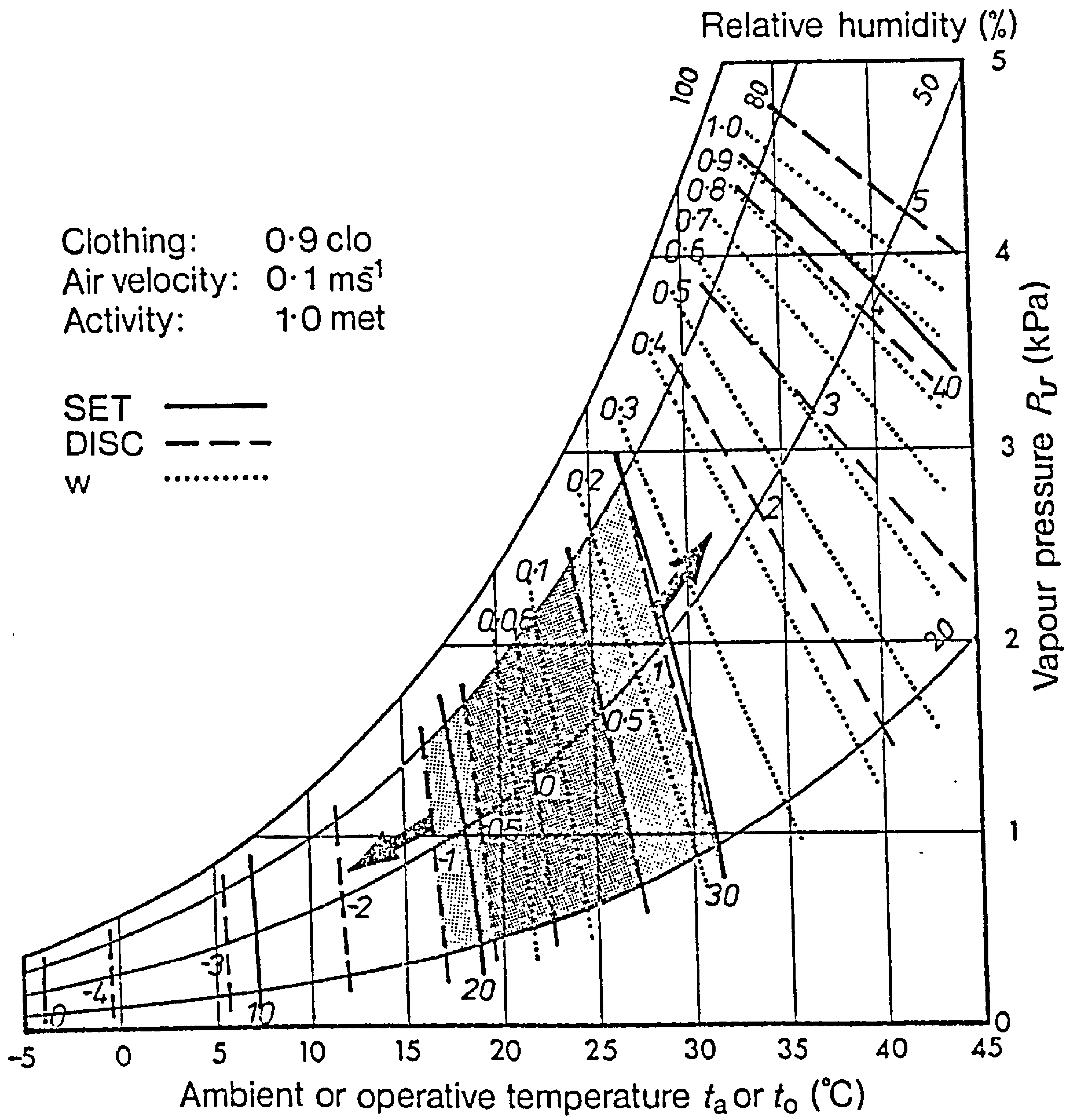
Thermal comfort is that condition when people desire neither cooling nor heating. The thermal comfort state depends not only on air temperature but on the combination of air temperature, mean radiant temperature, air velocity, relative humidity, activity level and clothing.

Often it is found that in a space with constant air temperature and velocity the atmosphere is judged to be hot, moderate or even cold depending upon the humidity. There is a substantial body of research on comfort limits with respect to all the variables affecting it. Much of it has been carried out, or supported by, those working on air conditioning. Architects later used these results and applied them in buildings having natural ventilation. The work of Bedford, Gagge and Fanger is widely accepted and Markus and Morris [Ref. 129] have proposed thermal comfort charts based on this work. They enable one to find comfort limits for most kinds of activities, clothing and practical wind velocities using Gagge's DISC comfort scale, which runs from -5 to +5, with thermal neutrality at 0, (see Figures 2.18 and 2.19). They specified two comfort zones (see Figure 2.17). The first, between -0.5 to +0.5, is the zone which meets the comfort judgement of 80% of the population and the second zone between -1.0 to +1.0 is that for 70% of the population.



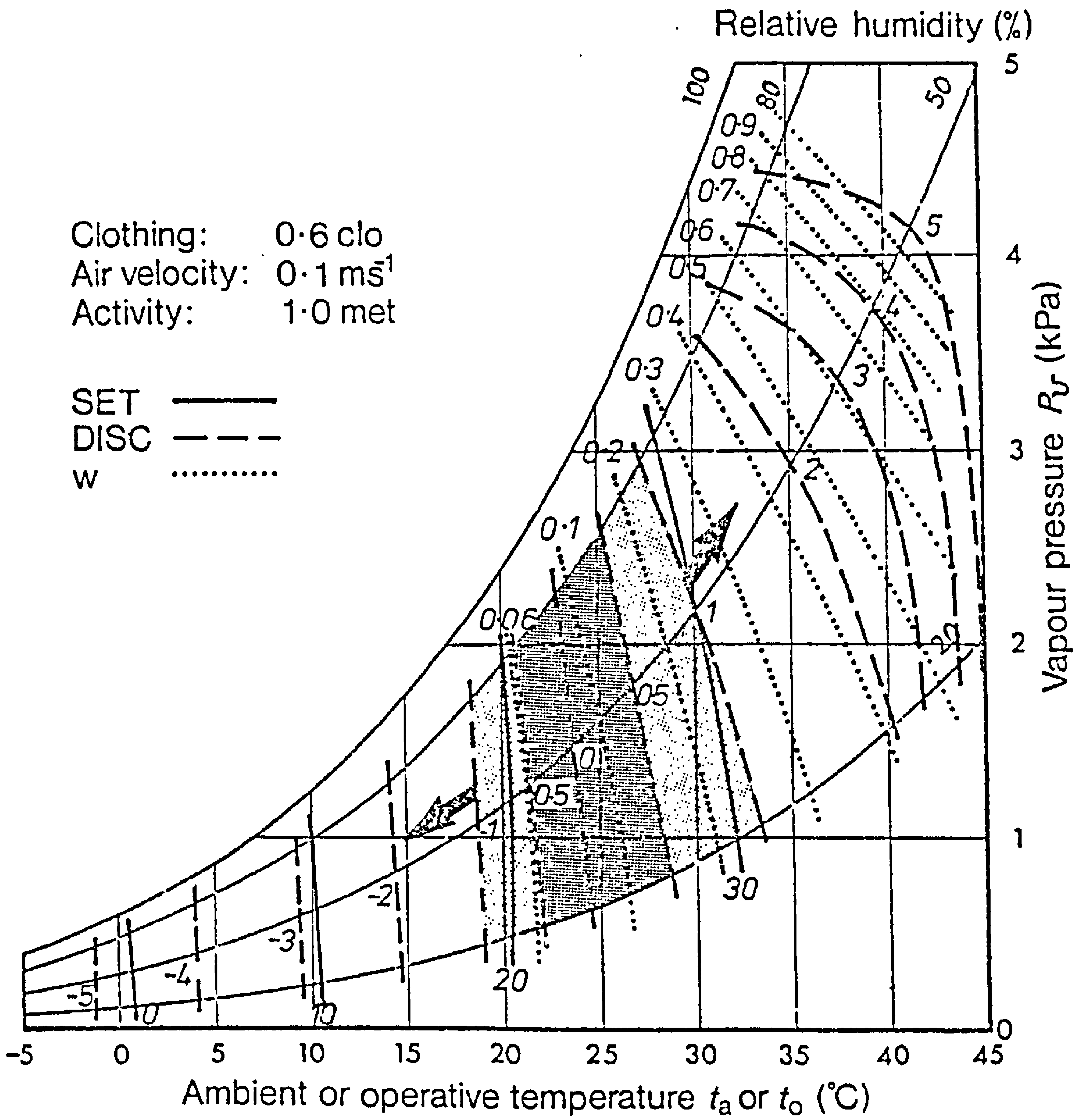
Key chart

Figure 2.17 (After Ref. 129)



Thermal comfort

Figure 2.18 (After Ref. 129)



Thermal comfort

Figure 2.19 (After Ref. 129)

A much simpler method was adopted by Mahoney who in his work, first published in 1971 by the United Nations [Ref. 212], introduced a Table for comfort limits which was based on the annual mean temperature of three different climatic regions, assuming low air velocity. Although Mahoney does not describe the basis on which his Table is constructed, when the author applied both methods, the DISC method introduced in the charts by Markus and Morris and the Table introduced by Mahoney for the Baghdad climate (see Table 2.3), he found that the thermal stress found by using the Mahoney Table is a little closer to his subjective experience of Baghdad than the result found by the DISC method. Therefore, until further work on determining the comfort limits for the Iraqi climate can be carried out, the Mahoney Tables are used as indicators of comfort for a climatic region with an annual mean temperature which is over 20 C .

Table 2.4 represents the result found from both the DISC charts (Figures 2.18 and 2.19) and the Mahoney Table (Table 2.4). For the former, the charts used were for 0.9clo, to determine day time comfort and for 0.6clo to determine night comfort (see figures 2.18 and 2.19).

Table 2.4 represents the Mahoney comfort limits and distinguishes between day comfort and night comfort. These limits are categorized according to the annual mean temperature of a region, and are presented in three categories.

Average R.H. %	H.G	AMT. over 20°C		AMT. 15°-20°C		AMT. under 15°C	
		Day	Night	Day	Night	Day	Night
0 - 30	1	26-34	17-25	23-32	14-23	21-30	12-21
30-50	2	25-31	17-24	22-30	14-22	20-70	12-19
50-70	3	23-29	17-23	21-28	14-21	19-26	12-19
70-100	4	22-27	17-21	20-25	14-20	18-24	12-18

Table 2.3 MAHONEY COMFORT LIMITS TABLE

LIST OF APREVIATIONS

AMT : Annual mean Temperature.

MMR : Monthly mean Range.

AMR : Annual mean Range.

HG. : Humidity group.

H : Above comfort limits (HOT)

M : Within comfort limits (COMFORTABLE)

C : Below comfort limts (COLD)

Month	Air Temperature °C		Relative Humidity Average %	DISC Value		Thermal Stress DISC		Thermal Stress Mahoney	
	Max.	Min.		Day	Night	Day	Night	Day	Night
January	15.4	5.8	67	-3	-3.8	C	C	C	C
February	17.8	7.4	59	-1	-3.6	C	C	C	C
March	22	10.8	52	-0.3	-2.8	M	C	C	C
April	27.9	15.8	46	+0.7	-1.7	M	C	M	C
May	35.1	21.3	34	+2	-0.6	H	M	H	M
June	40.4	25.0	24	+2.2	0.0	H	M	H	M
July	42.9	26.7	23	+2.5	+0.1	H	M	H	H
August	42.9	26.1	24	+2.5	+0.1	H	M	H	H
September	39.2	22.3	28	+2.5	-0.5	H	M	H	M
October	32.5	17.3	39	+1.6	-1.8	H	C	H	M
November	23.8	11.6	55	+0.4	-2.8	M	C	M	C
December	17	6.7	67	-1	-3.8	C	C	C	C

Table 2.4 Comparison of DISC and Mahoney.

A- A region where the annual mean temperature is under 15 °C.

B- A region where the annual mean temperature is between 15 °C and 20 °C.

C- A region where the annual mean temperature is over 20 °C.

The Mahoney method was used in this study to determine the thermal stress of each month for the three major cities in Iraq, which are located at latitude 30°, 33° and 36° north respectively (see Table 2.5, 2.6, 2.7).

Table 2.5C, which represents the south of Iraq, indicates that seven months are hot, two months are moderate and three months are cold.

Table 2.6C represents the middle area, Baghdad, and indicates six months are hot, two months are moderate and four months are cold.

Table 2.7C represents the north of Iraq, and indicates that seven months are hot to moderate and five are cold.

2.3.2 Periods When Direct Sunlight is Welcomed

From the information obtained from the implimentation of the Mahoney Tables, the months when sunlight has to be excluded, when no direct sun light is required and months when direct sunlight is most welcome were determined.

For direct sunlight control, moderate months are considered as the months where no direct sunlight is required, and hot months are the months where shading is essential. It was

BASRAH

	J	F	M	A	M	J	J	A	S	O	N	D	Highest	AMT
Monthly mean max.	17.7	20.2	24.2	29.5	35	38.0	39.7	40.5	38.6	34	25.7	19.1	40.5	24.1
Monthly mean min.	8.3	9.9	13.8	18.8	24.5	27.7	28.3	27	23.0	19.1	14.1	9.4	8.3	32.2
Monthly mean range	9.4	10.3	10.4	10.7	10.5	10.3	11.4	13.5	15.6	14.9	11.6	9.7	Lowest	AMR

Table 2.5a MAHONEY TABLE AIR TEMPERATURE ^{o} C

RH (percentage)		J	F	M	A	M	J	J	A	S	O	N	D	Total
Monthly mean max. a.m		89	85	79	74	66	60	59	59	62	70	81	88	
Monthly mean min. p.m		57	50	46	42	38	37	36	33	32	35	49	49	
	Average	77	71	64	59	53	50	49	48	50	55	68	78	
Humidity group		4	4	3	3	3	2	2	2	2	3	3	4	
Rain (mm)	Average of 30 days	22.5	13.8	20.2	20.4	7.8	0.0	0.1	0.0	0.0	1.0	22.8	30.3	162.5
	max. in 24 hrs	38.7	27.8	50.9	87.5	35.6	0.6	3.2	0.0	0.3	5.0	57.5	57.0	
Wind	Prevailing	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	
	Secondary	W	W	N	N	N	N	W	W	W	N	W	W	

Table 2.5b MAHONEY TABLE HUMIDITY, RAIN AND WIND

BASRAH

		J	F	M	A	M	J	J	A	S	O	N	D
Humidity group		4	4	3	3	3	2	2	2	2	3	3	4
AMT		24.1											
Monthly mean max.		17.7	20.2	24.2	29.5	35	38.0	39.7	40.5	38.6	34	25.7	19.1
Day comfort	Max.	27	27	29	29	29	31	31	31	31	20	29	27
	Min.	22	22	23	23	23	25	25	25	25	23	23	22
Monthly mean min.		8.3	9.9	13.8	18.8	24.5	27.7	28.3	27	23	19.1	14.1	9.4
Night comfort	Max.	21	21	23	23	23	24	24	24	24	23	23	21
	Min.	17	17	17	17	17	17	17	17	17	17	17	17
Thermal stress													
	Day	C	C	M	H	H	H	H	H	H	H	M	C
	Night	C	C	C	M	H	H	H	H	M	M	C	C

Table 2.5c MAHONEY TABLE DIAGNOSIS

H = Above comfort limits (HOT)

M = Within comfort limits (COMFORTABLE)

C = Below comfort limits (COLD)

BAGHDAD

	J	F	M	A	M	J	J	A	S	O	N	D	Highest	AMT
Monthly mean max.	15.4	17.8	22.0	27.9	35.1	40.4	42.9	42.9	39.2	32.5	23.8	17.0	42.9	22.9
Monthly mean min.	5.8	7.4	10.8	15.8	21.3	25	26.7	26.1	22.3	17.3	11.6	6.7	5.8	37.1
Monthly mean range	9.6	10.4	11.2	12.1	13.8	15.4	16.2	16.8	16.9	15.2	12.2	10.3	Lowest	AMR

Table 2.6a MAHONEY TABLE AIR TEMPERATURE ^{o}C

RH (percentage)		J	F	M	A	M	J	J	A	S	O	N	D	
Monthly mean max. a.m		84	77	70	63	48	34	32	35	40	50	71	83	
Monthly mean min. p.m		50	40	34	29	19	13	12	13	15	22	38	51	
Average		70	61	53	45	33	23	23	24	28	37	56	70	
Humidity group		4	3	3	2	2	1	1	1	1	2	3	4	Total
Rain (mm)	Average of 30 days	25.4	24.2	23.7	22.3	8.1	0.1	0.0	0.0	0.3	3.7	17.2	22.9	147.9
	max. in 24 hrs	52	47	50	71	65	2.5	0.0	0.0	6.2	22.3	48.9	40.0	
Wind	Prevailing	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	
	Secondary	SE	SE	SE	N	N	N	W	W	N	N	N	SE	

Table 2.6b MAHONEY TABLE HUMIDITY, RAIN AND WIND

BAGHDAD

		J	F	M	A	M	J	J	A	S	O	N	D
Humidity group		4	3	3	2	2	1	1	1	1	2	3	4
AMT							22.9						
Monthly mean max.		15.4	17.8	22.0	27.9	35.1	40.4	42.9	42.9	39.2	32.5	23.8	17.0
Day comfort	Max.	27	29	29	31	31	34	34	34	34	31	29	27
	Min.	22	23	23	25	25	26	26	26	26	25	23	22
Monthly mean min.		5.8	7.4	10.8	15.8	21.3	25	26.7	26.1	22.3	17.3	11.6	6.7
Night comfort	Max.	21	23	23	24	24	25	25	25	25	24	23	21
	Min.	17	17	17	17	17	17	17	17	17	17	17	17
Thermal stress													
	Day	C	C	C	M	H	H	H	H	H	H	M	C
	Night	C	C	C	C	M	M	H	H	M	M	C	C

Table 2.6c MAHONEY TABLE DIAGNOSIS

H = Above comfort limits (HOT)

M = Within comfort limits (COMFORTABLE)

C = Below comfort limits (COLD)

MOSUL

	J	F	M	A	M	J	J	A	S	O	N	D		
													Highest	AMT
Monthly mean max.	12.0	14.2	18.0	24.1	31.8	38.8	42.6	42.4	37.7	30.1	21.4	14.2	42.6	20
Monthly mean min.	3.8	4.5	7.3	11.2	16.6	21.6	24.7	23.2	17.7	12.5	8.1	4.5	3.8	38.8
													Lowest	AMR
Monthly mean range	8.2	9.7	10.7	12.9	15.2	17.2	17.9	19.2	20	17.6	13.3	9.7		

Table 2.7a MAHONEY TABLE AIR TEMPERATURE ^{o}C

RH (percentage)		J	F	M	A	M	J	J	A	S	O	N	D	
Monthly mean max. a.m		90	89	87	84	71	50	45.0	48	58	69	83	90	
Monthly mean min. p.m		63	55	49	41	27	16	15.0	16	19	28	44	59	
Average		82	76	71	64	48	31	28	30	37	47	67	79	
Humidity group		4	4	4	3	2	2	1	1	2	2	3	4	Total
Rain (mm)	Average of 30 days	67	64.2	69.6	50.8	24.7	0.7	0.1	0.0	0.7	9.9	36.1	67.3	391.9
	max. in 24 hrs	39.9	56.7	53.2	54.4	40.4	5.4	2.3	0.2	7.1	30.2	71.6	70.9	
Wind	Prevailing	E	E	W	W	W	W	W	W	W	W	W	W	
	Secondary	W	W	E	E	N	N	N	N	N	N	N	E	

Table 2.7b MAHONEY TABLE HUMIDITY, RAIN AND WIND

MOSUL

		J	F	M	A	M	J	J	A	S	O	N	D
Humidity group		4	4	4	3	2	2	1	1	2	2	3	4
AMT		20											
Monthly mean max.		12	14.2	18.0	24.1	31.8	38.8	42.6	42.4	37.7	30.0	21.4	14.2
Day comfort	Max.	27	27	27	29	31	31	34	34	31	31	29	29
	Min.	22	22	22	23	25	25	26	26	25	25	23	23
Monthly mean min.		3.8	4.5	7.3	11.2	16.6	21.6	24.7	23.2	17.7	12.5	8.1	4.5
Night comfort	Max.	21	21	21	23	24	24	25	25	24	24	23	25
	Min.	17	17	17	17	17	17	17	17	17	17	17	17
Thermal stress													
	Day	C	C	C	M	H	H	H	H	H	M	C	C
	Night	C	C	C	C	C	M	M	M	M	C	C	C

Table 2.7c MAHONEY TABLE DIAGNOSIS

H = Above comfort limits (HOT)

M = Within comfort limits (COMFORTABLE)

C = Below comfort limits (COLD)

decided to treat hot and moderate months as being equivalent periods, when direct sunlight control is necessary.

Referring to Tables 2.5, 2.6, 2.7 cold months in the southern area of Iraq (Basrah) amount to 3, for the middle (Baghdad) 4 and for the north (Mosul) 5. For the purpose of the present study, and taking into account the relatively small climatic difference between the north and the middle of Iraq and between the south and the middle, which amounts to just one cold month, and in order to generalize this work to cover the major part of Iraq, the middle area (Baghdad climate) was taken as being the reference climate. Accordingly direct sunlight is welcome inside houses for four months of the year, while protection from direct sunlight is required for the the remaining eight months. Therefore,the "summer" period is shown to be twice the "winter" period and this ratio will be considered as a tool in the process of direct sunlight control.

2.3.3 Sun Duration Time

In summer most parts of Iraq have a sun duration time of about 14 hours.

In spring and autumn the sun duration time is 12 hours. In winter-time, because of the presence of varied amount of cloud, the sun duration time is not the same in all regions, though, one can enjoy at least 4 hours of sun-shine in this season, especially since it is only 3.4 days a month that the sky is completely cloudy. For almost

10 days a month there is a clear sky and for the remainder of the month the sky is partially cloudy.
The present study provides designers with a Table of sun angles and sun exposure times on each of the 16 major orientations, so that they are free to decide and select the most suitable orientation for their building, windows and openings (see Table 2.8).

2.3.4 Wind Speed and Direction

Wind plays an important part in the body cooling process as well as for the cooling the building fabric. Thus, knowing the direction and speed of the wind helps in the process of choosing and obtaining the maximum benefit from this natural cooling facility.
Referring to the Table of analysis (Tables 2.5, 2.6, 2.7) the prevailing wind direction for the south and the middle of Iraq is north-west, while in the north it deviates slightly to become west especially during spring and autumn when natural ventilation is necessary for cooling in day-time and for the summer season when natural ventilation for cooling purposes is also needed at night. In the winter period in the northern part of Iraq the prevailing wind shifts its direction from west to east and occasionally it is north. In this study, and because natural ventilation is considered for body cooling purposes only, winter shifts in wind direction will not be considered

Table 2.8 Solar Angles in Baghdad for Eleven Declinations.

LATITUDE: 33.0 DATE: 22 JUNE DECLINATION: 23.4

TIME HR	HR ANG	Z	A	ORIENT:N=0 HS	VS	OR:22.5 HS	VS	OR:45.0 HS	VS	OR:67.5 HS	VS	OR:90.0 HS	VS	OR:112.5 HS	VS	OR:135.0 HS	VS
5	105	62	1	62	2	40	1	17	1	-5	1	-28	1	-50	2	-73	3
6	90	70	13	70	33	48	18	25	14	3	13	-20	13	-42	17	-65	28
7	95	77	25	77	64	55	38	32	28	10	25	-13	25	-35	29	-58	41
8	60	84	37	84	82	61	55	39	44	16	38	-6	37	-29	41	-51	50
9	45	92	50			69	73	47	60	24	52	2	50	-21	51	-43	58
10	30	107	62			80	85	57	74	35	66	12	63	-10	62	-33	66
11	15	122	74					77	86	55	80	32	76	10	74	-13	74
12	0	180	80									90	90	58	86	45	83
13	-15	238	74														
14	-30	258	62														
15	-45	268	50														
16	-60	276	37	-84	82												
17	-75	283	25	-77	64												
18	-90	290	13	-70	33												
19	-105	298	1	-62	2	-85	11										

TIME HR	OR:157.5 HS	VS	OR:180.0 HS	VS	OR:202.5 HS	VS	OR:225.0 HS	VS	OR:247.5 HS	VS	OR:270.0 HS	VS	OR:292.5 HS	VS	OR:315.0 HS	VS	OR:337.5 HS	VS
5																		
6	-87	79																
7	-80	70																
8	-74	69																
9	-66	71	-88	89														
10	-55	73	-78	84														
11	-35	77	-58	81	-80	87												
12	23	81	0	80	-23	81	-45	83	-68	86	-90	90						
13	80	87	58	81	35	77	13	74	-10	74	-32	76	-55	80	-77	86		
14			78	84	55	73	33	66	10	62	-12	63	-35	66	-57	74	-80	85
15			88	89	66	71	43	58	21	51	-2	50	-24	52	-47	60	-69	73
16					74	69	51	50	29	41	6	37	-16	38	-39	44	-61	58
17					80	70	58	41	35	29	13	25	-10	25	-32	28	-55	38
18					87	79	65	28	42	17	20	13	-3	18	-25	14	-48	13
19							73	3	50	2	28	1	5	1	-17	1	-40	1

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	106	4 54	62
SUN SET :	-106	19 6	298

Table 2.8a

LATITUDE: 33.0 DATE: 21 MAY OR 24 JULY DECLINATION: 20.0

TIME HR	HR ANG	Z	A	ORIENT:N=0 HS	VS	OR:22.5 HS	VS	OR:45.0 HS	VS	OR:67.5 HS	VS	OR:90.0 HS	VS	OR:112.5 HS	VS	OR:135.0 HS	VS
6	90	73	11	73	33	51	17	28	12	6	11	-17	11	-39	14	-62	22
7	75	80	23	80	68	58	39	35	27	13	23	-10	23	-32	27	-55	36
8	60	88	35	88	87	65	60	43	44	20	37	-2	35	-25	38	-47	46
9	45	95	48			74	76	51	61	29	52	6	48	-16	49	-39	55
10	30	108	60			86	88	63	76	41	57	18	62	-4	50	-27	63
11	15	130	71					85	88	63	81	40	76	18	72	-5	71
12	0	180	77									90	90	68	85	45	81
13	-15	230	71														
14	-30	252	60														
15	-45	264	48														
16	-60	272	35	-88	87												
17	-75	280	23	-80	68												
18	-90	287	11	-73	33												

TIME HR	OR:157.5 HS	VS	OR:180.0 HS	VS	OR:202.5 HS	VS	OR:225.0 HS	VS	OR:247.5 HS	VS	OR:270.0 HS	VS	OR:292.5 HS	VS	OR:315.0 HS	VS	OR:337.5 HS	VS
6	-84	63																
7	-77	62																
8	-70	64																
9	-61	66	-84	84														
10	-49	70	-72	80														
11	-27	73	-50	79	-72	84												
12	23	78	0	77	-23	78	-45	81	-68	85	-90	90						
13	72	84	50	78	27	73	5	71	-18	72	-40	76	-63	81	-85	88		
14			72	80	49	70	27	63	4	60	-18	62	-41	67	-63	76	-86	38
15			84	84	61	66	39	55	16	49	-6	48	-29	52	-51	61	-74	76
16					70	64	47	46	25	38	2	35	-20	37	-43	44	-65	60
17					77	62	55	36	32	27	10	23	-13	29	-35	27	-58	39
18					84	63	62	22	39	14	17	11	-6	11	-28	12	-51	17

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	104	5 5	66
SUN SET :	-104	18 55	294

Table 2.8b

LATITUDE: 33.0 DATE: 1 MAY OR 13 AUG DECLINATION: 15.0

TIME HR	HR ANG	Z	A	ORIENT:N=0		OR:22.5		OR:45.0		OR:67.5		OR:90.0		OR:112.5		OR:135.0		OR:157.5	
				HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS
6	90	77	8	77	33	55	14	32	10	10	8	-13	8	-35	10	-58	15	-80	40
7	75	85	21	85	77	63	39	40	26	18	21	-5	21	-27	23	-50	30	-72	51
8	60	93	33			71	63	48	44	26	36	3	33	-19	35	-42	41	-64	55
9	45	103	46			80	81	58	62	35	51	13	46	-10	46	-32	50	-55	60
10	30	116	57					71	78	49	67	26	60	4	57	-19	59	-41	64
11	15	139	67							72	83	49	75	27	70	4	67	-18	68
12	0	180	72									90	90	68	83	45	77	23	73
13	-15	221	67													86	88	63	79
14	-30	244	57															86	88
15	-45	257	46																
16	-60	267	33																
17	-75	275	21	-85	77														
18	-90	283	8	-77	33														

TIME HR	OR:180.0		OR:202.5		OR:225.0		OR:247.5		OR:270.0		OR:292.5		OR:315.0		OR:337.5	
	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS
6																
7																
8	-87	85														
9	-77	78														
10	-64	74	-86	88												
11	-41	73	-63	79	-86	88										
12	0	72	-23	73	-45	77	-68	83	-90	90						
13	41	73	18	68	-4	67	-27	70	-49	75	-72	83				
14	64	74	41	64	19	59	-4	57	-26	60	-49	67	-71	78		
15	77	78	55	60	32	50	10	46	-13	46	-35	51	-58	62	-80	81
16	87	85	64	56	42	41	19	35	-3	33	-26	36	-48	44	-71	63
17			72	51	50	30	27	23	5	21	-18	21	-40	26	-63	39
18			80	40	58	15	35	10	13	8	-10	8	-32	10	-55	14

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	100	5 19	72
SUN SET :	-100	18 41	288

Table 2.8c

LATITUDE: 33.0 DATE: 16 APRIL OR 28 AUG DECLINATION: 10.0

TIME HR	HR ANG	Z	A	ORIENT:N=0		OR:22.5		OR:45.0		OR:67.5		OR:90.0		OR:112.5		OR:135.0		OR:157.5	
				HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS
6	90	82	5	82	33	59	10	37	7	14	6	-8	5	-31	6	-53	9	-76	21
7	75	90	18	90	89	67	40	45	24	22	19	0	18	-23	19	-45	25	-68	41
8	60	98	31			76	67	53	45	31	34	8	31	-14	31	-37	36	-59	49
9	45	109	43			86	86	64	64	41	51	19	44	-4	43	-26	46	-49	55
10	30	123	54					78	81	55	68	33	59	10	55	-12	55	-35	59
11	15	146	63							78	84	56	74	33	67	11	64	-12	64
12	0	180	67									90	90	68	81	45	73	23	69
13	-15	214	63													79	85	57	75
14	-30	237	54															80	83
15	-45	251	43																
16	-60	262	31																
17	-75	270	18	-90	89														
18	-90	278	5	-82	33														

TIME HR	OR:180.0		OR:202.5		OR:225.0		OR:247.5		OR:270.0		OR:292.5		OR:315.0		OR:337.5	
	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS
6																
7																
8	-82	76														
9	-71	71														
10	-57	69	-80	83												
11	-34	67	-57	75	-79	85										
12	0	67	-23	69	-45	73	-68	81	-90	90						
13	34	67	12	64	-11	64	-33	67	-56	74	-78	84				
14	57	69	35	59	12	55	-10	55	-33	59	-55	68	-78	81		
15	71	71	49	55	26	46	4	43	-19	44	-41	51	-64	64	-86	86
16	82	76	59	49	37	36	14	31	-8	31	-31	34	-53	45	-76	67
17			68	41	45	25	23	19	0	18	-22	19	-45	24	-67	40
18			76	21	53	9	31	6	8	5	-14	6	-37	7	-59	10

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	97	5 33	78
SUN SET :	-97	18 27	282

Table 2.8d

LATITUDE: 33.0 DATE: 3 APRIL OR 11 SEPT DECLINATION: 5.0

TIME HR	HR ANG	Z	A	ORIENT:N=0 HS	VS	OR:22.5 HS	VS	OR:45.0 HS	VS	OR:67.5 HS	VS	OR:90.0 HS	VS	OR:112.5 HS	VS	OR:135.0 HS	VS	OR:157.5 HS	VS
6	90	86	3	86	33	63	6	41	4	18	3	-4	3	-27	3	-49	4	-72	9
7	75	94	15			72	41	49	23	27	17	4	15	-18	16	-41	20	-63	31
8	60	103	28			80	72	58	45	35	33	13	28	-10	28	-32	32	-55	42
9	45	114	40					69	66	46	50	24	42	1	40	-21	42	-44	49
10	30	129	50					84	85	61	68	39	57	16	52	-6	51	-29	54
11	15	150	59							83	86	60	73	38	64	15	60	-7	59
12	0	180	62									90	90	68	78	45	69	23	64
13	-15	210	59													75	81	52	70
14	-30	231	50															74	77
15	-45	246	40															89	88
16	-60	257	28																
17	-75	266	15																
18	-90	274	3	-86	33														

TIME HR	OR:180.0 HS	VS	OR:202.5 HS	VS	OR:225.0 HS	VS	OR:247.5 HS	VS	OR:270.0 HS	VS	OR:292.5 HS	VS	OR:315.0 HS	VS	OR:337.5 HS	VS
6																
7	-86	76														
8	-77	67														
9	-66	64	-89	88												
10	-51	63	-74	77												
11	-30	62	-52	70	-75	81										
12	0	62	-23	64	-45	69	-68	78	-90	90						
13	30	62	7	59	-15	60	-38	64	-60	73	-83	86				
14	51	63	29	54	6	51	-16	52	-39	57	-61	68	-84	85		
15	66	64	44	49	21	42	-1	40	-24	42	-46	50	-69	66		
16	77	67	55	42	32	32	10	23	-13	28	-35	33	-58	45	-80	72
17	86	76	63	31	41	20	18	16	-4	15	-27	17	-49	23	-72	41
18			72	9	49	4	27	3	4	3	-18	3	-41	4	-63	6

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	93	5 46	89
SUN SET :	-93	18 14	276

Table 2.8e

LATITUDE 33.0 DATE MARCH 21 OR 24 SEPT. DECLINATION 0 0

TIME HR	HR ANG	Z	A	ORIENT:N=0 HS	VS	OR:22.5 HS	VS	OR:45.0 HS	VS	OR:67.5 HS	VS	OR:90.0 HS	VS	OR:112.5 HS	VS	OR:135.0 HS	VS	OR:157.5 HS	VS
6	90	90	0	90	1	67	0	45	0	22	0	0	0	-23	0	-45	0	-68	0
7	75	98	13			76	42	53	20	31	15	8	13	-14	13	-37	16	-59	23
8	60	107	25			85	79	62	45	40	31	17	26	-5	25	-28	28	-50	36
9	45	119	36					74	69	51	50	29	40	6	37	-16	38	-39	43
10	30	133	47					88	88	66	69	43	55	21	49	-2	47	-24	49
11	15	154	54							86	87	64	72	41	61	19	56	-4	54
12	0	180	57									90	90	68	76	45	65	23	59
13	-15	206	54													71	77	49	64
14	-30	227	47															69	71
15	-45	241	36															84	82
16	-60	253	25																
17	-75	262	13																
18	-90	270	0	-90	1														

TIME HR	OR:180.0 HS	VS	OR:202.5 HS	VS	OR:225.0 HS	VS	OR:247.5 HS	VS	OR:270.0 HS	VS	OR:292.5 HS	VS	OR:315.0 HS	VS	OR:337.5 HS	VS
6																
7	-82	57														
8	-73	57														
9	-61	57	-84	82												
10	-47	57	-69	71												
11	-26	57	-49	64	-71	77										
12	0	57	-23	59	-45	65	-68	76	-90	90						
13	26	57	4	54	-19	56	-41	61	-64	72	-86	87				
14	47	57	24	49	2	47	-21	49	-43	55	-66	69	-88	88		
15	61	57	39	43	16	38	-6	37	-29	40	-51	50	-74	69		
16	73	57	50	36	28	28	5	25	-17	26	-40	31	-62	45	-85	79
17	82	57	59	23	37	16	14	13	-8	13	-31	15	-53	20	-76	42
18			68	0	45	0	23	0			-22	0	-45	0	-67	0

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	90	5 59	90
SUN SET :	-90	18 1	270

Table 2.8f

LATITUDE: 33.0 DATE: 8 MARCH OR 6 OCT DECLINATION: -5.0

TIME HR	HR ANG	Z	A	ORIENT:N=0		OR:22.5		OR:45.0		OR:67.5		OR:90.0		OR:112.5		OR:135.0		OR:157.5		OR:180.0		OR:202.5		OR:225.0		OR:247.5		OR:270.0		OR:292.5		OR:315.0		OR:337.5	
				HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	V	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS
7	75	103	10			80	45	58	18	35	12	13	10	-10	10	-32	11	-55	17	-77	38														
8	60	112	22			89	88	67	45	44	29	22	23	-1	22	-23	23	-46	30	-68	47														
9	45	123	39					75	72	55	49	33	38	10	33	-12	33	-35	38	-57	50	-80	74												
10	30	137	43							70	70	47	54	25	45	2	43	-20	44	-43	51	-65	65	-88	87										
11	15	157	49							89	89	67	71	44	58	22	51	-1	49	-23	52	-46	59	-68	72										
12	0	180	52									90	90	68	73	45	61	23	54	0	52	-23	54	-45	61	-68	73	-90	90						
13	-15	203	49													68	72	46	59	23	52	1	49	-22	51	-44	58	-67	71	-89	89				
14	-30	223	43													88	87	65	65	43	51	20	44	-2	43	-25	45	-47	54	-70	70				
15	-45	237	33															80	74	57	50	35	38	12	33	-10	33	-33	38	-55	49	-78	72		
16	-60	248	22																	68	47	46	30	23	23	1	22	-22	23	-44	29	-67	45	-89	88
17	-75	257	10																	77	38	56	17	32	11	10	10	-13	12	-36	12	-58	18	-80	41

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	87	6 13	96
SUN SET :	-87	17 47	264

Table 2.8g

LATITUDE: 33.0 DATE: 23 FEB OR 20 OCT DECLINATION: -10.0

TIME HR	HR ANG	Z	A	ORIENT:N=0		OR:22.5		OR:45.0		OR:67.5		OR:90.0		OR:112.5		OR:135.0		OR:157.5		OR:180.0		OR:202.5		OR:225.0		OR:247.5		OR:270.0		OR:292.5		OR:315.0		OR:337.5	
				HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS	HS	VS
7	75	107	7			84	50	62	14	39	9	17	7	-6	7	-28	8	-51	11	-73	23														
8	60	116	19					71	46	48	27	26	20	3	19	-19	20	-42	24	-64	38	-87	80												
9	45	127	29					82	76	60	48	37	35	15	30	-8	30	-30	33	-53	43	-75	66												
10	30	141	38							74	70	51	52	29	42	6	39	-16	40	-39	45	-61	59	-84	82										
11	15	159	45									69	70	46	55	24	47	1	45	-21	47	-44	54	-66	68	-89	88								
12	0	180	47									90	90	68	70	45	57	23	49	0	47	-23	49	-45	57	-68	70	-90	90						
13	-15	201	45											89	88	66	68	44	54	21	47	-1	45	-24	47	-46	55	-69	70						
14	-30	219	38													84	82	61	59	39	45	16	40	-6	39	-29	42	-51	52	-74	70				
15	-45	233	29															75	66	53	43	30	33	8	30	-15	30	-37	35	-60	48	-82	76		
16	-60	244	19															87	80	64	38	42	24	19	20	-3	19	-26	20	-48	27	-71	46		
17	-75	253	7																	73	23	51	11	28	8	6	7	-17	7	-39	9	-62	14	-84	50

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	83	6 26	102
SUN SET :	-83	17 34	258

Table 2.8h

LATITUDE: 33.0 DATE: 9 FEB OR 4 NOV DECLINATION: -15.0

TIME HR	HR ANG	Z	A	ORIENT:N=0 HS	VS	OR:22.5 HS	VS	OR:45.0 HS	VS	OR:67.5 HS	VS	OR:90.0 HS	VS	OR:112.5 HS	VS	OR:135.0 HS	VS	OR:157.5 HS	VS	OR:180.0 HS	VS	OR:202.5 HS	VS	OR:225.0 HS	VS	OR:247.5 HS	VS	OR:270.0 HS	VS	OR:292.5 HS	VS	OR:315.0 HS	VS	OR:337.5 HS	VS
7	75	111	4			88	66	66	10	43	5	21	4	-2	4	-24	4	-47	6	-69	11														
8	60	120	15					75	46	52	24	30	18	7	15	-15	16	-38	19	-60	29	-83	69												
9	45	131	26					65	81	63	47	41	32	18	27	-4	26	-27	28	-49	36	-72	57												
10	30	144	34							77	71	54	49	32	39	9	34	-13	35	-36	40	-58	52	-21	77										
11	15	161	40									71	69	48	52	26	43	3	40	-19	41	-42	48	-64	62	-87	86								
12	0	180	42									90	90	68	67	45	52	23	44	0	42	-23	44	-45	52	-68	67	-90	90						
13	-15	199	40											87	86	64	62	42	48	19	41	-3	40	-26	43	-48	52	-71	69						
14	-30	216	34													81	77	58	52	36	40	13	35	-9	34	-32	39	-54	49	-77	71				
15	-45	229	26															72	57	49	36	17	28	4	26	-18	27	-41	32	-63	47	-86	81		
16	-60	240	15															83	65	60	29	30	19	15	16	-7	15	-30	18	-52	24	-75	46		
17	-75	249	4																	69	10	47	6	24	4	2	4	-21	4	-43	5	-66	10	-88	66

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	80	6 40	108
SUN SET :	-80	17 20	252

Table 2.8i

LATITUDE: 33.0 DATE: 21 JAN OR 22 NOV DECLINATION: -20.0

TIME HR	HR ANG	Z	A	ORIENT:N=0 HS	VS	OR:22.5 HS	VS	OR:45.0 HS	VS	OR:67.5 HS	VS	OR:90.0 HS	VS	OR:112.5 HS	VS	OR:135.0 HS	VS	OR:157.5 HS	VS	OR:180.0 HS	VS	OR:202.5 HS	VS	OR:225.0 HS	VS	OR:247.5 HS	VS	OR:270.0 HS	VS	OR:292.5 HS	VS	OR:315.0 HS	VS	OR:337.5 HS	VS
7	75	115	1					70	3	47	1	25	1	2	1	-20	1	-43	1	-65	2	-88	24												
8	60	124	12					79	47	56	21	34	14	11	12	-11	12	-34	14	-56	21	-79	48												
9	45	134	22					69	88	67	45	44	29	22	23	-1	22	-23	23	-46	30	-68	47												
10	30	147	30							80	73	57	47	35	35	12	30	-10	30	-33	34	-55	45	-78	70										
11	15	163	35									73	67	50	48	28	38	5	35	-17	36	-40	42	-62	57	-85	81								
12	0	180	37									90	90	68	63	45	47	23	39	0	37	-23	38	-45	47	-68	61	-90	90						
13	-15	197	35											85	83	62	57	40	42	17	36	-5	34	-28	38	-50	48	-73	67						
14	-30	213	30													75	70	55	45	33	34	10	30	-12	30	-35	35	-57	47	-80	71				
15	-45	226	22															68	47	46	30	23	23	1	22	-22	23	-44	29	-67	45	-89	88		
16	-60	236	12															79	48	56	21	34	14	11	12	-11	12	-34	14	-56	21	-79	47		
17	-75	245	1															88	24	65	2			20	1	-2	1	-25	1	-46	3	-70	3		

	HR ANG	TIME(HR MIN)	Z
SUNRISE:	76	6 54	114
SUN SET :	-76	17 6	246

Table 2.8j

LATITUDE: 33.0 DATE: 22 DEC. DECLINATION: -23.4

TIME HR	HR ANG	Z	A	ORIENT:N=0 HS	VS	OR:22.5 HS	VS	OR:45.0 HS	VS	OR:67.5 HS	VS	OR:90.0 HS	VS	OR:112.5 HS	VS	OR:135.0 HS	VS
8	60	126	10					81	48	59	18	36	12	14	10	-9	10
9	45	137	19							69	44	47	27	24	21	2	19
10	30	149	27							82	74	59	44	37	32	14	27
11	15	164	32									74	66	51	45	29	35
12	0	180	34									90	90	68	60	45	43
13	-15	196	32											84	80	61	52
14	-30	211	27													75	64
15	-45	223	19													88	85
16	-60	234	10														

TIME HR	OR:157.5 HS	VS	OR:180.0 HS	VS	OR:202.5 HS	VS	OR:225.0 HS	VS	OR:247.5 HS	VS	OR:270.0 HS	VS	OR:292.5 HS	VS	OR:315.0 HS	VS	OR:337.5 HS	VS
8	-31	11	-54	16	-76	36												
9	-21	20	-43	25	-66	40	-88	85										
10	-8	27	-31	30	-53	40	-76	64										
11	6	32	-16	33	-39	38	-61	52	-84	80								
12	23	36	0	34	-23	36	-45	43	-68	60	-90	90						
13	39	38	16	33	-6	32	-29	35	-51	45	-74	66						
14	53	40	31	30	8	27	-14	27	-37	32	-59	44	-82	74				
15	66	40	43	25	21	20	-2	19	-24	21	-47	27	-69	46				
16	76	36	54	16	31	11	9	10	-14	10	-36	12	-59	10	-81	48		

	HR ANG	TIME(HR MIN)	Z
SUN RISE:	74	7 5	118
SUN SET :	-74	16 55	242

Table 2.8k

Therefore for the prevailing wind a north west direction has been used for the natural ventilation part of the present study

As shown in Table 2.9 the highest mean surface wind speed in the north of Iraq is 2.8m/s and the lowest mean is 1.6m/s

Table 2.1 shows that the highest surface wind speed in Baghdad is 4.5m/s and the lowest is 2.5m/s

The maximum surface wind speed in the south of Iraq indicated in Table 2.10 is 4.1m/s and the lowest is 2.5

In spring and autumn, when open, shaded spaces are comfortable, natural ventilation is nevertheless required inside buildings during daytime to cool the internal spaces which are heated by the impact of solar radiation.

Therefore the averages of the mean 24-hour wind speeds during these months in the three regions were found and the value of 2.7m/s was considered to represent a reasonable one for the measurements and calculations in this study.

2.3.5 Baghdad Sky Condition

Table 2.11 indicates that 205 days in the year have clear skies, 22 days cloudy and 20 days are dusty. The remainder of the year has semi-clear skies either because of the existence of some clouds or due to moderate levels of dust particles. Therefore, on average, the Baghdad sky has been considered as clear.

Month	Hours of Observation - Local Time								Mean
	0.0	0300	0600	0900	1200	1500	1800	2100	
January	1.6	1.5	1.5	1.9	2.9	2.9	1.9	1.8	2.0
February	1.8	1.7	1.6	2.2	3.4	3.4	2.4	2.0	2.3
March	1.7	1.4	1.7	2.2	3.1	3.3	2.7	2.1	2.3
April	1.9	1.5	1.5	2.3	3.4	3.6	3.0	2.2	2.4
May	1.9	1.7	1.7	2.7	3.5	4.0	3.5	2.4	2.7
June	2.1	1.8	1.8	2.9	3.5	4.0	3.5	2.8	2.8
July	2.2	2.1	1.9	3.1	3.3	3.5	3.0	2.8	2.7
August	2.0	1.7	1.6	2.9	3.1	3.5	2.9	2.9	2.6
September	1.5	1.4	1.2	2.4	3.0	3.4	2.4	2.4	2.2
October	1.3	1.2	1.3	2.0	2.5	2.8	1.8	1.7	1.8
November	1.1	1.1	1.3	1.8	2.3	2.5	1.5	1.3	1.6
December	1.1	1.2	1.3	1.6	2.5	2.5	1.5	1.3	1.6
Annual	1.7	1.5	1.5	2.3	3.0	3.3	2.5	2.1	2.2

Table 2.9 Mean Surface-wind Speed $^{m}/s$ for Mosul (1941-1970)

Month	Hours of Observation - Local Time								Mean
	0.0	0300	0600	0900	1200	1500	1800	2100	
January	2.3	2.2	2.2	2.7	3.9	3.8	2.6	2.5	2.8
February	2.5	2.4	2.3	3.0	4.5	4.6	3.1	2.7	3.1
March	2.8	2.6	2.7	3.5	4.7	4.9	3.4	2.9	3.4
April	2.8	2.5	2.3	3.4	4.4	4.8	3.3	2.8	3.3
May	3.0	2.8	2.5	3.5	4.6	4.7	3.0	2.7	3.4
June	3.9	3.5	3.3	4.5	5.3	5.3	3.5	3.6	4.1
July	3.4	3.1	2.9	4.0	4.6	4.7	3.3	3.5	3.7
August	3.1	2.7	2.5	3.5	4.5	4.6	2.9	3.2	3.4
September	2.6	2.5	2.2	2.9	3.9	4.2	2.3	2.5	2.9
October	2.3	2.3	2.0	2.3	3.3	3.3	2.2	2.3	2.5
November	2.3	2.1	2.0	2.4	3.3	3.3	2.4	2.2	2.5
December	2.2	1.9	1.9	2.4	3.5	3.4	2.3	2.2	2.5
Annual	2.8	2.6	2.4	3.2	4.2	4.3	2.9	2.8	3.1

Table 2.10 Mean Surface-wind Speed $^m/_s$ for Basrah (1941-1970)

	MOSUL				BAGHDAD				BASRAH			
	SKY		DUST		SKY		DUST		SKY		DUST	
Month	Clear	Cloudy	Storm	Rising	Clear	Cloudy	Storm	Rising	Clear	Cloudy	Storm	Rising
January	5.7	9.3	0.1	0.5	10.0	3.4	1.2	2.3	12.0	3.0	0.3	1.4
February	6.1	7.5	0.1	0.4	9.6	3.1	2.1	3.1	12.3	2.2	0.7	2.3
March	4.4	7.4	0.4	1.5	8.2	3.7	2.4	4.8	11.8	2.7	1.3	5.3
April	5.7	5.2	0.3	1.5	9.0	2.8	2.4	4.5	10.6	2.6	1.6	4.3
May	9.7	2.3	0.8	3.9	12.7	1.7	2.6	5.7	17.8	1.1	1.7	4.3
June	24.6	0.03	0.3	5.2	27.6	0.03	1.7	6.4	27.4	0.0	2.6	7.2
July	28.1	0.03	0.3	5.3	29.6	0.03	3.1	9.3	27.3	0.1	3.1	6.1
August	28.0	0.0	0.3	5.7	29.7	0.0	1.3	6.1	28.9	0.0	1.5	4.3
September	25.4	0.0	0.2	0.3	27.7	0.0	0.7	3.5	28.3	0.0	1.3	3.5
October	15.6	1.5	0.5	1.6	18.2	0.9	1.2	2.0	22.4	0.2	0.6	2.2
November	9.3	4.5	0.1	0.7	11.2	2.5	0.9	1.5	12.9	2.3	0.2	1.0
December	7.6	8.1	0.0	0.6	11.4	3.8	0.7	2.1	12.0	3.3	0.2	0.9
Annual	170.2	45.9	.4	30.2	204.9	22.0	20.3	51.3	223.7	17.5	15.1	42.8

Table 2.11 Mean Monthly & Annual Weather Phenomena (1941-1970)

CHAPTER 3

CHAPTER - 3 -
THE DESIGN MODEL

3.1 Estate Model

In order to put the researcher into the position of an urban designer and face the same restrictions and regulations, an estate model was designed.

3.1.1 The Residential Areas of Baghdad

From the land use map for Baghdad an unused residential area was chosen for the location of the model design (see Figure 3.1). It is widely believed that the selected area will be nominated for distribution in the near future and indeed might already be distributed during the period of this project. It is the author's hope to contact some of the house-holders in that particular area and persuade them to allow their houses to be used during the construction as an experimental site to verify the findings.

3.1.2 Urban Design Regulation for Baghdad

In the design of the model estate the urban design regulations issued by the Ministry of Planning (The Foundations and Norms for Urban Planning, Baghdad, 1977) were implemented. These lay down plot sizes and proportions, road widths, walkway widths, fence heights, and various types and numbers of service buildings. These

Figure 3.1 Baghdad land use map.

regulations and restrictions will be stated and explained during the discussion the design process used for the model estate.

3.1.3 Basic Elements Used in Designing the Estate

3.1.3.1 Plot Sizes

As a result of the extensive horizontal expansion of Baghdad, the government announced a new land distribution scheme which stated that plots for citizens of Baghdad have to be between 200 to 400m2. Therefore the site in the model has been divided into plots of 400m2 for each house, to meet this government programme.

3.1.3.2 Road Widths

According to the regulations for this type of estate roads have to be 10m wide. If one looks at the road widths used in this model, from an energy consumption point of view, one might think that reducing the width will cause a lower solar energy load on the building in summer. However, Figure 3.2 makes it clear that,in the age of the motor car, with any road with a width sufficient for cars there can be no valuable shading provided from the houses opposite in locations with high summer sun altitudes. Therefore as long as the road width is four metres or more the difference is negligible especially when pavement width and the 4m set back required by the regulations as a minimum distance between the building and the boundary are added .

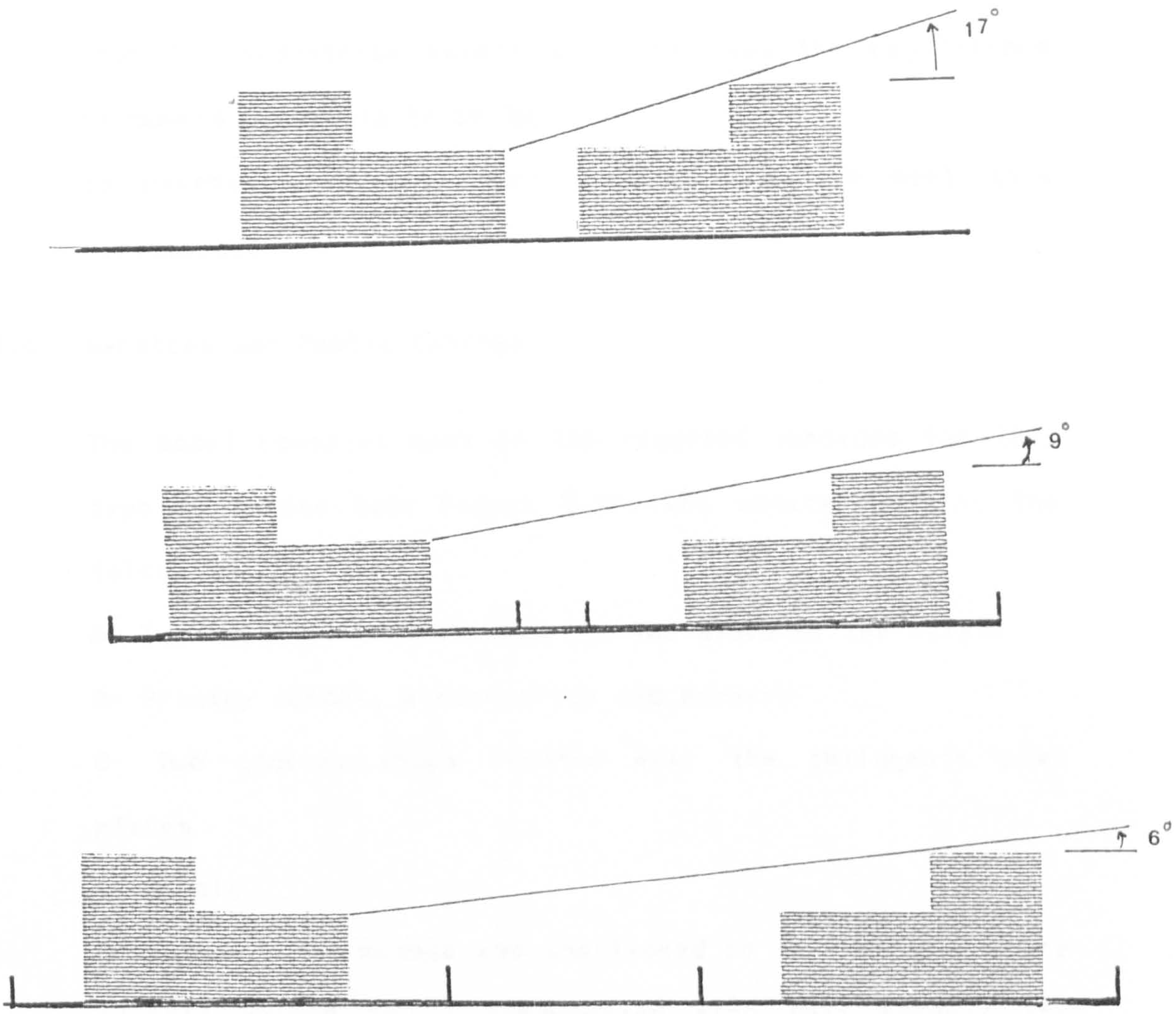


Figure 3.2

Showing the difference between road widths following road regulations and those using shading principles.

3.1.3.3 Pavements

From the pedestrian safety point of view the regulations recommend pavements to be 2m.
So pavements in the model were designed to meet this recommendation

3.1.3.4 Services and Public Centres

The model contains most of the required services for this type of estate (see Figure 3.3). The estate contains the following:

A- Two small markets serving the two sides of the estate

B- Primary school, kindergarten and nursery

C- Two grocery shops located near the children's play places

D- Clinic

E- Mosque. The mosque was positioned so that strangers are clearly guided to it remembering also that mosques are usually built with a minaret of 15 to 35m height (see Figure 3.4). which is clearly visible from a distance so that one can refer to it and to the mosque location in directing visitors

F- Sewage Pumping Station.
This station was located to the far south of the estate to serve the estate without affecting the residents.

G- petrol Station.

Figure 3.3 The Model Estate

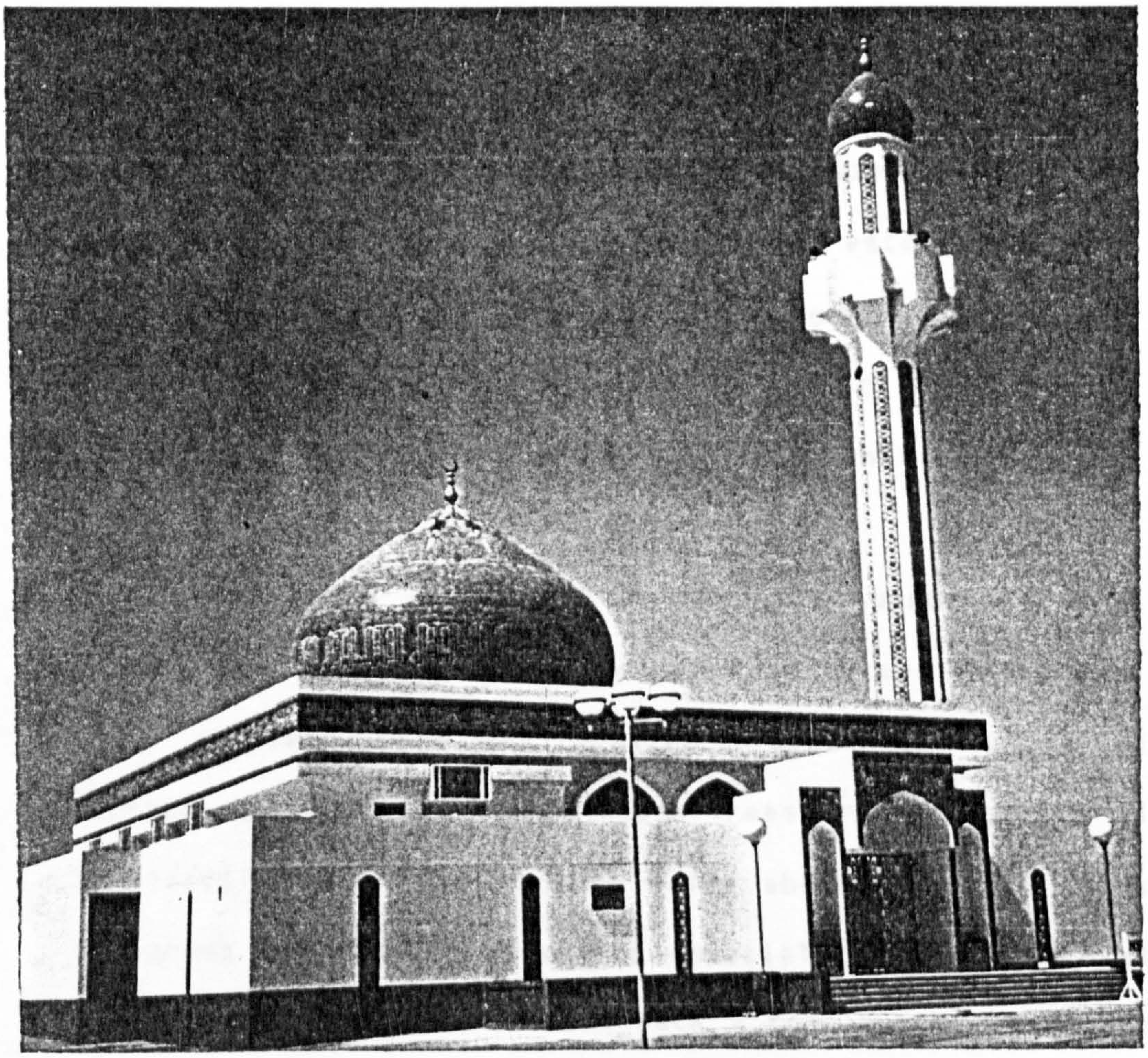


Figure 3.4 The Mosque

The station was located beside the sewage pumping station on one of the main roads on the boundary of the estate in order to protect the site from traffic noise and to maintain safety .

H- Traffic Safety

This was taken into account in the design - the number of cul-de-sacs existing in the model emphasizes this point, and also reduces traffic noise within the estate. One main street which links the estate to the surounding areas cuts the estate into two parts, and to avoid irresponsible driving, the police station was located on that street.

I- Noise Control

Since the estate is located in an area surrounded by a highway and busy dual carriage-way (see Figure 3.1), some green planted areas are created around the estate to decrease the noise load. Although trees are not considered as effective noise barriers or noise absorbers, both trees and grass will have some effect especially near the ground and when the the house is set back a considerable distance from the source (see Figure 3.5). The estate was set back a distance of more than 50m from both the dual carriageway and the highway.

Accordingly the noise level calculated for the house nearest to the dual carriage was reduced by 12dBA (see Figure 3.5, Ref. 34) and the noise level calculated for the house nearest to the highway was reduced by 15dBA (see Figure 3.6, Ref. 43). A noise level of 80dBA was found on

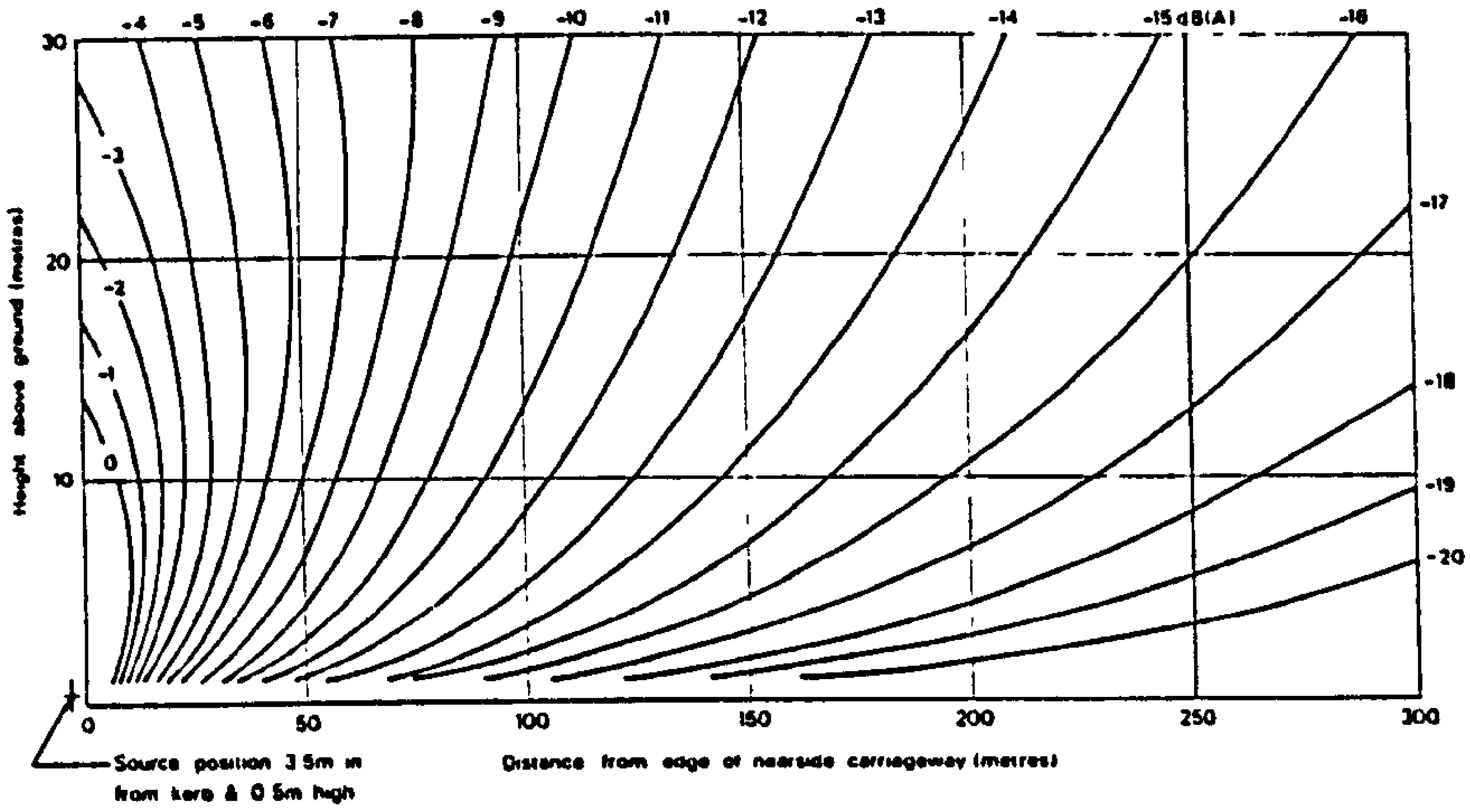


Fig3.5 Propagation over grassland: correction in dB(A) as a function of horizontal distance from edge of nearside carriageway (d) and height above ground (h) (Ref. 35)

(After Ref. 34)

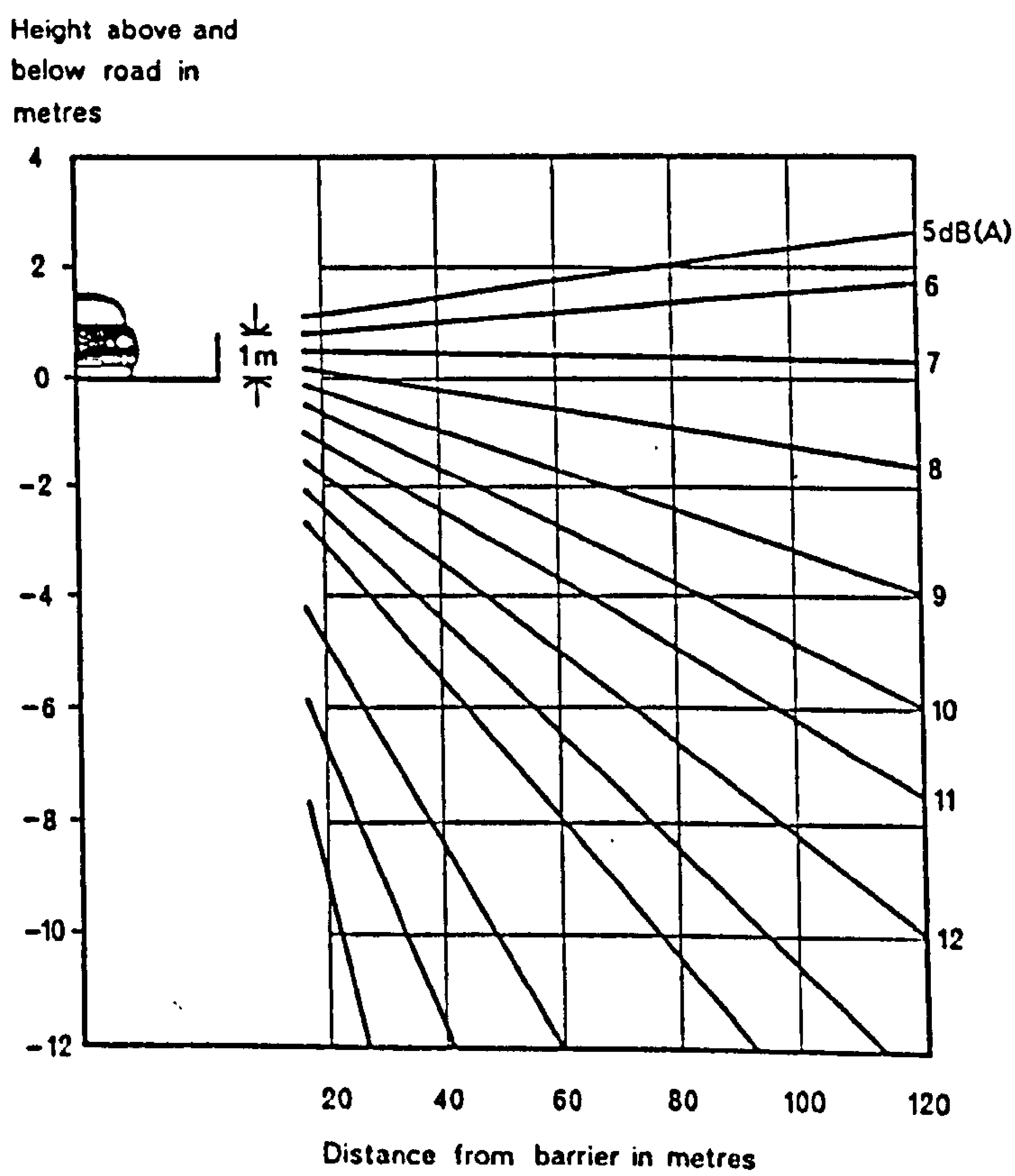


Figure 3.6 Reduction of L_{10} by 1m barrier positioned 25m from centre of carriageway .

(After Ref. 43)

roads similar to those which surround the estate, during the survey carried out by the author and one of his colleagues in 1981 when they evaluated traffic noise on Baghdad streets (see Figure 3.7, Ref. 20). Therefore the noise level predicted at the houses nearest to the dual carriage way is about 68dBA and at the ones nearest to the highway about 65dBA.

Houses located on the main road south of the estate are back-to-back with shops and the sewage pumping station as a solid barrier to decrease traffic noise.

3.1.3.5 The Layout of the Estate and the Climate

The most important factor in indoor thermal control is the thermal load on the building surfaces in summer. Therefore house facades in the model were orientated towards the north and the south on which summer incident radiation is low. East and west sides were designed to be shaded by adjacent houses. Although houses orientated south and north receive almost an equally small amount of direct radiation in summer, they receive a different amount in winter, the ones facing north receiving no direct radiation, while those facing south receive a very large amount. As each house has the north and south walls exposed to the sun in winter, though receiving different levels of radiation, it is considered the responsibility of the designer to reduce the shading effect of the surrounding houses on the south wall of the north facing

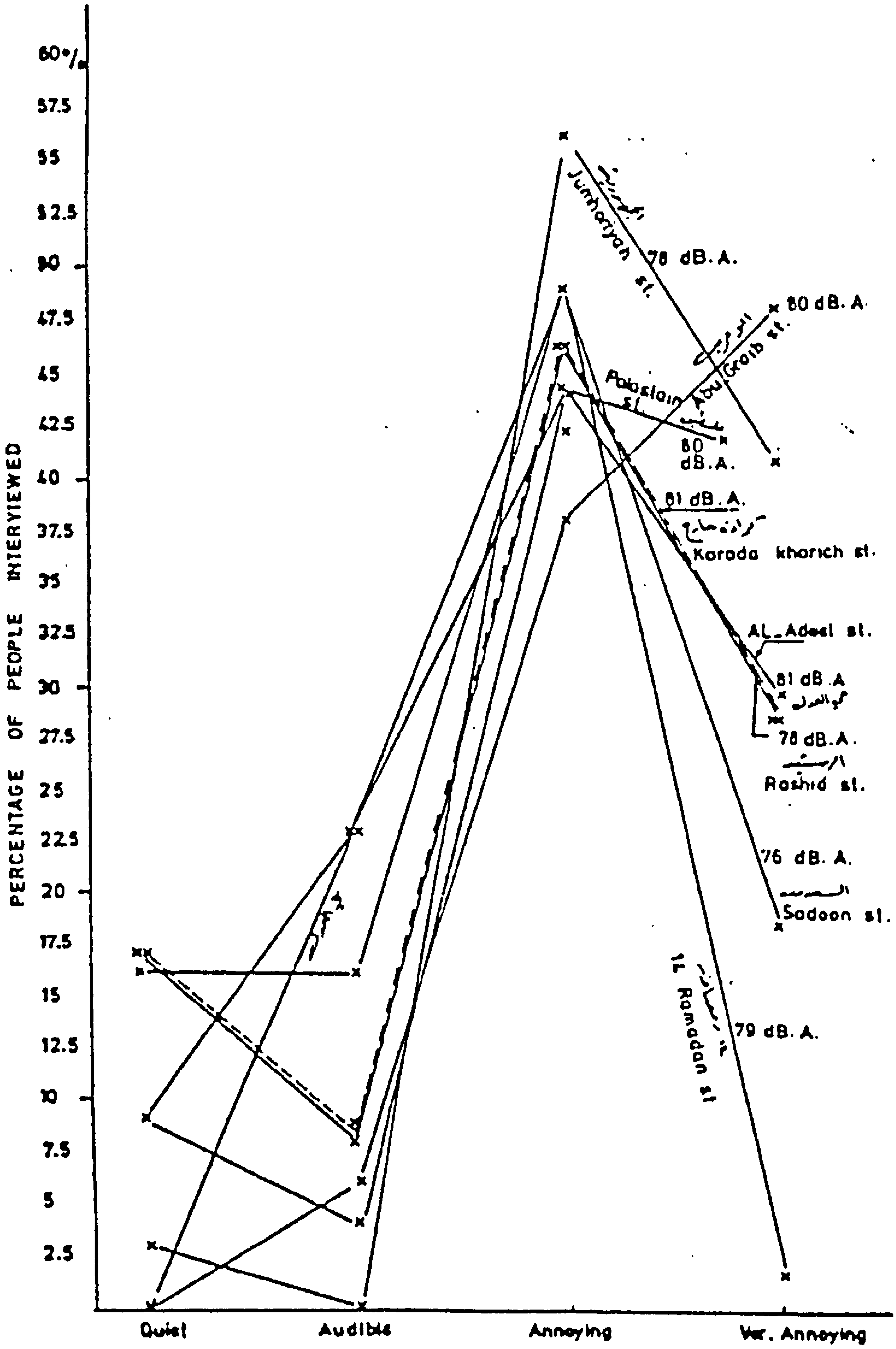


FIG. 3.7 IMPACT OF TRAFFIC NOISE .

house and this has been done in the model design suggested by the author (see Figure 3.8)

As described the prevailing wind in Baghdad is from the north west, and as been found by Givoni [Ref. 73] that the maximum wind speed in a room with two windows is when the wind direction is at 45° from the normal to the window. Moreover since the houses in the estate have a north- south orientation, the prevailing wind, which is at 45° on windows on the north and west orientated walls, will provide the rooms with a better wind flow for cooling. In addition, since the west walls receive an excessive amount of direct sunlight, the prevailing wind will also reduce the heat load due to the west wall. Further because of the narrow walkways between adjacent houses the space between pairs of houses functions as a tunnel, which helps to provide reasonable ventilation even from the east wall windows.

3.2 House Model

For the reasons explained in 3.1 models for houses were also designed. These designs were based on a questionnaire survey carried in east Baghdad 1979 by the author and Miss Azhar Jawad from the Iraqi Building Research Centre as one of a series of surveys carried out by the author as a preparation for this study and for his other research.

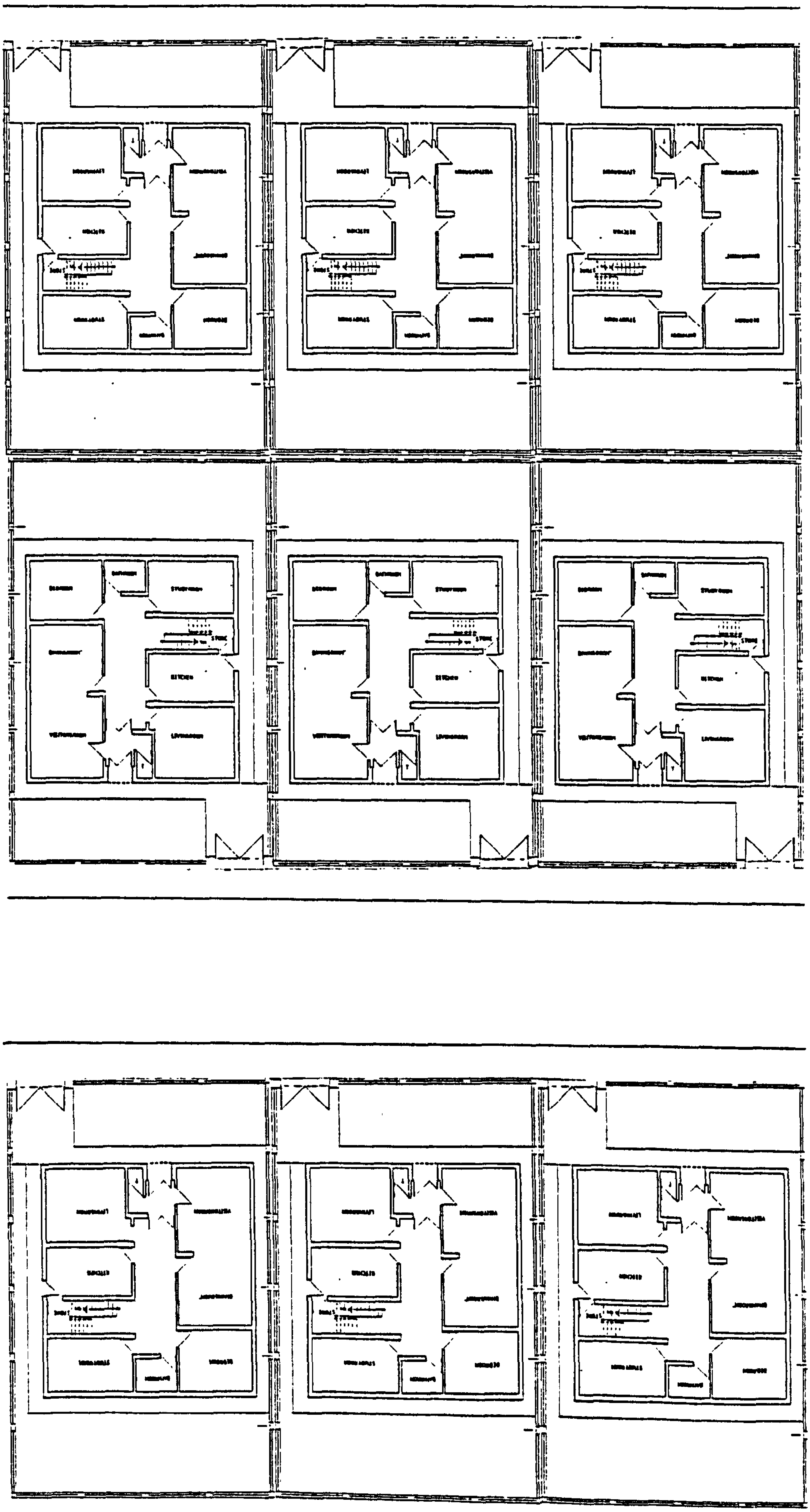


Figure 3.8 Plan

3.2.1 Housing survey

As the model has to reflect the existing house style the survey was carried out in a middle income area.

3.2.1.1 The Location of the Survey

The author, who is a Baghdad resident, decided to select the"14th July place" (Hai Arbata-ash Tammouze) and "Al-Muatansiryah place" to represent the middle income estates in Baghdad (see Figure 3.9). This particular area chosen is located five kilometres east of the centre of Baghdad, and the estate consists of about 1000 houses.

3.2.1.2 The Questionnaire

The questionnaire Figure 3.10 was designed by the author in consultation with the Iraqi Educational and Psychological Research Centre to cover most of the topics required for this research and also to serve the objectives of future work.

The questionnaire contains 28 open-ended questions, each containing more than one sub-question. The box tick type method was used to make the process easy and to reduce the apparent length of the questionnaire and the time taken to answer it. The form was selected after four types of questionnaire were designed and tested on friends from different social and educational levels in order to find that which required the least amount of time. The one shown in Figure 3.10 was selected and applied since all the questions could be answered in 20 to 25 minutes

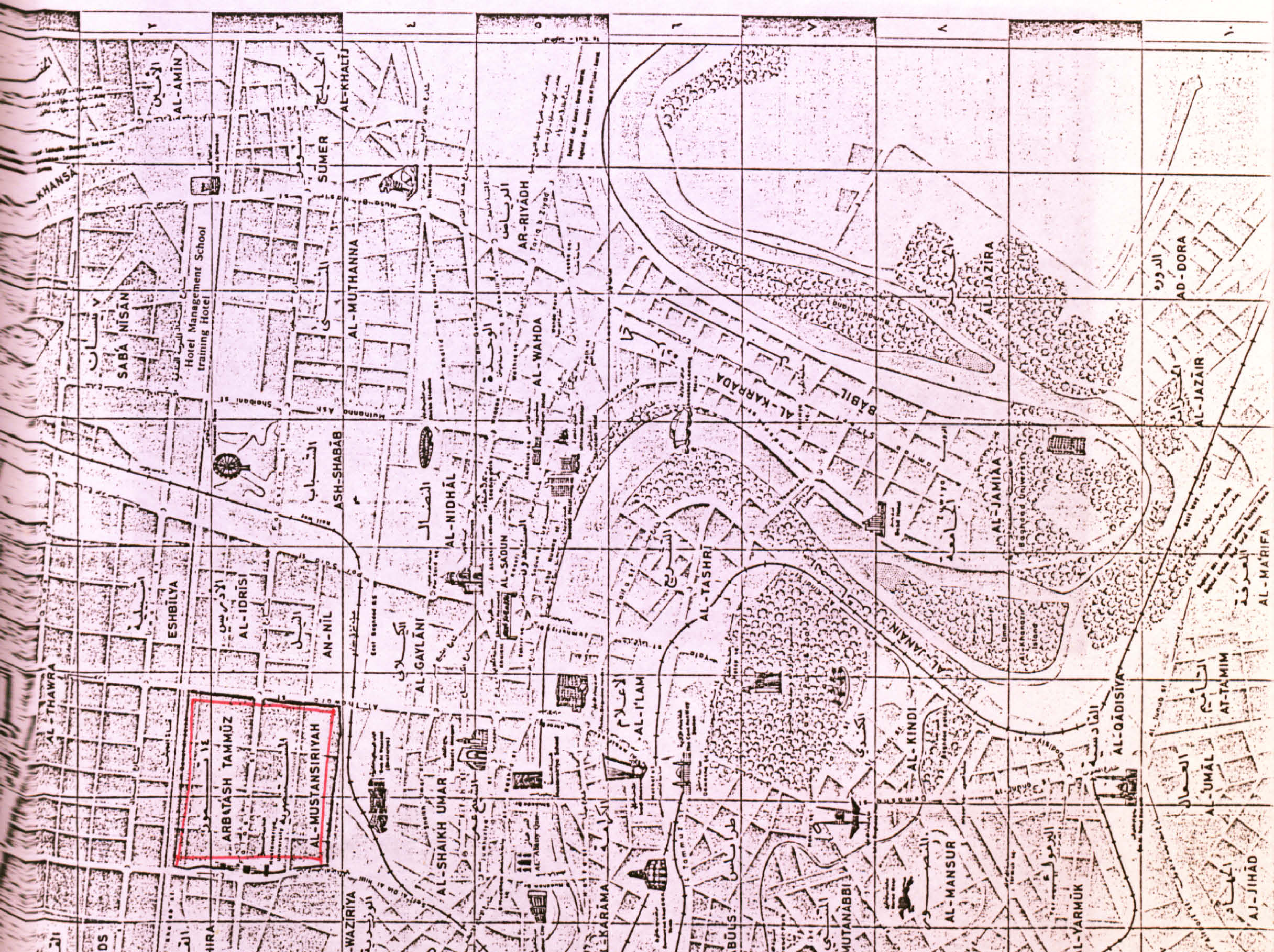


Figure 3.9 A 14th. July Place-- Area surveyed.

Figure 3.9b Area surveyed

[illegible]

مشروع البحث ٦/٧٥
التصاميم السكنية المريحة للبيوت
ذات الاجزاء الجاهزة

1 – ماهو عمل ساكن الدار

2 – ماهو عدد افراد عائلتكم

رجال	نساء	اطفال (١–٦) سنة	اطفال (٦–١٥) سنة

3 – ماهو عدد غرف دارك (A)   كم غرفة نوم (B)

	1 غرفة النوم	2 غرفة الضيوف	3 غرفة الجلوس	4 غرفة الطعام	5 غرفة المكتبة	6 الطارمات المسقفة	7 المخزن	8 المطبخ	9 الحمام	10 التواليت
4 – ماهو حجم غرف دارك حاليا										
5 – كم ترغب ان يكون حجم الغرف التالية										
6 – في اي وقت تستخدم الغرف التالية شتاء (قبل الظهر / بعد الظهر)										
7 – في اي وقت تستخدم الغرف التالية صيفا (قبل الظهر / بعد الظهر)										
8 – دون ارقام الغرف والمرافق التي ترغب ان تكون قريبة من الغرف التالية										
9 – هل تفضل الشبابيك الواسعة ام الضيقة ام المتوسطة في الغرف التالية										
10 – متى تستخدم الغرف التالية يوميا – اسبوعيا – شهريا										

Figure 3.10a
(a&b) Sample questionnaire.

11 ـ افضل العيش فـــي | الشـــقق | مجموعات سكنية | بيوت متفرقة

12 ـ اعتبر الحديقــــــة | ضرورية جدا | ضروريـــة | غير ضرورية

13 ـ أين تفضل الحديقة | خارجيـــة | مساحتها | داخليـــة ، | مساحتها

14 ـ افضل المدخل (كوريدور) (A) | ٢×٢ متر | ٢×١ متـر | ١×٥ر١ متر | وحاليا فى منزلـــى (B)

15 ـ افضل ان يكون عرض الممرات الموصلة بين مرافق الدار (A) | ١ متـــر | ٥ر١ متـر | ٢ متـــر | ٣ متـــر | وحاليا فى منزلى بعرض (B)

16 ـ هل تستخدم المطبخ لتناول الطعام (A) | نعـــم | لا | وهل غرفة الطعام مهمــــــة B | نعم | لا

17 ـ افضل ان يكون بيتـــــــــى ذا (A) | طابـــق | طابـــقين | أمّا عدد طوابق بيتى حاليـــا فهـــــى (B)

18 ـ ارغب فـــى وضـــع قطـــــع (A) | أفقيـــة | عموديـــة | من الكونكريت او المعدن على الشبابيك كاشبات شمس (B)

19 ـ هل ترغب أن يكون فى بيتك فتحة انارة فى سقف الدار (للانارة الطبيعيــــــــة) (A) | نعـــم | لا | وهل توجد فتحة انارة فى داركم الحالـــــى (B) | نعـــم | لا

20 ـ اعتبر النوافذ بالنسبة لى مهمة لـــــ (A) | ادخال الضوء | ادخال الهواء | رؤية المناظر | أمّا اللون الذى ارغب ان يقابل دارى من الجيران هــــو اللـــــــون (B)

21 ـ افضل الاشجار | دائمة الخضرة | النفضيـــة

22 ـ اذا كانت الاشجار النفضية تحلمك من حرارة الشمس صيفا وتسمح بدخولها الى الغرف شتاء هل تفضل غرسها داخـــل حديقتـــــــك | نعـــم | لا

23 ـ نوعية التدفئة المستعملة فى بيتى الآن هـــــى (A) | وافضل ان تكـــــون (B) | نوعية التبريد المستعملة فى بيتى الان (C) | وافضل ان تكـــــون (D)

24 ـ علاقتى بالجار | جيدة جدا | جيـــدة | ضعيفـــة

25 ـ علاقة ربة البيت بالجار | جيدة جدا | جيـــدة | ضعيفـــة

26 ـ علاقة اطفالى بالجـار | جيدة جـــدا | جيـــدة | ضعيفـــة

27 ـ أود ان اكون معزولا عن جارى | عزلة تـــامة | عزلة جزئيـــة

28 ـ اعتبر النوم على السطح | ضرورى جدا | ضـــرورى | غير ضرورى

Figure3.10b

As the questionnaire contains many questions, only these which relate directly to the present study will be deali with in this chapter. The reminder will be analysed and used for other work in the future .

3.2.1.2.1 The Questions

The questions related to the present study are

3a- How many rooms do you have in your house?

3b- How many bedrooms do you have in your present house ?

This question was asked in order that the design model should reflect the majority of preferences on the number of bedrooms required.

4- What is the dimension and the function of each room in your house ?

This question was asked to obtain data on the type of rooms in the houses.

6- At what time do you use each room daily in summer?

7- At what time do you use each room daily in winter?

Question 6 and 7 were asked to discover the morning and afternoon use of each room in the hope that the designer can try to orientate each room so that rooms will be protected from direct sunlight in summer during hours of occupation and so that the room will be provided with as much direct sunlight as possible during hours of occupation in winter.

8- Which rooms do you prefer to be close to each other?

This question was asked in order to provide designers with the occupants' opinion on the location of each room, and their general preferences on the relationships between them.

9- Which window size do you prefer for each room: small, medium or large?.

This question was to help the designer in the process of window selection.

11- Where do you prefer to live, in flats, terraced houses, or detached houses?

This question was asked to give information for the design model.

16a- Do you use the kitchen for daily meals ?

16b- Do you consider the existence of the dining room as important ?

17- Do you prefer your house to be one storey or two stories?

18- If sun-breakers are used on your windows, do you prefer the horizontal or the vertical type?

20a- Do you consider the window to be important for daylight, ventilation or simply to view the outside?

20b- What colour do you prefer the opposite house to have? Due to the clear sky conditions, externally reflected light plays a major part in the level of daylight inside houses. This question was asked in order to give results which could be used in the calculation of natural lighting.

28- Do you consider the use of the roof for sleeping at night in summer as very important, important, not necessary?

3.2.1.3 People's Responses and Contributions

People's response was encouraging and most of them welcomed the survey team and spent more time with them, after completing the questionaire giving their opinions on other aspects not included in it. From the one hundred and thirty houses visited only one person refused to fill in the form. Missing forms were due to the absence of the occupants during the visit to collect them .

3.2.1.4 Analysis of the Questionnaire

After the forms were collected the results were analysed and the preference percentages, the arithmetic mean and the standard deviation for the existing room sizes were found, and the results, which are shown below, were produced either in tables, graphs or diagrams.

Question No.3a was analysed and the results showed that, most of the houses have the following type of rooms: bedrooms, living room, visitors' room, dining room, kitchen, storage room, bathrooms, toilets and some have a study.

Question No3b showed that 22% have only one bedroom, 31% of the houses have two bedrooms, 27% have three bedrooms and 20% have four to five bedrooms.

Question No4 dealt with room sizes. This Question was analysed and the arithmetic mean of each room type and the standard deviation was found . The normal distribution curve was drawn and is presented in Figures 3.11 to 3.19 .

Question No6 dealt with the daily time when each room is used in summer. The findings are plotted in the histograms shown in Figures 3.20 to 3.24.

Question No.7, was similar to Question No6, dealing this time with winter, and the findings are plotted in Figures 3.25 to 3.29.

Question No.8 was analysed and gave a clear guide on the location of each room and the preferred relationship between the different domestic activities, which reflects the influence of religion, customs, culture and tradition. The preferences are presented in a diagram showing the percentages of the preferred relationships (see Figure 3.30).

Question No.9 was asked to find the opinion of house holders on the size of windows for each type of room. These preferences are plotted in Figure 3.31.

Question No.11 was concerned with the type of home people preferred (see Figure 3.32). As was expected 3% of the people preferred living in flats, 14% preferred to live in terraced houses and 83% prefered independent detached or semidetached houses.

Question No.16a was used to obtain the percentage of people who use the kitchen for daily meals. The analysis of this

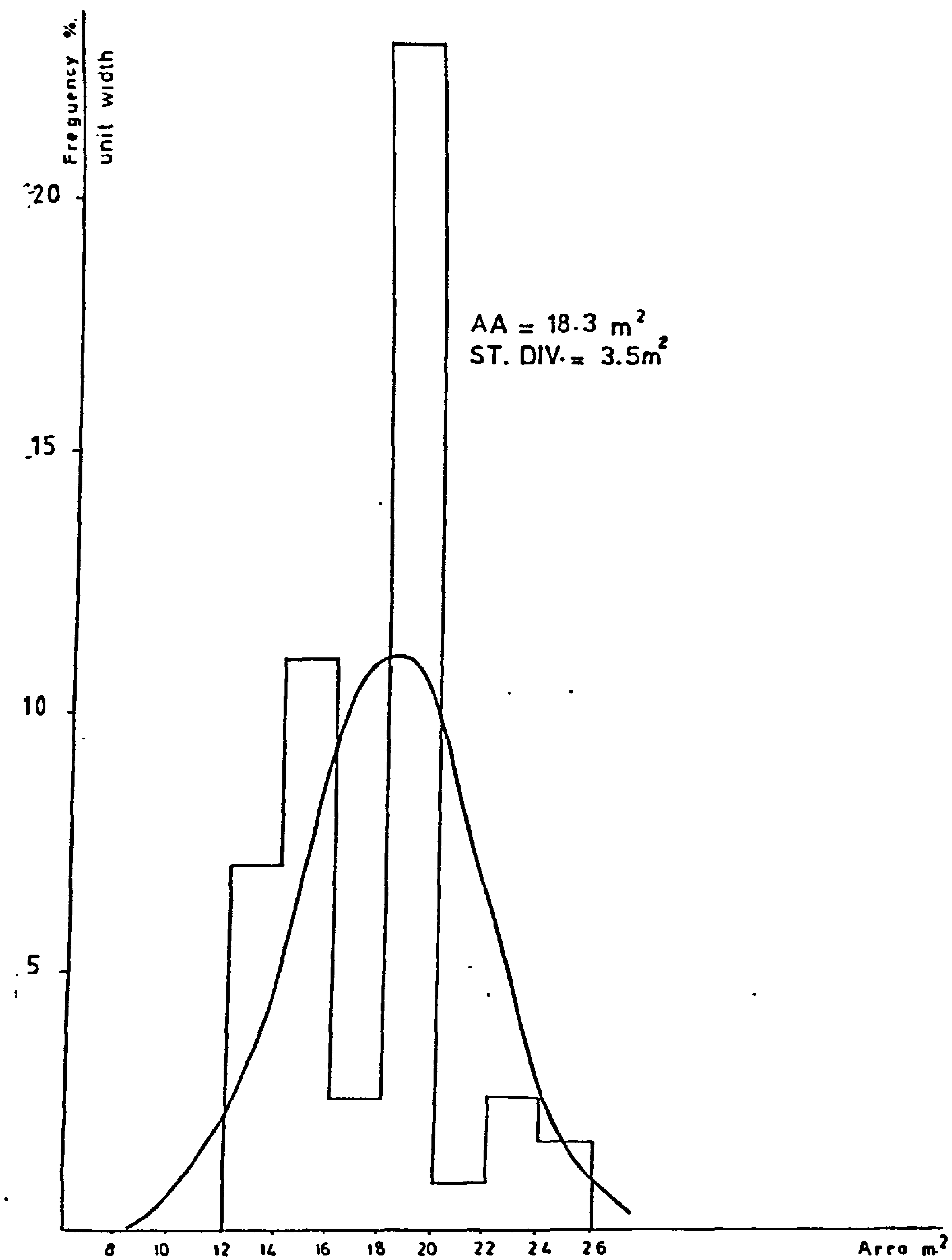


Figure 3.11 Graph showing the available bedroom areas and the average area (AA).

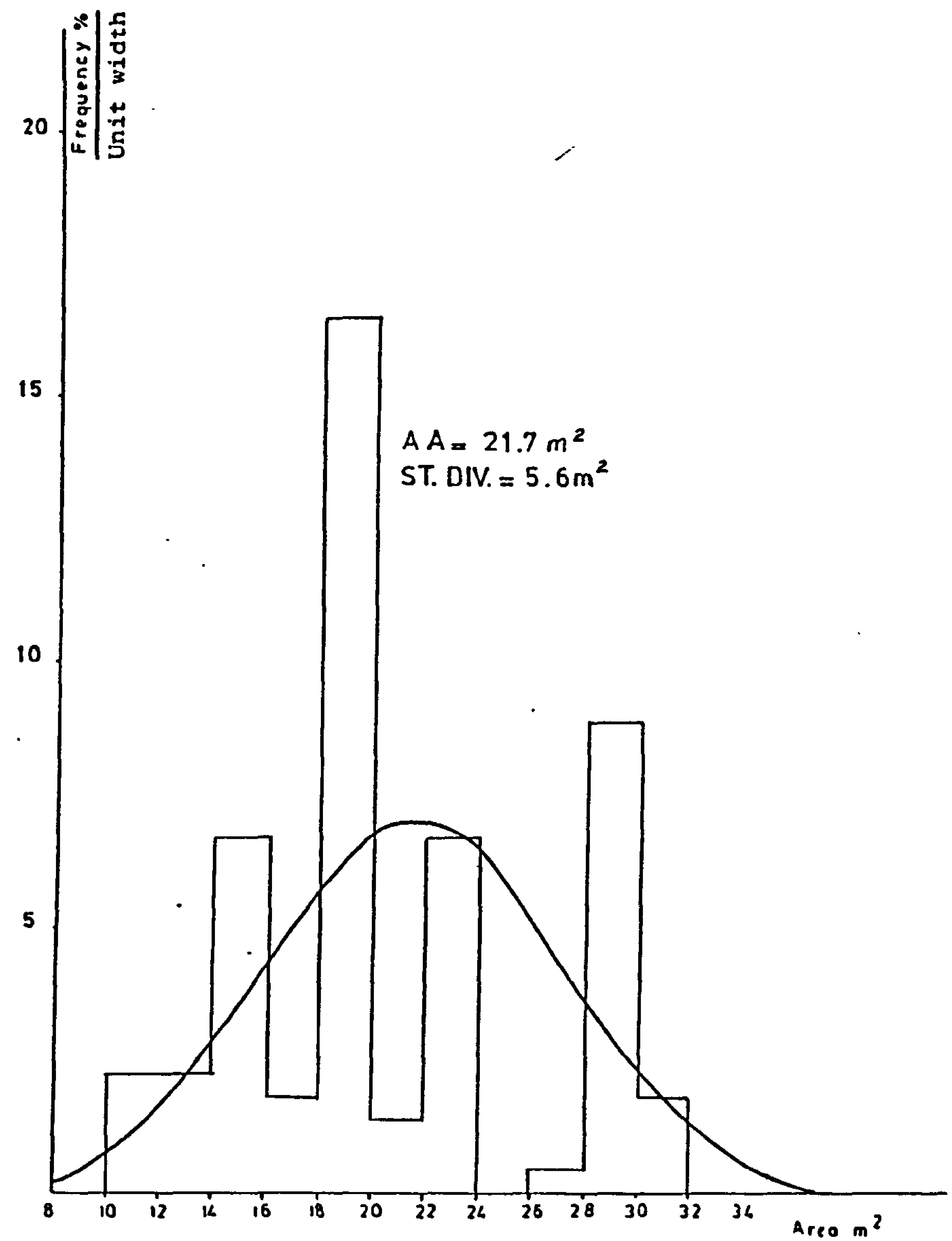


Figure 3.12 Graph showing the available visitors room areas and the average area (AA).

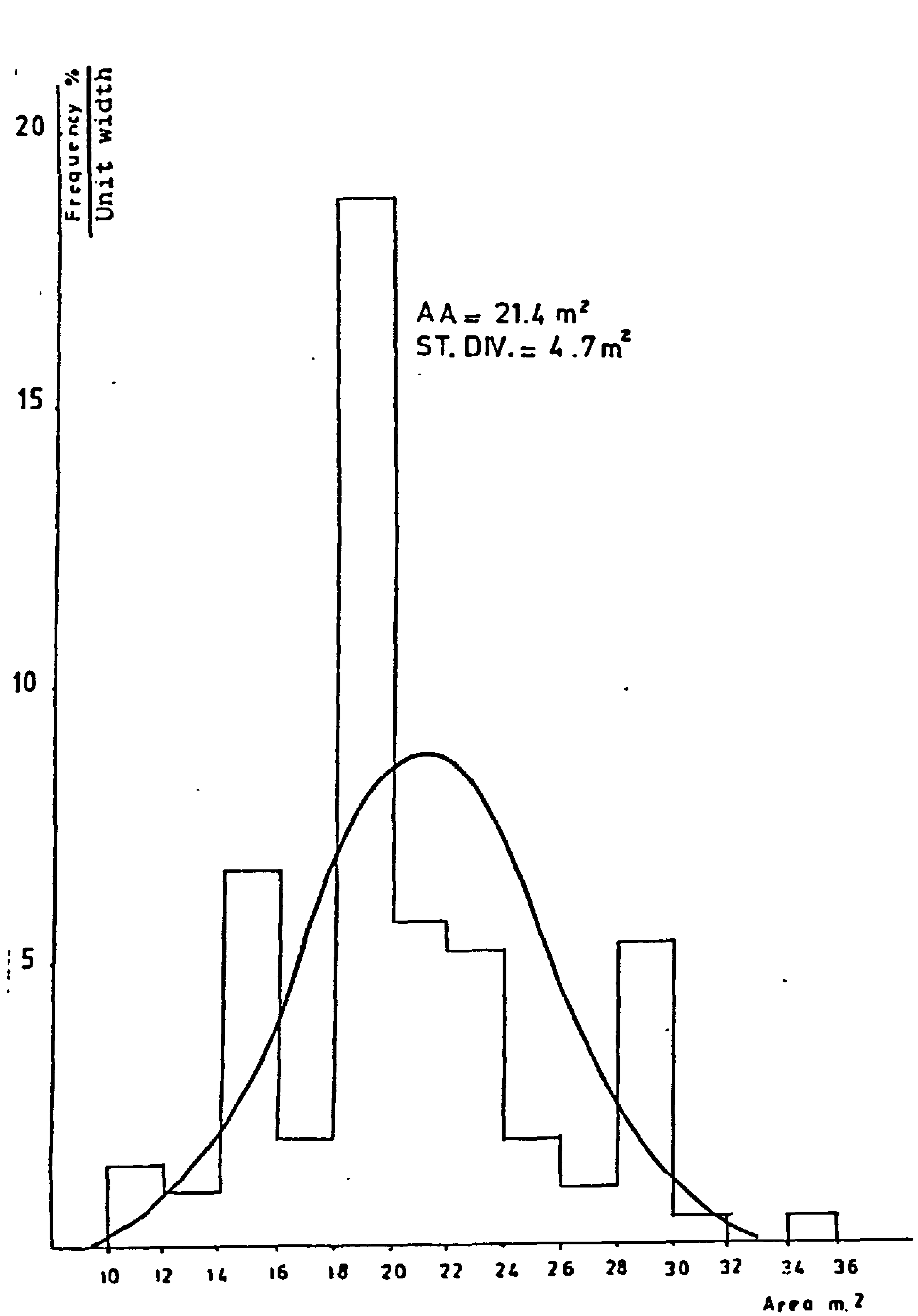


Figure 3.13 Graph showing the available living room areas and the average area (AA).

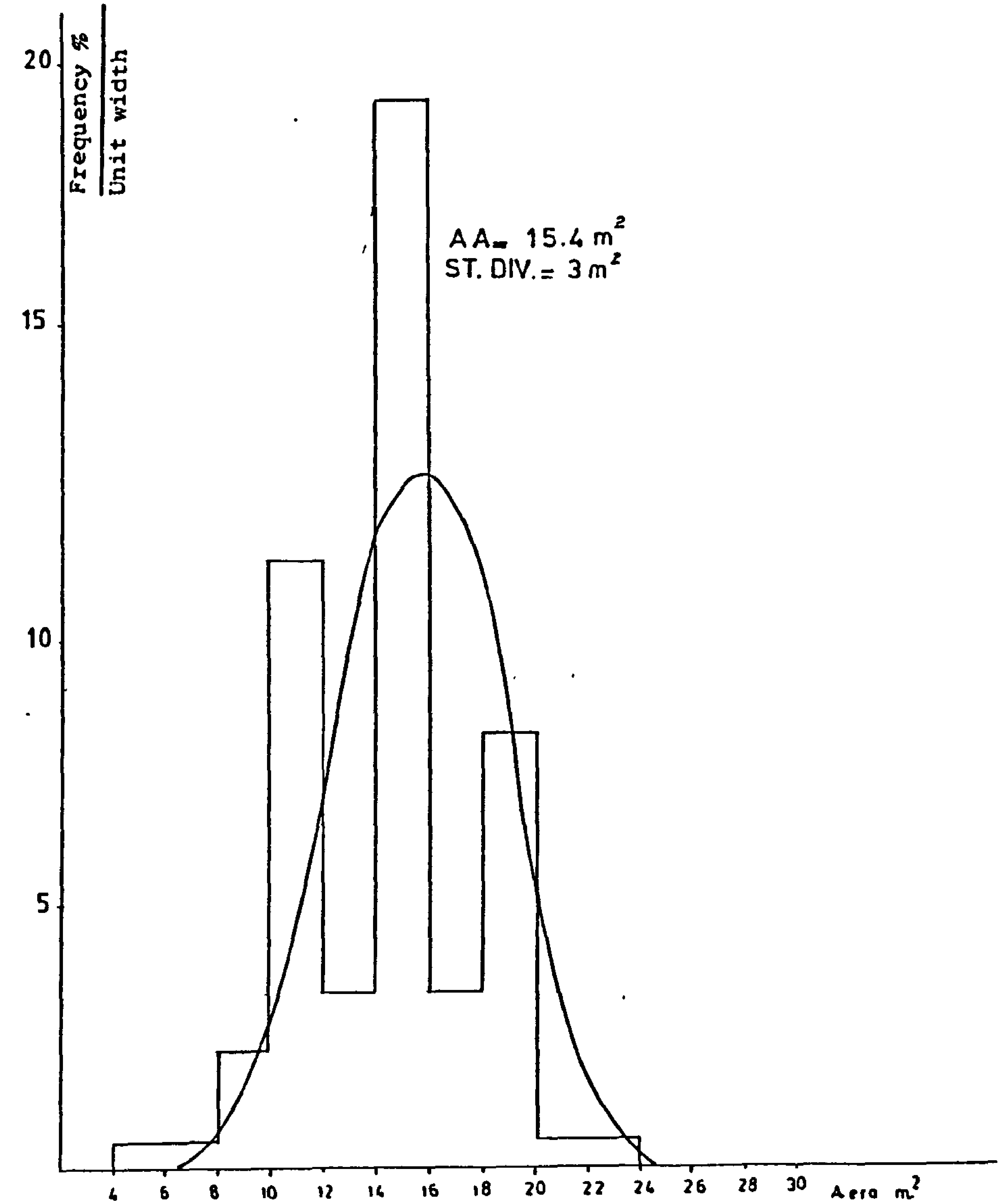


Figure 3.14 Graph showing the available dining room areas and the average area (AA).

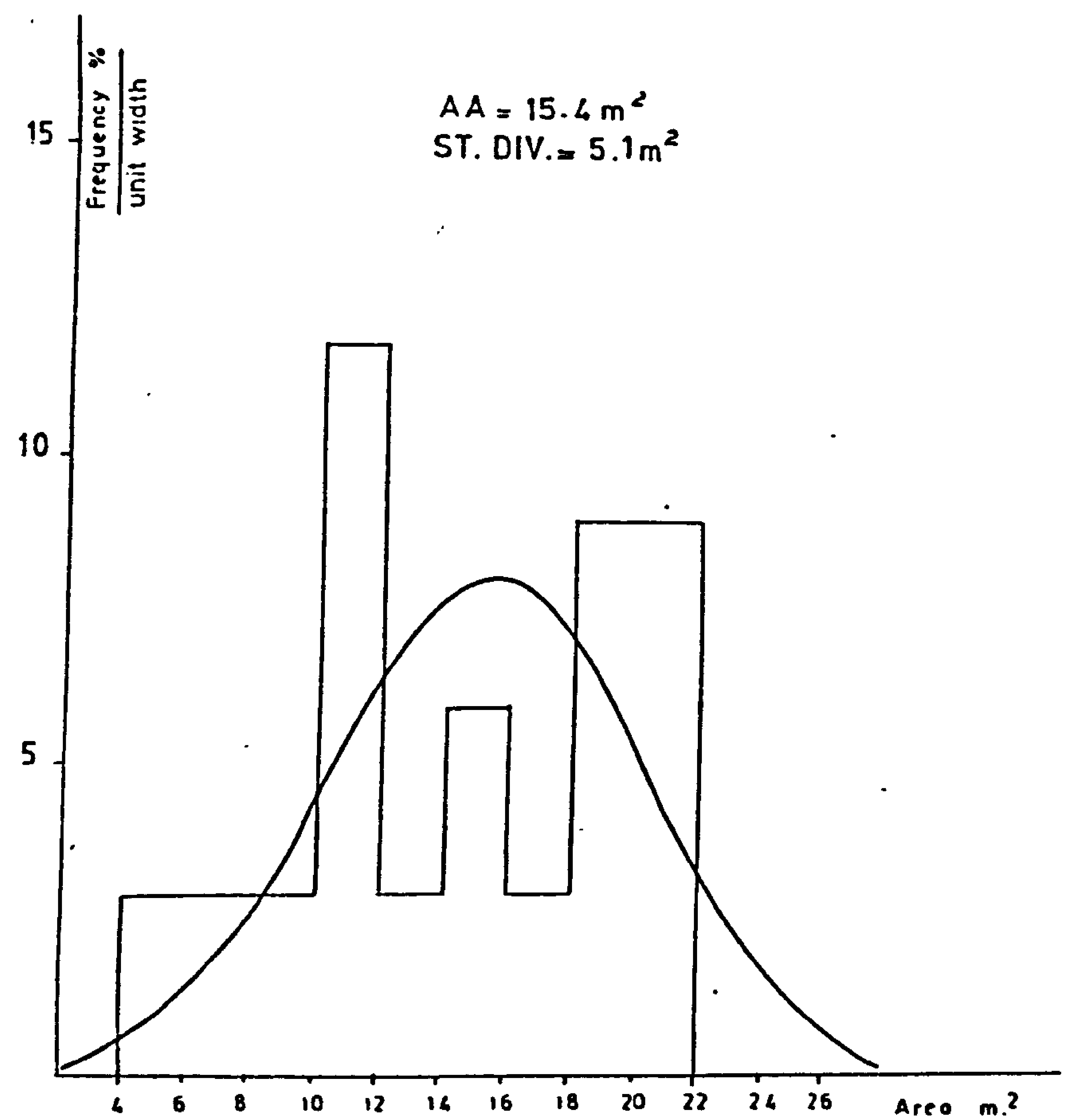


Figure 3.15 Graph showing the available library areas and the average area (AA).

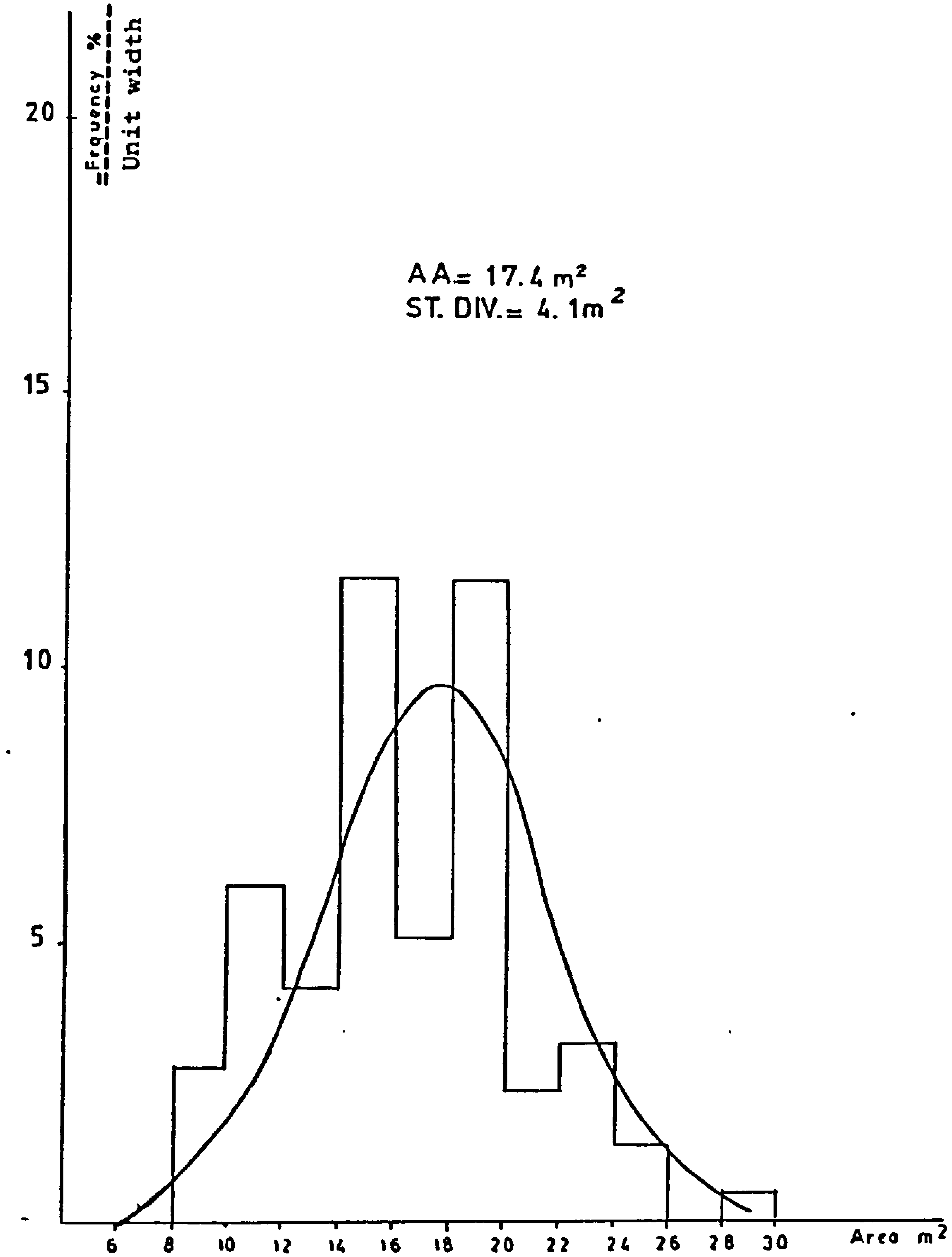


figure 3.16 Graph showing the available kitchen areas and the average area (AA).

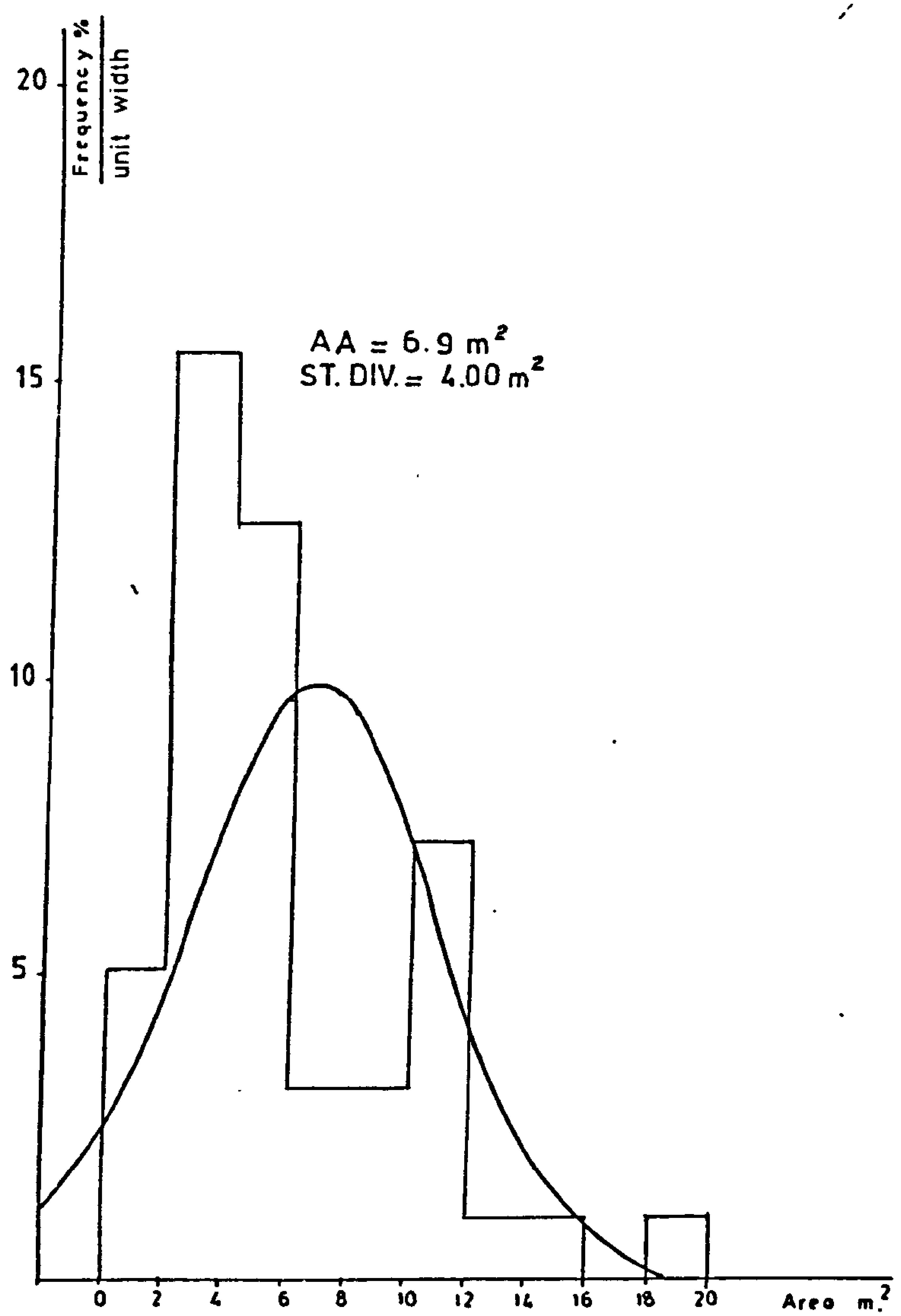


Figure 3.17 Graph showing the available storage areas and the average area (AA).

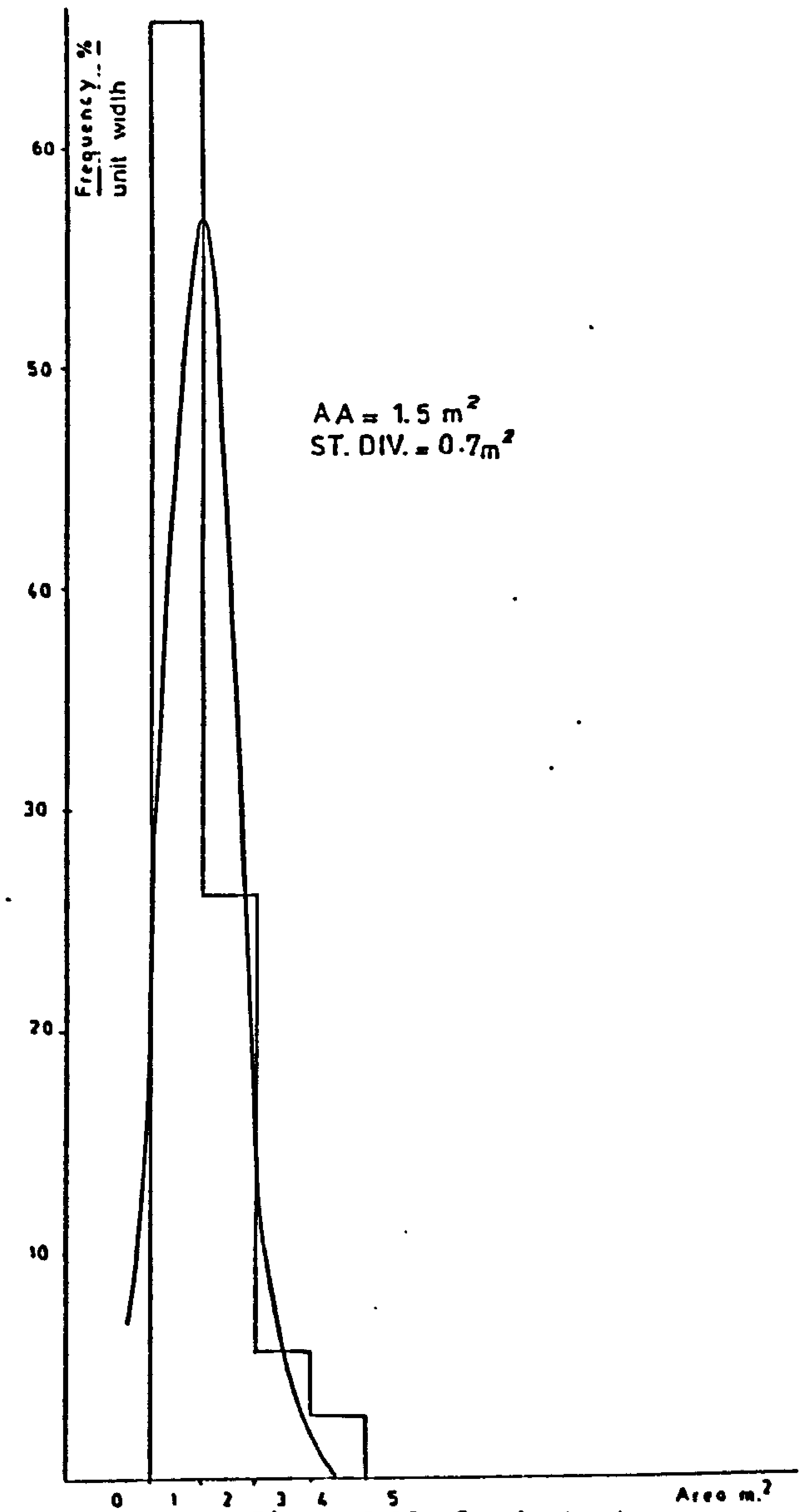


Figure 3.18 Graph showing the available toilet areas and the average area (AA).

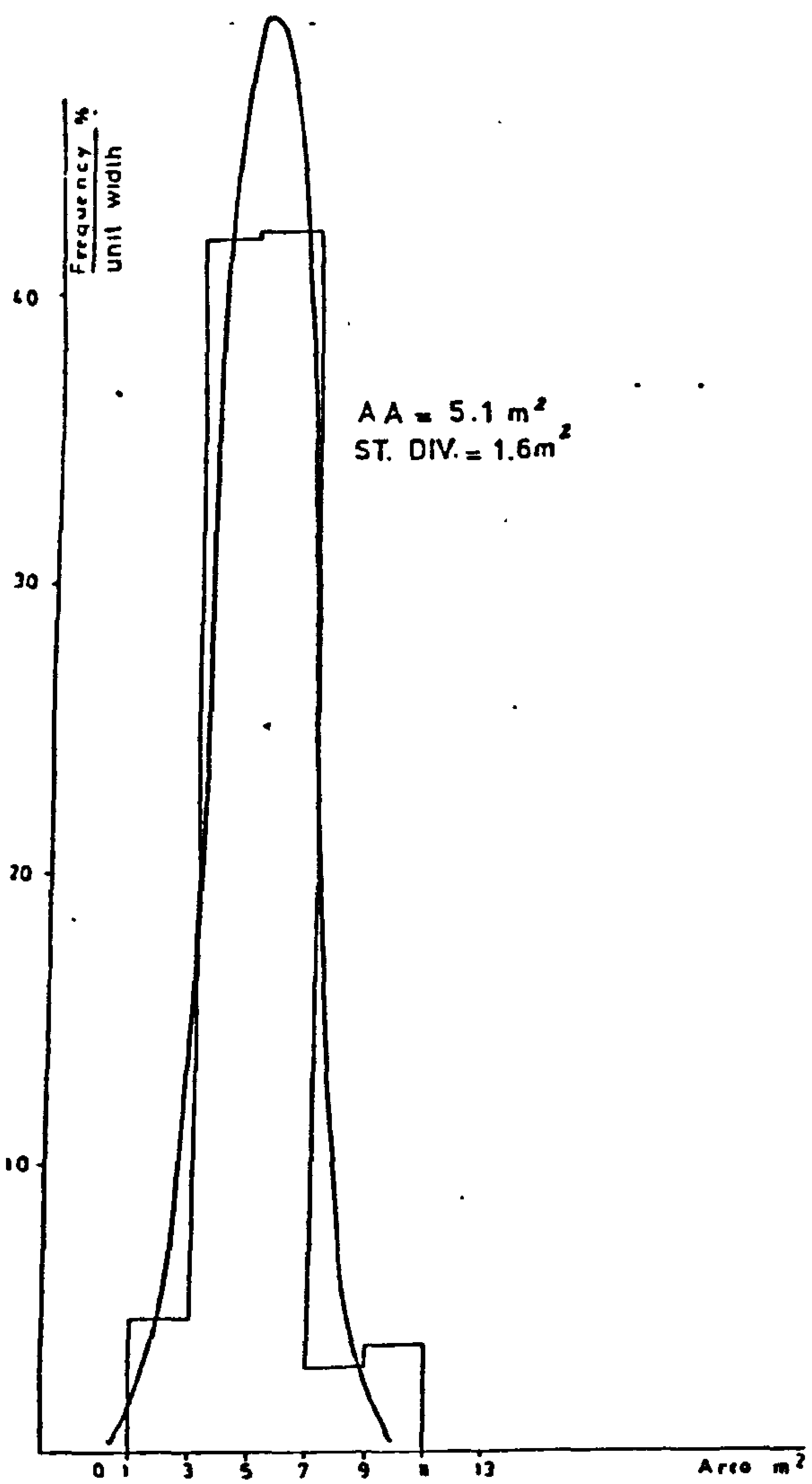


Figure 3.19 Graph showing the available bathroom areas and the average area (AA).

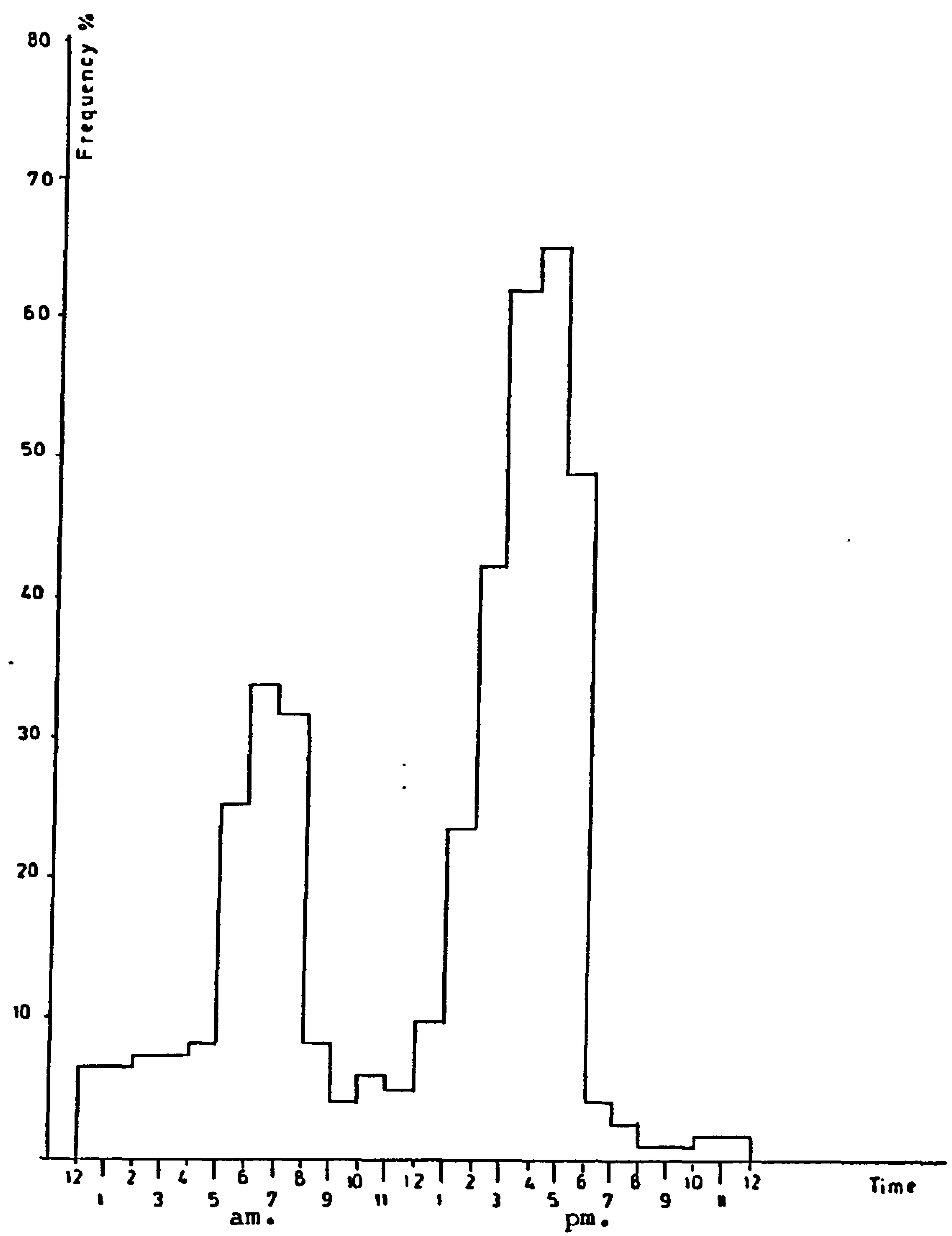


Fig. 3.20 GRAPH SHOWING HOURS BEDROOM IS USED IN SUMMER.

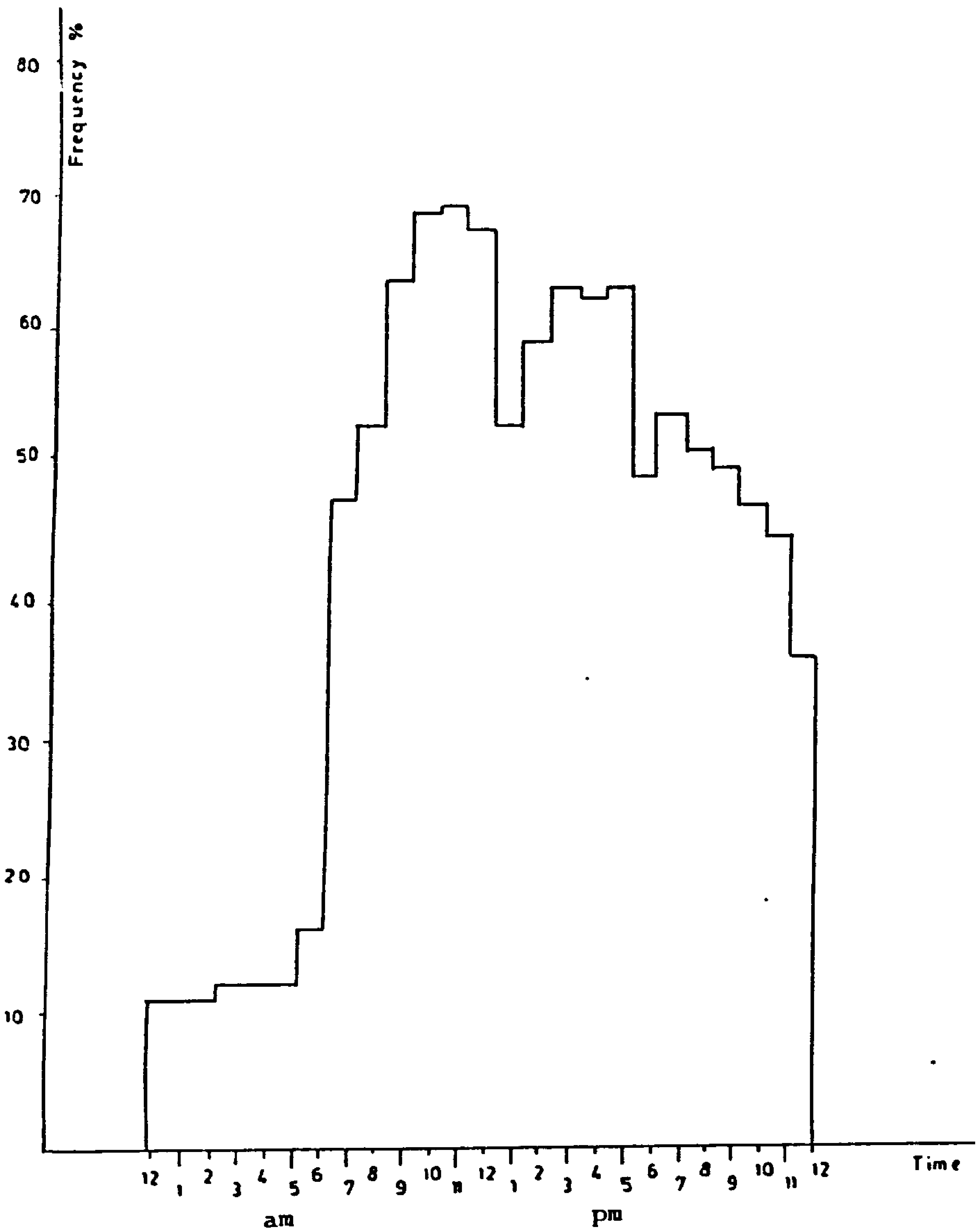


Fig 3.21
GRAPH SHOWING HOURS LIVING ROOM IS USED IN SUMMER.

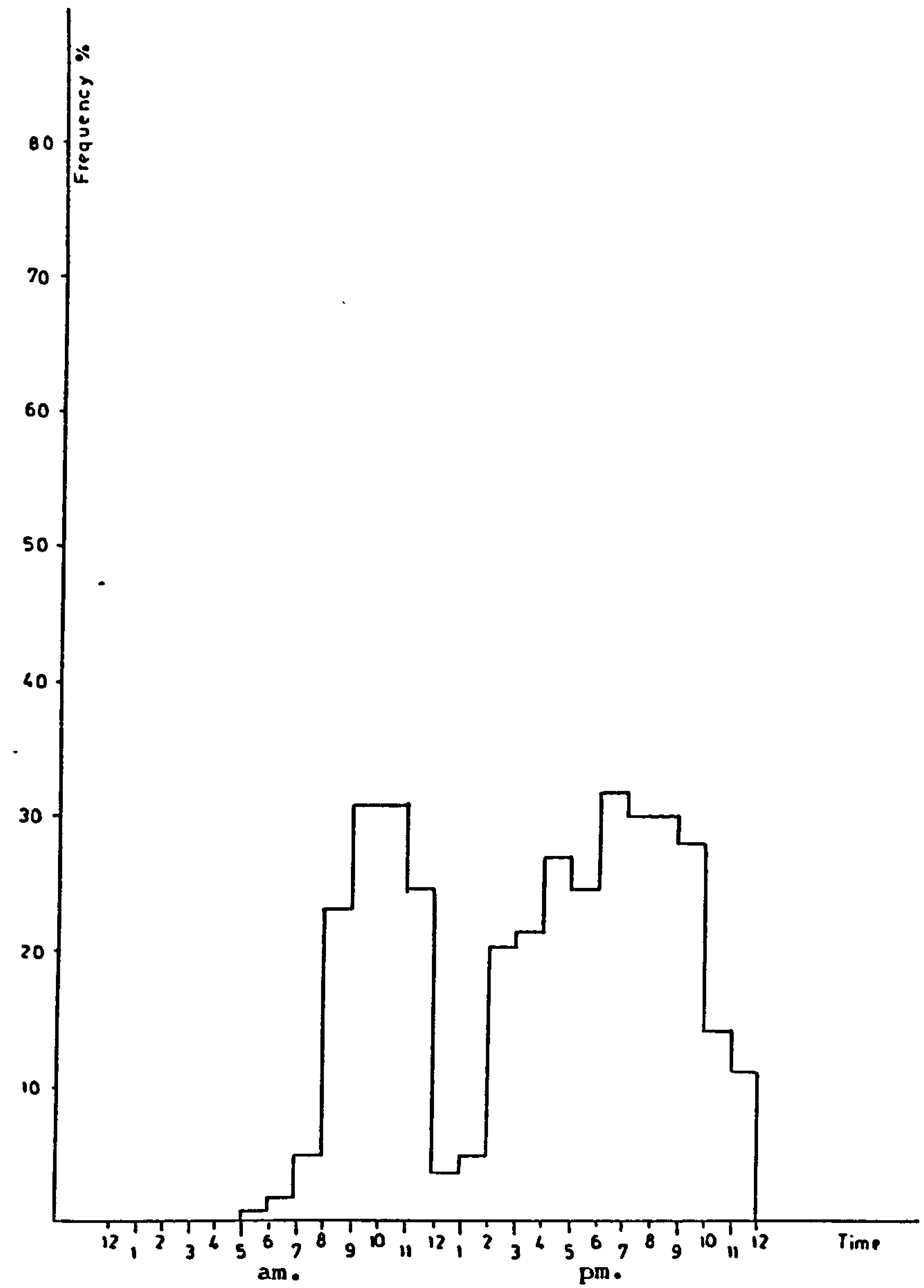


Fig. 3.22 GRAPH SHOWING HOURS VISITOR ROOM IS USED IN SUMMER.

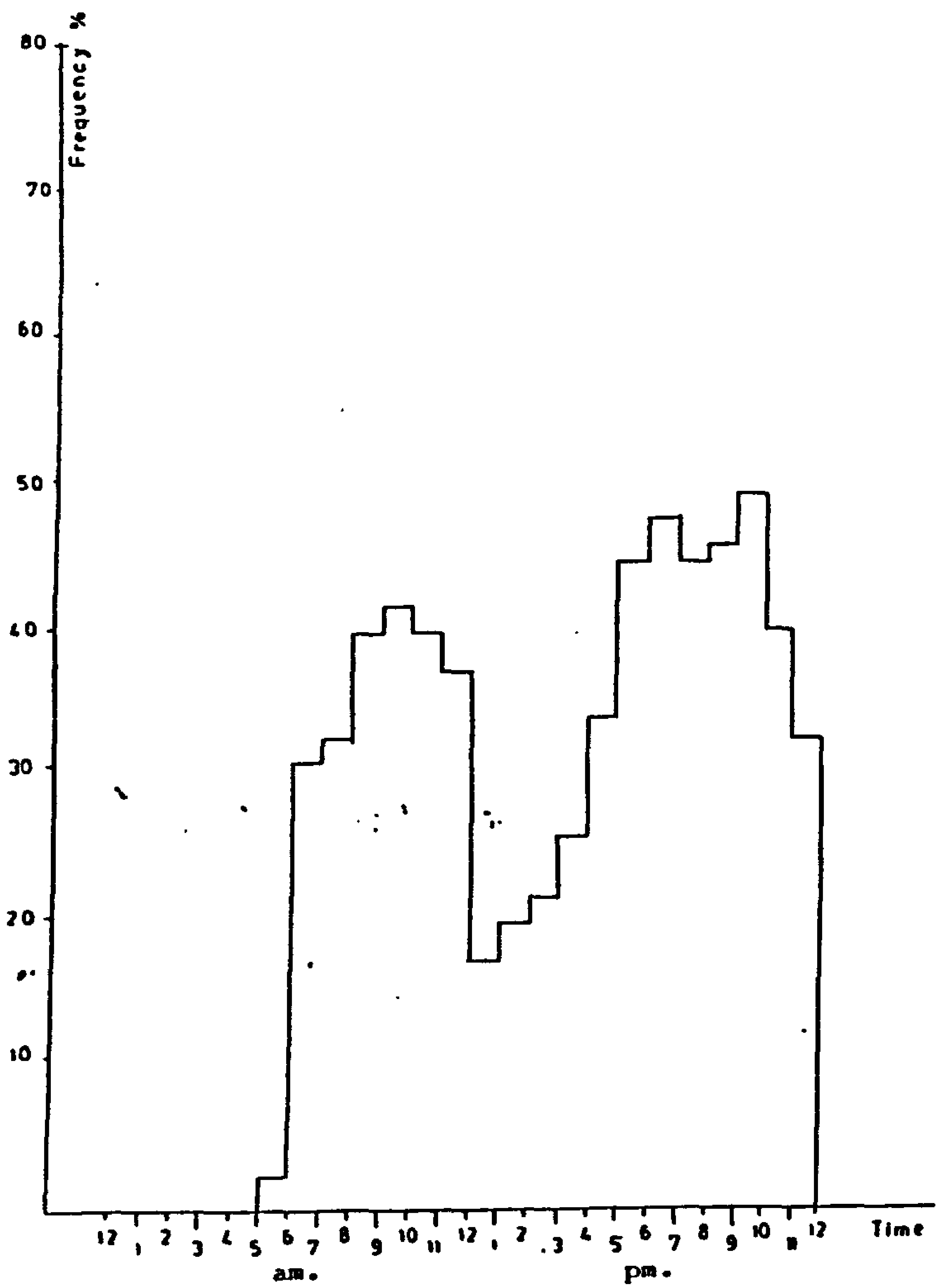


Fig. 3.23 GRAPH SHOWING HOURS LIBRARY IS USED IN SUMMER.

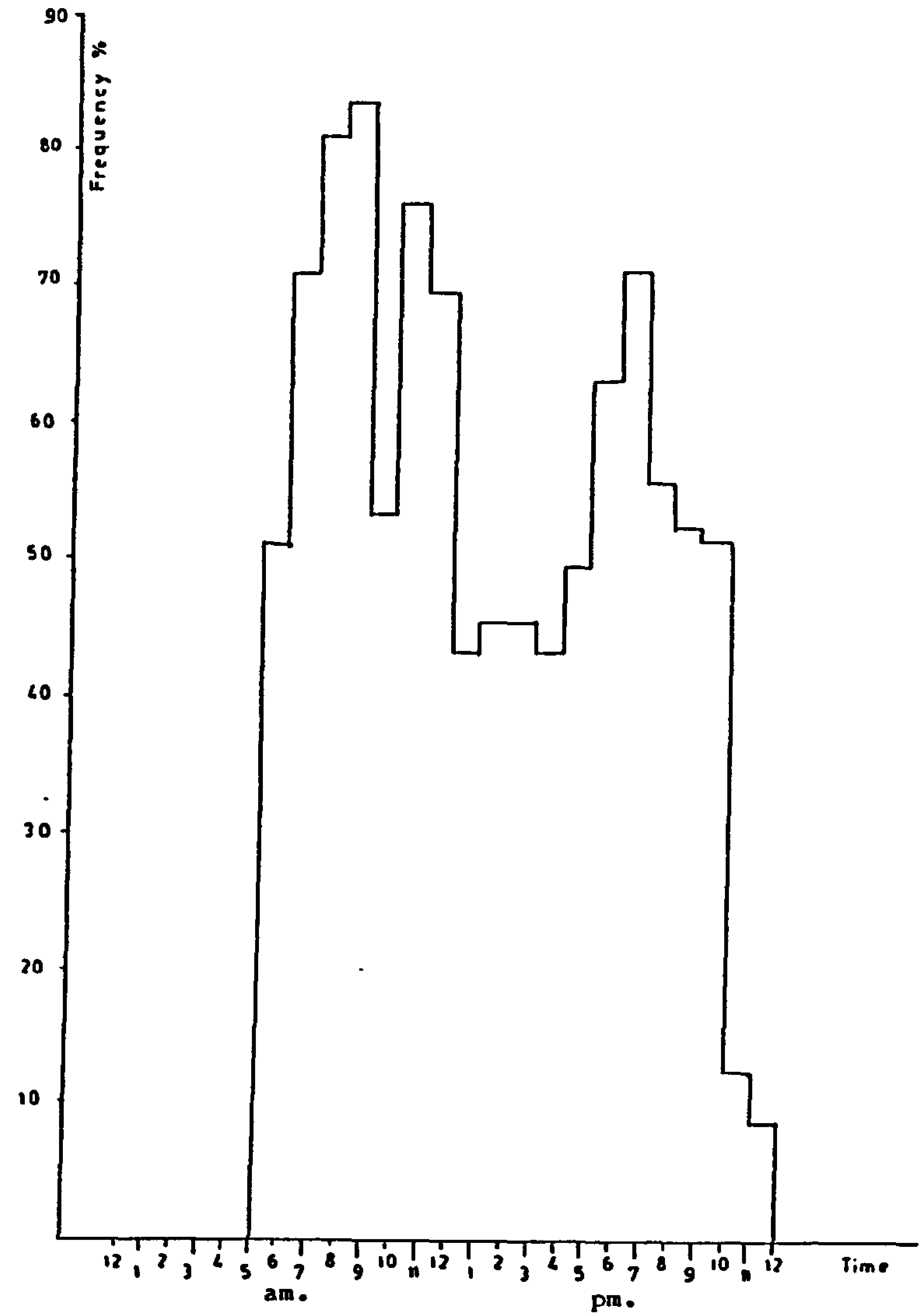


Fig. 3.24 GRAPH SHOWING HOURS KITCHEN IS USED IN SUMMER.

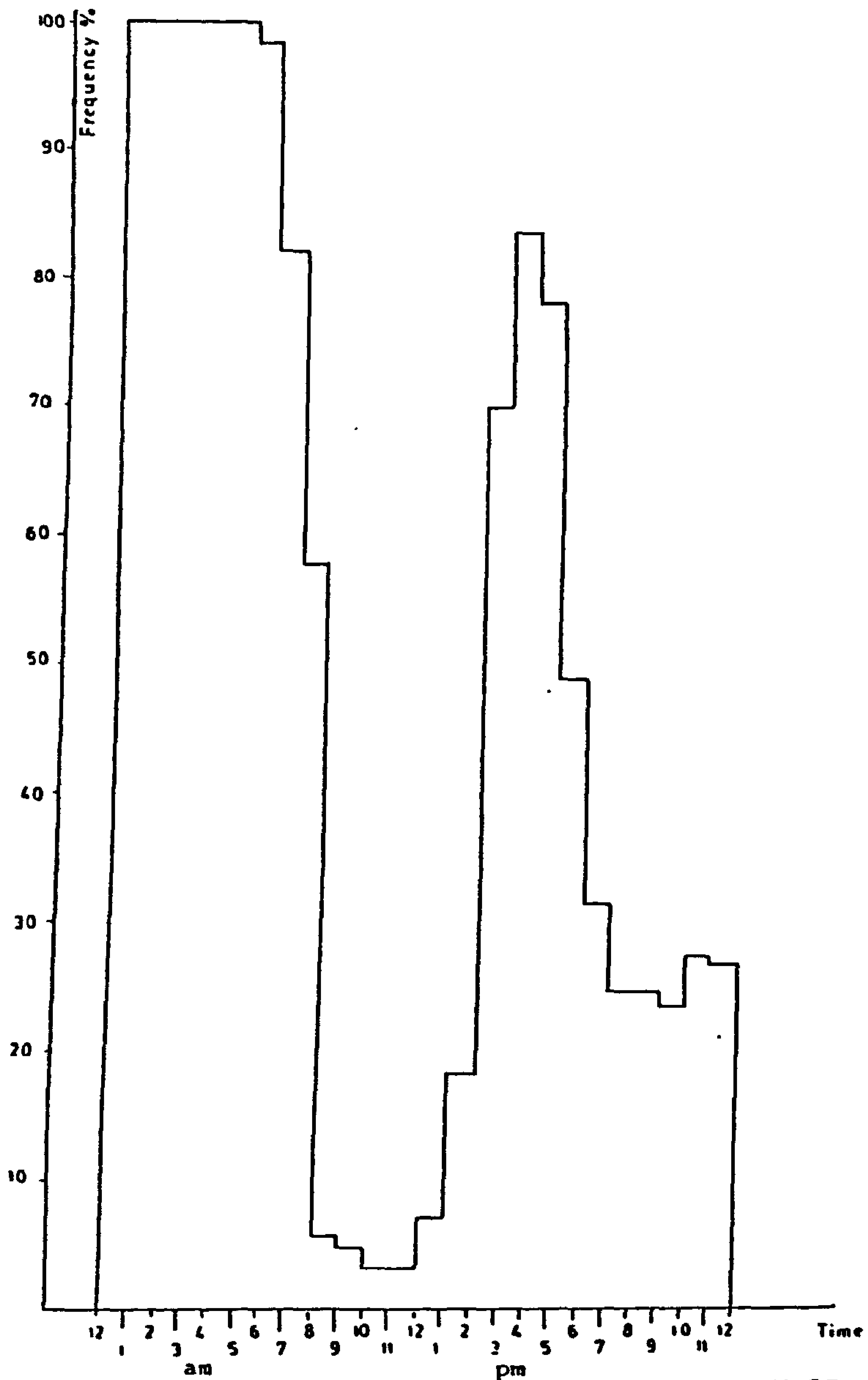


Fig 3.25 GRAPH SHOWING HOURS BEDROOM IS USED IN WINTER.

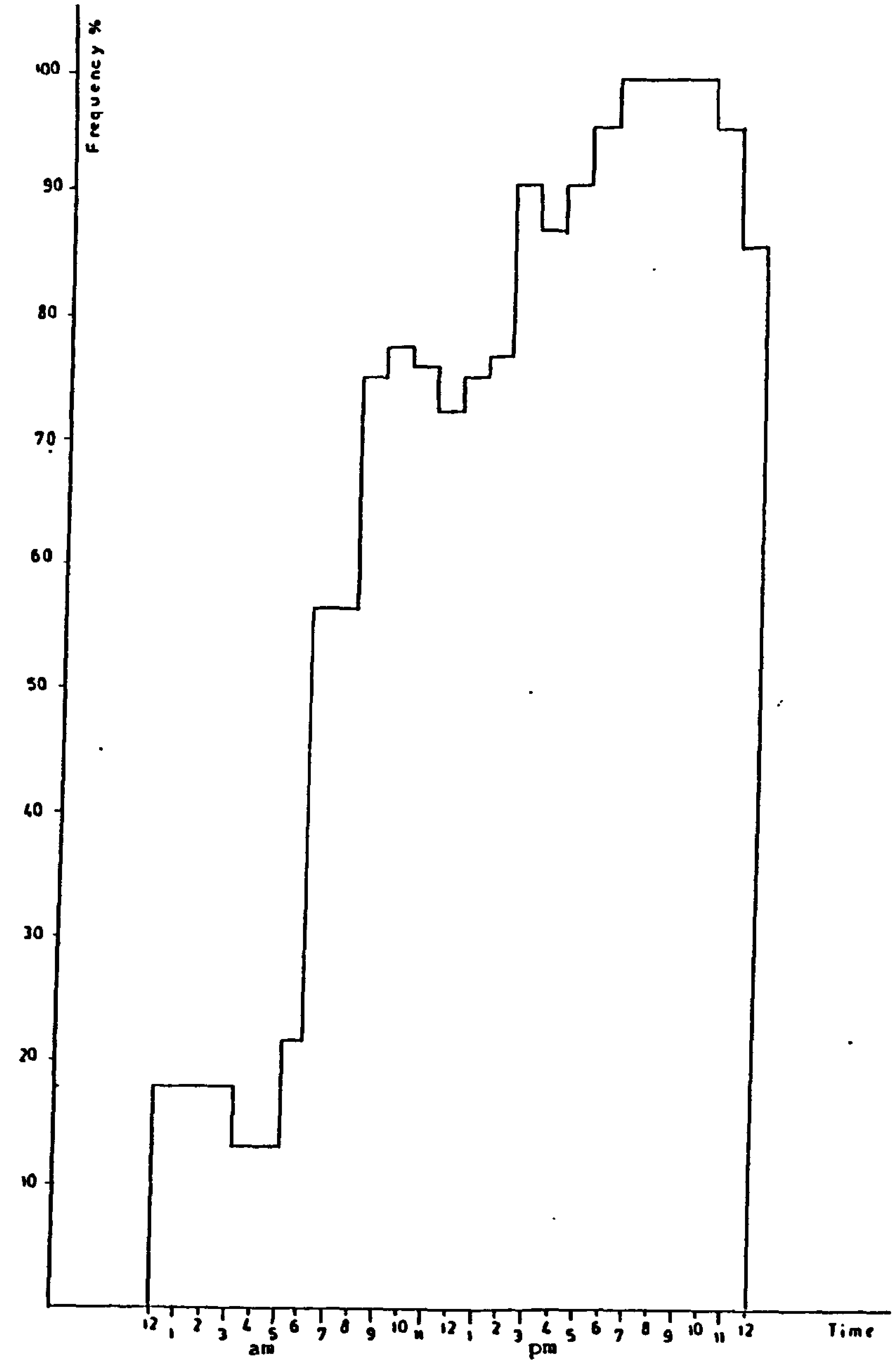


Fig 3.26 GRAPH SHOWING HOURS LIVING ROOM IS USED IN WINTER.

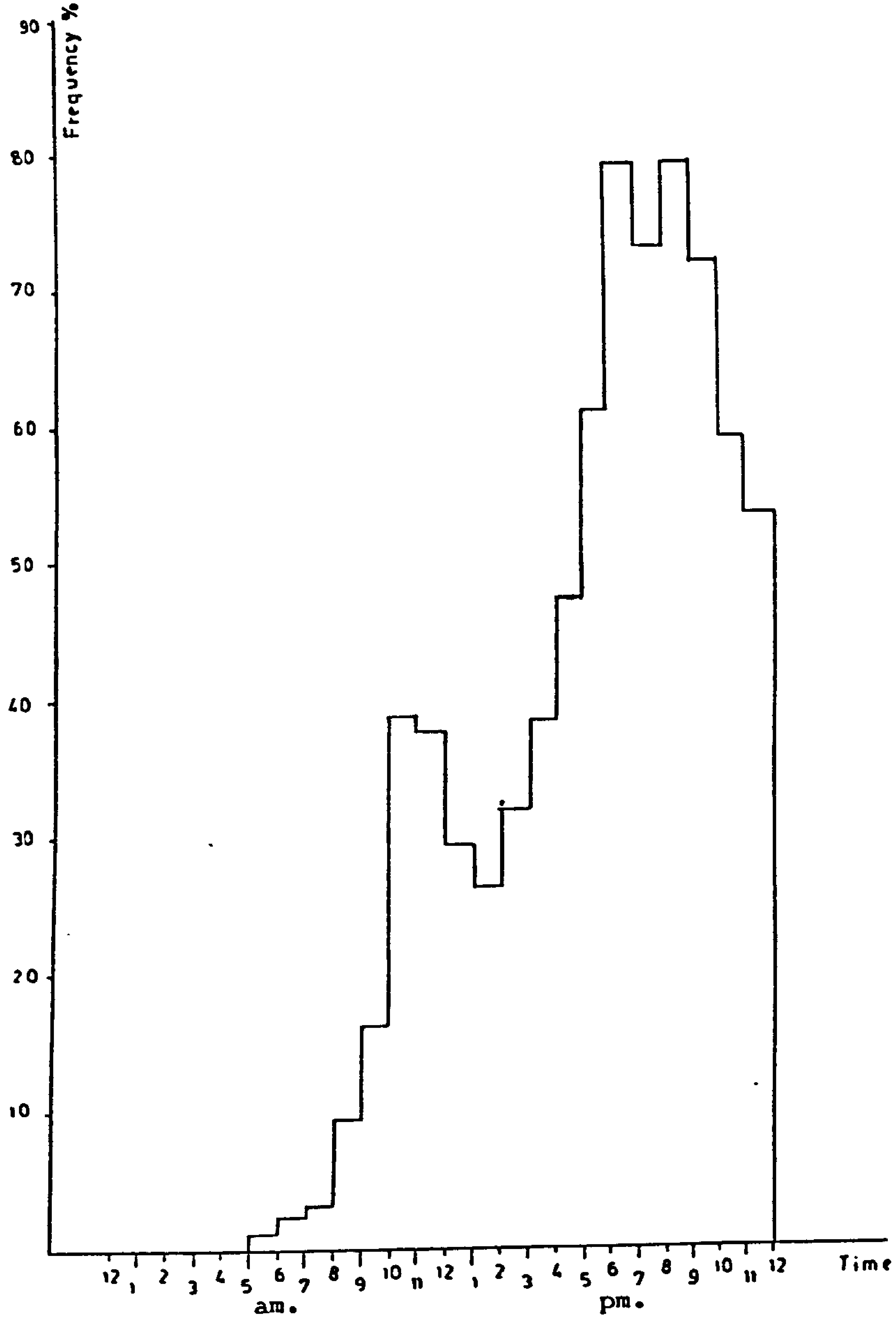


Fig. 3.27 GRAPH SHOWING HOURS VISITOR ROOM IS USED IN WINTER.

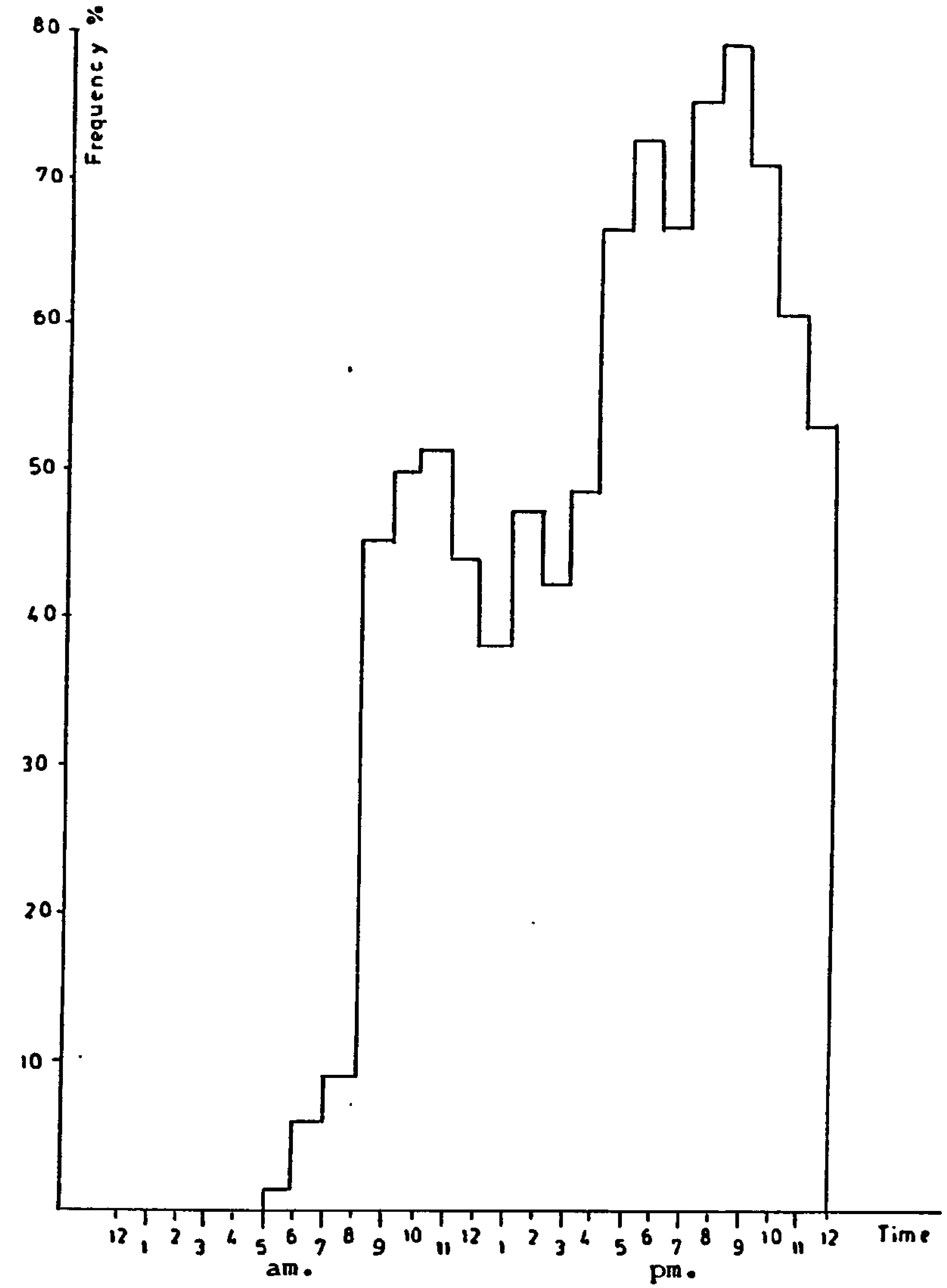


Fig. 3.28 GRAPH SHOWING HOURS LIBRARY IS USED IN WINTER.

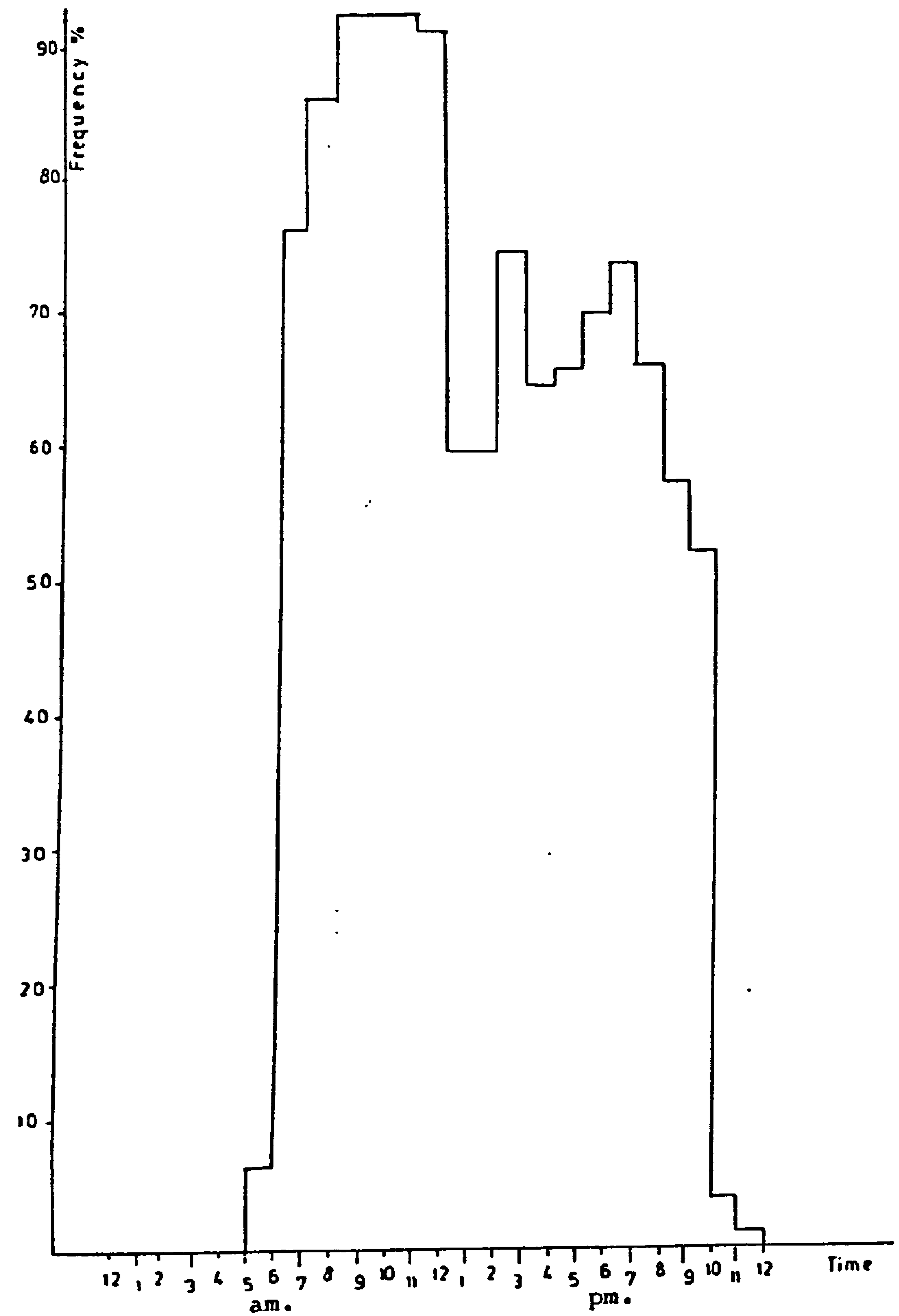


Fig. 3.29 GRAPH SHOWING HOURS KITCHEN IS USED IN WINTER.

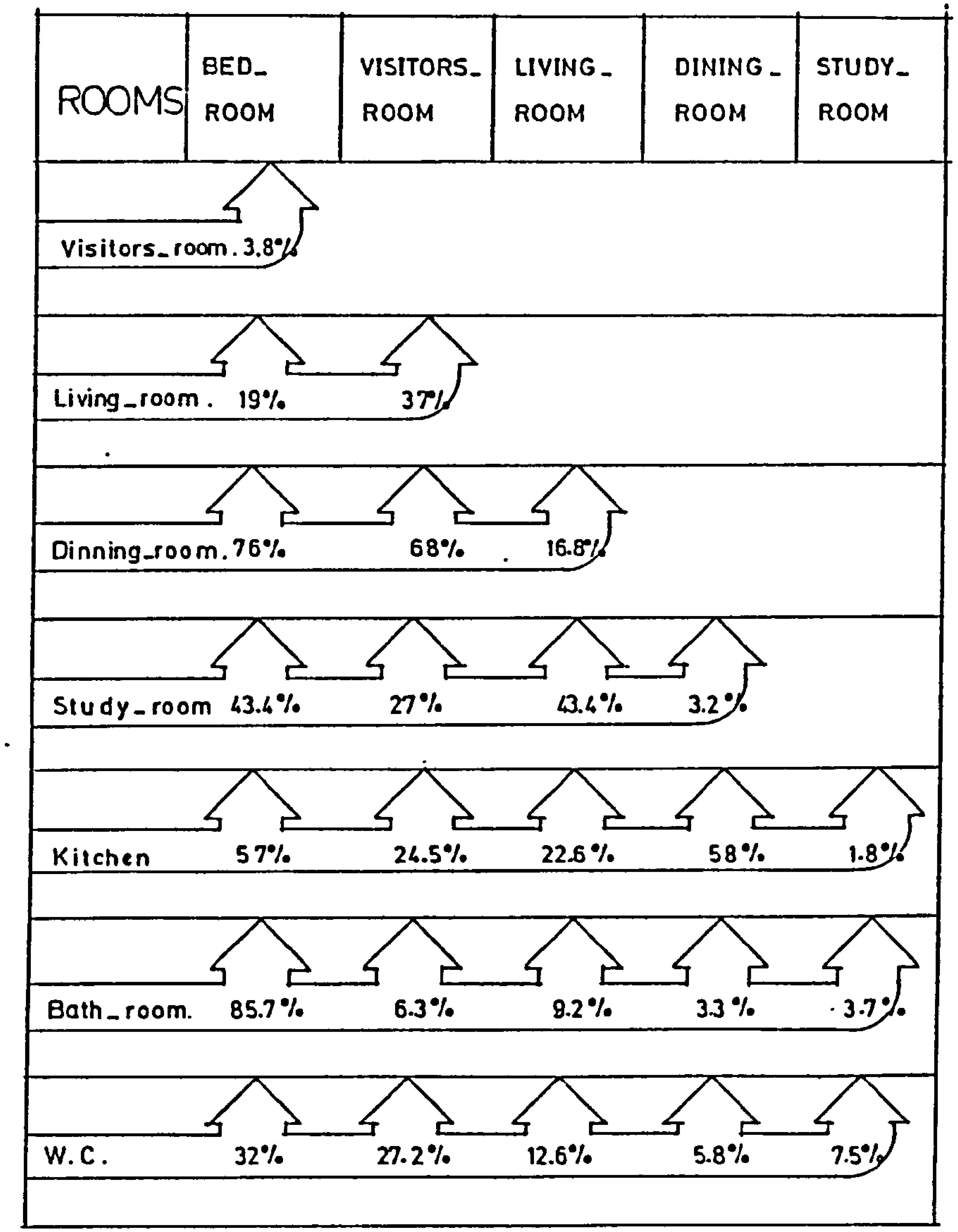


Figure 3.30

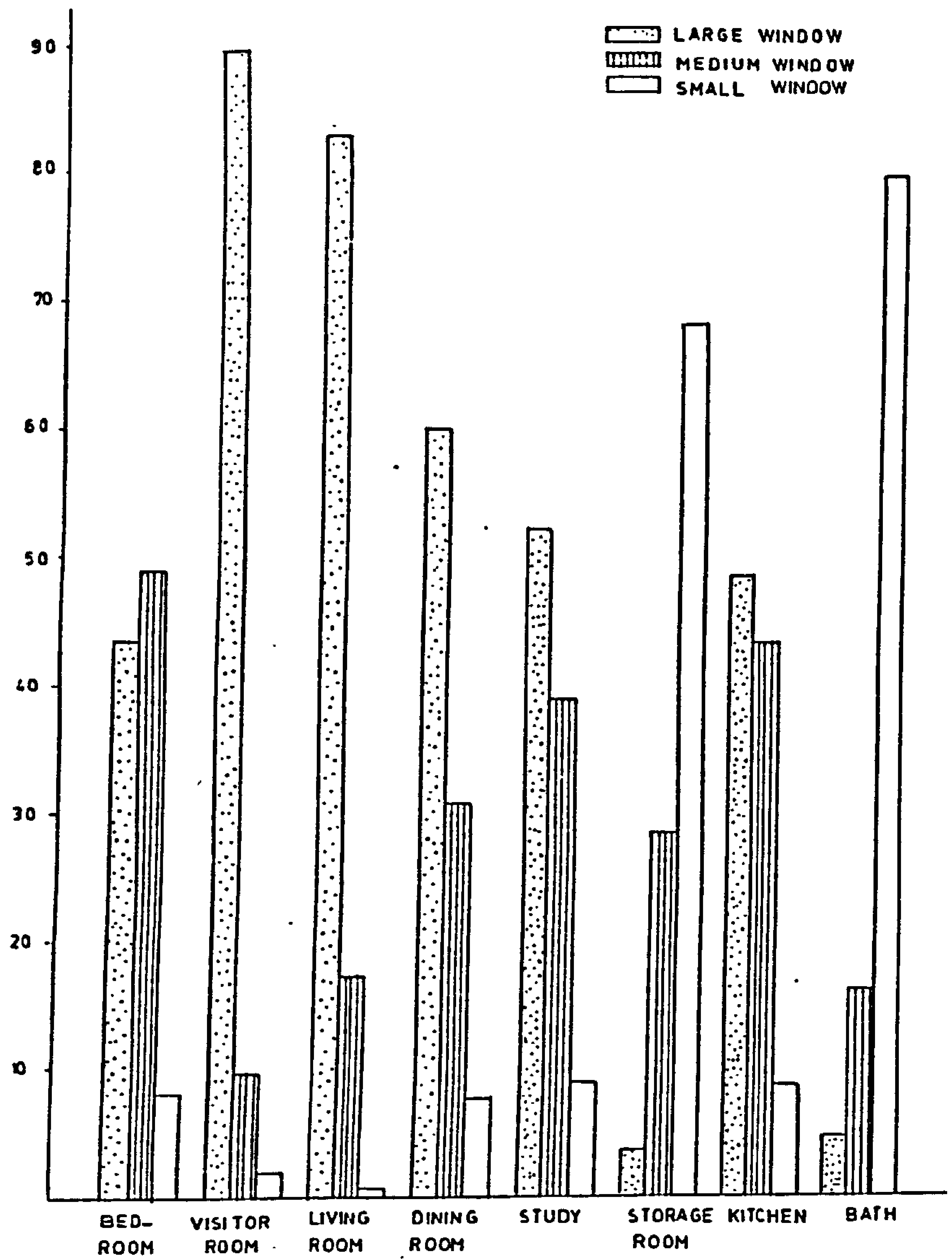


Fig. 3.31
HISTOGRAM SHOWING THE PREFERRED WINDOW TYPES FOR EACH ROOM IN HOUSE.

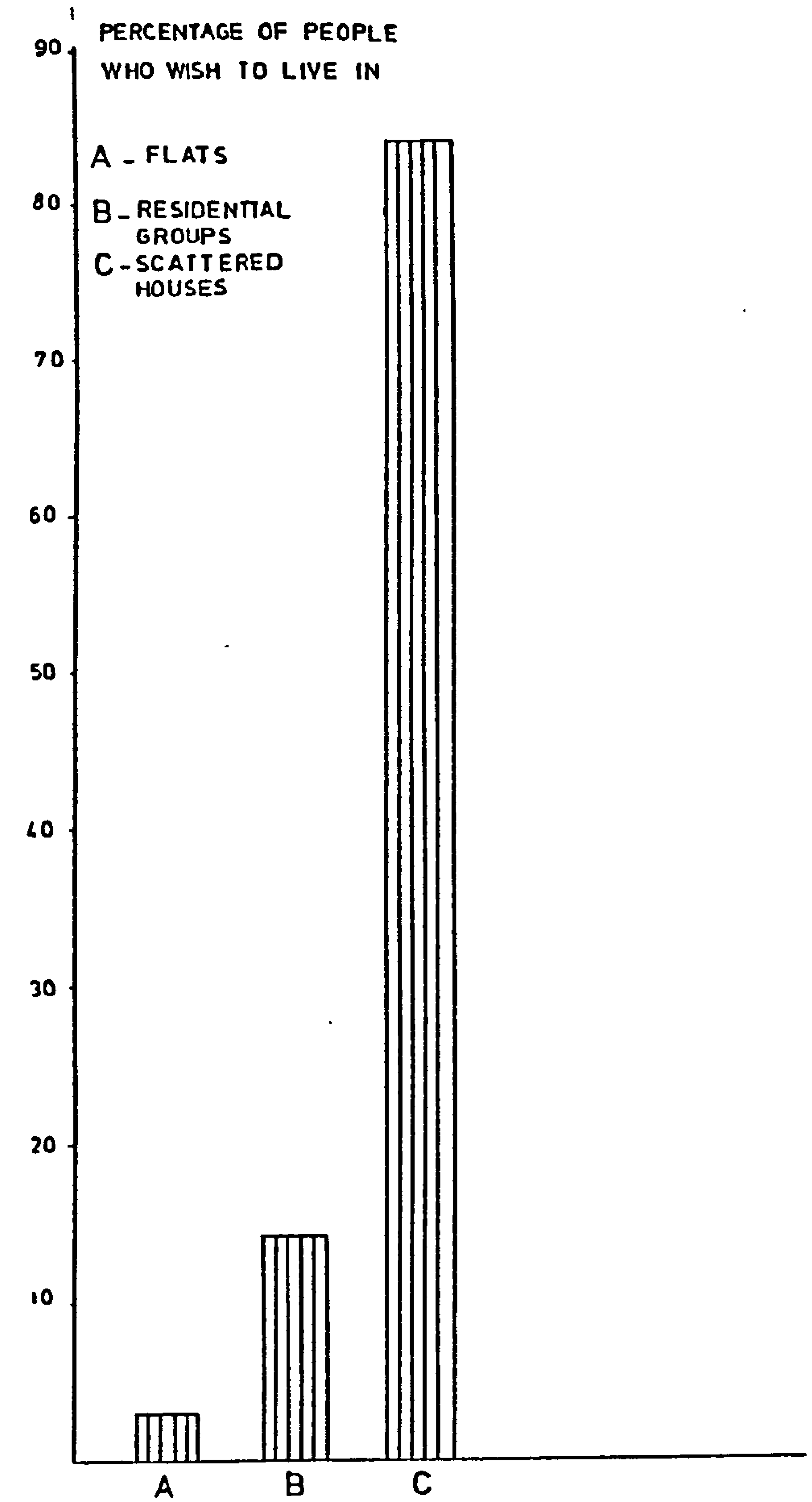


Fig. 3.32 Histogram of house type preferences.

question shows that 80% do so. In this Question the author was anxious to let people rethink, indirectly, the necessity of a dining room, in order to give opportunities for reductions in building cost, since some comments had been made which referred to the dining room as being unimportant (see Figure 3.33).

Question No.16b. Although this question came after the one asking about the use of the kitchen for daily meals, the analysis showed that 64% considered the dining room as important, despite the fact that 80% of those interviewed used the kitchen for daily meals.

The explanation of why people wished to have both a dining room and a large kitchen was because one of the social activities which occurs in most of the houses in the Muslim and Arab world is visits by relatives or friends, and often these visits are accompanied with a meal. Therefore the dining room is essential on those occasions.

The result obtained from this question was supported by the result from question No. 10 which indicated that 58% of the householders use the dining room daily to entertain guests. (see Figure 3.34).

Question No.17 was asked to find the preferences of people in the middle income group on house heights, (single or two storey). The result showed that 66% preferred two storey houses and 34% preferred single storey houses.

Question No.18 asked about the type of sun-breaker people prefer and these results are analysed and plotted in Figure 3.35A.

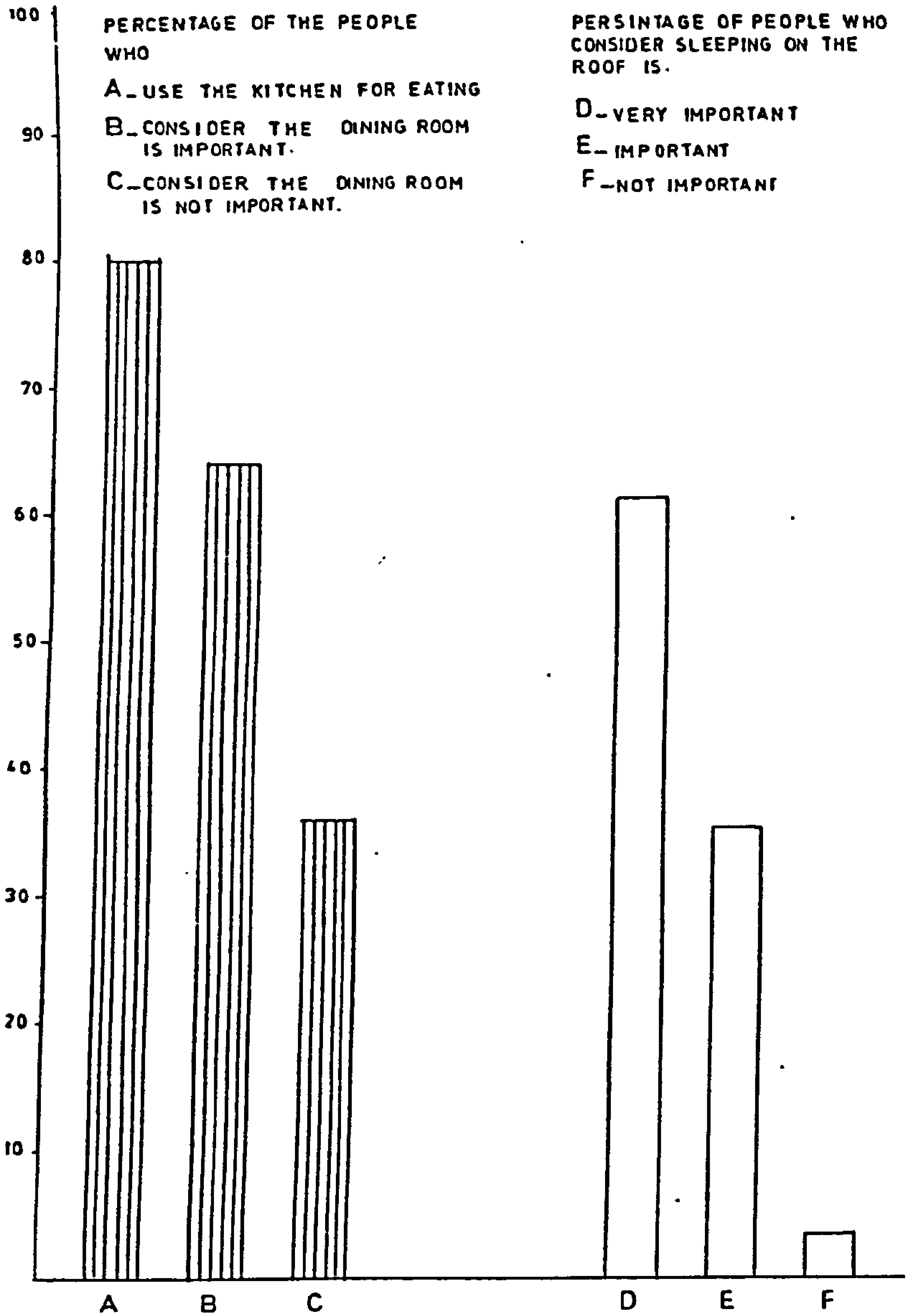


Fig. 3.33

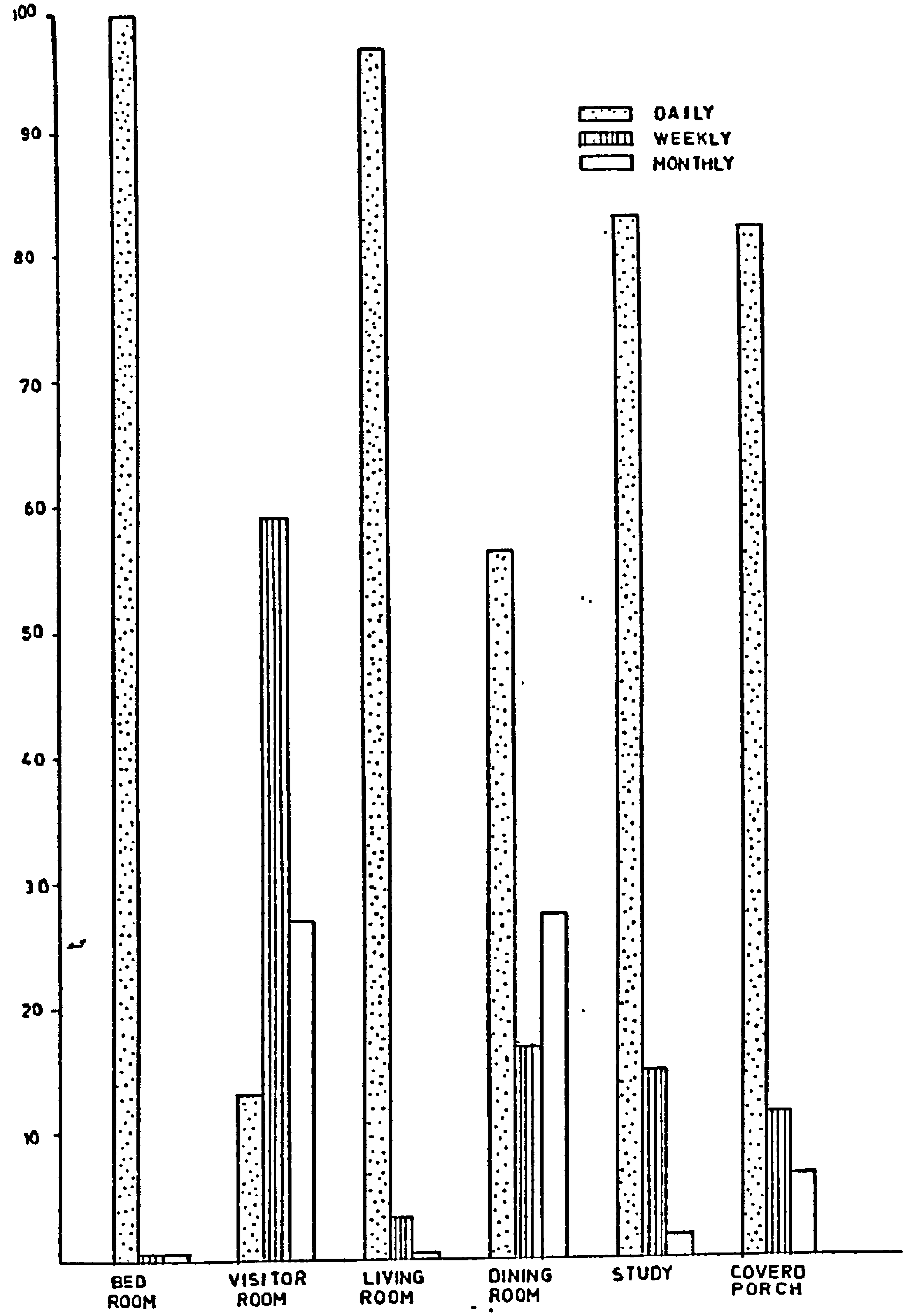


Fig. 3.34
HISTOGRAM SHOWING THE SCALE OF USAGE (%) FOR EACH ROOM IN THE HOUSE.

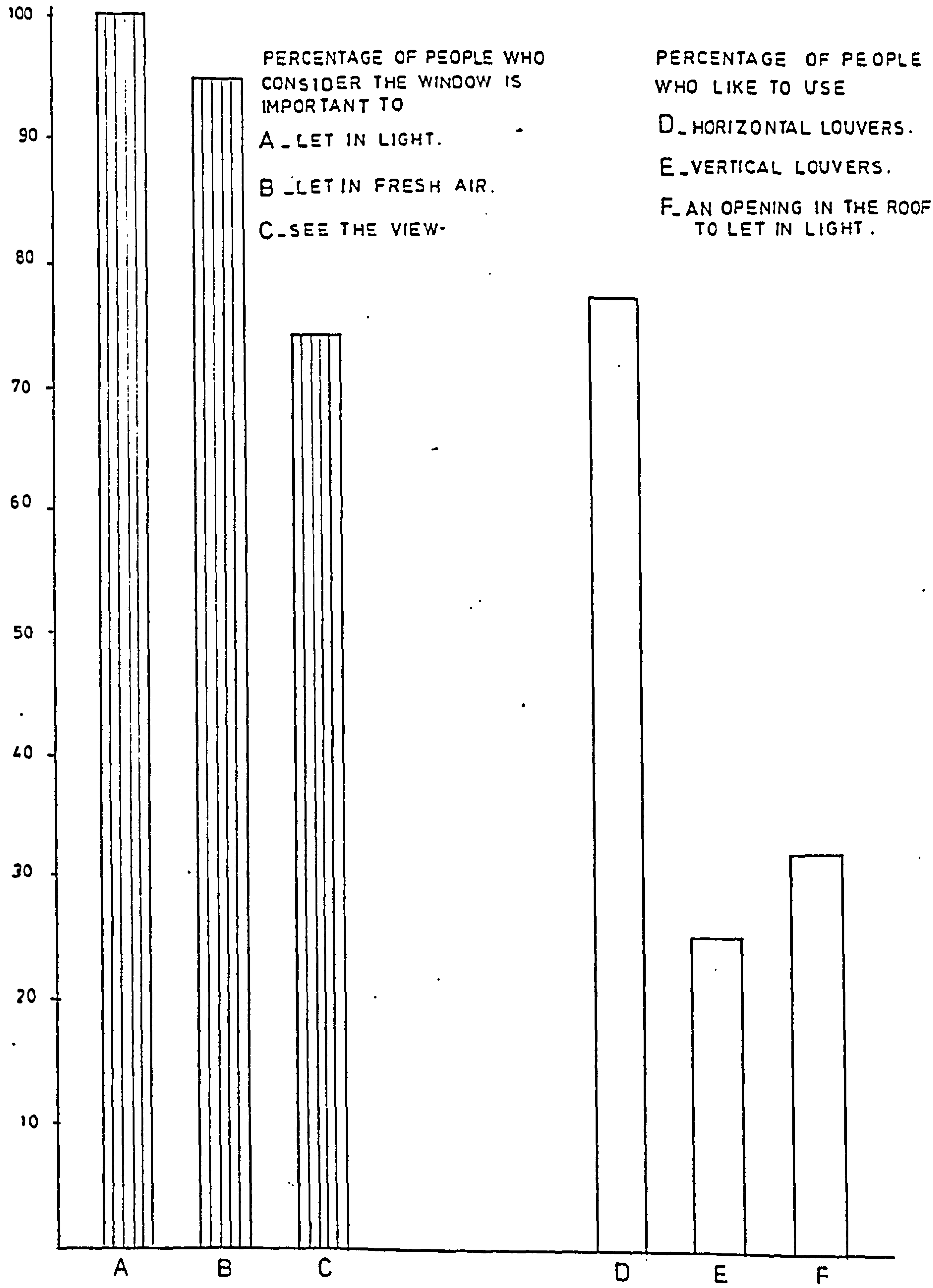


Fig. 3.35 a

Fig. 3.35 b

Question No.20a was designed to find people's views on window function. 100% of the occupants considered windows very important for lighting, 97% for ventilation and 74% for enjoyment of the view outside. These opinions are plotted in Figure 3.35B.

Question No.20b was asked to obtain people's opinions on the colours they prefer in order to decide on the external reflection so that the daylight level inside rooms could if possible be increased. The results showed that 85% preferred light colours, 61% white, 14% preferred light blue and 10% light green.

Question No28 was asked to discover the tendency to the use of the roof for sleeping in summer, especially since the introduction of artificial cooling systems. The results showed that 61% considered sleeping on the roof as very important, 36% considered it important and just 3% considered it not important.

3.2.2 Design of the Model Houses

In order to bring together the preferences and the requirements of the regulations into a practical situation the design model was adapted and the range of windows used in this study were applied.

3.2.2.1 Basic Requirements

3.2.2.1.1 Plot Sizes

Plots distributed by the government under the new scheme are between 200m2 and 400m2. The goverment stops 600m2 plots being distributed in the public sector, but they allow people to build "independent" houses in the urban areas on plots of not more than 800m2. Therefore since this study is firstly aimed to serve housing projects and secondly "independent" houses, the plots used in the model are 400m2

3.2.2.1.2 The Module of the Wall Construction Material

The most common building material in Baghdad is brick; other building materials are concrete blocks and stone which are available but people tend to dislike concrete blocks because of their high thermal conductivity, and the difficulties encountered when installing electric wires and fittings , and as they cannot afford to build in stone , it was found that for the most part people preferred to build in brick. Therefore the brick module was used as a basis for window sizes and proportions.

The dimension of the Iraqi brick according to the Iraqi Standard No.25-1969 is 240mm in length, 115mm in width and 75mm in height. Each side of the brick has a 5mm half mortar joint, therefore the effective length becomes 250mm and the effective width becomes 125mm (see Figure 3.36).

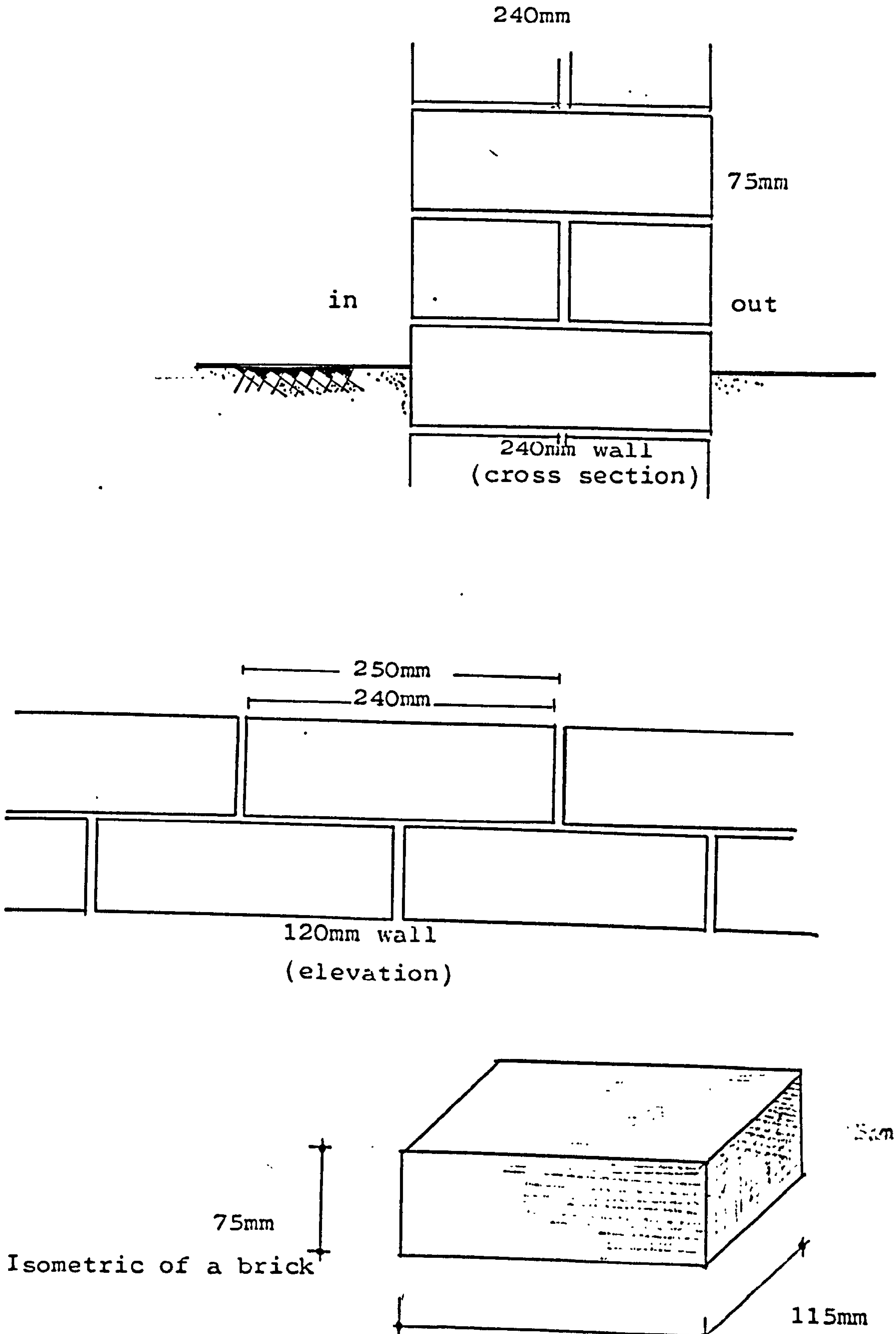

240mm
75mm
in
out
240mm wall
(cross section)
250mm
240mm
120mm wall
(elevation)
75mm
Isometric of a brick
115mm
240mm

Figure 3.36

Accordingly, 250mm (the brick module) was considered as the unit measurement for window widths and heights and 125mm was considered as the unit measurement for room width and length.

Wall thickness in practice is usually 120mm, 240mm and 360mm

3.2.2.1.3 The Building Regulations

Building Regulations are revised according to the expansion of the city, and research on environmental control and improvements. Presently new Building Regulations for Baghdad are about to be announced.

Nevertheless for the purpose of this research the Baghdad Building Regulations No.44-1935 as amended (English publication 1982) were used [Ref. 21].

As mentioned in Chapter 1, the Regulations allow one side of the house to be on one edge of any plot of a 400m2 area and more, and require two sides to be at least one metre in distance from the edges of the plot and the facade to be at least four metres from the front edge.

If the plot is less than 400m2 the facade has to be at least 2.5m from the front edge.

These regulations were followed in the design model.

The author received in January 1986 an unofficial letter from Iraq informing him that according to the new scheme of plot distribution, the Baghdad municipality has issued new Regulations, which state that plots with an area of 240 to 600m2 must have the facade not less than 2.5m from the front edge and plots with area of 601 to 800m2 not less than 4m.

3.2.2.1.4 Common House Elements

Referring to the housing survey, the house model designed to reflect houses in the middle income category. Therefore the model was designed with the following spaces:

A- a visitors' room with an average floor area of 21.7m2

B- a living room with an average floor area of 21.4m2

C- Several bedrooms, the bedrooms are different in size according to their category. The master bedroom is larger than the children's. Therefore bedrooms are found on different floors in the same house.

D- a kitchen with an average floor area of 17.4m2, which follows the results of the survey, according to which 80% of the occupants take their meals in the kitchen. Accordingly they require a large kitchen

E- a dining room. Although people usually use the kitchen for their meals, they still consider dining rooms to be important. The average area found from the survey was 15.4m2.

F- a study. Only 16% of the houses covered by the survey had a study and the average area of the study obtained from the survey was 15.4m2.

G- Storage room. The average area required of the storage room was 6.9m2

H- Several bathrooms, the average bathroom area required for each was 5.1m2

I- Several toilets. Although sometimes toilets were found in the bathroom, most people wanted separate toilets. The average area for the toilet was found from the survey to be 1.5m2

J- A small garden. As the plot sizes were reduced under the new government scheme on plot distribution, the garden area is now determined after the inner space requirements have been fulfilled.

3.2.3 The Model Plan

A model plan of a one and a half storey house, for plot sizes 400m2 was designed, following the findings from the survey, and the regulations (see Figures 3.37A and 37.B). As for room sizes, widths and lengths are determined in multiples of 125mm in order to follow the brick module (see paragraph 3.2.2.1.2). Sizes were achieved as close as possible to the average area determined from the survey.

Rooms and all other domestic activities were located according to required relationships between house spaces, as indicated in the survey. The number of bathrooms and toilets were also decided according to people's wishes.

The author attempted to make the plan fulfil all the necessary requirements and preferences found in the survey.

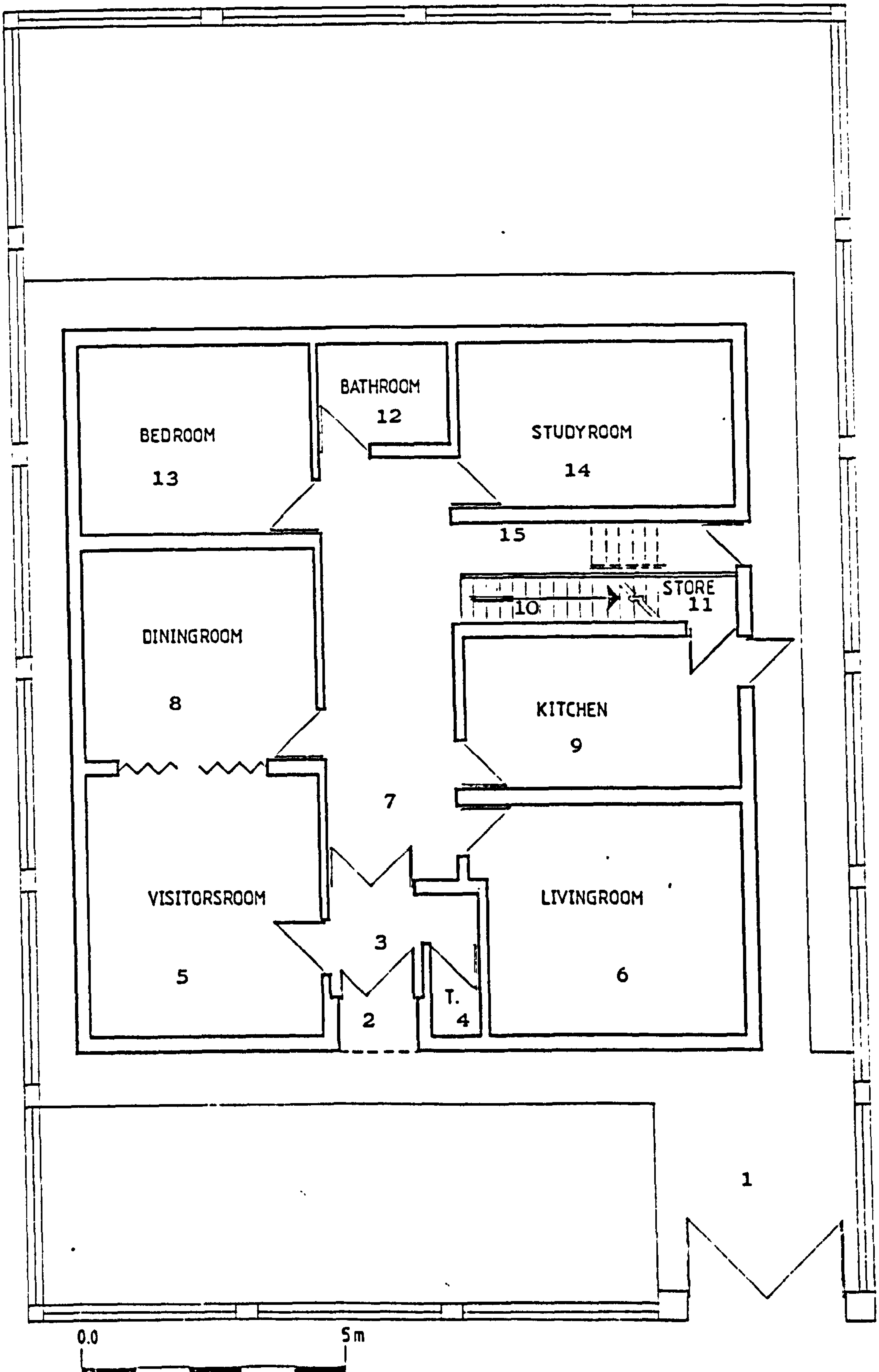


Figure 3.7a GROUND FLOOR PLAN

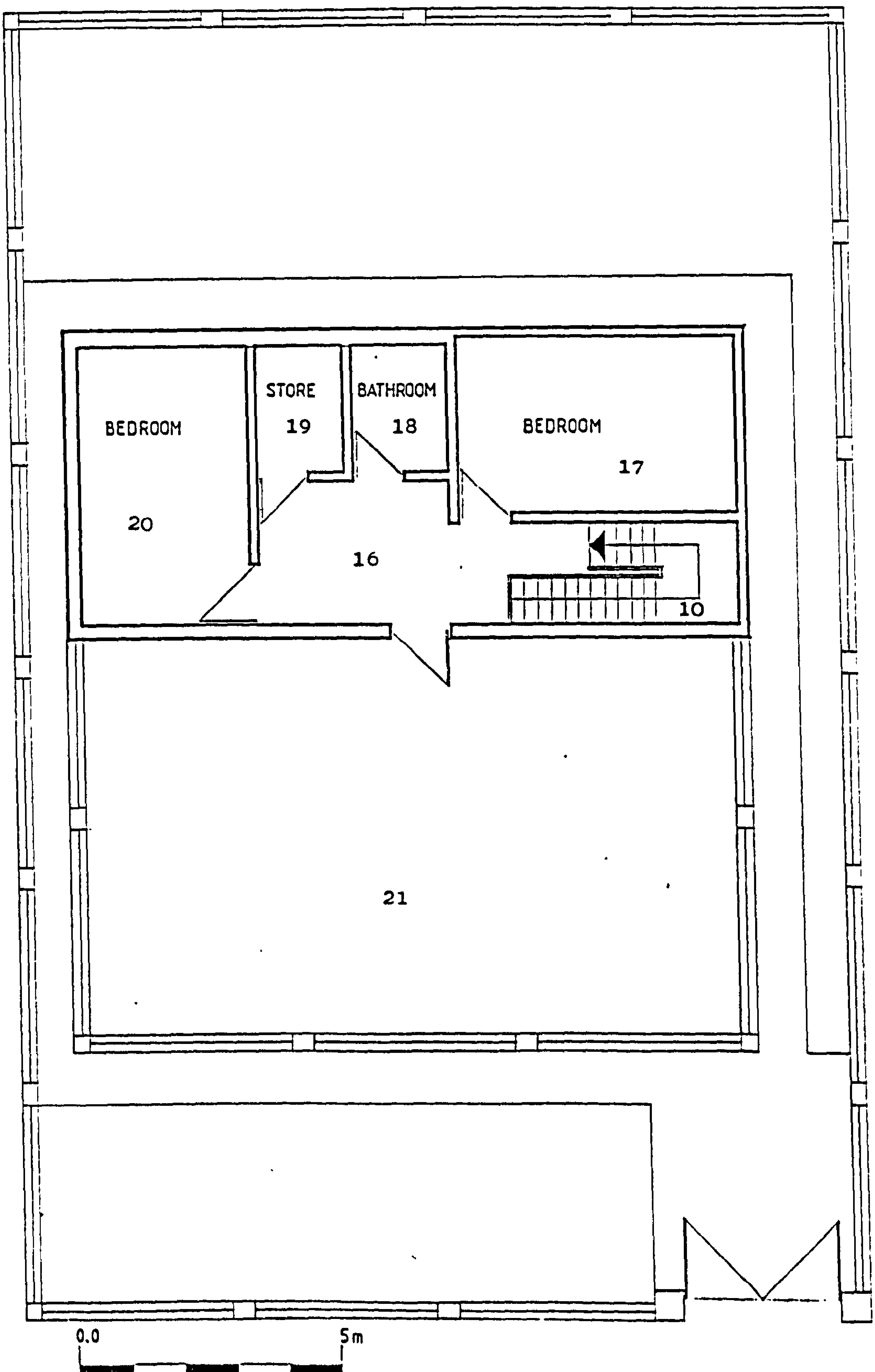


Figure 3.7b FIRST FLOOR PLAN

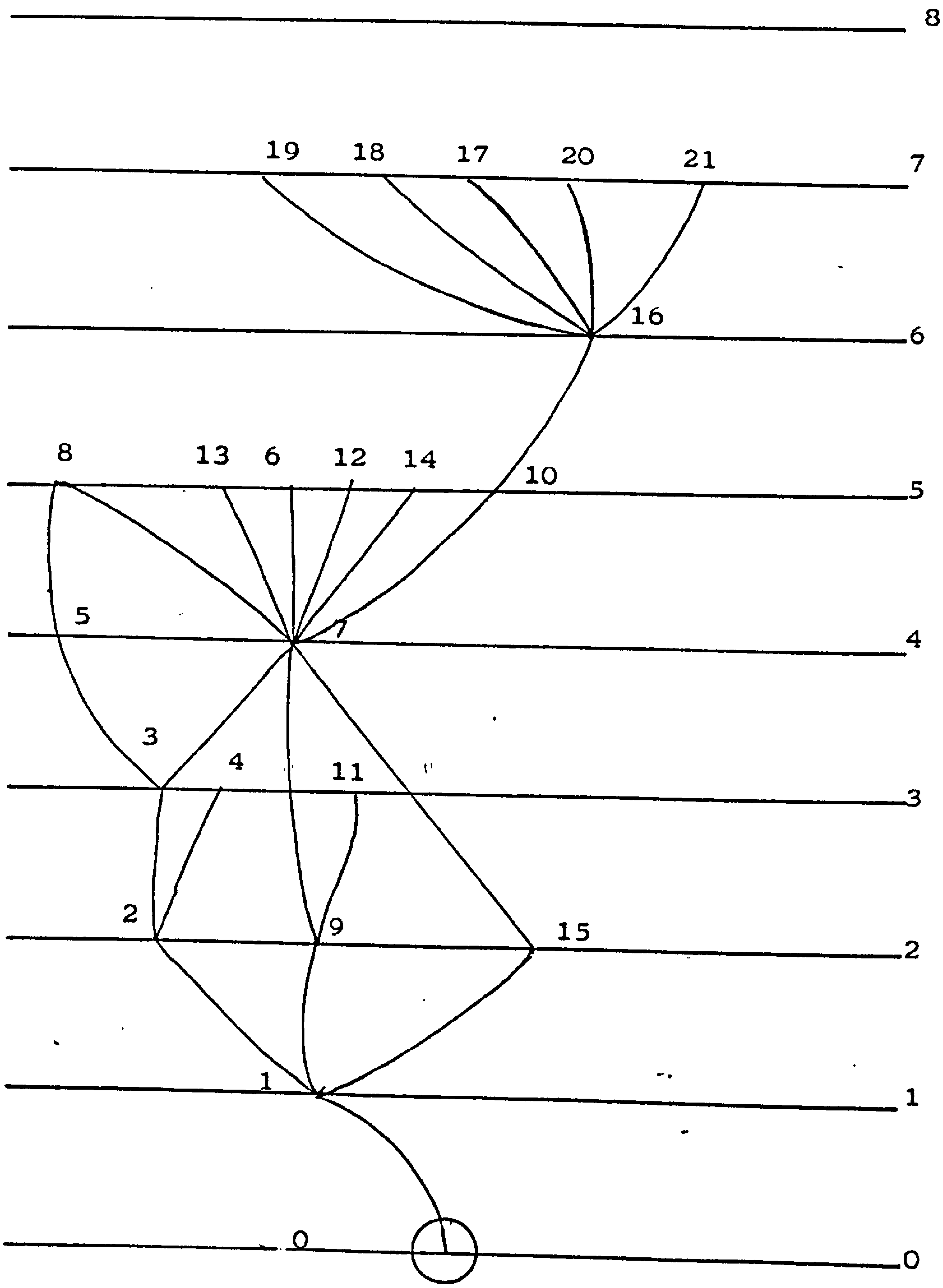


Figure 3.38 Space structure map

The plan was checked by drawing a space structure map to verify the ease with which it could be used (see Figure 3.38).

CHAPTER 4

CHAPTER - 4 -
SUNLIGHT

4.1 Direct Sunlight Control

Direct sunlight is considered as the most important factor to be controlled in hot regions like Baghdad which is located at Latitude 33° degree north, not only for reducing summer solar effects but to obtain as much useful winter energy as possible .

Controlling direct sunlight can be achieved by a number of methods but all of them have the same aim: to protect inner spaces of the building from direct sunlight penetration in summer and to allow as much winter sun as possible to penetrate. Direct sunlight control can be achieved mainly by the use of shading devices but these have disadvantages and the designer might not wish to depend on them considering them as ugly objects on the facade unless they are in corporated into the architectural design.

In order to let the designer obtain the maximum benefit of such devices, with least restriction, some useful data has to be presented to serve as guidelines to windows having the capability of controlling direct sunlight with as little reliance as possible on external shading devices.

4.2 The Geometry of Direct Sunlight

To understand methods of direct sunlight control, as well to provide designers and users with more information on sun movement and solar geometry inside and outside the house, information about sun and shade has to be explained so as to enable the designer to contribute, with a reasonable level of understanding, to the selection of suitable windows from the recommended range.

4.2.1 General View

As the earth moves once a year around the sun in an elliptical orbit, the axis of the earth is tilted about 23.4° from the ecliptic, so the north and south hemisphere tilt towards and away from the sun (see Figure 4.1). The observer is unaware of the increased angle between the earth's axis and the ecliptic plane as the cause for the low winter solar altitude in the northern hemisphere. The obverse applies to the southern hemisphere.
Thus variations in sun angles depend on the latitude, the season declination and time of day.

4.2.2 Fixing Sun Position

4.2.2.1 Graphically sun position can be found from the geometric projection of a gnomon on the ground (Figure 4.2). Sun position be defined with two angles azimuth angle (Z) and altitude angle (A)

4.2.2.2 Mathematically sun position can be found by using the following formulae:

$$A = \mathrm{Sin}^{-1}\,(\mathrm{Sin}\,L\ \mathrm{Sin}\,D + \mathrm{Cos}\,L\ \cos D\ \mathrm{Cos}\,T) \qquad \ldots .4.1$$

$$Z = \mathrm{Sin}^{-1}\,(\mathrm{Sin}\,T\ \mathrm{Cos}\,D\ \mathrm{Sec}\,A) \qquad \ldots .4.2$$

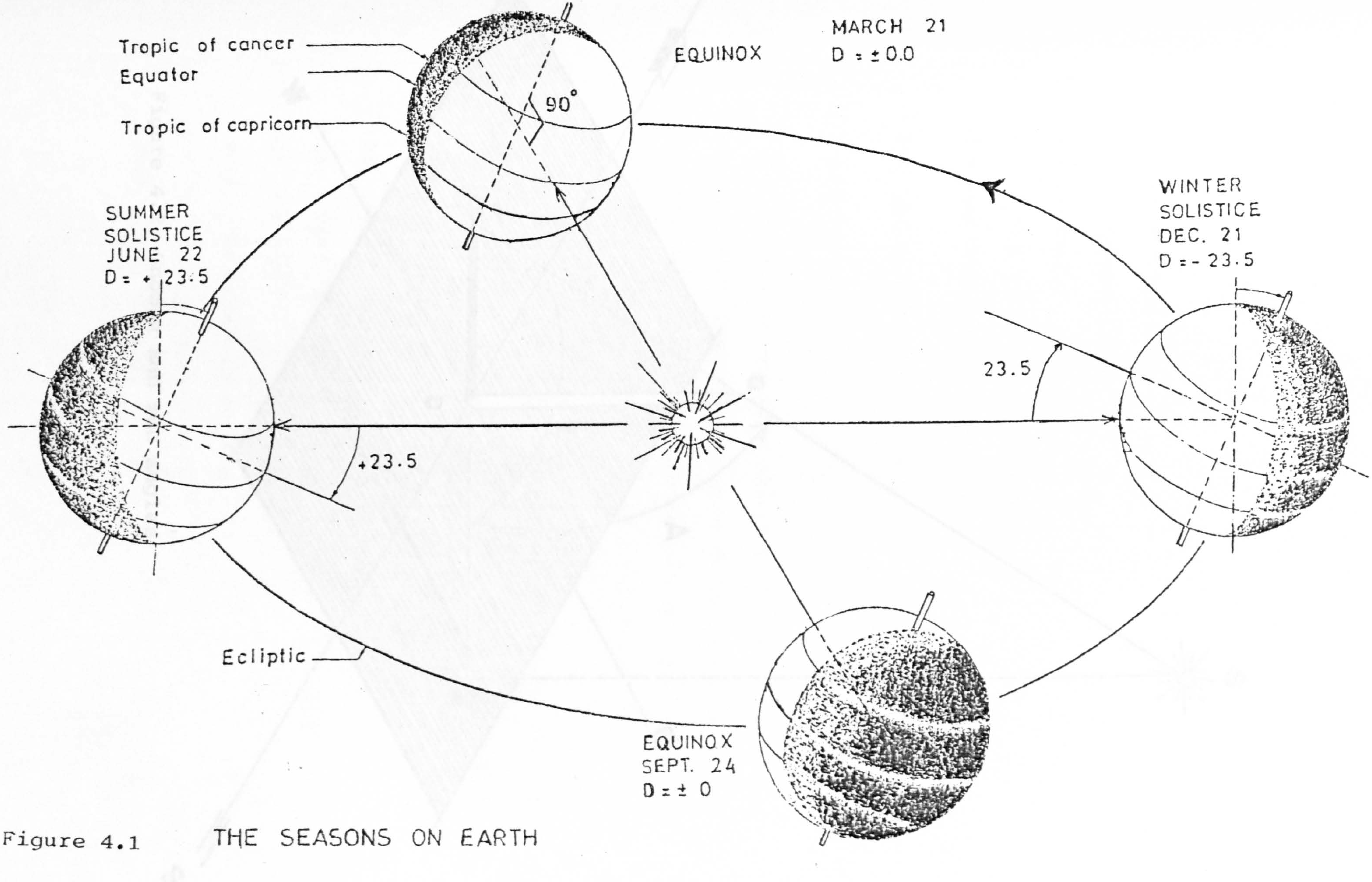


Figure 4.1 THE SEASONS ON EARTH

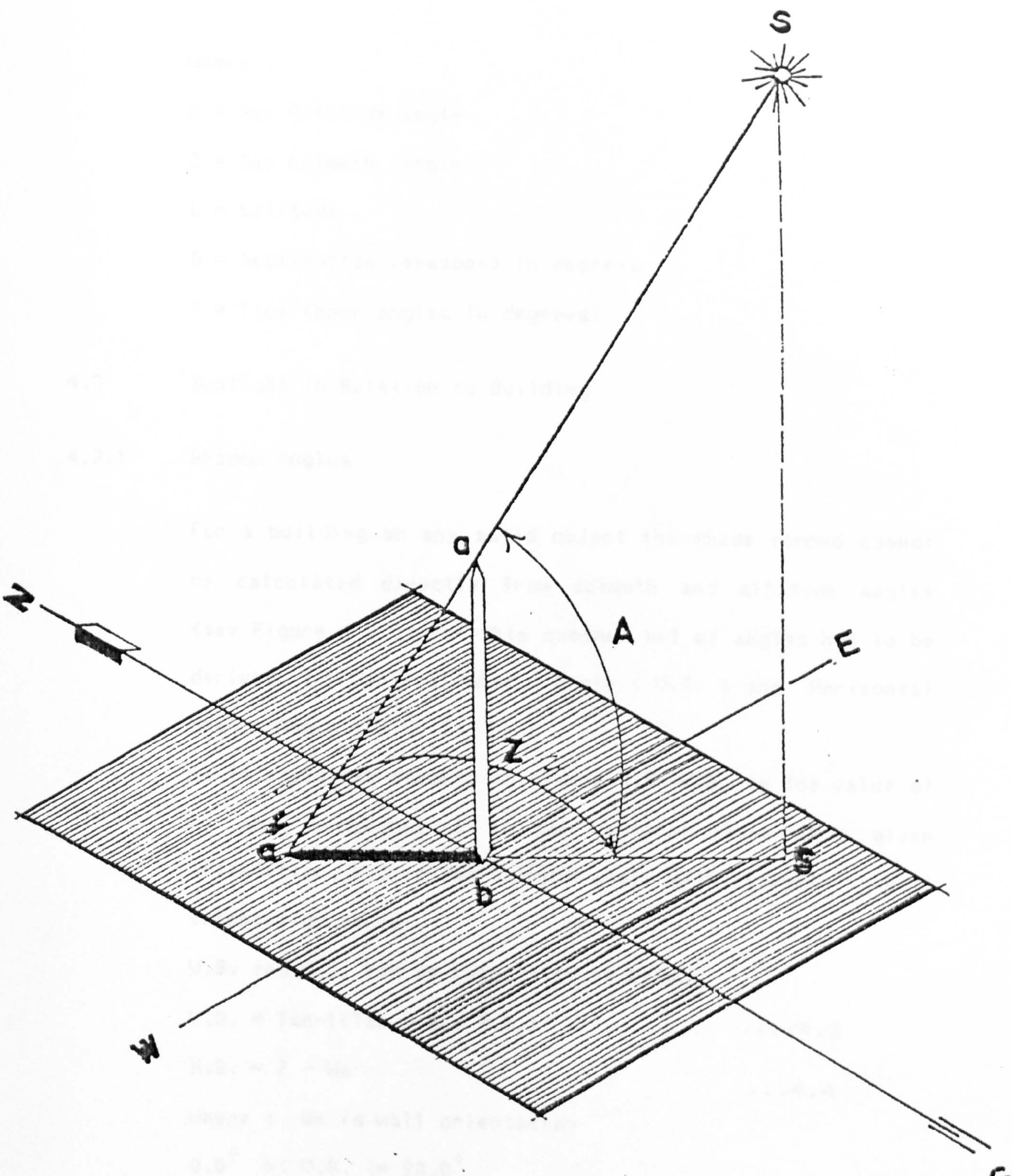


Figure 4.2 Gnomon and sun angles

Where :

A = Sun Altitude angle

Z = Sun Azimuth angle

L = Latitude

D = Declination (seasons) in degrees

T = Time (hour angles in degrees)

4.3 Sunlight in Relation to Building

4.3.1 Shadow Angles

For a building or any solid object the shade formed cannot be calculated directly from azimuth and altitude angles (see Figure 4.3); for this another set of angles has to be derived, the Vertical Shadow Angle (V.S.) and Horizontal Shadow Angle (H.S.)

As is explained clearly in Figure 4.3 V.S. is the value of A when projected on to the vertical plane of a given orientation. H.S.is the azimuth angle with respect to wall orientation angle.

V.S. and H.S. can be calculated as below:

$$V.S. = Tan^{-1}(Tan\ A\ Sec\ H.S.) \quad \quad ....4.3$$

$$H.S. = Z - Wa \quad \quad ....4.4$$

Where : Wa is wall orientation

$0.0^\circ =< V.S. <= 90.0^\circ$

$-90.0^\circ =< H.S. <= 90.0^\circ$

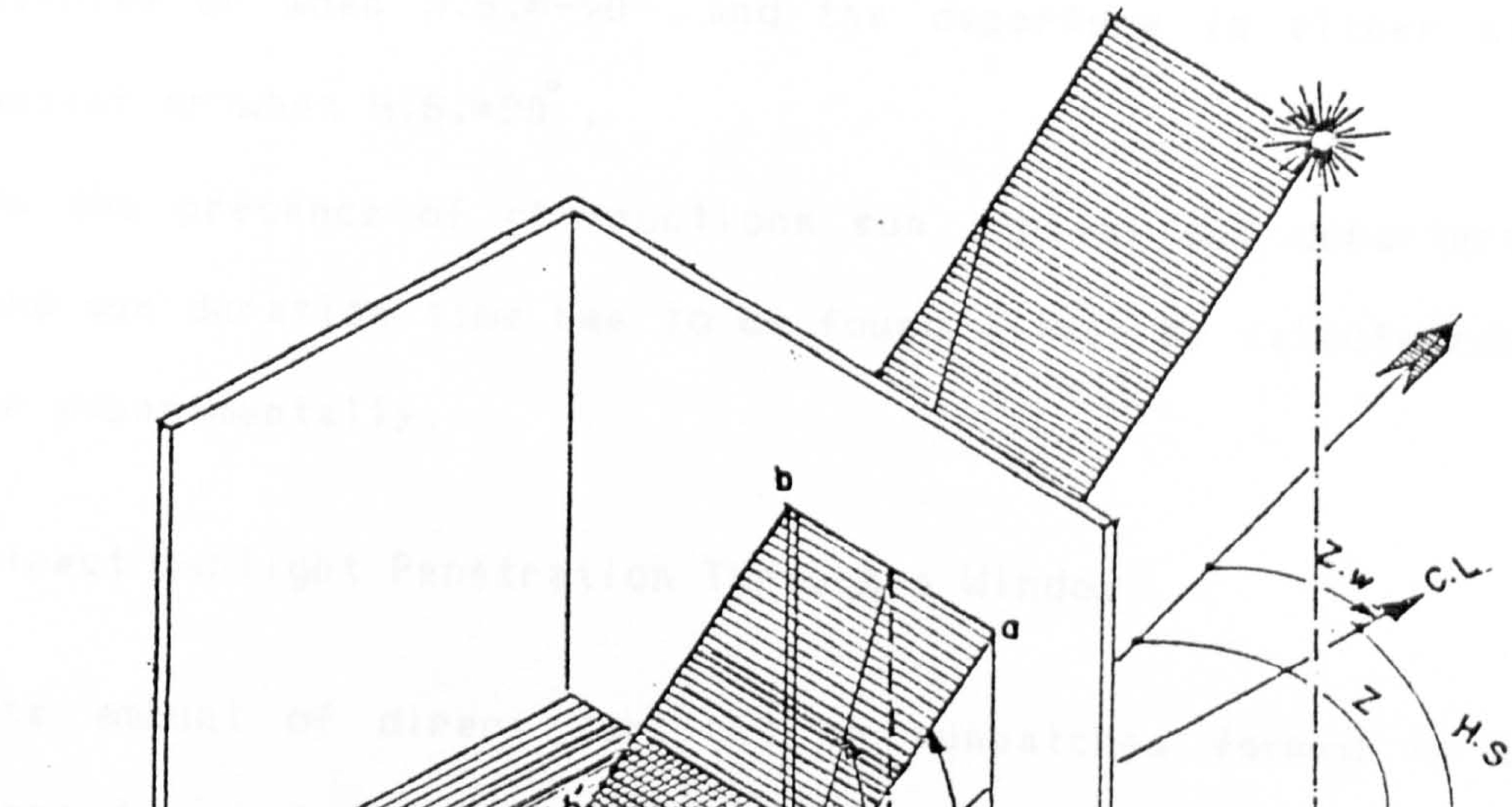


Figure 4.3 Solar angles

4.3.2 Sun Arrival and Departure

Insolation duration and time on any wall of the building are affected by: wall orientation , date, time, and presence of obstructions and clouds.

For unobstructed walls sun arrival time is either at sunrise or when H.S.=-90° and the departure is either at sunset or when H.S.=90° .

In the presence of obstructions sun arrival and departure and sun duration time has to be found either by calculation or experimentally.

4.3.3 Direct Sunlight Penetration Through a Window

The amount of direct sunlight or sunpatches formed in a room for a fixed orientation is affected by the value of vertical and horizontal shadow angle (see Figure 4.4), wall thickness (see Figure 4.5), window size and proportion (see Figure 4.6) and external obstructions.

4.3.4 Sun Patches and Solar Radiation

Although the intensity of solar radiation is the main factor in raising the temperature in a building, the area of a room's surfaces which are insolated is an approximate means of evaluating solar energy gain and, moreover, it is a phenomenon which people experience directly. Thus it was found from the survey that people consider sun patches significant; they are welcome in winter and unwelcome in

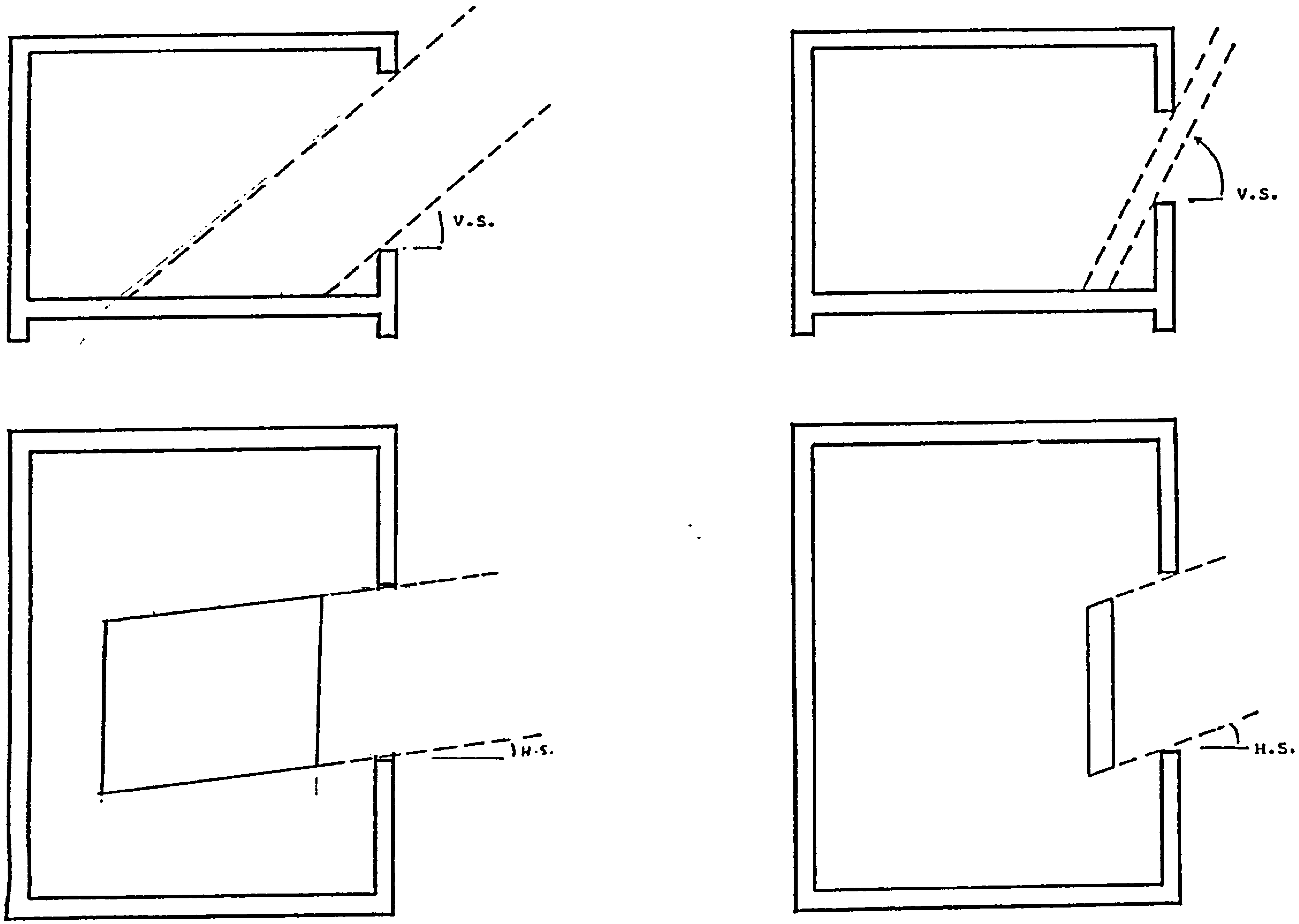


Figure 4.4

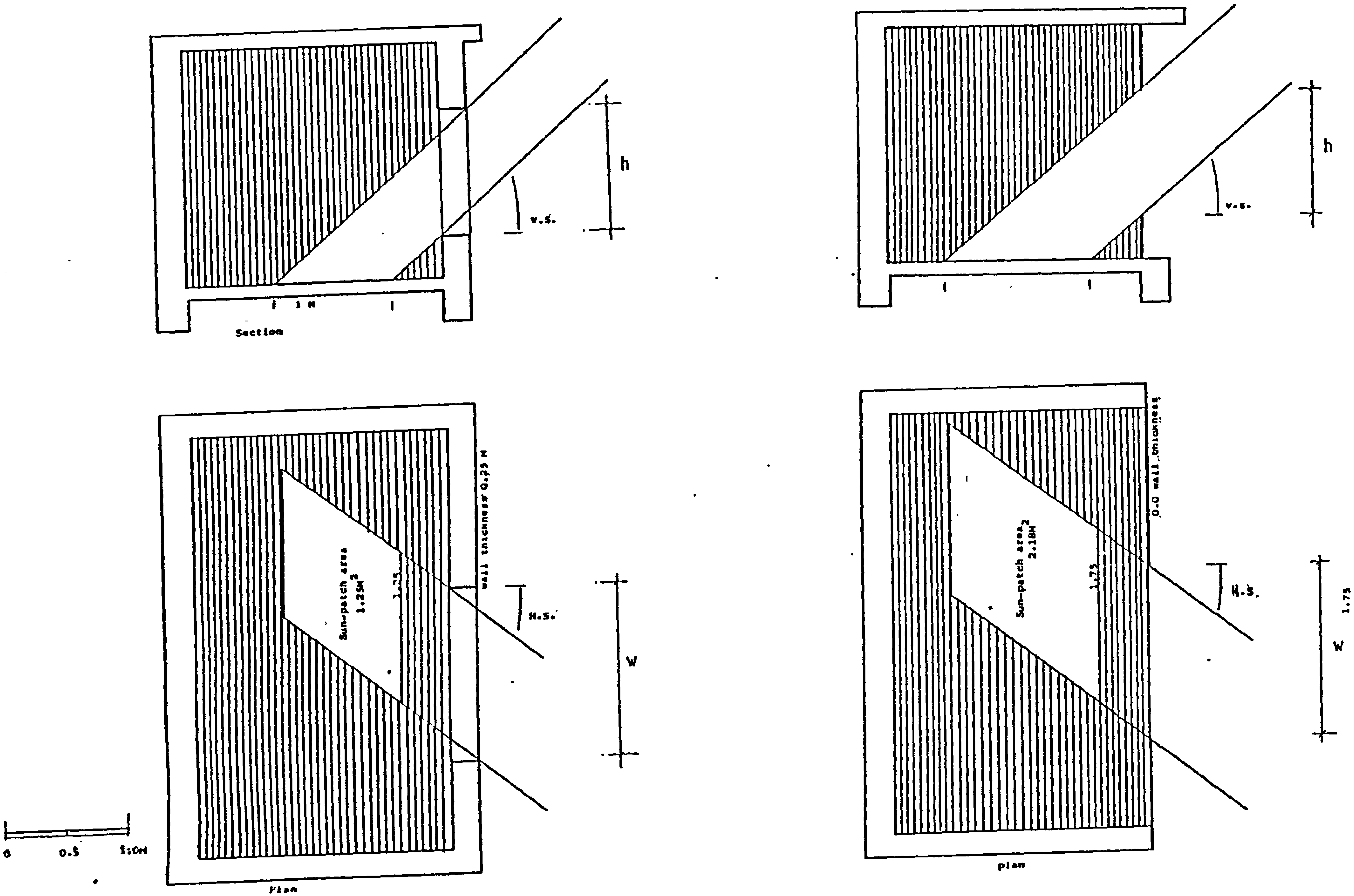


Figure 4.5 The effect of wall thickness

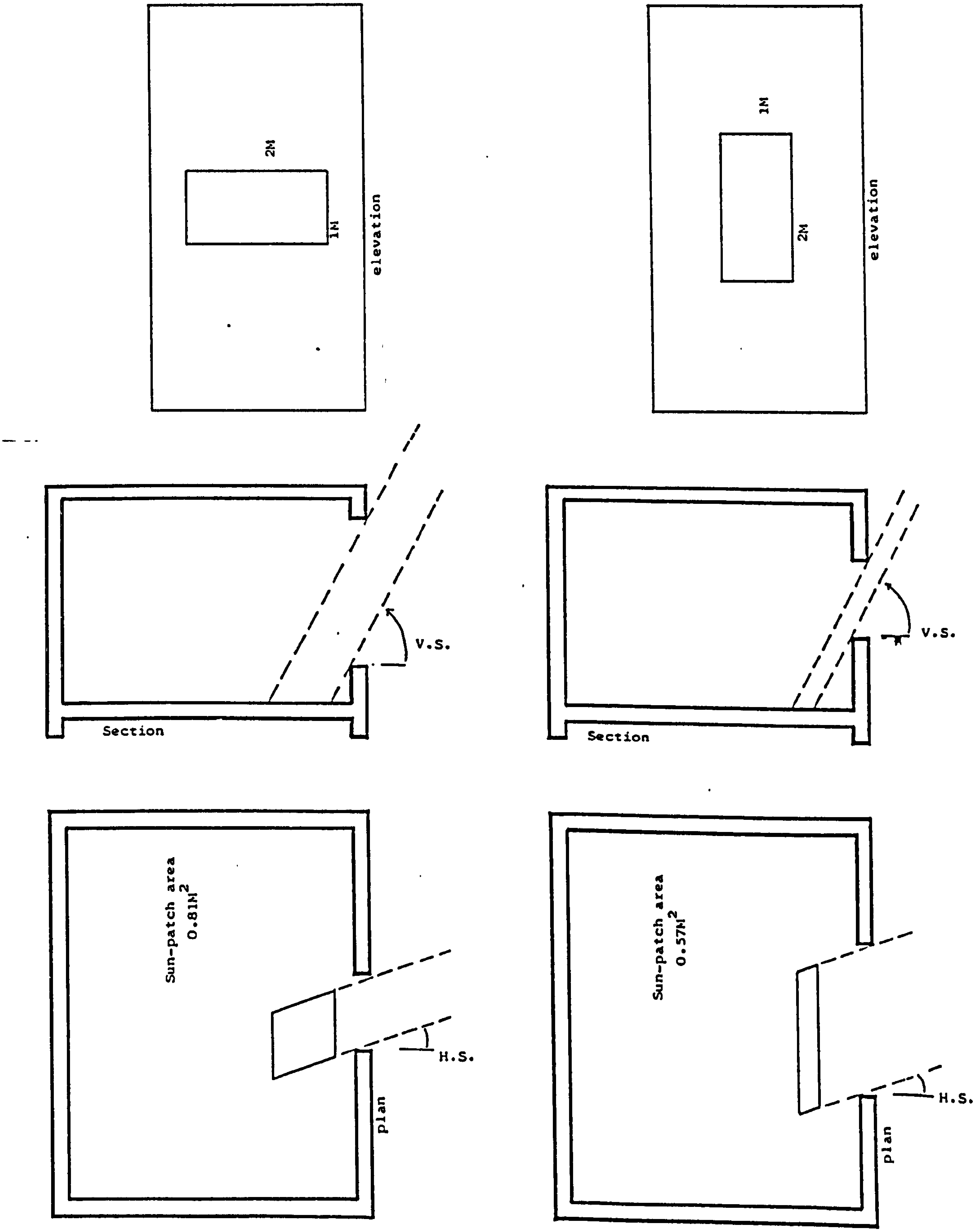


Figure 4.6 shows the effect of window proportions.

summer. Knowing that the area of sunpatches on room surfaces is directly related to the solar heat load, the use of the phrase "sunpatch areas", which the user experiences daily, was preferred. So for direct sunlight control, the availability of the largest sun patches in winter and smallest in summer were considered as the norm for determining the shape and size of windows.

4.4 Shading

One of the ways of controlling direct sunlight is by using shading devices. Generally speaking, they are divided into three kinds, the vertical, the horizontal and the combined. Further classifications distinguish between external and internal, and between fixed and movable devices.

4.4.1 Horizontal Shading Devices

As shown in Figure 4.7 this type of sun breaker is recommended when the value of vertical shadow angle is large and the value of horizontal shadow angle is small. Shade formed by this type of sun breaker might not cover the whole window unless a side extension is added (see Figure 4.8). Horizontal sun breaker depth (Sx) and side extension (Tx) to give 100% shading can be calculated as follows:

$$Sx = \text{window height} * \mathrm{Cot}(V.S.) \qquad \ldots .4.5$$

$$Tx = Sx * \mathrm{Tan}(H.S.) \qquad \ldots .4.6$$

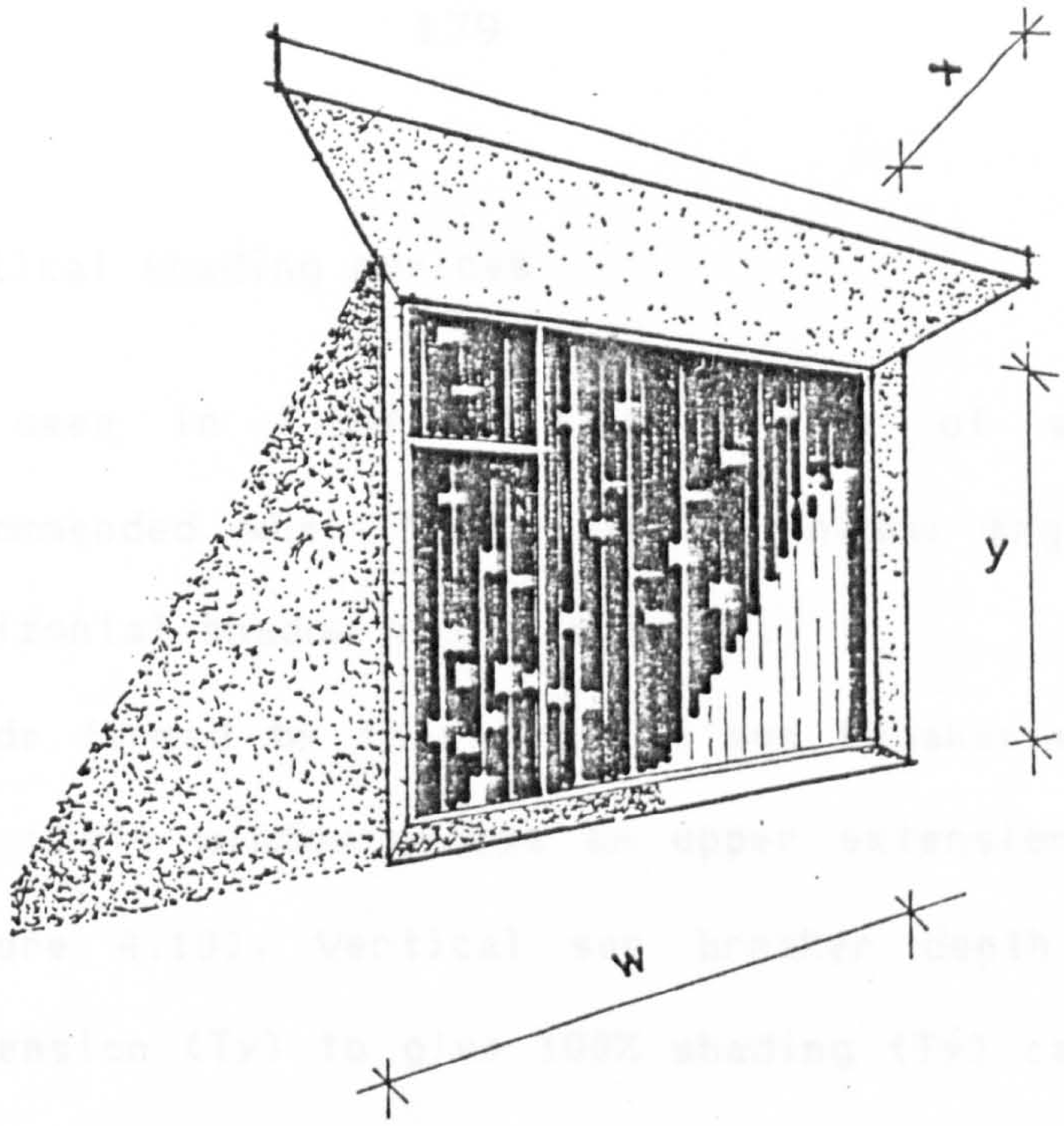


Figure 4.7

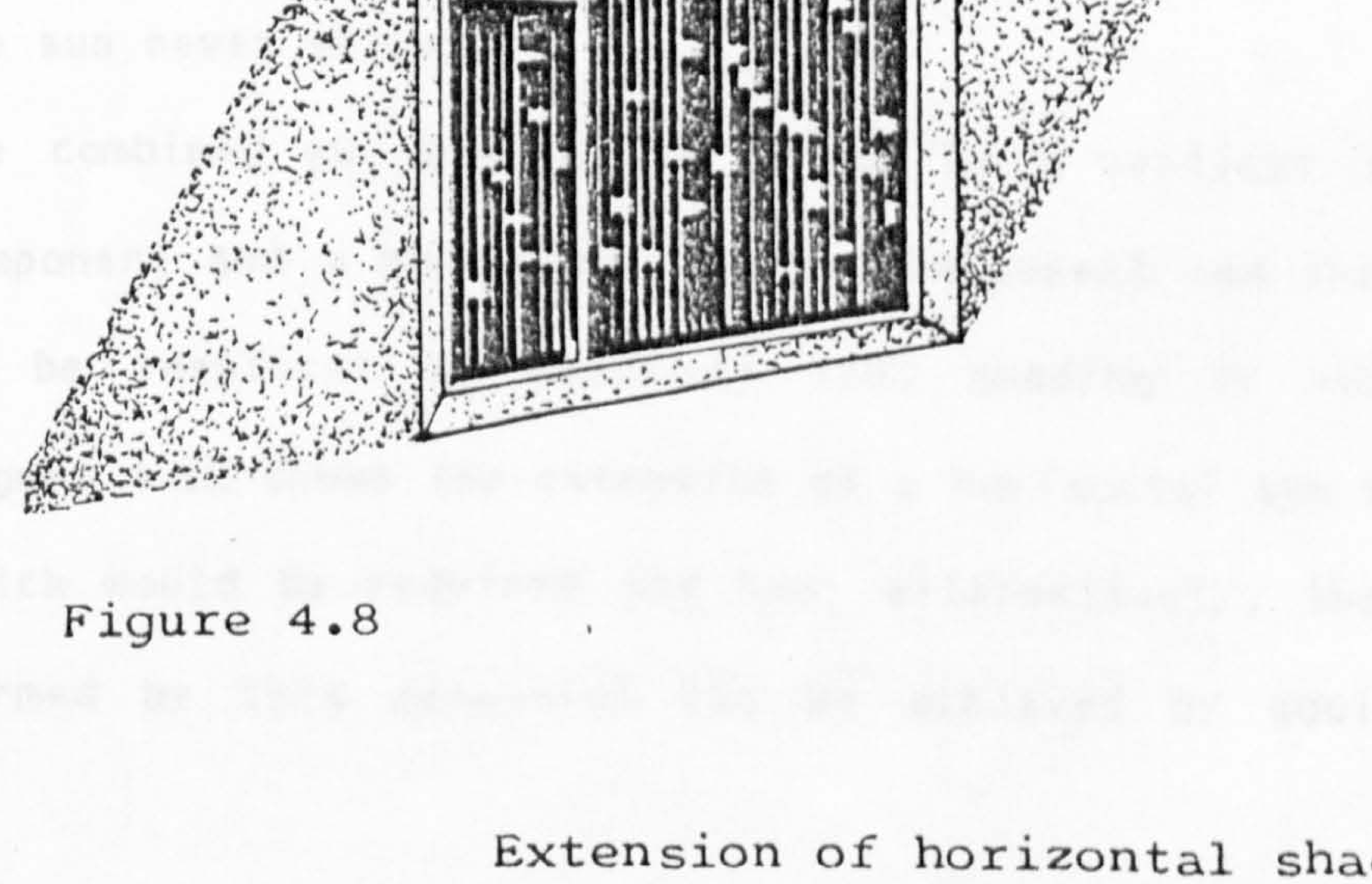


Figure 4.8

Extension of horizontal shading device to give 100% window shading.

4.4.2 Vertical shading devices

As seen in Figure 4.9 this type of sun breaker is recommended when the vertical shadow angle is low and horizontal shadow angle is large.

Shade formed by this type of sun breaker might not cover the whole window unless an upper extension is added (see Figure 4.10). Vertical sun breaker depth (Sy) and side extension (Ty) to give 100% shading (Ty) can be calculated as follows

$$Sy = \text{window width} * \text{Cot(H.S.)} \qquad \ldots.4.7$$

$$Ty = Sy * \text{Tan(V.S.)} \qquad \ldots.4.8$$

4.4.3 Combined Shading Devices

Figure 4.11 shows a type of sun breaker which is a combination of vertical and horizontal sun breakers. This type works, if properly designed , without the need of side extensions. But it always has some "redundancy" - that is it shields portions of sky (and hence daylight) from which the sun never shines.

The combined sun breaker is formed by a vertical shading component and a horizontal shading component and they have to be identical in depth if 100% shading is required. Figure 4.12 shows the extension of a horizontal sun breaker which would be required and how, alternatively, the shade formed by this extension can be achieved by adding any

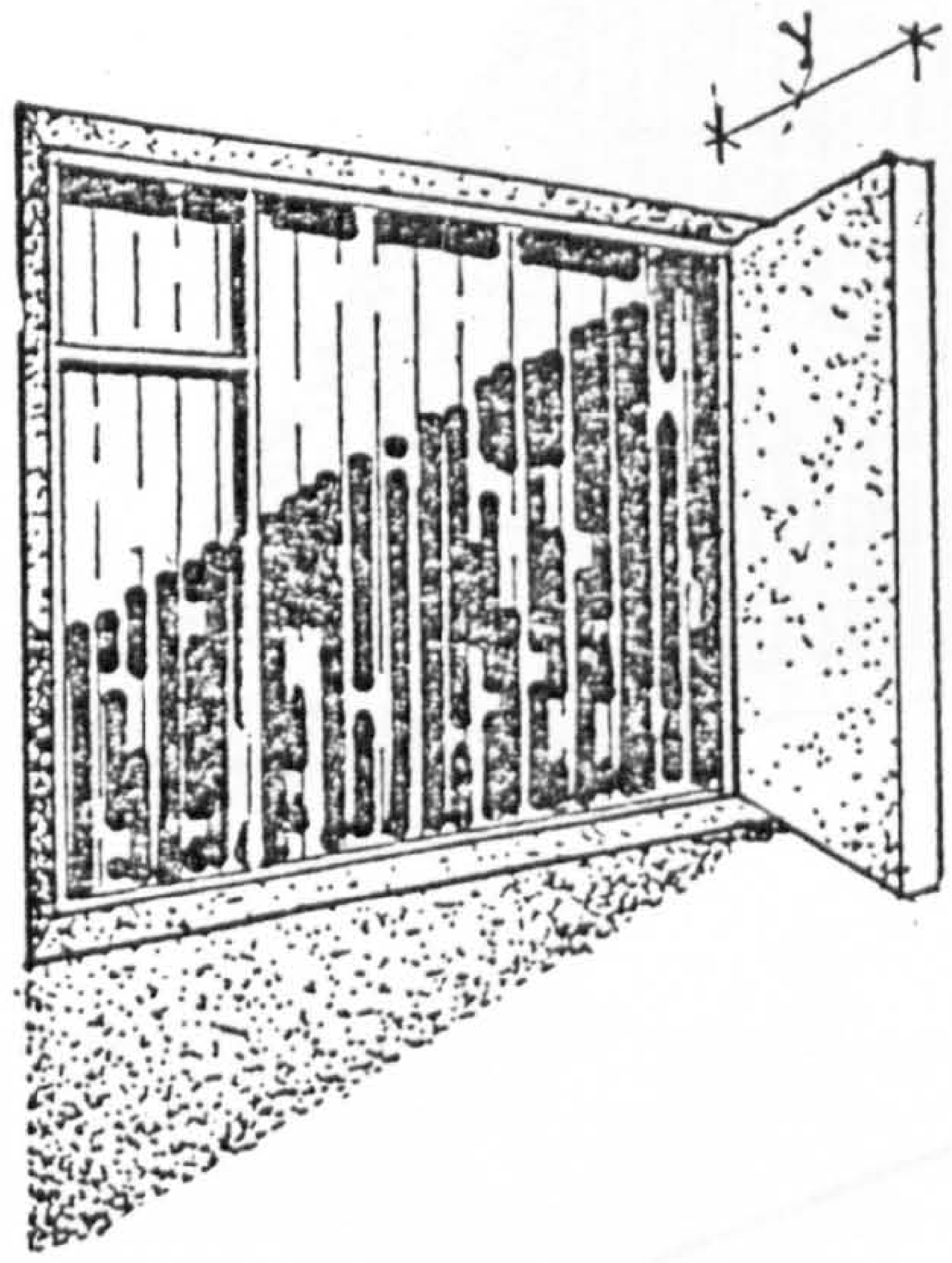


Figure 4.9

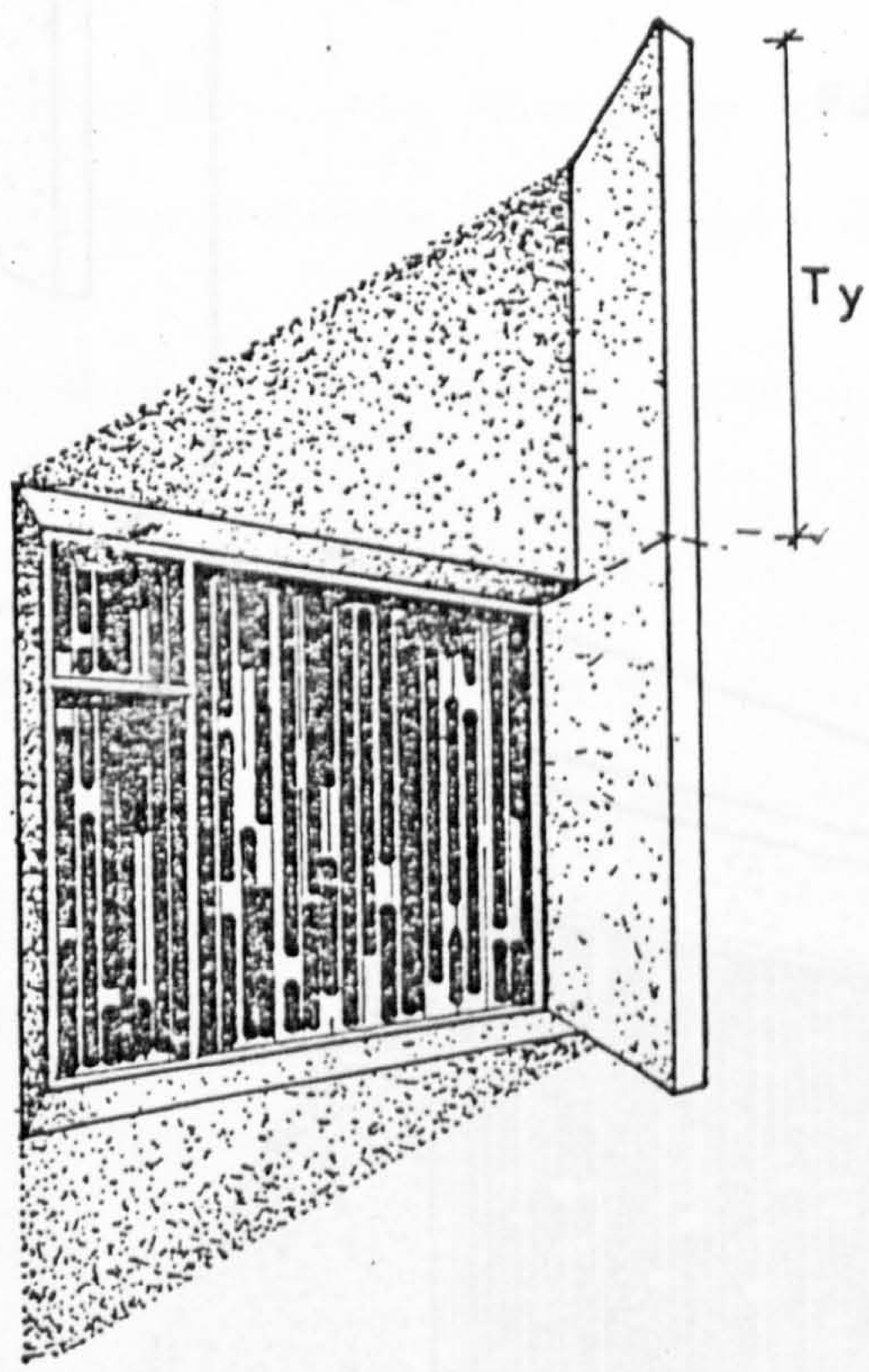
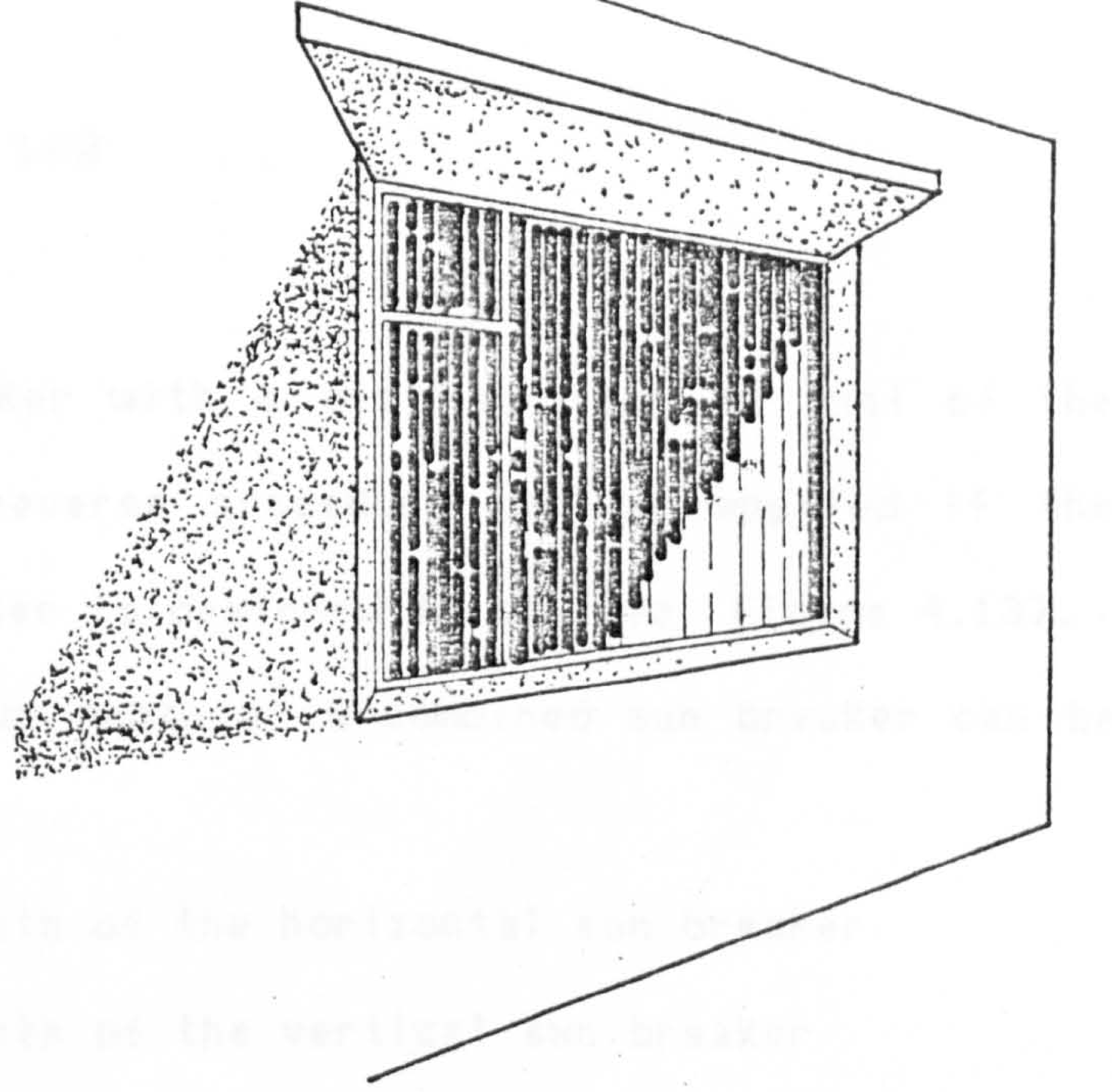


Figure 4.10

Extension of vertical shading device to give 100% window shading.

Figure 4.11



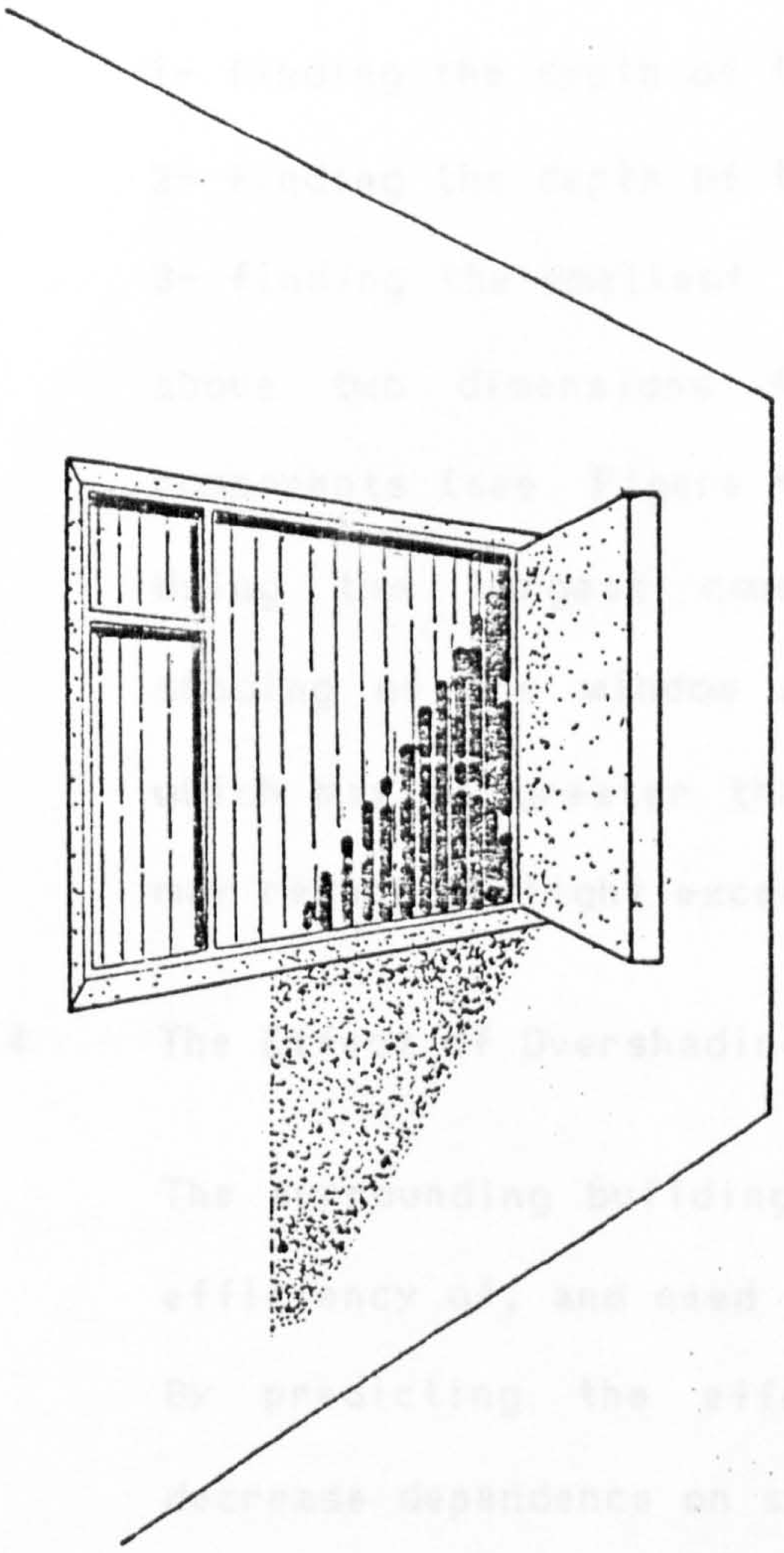
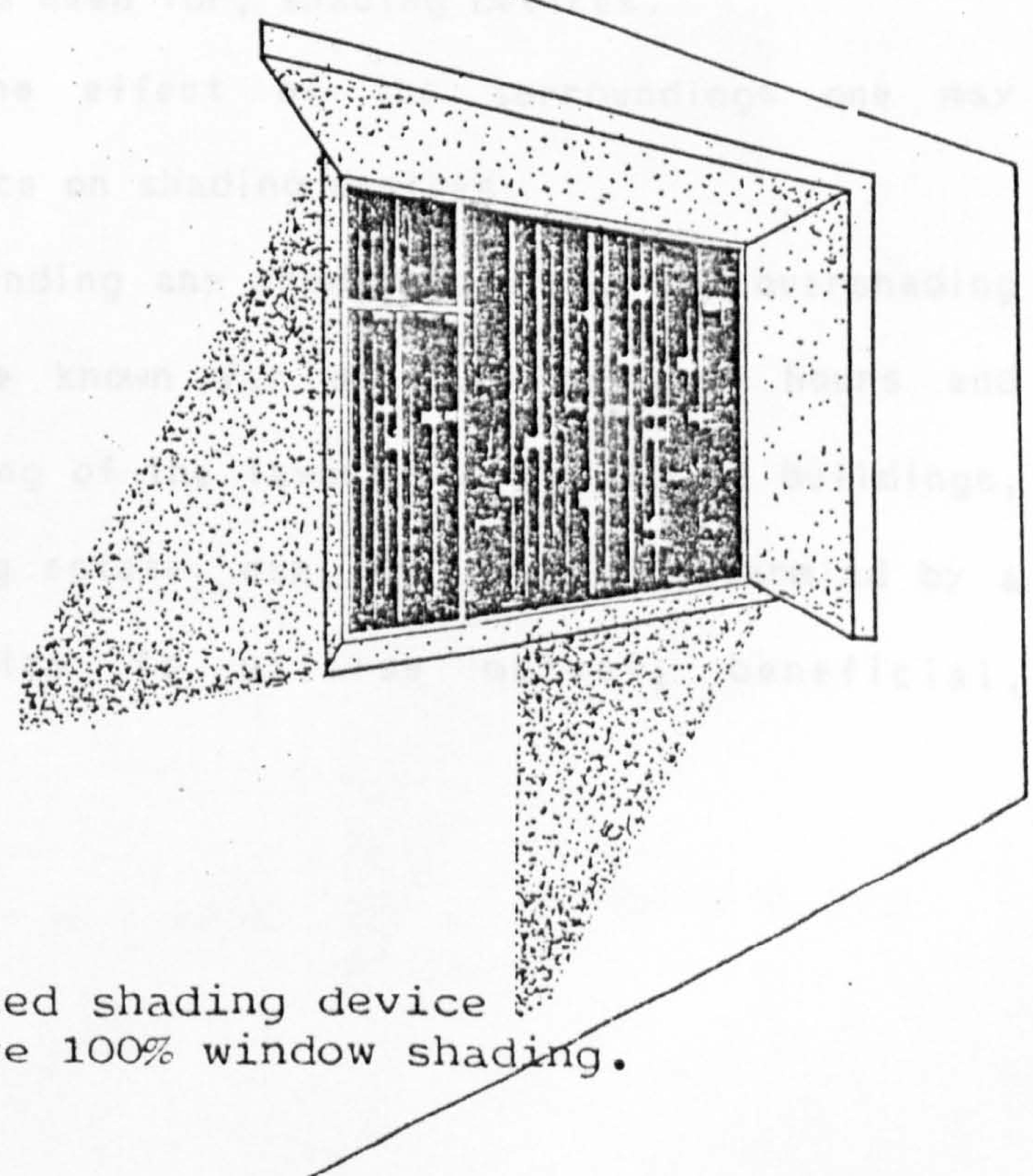


Figure 4.12

Figure 4.13



Combined shading device
to give 100% window shading.

vertical sun breaker with a depth similar to that of the horizontal. The reverse procedure can be applied if the vertical sun breaker is designed first (see Figure 4.13). Finding the optimum depth of a combined sun breaker can be achieved by:

1- finding the depth of the horizontal sun breaker

2- finding the depth of the vertical sun breaker

3- finding the smallest identical dimensions found from the above two dimensions for both vertical and horizontal components (see Figure 4.11).

Using the largest common values of dimensions causes shading of the window and part of the wall to a degree which may be greater than that sought by the designer and may reduce daylight excessively (see Figure 4.14).

4.4.4 The Effect of Overshading by Adjacent Buildings

The surrounding buildings have a significant effect on the efficiency of, and need for, shading devices.

By predicting the effect of the surroundings one may decrease dependence on shading devices.

So before recommending any shading device, the overshading effect has to be Known for all and relevant hours and dates. The planning of the layout for a group of buildings, such as a housing estate, can, in part, be determind by a deliberate policy to utilise mutual, beneficial, overshading.

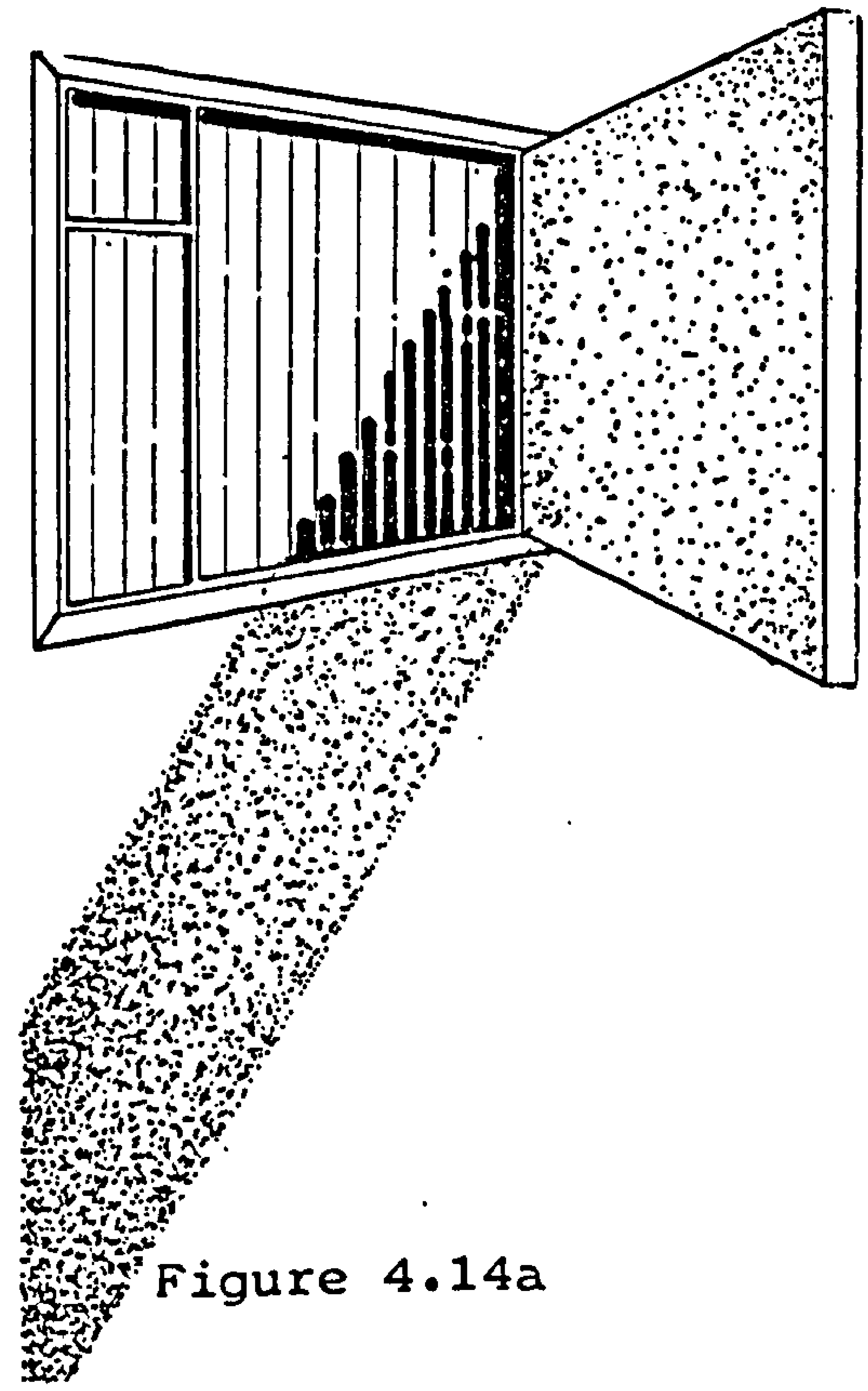


Figure 4.14a

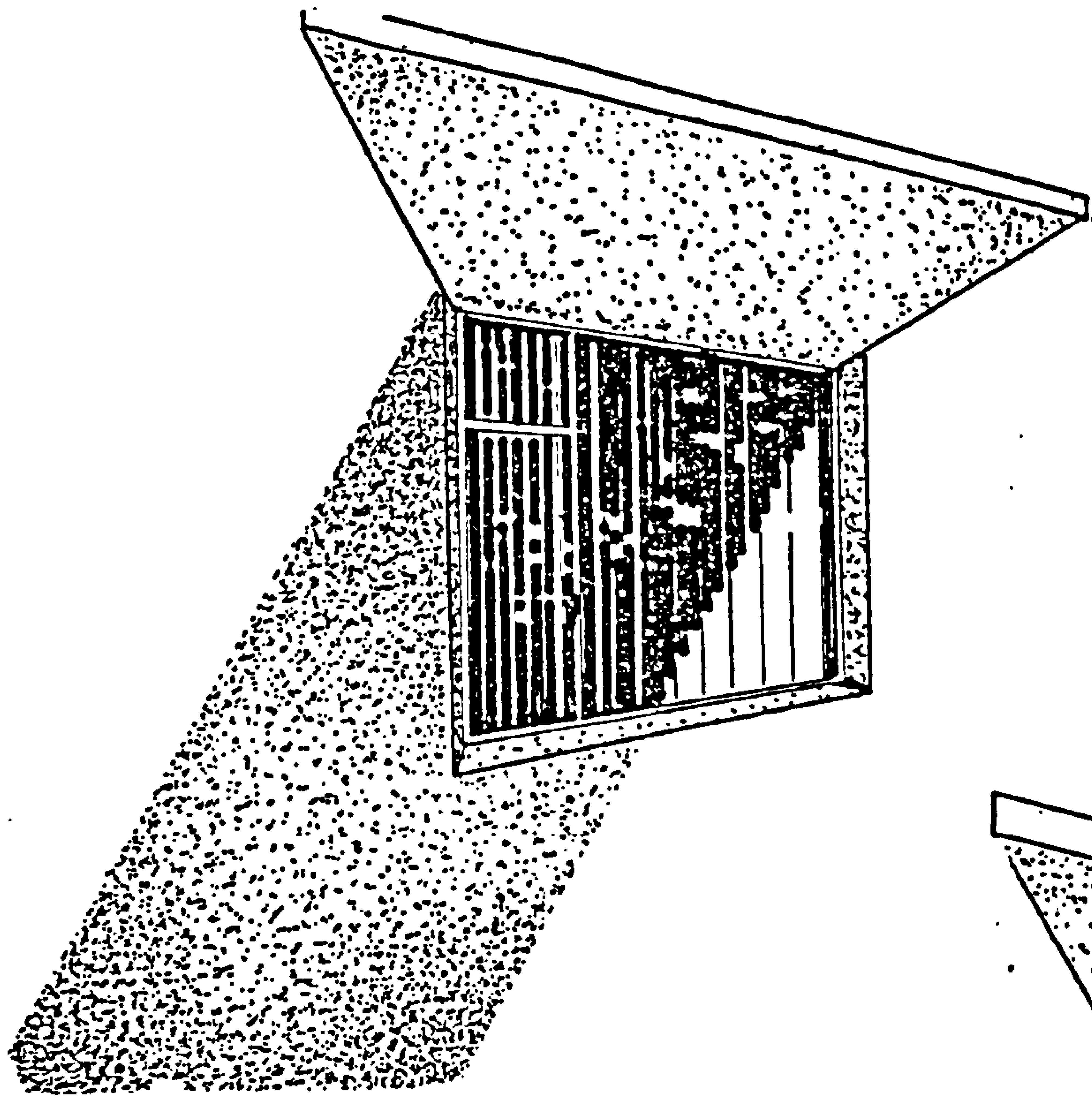


Figure 4.14b

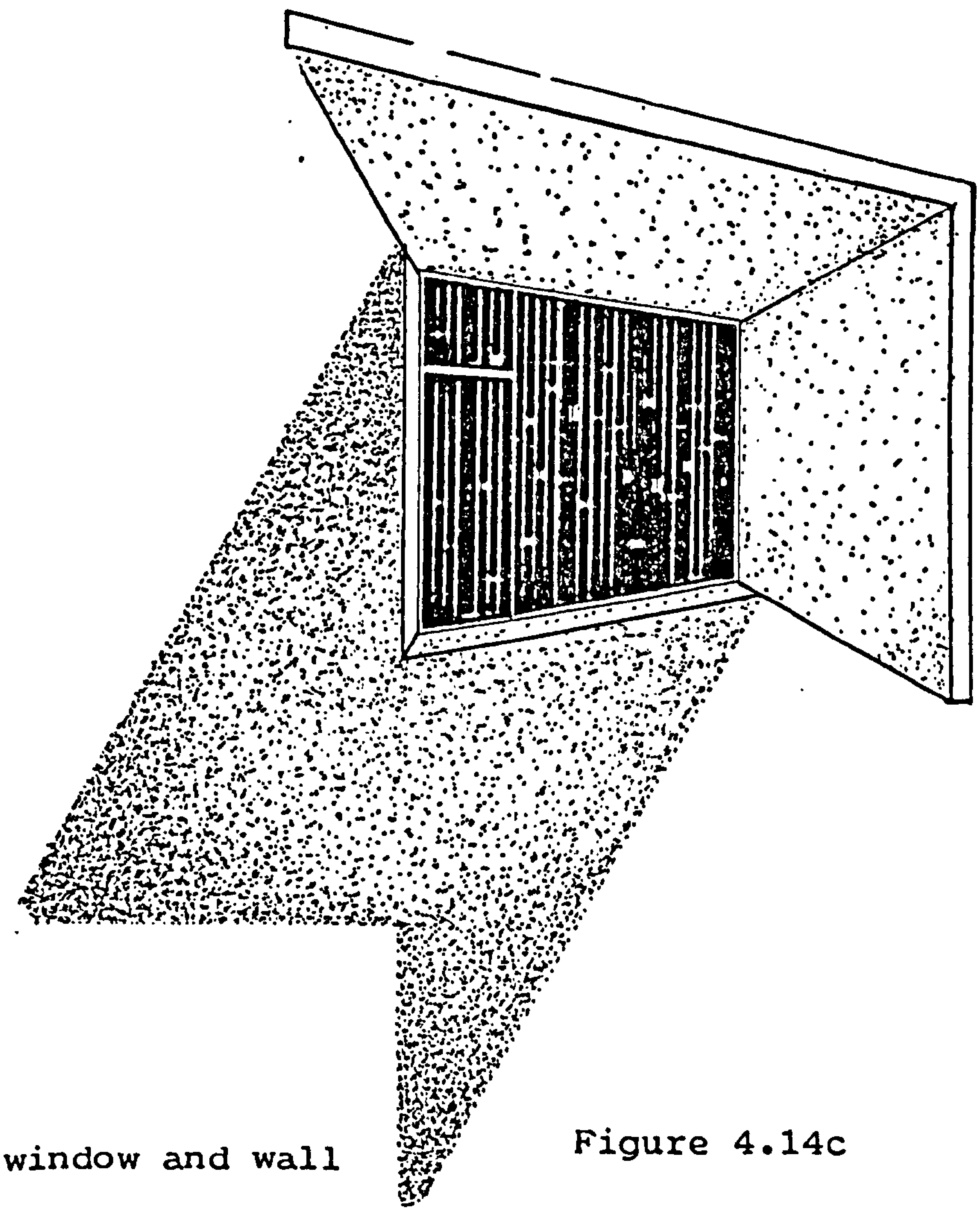


Figure 4.14c

Excessive window and wall shading.

4.5 The Window as a "Shading Device"

4.5.1 Wall Thickness

The wall thickness in any fenestration acts as a combined shading device, and has a great effect on the penetration of direct sunlight, especially in small widows (see Figure 4.5)

4.5.2 Wall Orientation

As shown in Figure 4.3 wall orientation is a basic determinant of the amount of direct sunlight in summer and winter. As an example a north facing wall in Baghdad receives some summer sun, but no sun at all during autumn, winter and spring while a south facing wall receives only a little direct sun in summer and a substantial amount in winter.

4.5.3 Inter-house Distances

As explained above adjacent buildings work as external obstructions and cause overshading on other buildings. As obstruction height decreases so does the shading effect. The critical ratio is that of obstruction height to inter-house distance and this ratio, on same orientations, gives favourable performance both summer and winter, whilst on other orientations it may impede useful winter sunshine but still give good summer shading.

4.5.4 Window Proportions

Obviously large windows allow a greater amount of sunlight to penetrate than small windows on the same day and same orientation, but apart from size, different proportions for the same window size act differently from the point of view of direct sunlight penetration and this difference is substantial when wall thickness is relatively large (see Figure 4.6).

If the wall thickness is negligible different shapes and proportions for a fixed size allow the same amount of sun patches to be formed.

4.6 Windows for Direct Sunlight Control

4.6.1 Window Dimensions and Proportions

The window dimensions used in the entire study ranged from 0.5m to 3.0m in width and from 1.0m to 1.75m in height, in increments of 0.25m; this gives 44 combinations of window sizes and proportions. These dimensions were based on the housing survey carried out in Baghdad as a part of this study, discussed earlier, but in this part of the study (direct sunlight control) some more data were included to cover windows of heights from 0.5m to 2.0m. which brought the total number to 77 windows. Time did not allow this extension of numbers to be examined for daylight (see Chapter 5).

4.6.2 Laboratory Experiments

In order to calculate sun patch areas formed by each of the windows, the effect of over shading by adjacent houses has to be known. For this purpose the computer program ESP, developed by ABACUS [Ref. 40] was initially used . However, as the program was not fully capable of handling the overshading problem at that time, the author decided to rely on experimental work, by the use of sun movement simulating equipment (the Heliodon). This equipment is for the study of shading on buildings for any latitude for any season, and for any houre (see Figure 4.15). The lamp represents the sun, and can slide up and down on the vertical post to simulate the required month, the rotating and tilting table simulates the latitude and the time at which the shading is to be found.

Models at a scale 1/200, representing the house described earlier and fourteen surrounding houses were studied on the Heliodon with varying inter house distances representing most of the real cases (see Figure 4.16).

The experiment was carried out for the summer solstice on 22nd June and the winter solstice on 21st December, for sixteen house orientations.

Each of the ground and first floor walls was divided into three parts: left, right and centre (see Figure 4.17).

For rear walls for both ground and first floors the left and right side can be considered as one case because of the

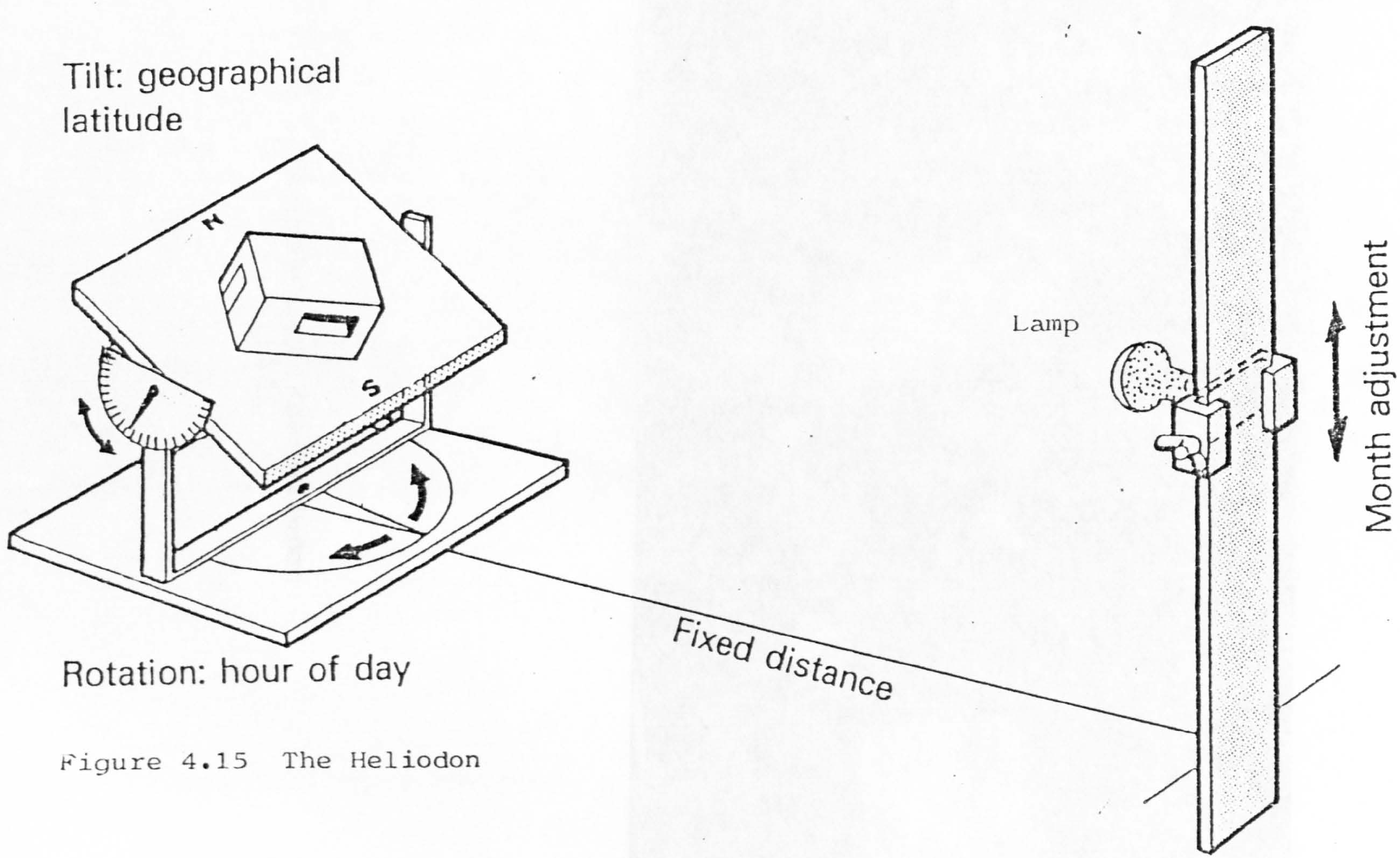


Figure 4.15 The Heliodon

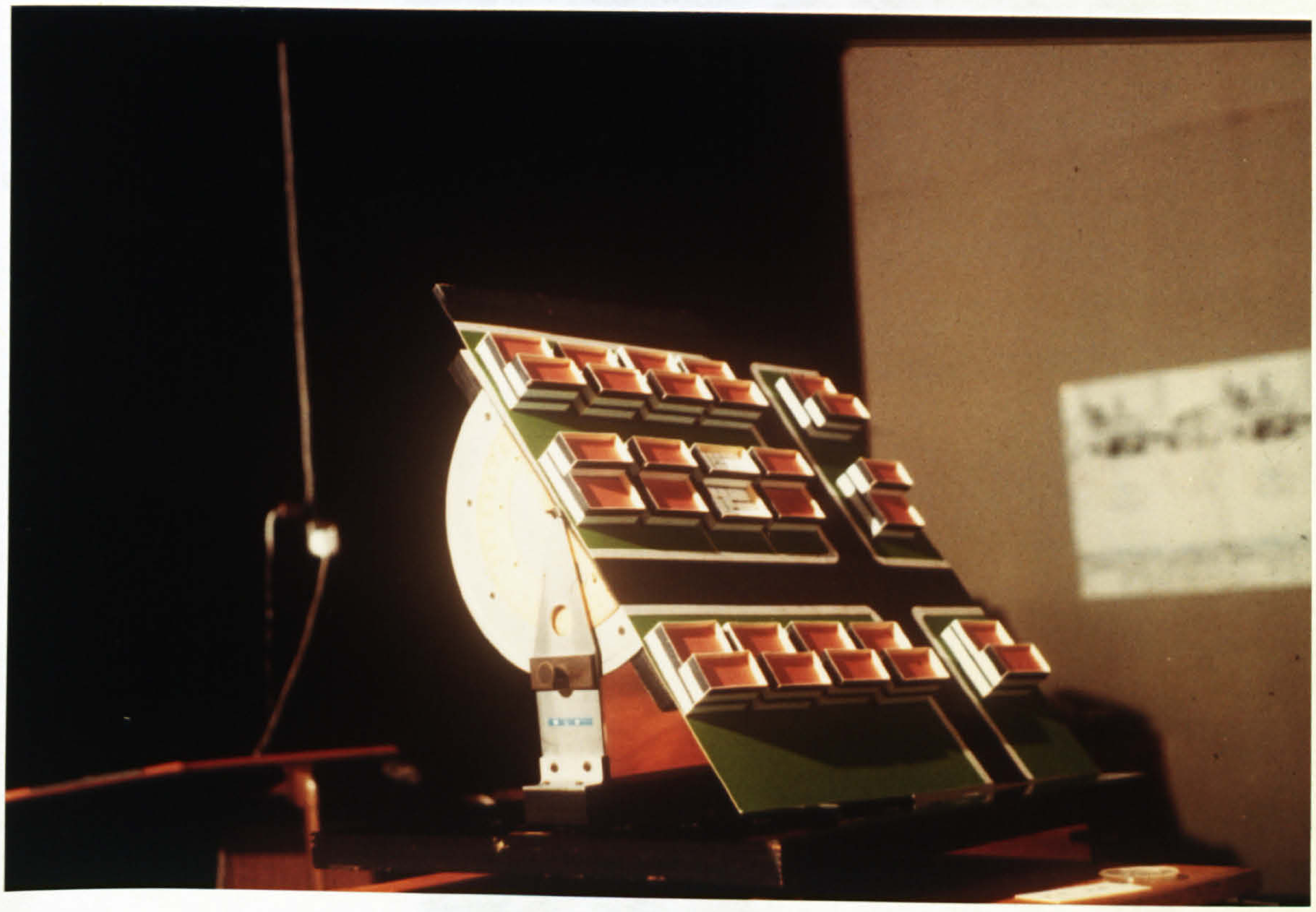


Figure 4.16 Scale model on the Heliodon

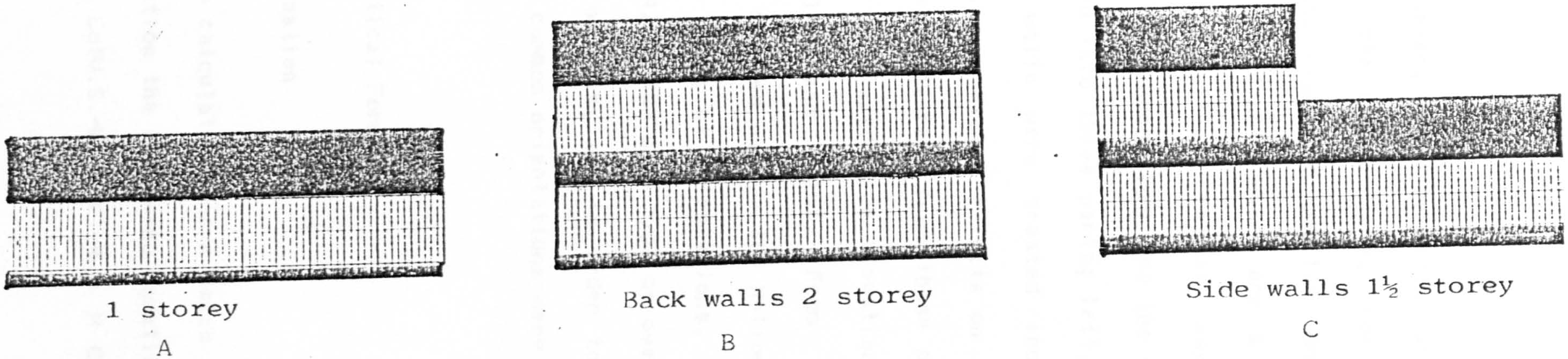


Figure 4.17 shows the model wall used to determine sun exposure time.

symmetry. However, the side walls, as seen in Figure 4.18, have considerable obstructions, from the closeness of the houses to the rear and smaller obstructions from those situated at the front, which are a considerable distance away, thus resulting in an asymmetrical situation. Accordingly the ground floor and the first floor level were again divided into three parts; left, right and centre and these side walls were treated individually. On most orientations overshading effects on the left side wall of the house are different from those on the right side wall due to the L-shaped side elevations of the houses (see Figures 4.17c and 4.18). From the results of the experiments carried out on the Heliodon, it was found that for various pairs of orientations, as shown in Table 4.1 and Figure 4.19, the same type of over shading occurred. On account of this, and in order to reduce the volume of the output, common orientations were presented in one graph or table.

4.6.3 The Mathematical Formulae

4.6.3.1 Sunpatch Equation

In order to calculate the sun patch area formed by a window or fenestration the following equation was derived

A = W * H CotV.S.-W * K -K * H CotV.S. * TanH.S.+K^2 * TanH.S. 4.9

Where:

Figure 4.18 Scale model on the Heliodon

HOUSE ORIENTATION (Side 1)	WALL ORIENTATION Side 2	HOUSE ORIENTATION (Side 1)	WALL ORIENTATION Side 4
0.0	90	0.0	270
22.5	112.5	337.5	247.5
45	135	315	225
67.5	157.5	292.5	202.5
90	180	270	180
112.5	202.5	247.5	157.5
135	225	225	135
157.5	247.5	247.5	112.5
180	270	180	90
202	292.5	157.5	67.5
225	3.5	135	45
247.5	337.5	112.5	22.5
270	0.0	90	0.0
292.5	22.5	67.5	337.5
315	45	45	315
337.5	67.5	22.5	292.5

Table 4.1

Pairs of angles for the house orientation (Side 1) with associated angles for the orientation of sides 2 and 4 giving equal shading on sides 2 and 4.

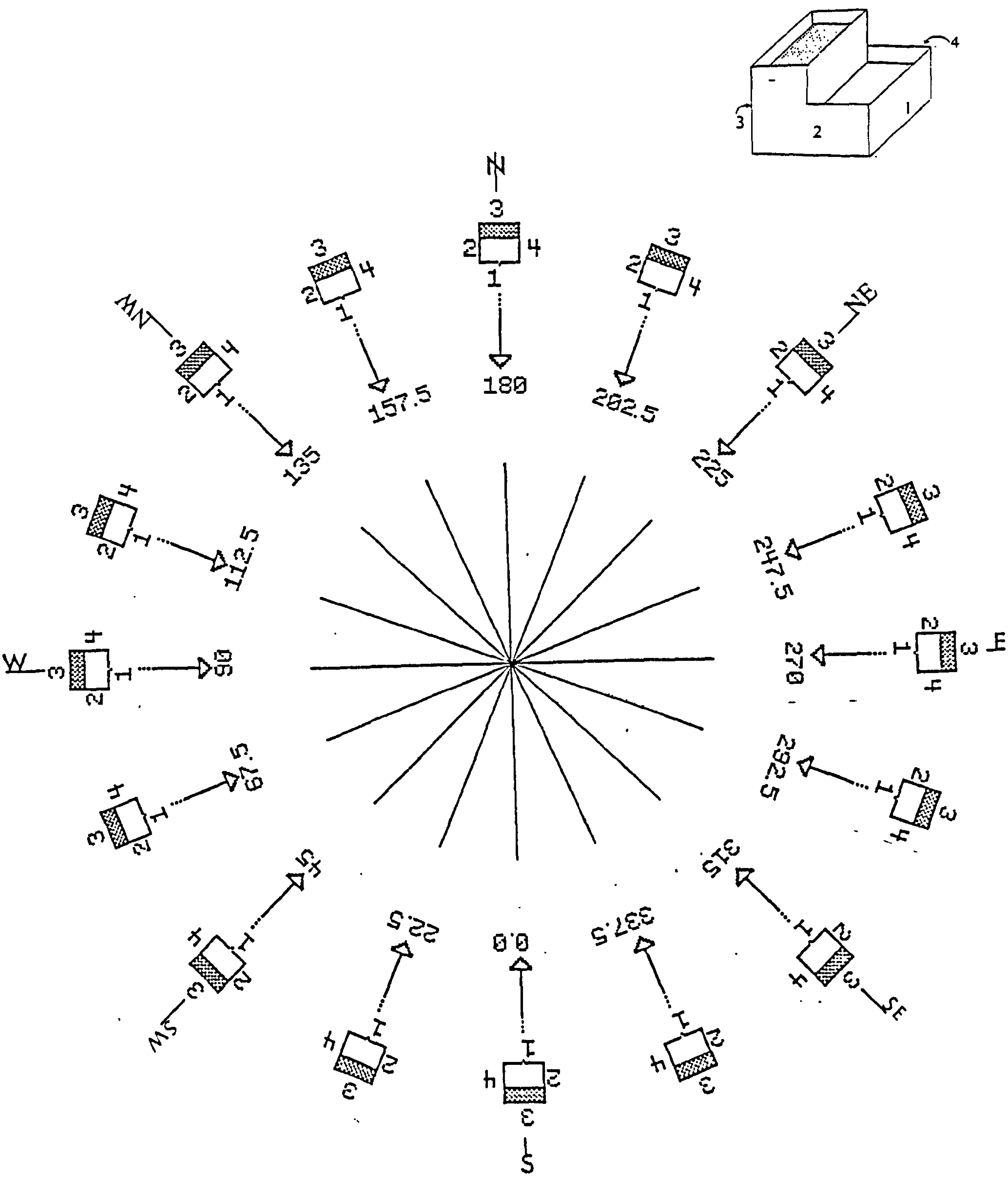


Figure 4.19 House orientations shown in table 4.1.

A= sun patch area

W= window width

H= window height

K= wall thickness

For the derivation of formula see Appendix 1

4.6.3.2 Sun Exposure Time and Sun Angles Data Files

Total sun patch areas formed by a window depend on the number of hours when no overshading from adjacent houses occurs. Accordingly values of H.S. and V.S. at each of those hours are needed.

By using the formulae given in 4.3.1, vertical shadow angles and horizontal shadow angles were found for summer and winter extremes for the period between an hour after sunrise to one hour before sunset. These angles were prepared as data files for the main computer program (see Appendix 1) which uses the formulae described above for calculating sun patch areas.

From the experiments carried out on the Heliodon data files were prepared representing 41 different cases of interhouse distances, obstruction heights and window positions .

4.6.4 Method of Selecting and Recommending Windows

4.6.4.1 The Yearly Efficiency

According to the analysis of the climate of Baghdad seven to eight months are considered hot to moderate months at which sun is to be excluded from rooms or minimised while four months were considered cold months in which sun patches are welcome as an additional energy source for internal space which decreases fuel expenditure. So it was considered that an efficient window is one with the capability of allowing an amount of winter sun penetration at least twice as high as that in summer. This was assumed to result in an approximate optimisation of the annual energy expenditure for cooling and heating.

So the ratio of the sun patches formed in winter (W) to twice the sun patches formed in summer (S) is used as the measure for yearly efficiency.

The most efficient window is that window with the highest numerical value of the ratio.

Any window with a value of the ratio W/2S less than one is not considered.

When none of the 77 windows lie on the yearly efficiency scale, in other words if on certain orientations none of the 77 windows has a value of one or more, windows on that orientation are selected and recommended on the summer efficiency scale only.

4.6.4.2 Summer Efficiency

Obviously a small window allows a small amount of direct sunlight to penetrate which is less than the quantity allowed by larger window. As shown in table 4.2, a window of 0.5m width by 0.5m height allows 0.1m2 sun patch to

ORIENTATION = 225 WALL THICKNESS = .24

X	Y	A1	SA	SA/A1
.50	.50	.25	.10	.38
.50	.75	.38	.29	.77
.50	1.00	.50	.50	.99
.50	1.25	.63	.70	1.12
.50	1.50	.75	.91	1.21
.50	1.75	.88	1.12	1.28
.50	2.00	1.00	1.33	1.33
.75	.50	.38	.41	1.09
.75	.75	.56	.92	1.64
.75	1.00	.75	1.46	1.94
.75	1.25	.94	1.99	2.13
.75	1.50	1.13	2.53	2.25
.75	1.75	1.31	3.07	2.34
.75	2.00	1.50	3.61	2.41
1.00	.50	.50	.73	1.46
1.00	.75	.75	1.57	2.09
1.00	1.00	1.00	2.44	2.44
1.00	1.25	1.25	3.32	2.65
1.00	1.50	1.50	4.19	2.79
1.00	1.75	1.75	5.06	2.89
1.00	2.00	2.00	5.94	2.97
1.25	.50	.63	1.05	1.68
1.25	.75	.94	2.22	2.37
1.25	1.00	1.25	3.43	2.74
1.25	1.25	1.56	4.64	2.97
1.25	1.50	1.88	5.85	3.12
1.25	1.75	2.19	7.06	3.23
1.25	2.00	2.50	8.28	3.31
1.50	.50	.75	1.37	1.83
1.50	.75	1.13	2.87	2.55
1.50	1.00	1.50	4.42	2.94
1.50	1.25	1.88	5.96	3.18
1.50	1.50	2.25	7.51	3.34
1.50	1.75	2.63	9.06	3.45
1.50	2.00	3.00	10.61	3.54
1.75	.50	.88	1.69	1.94
1.75	.75	1.31	3.52	2.68
1.75	1.00	1.75	5.40	3.09
1.75	1.25	2.19	7.29	3.33
1.75	1.50	2.63	9.17	3.49
1.75	1.75	3.06	11.05	3.61
1.75	2.00	3.50	12.94	3.70
2.00	.50	1.00	2.02	2.02
2.00	.75	1.50	4.17	2.78
2.00	1.00	2.00	6.39	3.19
2.00	1.25	2.50	8.61	3.44
2.00	1.50	3.00	10.83	3.61
2.00	1.75	3.50	13.05	3.73
2.00	2.00	4.00	15.28	3.82
2.25	.50	1.13	2.34	2.08
2.25	.75	1.69	4.82	2.86
2.25	1.00	2.25	7.38	3.28
2.25	1.25	2.81	9.93	3.53
2.25	1.50	3.38	12.49	3.70
2.25	1.75	3.94	15.05	3.82
2.25	2.00	4.50	17.61	3.91
2.50	.50	1.25	2.66	2.13
2.50	.75	1.88	5.47	2.92
2.50	1.00	2.50	8.36	3.35
2.50	1.25	3.13	11.26	3.60
2.50	1.50	3.75	14.15	3.77
2.50	1.75	4.38	17.04	3.90
2.50	2.00	5.00	19.95	3.99
2.75	.50	1.38	2.98	2.17
2.75	.75	2.06	6.12	2.97
2.75	1.00	2.75	9.35	3.40
2.75	1.25	3.44	12.58	3.66
2.75	1.50	4.13	15.81	3.83
2.75	1.75	4.81	19.04	3.96
2.75	2.00	5.50	22.28	4.05
3.00	.50	1.50	3.30	2.20
3.00	.75	2.25	6.77	3.01
3.00	1.00	3.00	10.34	3.45
3.00	1.25	3.75	13.90	3.71
3.00	1.50	4.50	17.47	3.88
3.00	1.75	5.25	21.03	4.01
3.00	2.00	6.00	24.61	4.10

X= window width

Y= window height

A1= window area

SA= Summer sun-patch area

SA/A1= Yearly efficiency

Table 4.2

penetrate, while a 3.0m width by 2.0m height window allows 24.61m2 .

Although the 3m X 2m window equals in area 24 windows of the 0.5m X 0.5m size, the area of sun patches formed by 24 windows of 0.5m X 0.5m is 2.4m2 while the area of sun patch formed by the 3m X 2m window is 24.61m2 a difference of a factor of ten.

So if windows are now to be considered with respect to their ability to prevent summer direct sunlight penetration, the area of sun patches per unit window area has to be used as the measure for summer efficiency. This scale seems to be a useful one for architects who prefer large area of window without excessive summer sun penetration.

Accordingly the most efficient window from the summer point of view is that which has a small numerical ratio of area of summer sun patches to area of window.

4.6.5 Computer Program

A series of computer programs were written by the author with the help of Mr. Jim Fleming and Mr. Don Evans to compute, tabulate, draw, and recommend the appropriate window or group of windows having the ability to allow the smallest amount of summer sun and, at the same time, the largest amount of winter sun to penetrate.

4.6.5.1 The first program was to compute the area of sun patches formed in a room with an infinite floor area (see Appendix

1), with three wall thicknesses, for sixteen room orientations, during the exposure hours, for 77 different windows, varied from 0.5m height and 0.5m width to 2.0m height by 3.0m width in increments of 0.25m.

In the computation a room with an infinite floor area was used in order to avoid the complication of computing sunpatches on walls since the radiant energy, though not the area of sun patches entering a room is the same whether it falls on the floor or a wall .

The computer program was designed to find the total area of sun patches formed by the window in summer, total area of sun patch areas formed in winter, summer sun patches per unit window area, winter sun patches per unit window area, the ratio between winter sun patch area to summer sun patch area and the yearly efficiency which was previously defined with respect to the analyses of the climate of Baghdad.

Table 4.3 shows the typical output where:

X is window width, Y is window height, A is window area (m2), SA is the sun patch area formed (m2) in summer, WA is the sun patch area (m2) formed in winter, SA/A1 is the ratio of summer sun patch area per unit window area, WA/A1 is winter sun patch per unit window area, WA/SA is the ratio of winter sun patch area to summer sun patch area and WA/2SA is the yearly efficiency as earlier defined.

4.6.5.2 The second program (see Appendix 1) was designed to pick out and present the output from the first program - the sun

ORIENTATION = 225 WALL THICKNESS = .24

X	Y	A1	SA	SA/A1	WA	WA/A1	WA/SA	WA/2SA
.50	.50	.25	.10	.38	2.38	9.53	24.97	12.48
.50	.75	.38	.29	.77	3.82	10.20	13.25	6.62
.50	1.00	.50	.50	.99	5.27	10.53	10.62	5.31
.50	1.25	.63	.70	1.12	6.71	10.73	9.55	4.77
.50	1.50	.75	.91	1.21	8.15	10.87	8.96	4.48
.50	1.75	.88	1.12	1.28	9.59	10.96	8.59	4.29
.50	2.00	1.00	1.33	1.33	11.03	11.03	8.33	4.16
.75	.50	.38	.41	1.09	3.75	10.00	9.21	4.61
.75	.75	.56	.92	1.64	6.06	10.77	6.57	3.29
.75	1.00	.75	1.46	1.94	8.36	11.15	5.73	2.87
.75	1.25	.94	1.99	2.13	10.67	11.38	5.35	2.67
.75	1.50	1.13	2.53	2.25	12.97	11.53	5.12	2.56
.75	1.75	1.31	3.07	2.34	15.28	11.64	4.98	2.49
.75	2.00	1.50	3.61	2.41	17.58	11.72	4.87	2.44
1.00	.50	.50	.73	1.46	5.12	10.24	7.02	3.51
1.00	.75	.75	1.57	2.09	8.29	11.06	5.28	2.64
1.00	1.00	1.00	2.44	2.44	11.47	11.47	4.69	2.35
1.00	1.25	1.25	3.32	2.65	14.64	11.71	4.41	2.21
1.00	1.50	1.50	4.19	2.79	17.81	11.88	4.25	2.13
1.00	1.75	1.75	5.06	2.89	20.99	11.99	4.14	2.07
1.00	2.00	2.00	5.94	2.97	24.16	12.08	4.07	2.03
1.25	.50	.63	1.05	1.68	6.49	10.38	6.17	3.07
1.25	.75	.94	2.22	2.37	10.55	11.26	4.75	2.38
1.25	1.00	1.25	3.43	2.74	14.62	11.70	4.26	2.13
1.25	1.25	1.56	4.64	2.97	18.69	11.96	4.03	2.01
1.25	1.50	1.88	5.85	3.12	22.76	12.14	3.89	1.94
1.25	1.75	2.19	7.06	3.23	26.83	12.26	3.80	1.90
1.25	2.00	2.50	8.28	3.31	30.89	12.36	3.73	1.87
1.50	.50	.75	1.37	1.83	7.85	10.47	5.72	2.86
1.50	.75	1.13	2.87	2.55	12.82	11.39	4.46	2.23
1.50	1.00	1.50	4.42	2.94	17.78	11.85	4.02	2.01
1.50	1.25	1.88	5.96	3.18	22.74	12.13	3.81	1.91
1.50	1.50	2.25	7.51	3.34	27.70	12.31	3.69	1.84
1.50	1.75	2.63	9.06	3.45	32.67	12.44	3.61	1.80
1.50	2.00	3.00	10.61	3.54	37.63	12.54	3.55	1.77
1.75	.50	.88	1.69	1.94	9.22	10.54	5.44	2.72
1.75	.75	1.31	3.52	2.68	15.08	11.49	4.28	2.14
1.75	1.00	1.75	5.40	3.09	20.94	11.96	3.87	1.94
1.75	1.25	2.19	7.29	3.33	26.79	12.25	3.68	1.84
1.75	1.50	2.63	9.17	3.49	32.65	12.44	3.56	1.78
1.75	1.75	3.06	11.05	3.61	38.51	12.57	3.48	1.74
1.75	2.00	3.50	12.94	3.70	44.36	12.67	3.43	1.71
2.00	.50	1.00	2.02	2.02	10.59	10.59	5.25	2.63
2.00	.75	1.50	4.17	2.78	17.34	11.56	4.16	2.08
2.00	1.00	2.00	6.39	3.19	24.09	12.05	3.77	1.89
2.00	1.25	2.50	8.61	3.44	30.84	12.34	3.58	1.79
2.00	1.50	3.00	10.83	3.61	37.59	12.53	3.47	1.74
2.00	1.75	3.50	13.05	3.73	44.34	12.67	3.40	1.70
2.00	2.00	4.00	15.28	3.82	51.10	12.77	3.34	1.67
2.25	.50	1.13	2.34	2.08	11.96	10.63	5.11	2.56
2.25	.75	1.69	4.82	2.86	19.60	11.62	4.07	2.03
2.25	1.00	2.25	7.38	3.28	27.25	12.11	3.69	1.85
2.25	1.25	2.81	9.93	3.53	34.89	12.41	3.51	1.76
2.25	1.50	3.38	12.49	3.70	42.54	12.60	3.41	1.70
2.25	1.75	3.94	15.05	3.82	50.18	12.75	3.34	1.67
2.25	2.00	4.50	17.61	3.91	57.83	12.85	3.28	1.64
2.50	.50	1.25	2.66	2.13	13.32	10.66	5.01	2.51
2.50	.75	1.88	5.47	2.92	21.87	11.66	4.00	2.00
2.50	1.00	2.50	8.36	3.35	30.41	12.16	3.64	1.82
2.50	1.25	3.13	11.26	3.60	38.95	12.46	3.46	1.73
2.50	1.50	3.75	14.15	3.77	47.48	12.66	3.36	1.68
2.50	1.75	4.38	17.04	3.90	56.02	12.81	3.29	1.64
2.50	2.00	5.00	19.95	3.99	64.56	12.91	3.24	1.62
2.75	.50	1.38	2.98	2.17	14.70	10.69	4.93	2.46
2.75	.75	2.06	6.12	2.97	24.13	11.70	3.94	1.97
2.75	1.00	2.75	9.35	3.40	33.56	12.20	3.59	1.80
2.75	1.25	3.44	12.58	3.66	43.00	12.51	3.42	1.71
2.75	1.50	4.13	15.81	3.83	52.43	12.71	3.32	1.66
2.75	1.75	4.81	19.04	3.96	61.86	12.86	3.25	1.62
2.75	2.00	5.50	22.28	4.05	71.30	12.96	3.20	1.60
3.00	.50	1.50	3.30	2.20	16.07	10.71	4.86	2.43
3.00	.75	2.25	6.77	3.01	26.39	11.73	3.90	1.95
3.00	1.00	3.00	10.34	3.45	36.72	12.24	3.55	1.78
3.00	1.25	3.75	13.90	3.71	47.05	12.55	3.38	1.69
3.00	1.50	4.50	17.47	3.88	57.38	12.75	3.28	1.64
3.00	1.75	5.25	21.03	4.01	67.70	12.90	3.22	1.61
3.00	2.00	6.00	24.61	4.10	78.03	13.01	3.17	1.59

Table 4.3

patches formed by the 77 types of windows - in graphic form, from which a clearer picture could be obtained with regard to the effect of sizes and proportional changes.

Due to the huge number of results produced and in order to reduce that volume, a version of the program was written to handle six sets of results and plot them on one graph.

Each graph represents three sets of results (one for each zone, left, centre and right) for ground floor and three for the first floor level for a defined side of the house, for a fixed inter-house distance. All the graphs represent the yearly efficiency of the 77 windows. Moreover, if for some orientations none of the 77 windows has a value of one or more, then the summer efficiency graph is introduced to serve that orientation. This type of graph gives a clear picture to the user, enabling a distinction to be made between the effects of sizes for a given wall thickness and orientation.

Figure 4.20 shows a graph prepared by this program. Curves 1, 2 and 3 are for ground floor windows representing the left, right and middle parts of the wall respectively. Curves 4, 5 and 6 are for first floor windows again representing left, right and middle parts of the wall respectively. The X axis is divided into two divisions, the lower part representing window heights and the upper part representing window widths for each constant height; the upper X-axis contains seven sets of eleven divisions, each

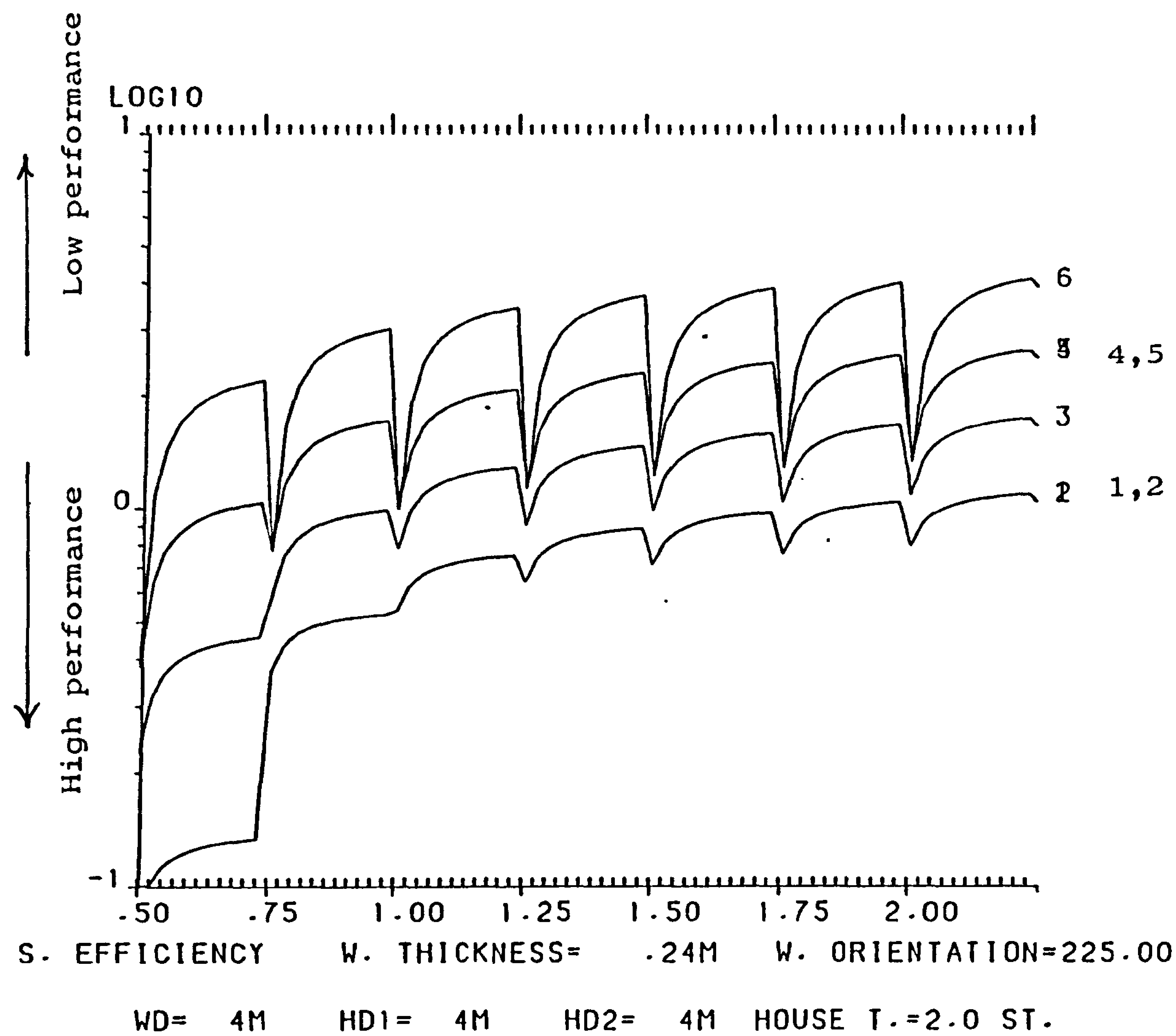


Figure 4.20 Summer efficiency sample graph.

division representing one of eleven window widths from 0.5m to 3.0m in increments of 0.25m.

An overlay was prepared and attached to each volume to make reading the graphs easier.

(see Appendix 2)

4.6.5.3 The third program (see Appendix 1) handles the output formed by the first program and selects those windows which allow at least twice the amount of winter as summer sun and ranks them in order of performance and presents them in tabular form.

Because of overshading effects or sun declination, winter sun never appears on some orientations or appears at angles at which no window has the ability of allowing winter sun penetration at least twice as great as summer; for such orientations yearly efficiency cannot be used as a norm of selection, so minimisation of summer sun is used as a criterion and the program selects only on the basis of summer sun data. It then ranks all windows in order of performance. The program ranks the 77 windows in order of efficiency and presents them in tabular form. The user is then provided by the means of a further program, with another set of tables showing the 20% highest rank windows.

4.7 The Output Results and Recommendations

4.7.1 The Tables

4.7.1.1 Detailed Tables

This type of table is an output of the first program which gives a guideline for the represention of the results. Table 4.3 gives useful information about the behaviour of each type of window in summer, in winter, the changes in the amount of sun patches per unit window area (summer efficiency SA/A and winter efficiency WA/A), the ratio of winter sun patches to summer sun patches WA/SA and the yearly efficiency WA/2SA. These tables are not included in this thesis since their inclusion would increase the volume by 1968 pages. So an alternative and abbreviated set of tables was developed which are described in 4.7.1.2 (see Appendix 3).

4.7.1.2 The General Tables

Since it was not possible to include the 1968 tables just for direct sunlight as an Appendix, and in order to present as much useful data as possible another program was written to form a summary of the most important information from the first and to lay out the results for each of the sixteen orientations in one table; the number of tables was thus reduced to 123. Each gives the window efficiency in rank order according to either the yearly or the summer

4.5 The Window as a "Shading Device"

4.5.1 Wall Thickness

The wall thickness in any fenestration acts as a combined shading device, and has a great effect on the penetration of direct sunlight, especially in small windows (see Figure 4.5)

4.5.2 Wall Orientation

As shown in Figure 4.3 wall orientation is a basic determinant of the amount of direct sunlight in summer and winter. As an example a north facing wall in Baghdad receives some summer sun, but no sun at all during autumn, winter and spring while a south facing wall receives only a little direct sun in summer and a substantial amount in winter.

4.5.3 Inter-house Distances

As explained above adjacent buildings work as external obstructions and cause overshading on other buildings. As obstruction height decreases so does the shading effect. The critical ratio is that of obstruction height to inter-house distance and this ratio, on same orientations, gives favourable performance both summer and winter, whilst on other orientations it may impede useful winter sunshine but still give good summer shading.

tables and graphs as possible extensive work will have to be undertaken on:

1- establishing a technique to generalize any shape of building in order to group the recommendations to a limited number of sets representing most common building shapes.

2- developing a computer program to predict over-shading by adjacent buildings in order to replace the experimental work which preceded the computer calculations and which is both tedious and slightly inaccurate due to the inbuilt geometrical errors resulting from the use of the Heliodon.

CHAPTER 5

C H A P T E R - 5 -

WINDOWS FOR DAYLIGHTING

5.1 Daylighting

It was found from the housing survey, that 100% of the population in the housing area interviewed considered windows very important for lighting purposes . Although wishing to eliminate excessive direct sunlight in summer, they wanted to enjoy natural light. Therefore it is necessary to provide building designers with as much as useful information as possible on how both these demands of the users can be met .

5.2 Sky Condition in Baghdad

It was noted previously that, an average of over 22 days in the year the sky in Baghdad is over-cast, for 20 days the days are dusty days and 205 days enjoy a clear sky, the remaining days are mixed condition (see Figure 2.11). Accordingly the typical Baghdad sky was considered as a clear sky.

5.3 Sky Illuminance

As no measurements have been carried out on sky luminance distribution in Baghdad which would enable design recommendations to be based on empirical data, this study depends on a theoretical model of sky luminance to calculate the absolute outdoor illuminance on a horizontal plane, as well as for the indoor daylight levels.

5.4 Factors Affecting the Sky Illuminance Level

By introducing a value for sky luminance in order to represent the outdoor illuminance for any type of building, one must bear in mind that it can be affected by more than one factor. Moreover before recommending any value, these factors and other relevant investigation will have to be carried out as follows.

5.4.1 Working Hours

Usually the value of the design sky is that luminance which occurs at the lowest illuminance level during working hours. However for houses, since there is no fixed time for house-work, as the housing survey illustrated, the whole day will be considered as "working hours". Moreover if one accepts the notion of designing for low sky illuminance levels one would have to recommend, for housing purposes, a light level based on zero sun altitude (sunrise or sunset) as working hours at home are unlimited. This would in practice be unacceptable especially when one considers that lighting according to zero sun altitude would result in extremely large windows in order to provide a sufficient amount of daylight at times of such low external illuminance. Since this would have a totally unacceptable effect on summer heat gain, winter heating and other design considerations another rule for recommending the lighting levels has to be used.

5.4.2 House Orientation Effect

For housing purposes it was decided that it was not practical to consider a fixed sky illuminance level for all house orientations because in clear sky conditions external reflection plays an important part in the level of lighting inside buildings.

It is clear that when a wall receives direct sunlight the wall opposite is in the shade, and while the window on the shaded wall receives sky light and a large quantity of reflected light from the wall opposite, the window on the wall facing the sun does not face a sunlit wall. Therefore the two rooms behind the two windows will have different sky and external reflected components, with that behind the sunlit wall having the lower one. Accordingly under identical, simultaneous sky conditions the daylight levels from similar windows facing different orientations are different. However if the outdoor sky luminance is considered when the sun is parallel to both facing walls, the sky and external reflected components resulting from the two identical windows will be the same, as long as the external walls have the same reflection factors, and thus at least two orientations will share one standard outdoor sky luminance.

5.4.3 The Basis for Recommending Outdoor Illuminance

Any norm survives if it proves useful and has the ability of being applied without negative influences on other factors.

Therefore with regard to daylight in hot regions the norm has to take into account that, although daylighting is important from the psychological and energy conservation points of view, excessive daylight in summer is not acceptable and people prefer to pay for lighting rather than for the greater cost of summer cooling.

Consequently, a low level of outdoor illuminance has to be considered objectively in order to make acceptable design decisions.

Thus one has to define:

1 - That sun direction azimuth values on each orientation which gives an equally low external reflection effect on two parallel neighbouring walls.

2 - The sun altitude values for each of the selected azimuth values, which yield standard sky luminance values to be used in the calculation of outdoor daylight.

5.4.3.1 Sun Direction

It is well-known that under clear skies the illuminance of the blue sky is quite low and as external reflection plays a major part in the lighting of indoor spaces, the lowest value of the indoor lighting is when the sun is lateral and the direct beam is tangential to the wall. Therefore the outdoor lighting level will be considered only when the solar wall azimuth = $+90^{\circ}$ or -90°

5.4.3.2 Sun Altitude

In order to find usable values for sun altitudes and recommend them for each orientation the sun altitudes in extreme summer and extreme winter were found for each of the 16 orientations, when the solar wall azimuth (horizontal shadow angle) was $+90^{\circ}$ or -90° (see Figure 5.1).

The average value between the summer sun altitude and the winter sun altitude for each orientation was taken as the recommended value for calculating and estimating the outdoor sky luminance for purpose of indoor daylight calculations.

5.5 Daylight Levels

5.5.1 The Number of Outdoor Values

As has already been said the study is concerned with houses having 16 orientations, starting in a clockwise direction from the north, 0.0°, and moving in increments of 22.5°.

Estimating sun altitudes for horizontal shadow angles at $-/+ 90.0^{\circ}$ shows some values to be common for more than one orientation, consequently the number of values to be used

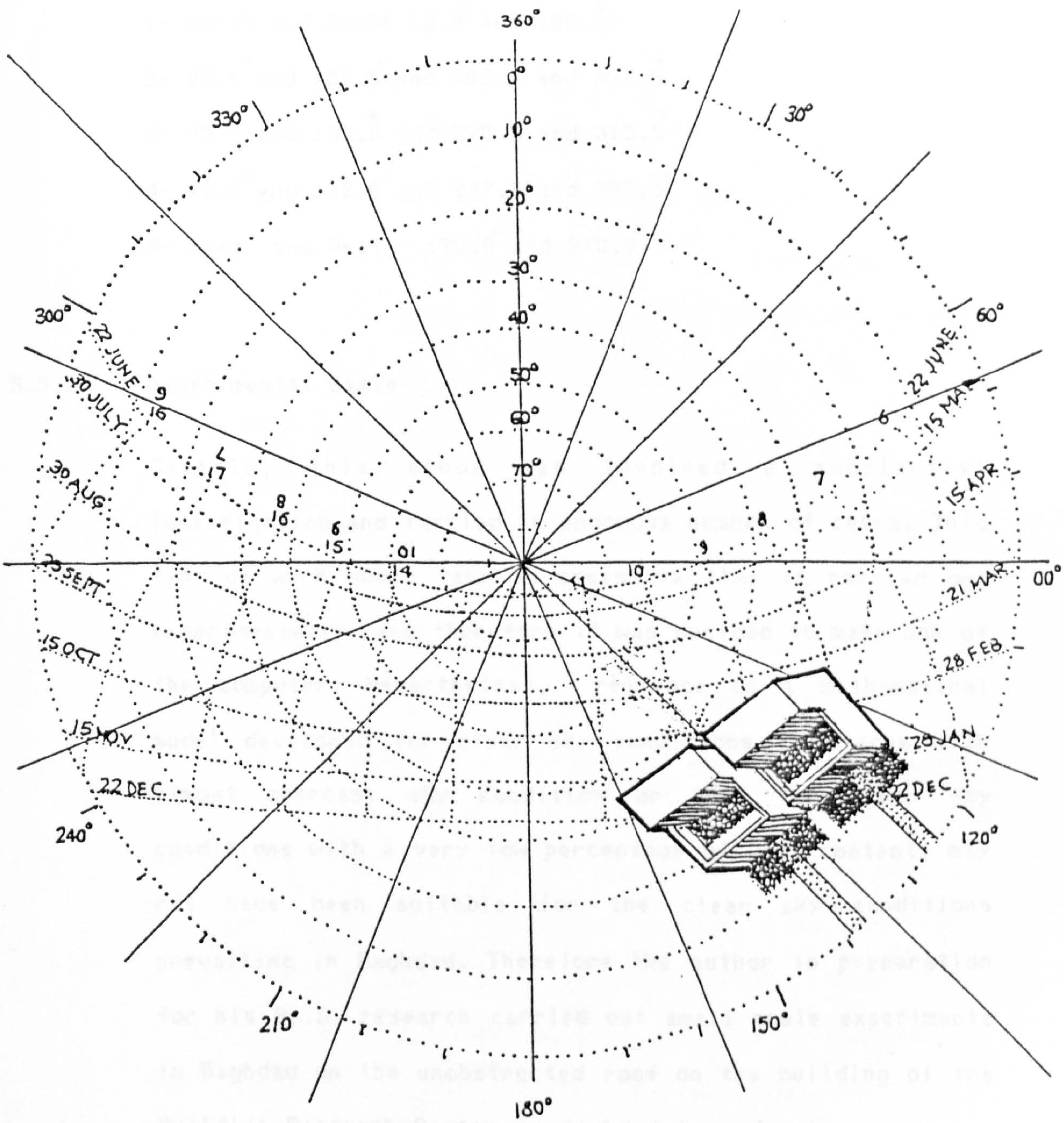


Figure 5.1 Stereographic projection with superimposed axonometric of one pair of houses, showing solar azimuth parallel to side walls.

is reduced (see Figure 5.1). Accordingly only 5 values are required for the following groups of orientations:

1- North and South (0.0° and 180.0°)
2- 22.5° and 157.5° and 202.5° and 337.5°
3- 45.0° and 135.0° and 225.5° and 315.5°
4- 67.5° and 112.5° and 247.5° and 292.5°
5- East and West (90.0° and 270.0°)

5.5.2 Experimental Basis

Clearly, this study has involved a substantial investigation and tackled an enormous number of cases. This type of work would take an excessive time if carried out experimentally, and therefore it was decided to make use of the computer. Nevertheless, reliance on a mathematical model developed for clear sky conditions in places with almost overcast sky condition or even for clear sky conditions with a very low percentage of dust content, may not have been suitable for the clear sky conditions prevailing in Baghdad. Therefore the author in preparation for his Ph.D. research carried out small scale experiments in Baghdad on the unobstructed roof on the building of the Building Research Centre in Baghdad in order to assess and select the nearest model which met the reqirements for sky conditions in Baghdad especially where the absolute outdoor illuminance is concerned.

5.5.3 The Experimental Model

A 1/10 scale model representing room dimensions of 4m * 5m * 2.8m high with two windows of 1m * 1m with and 0.8m high window sill and 0.25m wall thickness was constructed (see Figure 5.2).

The model was covered inside and out with black cloth (with a 3.31 % reflection factor) to keep out any inter-reflection. A black piece of cloth was fitted on each of the two windows so that the windows may be open or closed at any time.

A base for the outer cells was constructed and attached to the window opening in such a way that the cell could be placed horizontally to measure half sky illuminance just outside the threshold of the window, presuming that the external wall reflection from the black walls is zero.

The model represents a room 4m * 5m and measurements were recorded for each grid of 0.25m2. It was decided to use three cells, two of them were placed outside the room and the third was placed on a mobile ruler at a working level, heights of 0.8m and 0.5m. The ruler is moved on a groove in the middle of the base which is situated on the floor of the room (see Figure 5.3). The base was divided to represent a 0.25m2 grid. The ruler moves in the direction of the room depth , while the room was designed to move on the base grid in a direction perpendicular to the cell path, to enable sky components to be recorded at 0.5m metre

Figure 5.2 Experimental model on roof of Building Research Centre, Baghdad.

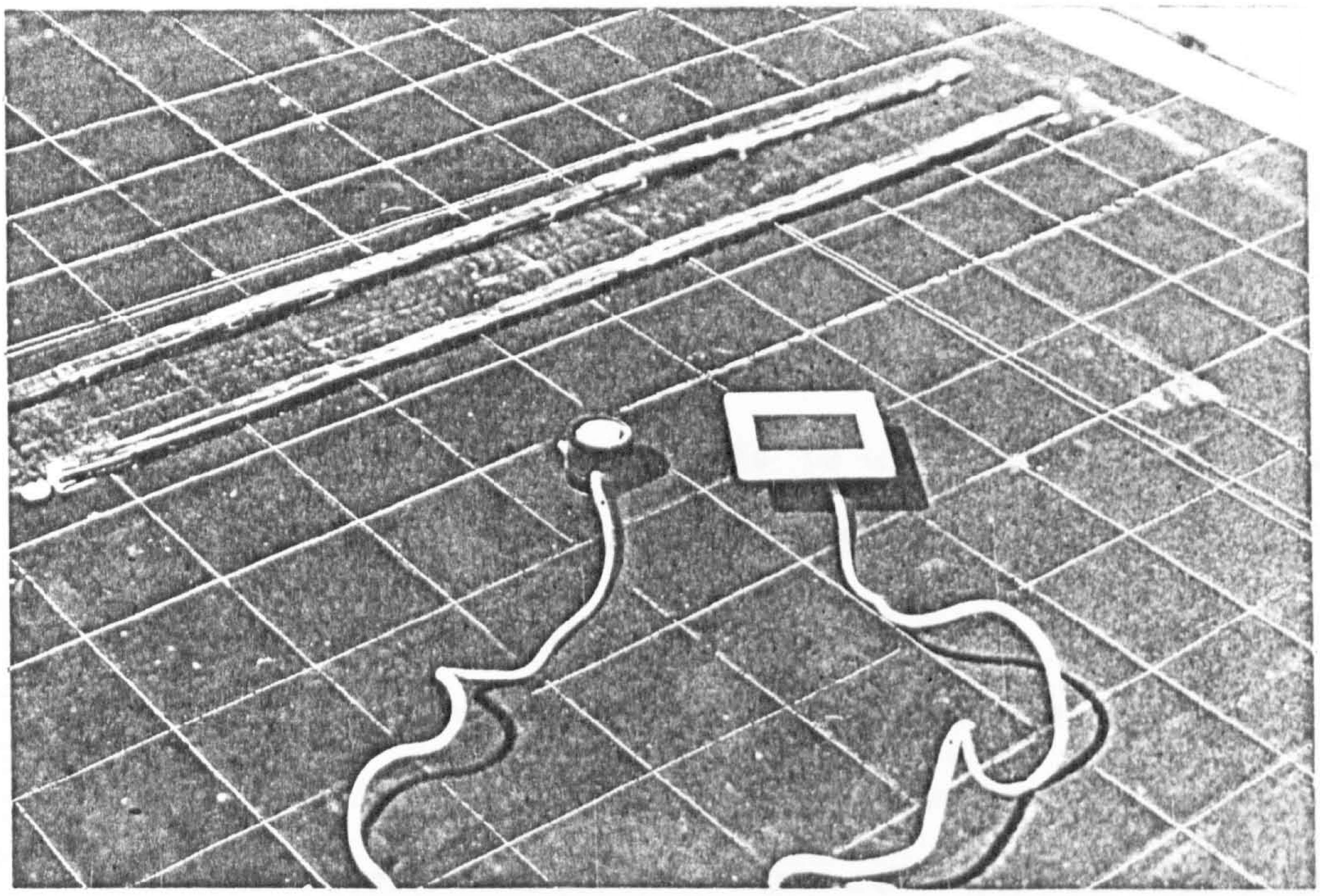


Figure 5.3 Floor of model room

intervals within the depth and width of the room. Using this technique the cell remained horizontal. It was chosen to speed up the recording of the results in order to minimize changes in the outdoor illuminance.

5.5.4 The Measuring Instrument

The experiments were carried out with a Megatron Architectural Model Lux Metre. The apparatus consists of twelve cells with an ability to measure a maximum of 10 kilolux. Three cells out of the 12 were selected as it was found that their responses were sufficiently similar whilst somewhat different from the remaining 9.

Since the maximum recording scale of the apparatus was only 10 kilolux, to use the apparatus for measuring absolute outdoor illuminance the cell was covered with a Kodak grey filter to enable the scale to be used by keeping measurements within the instrument's range (see Figure 5.3).

Although the transmission factor of the grey filter was unknown at the time experiment was carried out, it was the intention that the filter factor would be measured in the future.

During the author's visit to the Slovak Academy of Sciences to discuss the natural lighting part of his work with Dr. Kittler, the filter was calibrated under an artificial clear sky and a reduction factor of 31 was found as the filter power (ie. 3.23% transmittance).

5.5.5 Experimental Reasoning

As explained the experiment was carried out in Baghdad on an unobstructed roof of the Building Research Centre during the period between the 30th of May and the 16th of June 1982 between 7am. and 10am., for the following purposes:.

1- To find the illuminance level on the working plane given by the sky component in order to check mathematical models.

2- To discover the effect of a combination of a window to the front and one to the side on the illuminance given by the sky component.

3- To obtain an estimate of the absolute outdoor sky illuminance for Baghdad, in order to guide the author on the selection of suitable mathematical models.

Unfortunately experiments on external reflected components were not able to be carried out at the same time for a variety of unavoidable resons.

5.5.5.1 Sky Component Experiment

As described the floor of the room was divided into a 0.25m2 grid as seen in Figure 5.3 to enable measurements to be made of the illuminance at the centre line from each of the two windows and also the line across the two sides of both windows. They were carried out with both one window and two windows uncovered. The windows were oriented south and west to avoid direct sunlight penetration during the experiment. For each row of measurements, one corresponding record for an external cell was recorded. To avoid any time lag between pairs of measurements a tape recorder was used to take the recording. A row of 7 points took up to 1.5 minutes to completion.

The sky component for each point was found and the results were tabulated and prepared for mathematical comparison.

A difference of about 16 % was found between the measurements and the theoretical results (see Table 5.1) in part because the study is concerned with the mid point of the room and the curve was plotted only for those points falling on the line joining the midpoint of the lower edge of the window with the midpoint of the room.

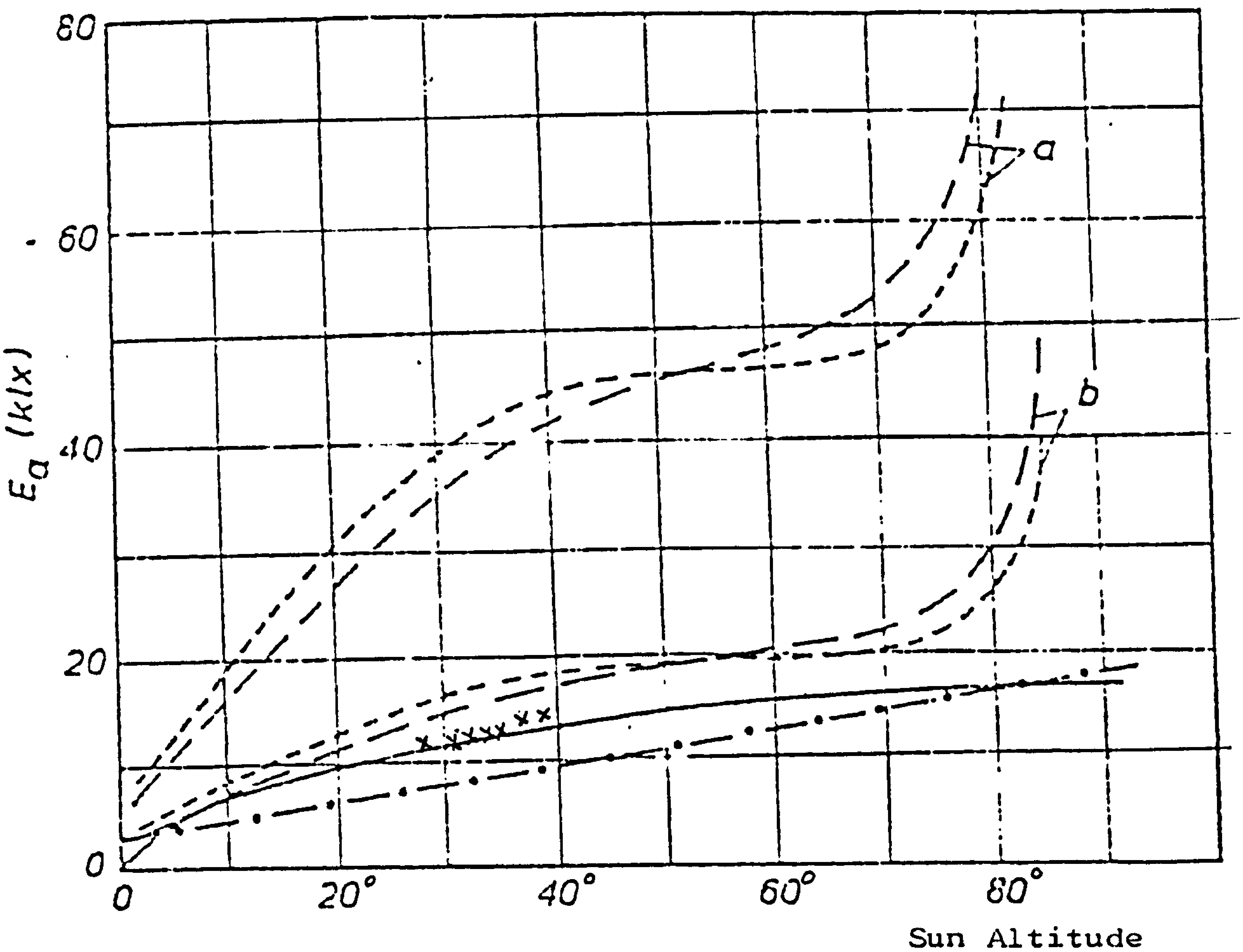
5.5.5.2 Absolute Sky Illuminance

It will be seen later that predicting the illuminance inside a room requires one to determine the value of the absolute sky illuminance and this value can be found experimentally and mathematically. As the scope of the the present study is rather large, it was decided that mathematical formulae were the most suitable tool to be used .

Accordingly a few of the records taken in Baghdad on the 2nd of June 1982 between 7.45 am. and 8.05 am., when the sun altitude was between 30° and 35° were compared with corresponding values from some of the internationally supported formulae [Ref. 110] (see Figure 5.4). From this Figure it is clear that Krochmann's formula is near enough

Sky Component Experimental	Sky Component Theoretical	Difference %
0.61	0.54	-13%
0.34	0.39	13%
0.2	0.24	16%
0.13	0.16	19%
0.08	0.10	20%
0.06	0.07	14%
0.04	0.05	20%

Table 5.1 shows the difference between the experimental findings and the CIE formula.



Illuminance on a horizontal plane from clear sky.

××××××× Experiment (by the Author)

—— —— *Dogniaux, Kittler*

-- — — *Dogniaux, Gusev*

———— *Krochmann (eqn. 5.2)*

—· — *Chroscicki (eqn. 5.1)*

a $T = 7.0$

b $T = 3.0.$

T = Turbidity

Figure 5.4

to meet the requirements of the Baghdad sky condition, and in the subsequant calculations it was used for estimating the absolute sky illumination (Ea)

5.5.5.2.1 The Formulae

1- Chroscicki formula [Ref.110]

Ea = [3 + 0.17* A/degree] Kilolux 5.1

2- Krochmann formula [Re. 110]

Ea = [1.1 + 15.5 Sin^1/2 (A)] 5.2

3- The American I.E.S (Dec. 1983)
For Half Sky Illuminance [Ref. 97]

Eah=8.2(Sin(A))^0.5+6.9(Sin(A))^1.3*CosA*CosH.S. 5.3

Where:

Ea :The illuminance on horizontal plane
Eah :Half sky illuminance on horizontal plane
A :Sun altitude
H.S.:Solar wall azimuth

5.5.5.2.2 The Recommended Levels

Using Krochmann's formula as illustrated above, for the calculation of absolute value of illuminance on the horizontal plane from a clear sky, the following values were found and recommended for the five groups of orientations :

1- Group 1 = 12838 LUX

2- Group 2 = 14133 LUX

3- Group 3 = 14514 LUX

4- Group 4 = 15128 LUX

5- Group 5 = 15294 LUX

5.6 Theory and Formulae

5.6.1 Background

It is well known that the multiple diffusion and reflection of sunlight on and through the gas and aerosol particles in the actual turbid environment of the atmosphere affects the spectral distribution of the radiation of the clear sky. Rayleigh (1899) [Ref.103] stated that, the relative diffusion of light caused by gas molecules in a so-called ideally clear atmosphere obeys:

$$f(G) = 1 + [\cos(G)]^2 \qquad \ldots.5.4$$

Where (G) is the arbitrary diffusion angular distance of the considered sky element from the sun.

After Rayleigh, Schonberg (1929) [Ref. 103] published his formula for a foggy condition by introducing some coefficients.

In 1929 Pokrowski submitted his formula for calculating the luminance distribution for clear skies, which was considerd at that time as a good approximation to the measured luminance distribution.

In 1961 Bareteneva found that neither Schonberg's nor Pokrowski's formulae corresponded fully to the measured average. According to Bareteneva, Pokrowski's formula could no longer be considered for the calculation of luminance distribution for clear skies.

Between 1929 and 1961 a number of scientists carried out many measurements and introduced further parameters and coefficients which they added to Rayleigh's formula to better represent actual sky conditions .

In 1964 Kittler [Ref. 103] proposed to the International Commission on Illumination (CIE) that the atmospheric condition for a CIE standard clear sky could be satisfactorily defined by the diffusion indicatrix within a tolerance zone between the curves:

A - For clear atmospheric air is,

$$f(G) = 0.955 + 5 \exp(-3 G) + 0.8[\cos(G)]^2 \quad \ldots.5.5$$

B - For polluted atmosphere in idustirial area is,

$$f(G) = 0.865 + 15 \exp(-3 G) + 0.33[\cos(G)]^2 \quad \ldots.5.6$$

The standared indicatrix:

$$f(G) = 0.9 + 10 \exp(-3 G) + 0.45[\cos(G)]^2 \quad \ldots.5.7$$

would corrresponed to the ideal luminance distribution, which would serve as a basis for the calculation of daylight factor under clear sky.

From 1964 to 1967 the CIE expert committee encouraged all experts and scientists to carry out the necessary measurements on the formula before the CIE committee adapted it.

In June 1967 Kittler's formula was approved and Dongniaux, Professor Gusev and Dr. Kittler were asked to to provide an additional indicatrix characterizing the clear sky luminance distribution in idustrial areas.

The intersessional meeting of the expert committee held in Bratislava September 1969 accepted Professor Gusev's proposal to define the indicatrix by a second twin formulae (see 5.6.2.).

In 1973 after graphs and tables were derived from the standared formula to ease its application in general practice CIE published CIE No.22(TC-4.2)1973, "Standardization of Luminance Distribution on Clear Skies" and recommended to adoption of Kittler's model.

5.6.2 CIE Standard Formula (Kittler's Formula)

The relative luminance distribution on clear skies is expressed by the following general formula

$$\frac{LCa}{Lz} = \frac{f(G)\ \varphi(C)}{f(Zo)\ \varphi(0)} \quad \ldots.5.8$$

Where:

$$f\ (G) = 0.91+10\exp(-3\ G)+0.45[\cos(\ G)]^2 \quad \ldots.5.9$$

$$f\ (Zo) = 0.91+10\exp(-3Zo)+0.45[\cos(Zo)]^2 \quad \ldots.5.10$$

$$\varphi(C) = 1 -\exp(0.32\ \sec\ C) \quad \ldots.5.11$$

$$\varphi(0) = 1 -\exp(-0.32)=0.27385 \quad \ldots.5.12$$

$$\cos\ (G) = \cos\ (Zo)\ \cos\ (C) +\sin\ (Zo)\sin\ (C)\cos\ (H.S.) \quad \ldots5.13$$

Zo = Zenithal sun angle

LCa = Luminance of an arbitrary sky element

Lz = Luminance at the zenith

C = Angular distance of the sky element from the zenith

H.S. = Azimouthal angle of the sky element from the sun meridian

In the above terms all angular dimensions are in angular coordinates (see Figure 5.5).

5.7 Daylight Level Calculation Inside Buildings

Illuminance levels in a room are the summation of direct daylight reaching the point from the sky and any light reflected into the room through the window from external obstructions, and the light, having once entered the room, reflected and interreflected at room surfaces before it reaches the reference point.

This can be expressed either in Lux or as a Daylight Factor.

5.7.1 The Daylight Factor

The daylight factor is the ratio of daylight illuminance at a point on a given plane due to the light received directly and indirectly from a sky of assumed or known luminance distribution, to the simultaneous illuminance on a horizontal plane due to the unobstructed hemisphere of this sky.

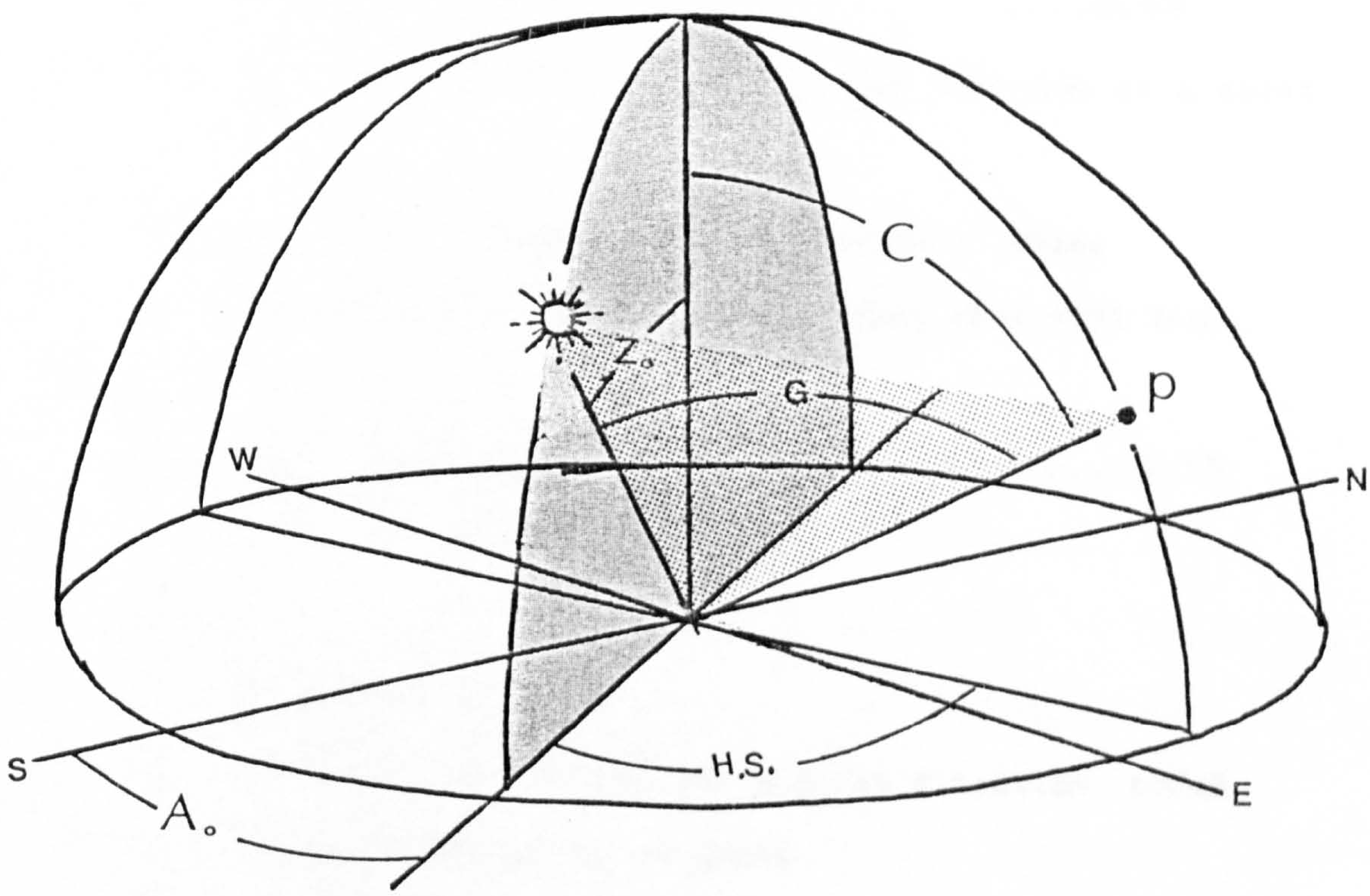


Figure 5.5

Direct sunlight is excluded for both values of illuminance [Ref.78].

Daylight Factor = Sky component + External Reflected Component + Internal Reflected Component

5.7.1.1 Sky Component Formula and Calculation

$$Sc = (Ep/Ea)*100\% \qquad ....5.14$$

Ep = the illuminance at a point inside the room at a point 'p'

Ea the external illuminance on a horizontal plane

Referring to Figure 5.8 Ep can be found [Ref.109] from:

$$Ep=K\int_{Wf}^{o} Lp.Ti.dw.Cos\ h \qquad ....5.15$$

Where:

K : Maintenence factor

Lp : Luminance of the sky for a given direction cd/m2

Ti : Transmission factor of glass

Wf : Solid angle of the glass area

h : Angle of incidence of light on the plane

$$W = \int_{Wf}^{o} dw = \int_{h1}^{h2}\int_{r1}^{r2} Sin\ h.dh.dr \qquad ....5.16$$

Referring to CIE standard formula

L(ha) = Lp is the sky illuminance and is f(h,r)

Cos h: is the correction for projection on to the horizontal plane

Ti is f(h,r)

Rivero [Ref. 78] found an approximation for glass transmission as f(B) (see Figure 5.6)

$$Ti(B) = 1.018To\ (Cos\ B + (Sin\ B)^{\wedge}3 * Cos\ B) \quad ....5.17$$

Ti(B)= Transmission of glass at angle B to the normal of the window

To : transmission at normal incidence

$$Sc = K/Ea \int_{h1}^{h2}\int_{r1}^{r2} Lp(h,r)(1.018To(Cos\ B+(Sin\ B)^{\wedge}3*Cos\ B))Cos\ h\ Sin\ h\ dh\ dr \quad ....5.18$$

From CIE Formula

$$Lp = Lz * f(a) * \varphi(q) / f(Zo) * \varphi(0) \quad ....5.19$$

Lz, f(Zo) and $\varphi(0)$ are independent of h and r so they can be moved out of the integration.

$$Sc = \frac{1.018To.K.Lz}{Ea.f(Zo).\varphi(0)} \int_{h1}^{h2}\int_{r2}^{r2} f(q)\ (h)(Cos\ B+(Sin\ B)^{\wedge}3*Cos\ B)Cos\ h\ Sin\ h\ dh\ dr \quad ....5.20$$

Lz / Ea .f(Zo) .φ(0) can be calculated independently and treated as constant values.

Lz can be found from Dogniaux's formula [Ref. 110]

$$Lz = [\ (1.234T-0.252)Tan\ q + 0.112T - 0.0169\ ]\ Kcd/m2 \quad ....5.21$$

For clear skies T = 2.25

Ea can be found from Krochmann Formula [Ref. 110]

$$Ea = (1.1 + 15.5\ (Sin\ q)^{\wedge}0.5\ )\ Kiloiux \quad ....5.22$$

$$f(Zo)\varphi(0) = 0.274(0.91 + 10\ exp(-3*Zo) + 0.45\ (Cos\ Zo)) \quad ....5.23$$

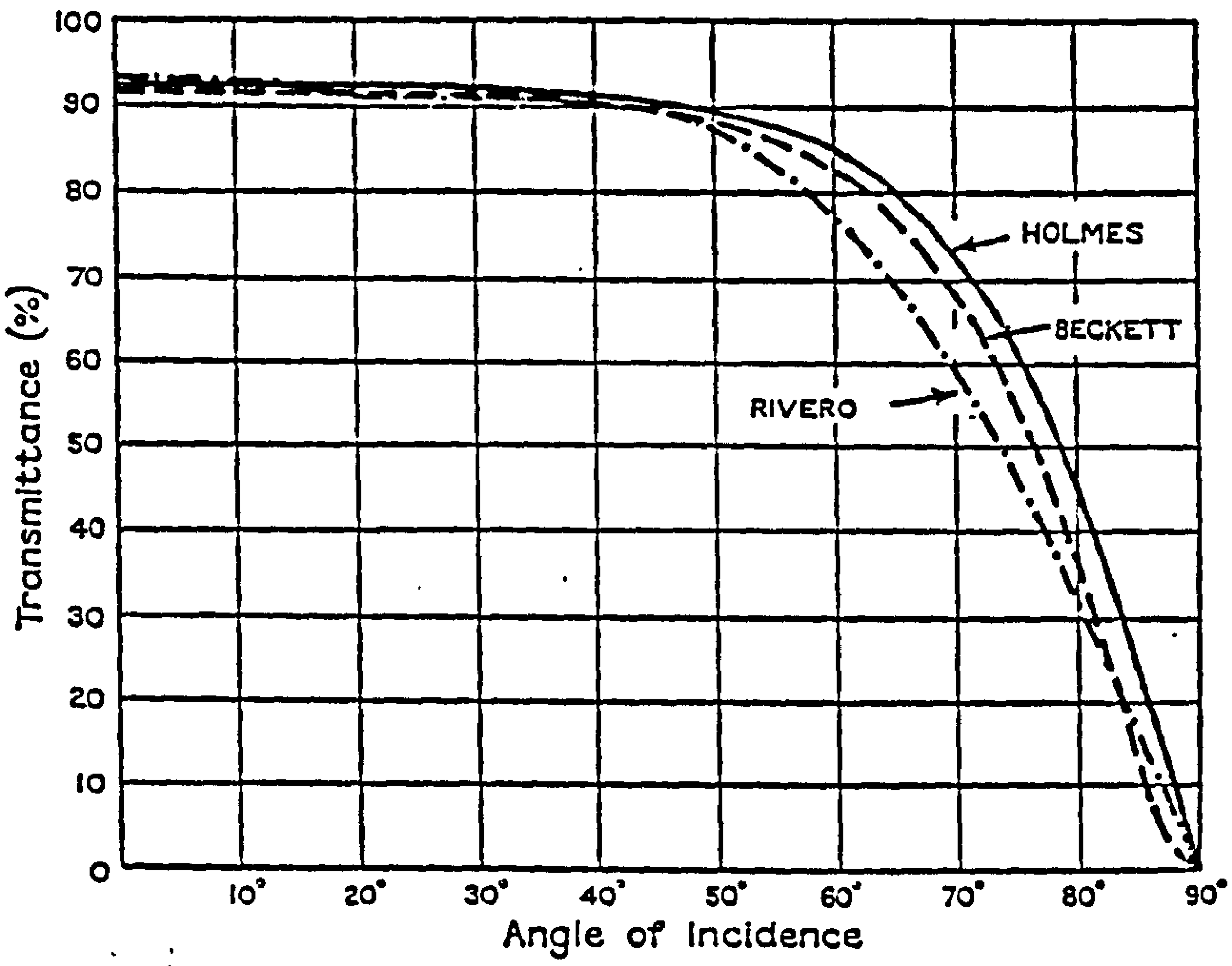


FIG. 5.6 The variation of the transmittance of ordinary clear window glass with angle of incidence. (After ref.78)

Lawrance Berkeley Laboratory, Univ. of California calculated

$Lz/[Ea * f(Zo) * \Upsilon(0)]$ [Ref.34] 5.24

and presented it in table form for each 10 degree sun altitudes, and called it Normalization Factor Nsc

With the present work the normalization factor is presented in graphical form (see Figure 5.7) for the range 30 to 70 sun altitude

For the purpose of integration and to unify the angles, q and h are expressed in term of angle G,r (see Figure 5.8) [Ref. 36].

In terms of G and r the value of Cos B ,Sin B, Cos h, Sin h and dh are derived and expressed as follows, (The derivation is in Appendix 1)

Cos B = Cos r *Sin G / {[(Cos G)^2*(Cos r)^2 + (Sin G)^2] ^ 0.5 }..5.25

$$\text{Sin B} = \frac{(\text{Sin G})^2 + (\text{Cos r})^2 [(\text{Cos G})^2 - (\text{Sin G})^2] ^{0.5}}{\{ [(\text{Cos G})^2 * (\text{Cos r})^2 + (\text{Sin G})^2]^{0.5} \}} \quad ....5.26$$

Cos h = Cos r *Cos G / {[(Cos G)^2*(Cos r)^2 + (Sin G)^2] ^ 0.5 }..5.27

Sin h = Sin G / {[(Cos G)^2*(Cos r)^2 + (Sin G)^2] ^ 0.5 } 5.28

dh = Cos r .dG 5.29

As given in [Ref. 37]

f(q) = 0.91 + 10 exp(-3*q) + 0.45 (Cos q) ^2 ....5.30

Υ(h) = 1- exp (- 0.32 Sec h) 5.31

f(Zo) = 0.91 + 10 exp (-3 *Zo) + 0.45 (Cos Zo) ^2 ....5.32

Υ(0) = 1- exp (- 0.32) = 0.27385 ....5.33

q = Cos^-1[Cos Zo *Cos h + Sin Zo *Sin h *Cos a] 5.34

a = r + rw - rs 5.35

r : Angle representing two corners of the window. (see Figure 5.8)

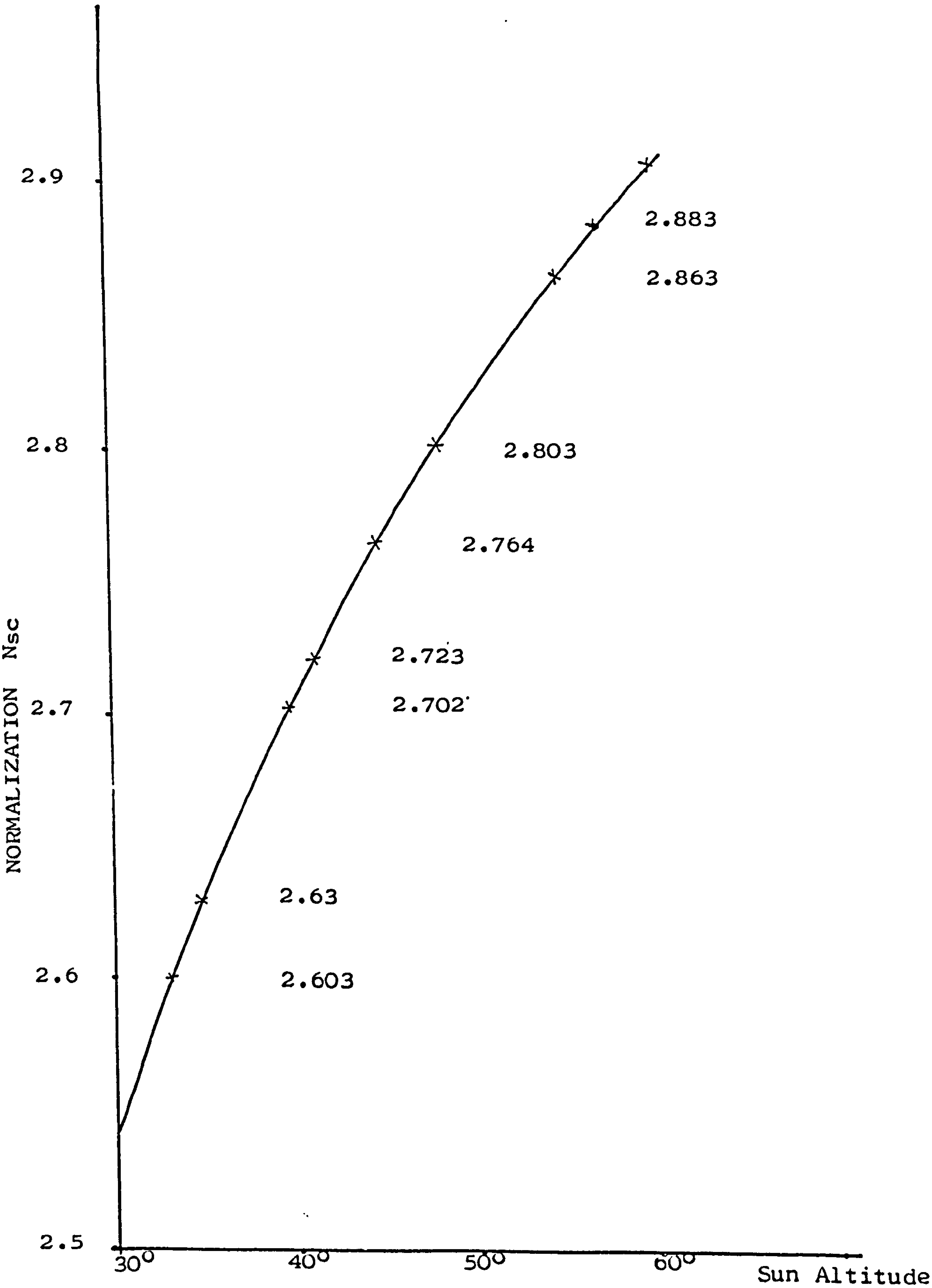

NORMALIZATION Nsc
2.9
2.8
2.7
2.6
2.5
2.883
2.863
2.803
2.764
2.723
2.702
2.63
2.603
30°
40°
50°
60°
Sun Altitude
degree

Figure 5.7

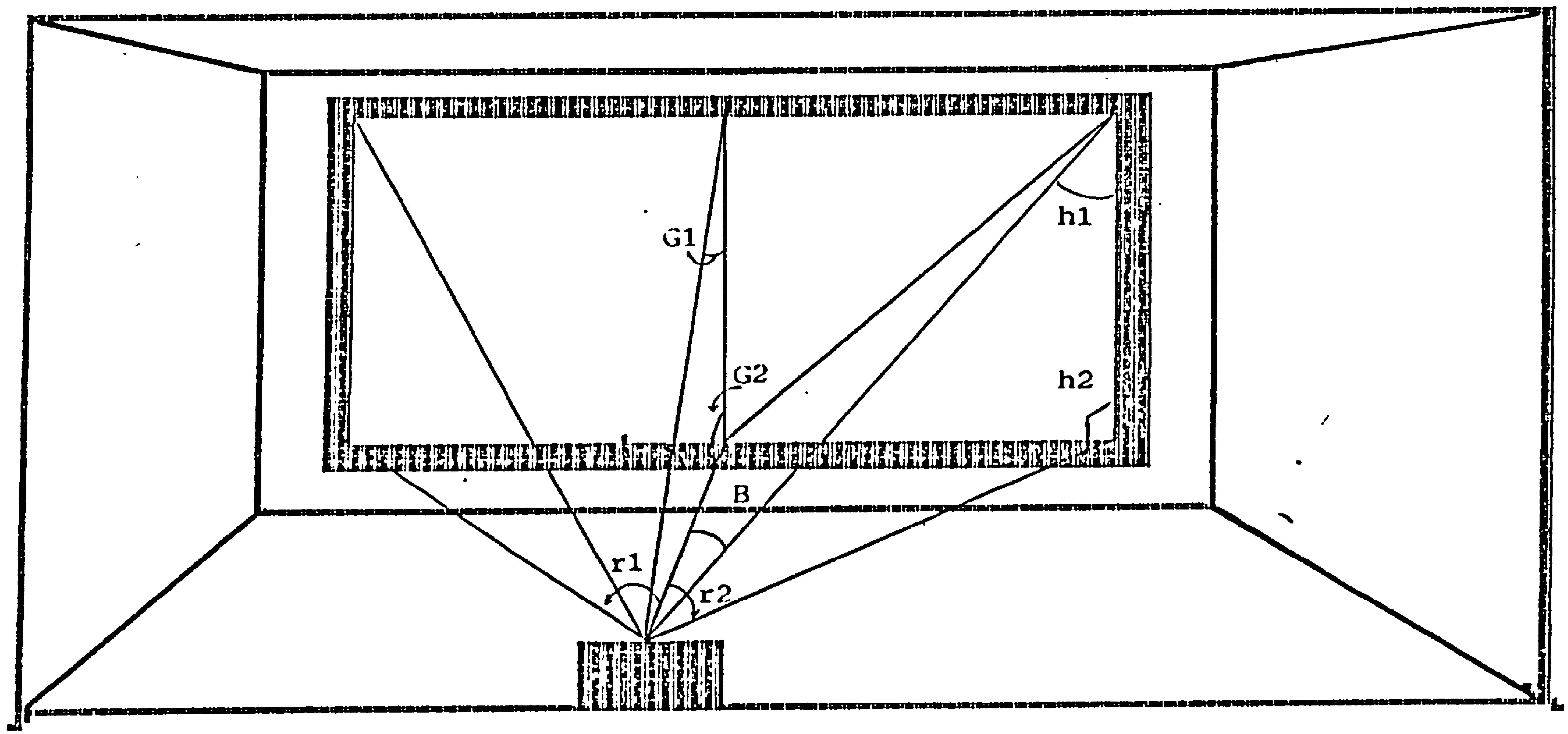


Figure 5.8

rw : Angular azimouthal distance of the window normal from the north

rs : Angular sun azimouth from the north

$$q = \text{Cos}^{-1}[\text{Cos Zo} * \text{Cos h} + \text{Sin Zo} * \text{Sin h} * \text{Cos}(r + rw - rs)] \quad ..5.36$$

$$\text{Let } (X) = (\text{Cos G})^2 * (\text{Cos r})^2 + (\text{Sin G})^2 \quad ....5.37$$

$$q = \text{Cos}^{-1}[(1/(X^{0.5}))(\text{Cos G}*\text{Cos S}*\text{Cos r}+\text{Sin Zo}*\text{Sin G}*\text{Cos}(r+rw-rs))] \quad ....5.38$$

$$(h) = 1 - \exp((-0.32 * X^{0.5}) / (\text{Cos G} * \text{Cos r}) \quad ....5.39$$

$$Sc = \frac{1.018\ To}{Nsc} \int_{G1}^{G2} \int_{r1}^{r2} \frac{[(\text{Sin G})^2 * (\text{Cos G})^2 * (\text{Cos r})^3]}{[X^{2.5}]} *$$

$$\frac{[1+[(\text{Sin G})^2+(\text{Cos r})^2((\text{Cos G})^2-(\text{Sin G})^2)^{1.5}]\ [1-\exp\frac{(-0.32*X^{0.5})}{(\text{Cos G}*\text{Cos r})}]}{[X]}$$

$$* \quad [0.91+10\exp(-3q) + 0.45(\text{Cos q})^2]\ .dr\ .dG \quad ....5.40$$

5.7.1.2 External Reflected Component

$$ERc = T*K*ev/(Wo)* f(h,A,rw-rs) \int_{Wv}^{o} dW * \text{Cos h} \quad [\text{Ref.}109]..5.41$$

T : transmittance of glass

K : maintenance factor of the window

Wv : solid angle of the obstruction within the glass area (see Figure 5.9)

rw : window azimouth

rs : sun azimouth

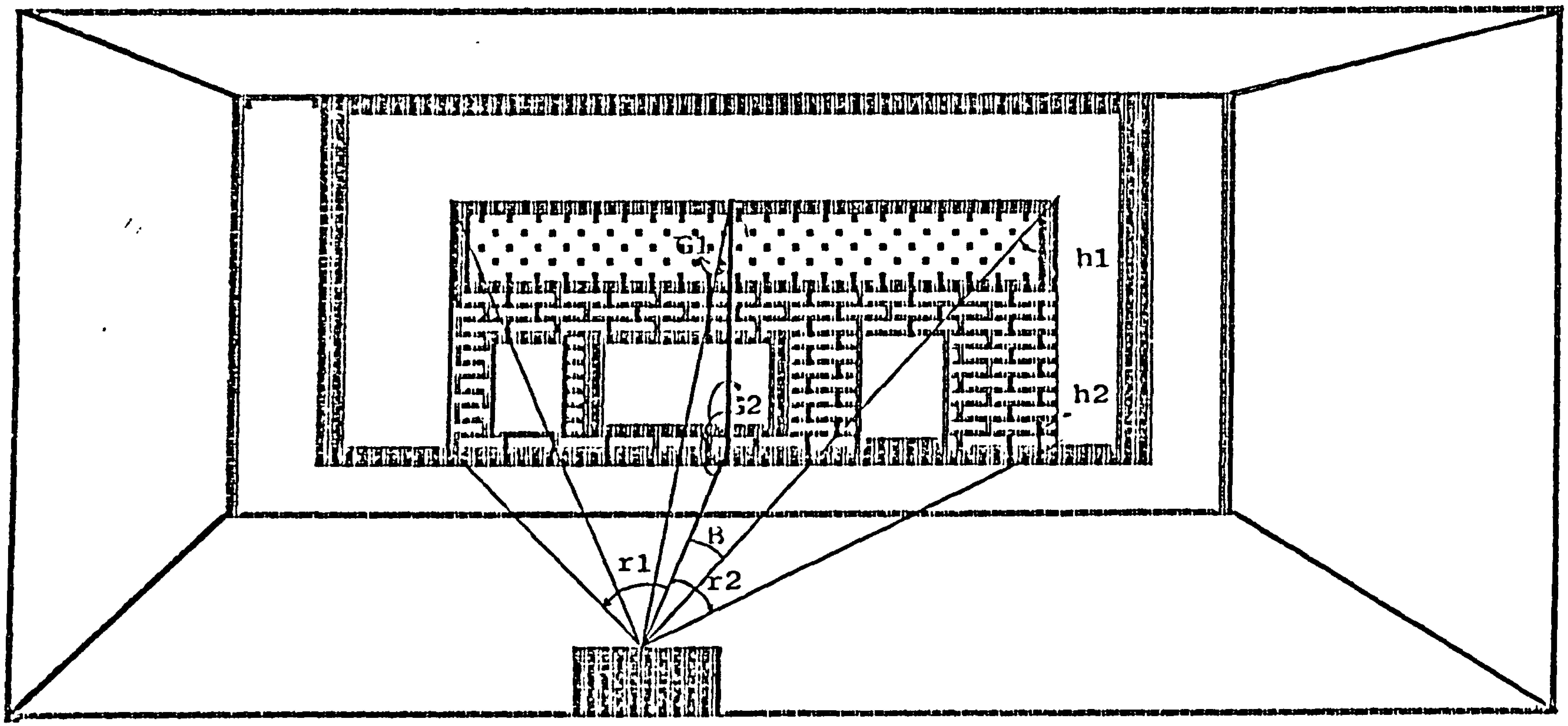


Figure 5.9

A : sun altitude angle

h : angle of incidence

Rv: reflectance of the obstruction

$$ERc = (T*K*Rv/\ \ *Wo)F\int_{G1}^{G2}\int_{r1}^{r2} [\,\mathrm{Sin}\,G / X\,\hat{}\,0.5]*[\,\mathrm{Cos}\,r / X]\ dG\,.\,dr \qquad ....5.42$$

$$ERc = (T*K*Rv/\ \ *Wo)F\int_{G1}^{G2}\int_{r1}^{r2} [\,(\mathrm{Sin}\,G * \mathrm{Cos}\,r) / X\,\hat{}\,1.5]\ dG\,.\,dr \qquad ....5.43$$

F :Window factor

F =FH + FV + FB

FH : Luminous flux incident from the sky

FV : Luminous flux incident from obstruction

FB : Luminous flux incident from ground

Krochmann presents FH in three graphs: Sun behind, Sun lateral (see Figure 5.10) and Sun frontal.

$$FV = Lv / Ea\int_{0}^{a} dW\,.\,\mathrm{Cos}\,V \qquad ....5.44$$

$$FV = (Lv / Ea)\,(\pi/2)\,(\,\mathrm{Sin}\,a\ *\ Wo) \qquad ....5.45$$

The integral of the projected solid angle of this equation is taken for an infinitely extended obstruction from the horizontal to the angle (a) of obstruction

V : Angle refers to the vertical plane

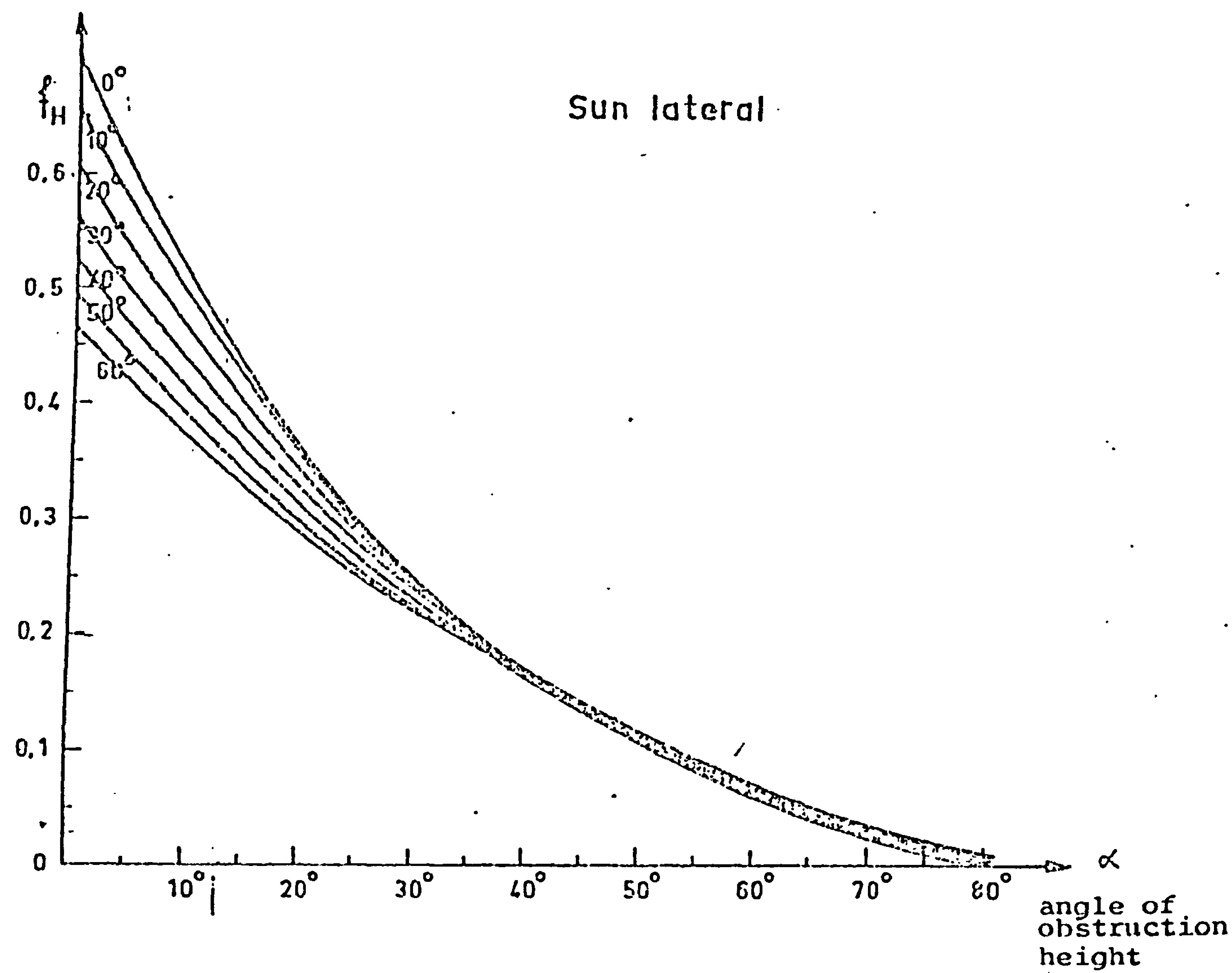


Figure 5.10 Component f_H of the window factor

$$FV \simeq (Rv / 2)*((Sin\ a)/(1-Rv*(Sina\ (FH/FH))) * (FH+(\pi *LB*Wo/2*Ea)) \quad ....5.46$$

$$FB = (\pi * LB * Wo) / 2Ea \quad ....5.47$$

The American recommended practice for the calculation of daylight availability (US. IES 1984 Ref. 79) is

$$LB = EdH = Edn * Sin\ A \quad ....5.48$$

$$Edn= Ext * exp (-C*M) \quad ....5.49$$

C : Atmospheric extinction coefficient= 0.21 for clear sky

M : Optical air mass = 1/ Sin A

EdH: Direct normal solar illuminance

Esc: Solar illumination constant

J : Julian date $(1 < J < 365)$

Ext : The Extraterrestrial solar illuminance

Extraterrestrial Solar Illuminance : Since the earth does not move in a circle around the sun, but in an ellipse, thus on any day of the year, the extraterrestrial solar illuminance has a value corresponding to that day

$$Ext = Esc\ [1+0.034\ Cos(\ (2\pi/365)(J-2)\ )] \quad ....5.50$$

$$LB = 127.5\ [1+0.034\ Cos((2\pi/365)(J-2))]*Sin\ A*exp(-C/Sin\ A)\ ..5.51$$

5.7.1.3 Internal Reflected Component

$$IRc = T*K*(Af/Ao)*(1/(1-Em))(Fo*Rbw + FB * Rdw) \quad [Ref.109]\ ..5.52$$

Af : Glass area

Ao : Room surface area

Em : Mean reflectance of the room

Fo : FH + FV = Window factor due to luminous flux incident from the upper hemisphere

Rbw : Mean reflectance of floor and lower parts of walls excluding the window wall

Rdw : Mean reflectance of ceiling and upper parts of walls excluding window wall

5.8 Window Sizes and Outdoor and Indoor Condition

5.8.1 Window Dimensions

As already stated the window sizes studied are 44 in total with widths of 0.5m to 3.0m in increments of 0.25m and with heights of 1.0m to 1.75m in increments of 0.25m

5.8.2 Surrounding Houses

House surroundings and interhouse distances in the natural lighting part of the study remain as they were for the direct sunlight control study (see Figure 4.18) .

5.8.3 External Walls

Referring to the housing survey 61% prefer the external walls to be painted white and 24% prefer other light colours. Thus in order to satisfy the majority (see Figures 5.11 and 5.12) and encourage those people working in the housing sector to choose white or light colours for the external walls, it was assumed for the purpose of this study that the external walls will be either

Figure 5.11

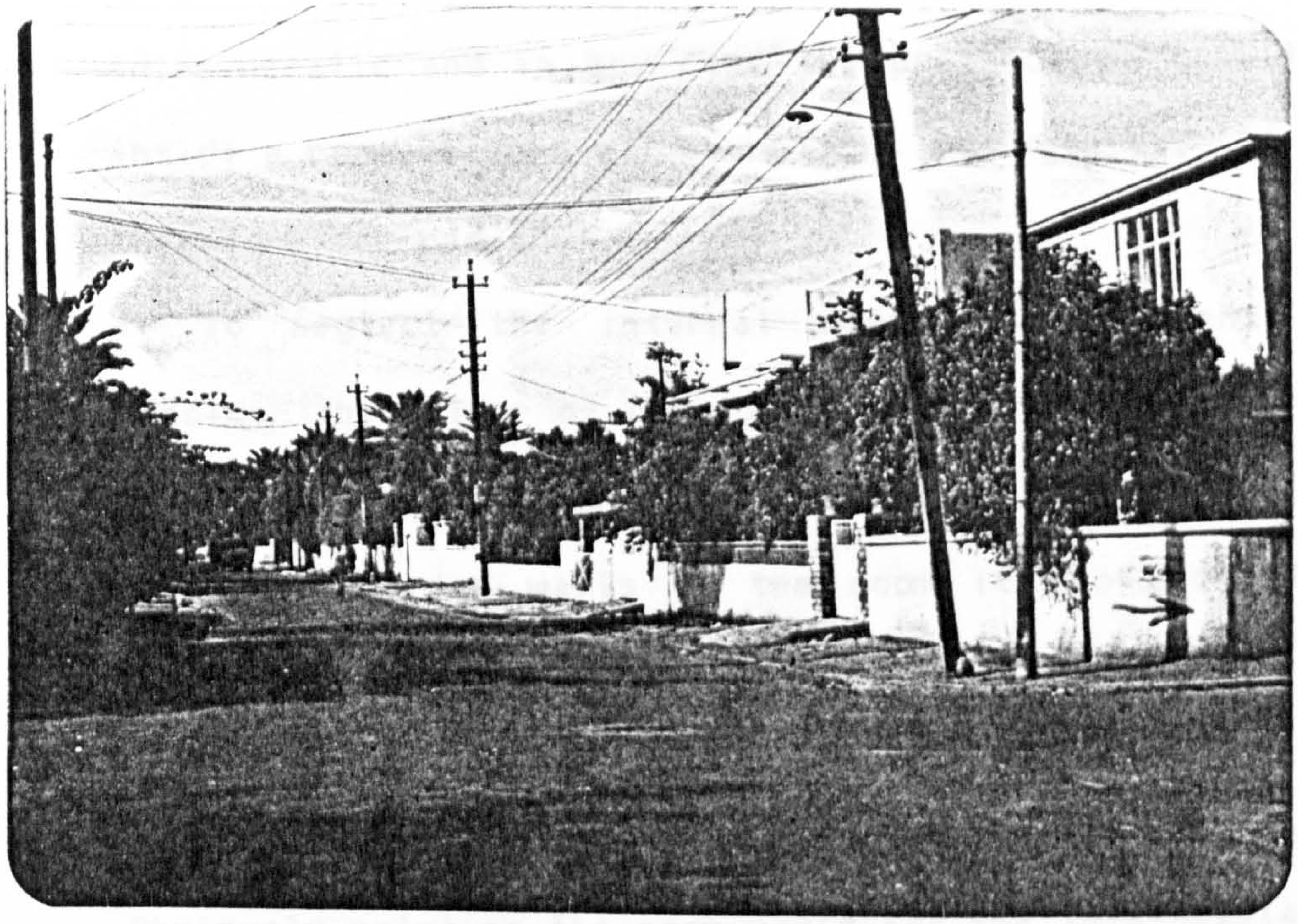


Figure 5.12

white with 70% reflection or in brick colour (yellow) with 25% reflection. The results are presented for both reflection factors.

5.8.4 Internal Wall Colour

People's colour preferences for interiors are highly idiosyncratic and in any case the presence of furniture inside a room changes all asumptions and results. It was therefore decided :

1- To neglect the internal reflected component and consider the colour of the room as black.

2- Instead of calculating the daylight factor near the corners and rear walls of the room it was decided to choose the centre of the room as the reference point for recommended lighting levels, resulting from the sky component and the external reflected component only. Obviously painting the room would add the inter-reflected component which would increase the lighting levels, especially in the parts of the room with low lighting levels. This approach is supported by BSCP 3 and British IES Code 1968 section 14.2 according to which 'It is not intended that the fenestration should be designed to give these factors (Daylight Factor) over the whole room area. The daylight factor recommendations can be satisfied over a greater portion of the working space in the room'.

5.8.5 Windows and Reference Point Positions

The study is concernd with windows positioned at a sill height of 0.75 m which in general is equal to the working plane in the room and the window is considered as sharing the window-wall centre line.

In 5.8.4 it was stated that the centre of the room was considered as the reference point and the necessary computation was done to find the daylight level at this point. During the optimisation analysis (section 7.3.1.2), it was found that the window types selected as being Pareto-optimal, were independant of the real distance from the window-wall to the room centre. On this basis it was decided to standardise on a distance of 2.50m, irrespective of the real distance to the room centre.

5.8.6 Lighting Levels for Domestic Purposes

The British IES code 1968 was found to be a useful tool for good internal lighting recommendations for different room types (see Table 5.2).

5.9 The Computer Program

A computer program [for clear sky conditions in Baghdad] was written to give the sky component and external reflected component, expressed both in Lux and as a modified Daylight Factor FA%, which excludes the Internal Reflected Component. It is for windows of 0.5m to 3.0m in width and 1.0m to 1.75m height, at 0.25m increments in

	Standard service illuminance lux (See page 47)	*Position of measurement*	

Homes

Homes			
Living rooms			
general	50	Working plane	In all home areas, attention should be given to the lighting of room surfaces. Luminaires should be selected and positioned to give occupants a compromise between attractive 'sparkle' and unwanted glare. Dimming is useful for changing atmosphere. Additional mirror lighting required in bedrooms
casual reading	150	Task	
sewing and darning	300	"	
Studies			
desk and prolonged reading	300	"	
Bedrooms			
general	50	Floor	
bedhead	150	Bed	
Kitchens			
working areas	300	Working surface	
Bathrooms	100	Floor	Additional mirror lighting required. Enclosed luminaires should be used
Halls and landings	150	Floor	High luminances should be screened from view when ascending or descending stairs
Stairs	100	Treads	
Workshops	300	Bench	
Garages	50	Floor	

Homes (old people's) Illuminances must be increased 50–100 per cent above recommendations for Homes. Particular attention must be paid to avoiding glare and to revealing steps and obstructions. Two-way switches should be installed for through-ways, stairs, etc

Figure 5.2a

Ceilings	0·8	White emulsion paint on plain plaster surface
	0·7	White emulsion paint on acoustic tile
	0·6	White emulsion paint on no-fines concrete
	0·5	White emulsion paint on wood-wool slab
Walls	0·8	White emulsion paint on plain plaster surface; white glazed tiles
	0·4	White asbestos cement sheet; concrete, light grey; Portland cement, smooth
	0·3	Bricks, fletton
	0·25	Concrete, light grey; Portland cement, rough (as board marked) Timber panelling: light oak, mahogany, gaboon
	0·2	Timber panelling: teak, afromosia, medium oak
	0·15	Brick, blue engineering
Floors	0·35	Timber: birch, beech, maple
	0·25	Timber: oak
	0·2	Timber: iroko, kerning
	0·1	Quarry tiles: red, heather brown

Figure 5.2b Approximate reflectances of typical building finishes

An excerpt from the IES code 1968

height and width, for sixteen house orientations and any interhouse distances for two house types and for two types of external wall colour.

The program was built on the formulae described in (5.6.) and(5.7) derived from the CIE standard formula for clear sky conditions,(see Appendix No.1 for computer listing). The program produces results in tabural form (see Table 5.3) in such a way that designers can make comparisons between windows and discover the effects of window shape, of window width and height, window area and of obstructions .

5.9.1 Tables

It will be seen from Table 5.3 that each Table presents two or more window orientations for one type of obstruction height, stated in the first two lines of the title of the Table. Each Table covers four sets of results representing four interhouse distances. Within each set are results for two types of external wall reflection and the results are expressed in Lux and FA%, (FA% = Sky Component+External Reflected Component).

5.10 Results and Recommendations

The results are presented in Tables according to obstruction height and width and the location and level of the room in the building.

ORIENTATIONS : 67.5 & 112.5 & 247.5 & 292.5

BEDROOM-2-(MIDDLE WINDOW) WINDOW ON SIDE WALL -FIRST FLOOR
OBST.HIGHT 4.50 POINT DIST. 2.5000

W I N D O W		INTER-HOUSE DIST.= 1.M SKY+EXTERNAL REFLECTION				INTER-HOUSE DIST.= 2.M SKY+EXTERNAL REFLECTION				INTER-HOUSE DIST.= 3.M SKY+EXTERNAL REFLECTION				INTER-HOUSE DIST.= 4.M SKY+EXTERNAL REFLECTION			
		25%WALLREFL.		70%WALLREFL.		25%WALLREFL.		70%WALLREFL.		25%WALLREFL.		70%WALLREFL.		25%WALLREFL.		70%WALLREFL.	
WIDTH	HEIGHT	FA %	LUX	FA%	LUX	FA %	LUX	FA%	LUX	FA %	LUX	FA%	LUX	FA %	LUX	FA%	LUX
0.50	1.00	0.02	4.	0.07	10.	0.05	7.	0.13	20.	0.07	11.	0.20	30.	0.12	19.	0.35	52.
0.50	1.25	0.03	5.	0.10	14.	0.07	10.	0.19	29.	0.10	15.	0.28	43.	0.18	27.	0.50	76.
0.50	1.50	0.05	7.	0.13	19.	0.09	14.	0.25	38.	0.13	20.	0.37	57.	0.25	37.	0.65	98.
0.50	1.75	0.06	8.	0.16	24.	0.11	17.	0.31	47.	0.18	27.	0.47	70.	0.34	51.	0.74	112.
0.75	1.00	0.03	5.	0.10	15.	0.07	10.	0.19	29.	0.10	16.	0.29	44.	0.18	28.	0.52	78.
0.75	1.25	0.05	8.	0.14	21.	0.10	15.	0.28	43.	0.15	23.	0.42	64.	0.27	40.	0.75	113.
0.75	1.50	0.07	10.	0.19	28.	0.13	20.	0.37	56.	0.20	30.	0.56	84.	0.37	55.	0.97	146.
0.75	1.75	0.08	13.	0.23	35.	0.17	25.	0.46	70.	0.26	40.	0.69	105.	0.50	76.	1.10	167.
1.00	1.00	0.05	7.	0.13	20.	0.09	14.	0.26	39.	0.14	21.	0.38	58.	0.24	37.	0.68	103.
1.00	1.25	0.07	10.	0.19	28.	0.13	20.	0.37	56.	0.20	30.	0.56	84.	0.35	53.	0.99	149.
1.00	1.50	0.09	13.	0.25	38.	0.18	27.	0.49	75.	0.26	40.	0.74	111.	0.48	73.	1.28	193.
1.00	1.75	0.11	17.	0.31	47.	0.22	33.	0.61	93.	0.35	53.	0.92	139.	0.66	100.	1.46	221.
1.25	1.00	0.06	9.	0.16	24.	0.11	17.	0.32	48.	0.17	26.	0.47	71.	0.30	45.	0.84	127.
1.25	1.25	0.08	12.	0.23	35.	0.16	25.	0.46	69.	0.25	37.	0.69	104.	0.44	66.	1.22	184.
1.25	1.50	0.11	17.	0.31	46.	0.22	33.	0.61	92.	0.32	49.	0.91	138.	0.60	90.	1.58	239.
1.25	1.75	0.14	21.	0.38	58.	0.27	41.	0.76	114.	0.43	65.	1.13	171.	0.82	124.	1.80	272.
1.50	1.00	0.07	10.	0.19	28.	0.13	20.	0.37	57.	0.20	30.	0.56	84.	0.35	54.	0.99	150.
1.50	1.25	0.10	15.	0.27	41.	0.19	29.	0.54	82.	0.29	44.	0.81	123.	0.51	78.	1.44	218.
1.50	1.50	0.13	20.	0.36	55.	0.26	37.	0.72	109.	0.38	58.	1.07	163.	0.71	107.	1.86	282.
1.50	1.75	0.16	24.	0.45	68.	0.32	48.	0.90	135.	0.51	77.	1.34	202.	0.97	147.	2.13	322.
1.75	1.00	0.08	12.	0.22	33.	0.15	23.	0.43	65.	0.23	35.	0.64	97.	0.41	61.	1.14	172.
1.75	1.25	0.11	17.	0.31	47.	0.22	34.	0.62	94.	0.33	50.	0.93	141.	0.59	89.	1.65	250.
1.75	1.50	0.15	22.	0.42	63.	0.29	45.	0.83	125.	0.44	67.	1.23	187.	0.81	123.	2.14	324.
1.75	1.75	0.18	28.	0.52	78.	0.37	56.	1.03	155.	0.58	88.	1.54	232.	1.12	169.	2.45	370.
2.00	1.00	0.09	13.	0.24	37.	0.17	26.	0.48	73.	0.26	39.	0.72	108.	0.45	67.	1.27	193.
2.00	1.25	0.13	19.	0.35	53.	0.25	38.	0.70	105.	0.37	56.	1.04	158.	0.66	100.	1.85	280.
2.00	1.50	0.17	25.	0.47	71.	0.33	50.	0.93	140.	0.49	75.	1.38	209.	0.91	138.	2.40	363.
2.00	1.75	0.21	31.	0.58	88.	0.41	62.	1.15	174.	0.66	99.	1.72	261.	1.26	190.	2.75	416.
2.25	1.00	0.09	14.	0.27	40.	0.19	28.	0.53	80.	0.28	43.	0.79	119.	0.50	76.	1.40	212.
2.25	1.25	0.14	21.	0.39	58.	0.27	41.	0.77	116.	0.41	62.	1.15	173.	0.73	110.	2.04	308.
2.25	1.50	0.18	28.	0.51	78.	0.36	55.	1.02	154.	0.54	82.	1.52	230.	1.00	152.	2.64	400.
2.25	1.75	0.23	35.	0.64	97.	0.45	69.	1.27	192.	0.72	109.	1.90	288.	1.39	210.	3.03	459.
2.50	1.00	0.10	16.	0.29	44.	0.20	31.	0.57	87.	0.31	46.	0.86	129.	0.59	89.	1.50	227.
2.50	1.25	0.15	23.	0.42	64.	0.30	45.	0.83	126.	0.44	67.	1.25	188.	0.85	128.	2.18	330.
2.50	1.50	0.20	30.	0.56	84.	0.40	60.	1.11	168.	0.59	89.	1.66	250.	1.16	175.	2.83	428.
2.50	1.75	0.25	38.	0.70	105.	0.49	75.	1.38	209.	0.79	119.	2.07	313.	1.58	239.	3.26	493.
2.75	1.00	0.11	17.	0.31	47.	0.22	33.	0.61	93.	0.33	51.	0.92	139.	0.68	102.	1.60	241.
2.75	1.25	0.16	24.	0.45	68.	0.32	48.	0.89	135.	0.49	73.	1.34	203.	0.97	147.	2.31	350.
2.75	1.50	0.21	32.	0.60	91.	0.42	64.	1.19	180.	0.65	98.	1.78	270.	1.32	200.	3.00	453.
2.75	1.75	0.27	40.	0.75	113.	0.53	80.	1.49	225.	0.86	130.	2.23	337.	1.78	270.	3.46	523.
3.00	1.00	0.12	18.	0.33	50.	0.23	35.	0.65	99.	0.42	64.	1.01	152.	0.76	116.	1.68	255.
3.00	1.25	0.17	26.	0.48	72.	0.34	51.	0.95	144.	0.61	92.	1.46	221.	1.10	166.	2.43	368.
3.00	1.50	0.23	34.	0.64	96.	0.45	68.	1.27	192.	0.80	121.	1.94	293.	1.48	224.	3.15	477.
3.00	1.75	0.28	43.	0.80	121.	0.56	85.	1.58	239.	1.05	159.	2.42	366.	1.97	299.	3.65	552.

Table 5.3 Sample data on illuminance in FA and Lux for 44 windows.

Under each of the above titles a set of five Tables follow representing all the 16 window orientations

It was decided that, instead of presenting the results, according to room type and function, merely as a list of windows which satisfy the standard daylight levels recommended in the Codes and Standards, and thus prevent the user from exploring the degree of inadequancy of other windows, the designer ought to be provided with Tables giving daylight levels found by each of the 44 windows, accompanied by a list of IES recommended lighting levels for each type of room (see Table 5.3). Thus the designer can choose a window or a combination of windows to provide an adequate lighting level and choose from the same Table for different types of room.

The sets of tables are attached in Appendix No. 4.

5.11 Future Work

Experimental work has to continue for the following reasons.

1 - To verify the formulae used for the external reflected components and produce suitable corrections to fit Baghdad sky condition.

2 - If these corrections to the external reflected component cause a difference greater than 5% from the results found in this study a correction factor will have to be introduced.

3 - More work has to be carried out, using the same procedures, to cover most of the building shapes found in practice.

4 - Finally to establish a generalized technique in which allows any shape to be represented and thus allows the grouping of recommendations in a limited number of sets, each representing a common building shape.

CHAPTER 6

CHAPTER - 6 -

NATURAL VENTILATION

6.1 The Need For Ventilation

Natural ventilation in general is needed to expel polluted air from a building and replace it with fresh air. In warm conditions, ventilation is required not only for air changes: it is very important for body cooling in facilitating sweat evaporation and for convective cooling when air temperature (Ta) is below skin temperature (Tsk).
It is normal in hot countries for people to provide their rooms with fans to increase air movement inside their house, and, in addition, they sometimes rely on artificial aids to cool the space.
As the aim is to encourage people to rely as far as possible on clean and natural energy, this study aims to provide those who wish to depend mainly on clean and natural energy with some of the information they require. The study however is not as broad as the author initially intended, since it was found impossible to handle all the variables with equal rigour within the confines of a Doctoral dissertation. The work will be continued at the Iraqi Building Research Centre. Therefore the ventilation component of the study should be considered as the first stage of an investigation which forms part of window design optimisation strategy. Since the object has been to

develop a window optimisation method suitable for further development in Iraq it has been necessary to generate as much comprehansive data as possible and, in other areas, to generate sample data only, suitable to test the overall method but capable of being enlarged in the future. It was decided that two complete data sets - on sunlight and daylight - and one sample set - on ventilation - adequately demonstrate the methodology for these variables. In yet other areas no data has been generated, but, since the method is capable of handling up to nine variables, further complete data sets can be added in the future.

6.2 Windows and Ventilation

Although the rate of wind flow increases in proportion to the increase of the size of openings, two rooms with the same opening area can have different ventilation rates. In fact this occurs when the same area is divided into more than one window and situated in different locations, levels or orientations.

Window dimension, proportion and location play not only a major part in the rate of air change, but also in the air flow pattern, which has significant effect on thermal comfort (see Figure 6.1 to Figure 6.8). These Figures are from experimental work carried out by Robert F. White [Ref.159]. They give a clear illustration on how window position and direction affect air flow patterns and distribution and these are useful visualisations which

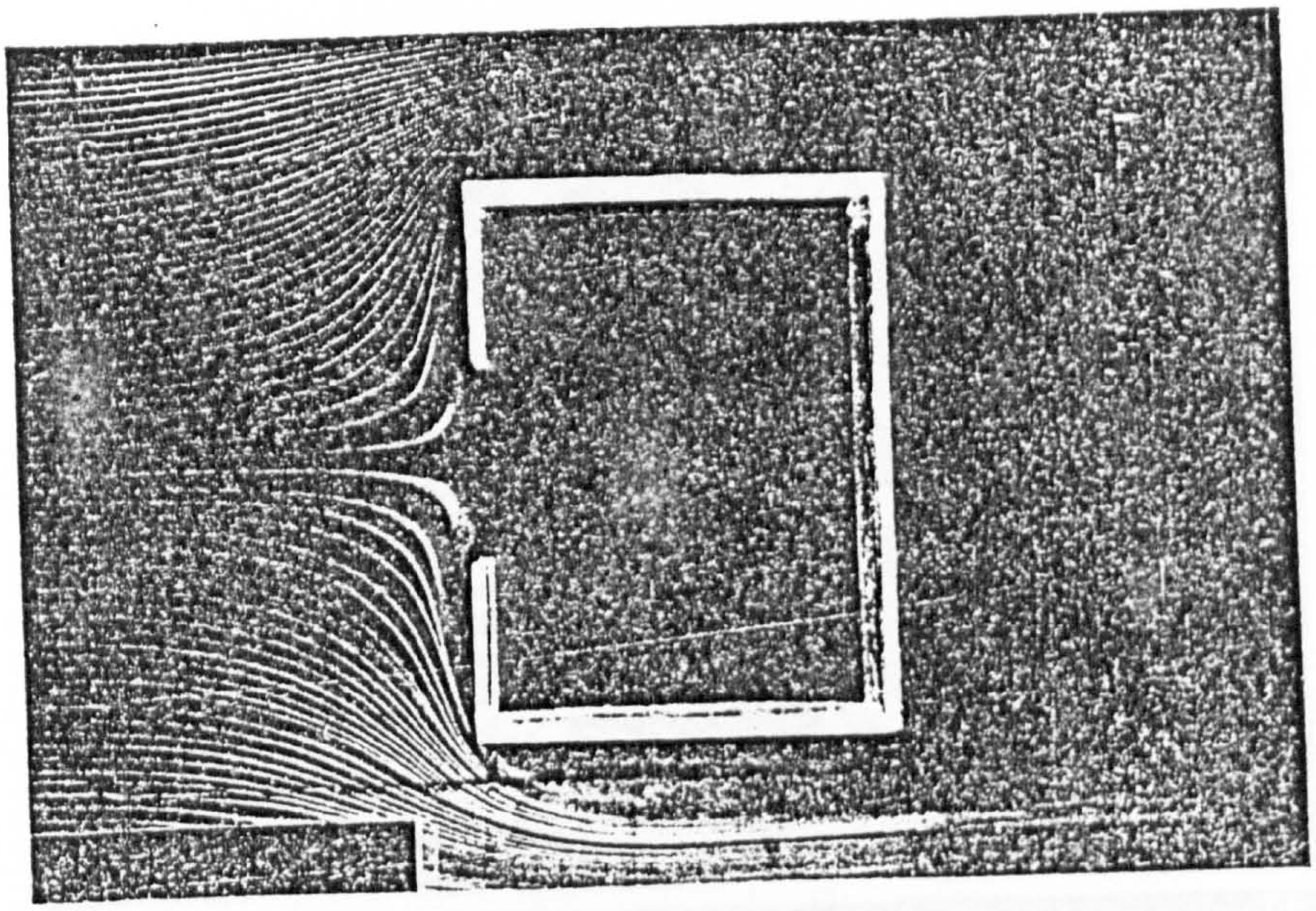


Figure 6.1

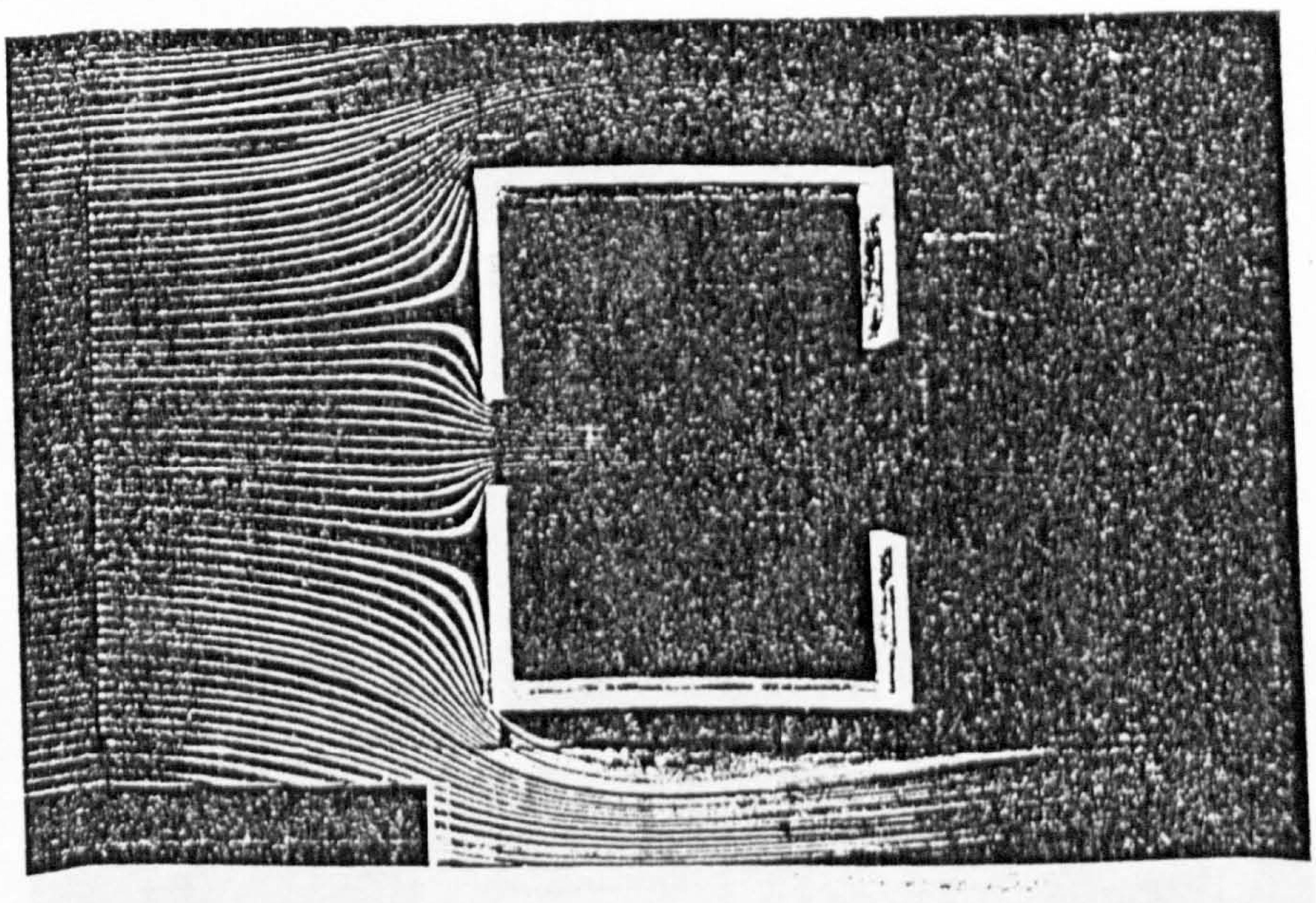


Figure 6.2

Air flow patterns for various windows and combinations.

(After Ref. 159)

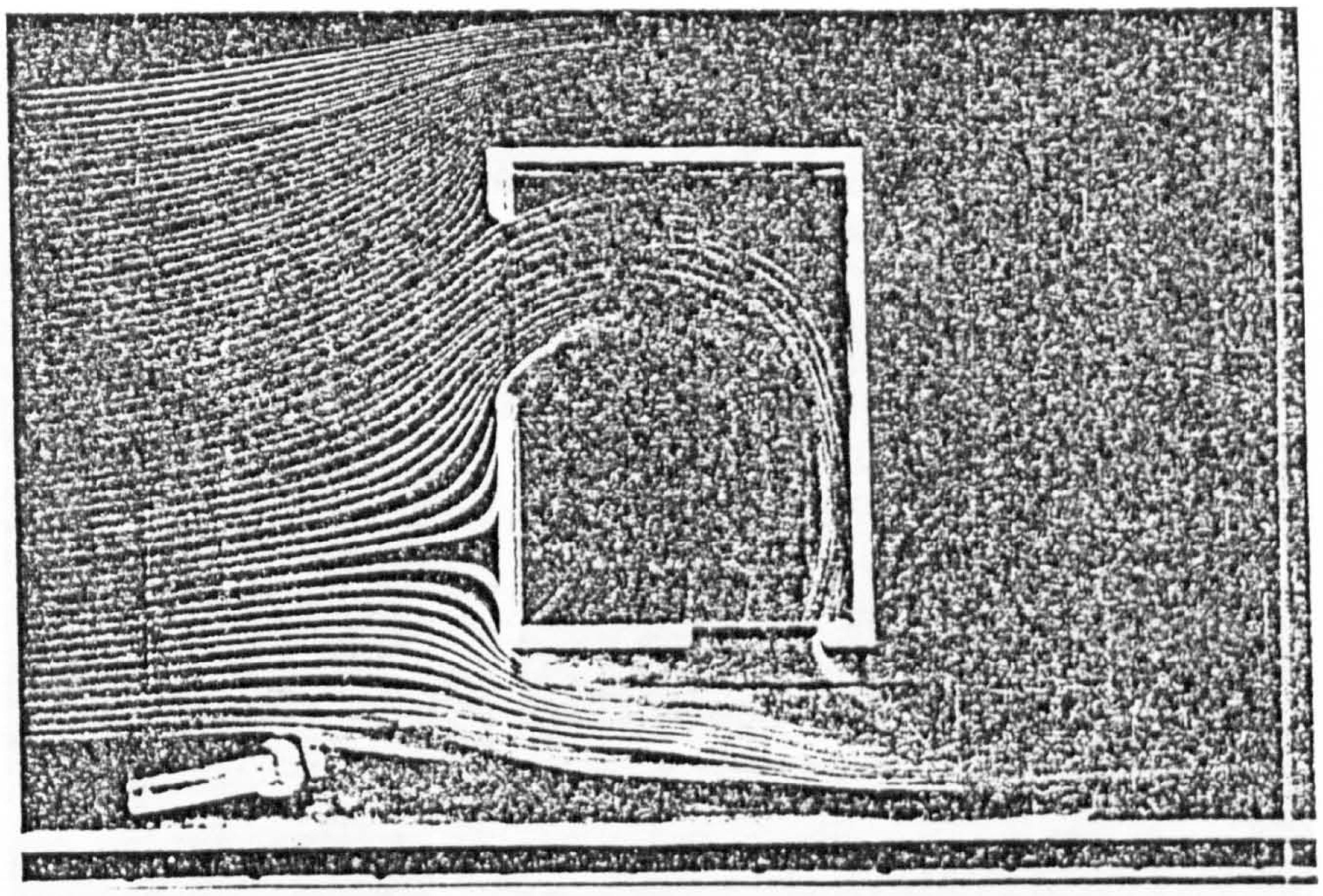


Figure 6.3

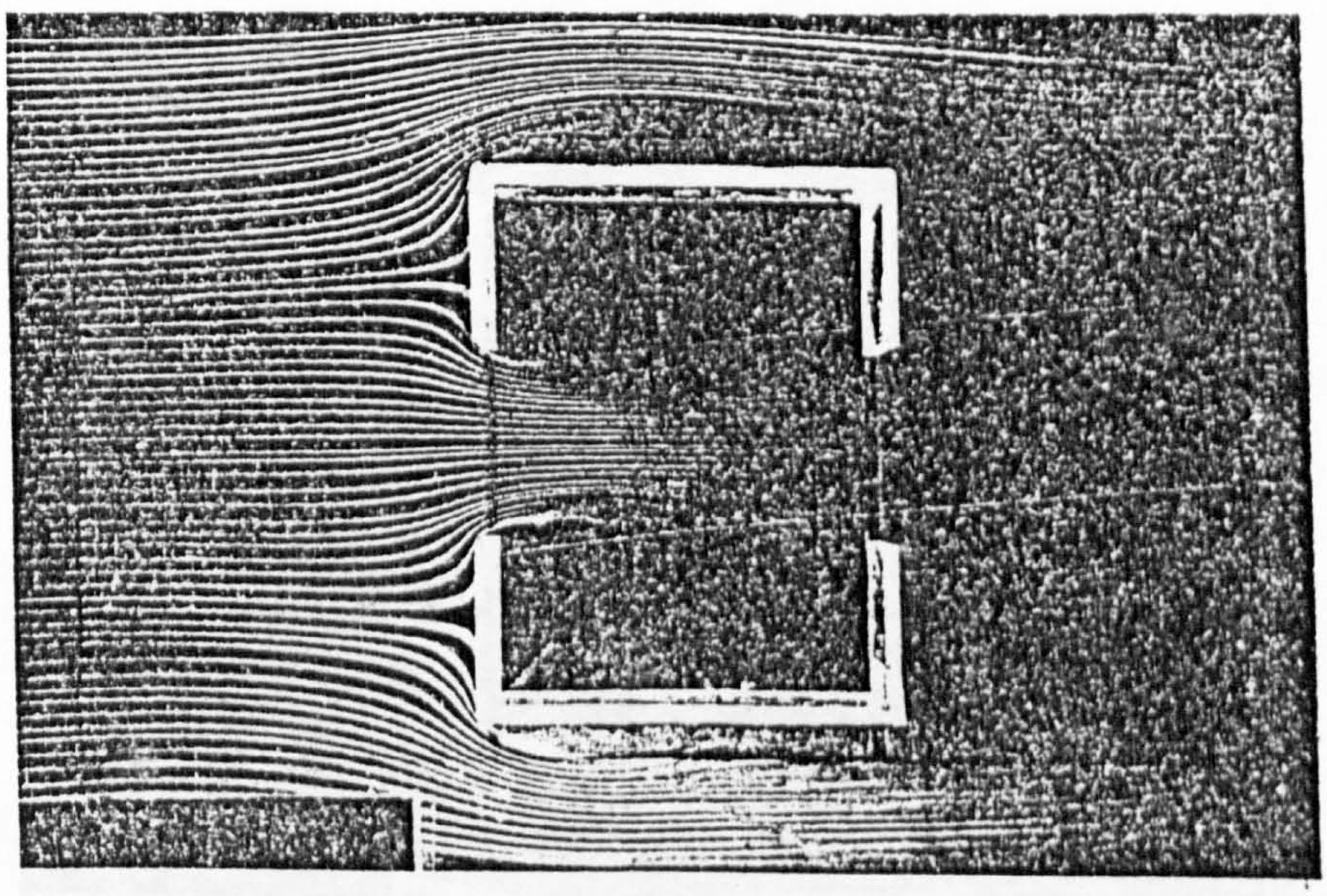


Figure 6.4

Air flow patterns for various windows and combinations.

(After Ref. 159)

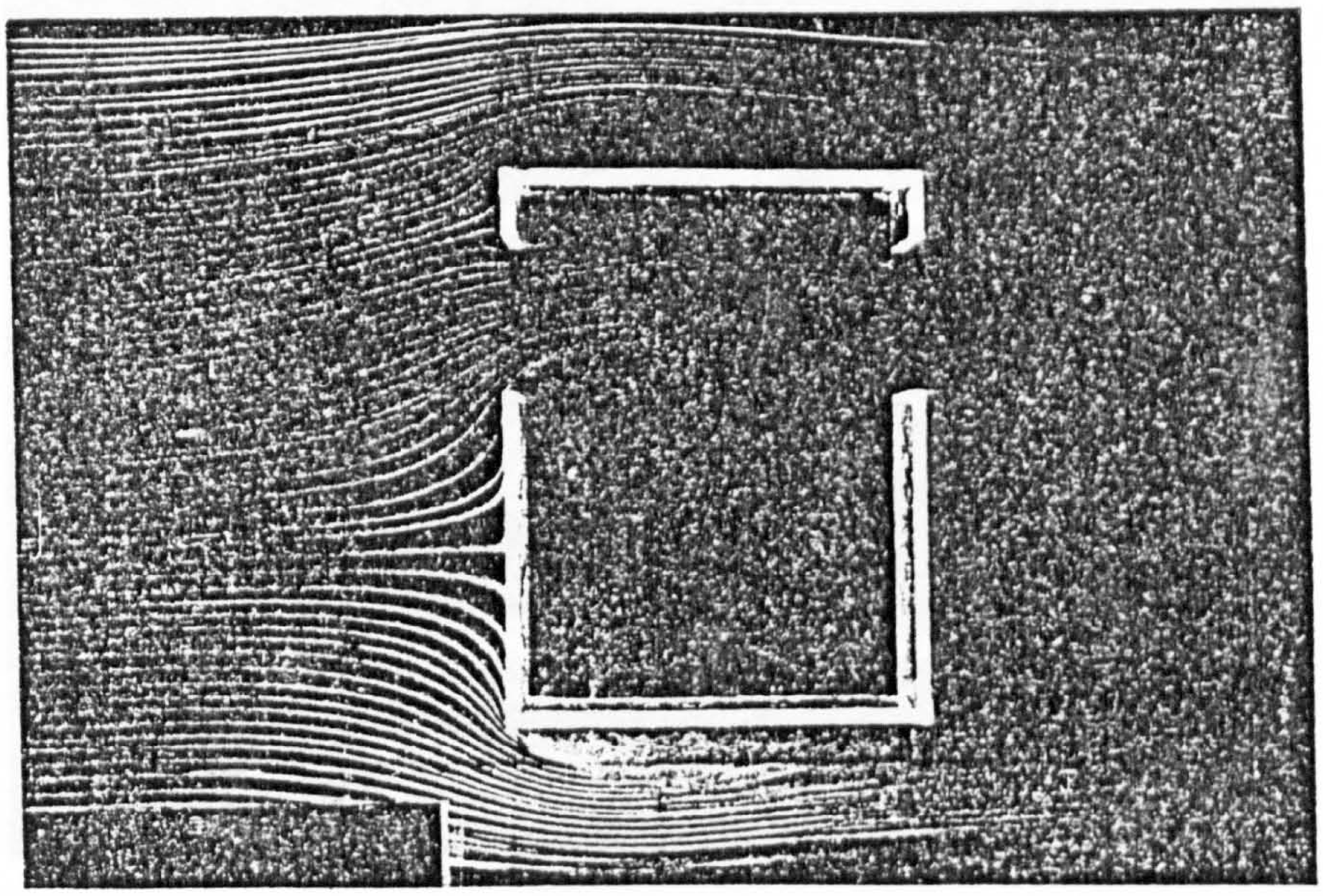


Figure 6.5

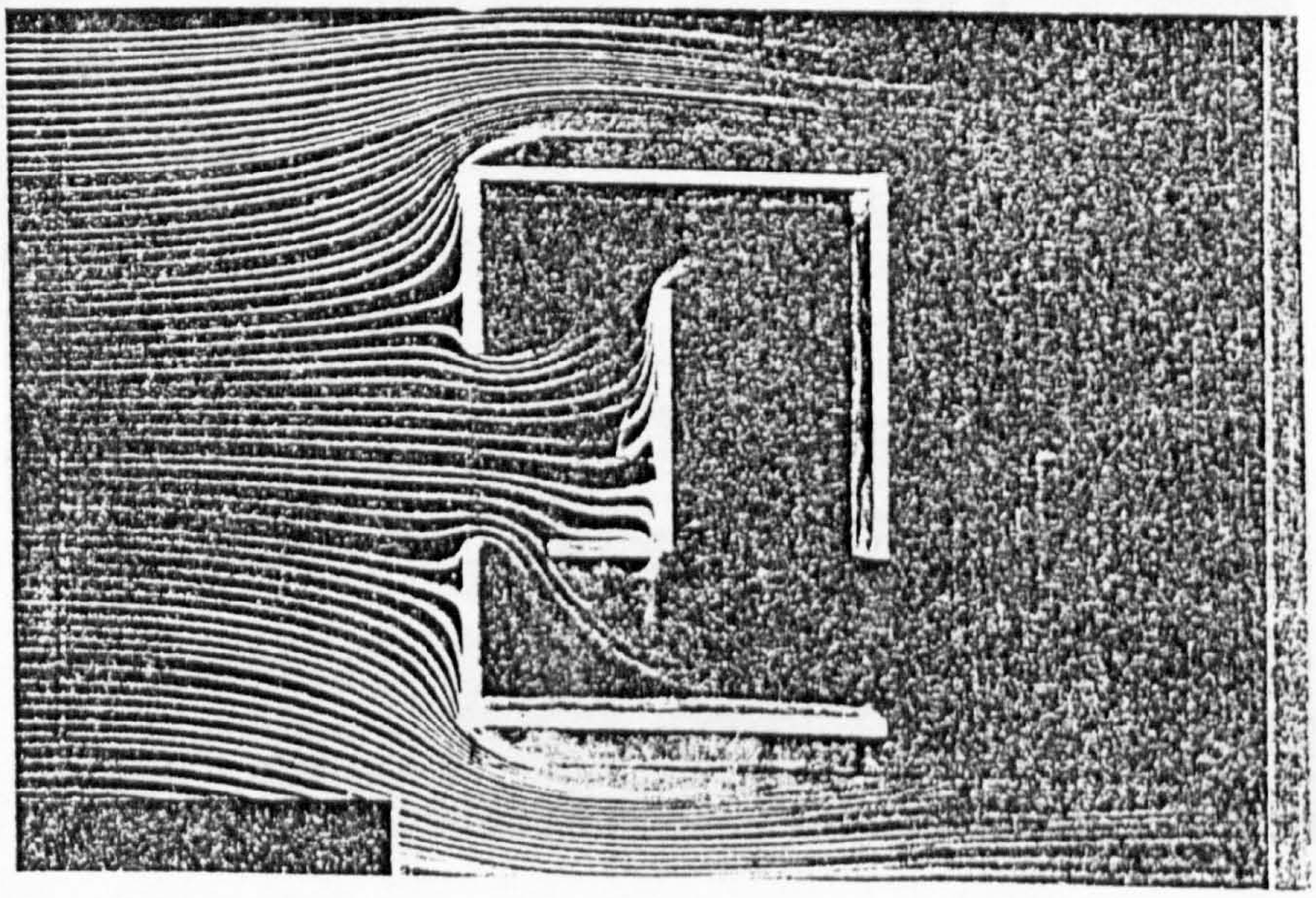


Figure 6.6

Air flow patterns for various windows and combinations.

(After Ref. 159)

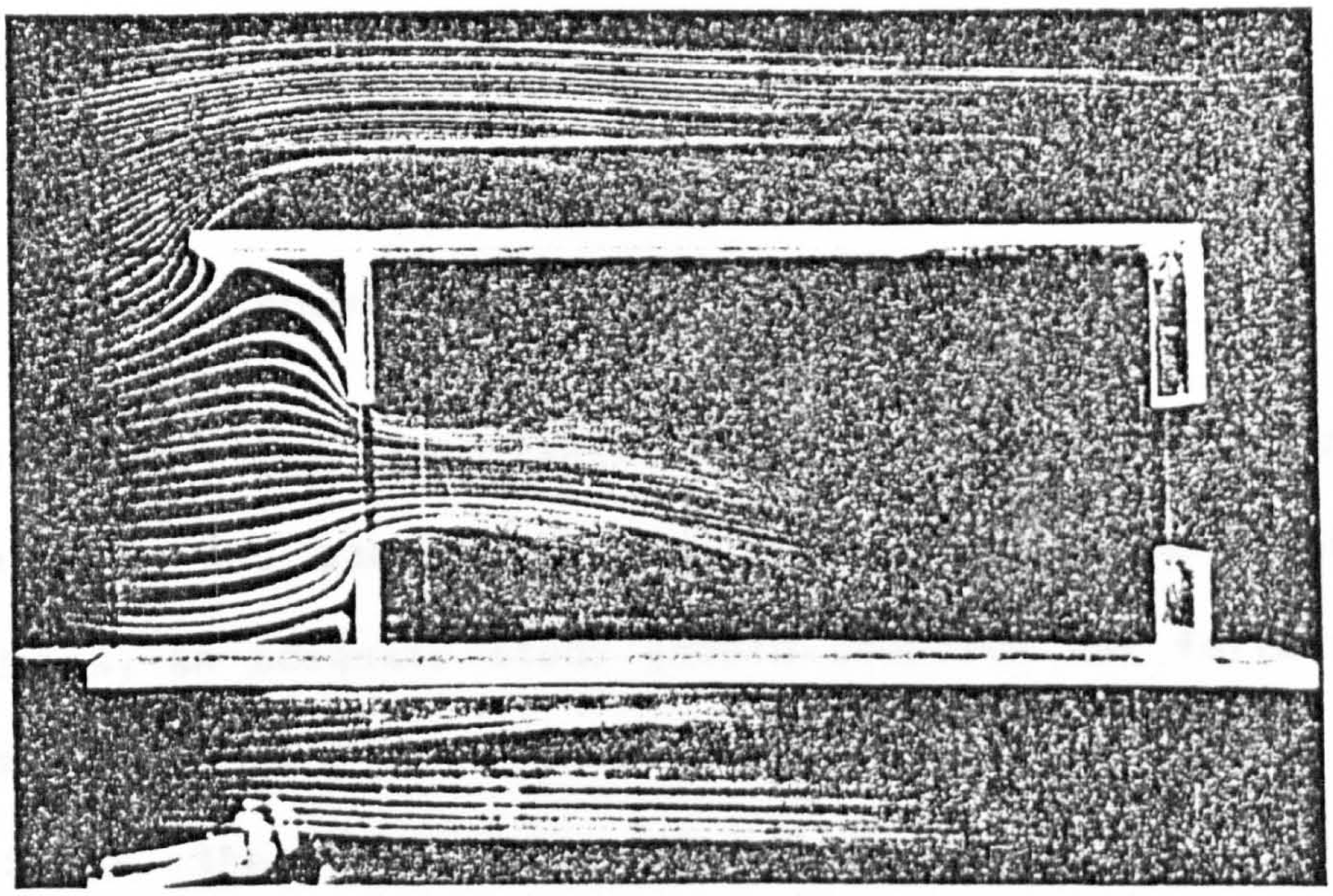


Figure 6.7

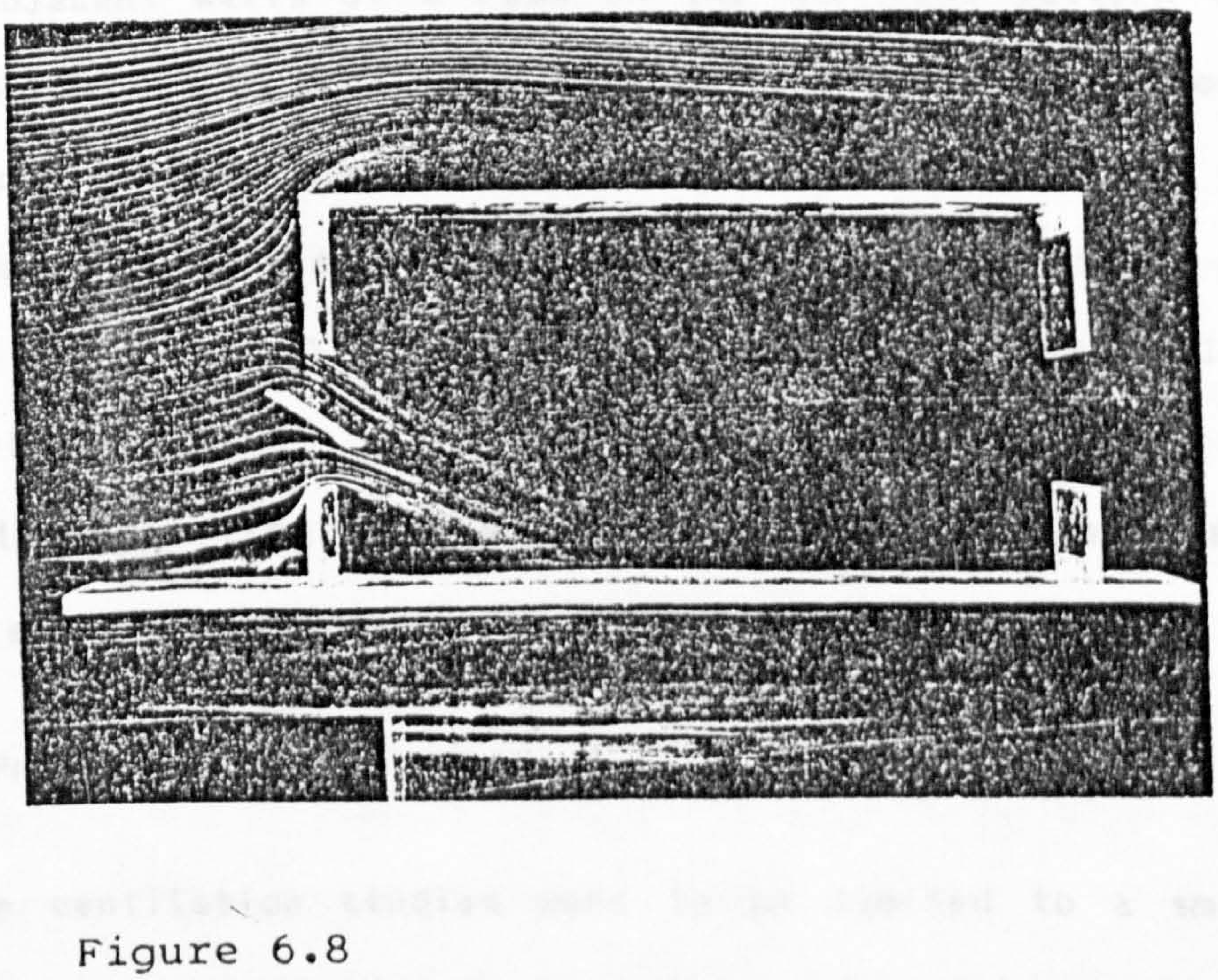


Figure 6.8

Air flow patterns for various windows and combinations.

(After Ref. 159)

represent numerical values arrived at theoretically or experimentally.

6.2.1 The Study of Windows for Natural Ventilation

Allowing for the importance of window position, size, orientation and partitioning of wind distribution inside buildings, an adequate study should comprise the following steps:

A- Study the wind flow direction within low rise residential areas, with houses surrounded by gardens with large trees, in relation to the wind directions recorded by the local meteorological station.

B- Study the effect of different window sizes located on two adjacent walls of a room on the air flow pattern at working level, in order to find sets of window combinations for good air flow distribution.

C- Study the effect of window positioning and divisions on one and two walls on the uniformity of air flow distribution.

D- Study air flow distribution in relation to window and door sizes and positions in rooms with one exposed wall.

6.2.2 The Present Stage

Since ventilation studies were to be limited to a small sample, it was decided to investigate the most useful and reliable methods for predicting air flow patterns, both as a base for future detailed studies in Iraq and as a means of generating the limited data necessary for optimisation on three variables.

6.3 Wind Direction

As has been mentioned earlier in paragraphs 2.2.4 and 2.3.4, the prevailing wind in the south and the middle of Iraq is mainly north-west, while in the north it is either north or west. Thus north-west wind was chosen to represent the prevailing wind for the ventilation study.

6.4 Wind Speed

Referring to the analysis of the climate of Iraq, the lowest mean surface wind speed in Baghdad is 2.5m/s and the highest is 4.5m/s which usually occurs in July. The meteorological records show that the highest wind speed in July occurs between 12.00 and 15.00 at a time when the air temperature is around 43 C and people usually close their windows and rely on mechanical devices for cooling the inner spaces, since opening windows at these temperatures would increase the thermal stress both on the house and on the body. At night the average velocity is about 3m/s. In the periods when wind is feasible for cooling both the structure and the people (spring and autumn) the wind speed is quite low averaging 3m/s (see Table 2.1) .

In the north of Iraq the highest day/night mean surface wind speed is 2.8m/s (in June) the lowest is 1.6m/s (in

November and December), and the average in spring and autumn is 2.1m/s (see Table 2.10).

In the south of Iraq the highest day/night surface wind speed is 4.1m/s in June and the lowest is 2.5m/s in October, November and December. The average surface wind speed in spring and autumn is 3m/s (see Table 2.11).

The mean of the average day/night surface wind speed in spring and autumn for the three regions in Iraq is 2.7m/s and this was chosen as a design value.

6.5 Available Methods

The complexity of predicting wind direction and speed around and inside the building, as well as the changes in inside/outside pressure differences, which is always affected by a range of external and internal factors, make it necessary to investigate alternative methods to understand their problems and capabilities.

The methods available are:

A- Wind tunnel experimental methods.

B- Computer simulation methods based on theoretical aerodynamic models.

6.5.1 Wind Tunnel Experimental Methods

These methods have been widely used in architectural aerodynamics to find the behaviour of the wind around and inside buildings on the assumption that air temperature inside and outside is uniform. All the wind tunnel research in architectural aerodynamics has been carried out in low speed wind tunnels, and in this type of tunnel one cannot achieve a realistic Reynolds number due to the limitation on wind speed. Moreover many low speed wind tunnels have not been designed to simulate wind velocity profiles, nor temperature gradients; this makes it impossible to simulate the effect of temperature differences caused by surrounding gardens, heated external walls and internal space temperature gradients. Thus even with the best low speed wind tunnels there is substantial error.

6.5.1.1 The Model Law (Reynolds Law)

Reynolds Law is that used when the natural fluid flow studied in connection with actual bodies has to be studied with models of reduced scale in wind tunnel. Provided the velocity is lower than the velocity of sound, the Reynolds number can be relied upon for model studies.

The Reynolds number is:

$$Re = (Vu * d) / v$$

Where Vu is the undisturbed velocity, d is a reference length v is the kinematic viscosity.

According to the above equation, if a building is to be studied in a wind tunnel, and represented by a 1/50 scale model, the wind velocity has to be 50 times the natural velocity if the viscosity is to remain the same, (i.e. a natural wind of 4m/s has to be substituted by a wind of 200m/s in the wind tunnel to achieve the same Reynolds number).

The Reynolds number was introduced as the principle of similarity in representing the full scale body by a model scale in the presence of boundary layer which is caused by the viscosity of the fluid and the shearing stress between the body and the fluid in the case when the fluid is in the form of laminar flow.

The fluid flow round cylinders and spheres may change its character completely if the Reynolds number is altered due to the fact that the point of separation may move some distance over the curved surface and the place of separation will depend on the condition of the boundary layer on the body. Therefore a model law has to be applied to achieve similarity in results.

Nevertheless in the case of buildings, with walls forming bluff bodies with sharp edges, even if the air blows in a state of laminar flow, the flow will change to turbulent flow because of the type of separation taking place due to the presence of the sharp edges (see Figures 6.9, 6.10 and 6.11).

In this case when separation occurs and vorteces form re-attachement is unpredictable and therefore the Reynolds number (scale factor) will lose its importance. Moreover, the wind flow around a building is naturally turbulent, so that in dealing with architectural surfaces in wind tunnel testing the Reynolds number can be ignored as its effect will be small on the overall result.

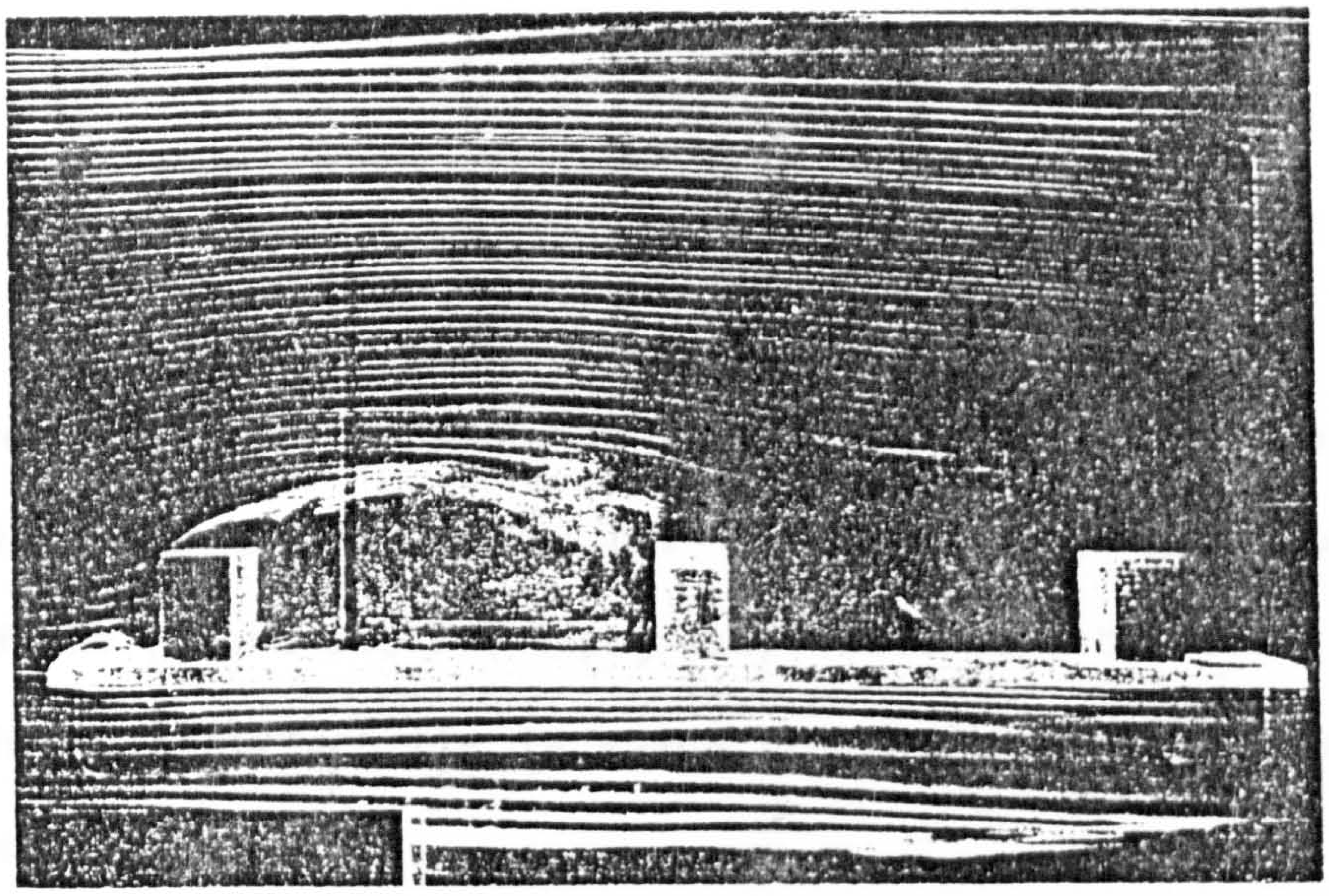


Figure 6.9

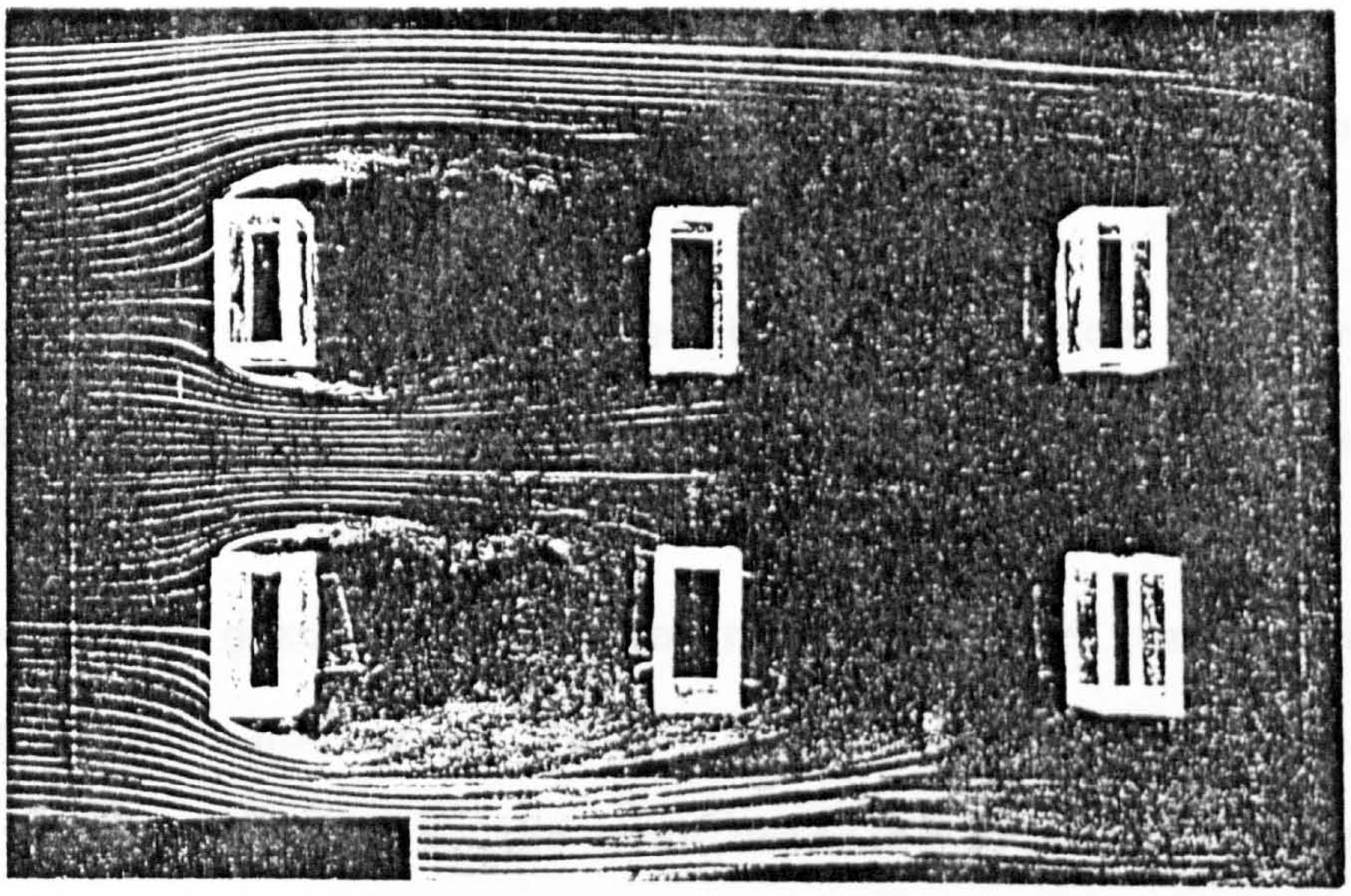


Figure 6.10 (After Ref.159)

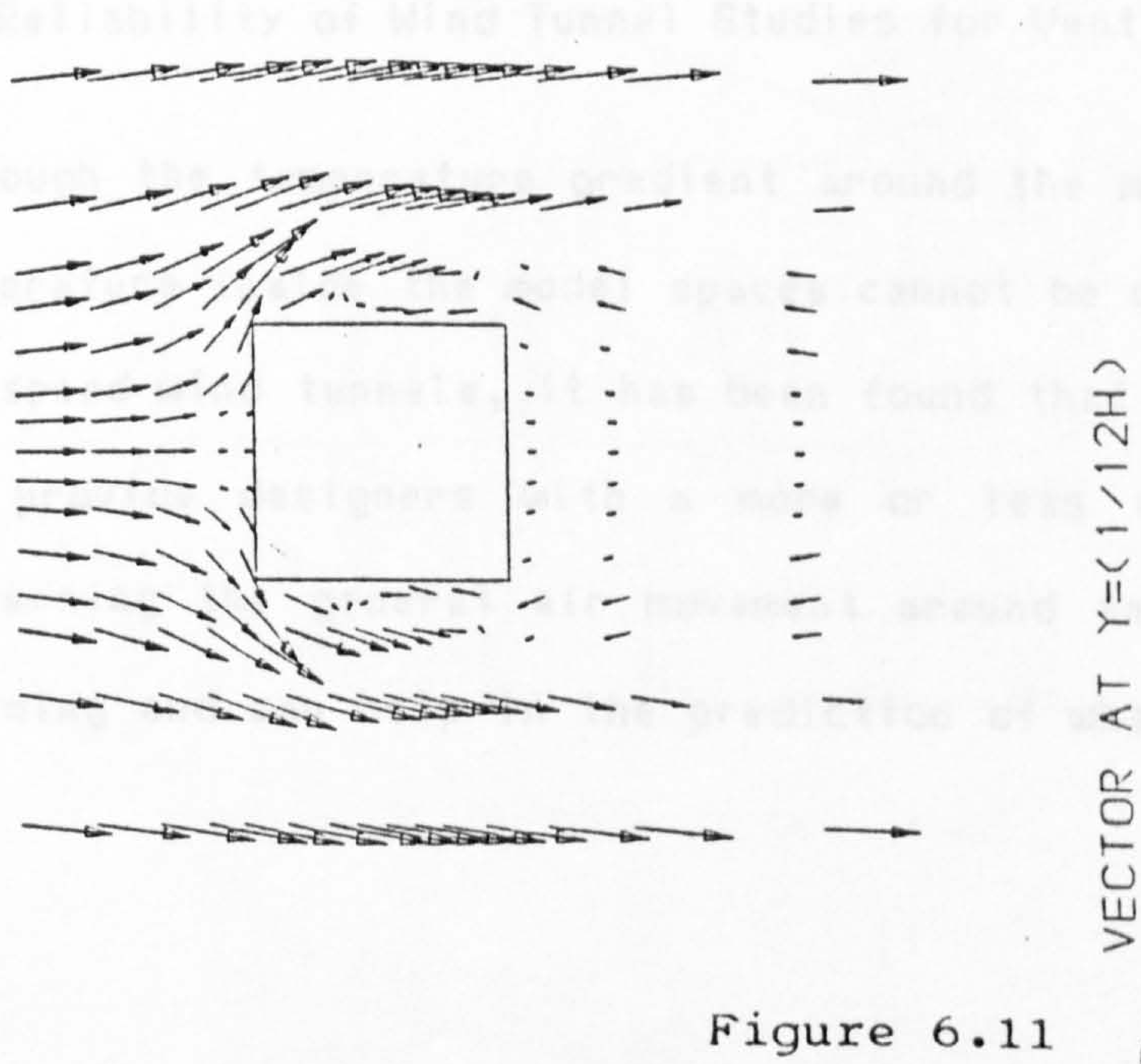


Figure 6.11 (A.Mustafa)

Wind flow around bluff bodies

6.5.1.2 Wind Velocity Profiles

The difference between air speed in the free atmosphere and flow near the ground is due to the friction and roughness of the ground and its topography (natural and artificial). The velocity profile is a function of height and roughness (see Figure 6.12).

Simulation of the velocity profile in a wind tunnel is necessary when the wind velocity is greater than 10m/s, which is the case for load impact studies on building structures.

For the use of natural ventilation for cooling purposes, wind velocity is less than 10m/s, accordingly the velocity gradient is weak and may be ignored (Ref.42). The velocity gradient is also necessary for tall buildings while for houses up to a height 7.5m, with which this study is concerned, the wind velocity profile simulation in the wind tunnel can usually be ignored.

6.5.1.3 The Reliability of Wind Tunnel Studies for Ventilation

Although the temperature gradient around the model and the temperature inside the model spaces cannot be controlled in low speed wind tunnels, it has been found that wind tunnels can provide designers with a more or less a clear idea concerning the general air movement around and inside the building and can help in the prediction of what one can be

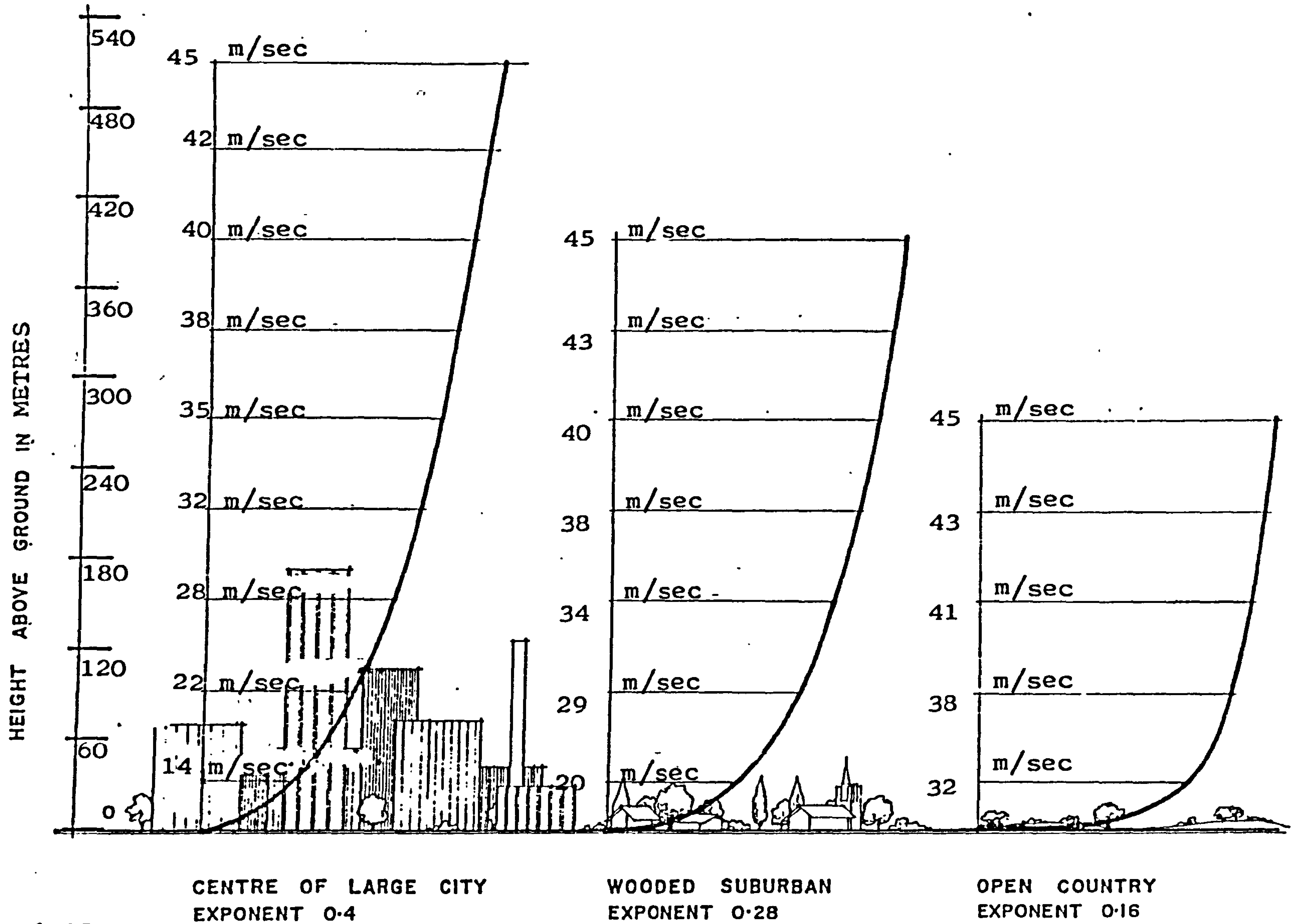


Figure 6.12

VELOCITY PROFILE VARIATION DUE TO TERRAIN ROUGHNESS (AFTER A.G. DAVENPORT 1960) done to increase air velocity or to improve distribution inside rooms for better ventilation.

Accurate prediction on how the natural wind behaves inside the building cannot be achieved, even if the wind tunnel is capable of simulating the thermal gradient, the internal space temperature and the velocity gradient. This is realized when one examines wind behaviour in reality and the changes in wind direction and velocity which occur all the time (see Table 2.1A and Table 2.1B). Therefore wind tunnel studies are limited to giving general predictions of the effects of shape, height, layout and window opening patterns on internal velocity <u>patterns</u> rather than accurate velocity data.

6.5.2 Computer Simulation Methods

From the modest knowledge the author had on types of computer programs dealing with wind behaviour in relation to buildings, it was believed that they all dealt with wind flow <u>around</u> buildings.

As mentioned before the ventilation part of the study has been mainly carried out to prepare a sample set of data on wind flow behaviour from the same 44 types of windows used for the direct sunlight control and the daylight studies. Accordingly, with this sample data, it is not possible to make comprehensive recommendations on dimensions, sizes and locations of windows for better wind flow for body cooling purposes. It was therefore decided to spend no further time searching for and evaluating computer simulations, especially after it was found that the thermal simulation available in the Department of Architecture and Building Scîence, (ESP) [Ref.40], was not designed to handle data for recommending window shapes, sizes and positions for improved ventilation. At this stage the author decided to use an experimental model test in the wind tunnel, for 44 different types of windows on the model house. The experiment was performed for one of the ground floor rooms of the house, which was surrounded by five houses, and the measurements were made by using hot wire probe techniques. Details are reported in section 6.6.2.

The author is intending to undertake further ventilation studies in Baghdad and he has contacted companies manufacturing aerodynamic measuring equipment in order to discover more about the capability of their apparatus so that he can make well-founded recommendations to the Iraqi Building Research Centre, since it become clear that, to fulfil the demands of this experiment, very expensive wind tunnel and measuring equipment is required.

During the search for a suitable tool for future research work the author discovered a powerful computer program developed by Professor Spalding called PHOENICS, [Ref.177], which is available in the Department of Thermodynamics and Mechanics of Fluids in the University of Strathclyde, Glasgow. Though at this point in the author's research this peogram it could not yet be run in that Department since many problems remained to be resolved, it was found to possess real potential in solving probems of internal air movement that it has been considered worthwhile to describe it here, so that its use might form part of a future research programme. Whilst finding out more about this program the author was invited by the holding Department to work on the package and although he was impressed with its capabilities, as indicated by the manual, he found that considerable development remained to be carried out. When it is, the program will have a promising future and indeed might be the tool for the work on which he has embarked experimentally.

6.5.2.1 PHOENICS Capabilities

The package can perform the following:

A-It can represent processes involving the flow of single or two phase fluids, whether steady or unsteady, in one, two or three dimensional space.

B-PHOENICS does this by solving equations governing the distribution through space and time of pressure, and of three velocity components x,y,z for each phase.

C-It also computes the temperature distributions of the two fluids, and of an optional third fluid by way of their enthalpies .

D-It can represent the composition of the fluid mixture at any location by way of two volume fractions (for the two distinct phases) and of four concentrations, and it solves equations for all these variables, when required to do so.

E-It can represent the turbulence characteristics of one of the fluids by way of its local turbulence-energy dissipation, for both of which it solves the relevant balance equations.

F-It can also be called upon to solve additional equations of the same general type, for example those for electric potential in a conducting medium, or for particle size.

It is for the user to determine which variables he wishes to solve and each equation contains the terms below, which can be used or rejected by typing in the SOLVAR array the word 'TRUE' or 'FALSE' respectively.

The terms are:

a- Time dependence

b- Mass transport (convection)

c- Laminar or turbulent diffusion, conduction or viscous action (as appropiate)

d-Sources and sinks.

e- Density and its dependence on pressure and temperature

f- Specific heat capacity.

g- Diffusion coefficients

h- Viscosity

i- Chemical Kinetic data

j- Absorption and scattering coefficients for radiation.

PHOENICS can deal with fluids which interact with the solid walls which enclose them and with the obstacles placed within the flow domain, and it does so if the friction factors and heat transfer coefficients are supplied.

The package can handle any type of buiding geometry and one can construct walls, windows, insect screens, overhangs, louvres or sun-breakers, by choosing the proper porosity, which varies between one for solid walls and zero for openings.

The real flow processes are three dimensional and unsteady, so in PHOENICS one can state the direction of wind and determine if it is steady or unsteady.

For heat transfer purposes PHOENICS can handle two phases if present simultaneously, such as hot air and cold air, steam bubbles rising through water or carbon particles burning in air.

Moreover, the manual states a number of other capabilities PHOENICS can handle which are not in the area of this study. Therefore if the claims of the manual are borne out in practice, PHOENICS is the ideal tool to carry out future work on window dimensions for ventilation and wind distribution.

6.5.2.2 The Output

As stated in the manual, PHOENICS has a built in output capability, which allows printing, with a frequency (in terms of 'sweeps as well as of 'time steps') and in which the user can select from:

A- Values of all variables at selected 'monitoring' locations in the grid

B- Values of all grid point values of whichever variables the user determines.

C- Values of residuals (ie. remaining errors) in the finite domain equations for any variable.

D- Line printer plot of contours representing the distributions of fluid variables, or residuals.

E- Although these output facilities are sufficient for many purposes, users may have special needs which are not included. So PHOENICS allows users to provide their own subroutines and attach them in a manner described in the manual.

F- Furthermore,because the graphical representation of three dimensional flows makes them easier to understand, provisions have been made to connect the GRAFFIC program with PHOENICS. This facility permits the PHOENICS output to be represented by way of a perspective view of stream lines, vector plots and contour diagrams.

6.5.2.3 Pictures and Illustrations Using PHOENICS

The PHOENICS manual presents many graphic demonstrations covering most of the capabilities of the package. In this paragraph the author is going to demonstrate the one related to buildings.

1- As the study of wind flow inside buildings is a combination of the wind flow around buildings, the temperature gradient outside the building, the wall temperature and the heat created inside the building they can all be represented by smoke movement and temperature-time history as seen in fire spread (see Figure 6.13) and smoke movement velocity as represented by vectors and streamlines (see Figures 6.13, 6.14 and 6.15).

2- For the study of wind flow around buildings the manual does not give an illustration, but it gives an illustration of the wind flow around a car and a van and demonstrates this with graphic illustrations in vector form or contour lines. In order to add to this chapter some illustrations related directly to buildings, Dr. Simon Fraser and his Ph.D. student Mr. Ahmad Mustafa Kindly agreed to provide the author with some of the available results.

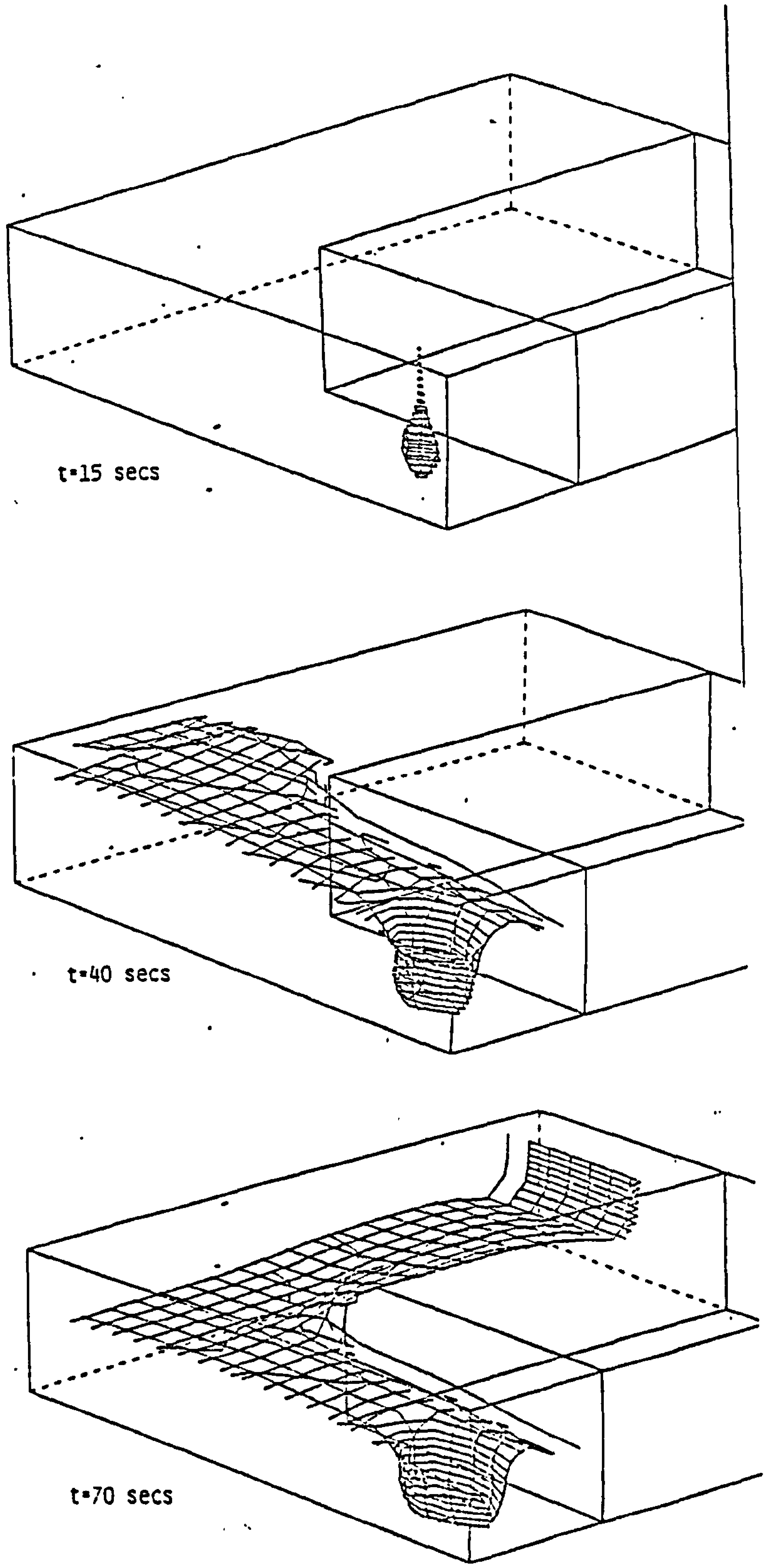
They are:.

Figure 6.16 and Figure 6.17 showing the wind pattern and vortex which occured between two buildings in stream line and vector form (vertical section).

Figure 6.18 and Figure 6.19 showing the wind pattern on a single building in stream line and vectors (vertical section).

Figure 6.10 showing the wind pattern around the building and the effect of sharp edges on the creation of vorteces when the wind is perpendicular to the bluff and sharp edge walls.

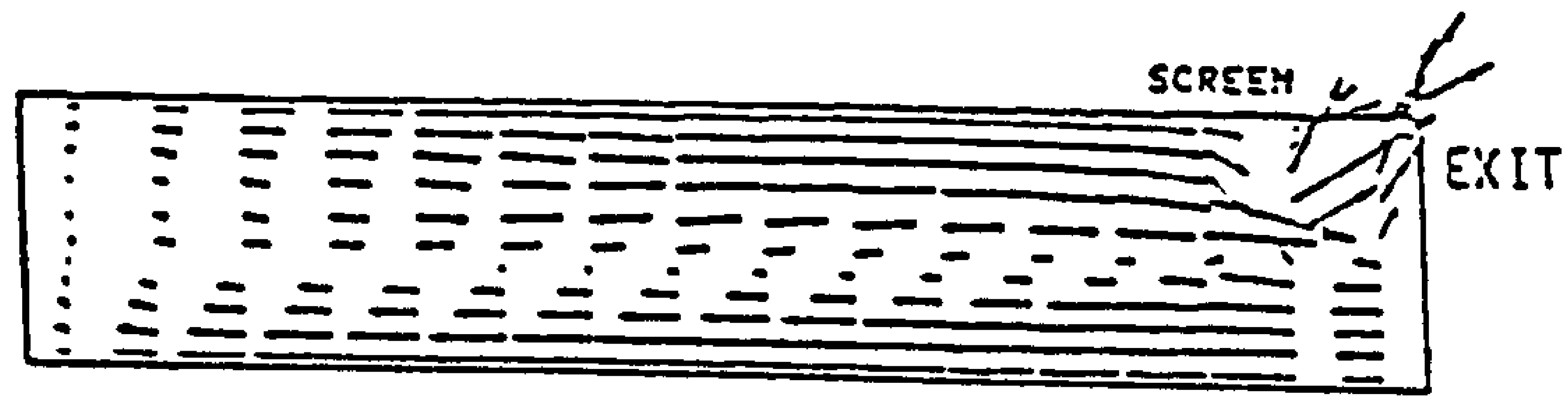
Figure 6.20 showing the wind pattern around a sharp edge building where the wind is at 45 to the wall. This Figure supports the author's assumption as stated in Chapter 3 on the decision to orientate the houses in the housing estate



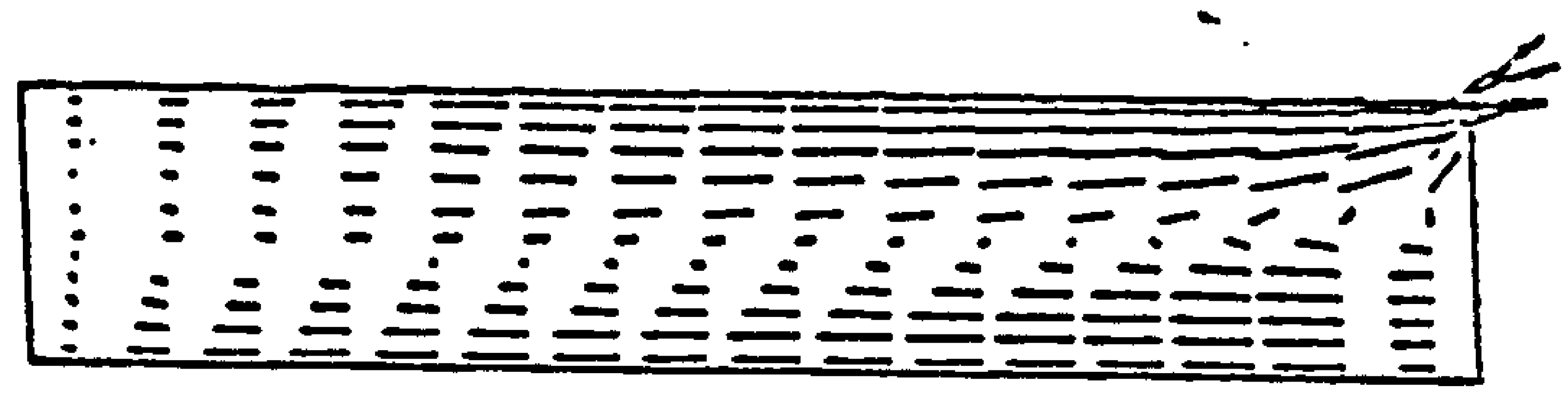
SMOKE MOVEMENT: TEMPERATURE TIME HISTORY,
$T=390^0K$

Figure 6.13

(After Ref. 177

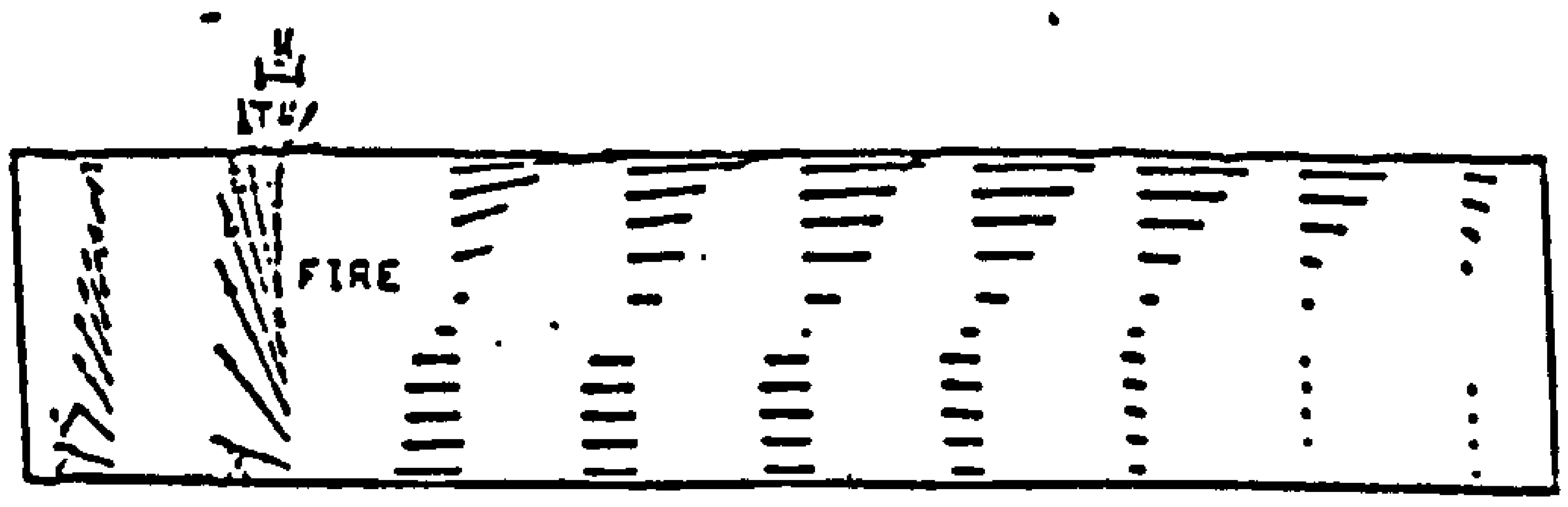


(a) With screen: Maximum velocity is 3.96m/s



(b) Without Screen: Maximum velocity is 4.40m/s

SIDE VIEW OF VELOCITY VECTORS (x=0.8, normalised)



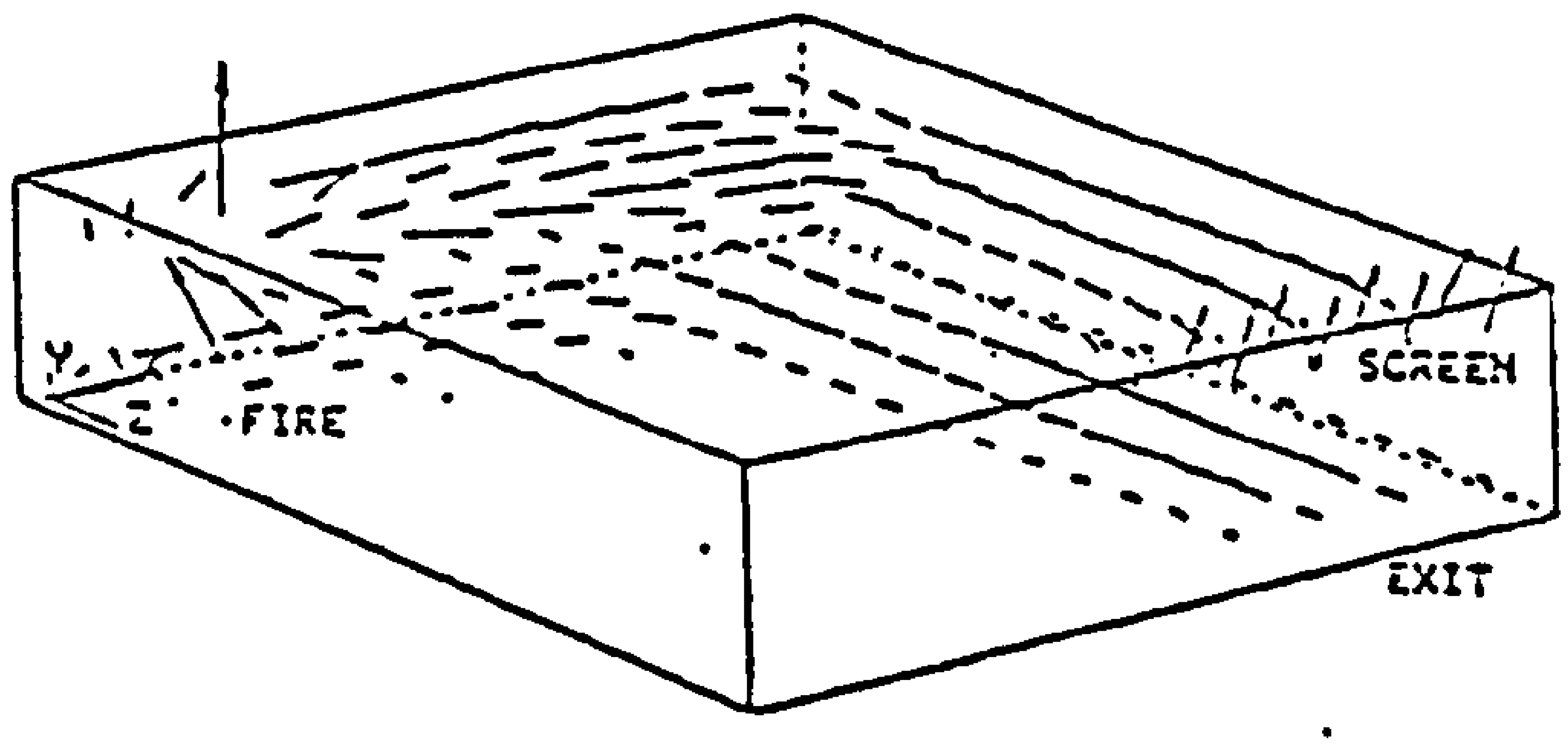
Maximum velocity is 5.6m/s

FRONT VIEW OF VELOCITY VECTORS (z=0.1, normalised)
NO SCREEN

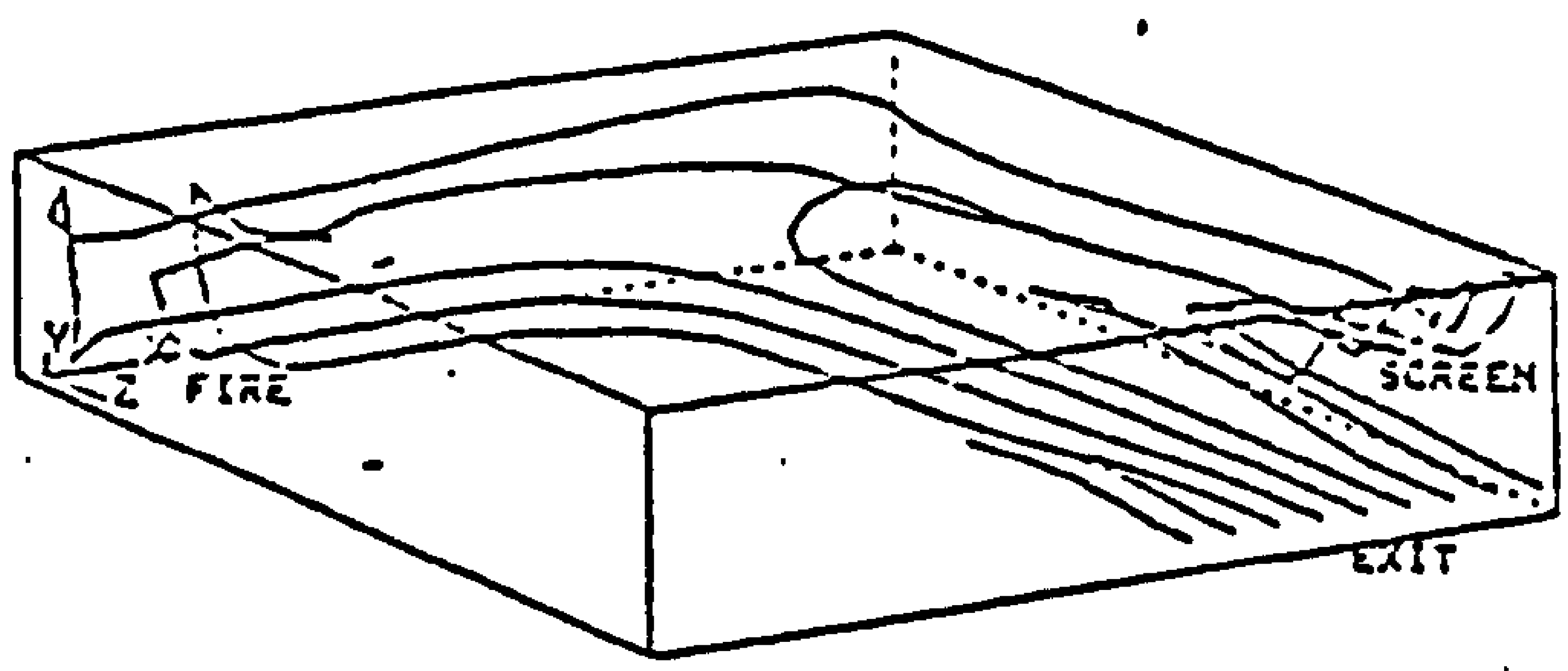
		SMOKE MOVEMENT, VELOCITY VECTORS: STEADY-STATE

Figure 6.14

(After Ref. 177)



(a) Velocity vectors at two x-z planes (y=0.15 and 0.8, normalised)



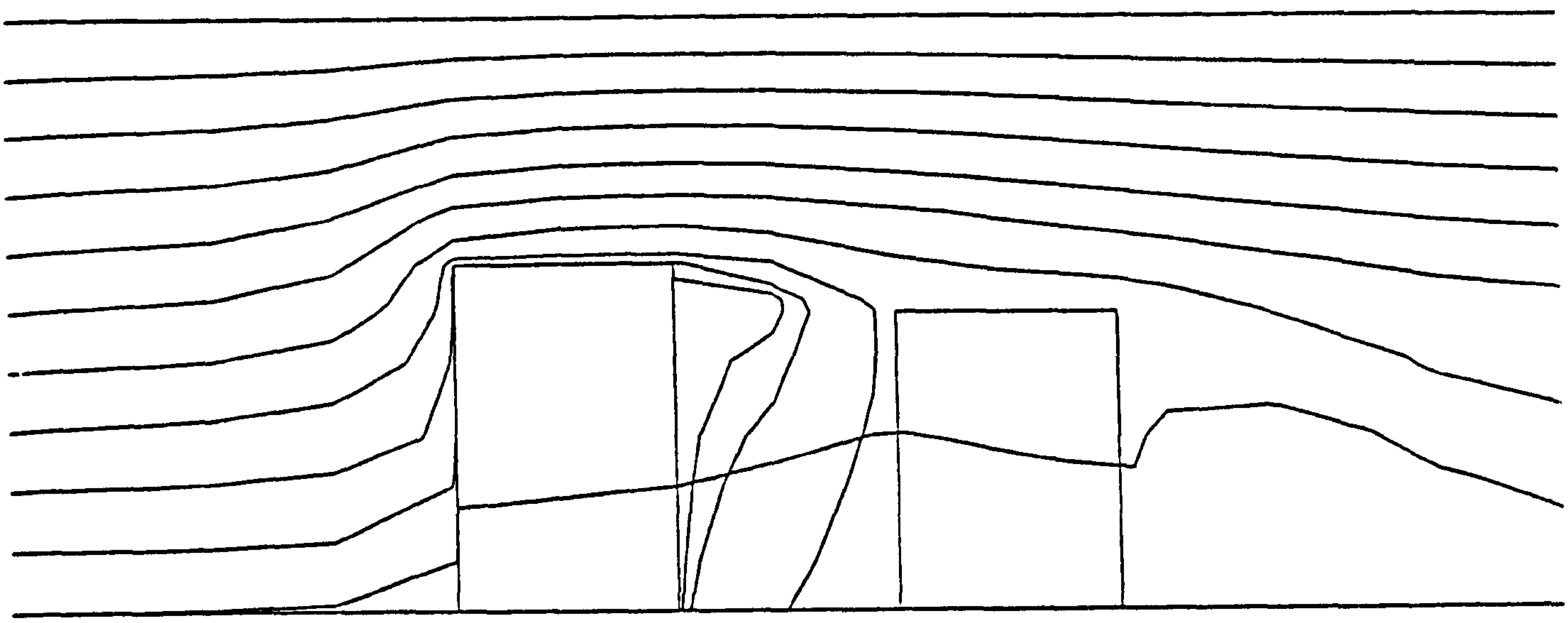
(b) Streamlines starting at (0.5, 0.1, 0.99) and finishing at (0.99, 0.1, 0.99)

VELOCITY VECTORS AND STREAMLINES FOR THE CASE WITH THE SCREEN IN PLACE

		SMOKE MOVEMENT, VELOCITY VECTORS AND STREAMLINES: STEADY-STATE

Figure 6.15

(After Ref. 177)



(A.Mustafa)

STREAM LINE AT X=.5

Figure 6.16

GRAFFIC: CHAM COPYRIGHT 1981

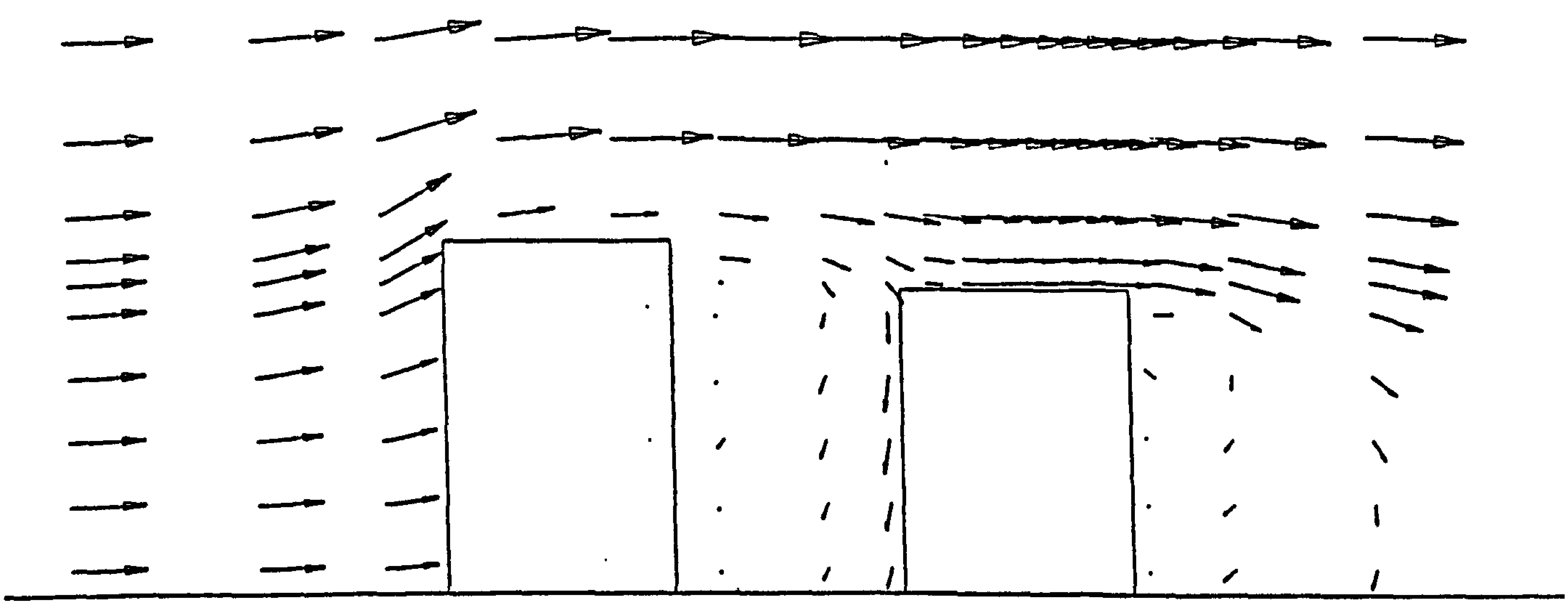
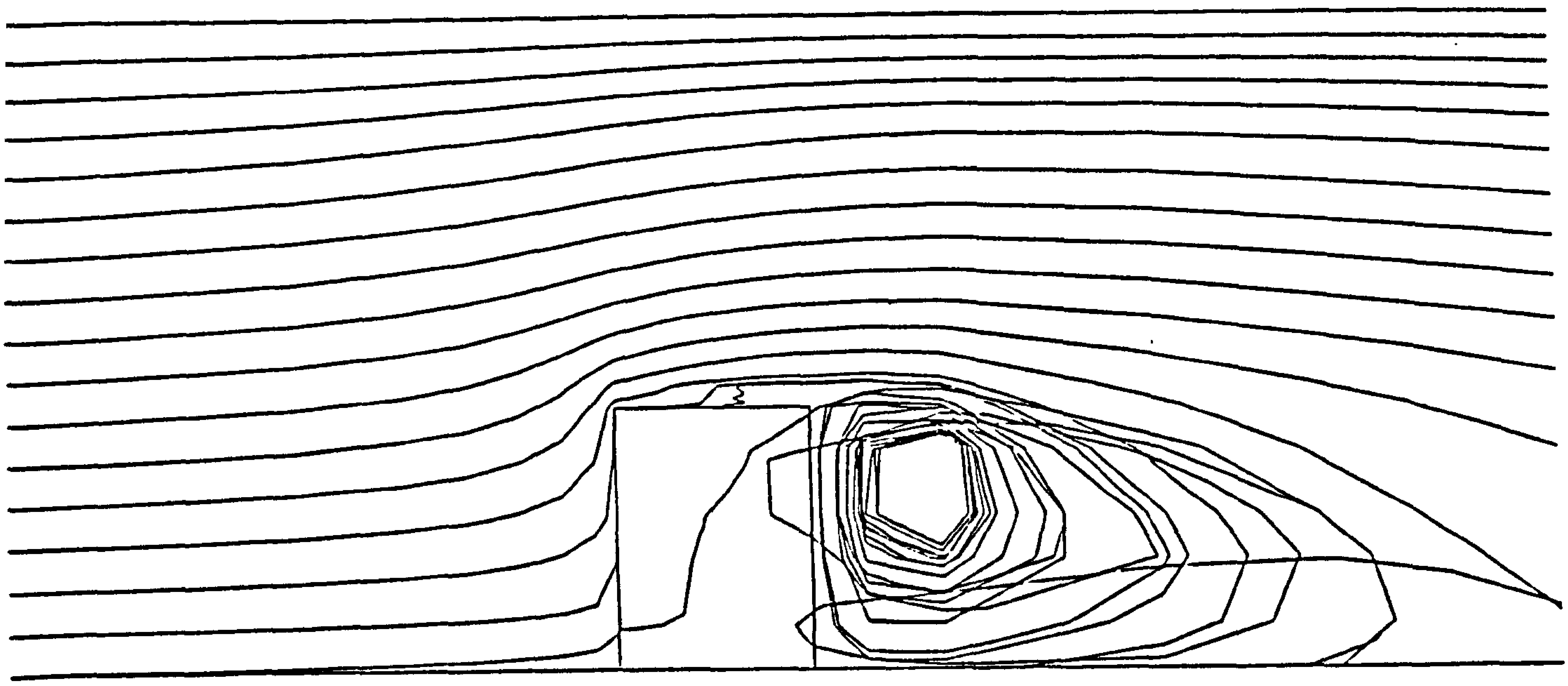


Figure 6.17

(A. Mustafa)

VECTOR VELO.AT X=.5

Wind patterns and various building configurations.



(A. Mustafa)

STREAM LINES AT X=.5

Figure 6.18

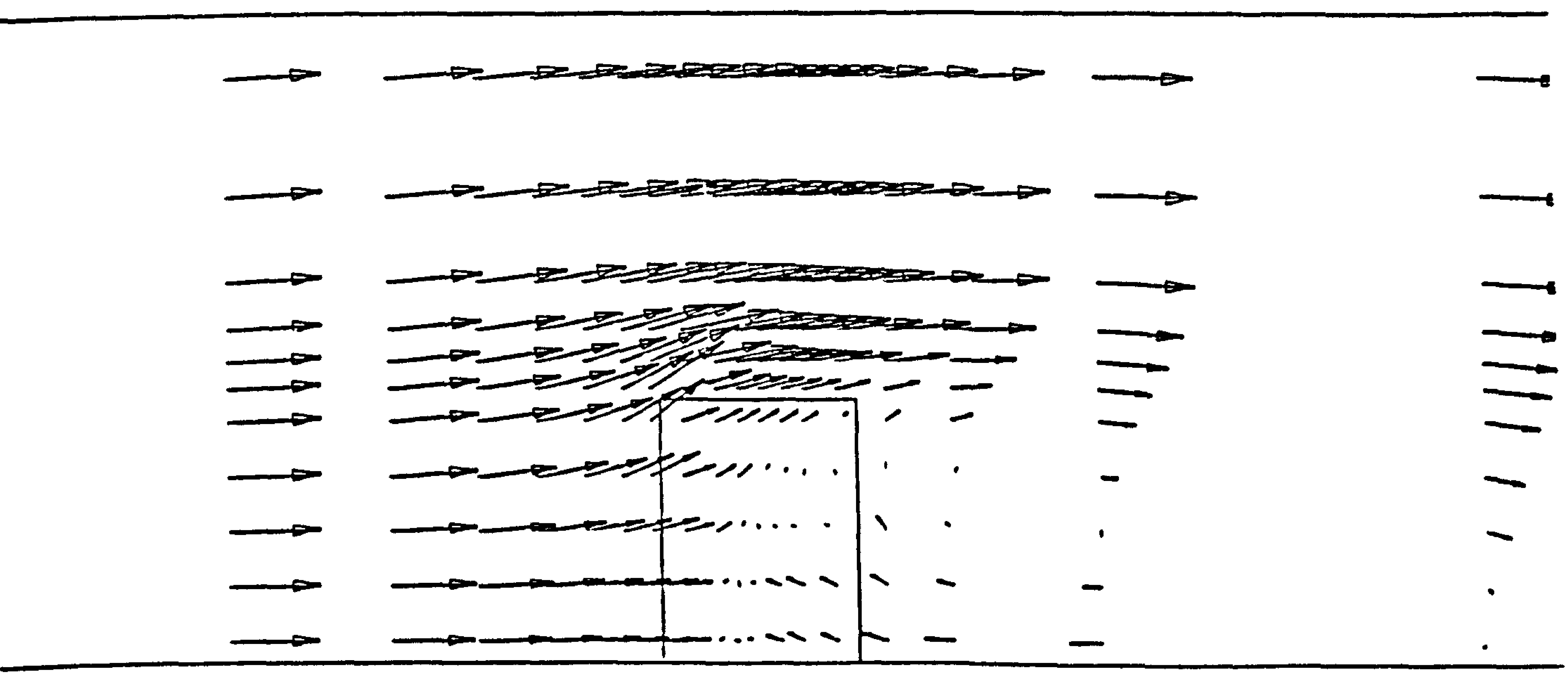
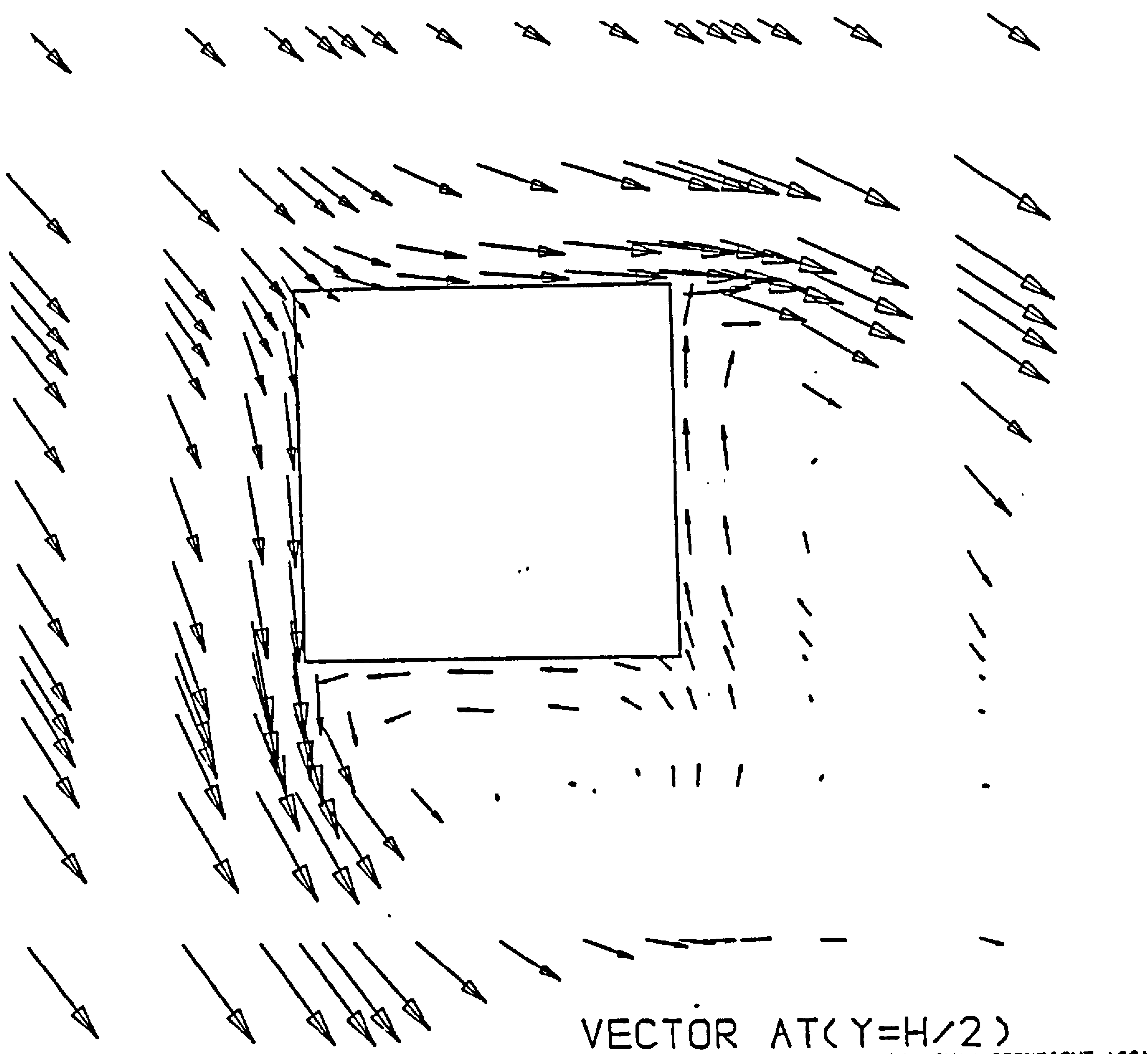


Figure 6.19 (A. Mustafa)

VECTOR NEAR THE SIDE(X=.454)

Wind patterns and various building configurations.



(A. Mustafa)

Figure 6.20 Wind patterns and various building configurations.

at 45 to the prevailing wind proving that the wind runs off very fast creating two vorteces (negative pressure), which help to increase wind velocity inside the house.

6.6 The Data Preparation

6.6.1 The Wind Tunnel Experiment

6.6.1.1 The Model

In order to make the experiment represent the actual situation a 1:50 scale wooden model of the house and six of the surrounding houses was made and placed in the wind tunnel in the same orientation as the design estate model suggested in Chapter 3. The visitor's room in the house under study was selected for the experiment. This room has two external walls; one orientated to the west and the other to the south (see Figure 6.21).

As 44 window dimensions were chosen for the study, the room in the model was designed with no external walls (see Figure 6.22).

44 wall panels were prepared, each one representing a wall with one of the 44 windows. The window openings were cut from each wall panel to simulate one of these windows (see Figure 6.23). Two sets of 44 panels were prepared for the two room walls. The walls were fixed in position by using two sided Sellotape stuck to the external edge of the slab of the room.

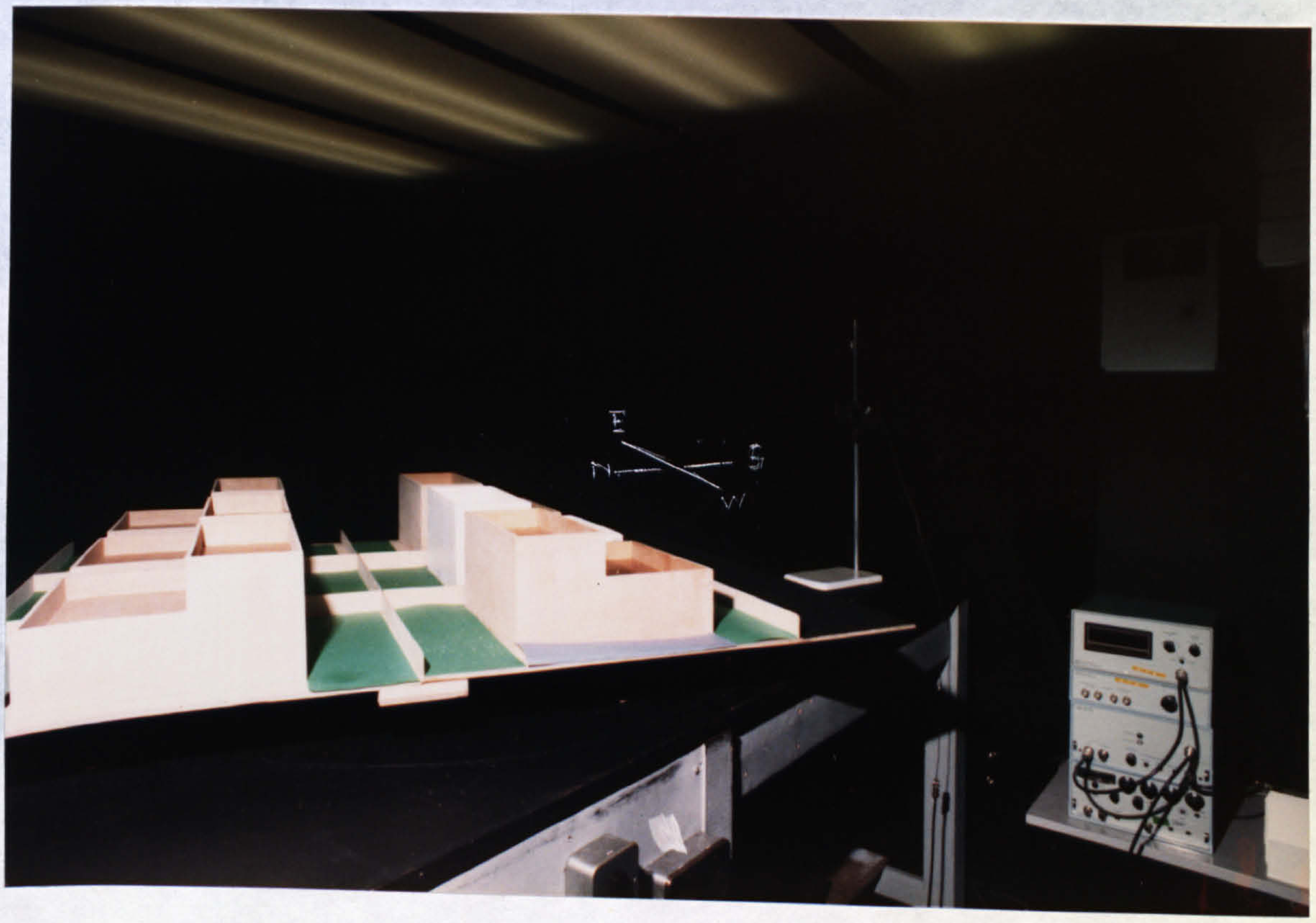


Figure 6.21 Scale model of a group of houses in wind tunnel.

Figure 6.22 Scale model of a group of houses in wind tunnel showing visitors-room with no external walls.

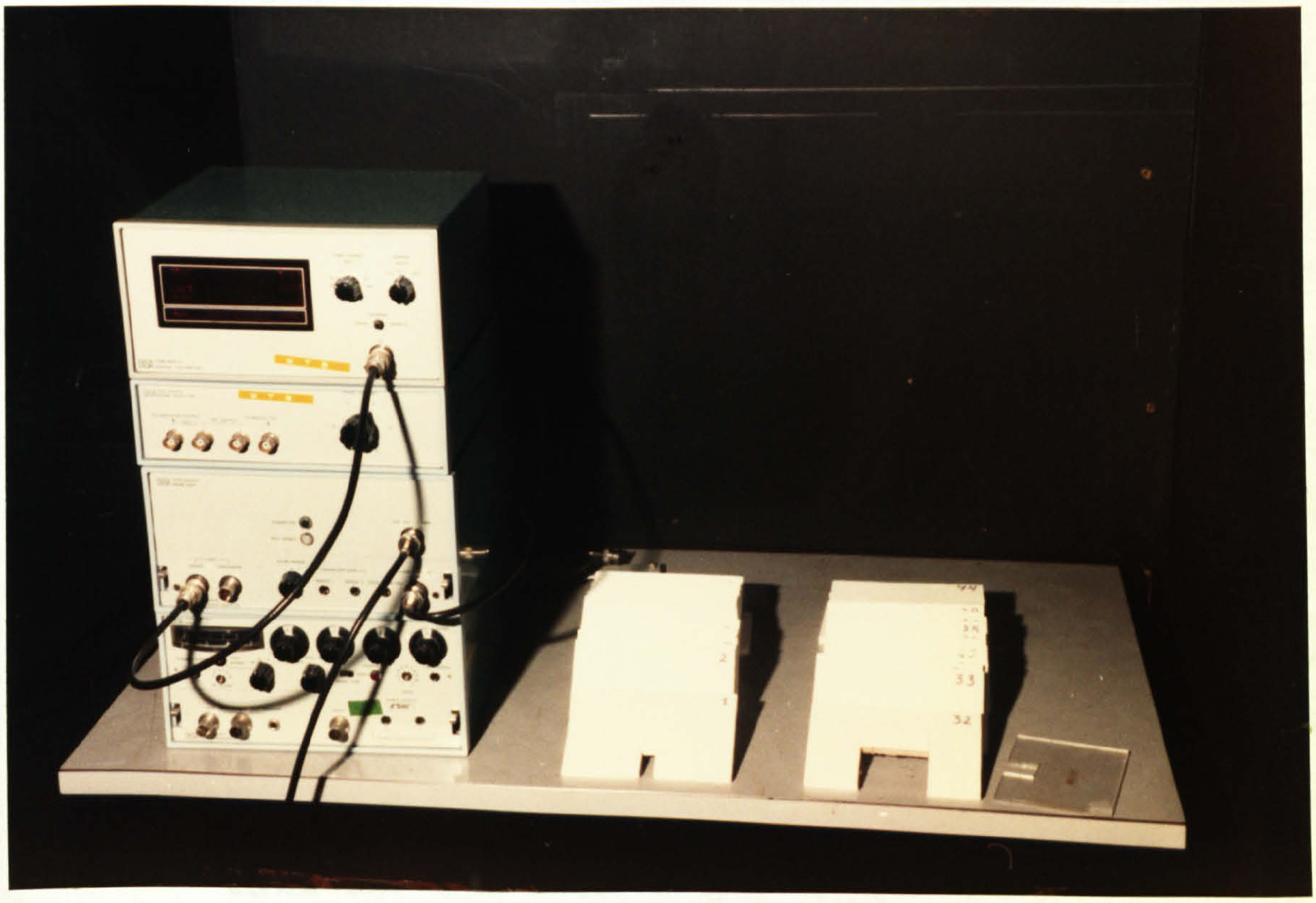


Figure 6.23 Measuring apparatus and Sets of window walls.

6.6.2.2 The Testing Equipment

As the scale of the model is small and any measuring cell has to be as tiny as possible, so that its volume cannot be considered as an obstruction, it was found that the hot wire anemometre was the ideal tool. For such a study three types of hot wire anemometer are recommended; Triple-sensor probe, Dual-sensor probe and Single-sensor probe (see Figure 6.24). All three probes are essential in the study of wind speed and wind direction measurements, but in this study the available probes were the single-sensor probe and these probes were placed in the direction perpendicular to the wind flow.

The air speed was measured by a DISA anemometry system which contains the DISA 55D31 Digital Voltmeter, the DISA55M14 Temperature Compensator (Probe Selector), the 55M12 CTA Symmetrical Bridge and the DISA 55M01 Main Unit and Prosser Air Velocity Metere AVM501TC (see Figure 6.23). The probes used in this experiment were DISA product 55p11.

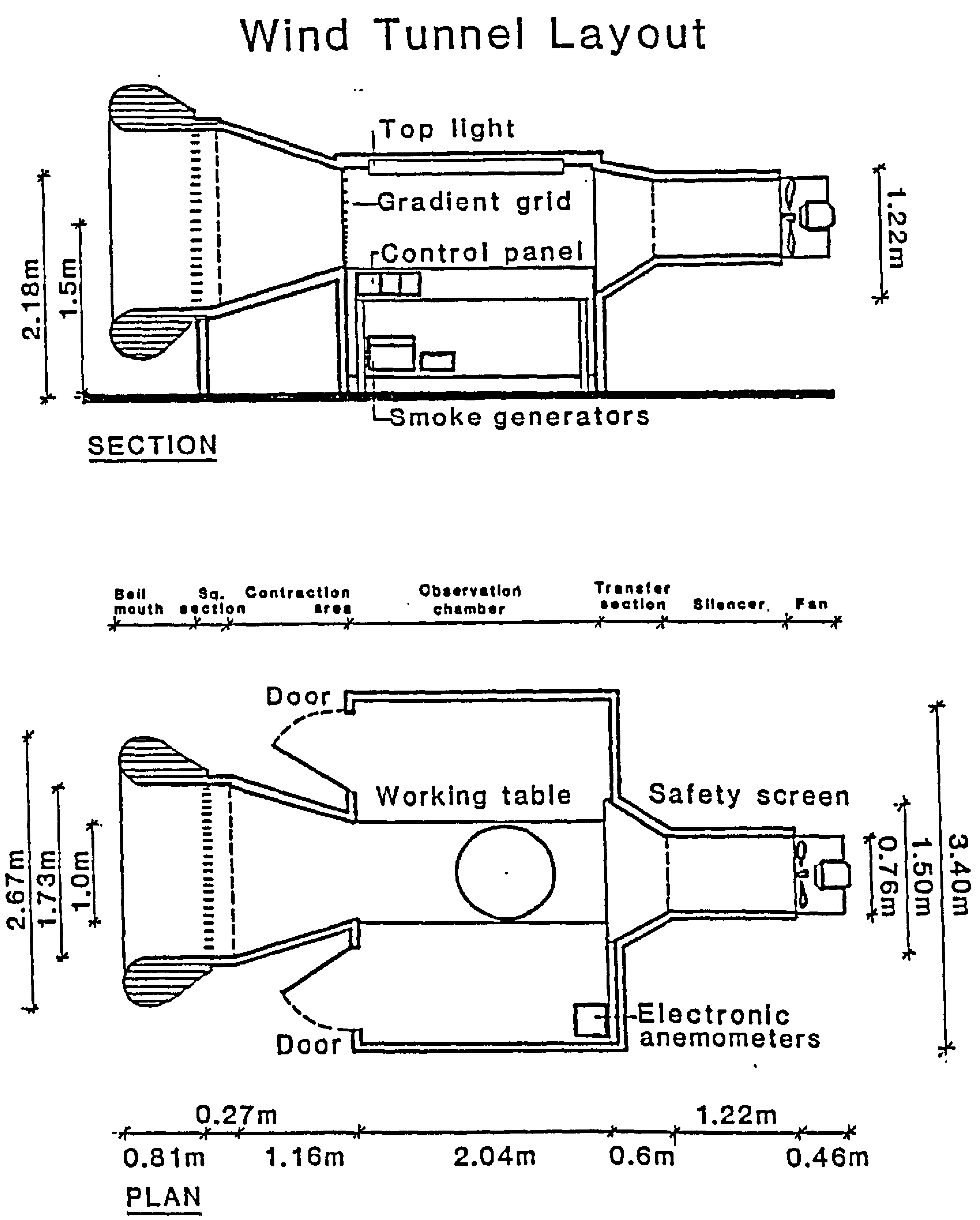
6.6.2.3 The Experiment

The experiment was carried out in the low speed wind tunnel of the Department of Architecture and Building Science at the University of Strathclyde.

The working section of the wind tunnel is 1.0m. in width and 2.0m. length (see Figure 6.25).

Figure 6.24

Variety of Probes for Velocity Measurements.



The wind tunnel ,
Department of Architecture & Building Science ,
University of Strathclyde

Figure 6.25

The model was designed to be 100mm above the working level and the hot wire probes were placed inside the room at 16mm from the room floor to represent a working level of 80cm. As the probe's height is 35mm., holes were drilled in the model floor and filled with rubber tubes to hold the probes and the probe supports and to assist in adjusting the probe height for measurement at different working levels, as well as to stop any air penetration through the floor.

As stated the experiment was carried out in the visitor's room, and the other rooms were merely blocked off in order to eliminate any unwanted air flow or any deviation in direction. Three probes were fixed in the model; one on the west side walk-way, the second in the middle of the visitor's room and the third in the front walk-way (see Figure 6.26).

Referring to paragraph 6.5.1.1, which shows that the Reynolds number is not very significant, the wind speed used during the experiment was 2.7m/s, which represented the average wind speed during spring and autumn.

In order to find the type of window combinations which offer good air distribution inside the room, the window dimension (1m X 1m) in the south side wall was kept unchanged and the windows on the west side of the room were changed 44 times; for each of these the wind speeds outside the room and at the centre of the room were measured.

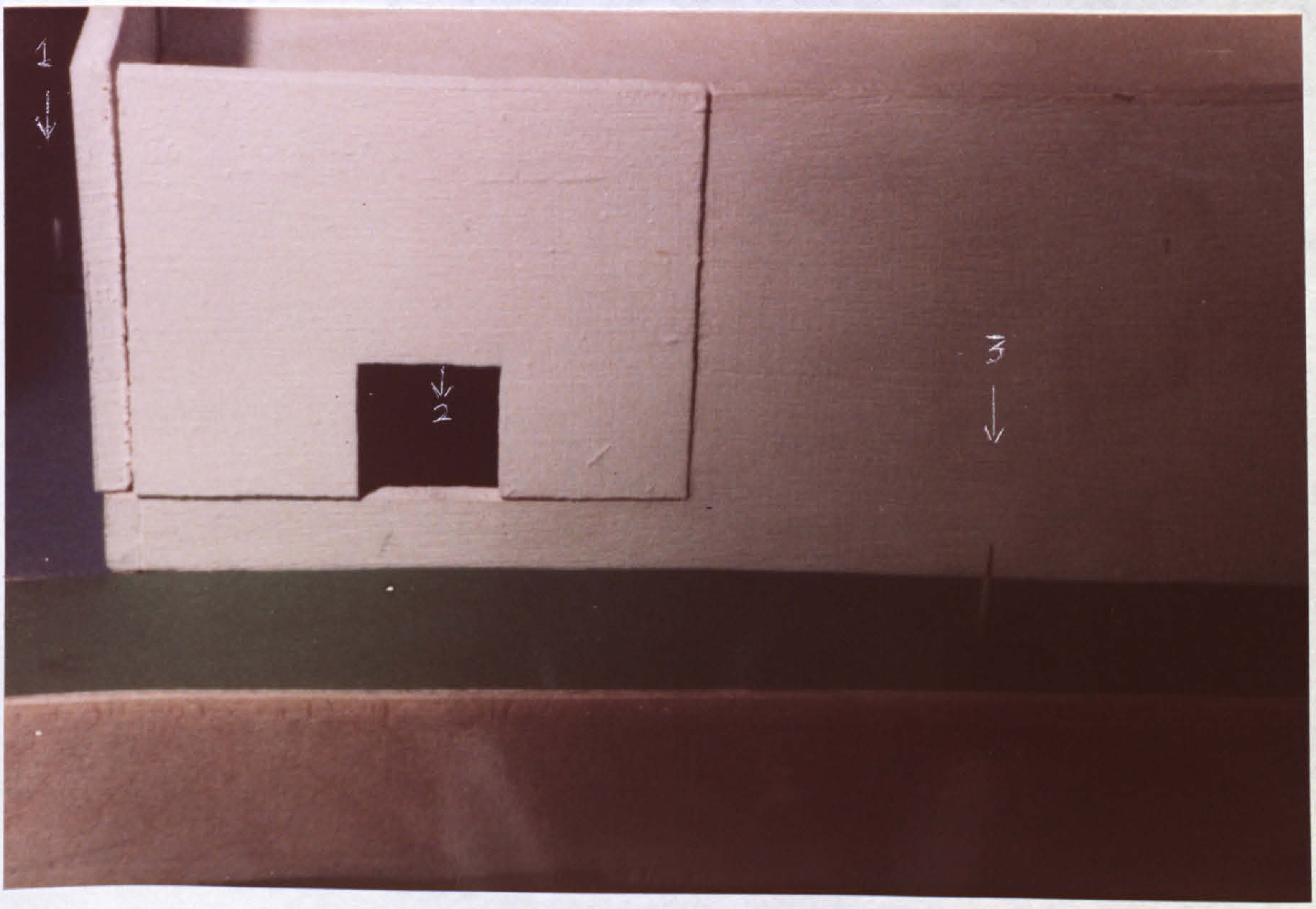
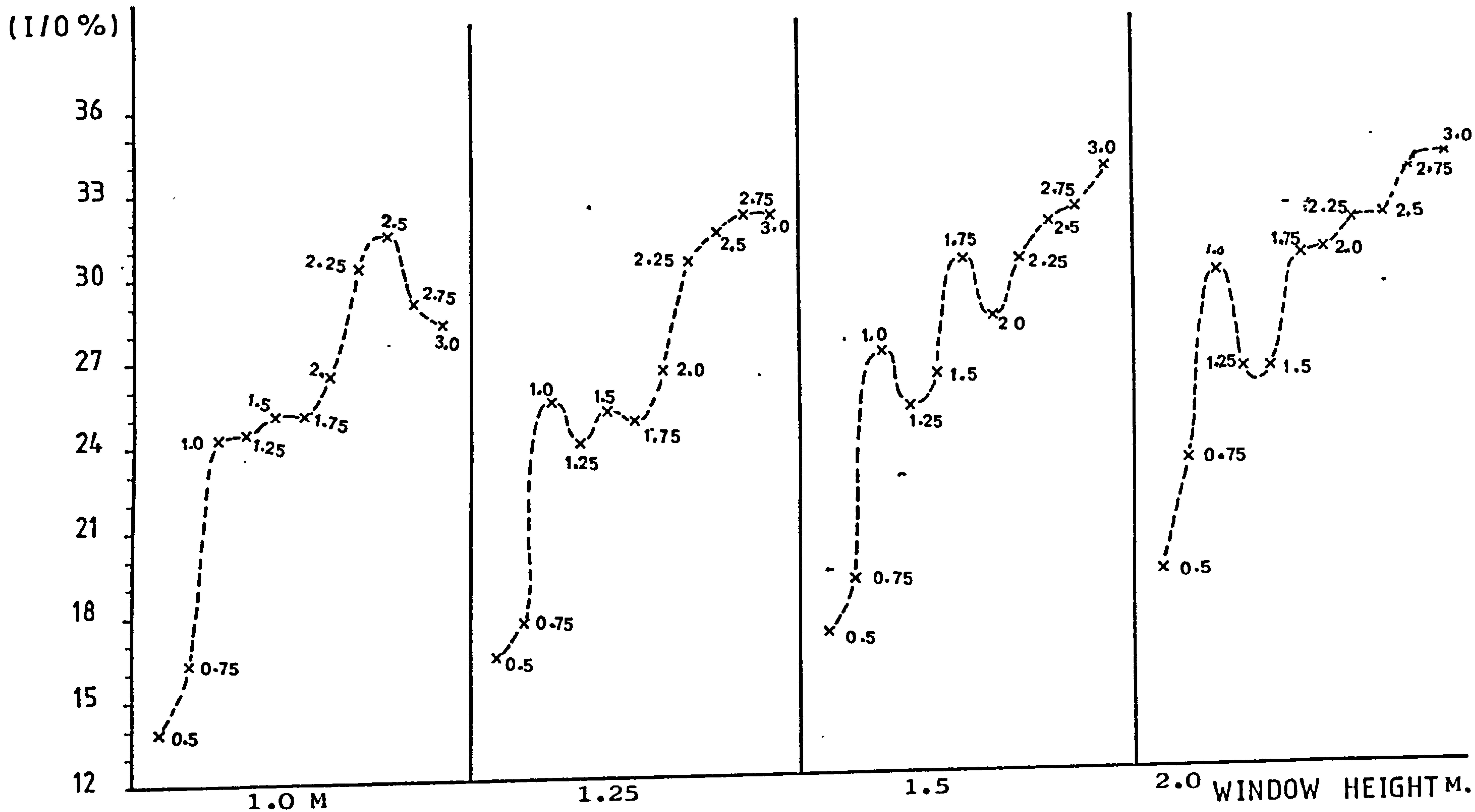


Figure 6.26 Position of probes

For a fully combinatorial experiment of this one room 44 X 44 measurements would have been necessary for the whole range of windows on both walls. In fact limitation of time allowed only one set of 44 measurements to be made - i.e. the full range of windows on one wall examined with a single, fixed-size, window on the other.
If dual sensor probes had been avaialable one could have measured the speed and direction simultaneously.

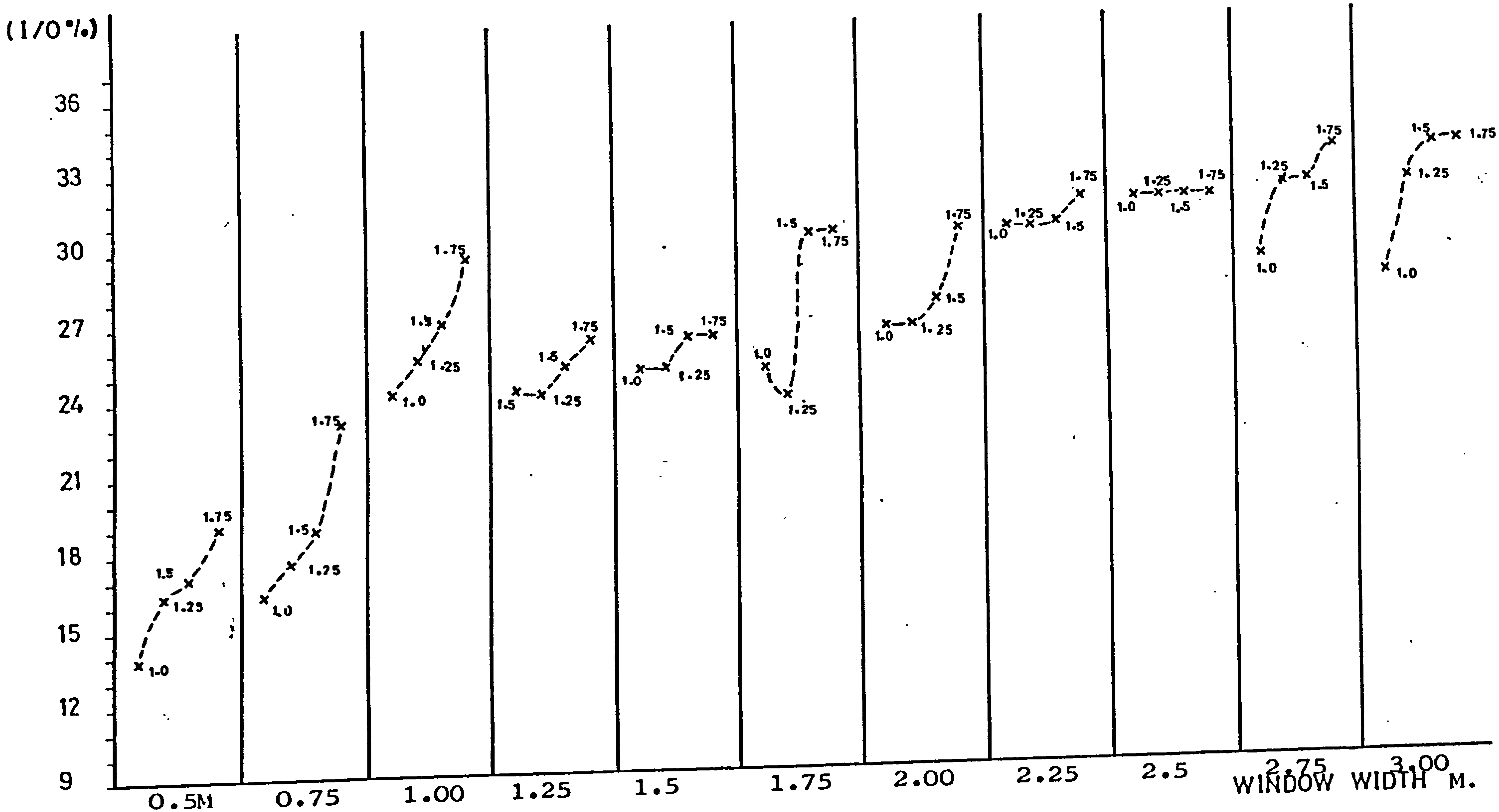
6.6.3 The Results

The recorded measurements were rectified by using the corresponding probe calibration chart.
As the study is concerned with the highest wind speed that can be provided at the centre of the room by a set of two windows, located in different walls, the best combination is the combination which can provide the highest ratio between the wind outside the room to the wind at the centre point of the room. Accordingly, the wind speed ratio was found and the results were ploted in two graphs. The first is for wind speed ratio changes with respect to window heights (see Figure 6.27), and the second for wind speed ratio changes with respect to window widths (see Figure 6.28).
The two graphs showed that wind speed increased sharply for all window heights between 0.5m to 1.0m width and this can be clearly seen in Figure 6.28. Looking at Figure 6.27 one can see that the wind speed increases as window height



I/O inner velocity/ outer velocity

Figure 6.27 Ratios of indoor/outdoor wind velocities for four window heights.



I/O Inner velocity/outer velocity

Figure 6.28 Ratios of indoor/outdoor window variation for eleven window widths.

increases for the narrower widths but when the window width is 2.25m increase in height increases wind speed only slightly whilst with a window width of 2.5m there is no change in wind speed as the window height increases. It was also found that a window of 2.75m width x 1.0m height and a window of 3.0m width x 1.0m height provide the room with a wind speed lower than that provided by a window of 2.25m width x 1.0m height and a window of 2.5m width x 1.0m height. This changed when the height became 1.25m or more. No firm recommendation can be drawn on the basis of these results because of the limited size of the experiment. But the results <u>do</u> enable realistic data to be used for the three-criteria Pareto optimisation technique described in Chapter 7.

CHAPTER 7

CHAPTER - 7 -

OPTIMIZATION AND RECOMMENDATIONS

7.1 The Designer and the Recommendations

In window design the designer needs to know what are the best and the worst situations and what is the performance given by windows lying between these extremes.

In practice architects are faced with a large number of criteria, preferences and constraints and therefore it is more convenient for them to to be provided with information on the consequences of alternative window choices and on the energy penalties resulting from rejecting the most energy-efficient window in favour of another to fulfil psychological requirements or to harmonise with the facade. Designers constantly need information on all window requirements and it is unacceptable for the information to be limited when they are asked to produce a beautiful, efficient and integrated design. Therefore any design tool has to posess a degree of flexibility enabling the designer to achieve a balance between function, aesthetic considerations, cost and energy conservation. Also designers prefer any such guide to give clear design orientations without involving too many calculations. Thus, as the aim of this research is, ultimately, to prepare a useful tool for designers, the author believes that the recommendations should be organized as follows:

A- They must deal with window sizes and proportions lying within the domain of common sizes in practice.

B- They must display the best as well as the worst window sizes and proportions.

C- They must show the degree to which each of other commonly available windows satisfy a range of criteria so that the designer has the choice of balancing the degrees of performance and satisfaction.

7.2 The Designer's Requirements

As mentioned in chapter one, designers in Iraq have expressed a need for data on window sizes, proportions and positions for:

A - Direct sunlight control.

B - Natural lighting.

C - Ventilation and air distribution for cooling purposes.

D - Optimisation between any pair of these variables and between the set of three variables.

7.3 Optimization Technique

7.3.1 Optimum Window Sizes for a Single Criterion

In the case of a single criterion, such as direct sunlight control, daylight or wind distribution, for each criterion there is an appropriate set of individual values, and a stated performance objective, which are used to find the

optimum window or group of windows for meeting that particular objective.
In order to find the requirements stated in A, B and C of 7.2 the following techniques are used .

7.3.1.1 Optimization and Recommendation Techniques for Window Sizes for Direct Sunlight Control

For this single criterion the recommendations are based on a specified weighting between summer and winter performance.The weighting as diescribed in chapters two and four specifies that the window is considered efficient if the amount of winter sun patches allowed to enter the room is at least twice that allowed to enter in summer. This is referred to as the yearly efficiency. Therefore a range of optimum windows will be considered efficient if they prove to have a yearly efficiency value equal to or greater than one. This value, as explained in chapter two, was based on the number of cold months compared with the number of moderate and hot months, during which direct sunlight is a disadvantage.
On some orientations no direct sunlight appears in winter and for such orientations the yearly efficiency weighting cannot be applied. In these cases it is difficult to specify a range of optimum windows, and the only windows that can be considered optimum are those which allow no sun to enter. However if none of the windows cuts out summer direct sunlight completely, it is considered there is no

optimum window and a new measure has to be introduced to help the designer to select a suitable window, or a number of smaller windows have to be substituted instead of one large window in order to obtain better direct summer sunlight control. This measure is called the summer efficiency value which is defined as the sum of hourly direct sunlight patches (excluding the first hour after sunrise and the last hour before sunset) per unit window area. Thus recommended windows for controlling summer direct sunlight are those which have the capability of reducing direct sunlight, the optimum being the one with the least summer efficiency.

Although the best window for summer is that with zero summer efficiency - which rarely occurs - there is no definable range for other windows' summer efficiency values and the only recommendation that can be made is that on any orientation the best window is that with the lowest summer efficiency value (ie the one with the lowest ratio of summer sunpatch areas per unit window area). The following data are provided to enable the designer to make a rational selection.

A- Graphs showing yearly efficiency (Appendix 2) for 77 windows.

B- As explained in Chapter four (4.7.2) for cases where at least one yearly efficiency curve falls entirely below 1.0, graphs of summer efficiency for 77 windows (Appendix 2 and sample in Figure 7.1).

C- Tables representing the window efficiency in rank order (see Appendix 3 and sample in Table 7.1).

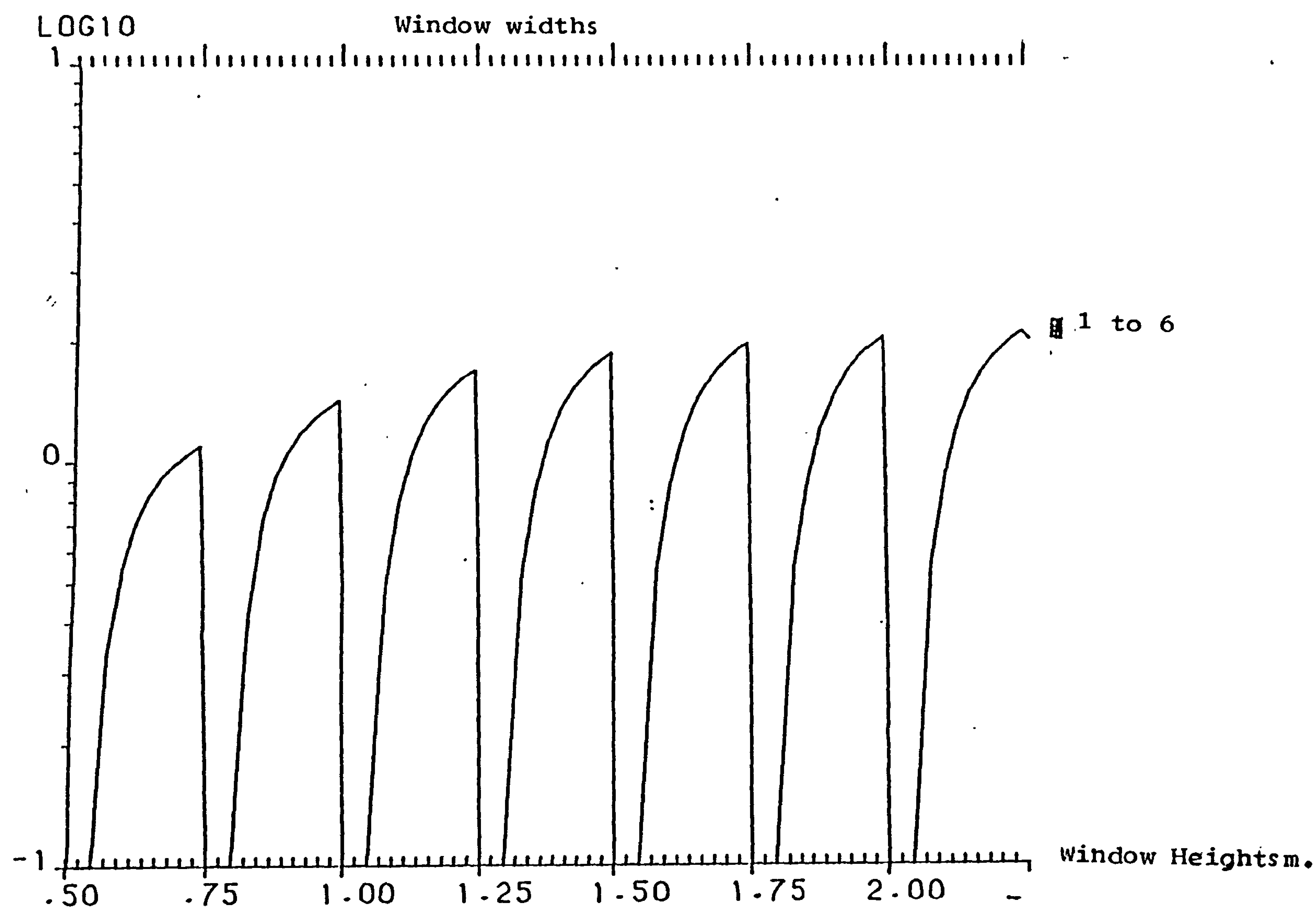


Figure 7.1

S. EFFICIENCY   W. THICKNESS= .36M   W. ORIENTATION= .00

WD= 12M   HD1= 3M   HD2= 3M   HOUSE T.=2.0 ST.

< W I N D O W > ----------<< O R I E N T A T I O N S >>----------

Width.M	Height.M	NORTH	22.5	45.0	67.5	EAST	112.5	135.0	157.5	SOUTH	202.5	270.0	247.5	WEST	292.5	315.0	337.5
.50	1.00	1	1	1	1	1	1	1	18	44	18	1	1	1	1	1	1
.50	1.25	2	2	2	3	12	2	2	16	43	16	2	2	2	3	2	2
.50	1.50	3	3	3	5	23	3	3	13	42	13	3	3	3	5	3	3
.50	1.75	4	4	4	10	34	5	4	12	41	12	5	5	4	10	4	4
.75	1.00	5	5	5	2	2	4	5	11	40	11	4	4	5	2	5	5
.75	1.25	6	6	6	9	13	7	6	3	39	3	6	7	6	9	6	6
.75	1.50	7	7	7	17	24	10	7	15	37	15	7	10	8	17	7	7
.75	1.75	8	8	9	21	35	16	8	21	36	21	8	16	11	21	9	8
1.00	1.00	9	9	8	4	3	6	9	9	38	9	9	6	7	4	8	9
1.00	1.25	10	10	10	16	14	11	10	14	35	14	10	11	10	16	10	10
1.00	1.50	11	11	12	22	25	20	11	20	33	20	11	20	14	22	12	11
1.00	1.75	12	13	16	29	36	25	12	27	30	28	13	25	21	29	16	13
1.25	1.00	13	12	11	6	4	8	13	5	34	5	12	8	9	6	11	12
1.25	1.25	14	14	14	18	15	17	14	17	31	17	14	17	15	18	14	14
1.25	1.50	15	16	20	28	26	24	16	24	28	24	16	24	23	28	20	16
1.25	1.75	16	19	25	33	37	31	17	31	25	31	18	31	28	33	25	19
1.50	1.00	17	15	13	7	5	9	15	1	32	1	15	9	12	7	13	15
1.50	1.25	18	18	18	19	16	21	18	19	27	19	19	21	19	19	18	18
1.50	1.50	19	23	26	30	27	30	21	30	22	30	23	30	26	30	26	23
1.50	1.75	20	28	31	38	38	35	25	35	19	35	27	35	33	38	31	28
1.75	1.00	21	17	15	8	6	12	19	2	29	2	17	12	13	8	15	17
1.75	1.25	22	22	23	20	17	22	20	22	24	22	22	22	24	20	23	22
1.75	1.50	23	29	29	31	28	32	26	32	18	32	28	32	30	31	29	29
1.75	1.75	24	33	35	39	39	38	31	38	13	38	32	38	36	39	35	33
2.00	1.00	25	20	17	11	7	13	22	4	26	4	20	13	16	11	17	20
2.00	1.25	26	27	27	23	18	23	23	23	20	23	25	23	25	23	27	27
2.00	1.50	28	32	34	32	29	33	29	33	14	33	31	33	34	32	34	32
2.00	1.75	29	37	38	40	40	40	36	40	9	40	36	40	39	40	38	37
2.25	1.00	27	21	19	12	8	14	24	6	23	6	21	14	17	12	19	21
2.25	1.25	31	30	28	24	19	26	28	25	16	25	30	26	27	24	28	30
2.25	1.50	32	36	36	34	30	34	35	34	11	34	35	34	35	34	36	36
2.25	1.75	35	40	41	41	41	41	39	41	6	41	39	41	41	41	41	40
2.50	1.00	30	24	21	13	9	15	27	7	21	7	24	15	18	13	21	24
2.50	1.25	34	31	30	25	20	27	32	26	12	26	33	27	29	25	30	31
2.50	1.50	37	38	37	35	31	36	38	36	7	36	38	36	37	35	37	38
2.50	1.75	39	42	42	42	42	42	42	42	4	42	41	42	42	42	42	42
2.75	1.00	33	25	22	14	10	18	30	8	17	8	26	18	20	14	22	25
2.75	1.25	38	34	32	26	21	28	34	28	10	27	34	28	31	26	32	34
2.75	1.50	41	39	39	36	32	37	40	37	5	37	40	37	38	36	39	39
2.75	1.75	42	43	43	43	43	43	43	43	2	43	43	43	43	43	43	43
3.00	1.00	36	26	24	15	11	19	33	10	15	10	29	19	22	15	24	26
3.00	1.25	40	35	33	27	22	29	37	29	8	29	37	29	32	27	33	35
3.00	1.50	43	41	40	37	33	39	41	39	3	39	42	39	40	37	40	41
3.00	1.75	44	44	44	44	44	44	44	44	1	44	44	44	44	44	44	44

TABLE (7.1) SHOWING WINDOW EFFICIENCY in RANK ORDER

WALL THICKNESS = .36 M

D- Tables representing windows with the top 20% of window efficiency values taken from the complete rank ordered values for all the windows (see Appendix 3 and sample in Table 7.2). The designer has a part to play in the selection of windows if direct sunlight control is the only factor of concern.

Appendix 2 contains the yearly efficiency and the summer efficiency graphs for approximately 2000 design cases for each of 77 windows.

Appendix 3 contains tables representing window efficiency rank order for direct sunlight control.

Appendix 3 also contains tables representing windows with the top 20% of window efficiency values for all windows

7.3.1.2 Recommendations on Windows for Daylighting

As required daylight levels depend on the function of the room, and in order to make the study capable of being used as widely as possible and cover as many cases as possible, the designer is provided with tables giving lighting levels formed by each of the 44 windows for each room, accompanied by a table of standard lighting levels required for each type of room in the house (see Appendix 4).

By referring to Table 7-3, the designer can select one window or a number of different windows to achieve the required lighting level for a room.

The lighting level achieved by each of the 44 windows is represented in the form of tables which give for each

<WINDOW>		-----------<<				O R I E N T A T I O N S											>>-----------
Width.M	Height.M	NORTH	22.5	45.0	67.5	EAST	112.5	135.0	157.5	SOUTH	202.5	270.0	247.5	WEST	292.5	315.0	337.5
.50	1.00	1	1	1	1	1	1	1	-	-	-	1	1	1	1	1	1
.50	1.25	2	2	2	3	-	2	-	-	-	-	-	2	2	3	2	2
.50	1.50	3	3	3	-	-	-	-	-	-	-	-	-	3	-	3	3
.50	1.75	4	4	4	-	-	-	-	-	-	-	-	-	-	-	4	4
.75	1.00	5	-	-	2	2	-	-	-	-	-	-	-	-	2	-	-
.75	1.25	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
.75	1.50	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
.75	1.75	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.00	1.00	9	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
1.00	1.25	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.00	1.50	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.00	1.75	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.25	1.00	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-
1.25	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.25	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.25	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.50	1.00	-	-	-	-	5	-	-	1	-	1	-	-	-	-	-	-
1.50	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.50	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.50	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.75	1.00	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-
1.75	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.75	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.75	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.00	1.00	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-
2.00	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.00	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.00	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.25	1.00	-	-	-	-	8	-	-	-	-	-	-	-	-	-	-	-
2.25	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.25	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.25	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.50	1.00	-	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-
2.50	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.50	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.50	1.75	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
2.75	1.00	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-
2.75	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.75	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.75	1.75	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
3.00	1.00	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-
3.00	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.00	1.50	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
3.00	1.75	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-

TABLE (7.2 SHOWING THE TOP 20% OF window efficiency in RANK ORDER

WALL THICKNESS = .36

ORIENTATIONS : 67.5 & 112.5 & 247.5 & 292.5

BEDROOM-2-(MIDDLE WINDOW)   WINDOW ON SIDE WALL -FIRST FLOOR
OBST.HIGHT 4.50   POINT DIST. 2.5000

W I N D O W		INTER-HOUSE DIST.= 1.M SKY+EXTERNAL REFLECTION				INTER-HOUSE DIST.= 2.M SKY+EXTERNAL REFLECTION				INTER-HOUSE DIST.= 3.M SKY+EXTERNAL REFLECTION				INTER-HOUSE DIST.= 4.M SKY+EXTERNAL REFLECTION			
		25%WALLREFL.		70%WALLREFL.		25%WALLREFL.		70%WALLREFL.		25%WALLREFL.		70%WALLREFL.		25%WALLREFL.		70%WALLREFL.	
WIDTH	HEIGHT	FA %	LUX	FA%	LUX	FA %	LUX	FA%	LUX	FA %	LUX	FA%	LUX	FA %	LUX	FA%	LUX
0.50	1.00	0.02	4.	0.07	10.	0.05	7.	0.13	20.	0.07	11.	0.20	30.	0.12	19.	0.35	52.
0.50	1.25	0.03	5.	0.10	14.	0.07	10.	0.19	29.	0.10	15.	0.28	43.	0.18	27.	0.50	76.
0.50	1.50	0.05	7.	0.13	19.	0.09	14.	0.25	38.	0.13	20.	0.37	57.	0.25	37.	0.65	98.
0.50	1.75	0.06	8.	0.16	24.	0.11	17.	0.31	47.	0.18	27.	0.47	70.	0.34	51.	0.74	112.
0.75	1.00	0.03	5.	0.10	15.	0.07	10.	0.19	29.	0.10	16.	0.29	44.	0.18	28.	0.52	78.
0.75	1.25	0.05	8.	0.14	21.	0.10	15.	0.28	43.	0.15	23.	0.42	64.	0.27	40.	0.75	113.
0.75	1.50	0.07	10.	0.19	28.	0.13	20.	0.37	56.	0.20	30.	0.56	84.	0.37	55.	0.97	146.
0.75	1.75	0.08	13.	0.23	35.	0.17	25.	0.46	70.	0.26	40.	0.69	105.	0.50	76.	1.10	167.
1.00	1.00	0.05	7.	0.13	20.	0.09	14.	0.26	39.	0.14	21.	0.38	58.	0.24	37.	0.68	103.
1.00	1.25	0.07	10.	0.19	28.	0.13	20.	0.37	56.	0.20	30.	0.56	84.	0.35	53.	0.99	149.
1.00	1.50	0.09	13.	0.25	38.	0.18	27.	0.49	75.	0.26	40.	0.74	111.	0.48	73.	1.28	193.
1.00	1.75	0.11	17.	0.31	47.	0.22	33.	0.61	93.	0.35	53.	0.92	139.	0.66	100.	1.46	221.
1.25	1.00	0.06	9.	0.16	24.	0.11	17.	0.32	48.	0.17	26.	0.47	71.	0.30	45.	0.84	127.
1.25	1.25	0.08	12.	0.23	35.	0.16	25.	0.46	69.	0.25	37.	0.69	104.	0.44	66.	1.22	184.
1.25	1.50	0.11	17.	0.31	46.	0.22	33.	0.61	92.	0.32	49.	0.91	138.	0.60	90.	1.58	239.
1.25	1.75	0.14	21.	0.38	58.	0.27	41.	0.76	114.	0.43	65.	1.13	171.	0.82	124.	1.80	272.
1.50	1.00	0.07	10.	0.19	28.	0.13	20.	0.37	57.	0.20	30.	0.56	84.	0.35	54.	0.99	150.
1.50	1.25	0.10	15.	0.27	41.	0.19	29.	0.54	82.	0.29	44.	0.81	123.	0.51	78.	1.44	218.
1.50	1.50	0.13	20.	0.36	55.	0.26	39.	0.72	109.	0.38	58.	1.07	163.	0.71	107.	1.86	282.
1.50	1.75	0.16	24.	0.45	68.	0.32	48.	0.90	135.	0.51	77.	1.34	202.	0.97	147.	2.13	322.
1.75	1.00	0.08	12.	0.22	33.	0.15	23.	0.43	65.	0.23	35.	0.64	97.	0.41	61.	1.14	172.
1.75	1.25	0.11	17.	0.31	47.	0.22	34.	0.62	94.	0.33	50.	0.93	141.	0.59	89.	1.65	250.
1.75	1.50	0.15	22.	0.42	63.	0.29	45.	0.83	125.	0.44	67.	1.23	187.	0.81	123.	2.14	324.
1.75	1.75	0.18	28.	0.52	78.	0.37	56.	1.03	155.	0.58	88.	1.54	232.	1.12	169.	2.45	370.
2.00	1.00	0.09	13.	0.24	37.	0.17	26.	0.48	73.	0.26	39.	0.72	108.	0.45	69.	1.27	193.
2.00	1.25	0.13	19.	0.35	53.	0.25	38.	0.70	105.	0.37	56.	1.04	158.	0.66	100.	1.85	280.
2.00	1.50	0.17	25.	0.47	71.	0.33	50.	0.93	140.	0.49	75.	1.38	209.	0.91	138.	2.40	363.
2.00	1.75	0.21	31.	0.58	88.	0.41	62.	1.15	174.	0.66	99.	1.72	261.	1.26	190.	2.75	416.
2.25	1.00	0.09	14.	0.27	40.	0.19	28.	0.53	80.	0.28	43.	0.79	119.	0.50	76.	1.40	212.
2.25	1.25	0.14	21.	0.39	58.	0.27	41.	0.77	116.	0.41	62.	1.15	173.	0.73	110.	2.04	308.
2.25	1.50	0.18	28.	0.51	78.	0.36	55.	1.02	154.	0.54	82.	1.52	230.	1.00	152.	2.64	400.
2.25	1.75	0.23	35.	0.64	97.	0.45	69.	1.27	192.	0.72	109.	1.90	288.	1.39	210.	3.03	459.
2.50	1.00	0.10	16.	0.29	44.	0.20	31.	0.57	87.	0.31	46.	0.86	129.	0.59	89.	1.50	227.
2.50	1.25	0.15	23.	0.42	64.	0.30	45.	0.83	126.	0.44	67.	1.25	188.	0.85	128.	2.18	330.
2.50	1.50	0.20	30.	0.56	84.	0.40	60.	1.11	168.	0.59	89.	1.66	250.	1.16	175.	2.83	428.
2.50	1.75	0.25	38.	0.70	105.	0.49	75.	1.38	209.	0.79	119.	2.07	313.	1.58	239.	3.26	493.
2.75	1.00	0.11	17.	0.31	47.	0.22	33.	0.61	93.	0.33	51.	0.92	139.	0.68	102.	1.60	241.
2.75	1.25	0.16	24.	0.45	68.	0.32	48.	0.89	135.	0.49	73.	1.34	203.	0.97	147.	2.31	350.
2.75	1.50	0.21	32.	0.60	91.	0.42	64.	1.19	180.	0.65	98.	1.78	270.	1.32	200.	3.00	453.
2.75	1.75	0.27	40.	0.75	113.	0.53	80.	1.49	225.	0.86	130.	2.23	337.	1.78	270.	3.46	523.
3.00	1.00	0.12	18.	0.33	50.	0.23	35.	0.65	99.	0.42	64.	1.01	152.	0.76	116.	1.68	255.
3.00	1.25	0.17	26.	0.48	72.	0.34	51.	0.95	144.	0.61	92.	1.46	221.	1.10	166.	2.43	368.
3.00	1.50	0.23	34.	0.64	96.	0.45	68.	1.27	192.	0.80	121.	1.94	293.	1.48	224.	3.15	477.
3.00	1.75	0.28	43.	0.80	121.	0.56	85.	1.58	239.	1.05	159.	2.42	366.	1.97	299.	3.65	552.

Table 7.3   FA% and illuminance values for 44 windows and four interhouse distances.

combination of house orientation, external obstruction height and width, inter-house distance and external wall reflection the level in Lux and as the FA factor (FA is equal to Sky Component plus External Reflected Component). The results are valid for levels at a distance of 2.5m from the external edge of the fenestration measured perpendicularly to the window on a working height of 0.8m. Due to the fact that decoration in the house cannot be controlled once the house is in use, the Internal Reflected Component has been excluded from the computation .

7.3.1.3 Natural Ventilation as a Single Criterion

This has not been explained in detail, only on a small sample of cases used in later triple-criterion optimisation.

7.3.2 Optimum Window Sizes for More Than One Criterion

The designer wishes to make a house as comfortable as possible by taking into account all relevant criteria, so that the design will have the attribute of integrity. Thus, for instance, cost reduction must not affect the occupants' level of comfort. When the designer has two or more objectives a solution which satisfies all of them must be found. This is not easy, or even possible, to achieve when one bears in mind the vast number of combinations to consider. According to the aim of this research, which is to provide designers with as much useful and direct information as possible, one useful set of results relates to performance on single criteria, such as sunlight control or daylight admission. But the study is also concerned with providing the user with recommendations on windows which can satisfy more than one criterion allowing the designer the opportunity to select from the wide range without having to examine solutions that are inefficient . Thus the requirement is for a technique which identifies the set of solutions, from the individual criterion sets of solutions, such that, for example, improved performance in direct sunlight control is always obtained with maximum daylight performance. Such a set allows the designer to select the solution which is based on the degree of relative importance of the criteria .. Such a method is found in the Pareto optimization technique.

7.3.2.1 The Pareto Optimization Method

As stated by Gero and Balachandran 1985 [Ref. 62] Pareto optimization is a methodology for solving multicriteria decision problems. The problems deal with two or more objectives. Pareto is a major concept in multiple objective decision-making and is defined formally as follows:

"A feasible solution to a multicriteria optimization problem is Pareto optimal (or non-inferior) if there exists no other feasible solution that will yield an improvement in one criterion without causing a decrease in at least one other criterion".

Pareto Optimality has been defined mathematically by Balachandran and Gero [Ref. 26] as:

"Letting $\max_{x}[\, Z1(x), Z2(x) \ldots\ldots Zp(x)]$ represents the multicriteria problem subject to

$gK(x) \le GK$ for $K=1,2,\ldots\ldots,m$ Where x is an N-component vector consisting of design variables $gK(x)$, $k=1,2,\ldots\ldots M$ are M constraints and $Z1(x), Z2(x), \ldots\ldots Zp(x)$ are p objective functions.

A feasible solution x* is a Pareto optimal solution to the problem if no other feasible solution x exists for which $Zi(x) > Zi(x^*)$ for some $i=1,2,,,,p$ and $Zj(x) \ge Zj(x^*)$ for all j not = i.

The Computer Application Research Unit in the Department of Architectural Science at the University of Sydney found that this technique is quite applicable to architectural problems, and they have put much effort in to testing this optimization technique and applying it to a range of architectural problems. It has designed computer programs for handling a large number of solutions and dealing with many criteria. The author found these programs were suitable for his needs for recommendations on window optimization. They met his aim of to providing designers with a set of window solutions which has the capability of fulfilling all the objectives that contribute to optimization, without causing any one criterion to be dominant over another.

7.3.2.2 Computer Programs Using Pareto

Computer programs in several languages have been developed by the Department of Architectural Science, University of Sydney - FORTRAN, PASCAL, PROLOG, LIPS [Ref. 62].

For this work the author used a program designed by Stephen Taylor from that Department [Ref. 199].

This package can handle 200 solutions and has the capability of carrying out the optimization on a maximum of nine criteria.

Although the package can handle two to nine criteria in the representation of optimal solutions it also has the ability to draw graphs for each pair of criteria and to list the pairs of results ranked according to the solution number rather than according to the solution order (see Table 7-4a). The package, even when representing the results ranked according to solution number, can list the results but cannot store the results in files.

The database also has to be typed in as the package has no facility to read from a data file. However, since the author wanted to use this package to cover the optimization of more than 30,000 solutions for each of the two objectives (daylight and direct sunlight control) and as it was impossible for him to type in all that data without the risk of error, he decided to make some modifications to the package and provide it with:

A- The facility of reading data files.

Window No.	Sunlight Y efficiency	Daylight lux
1.	249.60	73.00
5.	89.860	108.00
9.	54.260	143.00
13.	42.390	176.00
17.	35.140	208.00
21.	30.420	239.00
25.	27.730	268.00
29.	25.990	295.00
33.	24.780	321.00
34.	16.080	384.00
35.	13.010	446.00
37.	23.880	345.00
38.	15.580	413.00
39.	12.620	480.00
40.	10.840	544.00
41.	23.200	367.00
42.	15.180	440.00
43.	12.320	513.00
44.	10.590	582.00

Table 7.4a Ranking by solution number

Window No.	Sunlight Y efficiency	Daylight lux
1,	249.60,	73.00,
5,	89.86,	108.00,
9,	54.26,	143.00,
13,	42.39,	176.00,
17,	35.14,	208.00,
21,	30.42,	239.00,
25,	27.73,	268.00,
29,	25.99,	295.00,
33,	24.78,	321.00,
37,	23.88,	345.00,
41,	23.20,	367.00,
34,	16.08,	384.00,
38,	15.58,	413.00,
42,	15.18,	440.00,
35,	13.01,	446.00,
39,	12.62,	480.00,
43,	12.32,	513.00,
40,	10.84,	544.00,
44,	10.59,	582.00,

Table 7.4b Ranking by solution order

Window Ranking

B- The facility of representing the optimal solutions ranked according to solution order (see table 7-4b).

C- The facility of storing the results in files.

With the help of Harvey Sussock of ABACUS (Department of Architecture and Building Science) and Don Evans of the Computer Advisory Section, Strathclyde University, the modifications were made and the package can now be easily operated. Further, since the package had to be transferred from the University of Edinburgh computer to the Strathclyde University VAX computer, due to the closing down of Edinburgh's DEC10, and it was written in FORTRAN IV Extended which is not useable on the VAX, it had to re-written into FORTRAN 77, which was carried out with the help of Don Stearn of ABACUS.

The graphic representation is compressed and hence not clear; sometimes the solutions cannot even be recognized due to the overlap in the printing of the solution numbers (see Figure 7.2), and even in cases when the solution numbers can be read the graph will not help the designer to realize how the non-Pareto optimal values lie under the Pareto optimal solutions. Consequently the designer loses the benefit of seeing the values of the non-Pareto optimal solutions. The author therefore decided not to rely on the graphic system provided by the package but to construct a new computer program which would be able to read the solutions found by the package and draw them in a new form. The new form is listed below.

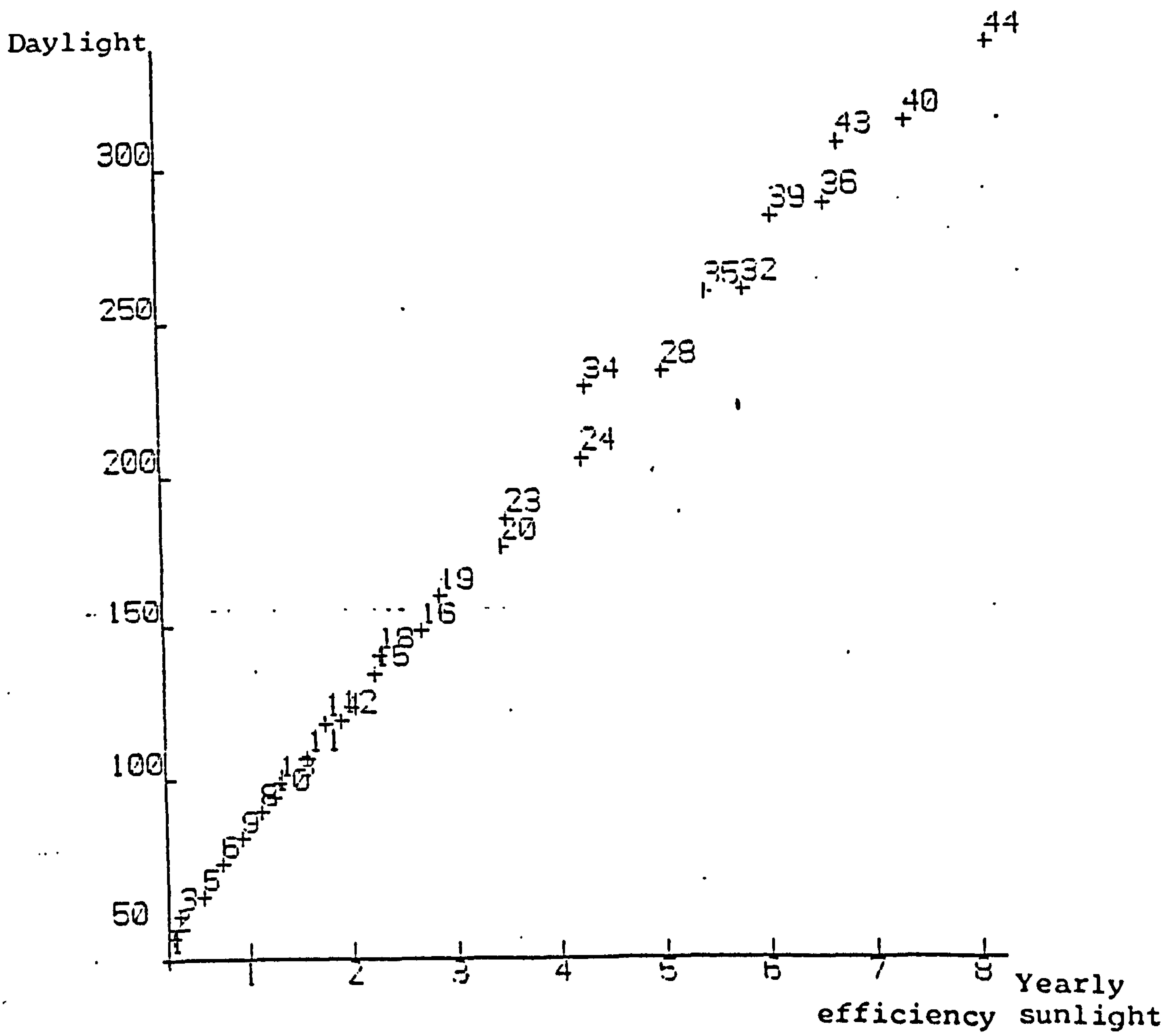


Figure 7.2 Pareto optimal solutions as printed by original graphic program.

a - All the solutions (Pareto and non-Pareto) were categorized and plotted according to the window heights so that the results could be easily read and would give more information to the designer about the effect of window heights and widths on the performance of the windows with regard to direct sunlight control and daylight provision.

b - All Pareto-optimal solutions were joined together with continuous lines, so that the user can distinguish between the optimal solutions and others (see Figure 7.3).

By joining the Pareto-optimal solutions together the graph demonstrates clearly the domination of the Pareto solutions on the non-Pareto solutions (see Figure 7.3).

The author decided not to replace the original graphic system within the Taylor package with the above new graphic system. It is intended that this development will be carried out in the future in Iraq jointly with the Computer Application Research Unit, Sydney University.

7.3.2.3 The Selection of Pareto-Optimal Solutions

In order to let a designer see how this technique finds and selects optimal solutions and to give confidence in the results which this project has produced, the following illustrations demonstrate examples of two criteria and three criteria problems to show how the Pareto optimization package finds Pareto optimal solutions.

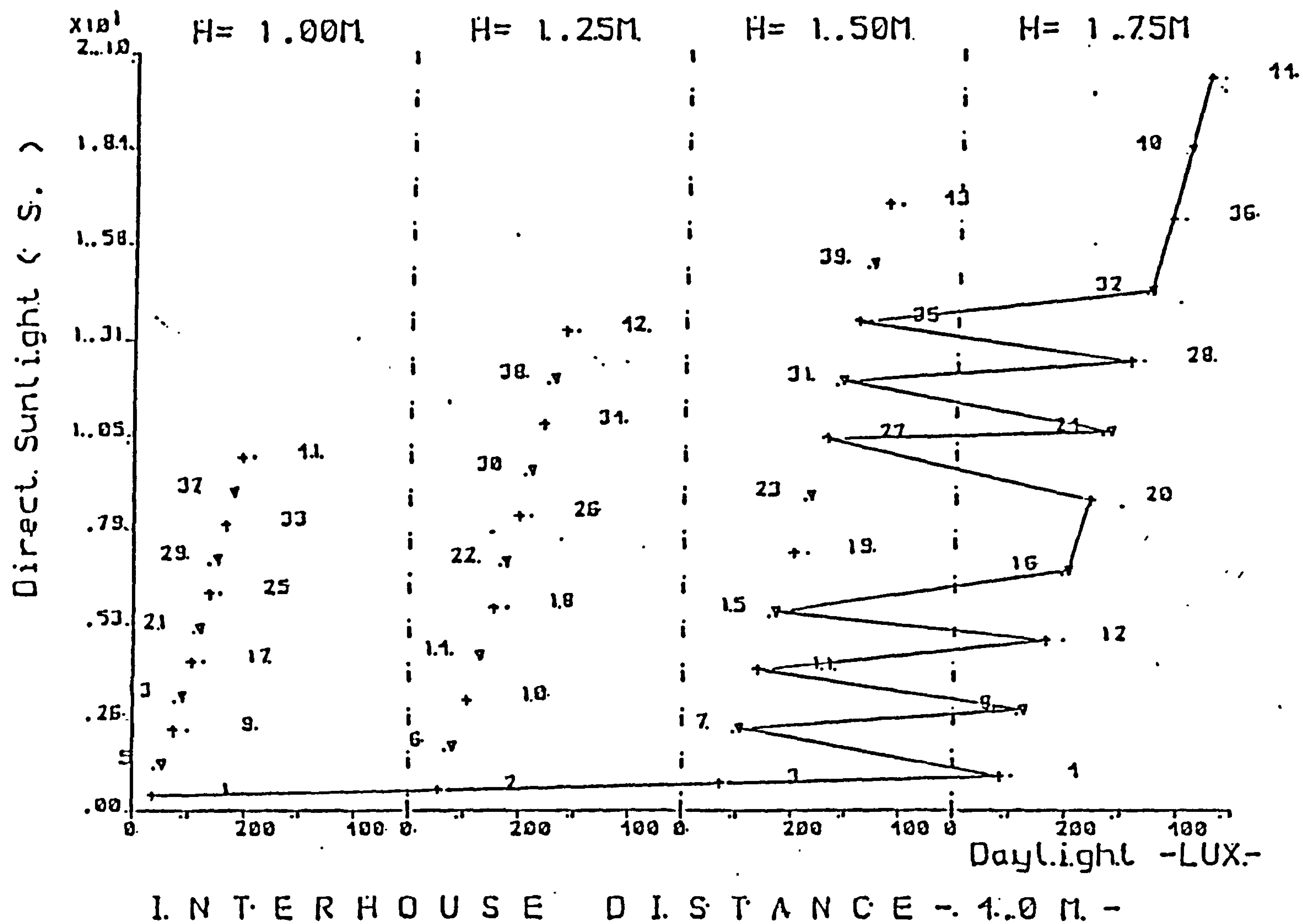


Figure 7.3. Pareto optimal solutions as printed by new program.

7.3.2.3.1 The Two Criteria Problem

Figure 7.4 represents a two criteria problem and the Pareto optimal solutions chosen by the computer program.

The first column in the Figure represents the solution number (window number), the second column is the direct sunlight control yearly efficiency and the third column is the amount of natural lighting (in Lux) provided by each window for the conditions stated in chapter five.

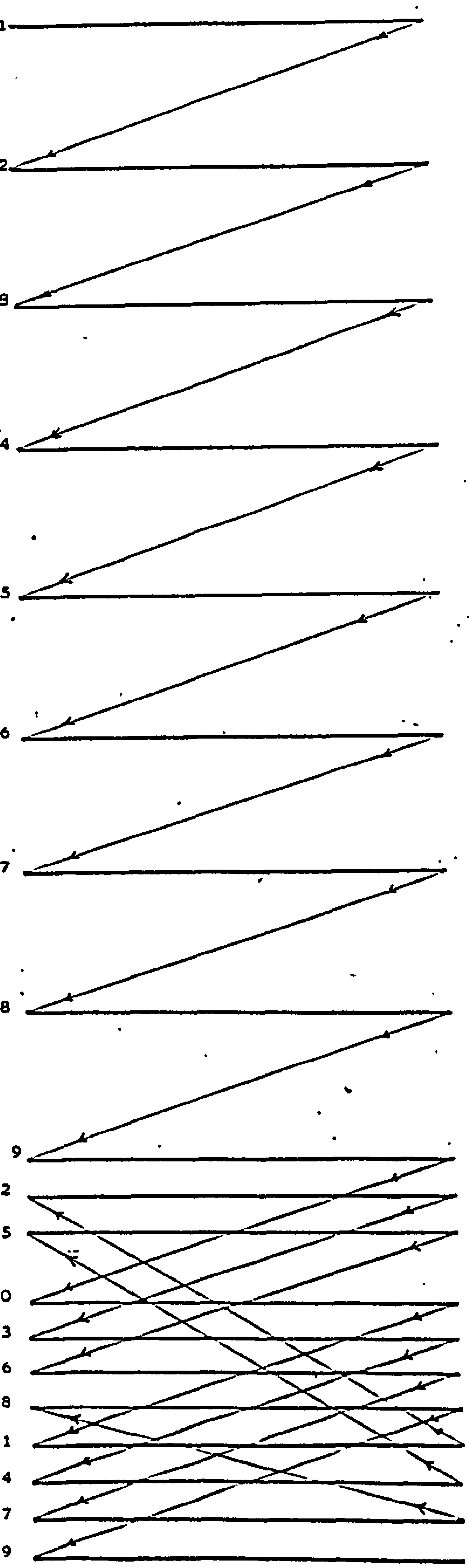
The requirement in window selection in this case is to find windows which have the capability of providing the room with as much daylight as possible and the ability to provide the room with as much winter and as little summer sun as possible (i.e.high yearly efficiency).

From the 44 windows, the Pareto program has selected 19 as Pareto optimal solutions. The selection was carried out as follows:

A- There is a search for the solution number having the highest direct sunlight yearly efficiency which also has a high daylighting performance.

B- There is a selection of the solution number with the second highest value of yearly efficiency and a daylight performance higher than that of the first window selected. This process is clarified when one observes the selection of solution 1 (window number 1) and solution number 2 (window number 5). Pareto has looked at the highest yearly efficiency and selected that with the highest value

Window No.		Sunlight Yearly Efficiency	Sequence	Daylight Lux
1	*	249.60	1	73.00
2		85.82		86.00
3		57.78		99.00
4		41.06		112.00
5	*	89.86	2	108.00
6		44.45		128.00
7		32.73		148.00
8		25.56		167.00
9	*	54.26	3	143.00
10		30.61		169.00
11		23.50		196.00
12		19.11		220.00
13	*	42.39	4	176.00
14		25.25		209.00
15		19.76		242.00
16		16.37		273.00
17	*	35.14	5	208.00
18		21.67		248.00
19		17.18		286.00
20		14.42		323.00
21	*	30.42	6	239.00
22		19.19		285.00
23		15.35		329.00
24		13.00		372.00
25	*	27.73	7	268.00
26		17.73		320.00
27		14.26		370.00
28		12.14		418.00
29	*	25.99	8	295.00
30		16.77		353.00
31		13.53		409.00
32		11.56		463.00
33	*	24.78	9	321.00
34	*	16.08	12	384.00
35	*	13.01	15	446.00
36		11.15		505.00
37	*	23.88	10	345.00
38	*	15.58	13	413.00
39	*	12.62	16	480.00
40	*	10.84	18	544.00
41	*	23.20	11	367.00
42	*	15.18	14	440.00
43	*	12.32	17	513.00
44	*	10.59	19	582.00



*Pareto Optimal Solution

Figure 7.4 Pareto selection sequence for high performance.

(249.60) and with the coresponding daylight performance (73.00). If two windows have the same yearly efficiency but different daylight performance the program selects that with the higher daylight value. Solution number 2, as is clearly seen (window number 5), came second in yearly efficiency and its daylight value is the highest value in the domain between the two yearly efficiency selected solutions. In observing how solution number 11 (window number 41) and solution number 12 (window number 34) were selected, the picture becomes clearer, since here the line linking choice moves upwords for the first time.

Figure 7.5 is another representation of the method. Here the program was instructed to select from the same set used in Figure 7.4, the <u>in</u>efficient windows which provide rooms with as little daylight as possible and have the lowest yearly efficiencies in controlling direct sunlight (i.e.high summer sun and little winter sun). Figure 7.4 illustrates that the first choice in Figure 7.4 has become the last in Figure 7.5 and most of the windows selected in Figure 7.4 have not appeared. The only ones to appear in common are these lying at the extremites (ie. the window ranked as number one now appears last and the window ranked last is now listed first).

The two examples give a clear demonstration of the method. The windows that disappear are those which are less qualified than any of the selected windows.

The two sets represented in Figures 7.4 and 7.5 are demonstrated again by using the graphic representation

Window No.	Sunlight Yearly Efficiency	Daylight Lux
1*	249.60	73.00
2*	85.82	86.00
3*	57.78	99.00
4*	41.06	112.00
5	89.86	108.00
6	44.45	128.00
7*	32.73	148.00
8*	25.56	167.00
9	54.26	143.00
10	30.61	169.00
11*	23.50	196.00
12*	19.11	220.00
13	42.39	176.00
14	25.25	209.00
15	19.76	242.00
16*	16.37	273.00
17	35.14	208.00
18	21.67	248.00
19	17.18	286.00
20*	14.42	323.00
21	30.42	239.00
22	19.19	285.00
23	15.35	329.00
24*	13.00	372.00
25	27.73	268.00
26	17.73	320.00
27*	14.26	370.00
28*	12.14	418.00
29	25.99	295.00
30	16.77	353.00
31	13.53	409.00
32*	11.56	463.00
33	24.78	321.00
34	16.08	384.00
35	13.01	446.00
36*	11.15	505.00
37	23.88	345.00
38	15.58	413.00
39	12.62	480.00
40*	10.84	544.00
41	23.20	367.00
42	15.18	440.00
43	12.32	513.00
44*	10.59	582.00

*Pareto Optimal Solution

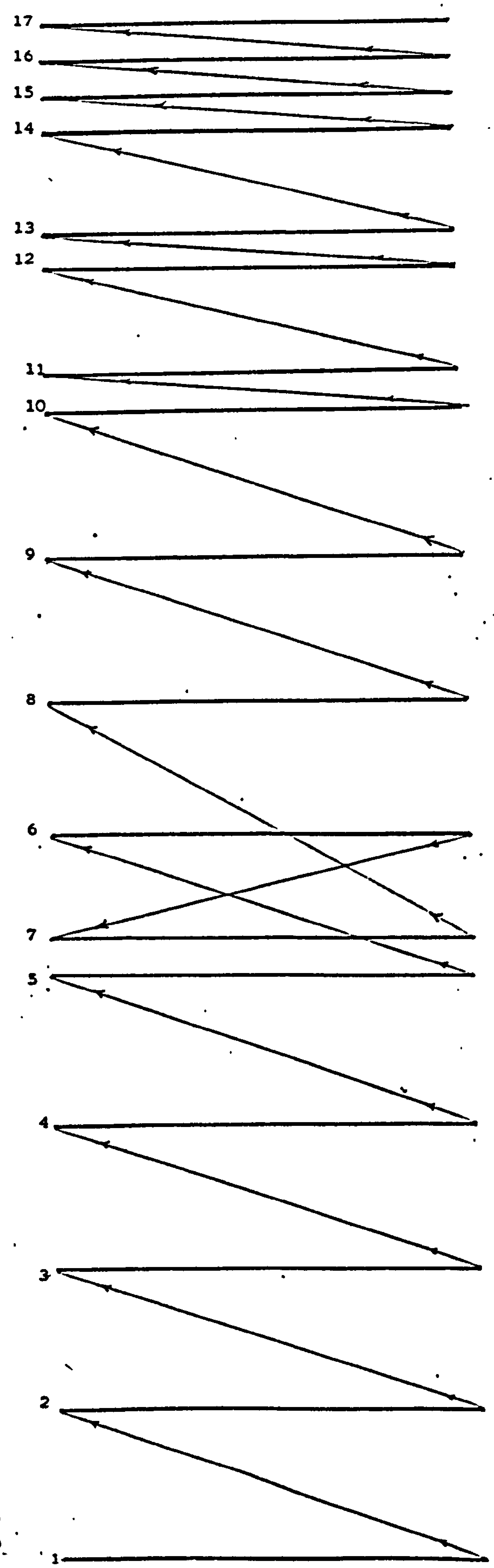


Figure 7.5 Pareto selection sequence for low performance.

method introduced by the author (see Figures 7.6), which gives a better picture on how the windows listed as efficient windows shown in Figure 7.4 dominate all the others which lie under the line joining the Pareto optimal solutions. While in Figure 7.7 the windows listed as extremely inefficient solutions, are dominated by all other solutions which lie over the line joining the solutions found by Pareto as ineffic̄ent.

However, although each of the selected windows has its own ability in contolling direct sunlight and providing the room with daylight, the responsibility still remains with the designer to balance out the relative priorities.

By setting out the result in this way, the designer has the choice of how to achieve the desired combination of enviromental conditions.

7.3.2.3.2 Three Criteria Problem

In this optimization example the data prepared is for three objectives, natural ventilation, direct sunlight control and daylighting. The set was handled by the computer package and as shown in Figures 7.8 to 7.11 the package selected the results as follows:

A- There is the optimization between the first two objectives (ventilation and direct sunlight control) and a determination of the Pareto optimal solutions for these two criteria (see Figure 7.8).

B- Next there is the optimization between the first and the third objective in the set (ventilation and daylight) and a

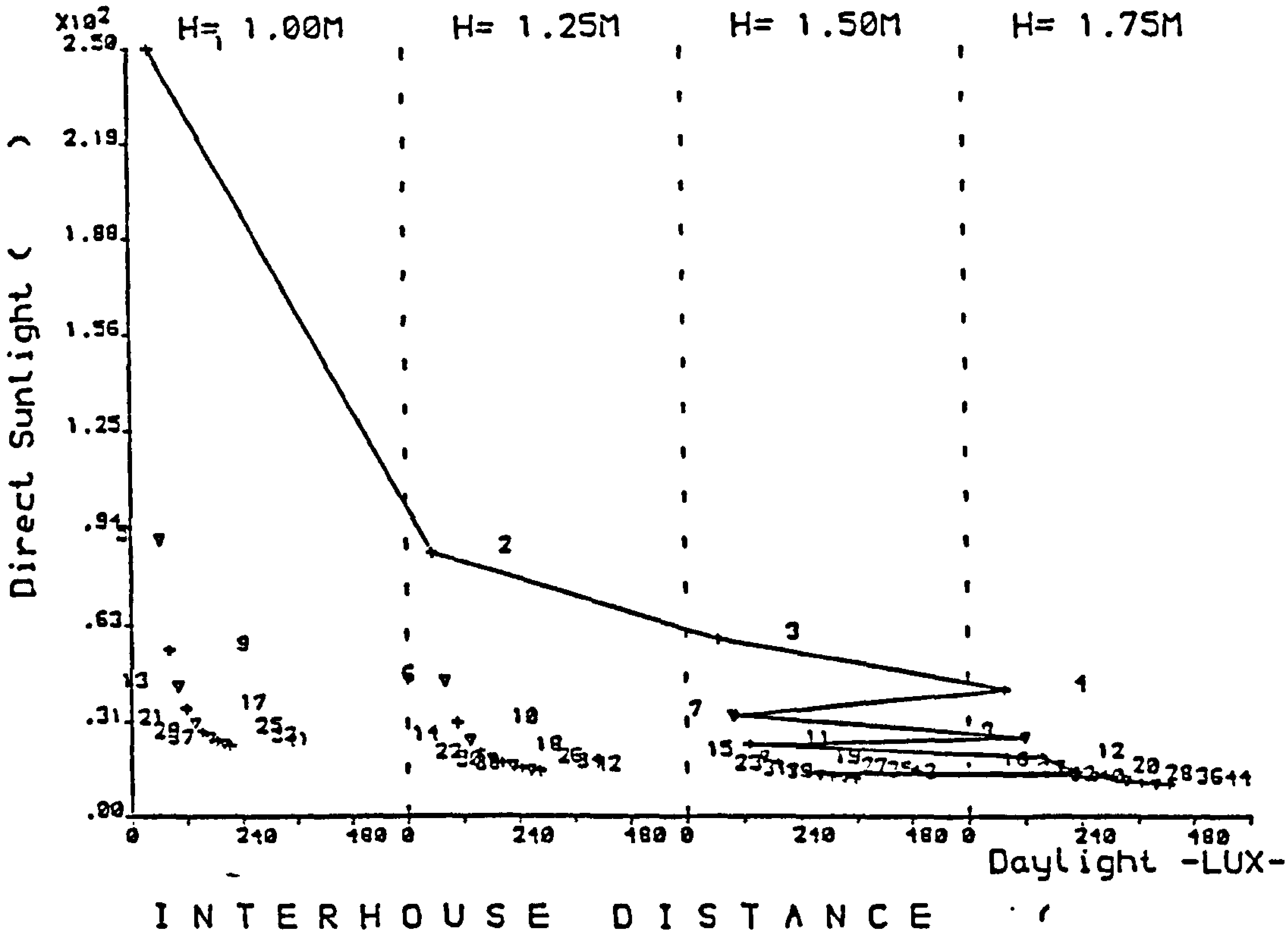


Figure 7.6 High Performance

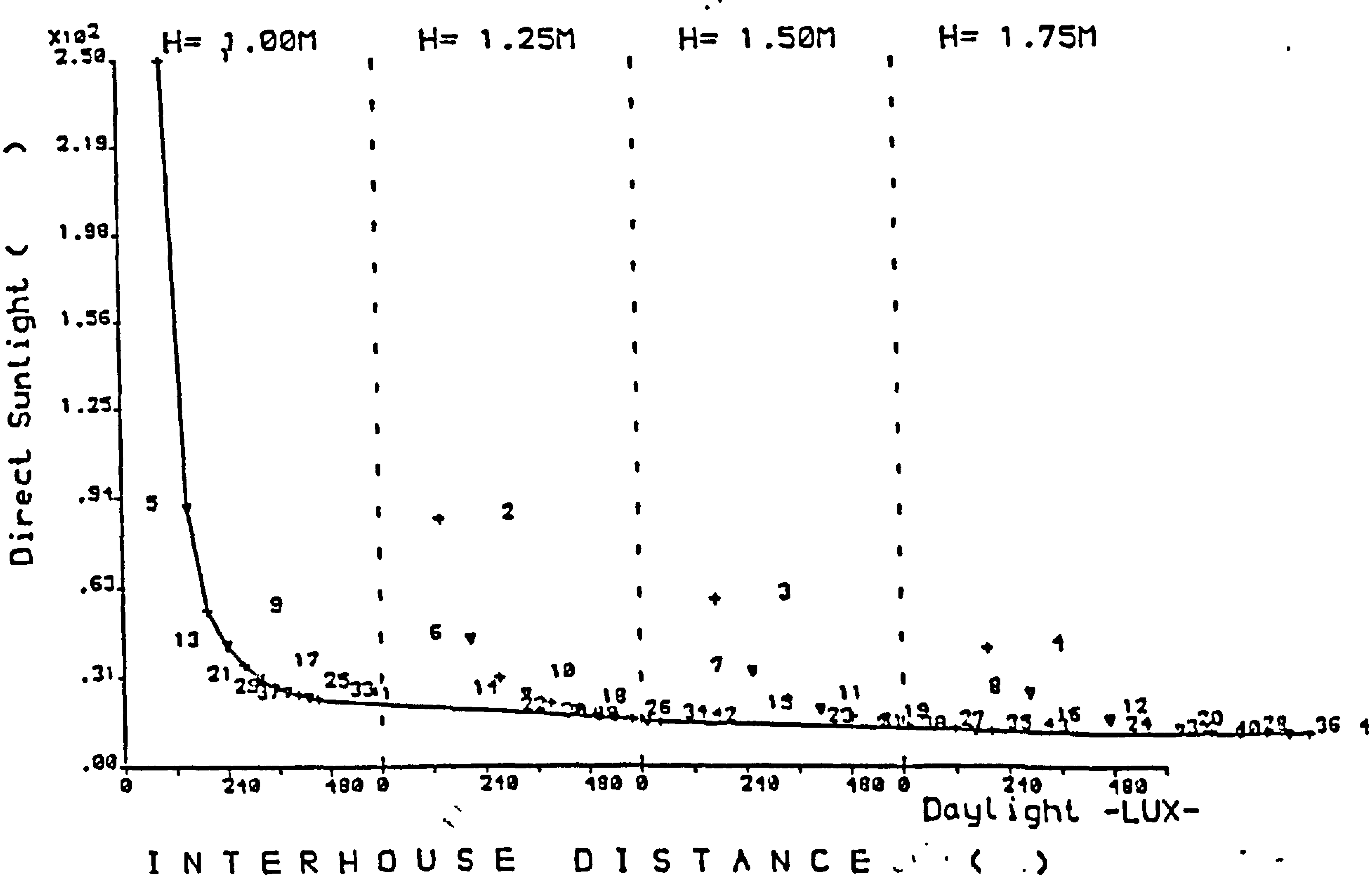


Figure 7.7 Low Performance

Graphic Representation of Pareto Optimal and Non-Optimal Solutions.

Window No.	Window Width	Height	Ventilation	Sunlight	Daylight
1	0.50	1.00	13.90	1.03	53.00
2	0.50	1.25	16.2	0.96	77.00
3	0.50	1.50	17.0	0.92	99.00
4	0.50	1.75	19.0	0.90	113.00
5	0.75	1.00	16.2	1.29	79.00
6	0.75	1.25	17.6	1.20	114.00
7	0.75	1.50	18.9	1.15	143.00
8	0.75	1.75	23.0	1.12	169.00
9	1.00	1.00	24.3	1.42	104.00
10	1.00	1.25	25.6	1.33	151.00
11	1.00	1.50	27.0	1.27	195.00
12	1.00	1.75	29.7	1.23	223.00
13	1.25	1.00	24.3	1.50	128.00
14	1.25	1.25	24.0	1.40	186.00
15	1.25	1.50	25.1	1.35	241.00
16	1.25	1.75	26.2	1.31	276.00
17	1.50	1.00	25.0	1.56	152.00
18	1.50	1.25	25.0	1.46	220.00
19	1.50	1.50	26.2	1.40	285.00
20	1.50	1.75	26.2	1:36	326.00
21	1.75	1.00	25.0	1.60	174.00
22	1.75	1.25	23.7	1.49	253.00
23	1.75	1.50	30.4	1.43	327.00
24	1.75	1.75	30.4	1.39	375.00
25	2.00	1.00	26.6	1.63	194.00
26	2.00	1.25	26.6	1.52	282.00
27	2.00	1.50	27.8	1.46	366.00
28	2.00	1.75	30.4	1.42	420.00
29	2.25	1.00	30.4	1.65	213.00
30	2.25	1.25	30.4	1.54	309.00
31	2.25	1.50	30.4	1.48	401.00
32	2.25	1.75	31.6	1.44	460.00
33	2.50	1.00	31.6	1.67	230.00
34	2.50	1.25	31.6	1.56	334.00
35	2.50	1.50	31.6	1.50	433.00
36	2.50	1.75	31.6	1.46	499.00
37	2.75	1.00	29.1	1.60	247.00
38	2.75	1.25	32.0	1.57	358.00
39	2.75	1.50	32.0	1.51	464.00
40	2.75	1.75	33.3	1.47	535.00
41	3.00	1.00	28.2	1.69	262.00
42	3.00	1.25	32.0	1.58	380.00
43	3.00	1.50	33.3	1.52	493.00
44	3.00	1.75	33.3	1.48	569.00

3 — Criterion

Pareto optimal solution sequence first pair.

Figure 7.8

determination of the Pareto-optimal solutions for these two criteria (see Figure 7.9).

C- There is then the optimization between the second and the third objectives (direct sunlight control and daylighting) and the determination of the Pareto-optimal solutions for these critera (see Figure 7.10).

D- Finally the combination of the three sets of Pareto-optimal solutions A, B and C are brought together to represent the Pareto-optimal solutions for the three criteria set (see Figure 7.11).

From the process set out above, the Pareto computer package proved to be capable of handling more than two criteria and demonstrated that it will be a useful tool for the author's future work when ventilation and other data on window performance will be generated.

7.3.2.4 Recommendations on Two Criteria Problems

It has been shown that the Pareto optimal solutions are the best in the whole set and all of them are recommended to fulfil the requirements for controlling direct sunlight and providing the room with a certain amount of daylight. But it is left to the designer now to select that window which can meet the level of required lighting for a specified space and balance that with the degree of direct sunlight control required. The graphs demonstrating the Pareto optimal solutions give a clear picture for the performance of each window from the objective points of

Window No.	Width	Height	Ventil-ation	Sunlight	Daylight
1	0.50	1.00	13.90	1.03	53.00
2	0.50	1.25	16.2	0.96	77.00
3	0.50	1.50	17.0	0.92	99.00
4	0.50	1.75	19.0	0.90	113.00
5	0.75	1.00	16.2	1.29	79.00
6	0.75	1.25	17.6	1.20	114.00
7	0.75	1.50	18.9	1.15	143.00
8	0.75	1.75	23.0	1.12	169.00
9	1.00	1.00	24.3	1.42	104.00
10	1.00	1.25	25.6	1.33	151.00
11	1.00	1.50	27.0	1.27	195.00
12	1.00	1.75	29.7	1.23	223.00
13	1.25	1.00	24.3	1.50	128.00
14	1.25	1.25	24.0	1.40	186.00
15	1.25	1.50	25.1	1.35	241.00
16	1.25	1.75	26.2	1.31	276.00
17	1.50	1.00	25.0	1.56	152.00
18	1.50	1.25	25.0	1.46	220.00
19	1.50	1.50	26.2	1.40	285.00
20	1.50	1.75	26.2	1.36	326.00
21	1.75	1.00	25.0	1.60	174.00
22	1.75	1.25	23.7	1.49	253.00
23	1.75	1.50	30.4	1.43	327.00
24	1.75	1.75	30.4	1.39	375.00
25	2.00	1.00	26.6	1.63	194.00
26	2.00	1.25	26.6	1.52	282.00
27	2.00	1.50	27.8	1.46	366.00
28	2.00	1.75	30.4	1.42	420.00
29	2.25	1.00	30.4	1.65	213.00
30	2.25	1.25	30.4	1.54	309.00
31	2.25	1.50	30.4	1.48	401.00
32	2.25	1.75	31.6	1.44	460.00
33	2.50	1.00	31.6	1.67	230.00
34	2.50	1.25	31.6	1.56	334.00
35	2.50	1.50	31.6	1.50	433.00
36	2.50	1.75	31.6	1.46	499.00
37	2.75	1.00	29.1	1.63	247.00
38	2.75	1.25	32.0	1.57	358.00
39	2.75	1.50	32.0	1.51	464.00
40	2.75	1.75	33.3	1.47	535.00
41	3.00	1.00	28.2	1.69	262.00
42	3.00	1.25	32.0	1.58	380.00
43	3.00	1.50	33.3	1.52	493.00
44	3.00	1.75	33.3	1.48	569.00

3-Criterion

Pareto optimal
solution sequence
second pair

Figure 7.9

Window No.	Width	Height	Ventil-ation	Sunlight	Daylight
1	0.50	1.00	13.90	1.03	53.00
2	0.50	1.25	16.2	0.96	77.00
3	0.50	1.50	17.0	0.92	99.00
4	0.50	1.75	19.0	0.90	113.00
5	0.75	1.00	16.2	1.29	79.00
6	0.75	1.25	17.6	1.20	114.00
7	0.75	1.50	18.9	1.15	143.00
8	0.75	1.75	23.0	1.12	169.00
9	1.00	1.00	24.3	1.42	104.00
10	1.00	1.25	25.6	1.33	151.00
11	1.00	1.50	27.0	1.27	195.00
12	1.00	1.75	29.7	1.23	223.00
13	1.25	1.00	24.3	1.50	128.00
14	1.25	1.25	24.0	1.40	186.00
15	1.25	1.50	25.1	1.35	241.00
16	1.25	1.75	26.2	1.31	276.00
17	1.50	1.00	25.0	1.56	152.00
18	1.50	1.25	25.0	1.46	220.00
19	1.50	1.50	26.2	1.40	285.00
20	1.50	1.75	26.2	1:36	326.00
21	1.75	1.00	25.0	1.60	174.00
22	1.75	1.25	23.7	1.49	253.00
23	1.75	1.50	30.4	1.43	327.00
24	1.75	1.75	30.4	1.39	375.00
25	2.00	1.00	26.6	1.63	194.00
26	2.00	1.25	26.6	1.52	282.00
27	2.00	1.50	27.8	1.46	366.00
28	2.00	1.75	30.4	1.42	420.00
29	2.25	1.00	30.4	1.65	213.00
30	2.25	1.25	30.4	1.54	309.00
31	2.25	1.50	30.4	1.48	401.00
32	2.25	1.75	31.6	1.44	460.00
33	2.50	1.00	31.6	1.67	230.00
34	2.50	1.25	31.6	1.56	334.00
35	2.50	1.50	31.6	1.50	433.00
36	2.50	1.75	31.6	1.46	499.00
37	2.75	1.00	29.1	1.68	247.00
38	2.75	1.25	32.0	1.57	358.00
39	2.75	1.50	32.0	1.51	464.00
40	2.75	1.75	33.3	1.47	535.00
41	3.00	1.00	28.2	1.69	262.00
42	3.00	1.25	32.0	1.58	380.00
43	3.00	1.50	33.3	1.52	493.00
44	3.00	1.75	33.3	1.48	569.00

3 – Criterion

Pareto optimal solution sequence third pair

Figure 7.10

Window No.	Width	Height	Ventil-ation	Sunlight	Daylight
1	0.50	1.00	13.90	1.03	53.00
2	0.50	1.25	16.2	0.96	77.00
3	0.50	1.50	17.0	0.92	99.00
4	0.50	1.75	19.0	0.90	113.00
5	0.75	1.00	16.2	1.29	79.00
6	0.75	1.25	17.6	1.20	114.00
7	0.75	1.50	18.9	1.15	148.00
8	0.75	1.75	23.0	1.12	169.00
9	1.00	1.00	24.3	1.42	104.00
10	1.00	1.25	25.6	1.33	151.00
11	1.00	1.50	27.0	1.27	195.00
12	1.00	1.75	29.7	1.23	223.00
13	1.25	1.00	24.3	1.50	128.00
14	1.25	1.25	24.0	1.40	186.00
15	1.25	1.50	25.1	1.35	241.00
16	1.25	1.75	26.2	1.31	276.00
17	1.50	1.00	25.0	1.56	152.00
18	1.50	1.25	25.0	1.46	220.00
19	1.50	1.50	26.2	1.40	285.00
20	1.50	1.75	26.2	1.36	326.00
21	1.75	1.00	25.0	1.60	174.00
22	1.75	1.25	23.7	1.49	253.00
23	1.75	1.50	30.4	1.43	327.00
24	1.75	1.75	30.4	1.39	375.00
25	2.00	1.00	26.6	1.63	194.00
26	2.00	1.25	26.6	1.52	282.00
27	2.00	1.50	27.8	1.46	366.00
28	2.00	1.75	30.4	1.42	420.00
29	2.25	1.00	30.4	1.65	213.00
30	2.25	1.25	30.4	1.54	309.00
31	2.25	1.50	30.4	1.48	401.00
32	2.25	1.75	31.6	1.44	460.00
33	2.50	1.00	31.6	1.67	230.00
34	2.50	1.25	31.6	1.56	334.00
35	2.50	1.50	31.6	1.50	433.00
36	2.50	1.75	31.6	1.46	499.00
37	2.75	1.00	29.1	1.68	247.00
38	2.75	1.25	32.0	1.57	358.00
39	2.75	1.50	32.0	1.51	464.00
40	2.75	1.75	33.3	1.47	535.00
41	3.00	1.00	28.2	1.69	262.00
42	3.00	1.25	32.0	1.58	380.00
43	3.00	1.50	33.3	1.52	493.00
44	3.00	1.75	33.3	1.48	569.00

3 – Criterion

Pareto optimal solution sequence fourth pair.

Figure 7.11

view, and because the graph is divided into four sub-graphs according to window height (see Figure 7.3) representing heights of 1.0m , 1.25m, 1.50m and 1.75m, the designer can also take into account the subjective effect of changing window height and window width.

If the designer wishes to achieve a minimum daylight level with as little summer sunlight as possible, this can be obtained by referring to the tables showing the window numbers (Pareto optimal solutions), and their corresponding direct sunlight efficiency (either summer efficiency or yearly) and daylight levels provided by each. The following example indicates how such a decision would be made.

7.3.2.4.1 Example

If Table 7-5 is for a certain orientation and room position and if this room required a lighting level of 510 Lux, the designer can decide either to use a group of five windows of type number 4 (0.50m width X 1.75m height) which would allow zero summer sun or face the penalty of using one of type number 44 (3.0m width X 1.75m height) which would allow summer sun of 13.9 times the window size, which means that the sun patch formed by this window on a summer day is equal to about 73m2. Any other window can be selected which meets the total performance and architectural requirements of the design. For example, if the minimum window width suitable to the design is 1.0m the

O R I E N T A T I O N =

(INTER-HOUSE DISTANCE= M)			(INTER-HOUSE DISTANCE= M)			(INTER HOUSE DISTANCE= M)			(INTER-HOUSE DISTANCE= M)		
WINDOW NO.	SUNLIGHT SY	DAYLIGHT LUX	WINDOW NO.	SUNLIGHT SY	DAYLIGHT LUX	WINDOW NO.	SUNLIGHT SY	DAYLIGHT LUX	WINDOW NO.	SUNLIGHT SY	DAYLIGHT LUX
4	0.	103.00	4	0.	73.00	4	0.	71.00	4	0.	172.00
6	0.31	119.00	6	0.31	75.00	6	0.31	72.00	6	0.31	186.00
7	0.38	137.00	7	0.38	93.00	7	0.38	89.00	7	0.38	226.00
8	0.44	154.00	8	0.44	110.00	8	0.44	106.00	8	0.44	256.00
10	1.15	158.00	11	1.41	123.00	11	1.41	118.00	11	1.41	297.00
11	1.41	181.00	12	1.67	145.00	12	1.67	141.00	12	1.67	337.00
12	1.67	203.00	15	2.65	153.00	15	2.65	147.00	15	2.65	366.00
15	2.65	224.00	16	3.16	181.00	16	3.16	174.00	16	3.16	416.00
16	3.16	252.00	19	3.93	182.00	19	3.93	175.00	19	3.93	431.00
19	3.93	266.00	20	4.69	215.00	20	4.69	208.00	20	4.69	490.00
20	4.69	299.00	24	6.23	248.00	24	6.23	240.00	23	5.21	493.00
23	5.21	306.00	28	7.76	281.00	28	7.76	271.00	24	6.23	561.00
24	6.23	344.00	35	9.06	289.00	35	9.06	278.00	28	7.76	627.00
34	7.28	358.00	32	9.29	312.00	32	9.29	302.00	35	9.06	650.00
28	7.76	387.00	39	10.34	313.00	36	10.83	331.00	32	9.29	687.00
35	9.06	415.00	36	10.83	342.00	40	12.37	359.00	39	10.34	694.00
32	9.29	428.00	40	12.37	371.00	44	13.91	386.00	36	10.83	743.00
39	10.34	447.00	44	13.91	398.00				40	12.37	794.00
36	10.83	468.00							44	13.91	840.00
43	11.62	478.00									
40	12.37	505.00									
44	13.91	540.00									

T A B L E : 7.5 PARETO OPTIMAL SOLUTIONS WITH RANK ORDER.

designer can use three windows of window number 11 (1.0m width X 1.50 m height).

CONCLUSION

CONCLUSION

As the Conclusion to this study it is necessary to evaluate the importance of the work, the way the problem was tackled, the practical usefulness of the results, the role of this kind of work in the age of the computer, in which computer simulation models or expert system packages are capable of producing a wide range of results and the directions of future research.

1- The Importance of Optimisation of Window Design

Since the window is a means of communication between the world outside buildings and the occupants and it has great environmental consequences it can work as one of the major factors in determining comfort, the activities inside the building, the level of energy consumption and psychological satisfaction. With this in mind, occupants expect the designer to design this element according to the function and the type of the building, environmental control and the psychological needs. But, due to many the demands made on designers in facing all the problems raised during design, they cannot afford the time to carry out all the calculations and measurements required for the selection of a good window in a specific situation. However, they <u>can</u> manage to find time to select what they need if the information is readily available. Consequently, carrying out any work on such an important element of the building will release pressure on designers and allow them to invest more time on the overall improvement of internal environment of the building, so that the global goal of giving pleasure as well as economical running cost can be achieved. Therefore this study can be considered as a modest contribution aimed to provide the designer with much wider information base, which for, the time being, not only fills a gap but forms a base for further study. It also can be used on a trial basis to observe the response of designers on the usefulness of this information before this further study is undertaken. It is intended to publish a condensed and practical document based on this study with the aim of immediately starting to obtain this feedback.

2- The Way the Problem Was Tackled

Many years before the author started this study the problem began to occupy his mind through his discussion with a large number of designers in Iraq and his involvement with the activity of the International Association of Housing Science. He realized that, to tackle such a problem one has to be involved from the early stage of the design in order to foresee all the later consequences of window design decisions. Therefore, although the author wanted to provide designers with data on window dimensions, prepared on the basis of calculations, in order to produce results having practical value as well as a sound theoretical base, he had to start the study from consideration of the early design stages before he could decide what type of data to produce. Originally, it was the author's intention to discuss the results of this study with window manufacturers and the people in the building industry before selecting a method for presenting the results and recommendations. However, since such a task was impossible at this stage, the results have been produced and presented in the hope that, with the future simplification, it will meet the present requirements and with a view to future discussions with window manufacturers and building designers before the proposed future work, mentioned in chapter 4,5,6 and 7, is carried out.

3- The Practical Usefulness of the Results

The recommendations give groups of windows and have not been restricted to single or very limited solutions. Thus the designer is free to select a window on the basis of whatever balance of performance is chosen.

Since all constructions depend on brick module, the builder will find that, any window selected by the designer or produced by the window manufacturer, if this dimensional range is adopted, will fit without difficulty.

4- The Value of this Work in the Age of the Computer

Computer simulation models, as well as being enumerative and rigorous, are capable of tackling many problems. Nevertheless, it is clear that most of these systems, apart from being expensive to buy and needing sophisticated software and hardware, also require training and sometimes even an expert on hand to run them. Moreover, with a large number of alternative solutions, it is time consuming to digitalize building plans and input relevant data to create usable files.

Although most designers are now aware of the powerful capabilities of the computer, they are unwilling and unable to tackle tasks regarding this amount of labour in formating and inputting design, climatic and other data, especially when these tasks have to be carried out iteratively. Until such time as expert and interactive system become available, handbooks and design guides, based on studies such as this one, will continue to be used. Once these new systems are available, studies of this type can become the basis of the new data banks. It is the author's hope to become involved in this future work.

5- Future Research.

At the conclusion of Chapter 4,5,6 and 7 summaries of future work are presented.

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APPENDIX 1

APPENDIX 1

I- Derivation of Sunpatch Calculation Formula 4.9

looking at Figure A1.1

W = Window width

H = Window height

K = Wall thickness

V.S.= Vertical shadow angle

H.S.= Horizontal shadow angle

If wall thickness = 0

$X = H \text{ Cot V.S.}$

Then sunpatch area = $W * H \text{ Cot V.S.}$

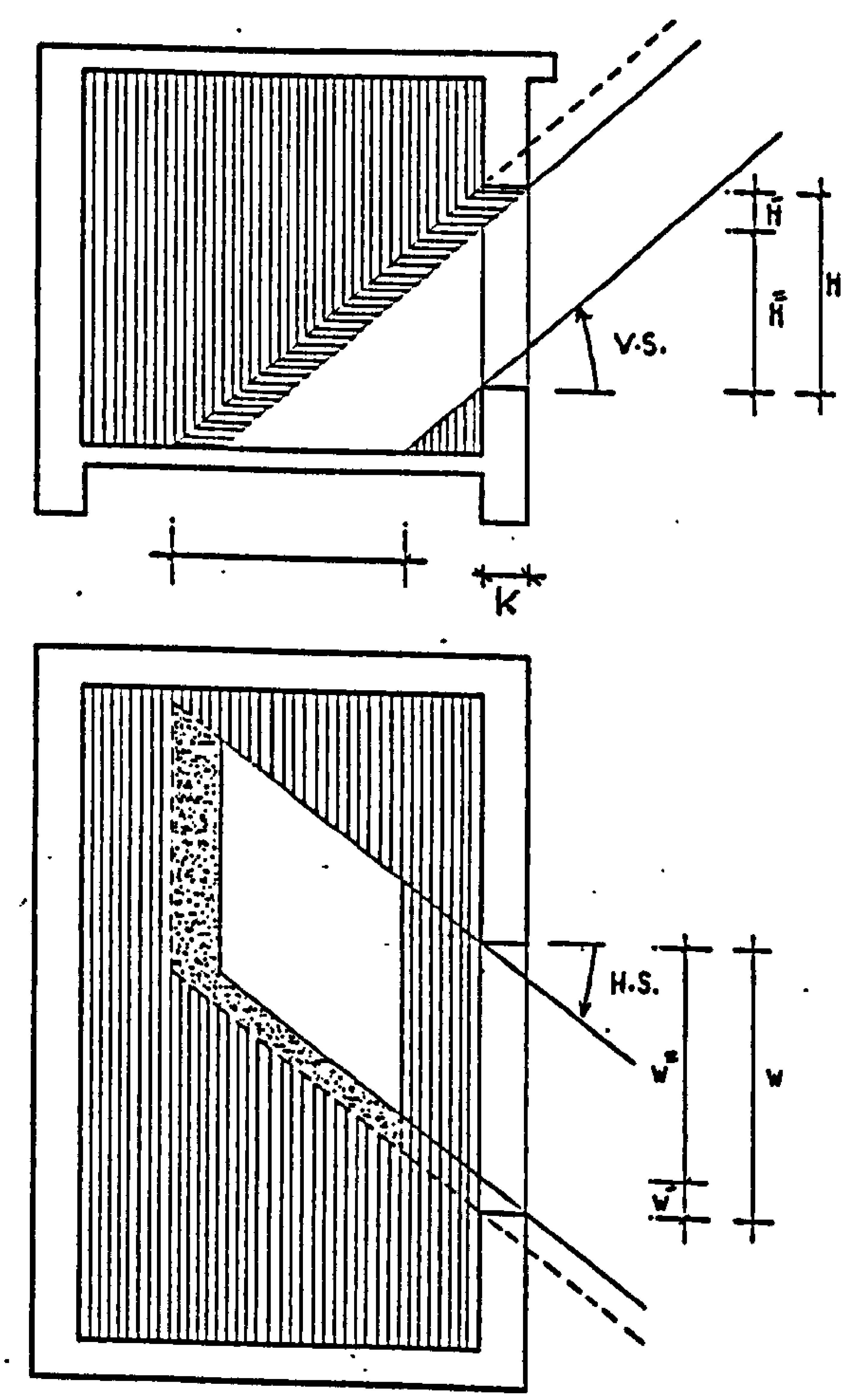
If the wall thickness = K

Then the effective window height

$H'' = H - H'$

and the effective window width is

$W'' = W - W'$



$H' = K \text{ Tan V.S.}$

$H'' = H - K \text{ Tan V.S.}$

$W' = K \text{ Tan H.S.}$

$W'' = W - K \text{ Tan H.S.}$

The sunpatch area A is:

$A = W'' * H'' \text{ Cot V.S.}$

Or

$A = (W - K \text{ Tan H.S.})(H - K \text{ Tan V.S.})(\text{Cot V.S.})$

$A = W*H*\text{Cot V.S.} - W*K - K*H*\text{Cot V.S.}* \text{Tan H.S.} + K\char`^2*\text{Tan(H.S.)}$

II- The Derivation of (Cos h, Sin h, Cos B, Sin B and dh) used in the calculation of sky component and external reflected component equation 5.25 to 5.51 in terms of angles G, r.

1-

$$\mathrm{Cos}\ h = H/N = H/(R^2 + H^2)^{0.5}$$

$$= (H*K/S*R)/((R^2*K^2/S^2*R^2)+(H^2*K^2/S^2*R^2))^{0.5}$$

$$= ((H/S)(K/R))/(((H^2/S^2)(K^2/R^2))+(K^2/S^2))^{0.5}$$

$$\mathrm{Cos}\ h = (\mathrm{Cos}\ G * \mathrm{Cos}\ r)/(((\mathrm{Cos}\ G)^2)(\mathrm{Cos}\ r)+(\mathrm{Sin}\ G)^2)^{0.5}$$

2-

$$R = (((\mathrm{Cos}\ G)^2)((\mathrm{Cos}\ r)^2)+((\mathrm{Sin}\ G)^2)-((\mathrm{Cos}\ G)^2)(\mathrm{Cos}\ r)^2)^{0.5}$$

$$R = \mathrm{Sin}\ G$$

$$\mathrm{Sin}\ h = (\mathrm{Sin}\ G)/((((\mathrm{Cos}\ G)^2)((\mathrm{Cos}\ r)^2))+((\mathrm{Sin}\ G)^2))^{0.5}$$

Let $X = (((\mathrm{Cos}\ G)^2)((\mathrm{Cos}\ r)^2)+((\mathrm{Sin}\ G)^2))^{0.5}$

Then

$$\mathrm{Cos}\ h = (\mathrm{Cos}\ G * \mathrm{Cos}\ r)/ X^{0.5}$$

$$\mathrm{Sin}\ h = (\mathrm{Sin}\ G)/ X^{0.5}$$

3-

$$\mathrm{Cos}\ B = K/N$$

As $N = X^{0.5}$, $K=R*\mathrm{Cos}\ r$ and $R=\mathrm{Sin}\ G$

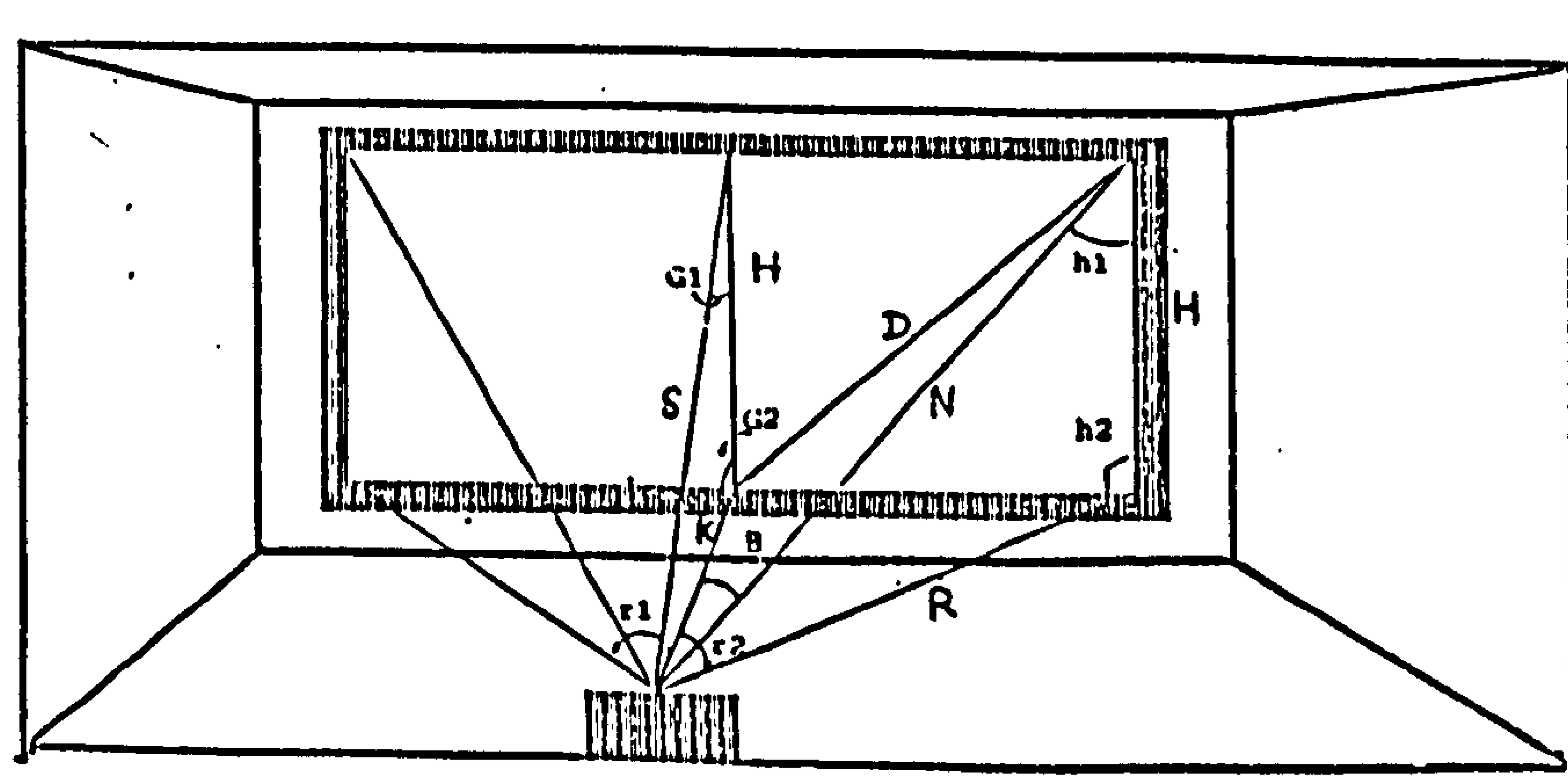
$$\mathrm{Cos}\ B = (\mathrm{Cos}\ r)(\mathrm{Sin}\ G)/X^{0.5}$$

4-

$$\mathrm{Sin}\ B = D/N$$

$$N^2 = D^2 + K^2$$

$$D^2 = N^2 - K^2$$



```
  D^2 = (((Cos G)^2)((Cos r)^2))+((Sin G)^2)-((Cos r)^2)((Sin
G)^2)

   D = [((Sin G)^2)+((Cos r)^2)(((Cos G)^2)-((Sin G)^2))]^0.5

         [((Sin G)^2)+((Cos r)^2)(((Cos G)^2)-((Sin G)^2))]^0.5
Sin B = -------------------------------------------------------
                                  X^0.5
5-
                  Cos G * Cos r
Cos h = ------------------------------------------
         (((Cos G)^2)((Cos r)^2)+((Sin G)^2))^0.5

dCos h                 dh
-----  = -  Sin h  ----
dG                     dG

d      Cos G * Cos r
--  ------------------------------------------
dG   (((Cos G)^2)((Cos r)^2)+((Sin G)^2))^0.5

If X = (((Cos G)^2)((Cos r)^2)+((Sin G)^2))
Then
d     Cos G * Cos r
--    -------------
dG       X^0.5

     - Sin G * Cos r
=   -----------------    -
         X^0.5

1   (Cos G * Cos r(-2Cos G * Sin G*((Cos r)^2)+2(Sin G)(Cos G))
- * -------------------------------------------------------------
2                            X^1.5

     - Cos r
=   ---------- *[(Sin G)((Cos G)^2)((Cos r)^2)+(((Sin G)^3)-
      X^1.5

        (((Cos G)^2)(Sin G)((Cos r)^2)+((Sin G)(Cos G)^2))]

     - Cos r * Sin G   [((Sin G)^2)+((Cos G)^2)]
=   ---------------
       X^1.5
```

As $((\sin G)^2) + ((\cos G)^2) = 1$ Then,

$$= \frac{-\cos r * \sin G}{X^{1.5}} = -\sin h \frac{dh}{dG}$$

$$dh = \frac{\cos r * \sin G}{X^{1.5}} * \frac{X^{0.5}}{\sin G} dG$$

$$dh = \frac{\cos r}{X} dG$$

III- The Computer Programs

1- The Computation of Sunpatch Areas

This program calculates the sunpatch area formed by 77 different windows as mentioned in Chapter 4 in a room with an infinite floor area and presents the results in tabular form. The program reads in the data or can read a data file consisting of the horizontal and vertical shadow angles, which simulate the overshading. The data files were constructed according to the findings from the experiment on the Heliodon. (The language: BASIC)

2- This program reads the result from a program similar to the first, but with the capability of reading six data files, and presents them in graphic form. (The language: FORTRAN)

3- This program calculates the Sky Component and the External Reflected Component formed by 44 different windows as explained in Chapter 5. The data required are: wall thickness, wall obstruction heights and widths, sun altitudes, external reflection factors, interhouse distance and fH values. The program has no comment or remark statements and this needs to be done in the future to make it available for use by others. (The language: FORTRAN)

4- This program is to read four output files of the Pareto optimal solutions formed by Stephen Taylor computer program

(PARETO Optimal Solution Database System Ref.200) and all the remaining solutions and prepares them to be read by another program which plots them in four graphs in one page. (The language: BASIC)

5- This program handles the information prepared by program No.4 and draws it in garaphic form. (The language: FORTRAN)

Computer Program No. 1

```
10 DIM J1(13,16),S1(13,16),O1(13,16),D1(13,16)
20 DIM J2(13,16),S2(13,16),O2(13,16),D2(13,16),T(3)
30 P=3.14159
40 FOR I = 1 TO 3
50 READ T(I)
60 NEXT I
70 FOR I = 1 TO 13
80 FOR J = 1 TO 16
90 READ J1(I,J),J2(I,J)
100 J2(I,J)=J2(I,J)*P/180.0
110 J1(I,J)=J1(I,J)*P/180.0
120 NEXT J
130 NEXT I
140 FOR I = 1 TO 13
150 FOR J = 1 TO 16
160 READ D1(I,J),D2(I,J)
170 D1(I,J)=D1(I,J)*P/180.0
180 D2(I,J)=D2(I,J)*P/180.0
190 NEXT J
200 NEXT I
210 FOR I = 1 TO 13
220 FOR J=1 TO 16
230 S1(I,J)=S1(I,J)*P/180.0
240 S2(I,J)=S2(I,J)*P/180.0
250 NEXT J
260 NEXT I
270 FOR I=1 TO 13
280 FOR J = 1 TO 16
290 O1(I,J)=O1(I,J)*P/180.0
300 O2(I,J)=O2(I,J)*P/180.0
310 NEXT J
320 NEXT I
330 FOR K=1 TO 16
340 D=22.5*(K-1)
350 FOR J= 1 TO 2
360 PRINT "ORIENTATION = ";D,"WALL THICKNESS = ";T(J)
370 PRINT
380 PRINT
390 PRINT "  X     Y      A1      SA      SA/A1      WA      WA/A1     ";
400 PRINT "WA/SA   WA/2SA"
410 PRINT
420 FOR X=0.5 TO 3.0 STEP 0.25
430 FOR Y= 0.5 TO 2.0 STEP 0.25
440 S9=0
450 W9=0
460 FOR I=1 TO 13
470 IF J2(I,K)<> 0 GOTO 500
480 IF J1(I,K) <> 0 GOTO 500
490 GO TO 580
500 A5=Y*COT(J2(I,K))-T(J)
510 IF A5 <= 0 GOTO 580
520 A6=X-T(J)*TAN(J1(I,K))
530 IF A6 <=0 GOTO 580
540 S=A5*A6
550 IF S >= 0 GO TO 570
560 GOTO 580
570 S9=S9+S
580 IF D2(I,K) <> 0 GOTO 610
590 IF D1(I,K) <> 0 GOTO 610
600 GO TO 690
610 A7=Y*COT(D2(I,K))-T(J)
620 IF A7 <= 0 GOTO 690
630 A8=X-T(J)*TAN(D1(I,K))
640 IF A8 <= 0 GOTO690
650 W=A7*A8
660 IF W >= 0 GOTO 680
670 GO TO 690
680 W9=W9+W
690 NEXT I
700 A1=X*Y
710 S1=S9/A1
720 W1=W9/A1
730 IF S9 <> 0 GOTO 750
```

```
740 S9=0.01
750 R1=W9/S9
760 R2=W9/(2*S9)
770 IF S9 <> 0.01 GOTO 790
780 S9=0
790 PRINT USING 800,X,Y,A1,S9,S1,W9,W1,R1,R2
800: #.## #.##   #.##   ####.##   ###.##   ####.##   ###.##   ###.##  ##.##
810 NEXT Y
820 NEXT X
830 PRINT
840 PRINT
850 PRINT
860 NEXT J
870 NEXT K
880 DATA 0.12,0.24,0.36
890 DATA 0,0,48,18,0,0,0,0,0,0,42,17,65,28,87,79,0,0,0,0,0,0,0,0,0,0
900 DATA 0,0,0,0,0
910 DATA 0,0,55,38,0,0,0,0,0,0,0,0,58,41,80,70,0,0,0,0,0,0,0,0
920 DATA 0,0,0,0,0,0,0,0
930 DATA 84,82,61,58,39,44,0,0,0,0,0,0,31,30,74,69
940 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
950 DATA 0,0,69,73,47,60,0,0,0,0,0,0,0,0,66,71,88,89
960 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0
970 DATA 0,0,80,85,57,74,0,0,0,0,0,0,0,0,0,0,78,84
980 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0
990 DATA 0,0,0,0,77,86,55,80,32,76,0,0,0,0,0,0,56,81,80,87
1000 DATA 0,0,0,0,0,0,0,0,0,0,0,0
1010 DATA 0,0,0,0,0,0,0,0,0,0,68,86,45,83,23,81,0,0
1020 DATA 23,81,45,83,68,86,0,0,0,0,0,0,0,0
1030 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,80,87,56,81
1040 DATA 0,0,0,0,10,74,32,76,55,90,77,86,0,0
1050 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,78,84
1060 DATA 0,0,0,0,0,0,0,0,35,66,57,74,80,85
1070 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,88,89,0,0,0,0,0,0,0,0,0,0
1080 DATA 0,0,69,73
1090 DATA 84,82,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1100 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0
1110 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1120 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0
1130 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1140 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0
1150 DATA 0,0,0,0,81,48,59,18,0,0,0,0,0,0,0,0,54,16,76,36,0,0,0,0,0
1160 DATA 0,0,0,0,0,0,0
1170 DATA 0,0,0,0,0,0,69,44,0,0,0,0,0,0,0,0,0,0,66,40,88,85,0,0
1180 DATA 0,0,0,0,0,0,0,0
1190 DATA 0,0,0,0,0,0,82,74,0,0,0,0,0,0,0,0,0,0,53,40,76,64,0,0
1200 DATA 0,0,0,0,0,0,0,0
1210 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1220 DATA 0,0,61,52,84,80,0,0,0,0,0,0,0,0
1230 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1240 DATA 0,0,0,0,68,60,0,0,0,0,0,0,0,0
1250 DATA 0,0,0,0,0,0,0,0,0,0,84,80,0,0,0,0,0,0,0,0
1260 DATA 0,0,31,45,74,66,0,0,0,0,0,0
1270 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1280 DATA 37,32,59,44,82,74,0,0,0,0
1290 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1300 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0
1310 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,81,48,0,0
1320 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1330 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1340 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1350 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
```

Computer Program No. 2

```
*

10*#RUN=(ULIB)LIBRARY/GINO/GINOLIB
20  DIMENSION E(77,3,16,6),EMAX(16),XX(77),THICK(3)
30 INTEGER WD,HD1,HD2
40 DATA EMAX/900.0,900.0,900.0,900.0,900.0,900.0,900.0,3000.0,
50  &3000.0,3000.0,900.0,900.0,900.0,900.0,900.0,
60  &900.0/
70  DATA THICK/0.12,0.24,0.36/
80 CALL ATTACH(8,"XMAS;",1,0,IIII,)
100  READ,WD,HD1,HD2
110  DO 8 IY=1,7
120  DO 8 IX=1,11
130  X=(IX-1)/44.0
140  Y=IY/4.0+0.25
150  8 XX((IY-1)*11+IX)=X+Y
160  DO 1 IDIST=1,6
170  DO 1 IORIEN=1,16
180 DO 1 ITHICK=1,3
190 DO 1 IX=1,11
200 DO 1 IY=1,7
210 IXY=(IY-1)*11+IX
220  READ(8,100)X,Y,EE
230  IF(EE.LE.0.1)EE=0.1
240 1E(IXY,ITHICK,IORIEN,IDIST)=EE
250 100 FORMAT(V)
260 CALL RCOSIZ(8000)
270  CALL RCO(10,'PFILE;')
280 CALL CHASIZ(2.6,2.6)
290 DO 2 ITHICK=1,3
300  DO 2 IORIEN=1,16
310 CALL AXISCA(4,10,0.1,EMAX(IORIEN),2)
320  CALL AXIPOS(1,20.0,20.0,120.0,1)
350 CALL AXIPOS(1,20.0,20.0,100.0,2)
360 CALL AXISCA(3,7,0.5,2.25,1)
370 CALL AXIDRA(-2,-1,2)
380 CALL AXIDRA(1,1,1)
400 CALL MOVTO2(20.0,1.0)
410 CALL CHAHOL('WD= *.')
420 CALL CHAINT(WD,2)
430 CALL CHAHOL('M    HD1= *.')
440 CALL CHAINT(HD1,2)
450 CALL CHAHOL('M    HD2= *.')
460 CALL CHAINT(HD2,2)
470 CALL CHAHOL('M  HOUSE T.=2.0 ST.*.')
475 CALL MOVTO2(5.0,10.0)
480 CALL CHAHOL('Y. EFFICIENCY    W. THICKNESS=*.')
490 CALL CHAFIX(THICK(ITHICK),6,2)
500 CALL CHAHOL('M    W. ORIENTATION=*.')
510 ORIENT = 22.5*(IORIEN-1)
520 CALL CHAFIX (ORIENT,6,2)
530 DO 3 IDIST=1,6
540 CALL GRAPOL(XX,E(1,ITHICK,IORIEN,IDIST),77)
550 CALL LINBY2(1.0,-1.1)
560 CALL CHAINT(IDIST,2)
570 3 CONTINUE
580 TICKS 1=1.1
590 TICKS 2=1.5
600  DO 4 IY=1,7
610 DO 5 IX=1,11
620  CALL GRAMOV(XX((IY-1)*11+IX),0.1)
630  CALL LINBY2(0.0,TICKS1)
640 CALL GRAMOV(XX((IY-1)*11+IX),EMAX(IORIEN))
650 CALL LINBY2(0.0,TICKS1)
660 5 CONTINUE
670  CALL LINBY2(0.0,TICKS2)
680 4 CONTINUE
690 2 CALL PICCLE
700 CALL DEVEND
710 STOP
720 END
```

Computer Program No. 3

```
*#RUN*(ULIB)LIBRARY/NAG/LIB
SUBROUTINE INTEGR(OMGLOW.OMGHIH.RHO1.RHO2.ANS,F)
IMPLICIT REAL*8(A-H,O-Z)
EXTERNAL F,P1,P2
 COMMON THETAS.PI.R1.R2.ITHETA
CALL FXOPT(89,1,1,0)
PI= ATAN(1.0D0)*4.0D0
ABSACC=1.0E-6
IFAIL=0
R1=RHO1
R2=RHO2
100 FORMAT(1X,'ANSWER=',F20.10)
CALL D01 DAF(OMGLOW,OMGHIH.P1,P2.F.ABSACC,ANS,NPTS.IFAIL)
RETURN
END
FUNCTION P1(OMG)
IMPLICIT REAL*8(A-H,O-Z)
COMMON THETAS.PI.R1,R2,ITHETA
P1=R1
RETURN
END
FUNCTION P2(OMG)
IMPLICIT REAL*8(A-H,O-Z)
COMMON THETAS.PI.R1.R2.ITHETA
P2=R2
RETURN
END
FUNCTION G(R.OMG)
IMPLICIT REAL*8(A-H,O-Z)
COMMON THETAS.PI.R1.R2.ITHETA
G=SIN(OMG)*COS(R)**2*COS(OMG)/(COS(OMG)**2*COS(R)**2+(SIN(OMG)**2))**2.0
RETURN
END
FUNCTION F(R,OMG)
IMPLICIT REAL*8(A-H,O-Z)
COMMON THETAS.PI.R1.R2.ITHETA
DIMENSION RS(5).RW(5)
DATA RS/ 3.1410D0, 2.7489OD0, 2.3560D0, 1.9630D0, 1.57070D0/
DATA RW/-1.57070D0,-1.1780D0,-.78530D0,-0.39260D0,0.00D0/
X=COS(OMG)**2*COS(R)**2+SIN(OMG)**2
DELTA=ACOS((1/(X)**0.5)*(SIN(OMG)*SIN(THETAS)*COS(R+RW(ITHETA)+RS(ITHETA))+
& COS(OMG)*COS(THETAS)*COS(R)))
AA=SIN(OMG)**2*COS(OMG)*COS(R)**3/X**2.5
BB=(SIN(OMG)**2+COS(R)**2*(COS(OMG)**2-SIN(OMG)**2))/X
CC=EXP(-(0.32*SQRT(X)/(COS(OMG)*COS(R))))
DD=0.91+10*EXP(-3.0*DELTA)+0.45*COS(DELTA)**2
 F=AA*(1+BB**1.5)*(1-CC)*DD
RETURN
END
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION THETAX(5).FH(4,5),RW(5),RS(5),ANORM(5).DIS(1).DFDF(4),DFDF1(4),SLUX1(4),SLUX2(4),RD1(4)
COMMON THETAS.PI.R1.R2.ITHETA
DATA THETAX/55.0D0.45.0D0,41.50D0,35.0D0,33.0D0/
DATA FH/0.020D0,0.020D0.0.020D0,0.020D0.0.020D0,
& 0.0500D0,0.050D0.0.050D0,0.050D0,0.050D0,
& 0.10D0,0.010D0,0.010D0,0.010D0.0.010D0,
& 0.150D0,0.150D0,0.150D0,0.150D0,0.150D0/
PI=ATAN(1.0D0)*4.0D0
DATA ANORM/2.630D0,2.769OD0,2.8030D0,2.8650D0,2.8830D0/
DATA DIS/2.500D0/
DATA RD1/1.00D0,2.00D0.3.00D0,4.00D0/
DO 20 IDIS=1.1
DO 20 ITHETA=1.5
CALL FPARAM(1,180)
WRITE(6,80)
80 FORMAT(1X,///////)
THETAS=THETAX(ITHETA)*PI/180.0
IF(ITHETA.EQ.1)WRITE(6.301)
IF(ITHETA.EQ.2)WRITE(6,302)
IF(ITHETA.EQ.3)WRITE(6.303)
IF(ITHETA.EQ.4)WRITE(6,304)
IF(ITHETA.EQ.5)WRITE(6.305)
WRITE(6,170)
170 FORMAT(40X,'  STAIRCASE THE WINDOW ON THE SIDE WALL -FIRSTD FLOOR')
HO=4.5
D=DIS(IDIS)
CALL FPARAM(1.180)
WRITE(6,101)HO.D
WRITE(6,81)(RD1(ID1),ID1=1,4)
WRITE(6.400)
WRITE(6,401)
WRITE(6,402)
WRITE(6,403)
EXTERNAL F.G
```

```
850 DO 20 IW=1,11
860 W=FLOAT(IW+1)/8.0
870  DO 20 IH=1,4
880 H=FLOAT(IH+3)/4.0
890 DO 51 ID1=1,4
900 D1=RD1(ID1)
910 81 FORMAT(18X,4('INTER-HOUSE DIST.=',F4.0,'M',7X))
920C W1=OBSTRACTION WIDTH RIGHT HAND SIDE
930 W1=1.0
940C W2=OBSTRACTION WIDTH LEFT HAND SIDE
950 W2=-5.0
960 HC=HO-1.75
970 WIDTH=2*W
980 PI=ATAN(1.0D0)*4.0D0
990 OMGLOW=ATAN2(D,(H+1.75))
1000 OMG1=OMGLOW
1010 OMGHIH=0.96007
1020  RHO1=ATAN2(-W,D)
1030 RHO2=ATAN2(W,D)
1040 RH1=RHO1
1050 RH2=RHO2
1060 CALL  INTEGR(OMGLOW,OMGHIH,RHO1,RHO2,SC1,F)
1070 OMGLOW=ATAN2(D+D1,HC)
1080 IF (OMGLOW.GT.ATAN(D/(H+1.75)))GOTO 1
1090 OMGLOW=ATAN2(D,(H+1.75))
1100 1  RHO1=ATAN2(W2,D+D1)
1110 IF ( (RHO1).GT. (ATAN(-W/D))) GOTO 2
1120 RHO1=ATAN(-W/D)
1130  2  RHO2= ATAN2(W1,D+D1)
1140 IF(RHO2.LT.ATAN(W/D))GOTO  3
1150 RHO2=ATAN(W/D)
1155 IF(OMGLOW>OMGHIH)OMGLOW=OMGHIH
1160 OMG2=OMGLOW
1170 RH3=RHO1
1180 RH4=RHO2
1190 CONSTA=ANORM(ITHETA)
1200 3  CALL INTEGR(OMGLOW,OMGHIH,RHO1,RHO2,OSC1,F)
1210 FINAL=(SC1-OSC1)*1.018*0.85*0.8/CONSTA
1220 CALL INTEGR(OMGLOW,OMGHIH,RHO1,RHO2,GG,G)
1230 DA=ATAN2(HO,D1)
1240 IF(DA .LT.PI/12)GOTO 71
1250 GOTO 72
1260 71 FS=0.783*(1-1.48*SIN(PI/2-THETAS))
1270 FG=0.05
1280 GOTO 8
1290 72 B1=ACOS((1/TAN(DA))*TAN(PI/12))
1300 B2=ATAN(TAN(B1)*COS(DA))
1310 FS=.783+.1845*SIN(B1)-.88*ALOG10((1+SIN(B2))/COS(B2))-.738*(1.57-B2)*SIN(DA)
1320 FG1=.5234+.7875*(B1)-.382*ASIN(SIN(DA*SIN(B1)))
1330 FG=FG1-1.159*(1-COS(DA)+0.637*B2*COS(DA))
1340 8 GFINAL=((GG)*0.85*0.8*0.25*(FH(ID1,ITHETA)+FS+FG))
1350 EGFINAL=((GG)*0.85*0.8*0.7*(FH(ID1,ITHETA)+FS+FG))
1360 FINAL=FINAL*100.0
1370 GFINAL=GFINAL*100.0
1380 EGFINAL=EGFINAL*100.0
1390 DF=FINAL+GFINAL
1400 EO=1.1+15.5*SIN((0.5*PI)-THETAS)**0.5
1410 SLUX02=EO*DF*10.0
1420 DF1=EGFINAL+FINAL
1430 SLUX07=EO*DF1*10.0
1440 DFDF(ID1)=DF
1450 DFDF1(ID1)=DF1
1460 SLUX1(ID1)=SLUX02
1470 SLUX2(ID1)=SLUX07
1480 101 FORMAT(45X,'    OBST.HIGHT',F5.2,'     POINT DIST.',F7.4////)
1490  51 CONTINUE
1500 WRITE(6,100)WIDTH,H,(DFDF(ID1),SLUX1(ID1),DFDF1(ID1),SLUX2(ID1),ID1=1,4)
1510 100 FORMAT(1X,2F6.2,4(4X,F5.2,2X,F5.0,2X,F5.2,2X,F5.0))
1520 301 FORMAT(//65X,'NORTH  &  SOUTH'//)
1530 302 FORMAT(///45X,'22.5  &  157.5  &  202.5  &  337.5'//)
1540 303 FORMAT(///45X, '45.0  &  135.0  &  225.0  &  315.0'//)
1550 304 FORMAT(///45X, '67.5  &  112.5  &  247.5  &  292.5'//)
1560 305 FORMAT(///65X,' EAST  &  WEST '//)
1570 400 FORMAT(1X,' W I N D O W',5X,4('SKY+EXTERNAL REFLECTION',7X))
1580 401 FORMAT(1X,'WIDTH   HEIGHT',3X,4('25%WALLREFL.  70%WALLREFL.',4X))
1590 402 FORMAT(17X,4('FA %    LUX    FA%    LUX',6X))
1600 403 FORMAT(1X,'______ ______     ',4('_____ _____ _____ _____',4X))
1610 20 CONTINUE
1620 STOP
1630 END
```

Computer Program No. 4

```
10 FILES ?M?DA;?M?.R1;?M?.R2;?M?.R3;?M?.R4;MOUT
20 DIM D(44,4),S(44,4),C(44,4),X(44),Y(44),N(4),L(44)
30 SCRATCH#6
40 FOR I=1 TO 44
50 INPUT#1,L,X1,X2,S(I,1),D(I,1),S(I,2),D(I,2),S(I,3),D(I,3),S(I,4),D(I,4)
60 NEXT I
65 PRINT"TYPE MAX. VALUE FOR X-AXIS  DAYLIGHT  FOR GRAPH 1    M1="
70 INPUT M1
75 PRINT"TYPE MAX. VALUE FOR X-AXIS DAYLIGHT FOR GRAPH 2    M3="
80 INPUT M3
85 PRINT"TYPE MAX. VALUE FOR X-AXIS DAYLIGHT FOR GRAPH 3    M5="
90 INPUT M5
95 PRINT"TYPE MAX. VALUE FOR X-AXIS DAYLIGHT FOR GRAPH 4    M7="
100 INPUT M7
105 PRINT "TYPE MAX. VALUE FOR Y-AXIS DIRECT SUNLIGHT FOR GRAPH 1 M2="
110 INPUT M2
115 PRINT"TYPE MAX.VALUE FOR Y-AXIS DIRECT SUNLIGHT FOR GRAPH 2  M4="
120 INPUT M4
125 PRINT"TYPE MAX.VALUE FOR Y-AXIS DIRECT SUNLIGHT FOR GRAPH 3   M6="
130 INPUT M6
135 PRINT"TYPE MAX.VALUE FOR Y-AXIS DIRECT SUNLIGHT FOR GRAPH 4   M8="
140 INPUT M8
150 FOR I=1 TO 4
160 J=I+1
170 INPUT#J,N(I)
180 FOR K=1 TO N(I)
190 INPUT#J,C(K,I),X1,X2
200 NEXT K
210 NEXT I
220 FOR P= 1TO 4
230 IF P=1 THEN 270
240 IF P=2 THEN 300
250 IF P=3 THEN 330
260 IF P=4 THEN 360
270 T=M1
280 R=M2
290 GOTO 380
300 T=M3
310 R=M4
320 GOTO 380
330 T=M5
340 R=M6
350 GOTO 380
360 T=M7
370 R=M8
380 K=-1
390 PRINT#6,7,T,R,999
400 PRINT#6,4,999,999,999
410 FOR I=1 TO 44
420 K=K+1
430 X(I)=(K)*2.5+D(I,P )/T*2.5
440 Y(I)=S(I,P)/R*6.9
450 IF I=5 THEN 670
460 IF I=6 THEN 670
470 IF I=7 THEN 670
480 IF I=8 THEN 670
490 IF I=13 THEN 670
500 IF I=14 THEN 670
510 IF I=15 THEN 670
520 IF I=16 THEN 670
530 IF I=21 THEN 670
540 IF I=22 THEN 670
550 IF I=23 THEN 670
560 IF I=24 THEN 670
570 IF I=29 THEN 670
580 IF I=30 THEN 670
590 IF I=31 THEN 670
600 IF I=32 THEN 670
610 IF I=37 THEN 670
620 IF I=38 THEN 670
630 IF I=39 THEN 670
640 IF I=40 THEN 670
650 PRINT#6,1,I,X(I),Y(I)
660 GOTO 680
670 PRINT#6,6,I,X(I),Y(I)
680 IF K<>3 THEN 700
690 K=-1
700 NEXT I
710 L=C(1,P)
720 PRINT#6,2,X(L),Y(L),999
730 FOR I=2 TO N(P)
740 L=C(I,P)
750 PRINT#6,3,X(L),Y(L),999
760 NEXT I
770 NEXT P
780 PRINT#6,5,999,999,999
790 STOP
800 END
```

Computer Program No. 5

```
10*#RUN=(ULIB)LIBRARY/GINO/GINOLIB
20 CALL ATTACH(12,"MOUT;",1,0,IREP,)
30 CALL RCD(10,'PFILE;')
40 CALL UNITS(10.0)
50 CALL DEVPAP(50.0,40.0,0)
60 CHSZ=0.252/2.0
70 CALL BROKEN(1)
80 CALL MOVTO2(0.0,1.0)
90 CALL LINTO2(0.0,22.0)
100 CALL MOVTO2(0.0,22.0)
110 CALL LINTO2(30.0,22.0)
120 CALL MOVTO2(0.0,1.0)
130 CALL LINTO2(30.0,1.0)
140 CALL MOVTO2(30.0,1.0)
150 CALL LINTO2(30.0,22.0)
160 CALL MOVTO2(0.0,7.0)
170 CALL LINTO2(1.50,7.0)
180 CALL MOVTO2(1.50,7.0)
190 CALL LINTO2(1.50,1.0)
200 CALL MOVTO2(1.0,7.0)
210 CALL CHAANG(-90.0)
220 CALL CHASIZ(CHSZ*3.0,CHSZ*3.0)
230 CALL CHAHOL(' 1 :F:H122:S11 *.')
240 CALL BROKEN(0)
250 CALL CHASIZ(CHSZ*1.5,CHSZ*1.5)
260 CALL CHAANG(0.0)
270 CALL MOVTO2(3.50,19.0)
280 CALL CHAHOL('H= 1.00M*.')
290 CALL MOVTO2(6.0,19.0)
300 CALL CHAHOL('H= 1.25M*.')
310 CALL MOVTO2(8.5,19.0)
320 CALL CHAHOL('H= 1.50M*.')
330 CALL MOVTO2(11.0,19.0)
340 CALL CHAHOL('H= 1.75M*.')
350 CALL MOVTO2(17.50,19.0)
360 CALL CHAHOL('H= 1.00M*.')
370 CALL MOVTO2(20.0,19.0)
380 CALL CHAHOL('H= 1.25M*.')
390 CALL MOVTO2(22.50,19.0)
400 CALL CHAHOL('H= 1.50M*.')
410 CALL MOVTO2(25.0,19.0)
420 CALL CHAHOL('H= 1.75M*.')
430 CALL MOVTO2(3.5,10.0)
440 CALL CHAHOL('H= 1.00M*.')
450 CALL MOVTO2(6.0,10.0)
460 CALL CHAHOL('H= 1.25M*.')
470 CALL MOVTO2(8.5,10.0)
480 CALL CHAHOL('H= 1.50M*.')
490 CALL MOVTO2(11.0,10.0)
500 CALL CHAHOL('H= 1.75M*.')
510 CALL MOVTO2(17.50,10.0)
520 CALL CHAHOL('H= 1.00M*.')
530 CALL MOVTO2(20.0,10.0)
540 CALL CHAHOL('H= 1.25M*.')
550 CALL MOVTO2(22.50,10.0)
560 CALL CHAHOL('H= 1.50M*.')
570 CALL MOVTO2(25.0,10.0)
580 CALL CHAHOL('H= 1.75M*.')
590 CALL MOVTO2(10.50,11.50)
600 CALL CHAHOL(' Daylight -LUX-*.')
610 CALL MOVTO2(3.0,11.0)
620 CALL CHAHOL(' I N T E R H O U S E  D I S T A N C E 22M (2S). -*.')
630 CALL MOVTO2(24.50,11.50)
640 CALL CHAHOL(' Daylight -LUX-*.')
650 CALL MOVTO2(17.0,11.0)
660 CALL CHAHOL(' I N T E R H O U S E  D I S T A N C E 38M (1S). -*.')
670 CALL MOVTO2(10.50,2.50)
680 CALL CHAHOL(' Daylight -LUX-*.')
690 CALL MOVTO2(3.0,2.0)
700 CALL CHAHOL(' I N T E R H O U S E  D I S T A N C E 300M  G & F -*.')
710 CALL MOVTO2(24.50,2.50)
720 CALL CHAHOL(' Daylight -LUX-*.')
730 CALL MOVTO2(17.0,2.0)
740 CALL CHAHOL(' I N T E R H O U S E  D I S T A N C E 38M (1S) STAIRCASE -*.')
750 CALL CHAANG(90.0)
760 CALL MOVTO2(2.10,14.0)
770 CALL CHAHOL('Direct Sunlight (    )*.')
780 CALL MOVTO2(16.10,14.0)
790 CALL CHAHOL('Direct Sunlight (    )*.')
800 CALL MOVTO2(2.10,5.0)
810 CALL CHAHOL('Direct Sunlight (    )*.')
820 CALL MOVTO2(16.10,5.0)
830 CALL CHAHOL('Direct Sunlight (    )*.')
840 CALL CHAANG(0.0)
```

```
CALL CHASIZ(CHSZ,CHSZ)
IDIAG=1
1 READ(12,100)KODE,X,Y,Z
100 FORMAT(V)
IF(KODE.LT.1.OR.KODE.GT.7)GOTO 999
GOTO(51,52,53,54,55,56,57),KODE
51 NUM=X
X=Y
Y=Z
CALL MOVTO2(X,Y)
CALL SYMBOL(3)
CALL MOVBY2(.5,0.0)
CALL CHAINT(NUM,2)
GOTO 1
56 NUM=X
X=Y.
Y=Z
CALL MOVTO2(X,Y)
CALL SYMBOL(2)
CALL MOVBY2(-.5,0.0)
CALL CHAINT(NUM,2)
GOTO 1
52 CALL MOVTO2(X,Y)
GOTO -1
53 CALL LINTO2(X,Y)
GOTO 1
54 CONTINUE
IF(IDIAG.EQ.1)GOTO 200
IF(IDIAG.EQ.2)GOTO 470
IF(IDIAG.EQ.3)GOTO 490
IF(IDIAG.EQ.4)GOTO 510
IF(IDIAG.EQ.5)GOTO 55
200 CALL SHIFT2(3.0,12.0)
1000 CALL AXIPOS(1,0.0,0.0,6.9,2)
CALL AXISCA(3.8,0.0,R,2)
CALL AXIDRA(-1,-1,2)
XV=0.0
DO 10 I=1,4
CALL AXIPOS(1,XV,0.0,2.5,1)
CALL AXISCA(3,5,0.0,T,1)
CALL AXIDRA(1,1,1)
XV=XV+2.5
IF(I.EQ.4)GOTO 9
CALL BROKEN(2)
CALL MOVTO2(XV,0.0)
CALL LINTO2(XV,6.9)
CALL BROKEN(0)
9 CONTINUE
10 CONTINUE
GOTO 900
470 CALL SHIFT2(14.0,0.0)
GOTO 1000
490 CALL SHIFT2(-14.0,-9.0)
GOTO 1000
510 CALL SHIFT2(14.0,0.0)
GOTO 1000
900 IDIAG=IDIAG+1
GOTO 1
55 CALL DEVEND
STOP
57 R=Y
T=X
GOTO 1
999 PRINT,'MIRSIM'
STOP
END
```