A BIO-CLIMATIC APPROACH TO HOUSE DESIGN FOR SEMI-DESERT AND HOT CLIMATES
(with special reference to Egypt)

VOLUME II

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Chapter 5 : ENVIRONMENTAL HOUSE DESIGN : Analysis of Historical Precedent in Egypt

5.1 Background to the Historical Analysis

History of buildings as a prototype of modern architecture seems to contain within it considerable values. In the context of this chapter the study of history will aim at better understanding of ourselves, our environment and our architecture, hoping to learn valuable lessons from the design process, rather than simply judging and criticizing. Therefore history will be considered as experimental evidence demonstrating both the advantages and the disadvantages of its architecture which resulted from the interactions between thoughts, social factors and physical environment prevalent at the time.

Looking back into the past, history will be considered from the point of view of our own place and time[1]; from this stand history comes down to us. There are other points of view from which the history of architecture would look different, but they will be relevant to ours in sharing the moment. Our stand will be an environmental one; we will look into history through an environmental window, the width of which is a function of the knowledge available at the time, and particularly that within the reach of the author.

Architectural design in history can be likened to the evolution of species, it is developed with the passing of time, one evolves from another. It is also like an ever

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1 The place here will refer to the western stand, while the time will mean the beginning of the eighties.

developing garden where beside the beautiful fully grown plants there are others still in progress, and more are decaying to enrich the soil. The gardeners may change, the external forces may differ from season to season, but the garden will continuously be enriched with the passing of time. Every period will have within it the seeds of the following one.

Architecture as a work of man is continuous and humane. Many ways have been suggested for categorizing the large body of architecture into types. Allsop (10) defines architecture as comprising five types - folk, vernacular, spiritual, monumental and utilitarian. There are inconsistencies in the index used to define these categories. Folk and vernacular architecture can be considered as two names for one section evolved from the architectural experience of the folk, ie the architecture in current use by the folk. These may include work of architects[1] who design within the folk traditions, and mainly relate to the natural environment. Spiritual architecture, as seen in most types of temples, is in itself a monument for God, a reminder of His presence, and is usually to glorify and symbolize the ideas of His superiority and the way the people offer their thanks. In many cases it includes a tomb to the memory of the person who built it and might have a cemetery yard within its vicinity. Spiritual and monumental architecture fall at one end on the architectural scale.

In early architecture one can detect the presence of different scales renging from human to monumental. The house of the tribesman can be considered to have been designed according to the human scale, while the chief's

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1 In Egypt the work of H Fathy in the New Gorna (105) and R Wiesa in El-Harania near Giza can be considered as examples of architects designing within the folk tradition.

house or the open space where the tribe may have gathered for group activity was designed in accordance with the monumental scale. Moreover, within folk architecture the presence of temples and tombs signifies the difference between the type and the scale in architecture. Finally utilitarian architecture is, by definition, dedicating a building to a kind of utility - a house to live in, a temple in which to pray and worship, or a tomb to be buried in. Within the utilitarian context the Bedouin tent, the peasant house, the flat in a multi-storey block and a king's palace, in spite of the differences in their environment, the way they have been designed and the type of society they serve, do the same function of accommodating people. Each should satisfy the needs and desires of their people however they differ in their architectural qualities.

Rapeport (221) suggested the built form to consist of three kinds. First primitive - including very few building types and models, with few individual variations between the buildings of the one zone. Secondly pre-industrial vernacular, comprising a much greater number of building types with more individual variation of models, and usually being built by tradesmen. Finally high-style, with many specialized building types. Rapoport does not take into consideration changes in either thoughts or environmental conditions which shape and control the final face of architecture. Moreover, he ignores the efforts spent to ease the problems relative to man's existance, which would use sophisticated techniques in comparison to the available facilities of the time.

The classifications of Allsop and Rapoport, and any others based on similar lines, are extreme simplifications of the nature of architecture and deny the essence of the changing needs and development of attitudes of mankind as reflected in his architectural form and space. Architecture, in combining form and space into a single essence, not only facilitates purposes but communicates meaning.

Generally, architectural space conditions the environment in which people live by forming an enclosure, In its simplest form this means the defining of the space by walls and may be completed by a roof. The space is there before the building, but is defined when it is developed into an enclosure. Most architectural space involves a spacial enclosure which may be one of two kinds - enclosure of space (inner environment) and enclosure of territory (outer environment). Enclosure of space creates a difference between the inside and the outside. In this section the unroofed space will be considered as enclosed territory while a roofed space will be considered as enclosed space.

The space defining factors consist of simple configurations of linear and planar elements that define the basic volumes of space. The spacial qualities will ultimately depend on the properties of the space, fig.(5.1). Most buildings incorporate more than one space where space composition depends on the relationships between them. Spaces can be contained within one another; they can overlap or be adjacent to each other, and they can be linked by a common space. Spaces can be organized in a centralized way around a point of interest, in a linear pattern along a main line of activity, in a radial way directed from or towards an important point, clustered to relate to each other by proximity and organized in a grid pattern.

The appreciation of a space will involve the consideration of its dimensions; every space has four dimensions, length, width, height and time. The last is concerned mainly with experiencing space through time[1] where movement is the

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1 The time dimension will include other factors like space dimensions, aclimatization, discovery of space and impression on the human mind.

PROPERTIES OF ENCLOSURE	QUALITIES OF SPACE
shape	proportion scale
shape configuration	form definition
surface edges	colour texture pattern
openings	enclosure light view

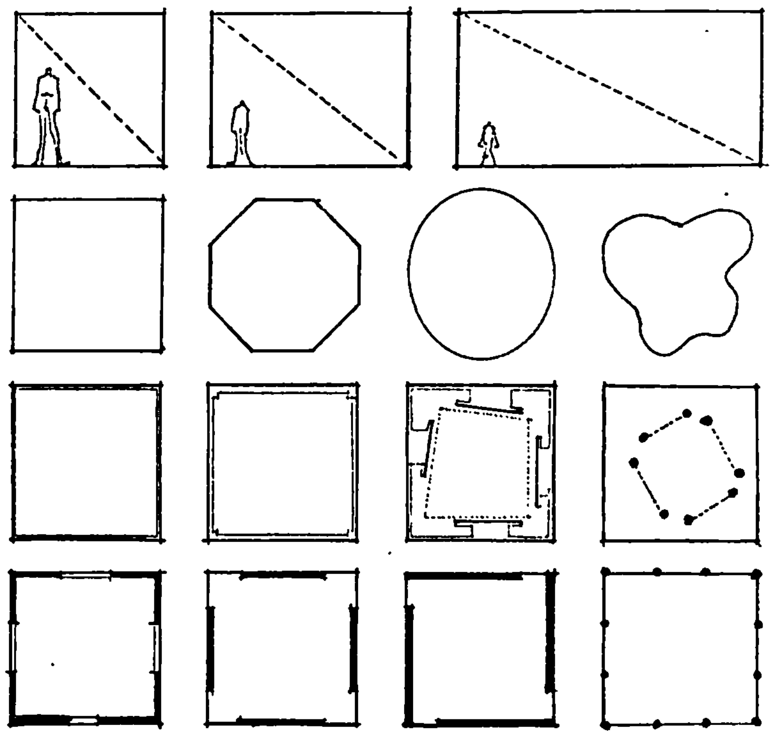

Figure (5.1) The spatial qualities depend on the properties of the space (67).

most effective way to encounter the impact of that dimension. Within a building our movement through the sequence of spaces is organized by the circulation paths. These can be consieved as the perceptual thread that links all spaces together. The relation between the above four dimensions will form the final proportions of space. Scale is the second factor concerning space dimension; man usually relates any scale to his own, the human scale. In architectural spaces we are concerned with two main scales, the human and the grand scale. The grand scale is big, monumental and great in comparison with the human scale.

When we experience a building the scale of it is revealed to us because we are subconsciously comparing its size with our own[1], ie the proportions and size of the human figure. Impressions of height and distance are received by the eyes through the medium of light rays which emphasises the importance of the eye level in relation to the enclosed space and sets the scale for architecture (80). The Ancient Egyptian cubit, fig.(5.18), and Le Corbusier's Modulor are scales developed from the human body dimensions and employed in the design process, fig.(5.2). However, the loss of the human scale in modern architecture is evident in many buildings and town plans. Fathy (31) suggests that there is a point on the architectural scale beyond which man will lose his relation to the environment, yet modern architecture does not recognize this.

Our visual field is usually made up of a number of different subjects. To better comprehend the structure of that field we tend to organize the elements within it into two opposing groups, positive elements that are perceived as

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1 The architectural elements have been designed for human needs in accordance with our own dimensions, ie staircases have a step height of 150 mm and a handrail of 900 mm so that any man can climb up comfortably; this, along with similar elements, embodies the human scale.

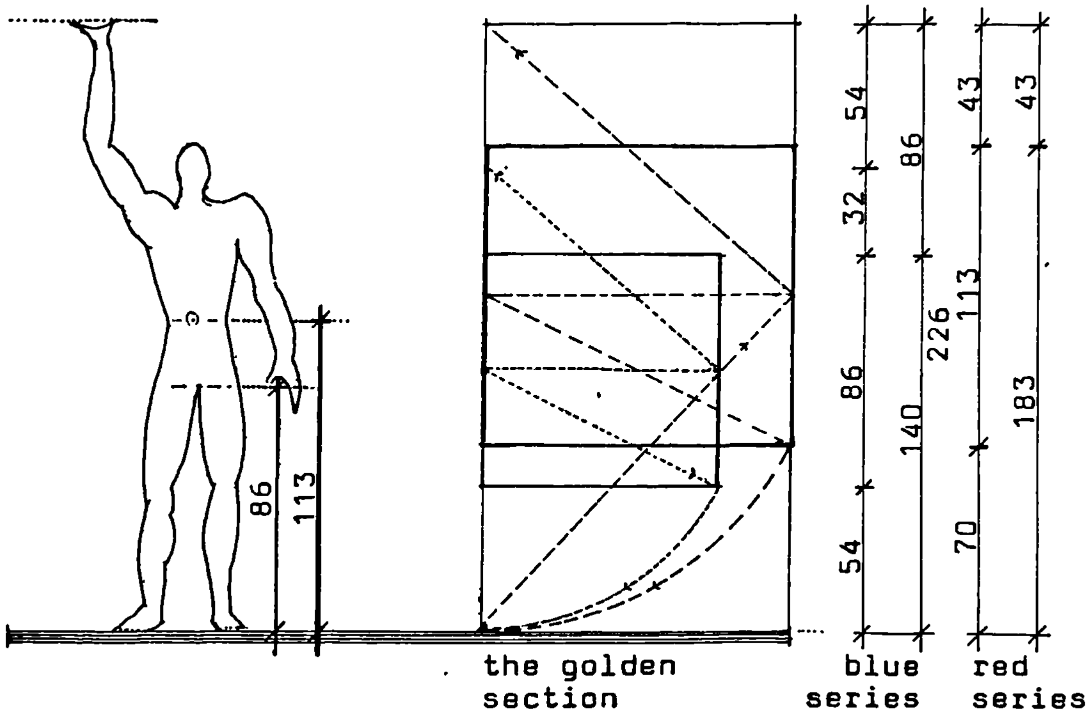
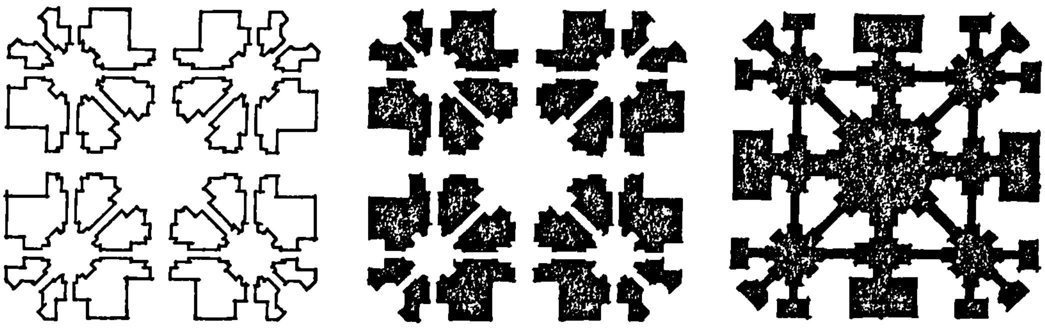


Figure (5.2) The Modulor of Le Corbusier (80).

figures and negative elements that provide the surrounding field, or background. Our perception and understanding of a composition depends on how we interpret the visual interaction between positive and negative elements within it. They begin to compete for our attention as figures. At times the relationship between figures and their surroundings is so ambiguous that we can switch their identities back and forth almost simultaneously, fig.(5.3). In all cases the positive elements, ie figures, that attract our attention could not exist without a contrasting surrounding. Together in a unity of opposites they generate figure, just as the elements of form and space generate architecture.

In architectural perception our reactions to space are governed not by what is actually there in terms of dimensions, but what appears to be there. The perception of forms in space occurs due to two main factors. Firstly we perceive the edges of the various surfaces of the object, and secondly we are aided in our perception of form by patterns of light and shade on objects. Every shape has its geometric characteristics which identify its shape and size. A cylinder is a curved wall with equal distance from a central point in the plan and its size is related to its diameter, while a prism is a shape having walls normal to each other and has a size identified by the distance between its edges. These geometrical and perceptual aspects of space properties can be employed as means of improving the impression of space proportions. In figure (5.4) the architect has moved the corners to achieve a wider visual impression.

Architectural spaces can be arranged to correspond with one of the following ordering principles. In axial form arranged around a line established between two points in the space, they may be symmetrical around that axis. Symmetry can be established around a centre or a point of

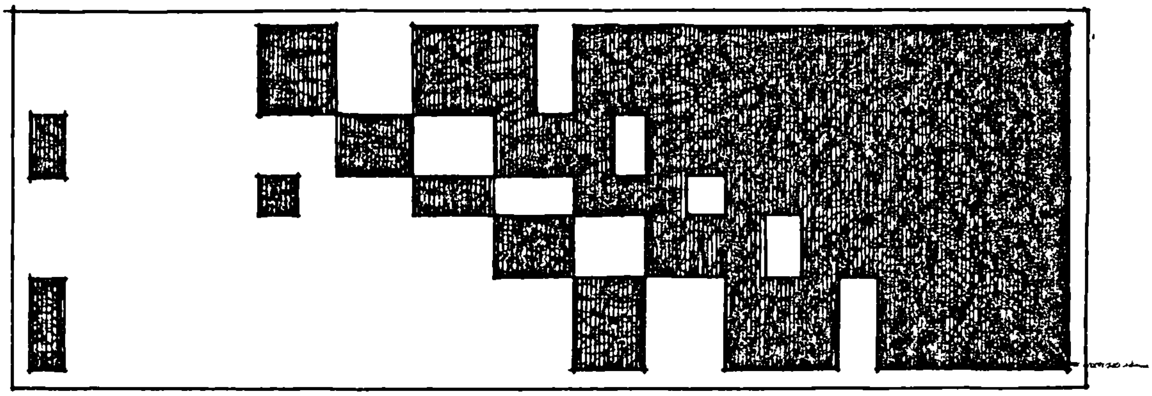


a) boundary between form and space

b) masonry form rendered as figure

c) space rendered as figure

Taj Mahal: Agra, India, 1630-53. (67)



White on black or black on white (67)

Figure (5.3) Visual interaction between positive and negative elements; unity of opposites.

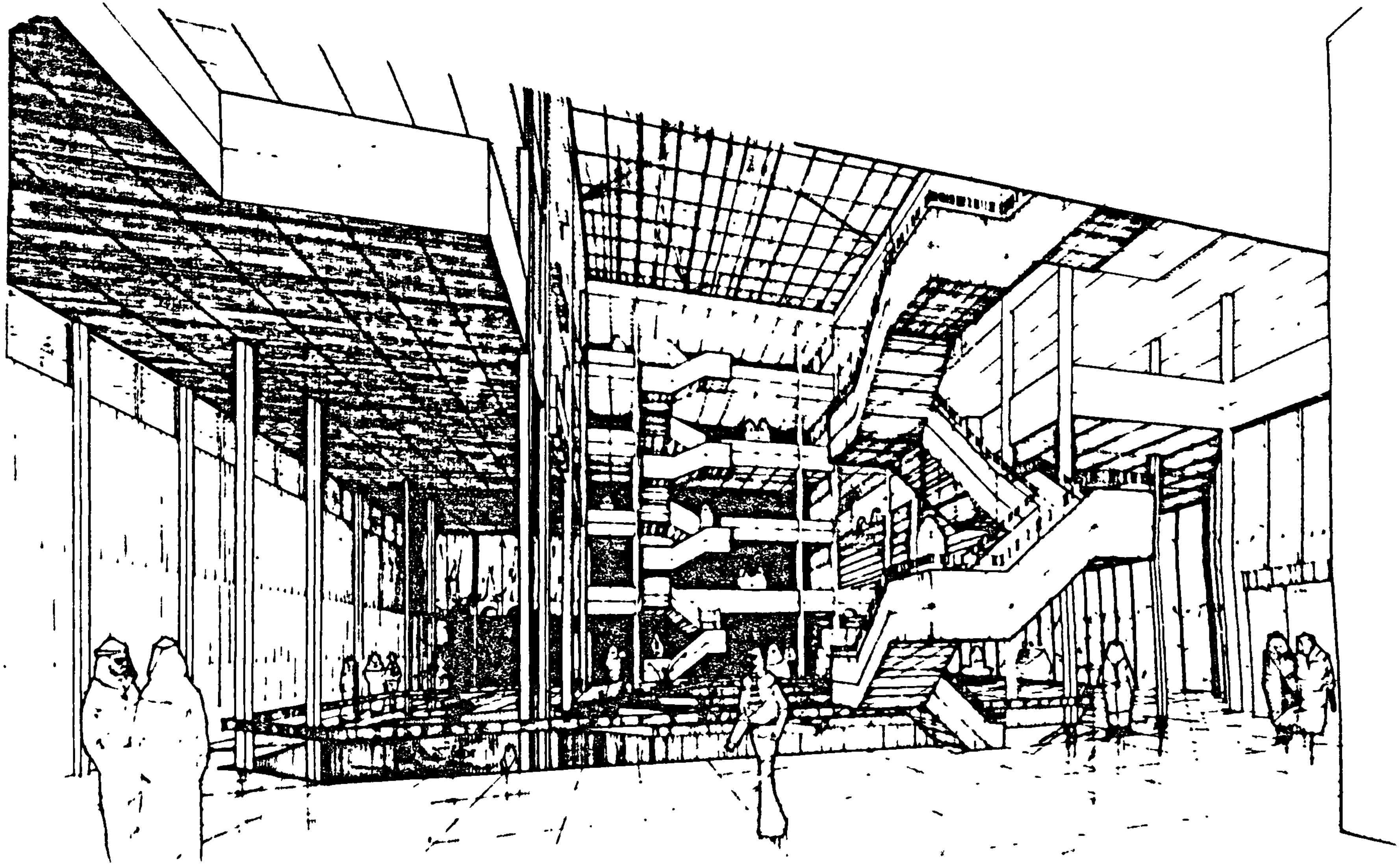
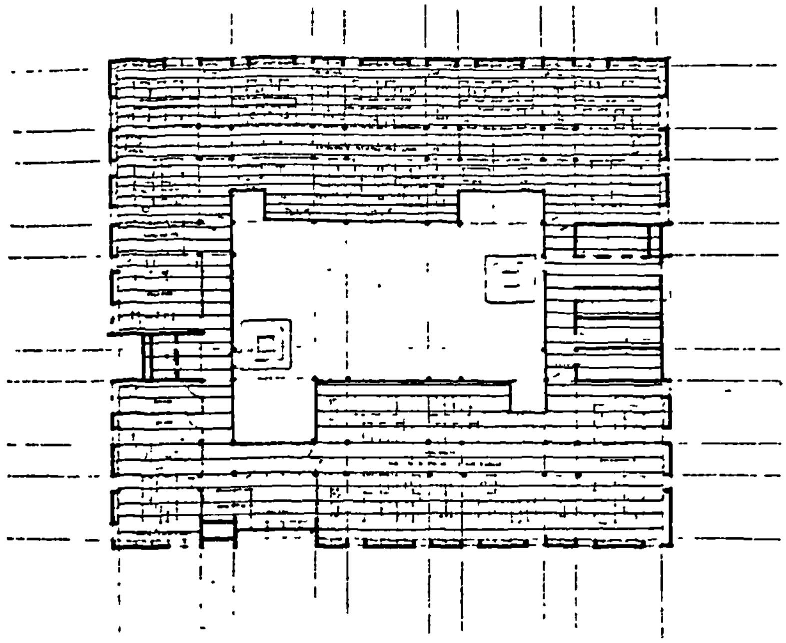
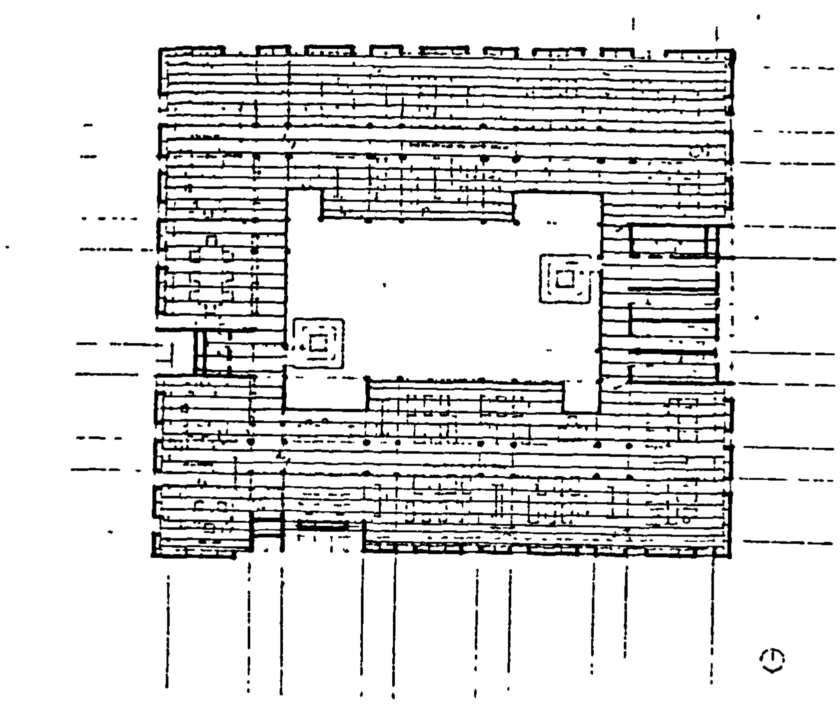


Figure (5.4a) Improving the impression of proportions in a narrow courtyard.
(Arab Investment Company Project) Architects A R Abdin & M Farahat.



first floor plan



second floor plan

Figure (5.4b) Improving the impression of proportions in a narrow courtyard. (Arab Investment Co. project) Architects A R Abdin & M Farahat.

interest. Spaces can be arranged in a hierarchy of pattern where the important object can be articulated by size, shape or placement relative to the other objects and spaces of the organization. They can be arranged in rhythmic ways using recurring patterns and their resultant rhythm to organize a series of similar objects or spaces. They can be arranged in relation to a datum where its continuity and regularity serve to organize a pattern of forms and spaces. They can be related to each other by evolution and transformation where the main features of the space are developed and built up from one object to the following.

Human behaviour within a space is the result of the social life as well as the function ascribed to that space. There is a great difference between private and public behaviour where the socio-cultural environment[1] sets the boundaries for human behaviour. Architectural space can excite and encourage the desired behaviour pattern, and at the same time can be discouraging to non-desirable behaviour. Moreover, all humans as social beings need socialising spaces as well as private ones. Privacy does not only exist in seclusion but can also exist in public spaces. Socially speaking space can be considered under two main sections.

Sociofugal spaces usually tend to keep individuals apart and can ensure some degree of privacy even in densely populated spaces.

Sociopetal spaces tend to bring individuals together to promote social interaction.

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1 Culture can be considered as the product of society and to a great extent defines the basic attitudes of an individual towards his environment. As an individual grows up he obtains all his concepts, his language and his behaviour scale from society (253).

A space can be transformed from sociofugal to sociopetal by providing minor changes, eg rearrangement of furniture or change in the lighting qualities. In modern societies the change from the slum to the tower block usually means a change from sociopetal to sociofugal urban patterns and can produce severe emotional stress[1]. Moreover, the need for communal activity, thus sociopetal spaces, and the need for privacy both in seclusion and in public, thus sociofugal spaces, varies from one culture to another where there are differences in the degrees and the length of time spent in communal activity and in privacy. Yet it is doubtful that a conclusion can be drawn regarding psychological requirements of all types of spaces even within a given culture (253). The architecture of a place is a function of its social and economical structure. Understanding of the social and economic forces of the time at which a building was constructed is vital to the full understanding of its architectural significance.

Another aspect of architectural appreciation is aesthetics, and is concerned with feeling and beauty. Beauty is not objective, it is not inherent in an object but is rather a matter of opinion; a definition of absolute beauty is still out of reach. Moreover, the study of aesthetic laws is the subject of environmental psychology which is out of the scope of the present study. This study is not concerned with the definition of beauty, it is rather aimed at understanding and appreciating the conditions conducive to the enjoyment and pleasurable experience of beauty.

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1 The number of accidents occurring within tower block communities which can be related to this change in space type is rising continuously. This emphasizes the importance of conserving the socio-type of the space when moving communities.

5.2 The Factors Affecting House Design

Architecture as an art expresses in a very real way the feelings and the characters of the people who make it and their relation to the environment.

> "We cannot understand ..... unless we are willing to bear constantly in mind two complementary truths. First the essential similarity of human nature in all ages, and secondly the dissimilarity of men's environment ..... This will explain the remarkable self-devotion of the best characters and ..... the carelessness of multitude, into which the theological seldom penetrated beneath the surface."
>
> G G Coulton (126)

To understand something of the history of architecture one must try to learn how people thought about different aspects of life as well as to know the factors which affected their thoughts and how ideas have changed with time. The main factors affecting house design can be included under three categories - social, cultural, and climatological. Architectural design in Egypt throughout history has been developed within social and cultural changes, though the climate has remained constant[1]. In each period the designers, sometimes unconsciously but most of the time consciously, have equipped their design process with the means to counteract the undesirable effects of climate.

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1 Climate is in continuous change due to the level of activity of the sun, as well as the changes in the atmosphere. However, for the purpose of this chapter climate will be considered constant throughout the history of architecture.

Social life is a reflection of the complicated psychological relationship between man and the environment. Both enclosed spaces and territories should satisfy man's needs for a peaceful relationship with his environment. This includes factors relating to the system of society as a whole, and others more personally dependent. Those related to the social system will include means of communication and human behaviour. They are functions of the space, the fashion of the time, available resources and economy.

Cultural factors may include technology, beliefs[1], scales of appreciation, thoughts and art. Human needs in general are functions of culture even in terms of physical needs. In this sense one may suggest that culture is the term we use to express the relationship between man and his environment. Moreover, culture as a product of society affects the attitudes of individuals towards the environment. History is the part of culture we inherit from our ancestors and it sometimes affects our society unconsciously[2]. Due to the close relations between man and his society the social and cultural factors are usually integrated into a single socio-cultural factor. The building as a function of the socio-culture forces can be considered as a living object, it affects the life of its occupants and is itself changed.

> 'First we shape our buildings and then our buildings shape us.'
>
> Sir Winston Churchill (80)

Climatological environment should be modified by the

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1 'Beliefs' will include religions and other political convictions, eg capitalism, socialism, communism.

2 Many of the existing festivals are inherited from previous cultures. Easter Monday, for example, was originally known in Ancient Egypt as the Spring Feast.

enclosure of space to bring it as near as possible to the comfort level. In general this includes the many aspects of the physical environment including visual, acoustic and thermal. The thermal environment forms the main thesis of this study. Chapter 2 (2.4) discusses the conditions of human comfort, while Chapter 3 examines the Egyptian climate and concludes with a thermal design basis for the Egyptian regions as well as Cairo microclimates. Ventilation due to wind forces seems to form the main factor governing the variation criteria in the different climatic zones.

Wind may vary in both magnitude and direction within the one region, depending on both topography and land cover which can be seen from the microclimatical analysis of Cairo. Moreover, wind seems to be the key factor for improving the environmental qualities[1] within any of those regions. In Chapter 4 examination of the ventilation requirements and wind effects on buildings resulted in a proposed procedure for calculating ventilation during the overheated season (summertime). Egypt usually enjoys clear skies with Cairo having annual sunshine of 9·9 hours per day. The zenith is deep blue and the sky is bright at the horizon. The brightest part of the sky is around the sun (fig 5.5). In this kind of climate the dominant problem is the excessive heat stress and bright sunshine. Buildings should therefore serve to keep occupants cool rather than warm for the greater part of the year and to keep the glare out[2]. In the next section it is intended

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1 With high ventilation rates the difference in air temperature between the two sides of the building element may be extremely small; effect of the wall properties on reducing heat gain will be low, with ventilation forming the main effective natural heat dispersal system.

2 The bright sky at the horizon made the builders aim at the elimination of glare by means of building forms and structural elements. The courtyard has been the most common of these.

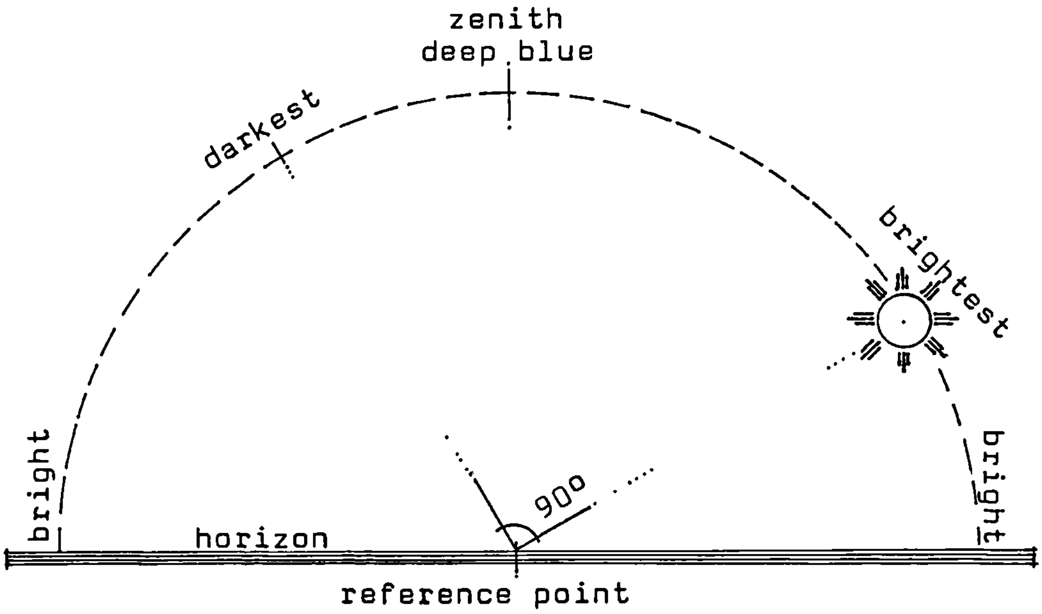

Figure (5.5) Luminence description for clear skies.

to consider the forces affecting building forms within the Egyptian regions.

5.2.1 Thermal Stress Impact on House Form

In nature form is responsive to the forces acting on it.

> 'The knowledge of the forces at work guides a better insight into the form itself ..... the diagram of its equilibrium represents that form.'
>
> V Olgyay (206)

Plant morphology in various climatic conditions seems to display some similarity to the formation of buildings. Temperature range, humidity and radiation are of similar importance as shaping forces for both buildings and plants. The cross sections of plant leaves in fig.(5.6) may draw attention to this similarity. According to either favourable or adverse environmental conditions plants open or close their surface pores. The plants of cool and hot arid regions have massive sections with large volume compared to their surface area, while those of temperate and humid zones are free and liberal in size and shape. The porous openings of a plant's outer skin change due to the climatic conditions, ie with the daily cycle as well as with seasonal changes. Similar forces to those influencing plant leaves can be considered in the human environment but in this case will comprise human activity and clothing along with air temperature, relative humidity, radiation and wind.

In all latitudes of the northern hemisphere the north side receives only a small amount of radiation, and this comes mainly during the summer, while the reverse is the case in the southern hemisphere. On the west side high temperature impact is amplified by the afternoon radiation effects, figs.(4.4) and (4.5). The amount of radiation received on

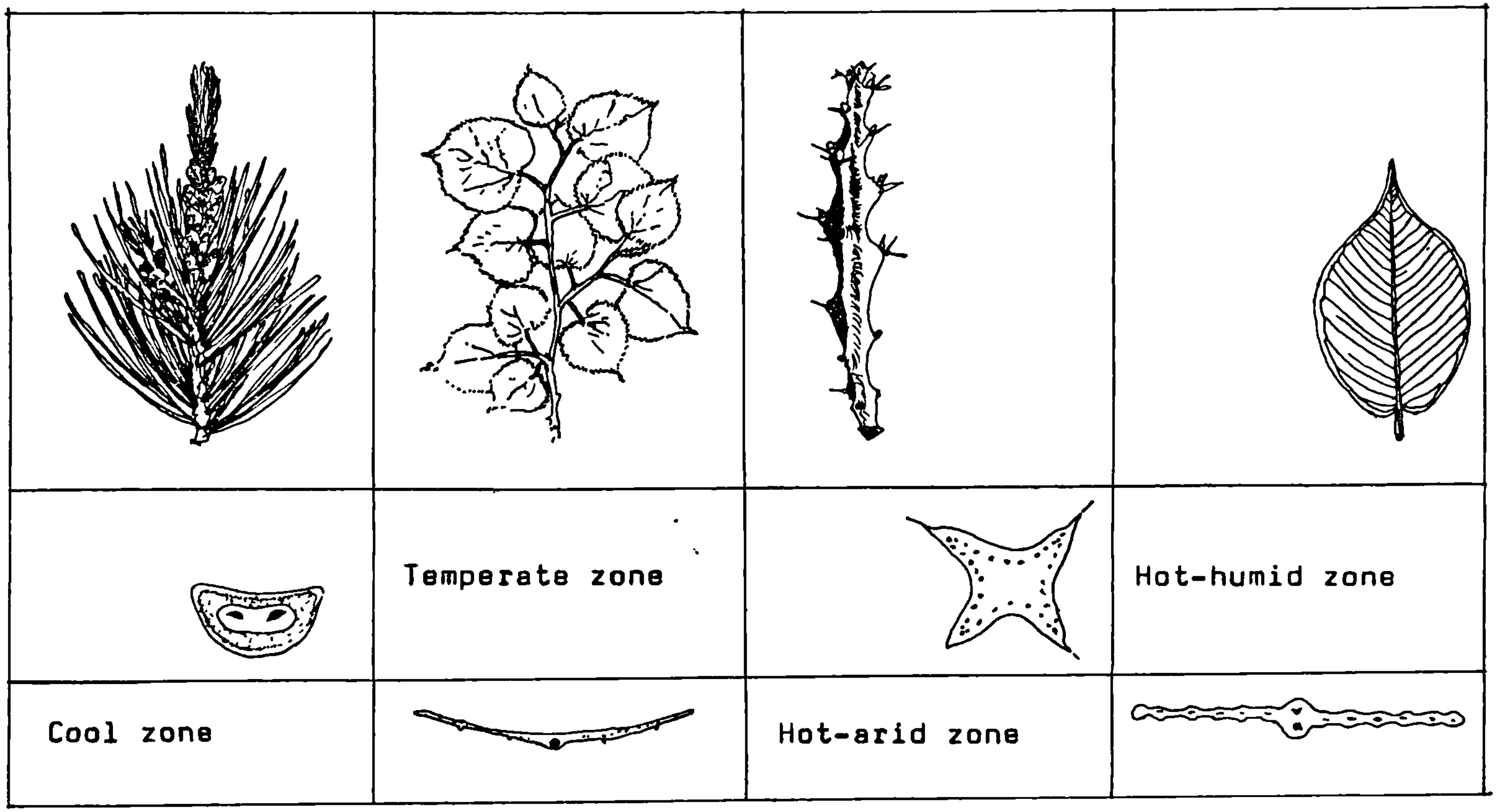

Figure (5.6) Plant morphology in various climatic environments (206).

a horizontal roof in summertime exceeds all other sides The relative importance of the regional thermal stress must be clarified to show the part it plays in shaping a structure. In both cool and hot arid zones, closed compact forms are preferable; the Eskimo have succeeded in modifying their severe environment by building a house bedded in the snow and insulating the cold walls with curtains of animal skins. The thermal behaviour of the Igloo is shown in figure (5.7). In hot arid zones massive shapes are advantageous, especially those slightly elongated towards the east-west axis. Like the Eskimo, the Nomads, desert dwellers of Siwa in Egypt, Matmata in Tunisia and hot arid regions of China, built their dwellings under the ground (206, 226). The ground temperature is almost constant at a depth of approximately one metre due to the high thermal capacity of soil as compared to that of air. Modern employment of such earth sheltered dwellings can be seen in the work of many architects and figs.(5.8) and (5.9) show modern applications of the system (258). In temperate zones there is the least stress from any specific direction, which allows considerable freedom in form, however orientation on an east-west axis is preferable. In hot humid zones buildings freely elongated in the east-west direction are advantageous. Therefore, low temperature tends to press buildings into a compact form, while heavy radiation impact tends to elongate the shapes, mostly in the east-west axis.

No matter how we approach the question of building forms, through mathematics, physiological considerations or across the accumulated experiences of traditions in architecture, the answer will be the same: where nature is friendly the shapes communicate with the surrounding environment while under adverse conditions the form closes its sensitive surfaces and tries to maintain the equilibrium of its own internal environment. No matter what technology is available, what material is in use, the aim

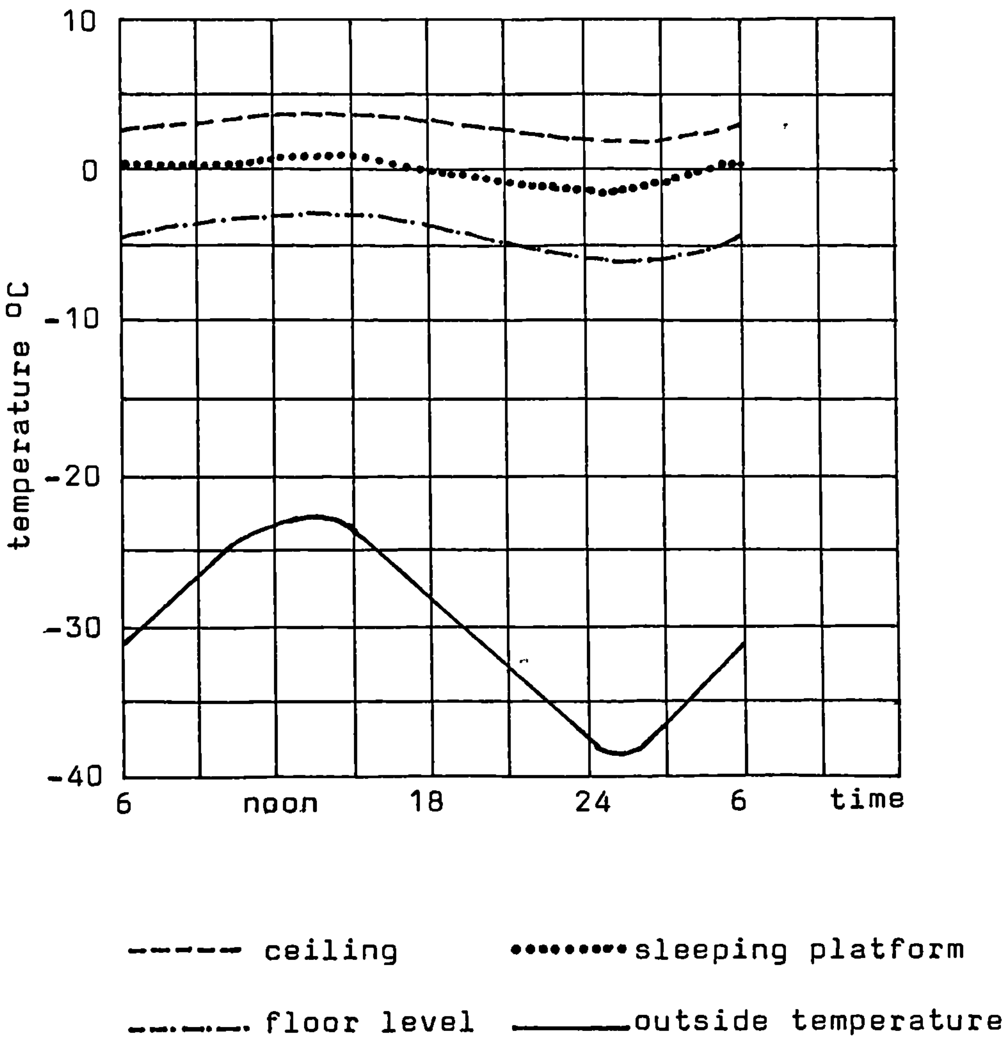

Figure (5.7) The Eskimo house (Igloo) temperature may run as much as 37°C higher than external air temperature. Heat sources are a few oil lamps and casual heat, (178).

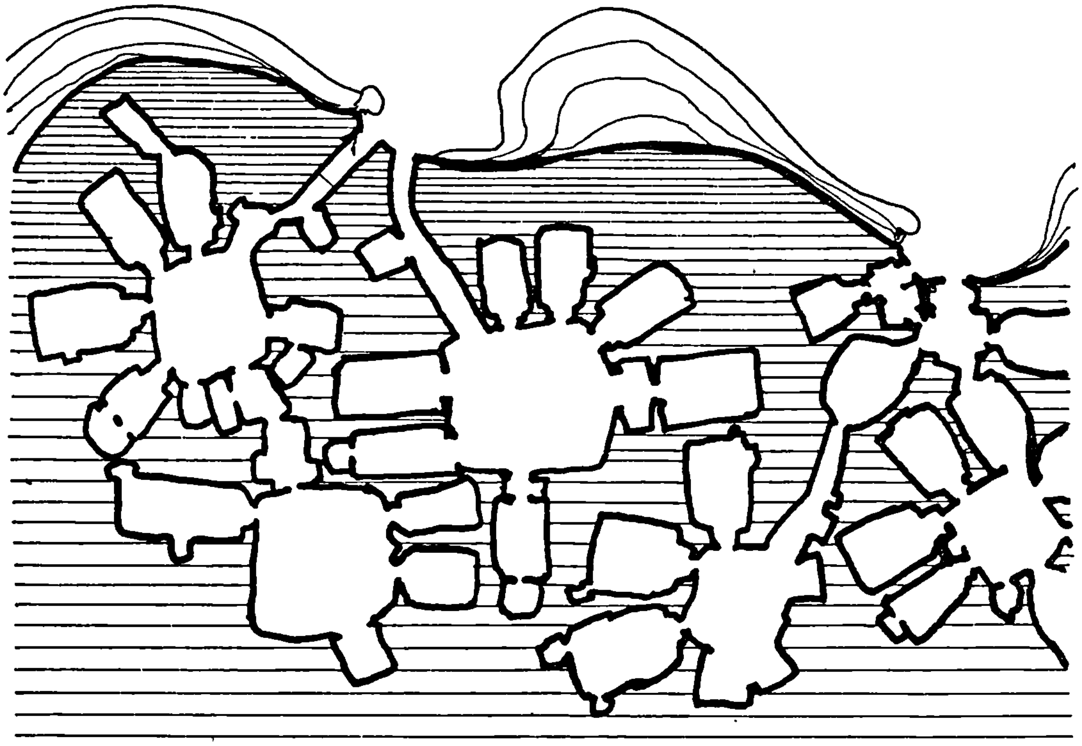

Figure (5.8) Earth sheltered houses in hot arid climates, Matmata village, Tunisia

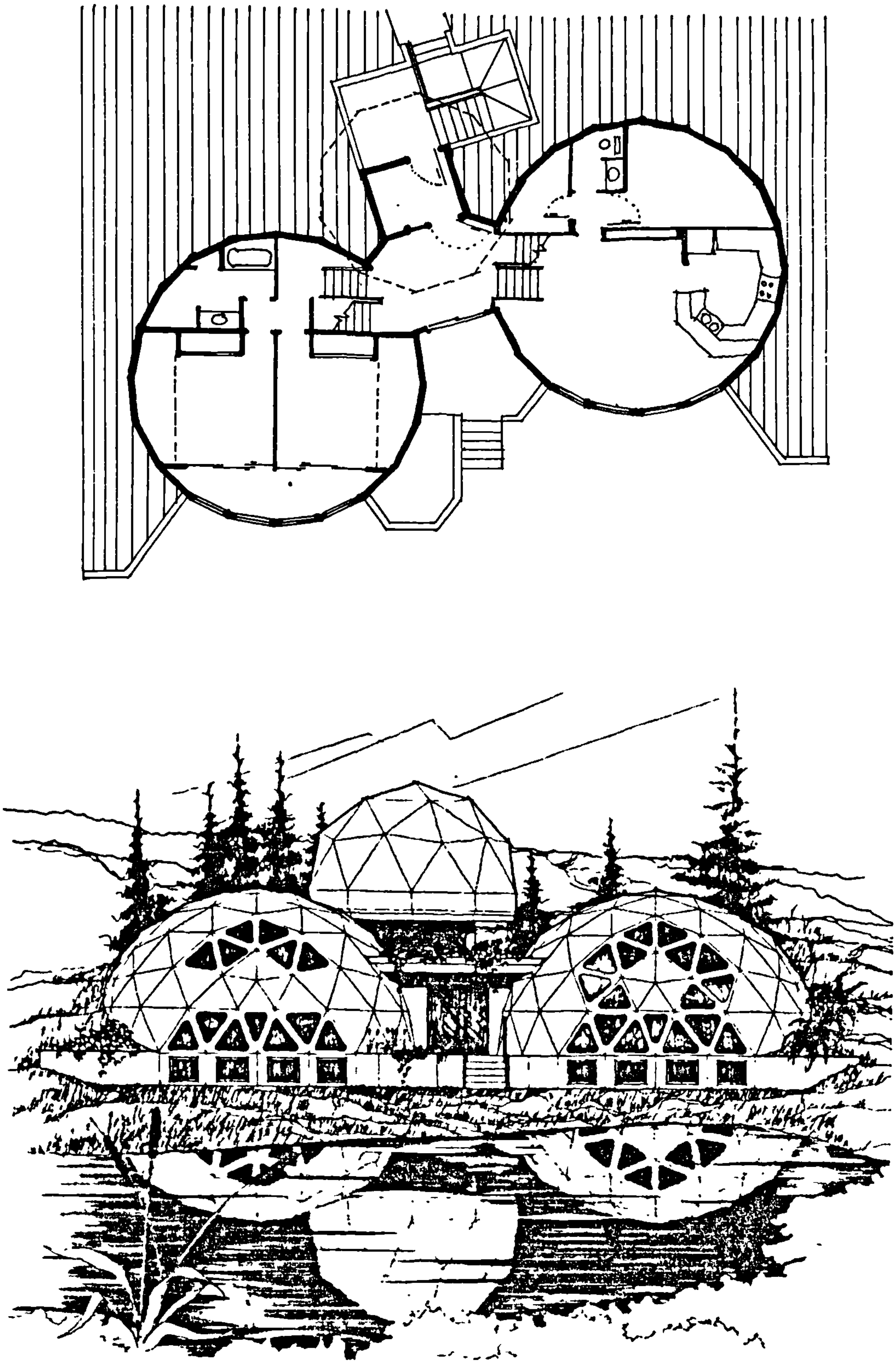

Figure (5.9) Earth sheltered houses in cool climates, dome project, Minneapolis.
Architects: The Big Outdoors People.

will remain the same - satisfying human needs for shelter with an indoor environment which most nearly approaches comfort conditions within the prevailing climatic conditions. Architecturally speaking, the design and construction of a building should utilize the available natural conditions to improve the comfort level without the use of mechanical apparatus. Analysis of the thermal behaviour of the structure, element by element, will lead to a knowledge of the relative importance of each as related to the whole. It also makes it possible to evaluate situations which overlap or run against each other, setting the basis for aiding the design process.

5.2.2 Heat Gain and Loss in Buildings

There are two forms in which heat may be present, sensible heat and latent heat. The sensible heat is the form which is associated with a change in the temperature of the substance, in other words, any addition or removal of heat is accompanied by increase or decrease in temperature. The latent heat is the thermal energy involved in the change of the state of the substance without changing its temperature. Heat is usually transferred from warmer to cooler bodies, or parts of the same body. This transfer occurs in four modes, conduction, convection, radiation and due to latent heat loss or gain. Heat may change its mode of transfer during its flow through a building element. For instance, solar radiation falling on a cavity wall[1] in the form of radiant heat may be absorbed at the external surface and transferred across the external portion of the wall by conduction. Then heat flows by radiation and convection through the air cavity to the other surface. Heat continues its flow by conduction through the inner

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1 This is theoretically assumed a perfect cavity wall having no thermal bridges which may alter the theoretical heat transfer system.

wall. Finally it will be transferred to the indoor air by convection and to the internal surfaces by radiation while a small proportion of this heat will be conducted across the edges to the adjacent walls, floor and roof, fig.(5.10). Heat transfer will follow a similar mode depending on the nature of the structural element, and differences between the inside and outside conditions. The outer environment will change with the progress of the daily cycle and heat flow through the element may reach the point where it will start flowing in the reverse direction. Therefore, a proportion of the heat, depending on the nature of the structural element, will not reach the inner environment and the building component can be considered as a filter between the outside and the inside environments. The effectiveness of this filter will depend on the properties of its constituents. Building material properties affecting heat flow are:

a) thermal conductivity (C), resistance (R), and transmittance (U)
b) surface characteristics with respect to radiation - emissivity (E), absorptivity (α) and reflectivity (r)
c) surface convective coefficient
d) heat capacity
e) transparency to radiation of different wavelengths.

The building will have to accommodate certain functions, its materials should be durable, suited to the construction technique and thermally stable.

In Egypt the alluvium mud of the Nile valley is the most commonly used building material and in rural areas is usually found in the form of sun-baked brick, it is also used for plastering the houses in artistically decorated patterns. The average thickness of these walls is 500 mm, and, since mud has a high heat capacity, the time lag for such a wall is around 8 hours. Therefore, one finds that the interior of these buildings is always cool during the

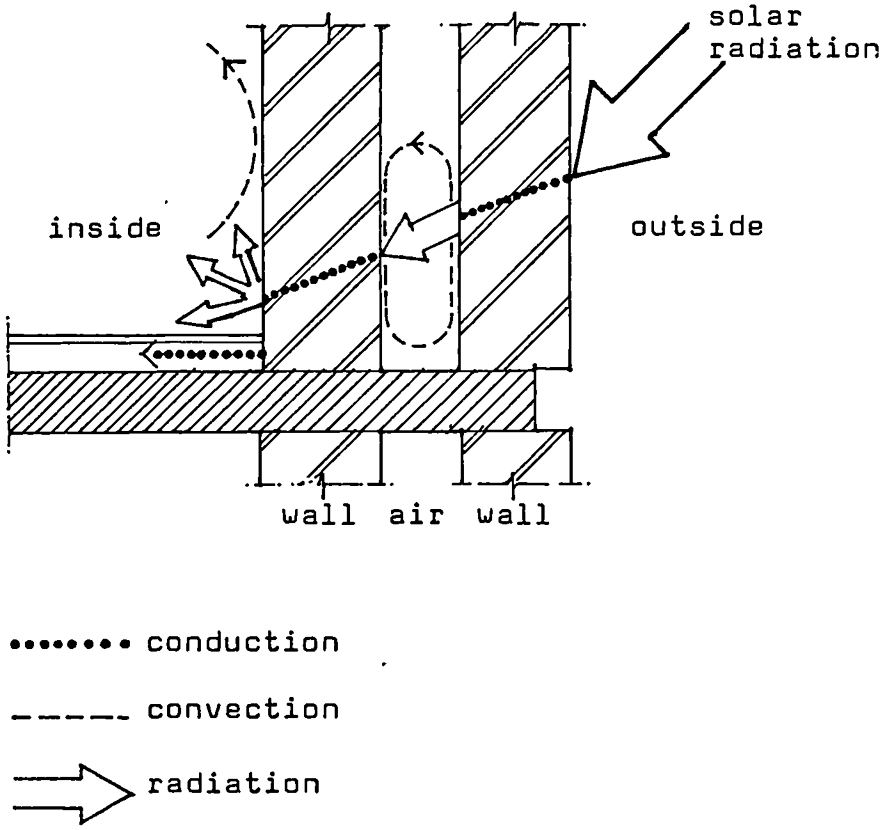

figure (5.10) The modes of heat transfer through a cavity wall.

day. Only at night when the air has cooled down at a faster rate do the walls start to radiate heat to the inner spaces, and the inhabitants are accustomed to sleeping on the roofs of their houses, so avoiding excess heat stress. Limestone is also used a great deal in Cairo houses because of is availability in the nearby Mukkattam Hills. It is usually used in ground floor construction and sometimes dressed with narrow joints. Wall thickness varies greatly but in general exceeds 500 mm. Like mud, limestone is a high thermal capacity material; the time lag for a wall of 500 mm thick and 1920 kg/m^3 is about 15 hours. Both these materials are advantageous in keeping the building cool for most of the day. In the northern parts of Upper Egypt sandstone is more commonly used while in the very south near Aswan granite is one of the materials in common use for decoration. Analysis of the geological resources related to building materials in Egypt is shown in Chapter 3 (section 3.1).

New building materials[1] were introduced after the completion of the High Dam, including sandbrick and cement blocks. Sandbrick as a replacement to mud brick in Egyptian urban communities has shown considerable success, which can be seen in numerous buildings in the major centres, but mud brick is still in demand especially for rural areas.

New materials are continuously appearing on the market. Husks bonded with cement and new lightweight concrete blocks have been introduced as thermal insulating materials. With a bulk density ranging from 560 to 800 kg/m^3 the husks thermal conductivity ranges between 0·11 and 0·29 W/m^{o}C, compared with values for solid brick and limestone of 0·96 and 1·5 respectively. The properties of some building materials in common use in Egypt are listed in table (5.1).

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1 Prefabrication systems, mainly panel systems and lift slabs, have been introduced but are still being assessed.

Table (5.1) Thermal properties of some building materials and construction elements in use in Egypt (149).

Construction Materials		U-Value W/m² °C			Material	Thermal Properties	
		Sh	St	Sc		Density kg/m³	Conductivity W/m °C
Brickwork							
1 Solid wall unplastered	105 mm	3•0	3•3	3•6)			
	220	2•2	2•3	2•4)	Brick	1700	0•84
	335	1•6	1•7	1•8)			
2 Solid wall, 16 mm plaster on inside face							
a) dense plaster	105 mm	2•8	3•0	3•2)			
	220	2•0	2•1	2•2)	Plaster	1300	0•50
	335	1•6	1•7	1•8)			
b) light plaster	105	2•3	2•5	2•7)			
	220	1•8	1•9	2•0)	Plaster	600	0•16
	335	1•4	1•5	1•6)			
3 Cavity wall, unventilated, outer and inner leaves with 16 mm plaster on inside face	260 mm						
a) with dense plaster		1•4	1•5	1•6	Brick (outer)	1700	0•84
b) with light plaster		1•3	1•3	1•3	Brick (inner)	1700	

Table (5.1) continued.

Construction Materials		U-Value W/m^2 ^oC			Material	Thermal Properties	
		Sh	St	sc		Density kg/m^3	Conductivity W/m ^oC
4 As (3) but 230 mm outer leaf, 105 mm inner leaf	375 mm						
a) with dense plaster		1·2	1·2	1·2	Plaster	1300	0·50
b) with light plaster		1·1	1·1	1·1	Plaster	600	0·16
Brickwork/lightweight concrete block							
5 Cavity wall, unventilated, 105 mm brick outer, 100 mm concrete block inner, 16 mm dense plaster inside face.	280 mm	0·93	0·96	0·98	concrete block	600	0·19
Concrete							
6 Cast	150 mm	3·2	3·5	3·9	concrete	2100	1·40
	200	2·9	3·1	3·4			
7 Pre-cast panels	75	3·9	4·3	4·8			
Windows							
8 Single glazing							
a) wood frame	30%	3·8	4·3	5·0			
b) metal frame	20%	5·0	5·6	6·7			
9 Double glazing							
a) wood frame	30%	2·3	2·5	2·7			
b) metal frame with thermal break	20%	3·0	3·2	3·5			

The architectural approach to thermal problems should emphasize the creation of a structure that under general conditions avoids extreme thermal fluctuation, and therefore retains a balanced state close to comfort criteria. This differs from the engineering approach in the following points:

a) The design data selected should emphasize the climatic criteria of all the climatic factors within which the building will exist, and the interaction between the inner and outer environments should dominate.
b) The engineering calculation methods should be reversed. This may be achieved by first considering man under the existing climatic conditions then calculating the building sectional elements form and properties rather than considering the existing building and then examining its environmental performance.

Hence, minimizing heat gain during the overheated period as well as reducing heat loss during the underheated period should form an important section within the design process. However, this section is intended to present this chapter as a qualitative rather than quantitative analysis of the environmental conditions. Therefore, the calculation of thermal forms[1] for specific regions and their climatic data will be examined later along with the main forces affecting the thermal design process. The climatic conditions in the Egyptian regions are examined in Section 3.3.2, and their effect on human comfort is illustrated in the charts shown in figures (3.17a to 3.17e). Cairo microclimates are analysed in Section 3.4.

Inside buildings during the overheated periods, the first

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1 Procedure for calculating building forms is developed by Page (211), and a practical application procedure is given by Yaneski (274).

aim of the architect should be towards minimizing the solar heat gain. The improvement in the environmental conditions due to the exclusion of solar radiation is illustrated in table (5.2) which covers the five Egyptian regions. However, during the underheated periods the architect should allow in as much solar radiation as possible, table (5.3), and eliminate or redirect cold winds away from the living spaces, table (5.4). Therefore, building design for thermal comfort should consider mainly the excess heat stress[1] during the overheated periods, and architectural design should aim at reducing any deviation from comfort conditions and bringing them within the comfort zone. This may be achieved through:

- designing an optimum form which should secure minimum possible heat stress upon the building
- the selection of the proper material, which should mainly be a function of the heat transfer mode, in order to reduce the effect of external heat stress on the internal environment
- suitable openings to satisfy illumination needs while minimizing solar heat gain, with the maximum utilization of ventilation

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1 With the reduction in wind speed in urban areas, which is enevitable as explained in Section 4, the heat stress mentioned will be amplified and the overheated perion prolonged.

Table (5.2) The effect of the climatic elements (excluding solar radiation) on human comfort in the Egyptian regions, expressed in DISC scale.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Lower Egypt (1)	-2·2	-2·1	-1·5	-0·7	0·0	+0·2	+0·4	+0·5	+0·4	+0·2	-0·5	-1·6
Cairo (2)	-1·9	-1·7	-0·8	+0·1	+0·4	+0·7	+1·2	+1·2	+0·8	+0·4	-0·3	-1·2
Red Sea (3)	-1·3	-1·0	-0·4	+0·2	+0·5	+0·9	+1·3	+1·4	+0·8	+0·5	-0·1	-1·0
Upper Egypt (4)	-0·5	-0·2	+0·2	+0·5	+0·8	+1·1	+1·2	+1·3	+1·0	+0·8	+0·5	0·0
The Desert (5)	-1·6	-1·0	+0·2	+0·3	+0·7	+1·0	+1·3	+1·4	+1·0	+0·7	+0·2	-0·2
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

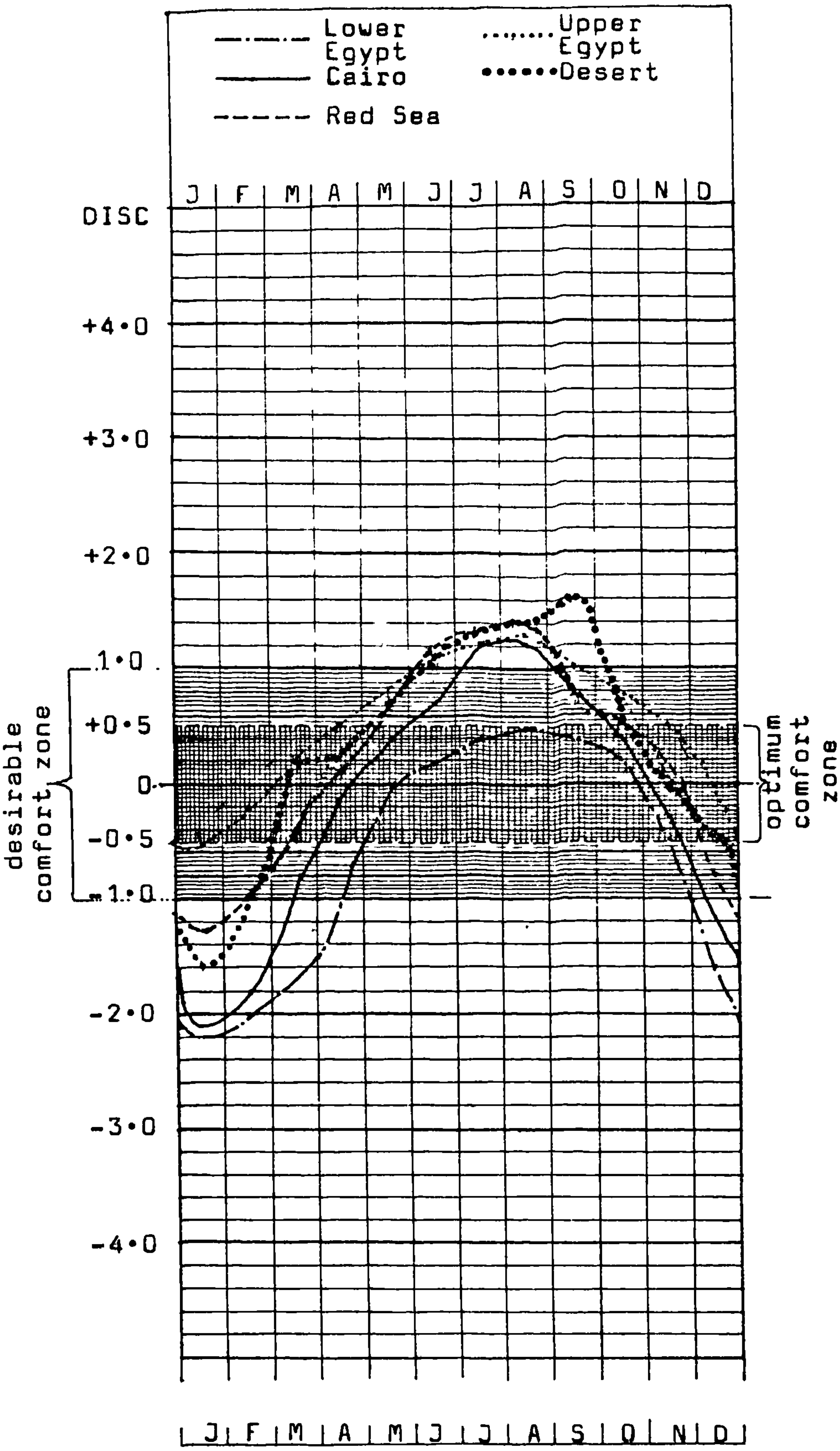


Figure (5.11) The deviation of the human physiological comfort from the optimum comfort conditions in the Egyptian regions.

Table (5.3) The effect of the climatic elements, including solar radiation for under-heated periods only, expressed in DISC scale.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Lower Egypt (1)	-1•6	-1•0	-0•1	+0•2	0•0	+0•2	+0•4	+0•5	+0•4	+0•2	-0•5	-1•0
Cairo (2)	-1•0	-0•3	+0•3	+0•1	+0•4	+1•7	+1•2	+1•2	+0•8	+0•4	-0•3	-0•8
Red Sea (3)	-0•7	-0•2	-0•4	+0•2	+0•5	+0•9	+1•3	+1•4	+0•8	+0•5	-0•5	-0•8
Upper Egypt (4)	-0•2	+0•2	+0•2	+0•5	+0•8	+1•1	+1•2	+1•3	+1•0	+0•8	+0•5	0•0
The Desert (5)	-0•2	+0•2	+0•2	+0•3	+0•7	+1•0	+1•3	+1•4	+1•0	+0•7	+0•2	-0•2
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

Table (5.4) The effect of the climatic conditions excluding solar radiation during the over-heated periods and eliminating ventilation during the under-heated periods, expressed in the DISC scale

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Lower Egypt (1)	-0•2	+0•3	-0•1	+0•2	0•0	+0•2	+0•4	+0•5	+0•4	+0•2	-0•5	+0•2
Cairo (2)	0•0	-0•3	+0•3	+0•1	+0•4	+0•7	+1•2	+1•2	+0•8	+0•4	-0•3	+0•1
Red Sea (3)	+0•3	-0•2	-0•4	+0•2	+0•5	+0•9	+1•3	+1•4	+0•8	+0•5	-0•1	+0•1
Upper Egypt (4)	-0•2	+0•2	+0•2	+0•5	+0•8	+1•1	+1•2	+1•3	+1•0	+0•8	+0•5	0•0
The Desert (5)	-0•2	+0•2	+0•2	+0•3	+0•7	+1•0	+1•3	+1•4	+1•0	+0•7	+0•2	-0•2
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

5.2.3 The Optimum Form

The rate of heat loss (or gain) from a building can be expressed as the algebraic sum of heat loss (or gain) through fabric and heat loss by ventilation. Heat transfer through fabric is a function of the temperature difference between inside and outside, the properties of building materials used and the surface area of the building, while heat loss by ventilation[1] is a function of the temperature difference as well as the ventilation rate.

$$Q_t = \Sigma AU\Delta t_1 + (Vol \times n/3)\Delta t_2$$

where:

A	=	fabric areas
U	=	thermal transmittance of building elements
Δt_1	=	temperature difference between the two faces of the element
Vol	=	volume of the enclosed space
n	=	number of air changes per hour
Δt_2	=	temperature difference between air inside and air outside

In hot dry climates, during the restricted ventilation times, there will be low ventilation rates and the difference in temperature between the inside air and the inner surface can be considered negligible. Thus, Δt_1 and Δt_2 can be taken as equal and the amount of heat transfer per degree centigrade difference per unit volume (m^3) can be expressed as:

$$Q = \Sigma AU/Vol + n/3 \qquad (5\text{-}1)$$

---

1 This expression is applicable for very low ventilation rates, ie restricted ventilation.

The term $\sum AU/Vol$ is dependent on both the U-value of the building and the 'surface area/volume' ratio (178). It is therefore a function of both the size and the proportions of the building. Olgyay (206) shows the effect of size on that ratio which is illustrated in figure (5.12). Enlarging a cube volume from 1 to 8 to 64 to 512 m^3 will reduce the surface area/volume ratio from 6 to 3 to 1·5 to ·75 respectively. Markus and Morris (178) show the effect of proportion on the ratio; changing the proportion of a volume of 64 m^3 away from the cube increased surface area/volume ratio from 1·5 to ·63, fig.(5.13). They derived an expression indicating the deviation of this ratio of a particular prizm from that of the cube as follows:

$$\sum A/Vol = 2/H \times \gamma \qquad (5\text{-}2)$$

where:

$\gamma = (1 + \beta)/\alpha\beta + 1$

H = height of the building

B = breadth of the building $= \alpha H$

L = length of the building $= \beta B = \alpha\beta H$

γ = a dimensionless factor depending on the shape of the building

Considering a cube of side H_o ($Vol = H_o^3$) and a prism ($Vol = \alpha^2\beta H^3$) having equal volumes, then:

$$H_o^3 = \alpha^2\beta H^3$$

Hence:

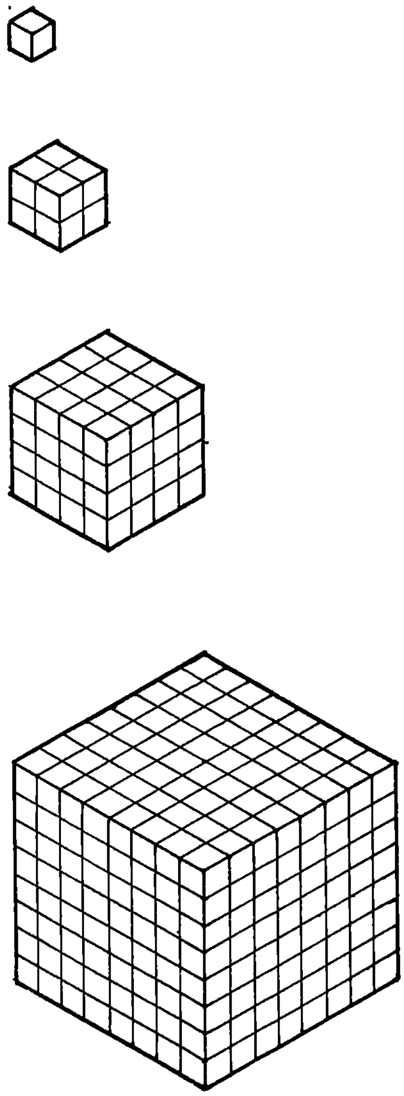
$$H_o/H = (\alpha^2\beta)^{\frac{1}{3}} \qquad (5\text{-}3)$$

Surface area/volume of a cube $= 6/H_o$

Surface area/volume of a prism $= 2/H \times \gamma$

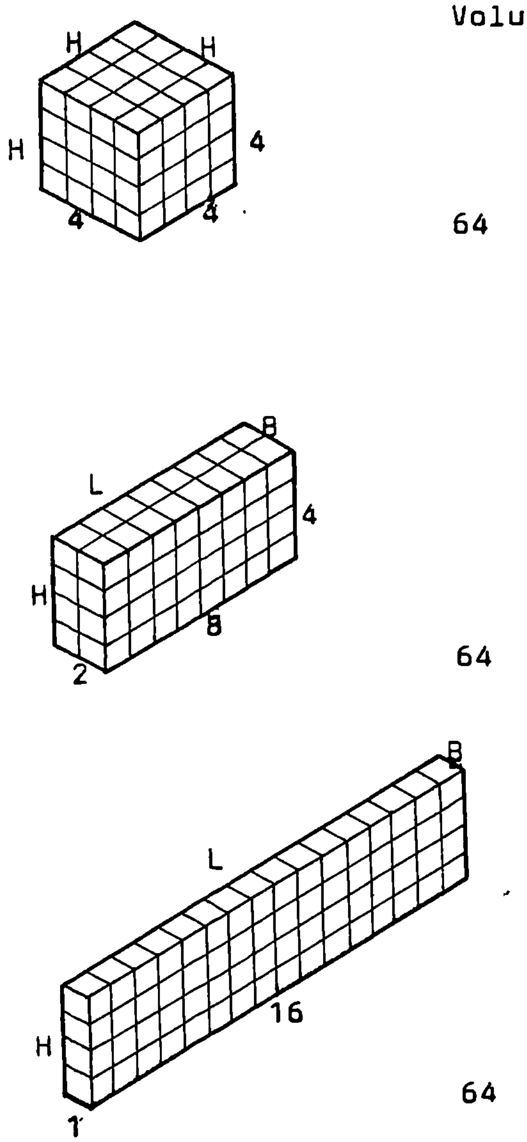
Ratio of change $= \gamma/3 \times (\alpha^2\beta)^{\frac{1}{3}}$

This ratio is independent of the actual size. Table (5.5) gives values for both γ and the ratio of change. The



side	Volume	Surface	Ratio
1	1	6	6
2	8	24	3
4	64	96	1·5
8	512	384	0·75

Figure (5.12) The effect of size on the 'surface area/volume' ratio (206).



Volume	Surface	Ratio
64	96	1·5
64	112	1·75
64	168	2·63

Figure (5.13) The effect of proportions on the 'surface area/volume' ratio (178)
($L = \beta B = \alpha\beta H$)

Table 5.5 The values of the shape factor $\gamma = (1 + \beta)/\alpha\beta + 1$ and the ratio of change $\gamma/3 \times (\alpha^2\beta)^{\frac{1}{3}}$.

(a) Values of γ

α	β 0·25	0·5	1·0	2·0	3·0	4·0	5·0
0·25	21·00	13·00	9·00	7·00	6·33	6·00	5·80
0·50	11·00	7·00	5·00	4·00	3·67	3·50	4·40
1·00	6·00	4·00	3·00	2·50	2·33	2·25	2·20
2·00	3·50	2·50	2·00	1·75	1·67	1·63	1·60
3·00	2·67	2·00	1·67	1·50	1·44	1·42	1·40
4·00	2·25	1·75	1·50	1·38	1·33	1·31	1·30
5·00	2·00	1·60	1·40	1·30	1·27	1·25	1·24

(b) Values of $\gamma/3 \times (\alpha^2\beta)^{\frac{1}{3}}$

α	β 0·25	0·5	1·0	2·0	3·0	4·0	5·0
0·25	1·75	1·37	1·19	1·17	1·21	1·26	1·31
0·50	1·46	1·17	1·05	1·06	1·11	1·17	1·22
1·00	1·26	1·06	1·00	1·05	1·12	1·19	1·25
2·00	1·17	1·05	1·06	1·17	1·27	1·37	1·45
3·00	1·17	1·10	1·16	1·31	1·44	1·56	1·66
4·00	1·19	1·17	1·26	1·46	1·61	1·75	1·87
5·00	1·27	1·24	1·36	1·60	1·79	1·93	2·07

surface area/volume ratio could be an index for comparing the environmental thermal impact on buildings if all the surfaces have the same U-value and the same external heat stress. This would be the case if the effect of all the climatic factors except air temperature are neglected. However, the U-values as well as orientation must be taken into account.

Olgyay (206) calculated the house plans which are most suitable for four different climatic zones - cool, temperate, hot arid, and hot humid. First he calculated the thermal stress on the surface of a square plan building which he called 'Orthodox house'. He took this as the norm from which the deviation, expressed as a percentage, is taken as an index. The optimum plans recommended for the four climatic zones have the following percentages: cool = 1·1; temperate = 1·6; hot arid = 1·3; hot humid = 1·7. Therefore the square house is not the optimum form for any location. Elongated shapes on the north-south axis are less efficient than the square house, while the optimum lies in a form elongated east-west.

A significant understanding of the thermal qualities of building size and shape has been achieved but the approach to the problem was an engineering one, which limited the flexibility of the solution as well as reducing its accuracy.

Page (211) derives an expression for optimizing multi-storey building forms to minimize fabric heat loss by conduction in terms of the number of floors. The structure is considered as consisting of three main thermal components - floors, walls and ceilings. The optimum form is then calculated as a function of a known floor height. Markus and Morris (178) applied Page's approach with respect to the effect of the thermal properties of the surface, ie AU, which was assumed as the thermal surface.

Considering the definition of the building form as shown above, the optimum thermal surfaces should have equal heat transfer into the enclosed space, the heat transferred through the fabric being:

$$Q_F/^oC = A_W U_W + A_R(U_R + U_F)$$

where:

A_W = area of walls with the U-value = U_W

A_R = area of floor (or roof) with U-value = U_F

let $\bar{U} = 0{\cdot}5(U_R + U_F)$

$U_W = r\bar{U}$

then,

$$Q_F/^oC = A_W r\bar{U} + 2A_R\bar{U}$$

from figure (5.14),

$$A_W = 2\alpha_1 H^2(1 + \beta_1)$$

$$A_R = \alpha_1^2\beta_1 H^2$$

$$Vol = \alpha_1^2\beta_1 H^3$$

thus,

$$Q_F/^oCm^3 = (2\alpha_1 H^2(1 + \beta_1)\bar{U}r + 2\alpha_1\beta_1 H^2\bar{U})/\alpha_1^2\beta_1 H^3$$

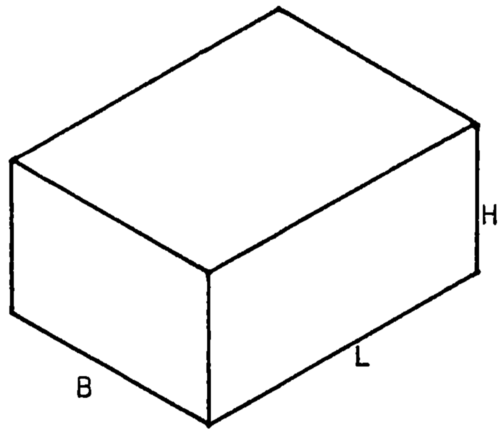
$$= 2\bar{U}((1 + \beta_1)r/\alpha_1\beta_1 + 1)/H$$

and for the cube with walls having equal U-value to $\bar{U}$:-

$$Q_F/^oC\ m^3 = 6\bar{U}/H$$

The optimum form will be that which has equal heat transfer to the above cube, hence:

the optimum form for conduction



$$L = \beta_1 B = \alpha_1 \beta_1 H$$

$$H = (Vol/\alpha_1^2 \beta_1)^{\frac{1}{3}}$$

β	1	2	3	4
α	1·0r	0·75r	0·67r	0·625r

Figure (5.14) The values of α_1 and β_1 in relation to the building form (178).

$$\alpha_1 = (1 + \beta_1)r/2\beta_1 \tag{5-3}$$

$$H = (Vol/\alpha_1^2\beta_1)^{\frac{1}{3}}$$

$$B = \alpha_1 H$$

$$L = \beta_1 \alpha_1 H$$

The same approach was applied to solar heat gain and it was suggested that buildings should be oriented with the long axis to the east-west, and the long walls facing north and south in lower latitudes, while long walls facing the east-west are advantageous in higher latitudes (178). However, there are two main factors which are expected to alter this suggestion. The first is that the amount of solar radiation recieved in a region is not symmetrical around the Equinox[1] (table (3. 9)), as it will be affected by the sky conditions, the geographical cover as well as the pollution pattern. The second deviating factor is a function of the spaces within the building which will suggest a certain level of comfort[2] and the occupation time[3]. Kuba (161) suggested a Minimum Thermal Axis for a meteorological zone which will be altered due to the building form. Olgyay's (206) orientation charts define the year into underheated and overheated periods for each region, based on the solar radiation falling on the vertical surfaces of a rotating building every 15^o.

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1 Kuba (161) regards the asymmetry of received radiation in relation to the north-south axis as due to the dust present in air during the late forenoon and afternoon.

2 Thermal comfort is a function os six main factors, of which solar radiation is one.

3 The time of occupancy may vary dramatically, from a holiday house to a permanent dwelling, or from a research laboratory to a grammar school.

He suggests a desirable orientation range within which the optimum orientation falls, without any reference to the building form, and based only on the solar heat load on a unit area of the surface. Both Kuba and Olgyay assumed a constant area for their experimental buildings. The optimum orientation concept is applicable for the design of window patterns in the outer skin as well as the zoning of functions along the building faces. This can act as a guide for street orientation in town planning where it may minimize the solar heat gain.

Orientation studies should, however, proceed on both the calculation of optimum form (for conduction and radiant heat transfer), and the choice of building materials for the structural elements. This approach to solving the problem of the thermal impact on building forms offers a better understanding of the different thermal forces, but does not include the final integral effect of all the thermal forces.

Thus, one may conclude that:

1 The cubic house is not always the optimum form except in one theoretical case when all the walls have the same U-value, the temperature difference for each surface is the same, and the radiant heat received by all the faces is the same.
2 Because of the solar radiation effect the optimum form for minimum radiation and conduction heat transfer is a function of the thermal requirement in relation to the ambient climate, ie it is a function of overheated and underheated seasons.
3 Compact buildings are advantageous with respect to heat transfer limitation. The volume effect can be utilized architecturally where early design decisions concerning the formation of the structure may have a great influence on the building's thermal behaviour.

4 Choice of materials should be made with consideration to their thermal properties. It should be a function of the mode of heat transfer.

These, together with the other considerations discussed in Sections (2.5.2), (3.5), (4.2.4), (4.5) and (5.1.1), will form the basis for the stand from which we shall look at the historical precedent.

5.3 The Evolution of the Egyptian House

In a country like Egypt the face of architecture has been continuously developed throughout history. Since the beginning of the Pharaonic period Egyptian society has undergone many changes which, in most cases, were the expression of social changes following in the wake of shifts in thoughts and religion. These were accompanied by technological diversity which, besides the fashions of the time, dictated the ways in which the Egyptians employed their resources to satisfy their needs. This does not indicate a sudden disappearance of any particular style; the previous styles co-existed along with the new ones for some time during the transition period.

Very little is known about life in Pre-historic Egypt, in contrast with that of the recorded dynastic Pharaonic period. Cylindrical granaries were found in the Neolithic village of Faiyum, and reed huts in Neolithic Merimdeh. Early Ma'adi and El-'Omari, near Cairo, had round and oval huts. The fifth millennium and the first half of the fourth show primitive relics, pottery and figurines. From the second half of the fourth millennium primitive figurines in terra-cotta and ivory and pottery vessels engraved with animals, men and lattice-like hatchings were found. Occasional glimmerings of later cosmic concepts appear (117).

The oval huts found in Merimdeh, Ma'adi and El'Omari were constructed of mud blocks, and seem to have accommodated the inhabitants and their flocks.During this period both the type of architecture and the materials used had already embodied the basic elements that influenced later techniques and styles. The Egyptian cavetto cornice can be considered a development of the reed dwelling conrnice, fig.(5.15), while most of the Ancient Egyptian columms are representations of bundles of papyrus and reed stems. They may differ in the shape and type of plant they represented, or in their proportions but the main idea survived throughout the Pharaonic epoch, fig.(5.16), just like the Greek and Roman classical orders which survived till the end of the last century.

By 3300 BC the Egyptian people were living in two kingdoms, each having its own king, symbols, national gods and army. Upper Egypt had its white crown and was under 'Nekhebet', the vulture goddess, while Lower Egypt had the red crown and the cobra goddess 'Butos'. The Upper Egyptians, as still regarded, were hardy, quarrelsome, suspicious of refinement, forthright and puritanical, while the Lower Egyptians were clever, pleasure loving and eager for novelties. The strong king of Upper Egypt Narmer (Menes) had succeeded in unifying both regions into one country by 3100 BC, and to symbolize the unification he wore a crown combining the red and the white crowns of the two regions.

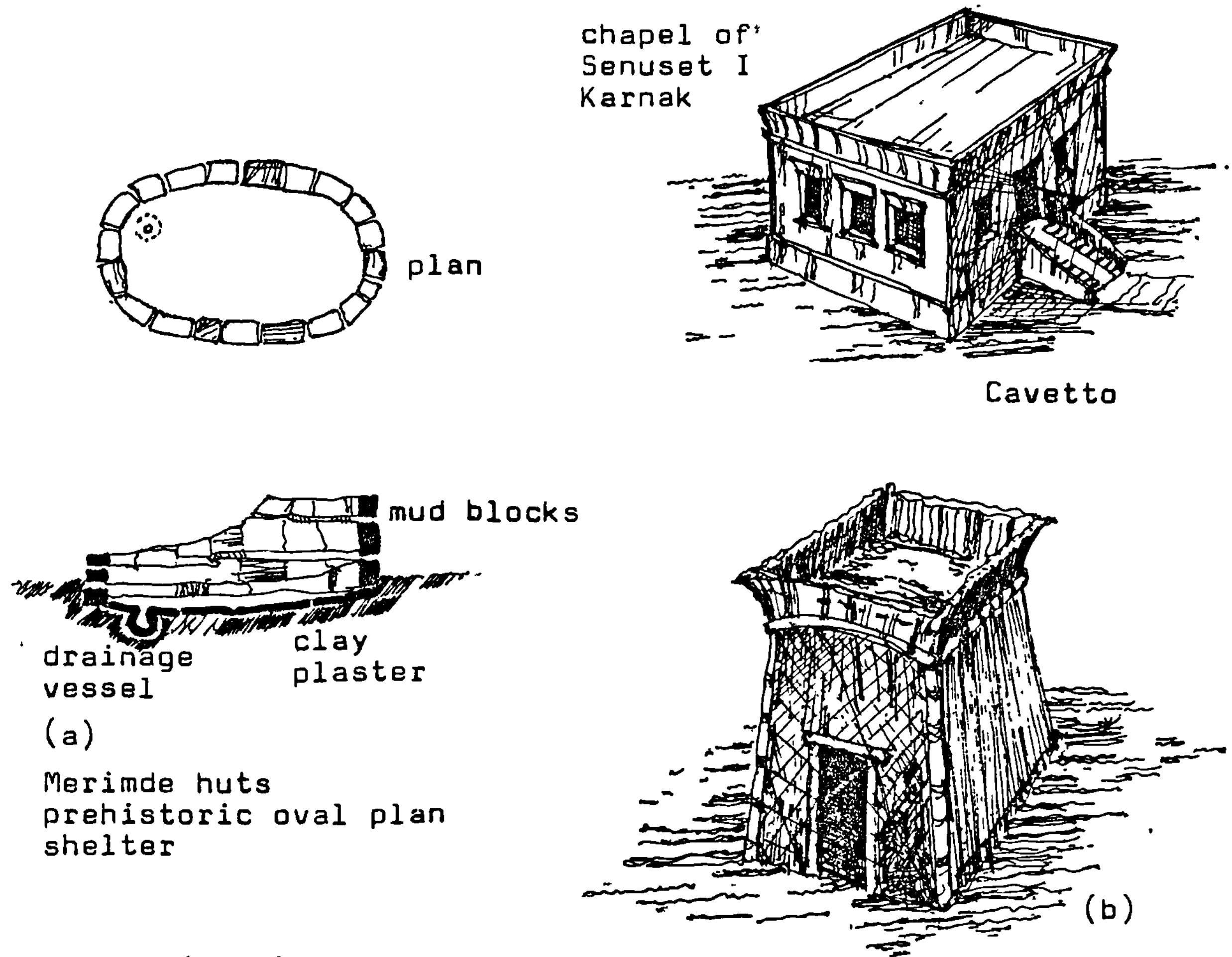
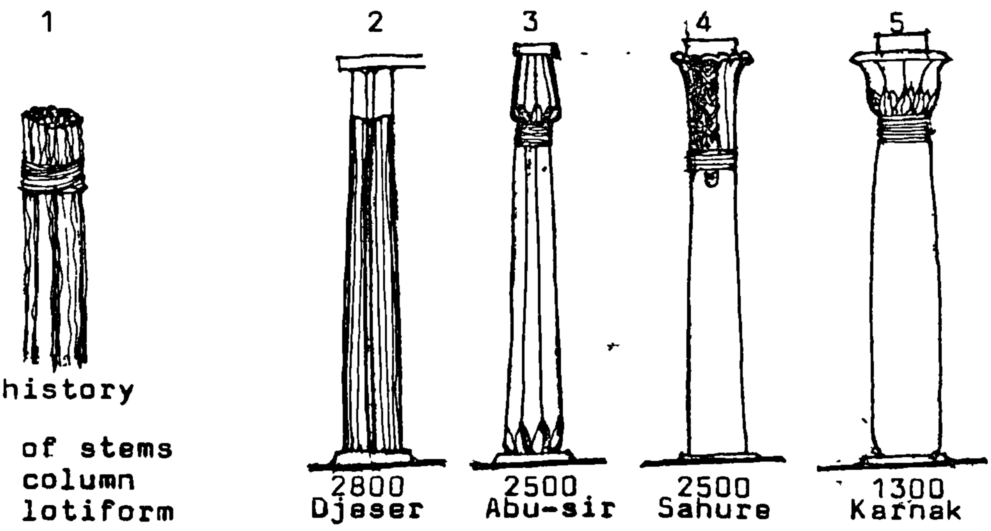


Figure (5.15) The Egyptian cornice.



1 Bundle of stems
2 Bundle column
3 Bundle lotiform
4 Palmiform
5 Open papyriform

Figure (5.16) The Egyptian orders.

5.3.1 The Ancient Dynastic Egyptian Period

> "No people, either ancient or modern, have had a national architecture at once so sublime in scale, so grand in expression, and so free from littleness as that of the ancient Egyptians."
>
> Champollion (219)

As architecture is expressive of man's ideas and emotions, one can learn much about the character and the society of the ancient peoples through their architecture. However, the reverse is also true, that is knowing the character, the environment and the thoughts of a society, one can have a better insight into their architecture.

The Nile is the most important environmental factor that has affected Egyptian life from ancient times.

> "The Egyptians live in a peculiar climate, on the banks of a river which is unlike every other river, and they have adopted customs and manners different in nearly every respect from those of other men .... Egypt is a gift of the Nile."
>
> Herodotus (177)

In form the Nile resembles the lotus, from which the sun god was born (177). The ancient Egyptians identified the river and the soil with their best-loved god 'Osiris', while the desert was associated with his murderer 'Seth'. As rainfall is negligible in Egypt, agriculture had to rely entirely on the Nile and its benificent flood. Besides this immediate relationship of the Nile to rural life, several other aspects of civilization, and particularly architecture, were influenced by the river. In a land deprived of rain or springs settlements grew up along the river and the canals, because water meant life as well as ease of communication and even accommodation by the use of house-boats. The flood effect on town structure in Egypt was described as follows:

> "When the Nile over flows, the whole country is covered into a sea and the towns ..... look like the islands in the Aegean."
>
> Herodotus (19)

Control of the flood and the water supply to towns away from the river was provided by an elaborate system of dikes and canals since protodynastic times. The regularity of the Nile flood and early invention of geometry underlie the sense of order and regularity throughout Egyptian culture, and particularly its architecture and art. The Nile was the main highway of Egypt by which most of the transport was carried, while during the flood water transportation extended over all the flooded land. Considerable amounts of building materials were transported employing field labourers whose lands were flooded. Granite from Aswan, alabaster from near Amarna, red sandstone from Gebal Ahmar, opposite Heliopolis, and limestone from Tura, near Cairo, were transported all over the country. The waterways and the Nile contributed to the cultural unity, for the craftsmen and labourers could travel to various parts of the country with their trades where social contacts were established.

The Nile provided the cheapest and most effective construction materials. Reeds and plants that grew freely along the banks of the canals and in the marshes of the delta were used for building the earliest huts and house-boats. Badawy (19) traces the Egyptian frieze, which was painted or carved along the tops of the walls, to the upper end of the vertical reeds of the wall bound into bundles, fig.(5.15). The alluvium clay freely transported by the Nile was extensively used for massive walls and domestic buildings.

The climate of Egypt is mild; the wind is cool and the sun shines down in full majesty and is seldom obscured. The steady sunlight lent stability to whatever it illumined, while its dry heat ensured the preservation of objects buried beneath the sand. Generally, these climatic conditions encouraged living outside. In domestic architecture courtyards and gardens with ponds were common features. In country estates columned porticoes, always facing north to take advantage of the cool breeze, were sometimes independent of the orientation of the house. Because of this cool breeze towns also grew northward. Another feature of domestic architecture illustrating the importance of wind as a shaping force is the roof ventilator. These consisted of intake channels opening northward, conveying fresh air to the hot rooms below, fig.(5.20). This system was employed and developed to a more sophisticated ventilating system during the Islamic epoch in Egypt, and was in use till the beginning of the present century. Ancient Egyptian houses were plastered with mud mortar, decorated in natural or geometric patterns, and painted with coloured lime washes.

The Egyptians lived in a valley rich in natural resources and bordered by quarries and gold mines. These were exploited regularly in Sinai and Nubia to provide stone, gold and copper. Most of the common metals were known and used by the ancient Egyptians. They produced bronze by mixing tin with copper by 1500 BC, and imported iron by 1000 BC.

During the last 6000 years the Nile valley had no forests and the Egyptians imported the wood they needed from Africa and the Lebanon. They used wood with utmost care, developing a very high technical level in joinery. It is interesting to note their ingenious technique for ship-building since the 4th Dynasty, they did not nail the wood, instead they used ropes which shrunk when wet to tightly hold together the wood which itself expanded on absorbing water. This is clearly seen in the solar ships (funeral sun ships) of the Giza pyramids. Most of their techniques are still in use in todays rural joinery.

The Egyptians developed many tools which enabled them to exploit their natural surroundings. Irrigation equipment like the 'shadouf' was used for raising water, later the screw system, the 'tanbour' and the water wheel, the 'saquya', were developed. The plough was discovered in very early times, freeing man for the massive tasks in building. Weaving, metalwork and other innovative developments such as the wheel for transportation and various tools for industry were also employed. Techniques for sun baked brick making were developed, and sails were devised to capture wind power. The healthy effects of the sun were recognised for medical purposes and herbs and plants for curing diseases were in use. The mummification of bodies is but one of the many achievements of this epoch.

Briefly, the ancient Egyptian possessed a high ecological sense. It may also be said that they were the healthy root of the civilization tree of man.

Religion had the strongest influence on the lifestyle of the Ancient Egyptians, clearly seen in their eternal temples and majestic tombs on the eastern and western banks of the Nile. These were constructed from the most durable materials available at the time and according to the grand scale to express their thoughts of eternity and religious beliefs in the after-life. They had cosmic gods like Ra (sun), Nut (sky), Geb (Earth), Aton (the sun disk) besides many local gods such as Amun (the hidden one) of

Thebes, Ptah[1] the bull god of Memphis, Osiris (resurrection) and his wife Isis and their begotten son Horus (the high one). These later ones attained over the passage of time the status of the cosmic gods. When the worshipping of the sun Ra was upheld the Pharaoh was thought of as the Son of Ra, and when Osiris- worship gained favour another concept developed, for Horus was his son and his legitimate successor, so every new Pharaoh was considered as the incarnation of Horus, while every dead one was Osiris.

Religious thinking developed throughout history and established concepts of those religions that came later. In a way, the Egyptians discovered the need for a god for survival, presenting the ideology of both Christianity and Islam. This prepared the Egyptian mind with the basis and fundamentals of conceptual thought that made him flexible enough to accept first Christianity and then Islam as soon as they were introduced to the Nile valley.

The temple was the house of god, where a small statue resembling the god was set in the sanctuary and serviced by the Pharaoh or his delegate priests. Ra and Aton were worshipped in the shape of the sun in the sky. The ancient Egyptians believed in resurrection, judgement, redemption, hell, heaven and life after death. The person whose soul 'Ka' had been justified, and whose body 'Ba' could be preserved from corruption would enjoy eternal happy after life. Cities of the dead grew up in the arid desert west of the Nile, reminiscent of the daily death of the sun. The sun Ra (later, with the high power of the Theban god Amon, he became known as Amon-Ra) was the most important cosmic god in Ancient Egypt, whose bright light and heat imparted life to people, animals and plants. Houses were provided with small windows set high in the walls providing

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1 To the Ancient Egyptians Ptah was the god of Memphis, Lord of the Mighty Word, the Word of Creation. The bull Apis was a reincarnation of Ptah (177).

sufficient light while eliminating glare. Sunk reliefs and overhangs were used outdoors for direct sunlit areas and low reliefs for shaded ones, with lavishly coloured decorations.

The Ancient Egyptian period marks the beginning of architecture based on geometry and mathematics. Pyramids were built during the third and fourth dynasties illustrating sophisticated techniques in design, siting, orientation and construction methods. The proportions of the golden section[1] play an important role in the pyramids' design and can be established throughout the Egyptian development. Giedion (117) summarizes the way the Egyptians divided a line by the golden section, fig.(5.17). This simple method of division is reminiscent of that by which the Egyptians determined the inclination of an angle, keeping the height constant and varying the base line. The lines and planes of the great pyramid reveal many aspects of the golden section. The so-called Equation of Herodotus states that the square of the pyramid's height equals the area of one of the side triangles. The golden section also governs the relationship of the actual surface planes of the pyramids to one another. The surface of the square base is in the same ratio to the sum of the four sloping triangles as these are to the total surface area.

The way in which the Egyptian sculptor created his statues reflects the sophisticated dimensioning system employed in both sculpture and architecture. The sculptor starts from a block hewn into the shape of a prism, on whose sides he marks a square grid. Then he draws the figures on the sides, each of which has a deeply marked vertical centre

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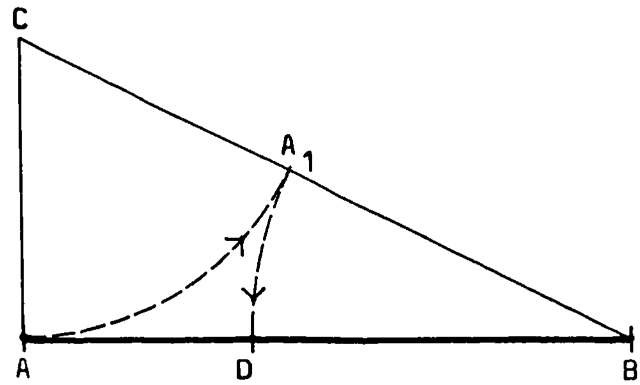
1 The golden section consists of the division of a straight line into two unequal parts, the smaller part being in the same ratio to the larger part as the larger part is to the whole.



"The starting points are the vertical, the horizontal and a right-angled triangle whose long cathetus (AB) measures twice the length of the small one (AC). Swinging the small cathetus onto the hypotenuse, we find point A_1. A second curve from the point A_1 to the long cathetus gives point D which divides AB in the proportion of the golden Section."

Figure (5.17) The Golden Section

line. The vertical planes slice centrally through the centre line of the drawn figure and intersect the other planes into right angles through the vertical axis of the produced statue. The square grid was closely related to both the proportions of the human body and the measuring system. The unit of measurement upon which all proportions were based was the hand; that part of the body that transfers thoughts into objects. The basic measure of the hand was the closed fist which equals the side-length of the square in most of the discovered grids. It is also equal to 1⅓ hand breadths. From the outstretched hand and arm was derived the decisive linear measurement the cubit[1] figure (5.18). This was measured from the elbow to the tip of the thumb, comprising 4½ squares or 24 fingers. The finger was further divided into units as small as millimetres. Human height was measured from the sole of the foot to the point where the wig or head covering joined the forehead. It was equal to 18 squares, or 4 cubits, or 6 feet, or 24 handbreadths. These indicate the interlacing of the proportions, form, and linear measure. Besides this cubit there was also the larger 'Royal Cubit' which exceeded the former by a handbreadth, and was measured from the elbow to the tip of the middle finger. This was older than the oldest stone monuments in Egypt for it was employed upon the Zoser complex at Saqqara of 2780 BC. The cubit spread throughout the Mediterranean and the Middle East. In contrast to the metre the cubit is a human measurement, originating in the relationships between hand, arm and body.

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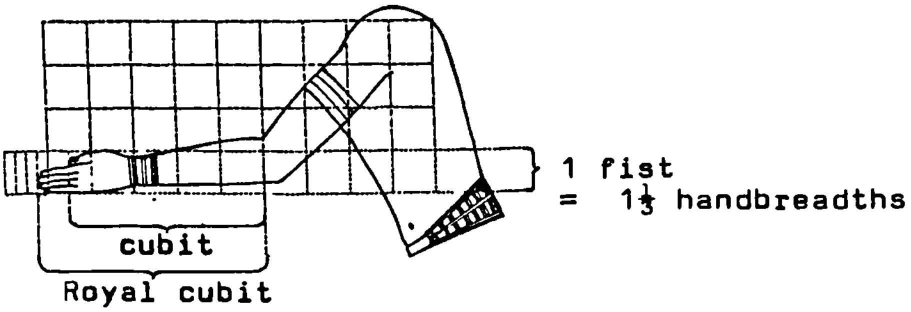
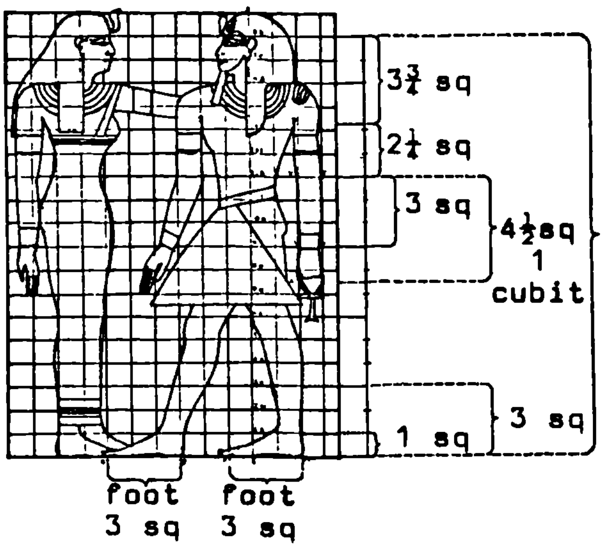
1 It is interesting to note that the cubit (zera'a) as a unit of measurement, consisting of 6 handbreadths and equal to 24 fingers (24 carat), has been in use in present-day Egypt right up to the forties and fifties. Moreover, in the Egyptian dialect the expression '24 carat' is still used to indicate the perfection and precision of an object.



a) cubit = 4½ squares = 6 handbreadths
b) Royal cubit = 5¼ squares = 7 handbreadths

The fist as the basic module in Egypt



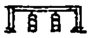
The human body and the square grid

Figure (5.18) The Square Grid and the Cubit. (117)

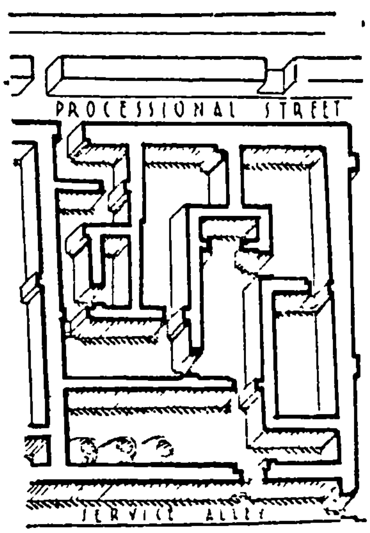
Proportions in Egyptian architecture were bound up with symbolic meanings. The Egyptian demanded an all-embracing oneness in his conceptual image of the world, which came to the fore in the careful cosmic orientation of the great pyramid of Khoufo (2600 BC). This unity was expressed in the Egyptian sanctuary where no detail without significance existed. Even when the temple was built over a long period of time, like the temple of Amon at Karnak, the part that was added was integrated into the whole by the use of the same system of proportions. Just as the proportions of the human figure were submitted to a grid based on the dimensions of the human hand, all proportions in architecture were related to the same basic system. Egyptian architecture was a projection of the proportions of the human body transposed into a larger eternal human scale. This was true of the great temples and their artifacts as well as of the tombs of the kings and nobles with their wall paintings[1].

1 One cannot help but wonder over the achievements of the Ancient Egyptians, though it must be remembered that what we know about their mathematics and science is what they chose to let us know, since these were kept secret and hidden.

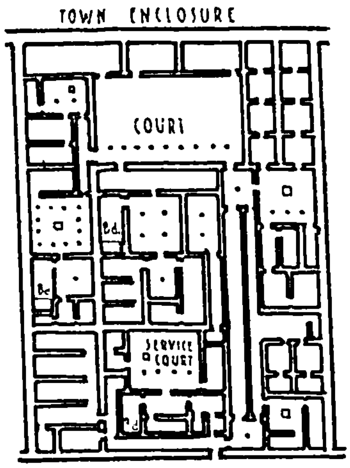
5.3.2 The Ancient Egyptian House

Egyptian houses were built of less durable materials than the temples and tombs. However, both house and town design showed concern for the pleasures of life and adaptation to the ambient environment. The hieroglyphic sign for town is either  or  expressing either radial or gridiron planning pattern respectively. Most of the towns excavated in Upper Egypt show orthogonal street patterns with main streets running north-south, and secondary ones running east-west, as in El-Lahun (1906 - 1850BC) and Amarna East (1372 - 1354BC). This shows the importance of channelling the north breeze. Badawy (19) suggests that the axial layout of towns may have existed in earlier times. Another characteristic of Egyptian towns was their compact layout and the protective walls around them. Environmentally, this would have reduced the total exposed surface area of the town and protected it against the severe climate of the desert. Among the hieroglyphic representations for buildings was the word house, representing the plan of a simple rural homestead in the shape of a rectangular courtyard surrounded by an enclosing wall  , and the term  for a covered enclosure. The facade of a columned portico was  and a cross-sectional elevation of a shallow-vaulted hypostyle hall  . The domed room for the women was written as  ; granaries were expressed as  . It appeared that the Egyptians were familiar with the idea of the vault and the dome well before Roman times. The signs described above first appeared in early dynastic times, and became common from the 3rd dynasty onward.

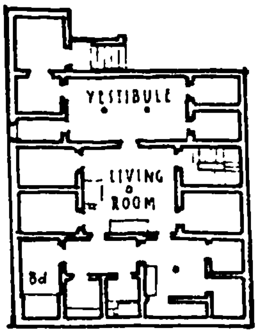
During the Old Kingdom, and from the 4th dynasty (2723-2563BC) houses of uniform plan were constructed side by side in one row. The brick walls were thick and the rooms long and narrow, in a shape suggesting that they were roofed with brick vaults. Figures (5.19 to 5.21) show a variety of



(a) Old Kingdom
Row House, Giza
26th century BC
5th Dynasty



(b) Middle Kingdom
Row house,
El-Lahun
19th century BC



(c) The New Kingdom
Amarna typical villa
14th century BC

Figure (5.19) Ancient Egyptian houses.

1 roof ventilation
2 courtyard
3 staircase

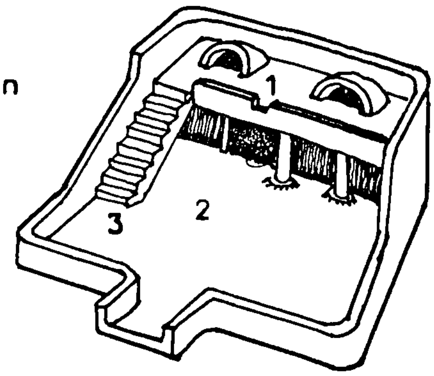


Figure (5.20) Mud model of an Egyptian house, (British Museum).

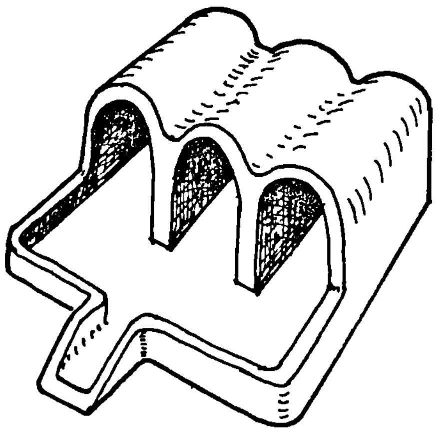


Figure (5.21) Mud model of Egyptian house (Egyptian Museum).

models found in tombs presenting a selection of rural and urban house types. These houses had front courtyards with small water basins, an oven and grain bins. Window openings were high in the walls, with half domes projecting from the roof facing north to channel air into the rooms below, figure (5.20).

The workmen's town of El-Lahun, near Fayum, belongs to the Middle Kingdom; the large houses were situated at the most northerly end of the town to benefit from the cool breezes. The typical house was divided into two main sections by two corridors from the entrance lobby. The eastern part was narrow with three courtyards and was used as offices. The western part, used as residence, was much bigger and had the main courtyard near the back. The house had many courts facing north with columned porticos along the south side, fig.(5.19b). The functional zoning of the plan shows easy circulation between the different zones. The hierarchy of the spaces served from an entrance, and their alliance to climatic conditions are evidence of a high level of awareness to providing for architectural needs in relation to the prevailing environmental conditions. The bedrooms usually included an alcove at their ends, raised one step and slightly narrower than the room itself, with roof ventilators employed for space ventilation.

More remains from the New Kingdom than from previous periods, in Thebes houses three stories high were built, as recorded in the tomb of Thutnefer (1500 BC), figure (5.25c) (21). The villas of Amarna (1365 - 1350 BC) must have been part of a luxurious complex, comprising granaries, storerooms, kitchens, chariot houses and chapels all laid out in a large garden. The house itself was a square with the hypostyle hall in the centre higher than the surrounding parts and lit by clerestorey windows, this was the living room. To the north was a two storied section with its upper level as an open loggia facing north and west, figure (5.22). Bedrooms and bathrooms were arranged around the main hall. Fresh water was carried from the Nile and waste water drained to soak into the desert. The plan was modular in system, harmonious in space relations and compact in form, securing the minimum surface area to volume ratio. Maximum benefit from the cool northern breezes and the daylight were achieved without glare.

Deir el Medina (1530 - 1100 BC) was constructed as an artisan village and occupied for about four centuries. The houses were very deep in plan (5·0 x 15 m), having one storey and no corridors, with extreme economy and efficiency in space. A house typically consisted of a front room, having its own altar, followed by a hypostyle hall with one central column, then a bedroom and a roof-less kitchen from which a staircase rose to the terrace. Storage places were in a basement cellar and cellaretto in the kitchen, fig.(5.23). The main doors were staggered so that maximum privacy was secured. The hypostyle hall was lit by clerestory windows, figure (5.23a), while the outer hall was ventilated by a roof ventilator like those of earlier times.

No doubt Egyptian religious architecture was more developed and more sophisticated than the domestic architecture which has already been investigated, however the study of the temples and tombs of Ancient Egypt is out of the scope of this research. One may only conclude that Egyptian architecture succeeded in fulfilling functional requirements in an aesthetic and technological manner conforming to their religious symbolism and moral ideals.

> 'Endowed with originality, the Egyptians invented the basic elements of both trabeated and voulted systems of construction in stone and brick and devised the stylistic canons and components that

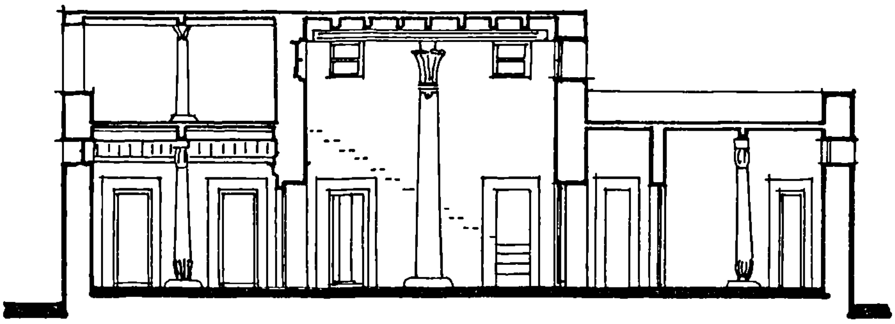


Figure (5.22) Section through Amarna Villa

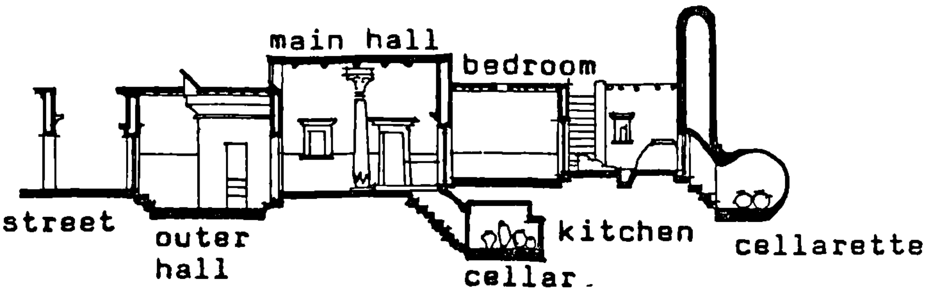


Figure (5.23) Section of Deir el Madina House.

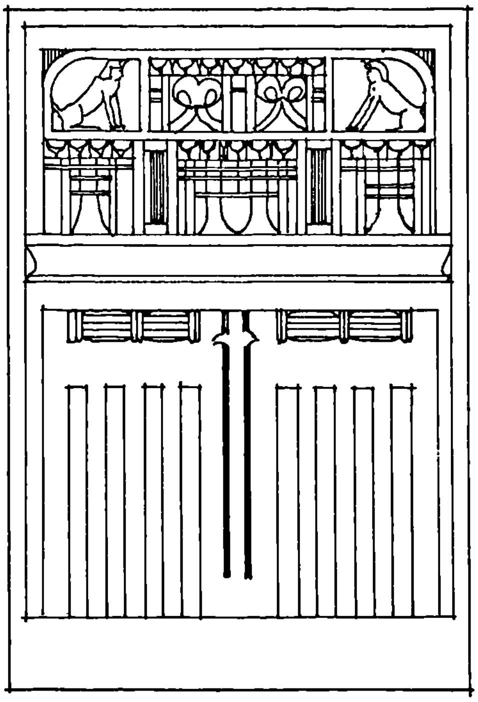


Figure (5.23a) Window of the throne room of King Merenptah. Stone grill of the clearstorey window, the light filtered through narrow vertical slits.

were transformed by Greeks into classical architecture, the basis of architecture till the turn of the century'.

A Badawy (19)

Both houses and streets in towns were designed in accordance with the human scale but the grand scale was introduced in common public spaces, and even inside the house, in the living rooms whenever needed. The Egyptian house showed an established order reflecting the regular life style. It always had three sections; an entrance for reception which was sometimes uncovered; a living area which usually comprised a hypostyle hall; and the private area including bedrooms, kitchen and bathrooms. The quality of light seems to have played an important part in reinforcing space hierarchy within the house while eliminating the glare of the bright sky. The hot climate encouraged living outdoors and courtyards were an essential part of the house. Wind (cool breeze) was the most important climatic factor influencing house design and this could be seen in both space arrangement and orientation. When there was an open courtyard the loggia was located on the south side in order to receive the north breeze, figure (5.19b), but if the house had no inner court a first floor loggia facing the north was introduced, figure (5.22). The roof ventilators, usually positioned to face the most desirable wind direction, were a characteristic feature of the Egyptian architecture. Both the loggia (maka'ad) and the roof ventilators (malkaf) had been a cornerstone in house design from Ancient Egyptian times, through the Coptic era and the Islamic period, till the end of the last century.

The Ancient Egyptian compace house plan was arranged in rows to achieve minimum surface area to volume ratio. When the house contained a courtyard it was deep enough to provide shade for most of the daytime hours. It also acted as a source of cool air to supply the inner enclosure.

Bricks of mud mixed with chaff or sand were used for the thick, massive walls, and elaborate interlocking brick moulds had been developed for constructing true arches and ribbed vaults (5th Dynasty at Giza and Saqqara, 2563 - 2423 BC). The majority of houses and palaces were built of these bricks and roofed with vaults and domes. Moreover, during the Amarna period (1366 BC), concrete beds were used as foundations for the houses of the artisans' village.(21). The high thermal capacity of the adobe used in constructing the domestic buildings modified the indoor climate to a more comfortable one; this was due to its long time lag of about 8 hours[1].

In spite of the decline of the Egyptian Empire with the Persian invasions (525 - 404 BC and 344 - 333 BC) and the Macedonians (332 BC), the Egyptian architectural style survived in most of the country to re-emerge during the Ptolomeic Dynasty (304 - 30 BC), and to influence the Coptic[2] period afterwards.

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1 The time lag is a function of the thermal capacity of the material as well as the cross section of the element.

2 The term 'Copt' is used in modern Egypt to indicate an Egyptian Christian, including the original Egyptian followers of Christianity, the Roman Orthodox and other Christian minorities. The word itself is derived from the Greek 'Ai-gy-ptios' from the original 'Het-Ka-Ptah' meaning the house of the Ka (soul) of Ptah, the bull god of Memphis. This was further transformed in Arabic, the native tongue in Egypt after the Arab conquest, as 'Copt' (218). In the context of the next section this will be used to designate the native Christian Egyptian from the Roman Christian during the so-called Coptic period.
It has also been suggested that the word 'Quefty' was used to refer to the inhabitants of Queft, a town in Upper Egypt famous for trade in ancient times, and the words Coft, Copt and Copti have been derived from it.

5.3.3 The Coptic Period

The Coptic period can be considered to have three principal divisions, marked by three major events. Firstly, Egypt was incorporated into the Roman Empire in 30 BC; secondly, the transfer of the imperial capital from the west to Byzantium and the recognition of Christianity as the official religion in 313 AD; thirdly, the Arab conquest of Egypt in 641 AD.

Christianity came to Egypt[1] in an unauthorized way during the Roman occupation, which had already begun the destruction of the older Egyptian religion[2]. To the Egyptians this meant the destruction of the pivot of popular resistance and the main source of pride. However, they found a new strength in the new religion, Christianity, which matched the myths and ideologies prevalent at the time:

> 'It is not improbable that the conception of trinity, which formed no part of the original Jewish Christianity, may be traced to an Egyptian origin, the whole of the older Egyptian theology was permeated with the idea of triple[3] divinity.'

J G Milne, in vol. V of 'The History Of Egypt' (1898);(43).

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1 Fedden (106) suggested that the fortress of Babylon has been inhabited by Christians since St Mark evangelized Egypt in the 1st century (about 63 AD).

2 All the reilgious properties were removed from the temples to the state treasury, leaving the Egyptian priests with no means of power.

3 The Egyptian Mysteries of Osiris, the wise king who made Egypt the centre of the world, his beloved wife Isis, and their begotten son Horus, are said to bear some parallelism to the trinity concept in Christianity (177, 218, 22 , 106, 7).

The Ancient Egyptian mind had been conditioned by their belief in the spiritual awakening through the self-sacrifice of IAI[1], and in resurrection, the day of judgement, redemption, hell and heaven, life after death and the trinity concept, which were all part of their ancient faith and were accepted readily in the new religion. Christianity was very quickly at home in Egypt.

At the beginning the Coptic Christians were from the colonial artisans, the revolutionary natives, the rebellious peasants, and the persecuted and badly treated minorities. Christianity was a simple creed that helped them bear their miseries and unify their rebellious resistance. They were the mass of the Egyptian people who, in addition to being subject to forced labour, had to provide a tribute, the 'annona'[2], which was destined for the provision of Rome.

The shift of the Empire's capital to Byzantium and the adoption of Christianity as the official religion was complete by 313 AD (218). Suddenly there were two kinds of Christianity in Egypt: the Coptic Christianity of the opressed Egyptians and the Melchite Christianity of the new opressive Byzantine rulers. A conflict was inevitable and it concerned the nature[3] of the Christ. Technically Coptic Christianity was now legal, and even orthodox, but

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1 IAI, the great Ass in the ninth hour of the sun's progression through the night, offers himself to the double monster as a sacrifice so that the Barque of the sun can traverse the night to the light of dawn. IAI proclaims the same message as John the Baptist.

2 The annona was a heavy tax payable in the form of a quantity of corn, and fixed annually according to the harvest, the domestic animals and the requirements of Rome. Egyptians were subject to this form of taxation whatever they were - labourers, peasants or landowners.

3 The Copts said Christ had 'one nature' only, a divine one. Their rivals the Melchites said He had two natures the divine and the human. This was no more than a doctrinal argument, but it was enough for the Roman Church to set about damping the Egyptian Copts (177,22,7,209,106).

Roman executions of Copts went on more viciously than ever before, only now they were done in the name of Christian dogma. For approximately three hundred years Roman (and Byzantine) Christianity tried to suppress the Egyptian mind but the Egyptians went on resisting with a unique national ideology[1]. Babylon, the Roman fort which falls within the boundaries of present day Cairo, was one of the places where the conflict[2] was sharpest, because it was the principal stronghold in Central and Upper Egypt. The conflict with Byzantine orthodoxy came to an end with the Arab conquest and the Coptic church was overjoyed at being finally liberated from the Byzantine opression (218).

Therefore Coptic art and architecture has been developed from a people in the process of converting to Christianity under difficult circumstances. The deprivation of the Egyptian Copts from both official financial and professional artictic support contributed to freeing their art from the Hellenistic traditional and stylistic influences, and led them to adopt the folk traditions of their ancestors. They

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1 Badawy (22) reports that Philo, the Greek philosopher of Jewish origin who lived in Alexandria at the beginning of the first century, described monastery life in 'De Vita Contemplativa' as of people called upon by divine vocation to abandon urban life, seeking friendship with God, and curing the passions. This move towards the spiritual life was allied to the abandonment of villages in the second century AD and the fleeing of the people from these places to escape from taxation and religious opression. The move gained strength following the establishment of Christianity as the state religion for the Byzantine Empire. By the end of the fourth century these men were already organized in communities and building for themselves common meeting places and churches, and the movement later spread to western Europe (248).

2 Bishop Cyrus, the Roman Viceroy of Egypt for the last ten years before the Arab conquest, had been persecuting the rebellious Copts; most of the Coptic churches in the fort of Babylon had been closed. The Coptic historian John of Nikion described the state of those Copts who welcomed the Muslim Arab into Egypt (7).

moulded the exteriors of their churches after the Egyptian temple expressing simplicity on a monumental scale, with the interiors related carefully to the human scale. Their roofs expressed the domestic architecture of the Ancient Egyptians, especially the mud domes and vaults. Occasionally they borrowed decorative subjects from Hellenistic Syria,(129), figure (5.24).

5.3.4 The Coptic House

The critical conditions of life in Coptic communities, mirrored in their dense urban settlements enclosed within protective walls, provided the necessity for the adoption of multistoried houses similar to those of Thebes and Greco-Roman Egypt, on exceedingly small, deep and narrow plots[1]. Houses might be as small as one room on each floor with an internal stairway, or they might be much bigger comprising as many as four rooms per floor. Badawy (22) describes the typical house at Djime, figure (5.25a & b), having a central staircase flanked by a room on either side. The staircase rose from an underground cellar to three upper stories and was connected to the street by a corridor.

Houses were built in rows or free standing patterns served by narrow streets. They were constructed mainly of mud brick[2] formed into massive walls (0•75 - 0•80 m) and vaults of catenary shape 3•6 m high. Arched doorways and staircases were remarkably narrow (0•6 - 0•8 m); the staircase was very steep (the rise 0•22 m and the tread 0•20 m) with the steps usually made of baked brick often overlaid

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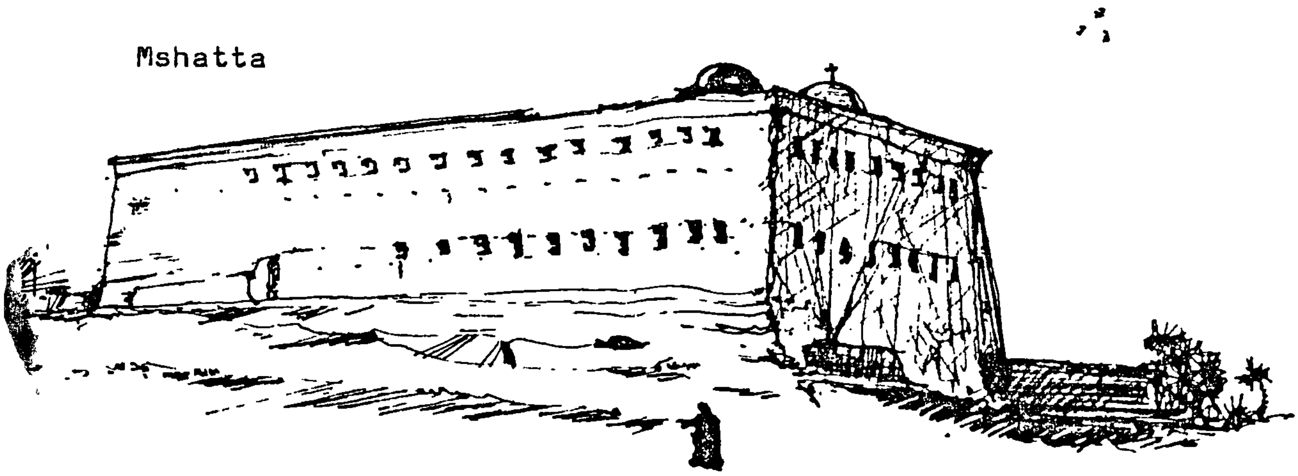
1 In Djime houses were built on plots of 8 x 4, 6•5 x 6•5, and 9 x 3•5 metres, while at Tell Edfu they ranged from 6 x 2•3 to 10•5 x 9 metres (22).

2 The mud bricks in the walls were 30 x 14 x 6 cm to 31 x 15 x 7 cm, while in the vaults they were 24 x 15 x 5•5 cm to suit vault construction.

Mshatta



plan

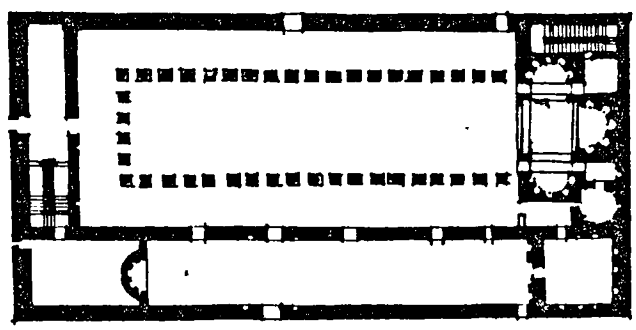


Figure (5.24) Deir el Abiad near Sohag. Imitation of Ancient Egyptian style (temple), with battered blank walls crowned by a cavetto cornice. The aisles arrangement takes that of Egyptian temples (courtyards).

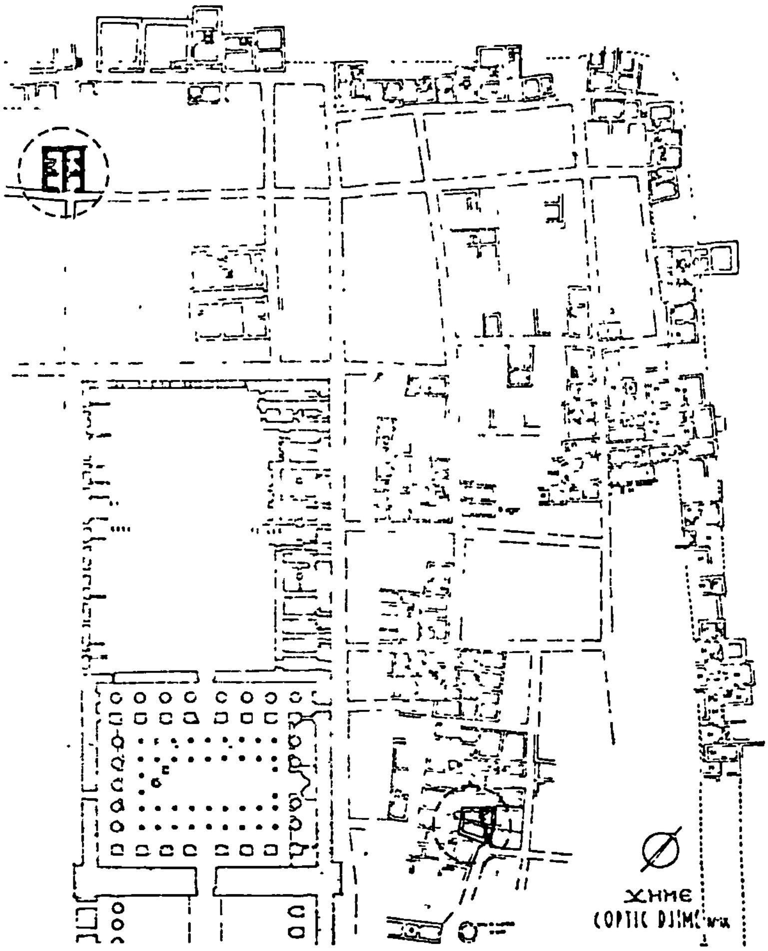


Figure (5.25a) Plan of Djime (Coptic town in Medinet Habu). (22)

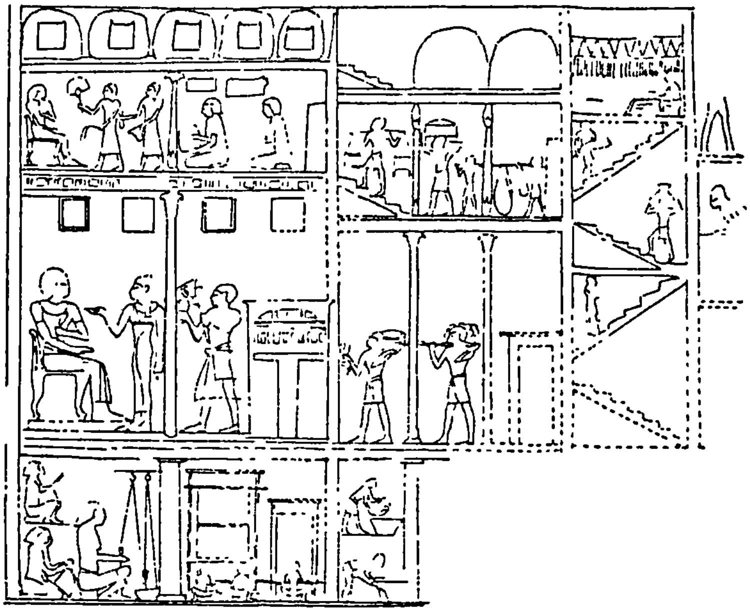


Figure (5.25c) An example of Ancient Egyptian city house (20).

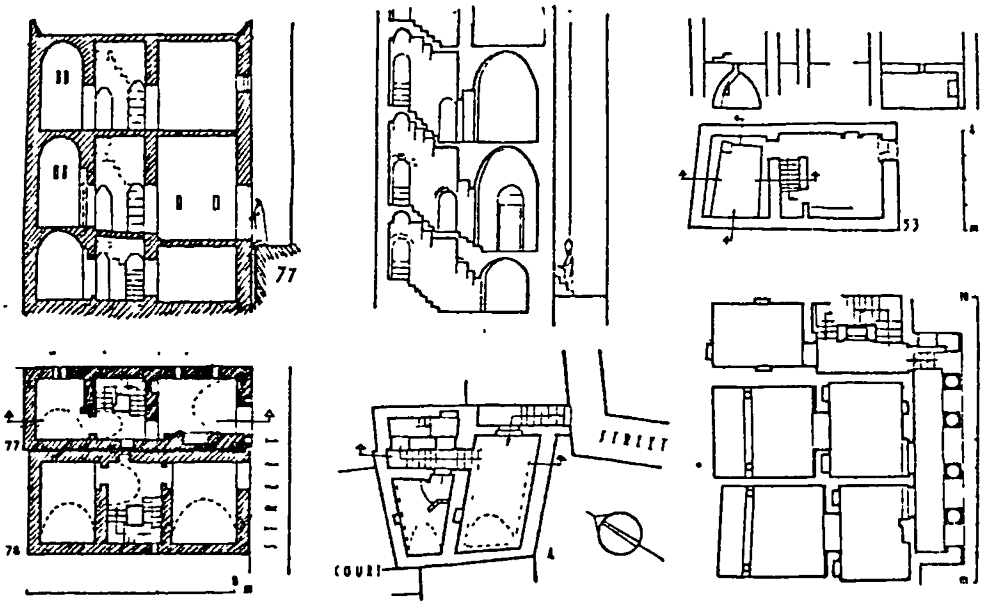


Figure (5.25b) Plans and sections of houses 4, 53, 77, and 78 at Djime of Medinet Habu (22).

with stone slabs. It was carried on short stretches of vaults stepped accordingly to the gradient of the flight. Both head room and doorways were often lower than human height, the latter spanned by stone lintels decorated in relief with rosettes, crosses and occasionally floral patterns. The scale of the circulation elements may be interpreted in two ways: a search for security, and the economic forces of that period. Low cellars extending beneath the entire floor, or a part of it, were accessible through a hatch in the crown of the vault at the small end of the room above. Beneath the hatch, sometimes at the bottom of a funnel in the thickness of the wall, a few steps were set to help one alight, fig.(5.26). A system of ventilation comprising a terra-cotta pipe 10 to 12 cm in diameter set vertically in the crown of the cellar has been found (22). Ground floor windows were very small (0·2 x 0·4 m) and opened at the upper part of the walls; larger windows might have been used on the upper floors.

The walls were plastered both outside and inside, with the interior surface whitewashed. Occasionally small courtyards were arranged at the rear above a cellar. Floors were paved either with a mud screed or with baked bricks. Elements which can be interpreted as baths have been found at Tell Edfu, fig.(5.27). Badawy reports some stone houses at the town of Ostracina (with walls 0·4 - 0·5 m) having two to three rooms each. They were lit through upper windows. The regular stones of these houses reflected the type of masonry used in the religious architecture of the Ancient Egyptians, and which was commonly constructed by the Byzantines in Syria during this period. The contrast between buildings constructed and sponsored by Byzantium and those of the native Copts was very pronounced; the Byzantines built mainly in stone and wood using imported materials, while the adobe construction of domes and vaults was the native technique in Egypt.

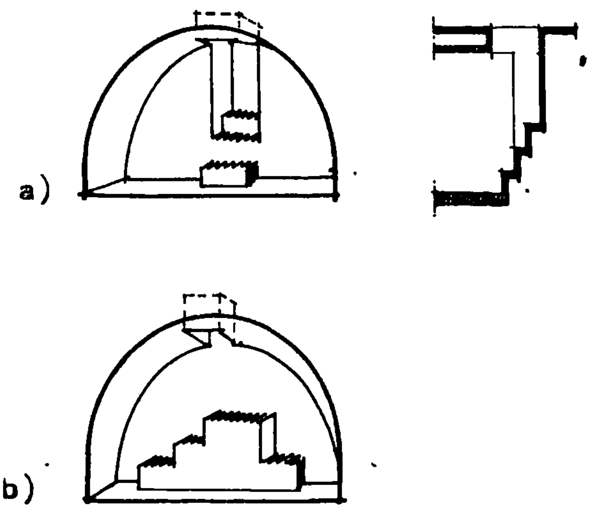


Figure (5.26) Funnel, hatch and steps to the cellars in Coptic houses (22).

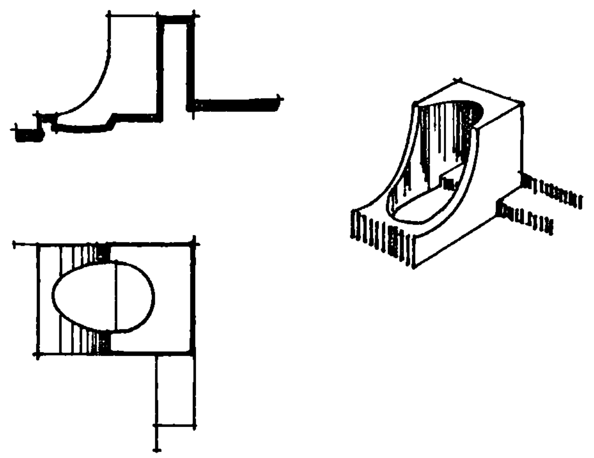


Figure (5.27) Details of baths at Tell Edfu (22).

The domestic architecture of Coptic Egypt displayed the continuity of Egyptian domestic architecture with the emphasis on security and economy. The town houses followed a tradition carried over from Ancient Egypt, it can be seen clearly in the painted representations of many tombs. The tomb of Thutnefer from the eighteenth dynasty shows these similarities, figure (5.25c). Later the same elements and techniques were used in the same ways but with a decrease in scale and less ornamentation. The Copts realised the environmental qualities of massive structures and the economy of this technique, and constructed their buildings using thick mud walls and covering them with vaults and domes.

Multi-storey houses had a small surface area compared to that of single storey houses of equal volume. Moreover, in the Egyptian climate the roof is subject to the highest thermal stress because of solar radiation and the Coptic houses, like those of the Ancient Egyptians, had the roof area reduced to a minimum. The narrow streets of their towns and monasteries, with their dense urban structure, had introduced a very low total surface area to occupied volume ratio. In Coptic architecture little attention was paid to orientation[1] which may have been a result of the dense urban structure as well as the predominant feature of very narrow windows. Factors affecting the size of windows included the intensity of the sunlight and the need for privacy. The absense of the Malkaf as a ventilation device may be because of the overriding trend of reduced openings.

It was indeed to the credit of the Coptic architect that he succeeded in creating, independently from Byzantium and

---

1 Except in religious architecture where the orientation of the altar to face east, Jerusalem, was a common feature

under the difficult circumstances explained above, a style so functional that at its best it was endowed with as much aesthetic quality as the finest of its Byzantine contemporaries. The success of Coptic architecture was as much due to creativeness as to borrowing from a rich Ancient Egyptian heritage. The influence of Coptic art and architecture extended far beyond their place and their time.

Coptic bishops, accompanied by monks and followers, sailed abroad to attend congresses and more often than they wished were sent into exile. On these travels they carried with them their beliefs and ideas influencing the peoples and places they went to, and spreading Coptic art by personal contact. Trade activities also contributed to the influence of Coptic art on places beyond the reach of the Copts themselves. Southward Coptic printing was the primary source of pictorial style in the Christian kingdoms of the Sudan and in early Ethiopia. Northward it is certain that it exerted some impact on Italy. The complex and precise interlacings of Coptic patterns seen in the 'Book of Kells' demonstrate the Coptic influence on the Irish-Northumbrian school; as Osborne (209) suggests, this may have been exercised through some imported church hangings.

Coptic art and architecture has influenced that of Islam, even outside the borders of Egypt. The combination of the trefoil apse with the basilican hall, as carried out in the Umayyad palace of El Mushatta, south of Amman (743 - 744) figure (5.28), has been identified by Creswell(77) as an influence from Coptic architecture which can be seen in Deir-el-Abiad, figure (5.24). This was probably transferred by Copts converted to Islam as well as by those Copts employed on Muslim construction sites.

The conquest of Egypt by the Arabs in 641 AD had little mmediate effect on Coptic art and architecture[1]. A century later the character of the Coptic community was beginning to change, and its culture was becoming more urban. At the end of the Byzantine rule many of the Melchite merchant classes had become Copts or Muslims. Islam was also accepted in most of the rural areas of the country. Under the normally tolerant rule of the Tulumids and the Fatimids (868 to 1171 AD) a new phase in Coptic art came into being. Egyptian Muslims and Copts had been employed in many early Islamic buildings affecting the designs and decorations, but gradually geometrical and spiritual designs inspired and developed by the many races that accepted Islam became dominant.

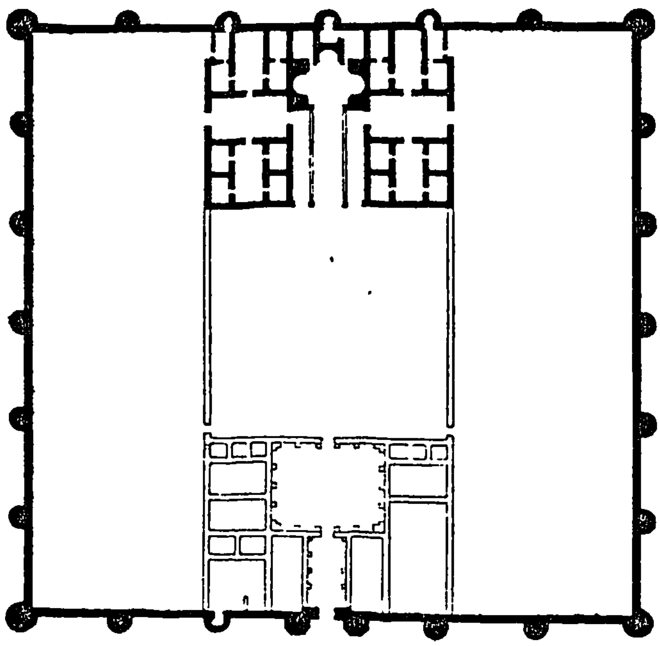


Figure (5.28) Mshatta palace of the Umayyad period (77).

1 The Arab, bedouin by nature, dwelled outside Babylon where they established their new capital 'El-Fustat', leaving the fort itself to the natives, It is interesting to note that till 1981 there are no mosques within the boundaries of the fort, though it is crowded with both old and new churches.

5.3.5 The Islamic Period

After 641 AD Egypt became a part of the Islamic Empire and most often its flourishing centre. For the purposes of this section, the Islamic period in Egypt may be considered as comprising three main parts, each coming as the result of a major event. The first period started with the Arab conquest (641 - 968), then came the Fatimid period (969 - 1169), followed by the third period comprising the Ayyobied dynasty, the Mamelukes and the Ottmans. The developments occurring in this time are best examined by following the developments of the city we know as 'Al-Kahira' ('the conqueror' or 'the victorious'), also known by its European name 'Cairo', figure (5.29).

Islamic culture developed as a result of the rapid military and religious conquest of diverse territories and ancient cultures by the Arabs, the inhabitants of the Arabian peninsula.

> 'The golden age of the Saracens[1] was the twelve years, AD 632 to 644, comprised in the reigns of Abu-Bakr and Omar. This was a period of uninterrupted internal harmony and external conquest.'
>
> Freeman
>
> (in 'History of the Saracens') (126)

By 641 AD the Arabs had occupied Egypt, Persia, Iraq, Syria and Palestine. The population of Arabia was quite inadequate to cause much change in any of the

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1 'Saracen' was a name given by Greek writers of the 1st century AD to the Bedouin Arabs who lived in Mesopotamia (284). During the Middle Ages it was employed for all infidel nations against which crusades were preached (283). It was also used by Sir Christopher Wren to refer to pointed arches and Islamic architecture in general (107, 282).

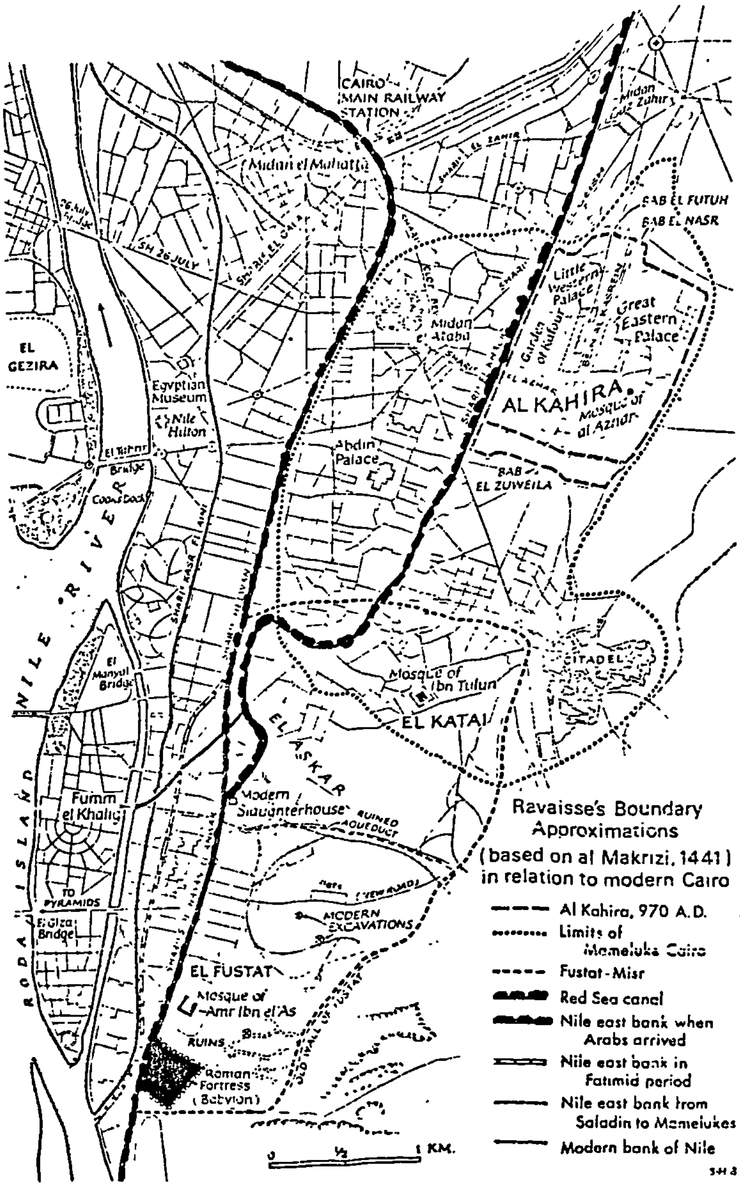


Figure (5.29a) El-Kahira (Cairo) before the Arab Conquest was known as The Roman Fortress 'Babylon' (before 641).

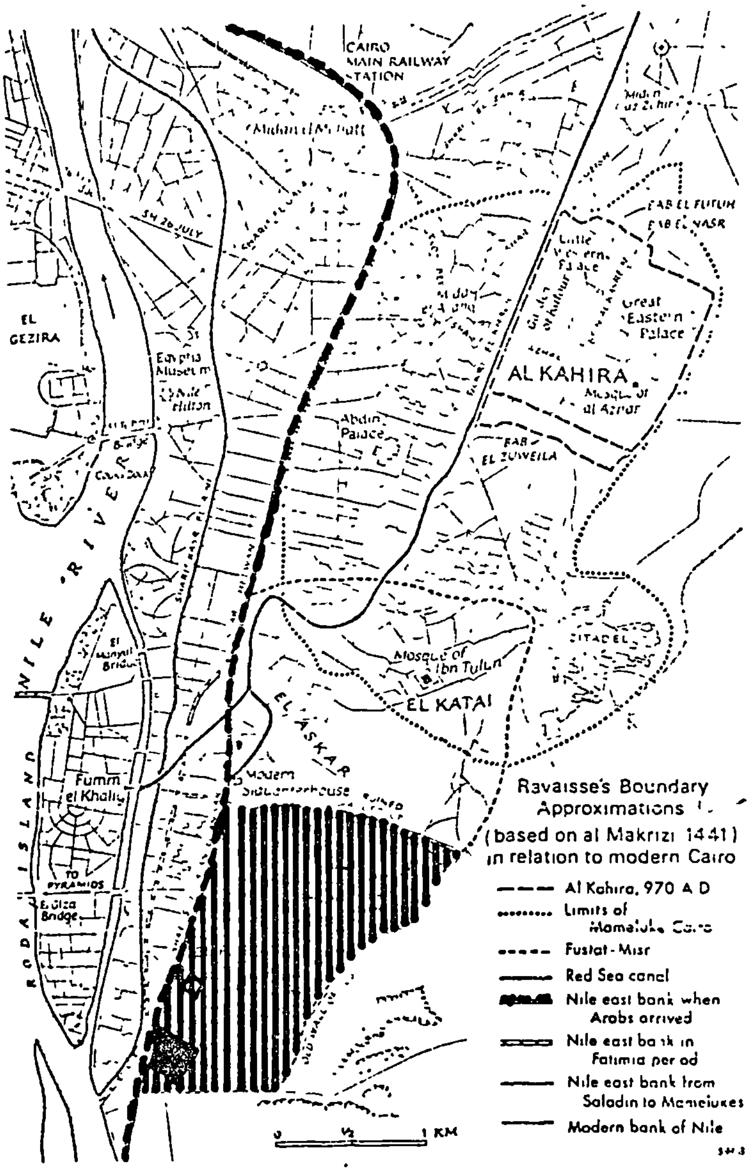


Figure (5.29b) El-Kahira (Cairo) during the Umayyad period was known as Fustat (641 - 750)

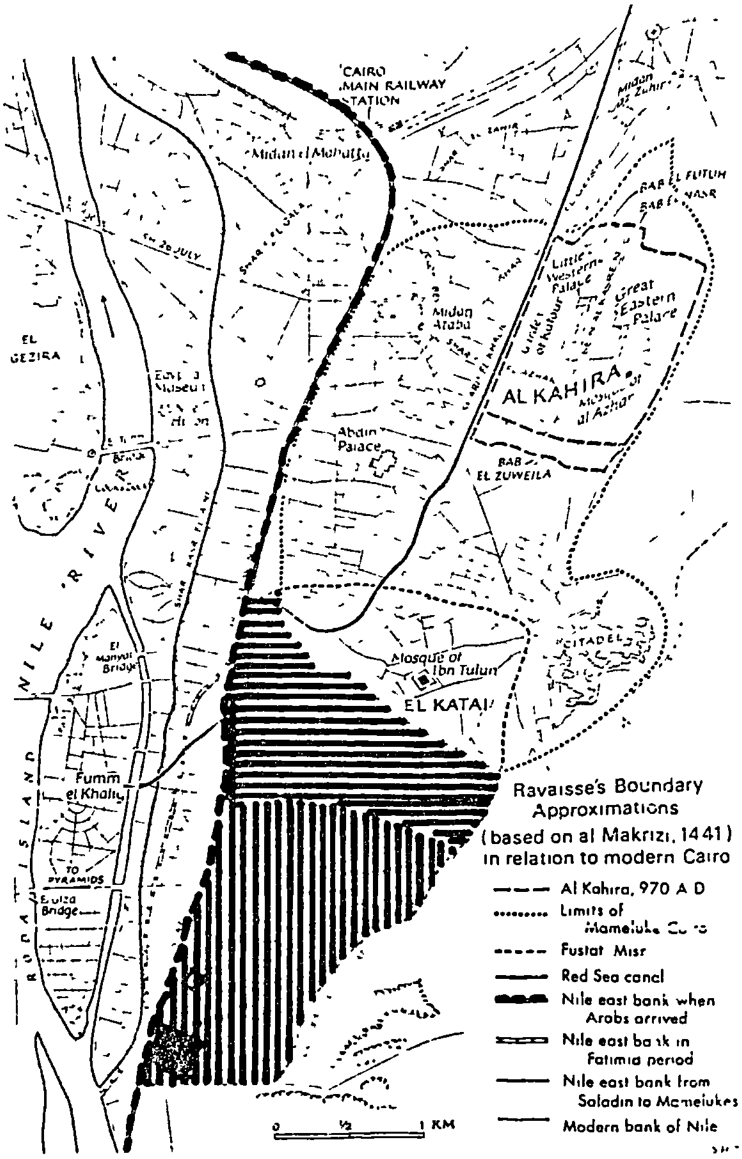


Figure (5.29c) El-Kahira (Cairo) during the Abbasid period comprised El-Fustat and El-Askar (750 - 870)

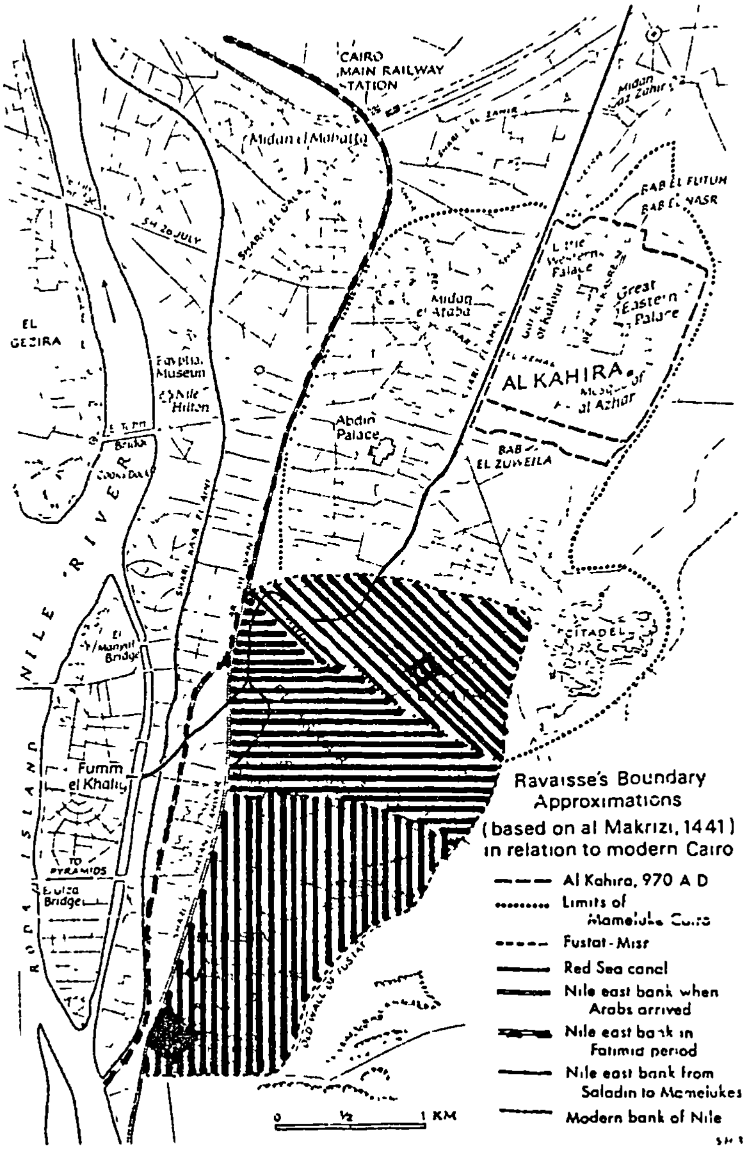


Figure (5.29d) El-Kahira (Cairo) during the Tulunid period comprised El-Fustat, El-Askar and El-Katai (870 - 969).

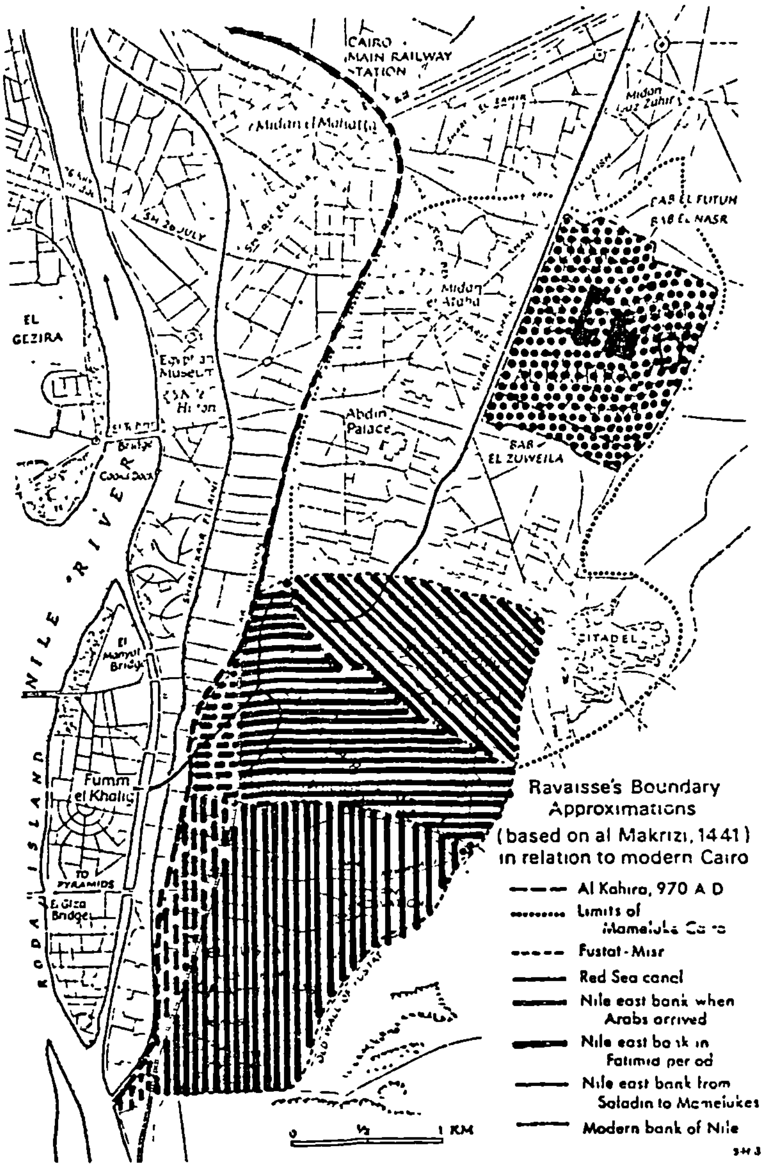


Figure (5.29e) El-Kahira (Cairo) was first known by this name during the Fatimid period, and comprised El-Fustat, El-Askar, El-Katai and El-Kahira (969 - 1169).

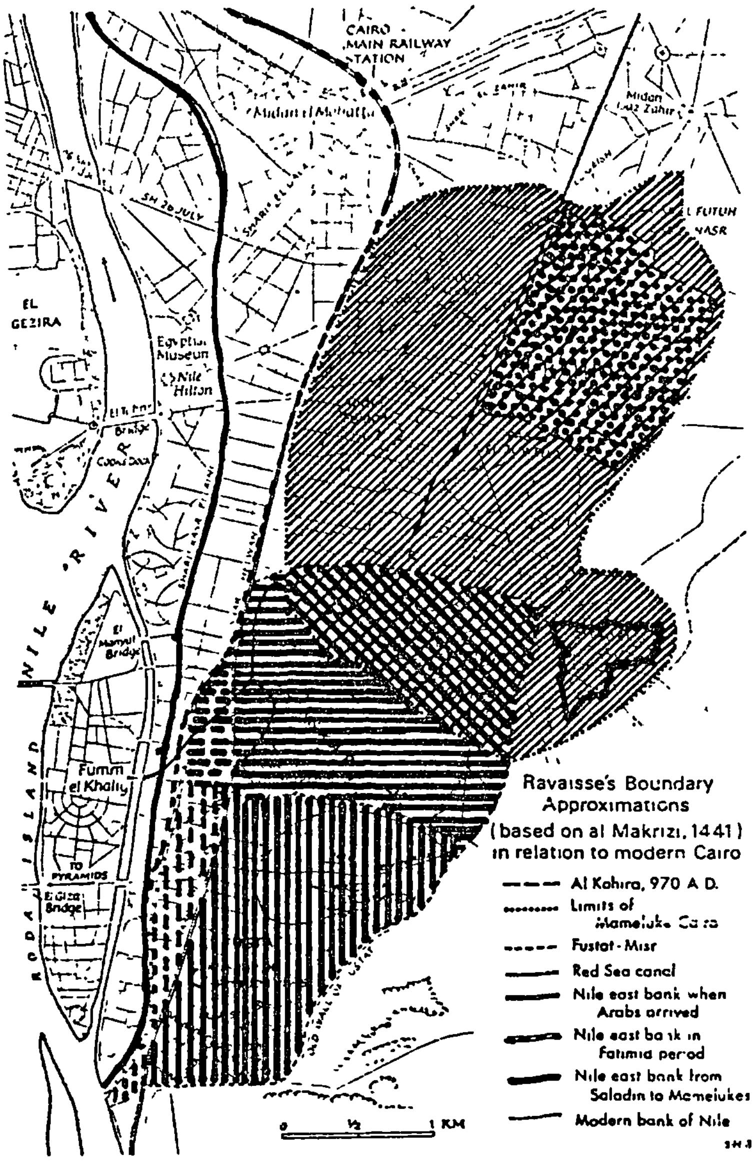


Figure (5.29f) El-Kahira (Cairo) before Muhammed Ali's dynasty, including the Ayyubid, Mamluk and Ottoman periods, and known as Mamluk Cairo.

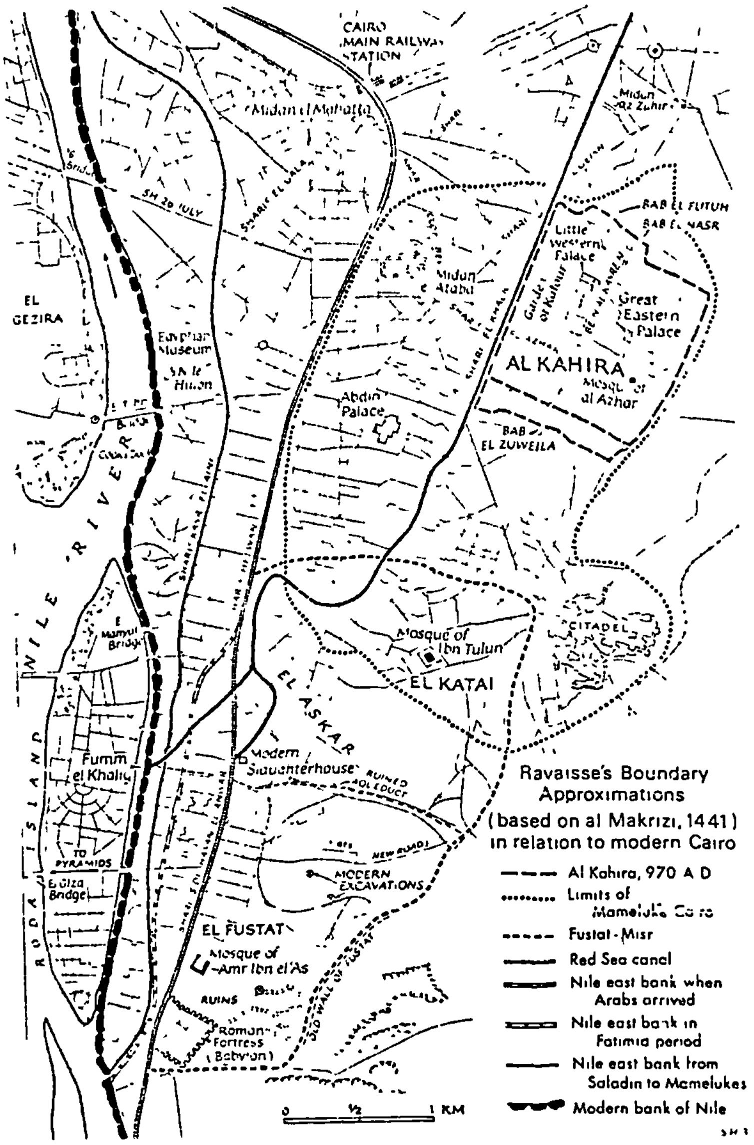


Figure (5.29g) The old part of El-Kahira (Cairo) during and after Muhammed Ali's dynasty.

conquered regions, some of which had a population greatly exceeding that of Arabia itself[1]. The principal source of intermixture of Arab blood in Egypt after the conquest would have arisen from the garrison of Fustat whose early inhabitants acquired Egyptian wives, and in a few generations their descendants were very nearly pure Egyptian. Moreover, at the time of ratification[2] of the treaty concerning Alexandria, many Christian Egyptians adopted Islam, securing a lighter system of taxation as well as equality in law with their rulers[3]. The whole ideology of the Great Arab Conquest was centred around introducing the new religion to the world, and their strongest influence on the countries they conquered was a spiritual one. However, Islam as a religion was not strange to the Christians of Egypt, on the contrary it was held by many as the logical successor to Jewish and Christian teaching. Islam preached a doctrine of tolerance towards Jewish, Coptic and all other Christian religions; moreover, belief in Islam demanded a belief in Judaism and Christianity.

'Say: we believe in God and that which has been

---

1 The Arabs who migrated at the time were entirely bedouin, and they considered the innumerable deep, muddy water channels, urban cities and damp valley of Egypt polluted and utterly uncongenial. Many of them settled in the desert areas (126). By 1970 the estimated number of nomads in Egypt was 50,000 (equivalent to 0·1% of the total population), of whom the immigrant Arabians form a considerable section (26).

2 Egypt fell to the Arabs by two treaties and with very little fighting. First Babylon surrendered, and a few months later Alexandria followed (126). The Arabian people, accustomed to open-land (desert) war would never have been able to capture Egypt without the help of its people.

3 Glubb (126) attributes the tendency of the Egyptian Muslims of the time to call themselves Arabs to the confusion of thoughts between race and religion. However, the word Arab, in the modern sense, refers to the Arabic speaking nations regardless of their race or religion.

> sent down to us and sent down on Abraham, Ismail, Isaac, Jacob and the tribes and that which were given to Moses and Jesus and which were given to the Prophets of their Lord, we make no segregation between any of them and to Him belongs our submission.'
>
> Interpretation of verse 136 of Sura 'El-Baqara'
> 'The Koran Interpreted' (13)

To a Muslim Islam is the religion of Adam, Abraham, Noah, Moses, David, Mary, Jesus and all the prophets. So, Islam came to an Egyptian people already believing in the existance of God, and the prophets preceding Jesus. Islam stressed that the Unity of God resulted in the unity of his divine message.

> 'Islam carries the sense of peaceful submission to God, abandonment to His providence, unfragmented bare acceptance of His unity and incomparable will.'
>
> R Eyre (102)

The Islamic faith is a complete philosophy of life which depends on three works. First comes the heart of the religion, the Holy Koran, regarded as the revelation of God's will to his Prophet; secondly the 'Hadith', which is the collection of Sayings of the Prophet; and thirdly the 'Shariah', comprising the interpretations of the Holy Koran, the Hadith and the Prophet's instructions on matters concerning daily life. Although the Koran and the Hadith are constant in most Islamic societies the Shariah varies, allowing for some differences in social character and customs with the changes in space and time.

Islamic civilization can be seen as an example of traditional civilization wherein can be clearly observed the presence of certain immutable, dominant principles. Islamic art is no more than a reflection in the world of matter of the spirit, and even the form, of the Koranic revelation.

> 'Sensible knowledge of this world, that is, the world of becoming, is a symbol of the intelligible knowledge of that world. The physical world is the symbol and image of the spiritual world.'
>
> Afdal Al-Din Al-Kashani
> 'Musannafat' 14th Century, (14)

The people of Arabia in the early days of Islam had very little art and architectural tradition, but had a high level of philosophy based on the belief in the Unity of the universe as a revelation of God's presence. This philosophy meant Islamic art and architecture would be intimately related to cosmology. This can be observed in the 'Sufi'[1] way of thinking.

> 'The visible world was made to correspond to the world invisible and there is nothing in this world but is a symbol of something in that other world.'
>
> Abu Hamid Muhammad Al-Gazzali
> 11th Century (14)

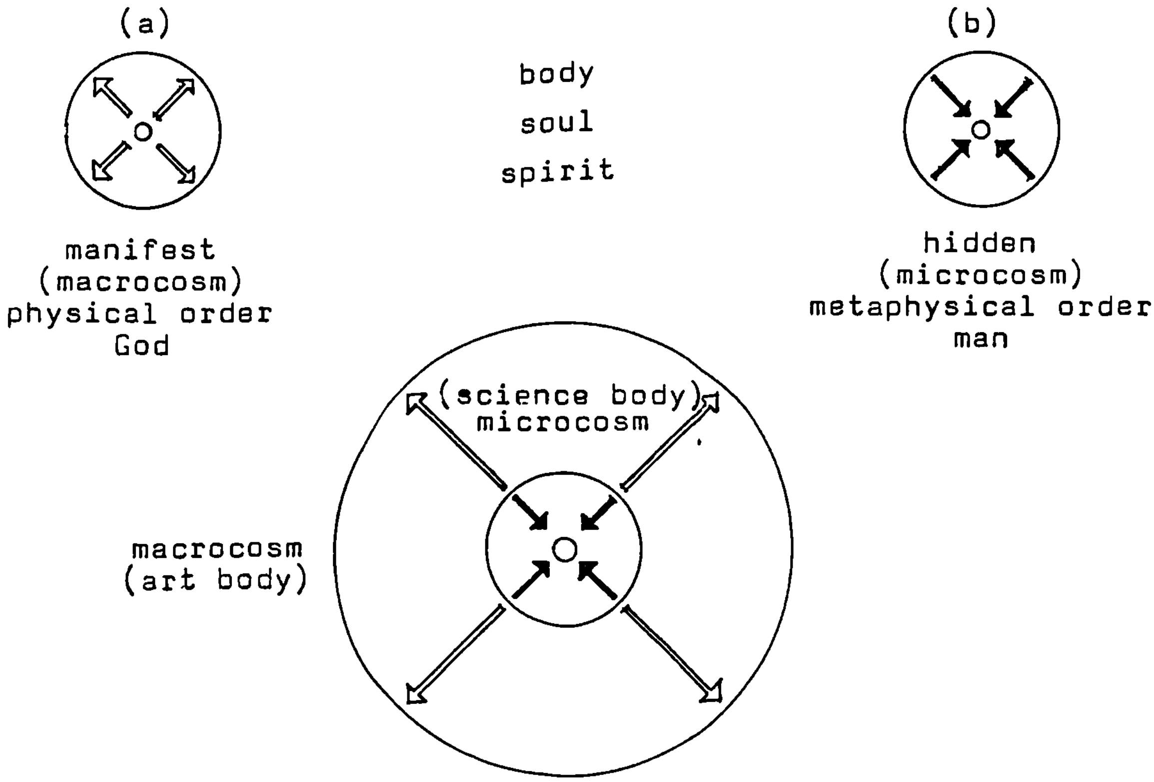
Sufi theology permeated both formal sciences and crafts, and all aspects of Islamic art are generated from the interpretation of these two. Science revealed to man, not only the physical processes of nature but knowledge of the laws and principles which govern things and which are then related to the metaphysical order. Crafts were not merely ways of making things, but also the externalizations in

---

1 'Sufi' is a term used to describe those people who acquire 'knowledge', the very force which maintains humanity. The purpose of exercise of the science of knowledge is to gain an eternally durable existance. 'Whoever has knowledge and who works and teaches, he shall be mighty in the Kingdom of Heaven' (attributed to Jesus). (242)

the world of forms of the realization of science; therefore they possess their own laws and regulations. Every external form (macrocosm) is complemented by an inner reality (microcosm) which is its hidden internal essence, fig.(5.30). Islamic crafts are like works of nature: functional, cosmic, and possessing a nobility of expression that seeks the Truth of the Universe through its own way. The manifest (macrocosm, figure (5.30a))is the sensible form which emphasizes the quantitative aspect such as the shape of a building, the form of a pool, or the body of a man. The hidden (microcosm, figure (5.30b)) is the essential or qualitative aspect which all natural things possess. In order to understand these complementary manifestations of the Divine in the fullest sense as outer and inner, or phenomenon and noumenon, one must be able to carry them back to their origin.

Symbolic forms, which are sensible aspects of the metaphysical reality of things, exist whether or not man is aware of them. Man does not create symbols, he is transformed by them. There are two fundamental kinds of symbol: the natural, and the revealed; or the general, and the particular. Natural symbols such as the processes of nature form certain systems of order that are symmetrical or rhythmical, or both. Man, through his art forms, emulates these orders by creating geometric forms which are symmetrical with respect to a centre and which symbolize 'Unity within Unity', the first principle of Islam, 'Tawhid'. The complementary system is nature in its profusion of rhythms expressed in infinite patterns, which are simultaneous, staggered or harmonious cycles with no beginning and no end - a system symbolizing the continuity of creation emanating from the One, and expressing 'Multiplicity within Unity'. The iconic form of art was prohibited in many Islamic societies, in its place words themselves, in the form of sounds, letters and corresponding numbers, assumed a primary role. Numbers, in particular, became a powerful



"From the pure star-bright souls replenishment is ever
coming to the stars of heaven
Outwardly we are ruled by these stars, but our inward
nature has becone the ruler of the skies
Therefore while in form thou art the microcosm, in
reality thou art the macrocosm.
Externally the branch is the origin of the fruit:
intrinsically the branch came into existance for
the sake of the fruit
Had there been no hope of the fruit, would the gardener
have planted the tree?
Therefore in reality the tree is born of the fruit. though
it appears to be produced by the tree."

from Jalal al-Din Rumi, Mathnawi (13^{th} Century)
in 'Rumi, Poet and Mystic' p124.

Figure (5.30) The relation between the Macrocosm and the Microcosm (14); (a) God as manifested is the reality that englobes all; (b) Man's physical body is the manifested aspect of his spiritual nature, the most Hidden kind of symbolism which can be found in different forms perceivable by each of the senses.. In mathematical symbolism all numbers and all heometrical forms are related to the centre. This kind of symbolism reflects 'Unity within Multiplicity'.

The architect is but a typical product of a society's educational system. He is given the title 'Muhandis'[1], he who geometricizes, and who thereby embodies in his name the fundamental emphasis of the design process. Architects, like both artisans and scientists, received their education within the 'Madrasah' (school), figure (5.31), where the basic programme may have included the science of nature, arithmetic, geometry, astronomy, music and optics. The student chose a particular college because of the professor whose methods and philosophy he wished to learn and to develop. Through the learning process the architect, as a master artisan, would be prepared to create works of art and forms that were not only easily integrated within the tradition, but also reflected and balanced with forms in the universe. Thus the master artisan (architect) sought, through art, to build a world that reflected equilibrium, serenity and peace. Architecture presented the most vital and all-encompassing artifact, which exhibited a multiplicity of means by which unity could be achieved. Therefore, the desire of the artist/architect was not consciously to express himself, but to be a vehicle of the realization of his creative art expressed in the fundamental elements involved in generating architecture (space and form).

Man tended towards a mode of comprehension which provided a metaphysical interpretation of life, and this affected his perceptions. This began by placing himself in the

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1 'Muhandis' is a Persian word adopted in the Arabic language and having the same meaning in both languages. Today this word is applied to engineers in all fields.

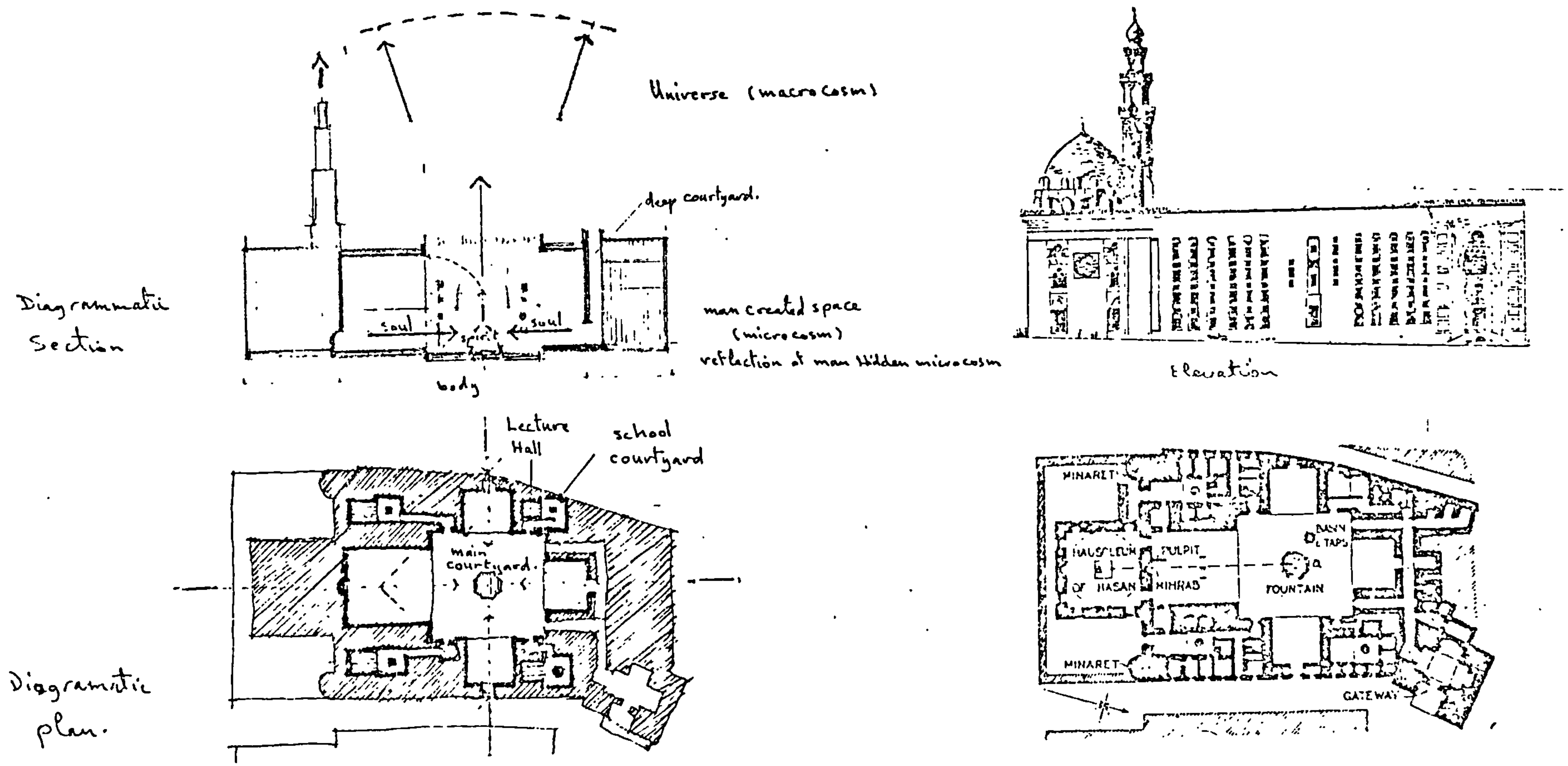

Figure (5.31)
Madrasah of Sultan Hassan in Cairo (1356 - 62)

The design concept stresses the geometric order of the creation system, 'Multiplicity Within Unity', as can be seen in the courtyard system. At the same time the space concept is centred around the interpretation of the microcosm of the Hidden as the building and its relation to the macrocosm as the sky dome which is stressed from the form point of view by the minaret form. In the horizontal the plan is directed towards Mecca which is stressed by the domination of the Iwan and the Abse in the Kebla wall in the main section and in the lecture halls in every school.

universe, thus determining his awareness of the cosmos as an externalization of the macrocosmic creation, which is analogous to his own microcosmic self. In this sense man's universe is composed of a macrocosm and a microcosm[1]. Reinforcing this universal order were the physical creations of the macrocosm and microcosm which exhibited strong directional characteristics, leading man to the realization of his entity. Once the qualitative aspects of the space were made apparent, their quantitative uses followed directly. Thus, the positive and vital concept of space generated architectural creations, figure (5.31). This concept of space as leading to the generation of form is central in the understanding of Islamic architecture. Other considerations, especially the regional ones, determined the primary role of a space. These introduced many elements, such as the entrance, the courtyard, the maka'ad, the ka'ah, the malquaf and the mashrabieh, which were among the more important architectural features characterizing the Islamic house in Egypt.

Form in Islamic architecture was related closely to mathematics and was seen as a manifestation of the unity of the creator. All creation of man and nature was viewed as forms observable through mathematical laws of similitude, symmetry and geometry. Snow crystals are formed through the combination of a variety of factors - chemistry, wind speed, air temperature, humidity and air pressure, but their beauty depends on both their geometry and their capacity to reflect a higher order. Order and proportion

---

1 There are two interpretations of this concept which may differ in their appearance but are in fact the same. In the first 'God as Manifest' is the reality of the universal externalization. In the second, complementary view of 'God as Hidden', there is an inward movement within the microcosm of man, beginning with his physical presence and moving towards his spiritual centre, the hidden treasure. The two schemes correspond to each other; at the same time the one is the reverse of the other, figure (5.27).

were viewed as cosmic laws whose processes man undertook to comprehend through arithmetic, geometry and harmony. Mathematics was an abstraction with respect to the senses. Moreover, the concept of numbers in Islam was similar to that of the Pythagorean system where numbers were considered as both qualitative as well as quantitative entities, and were not simply identified with addition, subtraction, multiplication and division. The outer expression or form of a number did not exhaust its possibilities; it contained an essence which distinguished it from any other. This essence was a projection of the unity which continuously linked the number to its source, table (5.6). The creation of the universe began with one descending through the multiple states of being and ending with man. The expression of the 'personality' of numbers permitted man a further exploration into the morphólogy of nature. These concepts of forms lead the mind from the manifest to the hidden nature of a number. Thus, the point was the start, representing the creator, which, when moved by intellect through two, made the line, whose action, if rotated as a radius, generated the circle and the sphere, the most evident symbol of unity. It contains the basic five regular polygons known as the 'Platonic Bodies'[1], figure (5.32), which form the basis of Islamic order in art and architecture.

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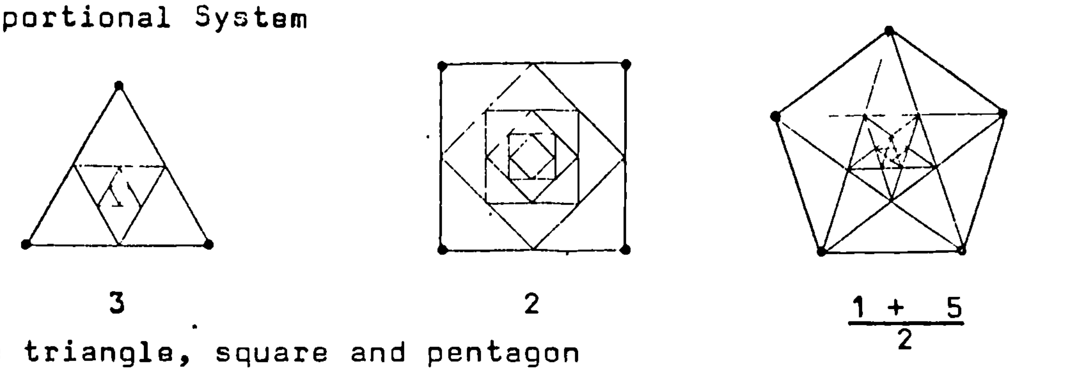
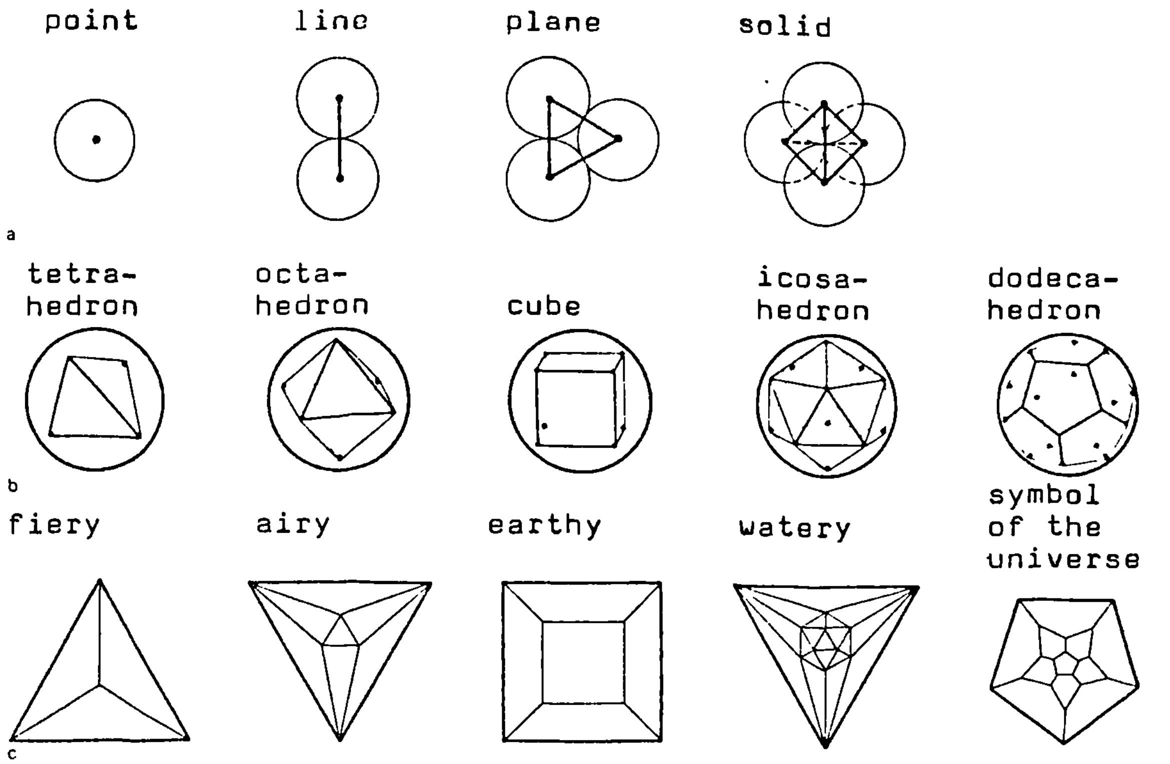
1 The Platonic Bodies have been described by Al-Biruni as follows, 'These five are related by resemblance to four elements and the sphere (the universe). With regard to the five, they are first, the cube (hexahedron) bound by six squares called 'earthly', second, the icosahedron, by twenty equilateral triangles, the 'watery' one, third the octahedron, by eight equilateral triangles, the 'airy' body, fourth, the tetrahedron, by four equilateral triangles, the 'fiery' body, and fifth the dodecahedron, by twelve pentagons, 'the symbol of the universe'. The diminishing harmonic patterns of the pentagon embodies the Golden Mean Ratio which was introduced to Europe from the Islamic world by the Italian merchant Fibonacci (14).

Proportional System



The triangle, square and pentagon related to Platonic bodies generate diminishing harmonic patterns.

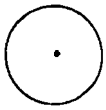
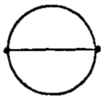
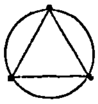
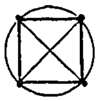
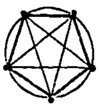
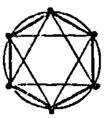
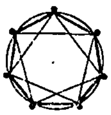
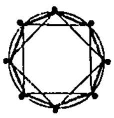
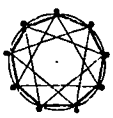
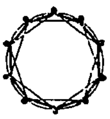
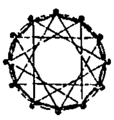
the Golden Mean Ratio



a) The dimensions of space begin with the morphic point, move through the line, the plane and the solid.
b) The regular polyhedra of Plato 'The Platonic Solids'; multiplicity within unity.
c) Planar graph representations of the five regular solids.

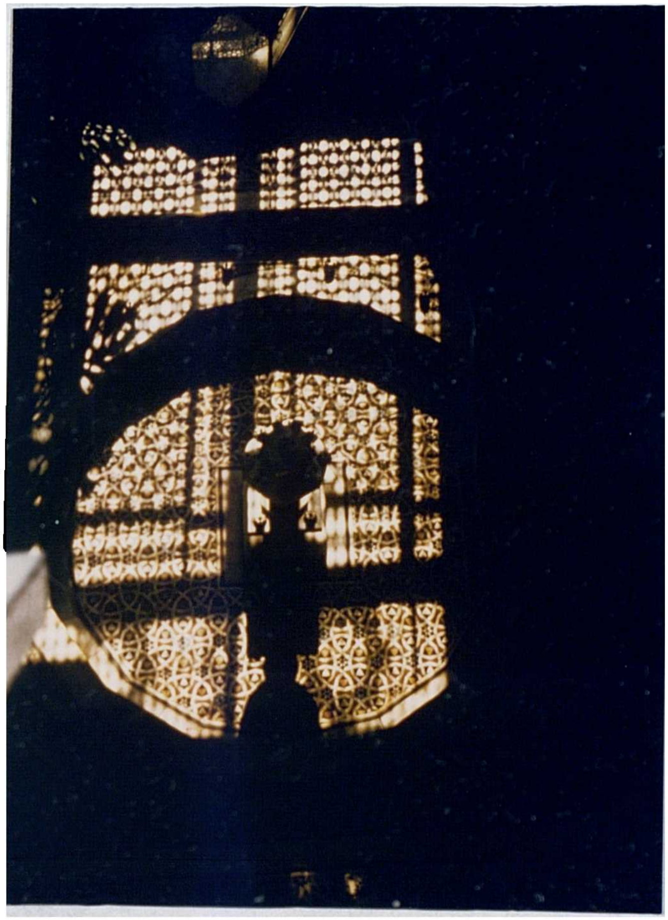
Figure (5.32) The Platonic Bodies

Table (5.6) The Concept of Numbers (14).

Static		Dynamic	
GEOMETRY No	MACROCOSM	MICROCOSM	MATHEMATICAL ATTRIBUTES
0	Divine Essence	Divine Essence	
1 	CREATOR One; Primordial; Permanent; Eternal	CREATOR One; Primordial; Permanent; Eternal	The point. Principle and origin of all numbers.
2 	INTELLECT Innate; Acquired	BODY DIVIDED INTO TWO PARTS Left; Right	Half of all numbers counted by it
3 	SOUL Vegetative; Animal; Rational	CONSTITUTION OF ANIMALS 2 extremities and a middle	Harmony. First odd number. A third of all numbers counted by it.
4 	MATTER Original; Physical; Universal; Artifacts	FOUR HUMORS Phlegm; Blood; Yellow bile; Black bile	Stability. First square number.
5 	NATURE Ether; Fire; Air; Water; Earth	FIVE SENSES Sight; Hearing; Touch; Taste; Smell	First circular number.
6 	BODY Above; Below; Front; Back; Right; Back	SIX POWERS OF MOTION IN SIX DIRECTIONS Up; Down; Front; Back; Right; Left	First complete number. The number of surfaces of a cube.
7 	UNIVERSE Seven visible planets and seven days of the week.	ACTIVE POWERS Attraction; Sustenance; Digestion; Repulsion; Nutrition; Growth; Formation	First perfect number.
8 	QUALITIES Cold, dry; Cold, wet; Hot, wet; Hot, dry.	QUALITIES Cold, dry; Cold, wet; Hot, wet; Hot, dry.	First cubic number and the number of musical notes.
9 	BEINGS OF THIS WORLD Mineral; Plant; Animal (each containing three parts).	NINE ELEMENTS OF THE BODY Bones; Brain; Nerves; Veins; Blood; Flesh; Skin; Nails; Hair	First odd square and last of single digits.
10 	THE HOLY TETRACTYS First of four universal Beings.	BASIC DISPOSITION OF THE BODY Head; Neck; Chest; Belly; Abdomen; Thoracic cavity; Pelvic girdle; Thighs; Legs; Feet	Perfect number. First of two-digit numbers.
12 	ZODIAC Fire, hot, dry, east; Earth, cold, dry, south; Air, hot, wet, west; Water, cold, wet, north	TWELVE ORIFICES OF THE BODY 2 eyes; 2 ears, 2 nostrils; 2 nipples; 1 mouth; 1 navel; 2 channels of excretion.	First excessive number.

Forms are bounded by their outer shell, a surface that can perform a twofold function; physically it can delimit shape, and mentally may guide the soul to higher planes of realization that lie beyond the created place of man. The transcendental qualities of surfaces can evolve in any of the following ways: through the inherent nobility and richness of materials themselves; through the surface configuration and its adornment; or through the combined effects of noble materials developing configurations upon the surfaces. The nature of the transcendental quality of materials is an outgrowth of the material's physical composition and opacity. A translucent marble, reflecting a variegated metamorphism, communicates a cold, implacable feeling of eternal richness, while ceramic conveys a warm feeling. The richness of wood was developed, and assemblies created in geometric patterns using wood in combination with other materials. These patterns depended less on the natural attributes of the material than on the transcendental qualities of the assembled surfaces.

The fountains in many Islamic houses combined the fluidity of nature (represented by the water) with the geometric transfiguration of material surfaces (marble or mosaic) figure (5.33). Man observed nature's mode of operation and was overwhelmed by the amplitude of patterns, designs and colours, all adding to the manifestation of one divine pattern. Man sought to express the same multiplicity (within unity) in a symbolic art that emulated nature. The result was to draw the object away from any subjective interpretation and to place art as symbolic of the eternal creator. Vaults and arches were carved with floral and geometric designs of great star clusters, sunbursts and mandalas, so that they may escape the heaviness which kept them from the Divine. The wall symbolizes the transcending third dimension of space. The complementary vertical ascension of form to receive a descending gravity force becomes



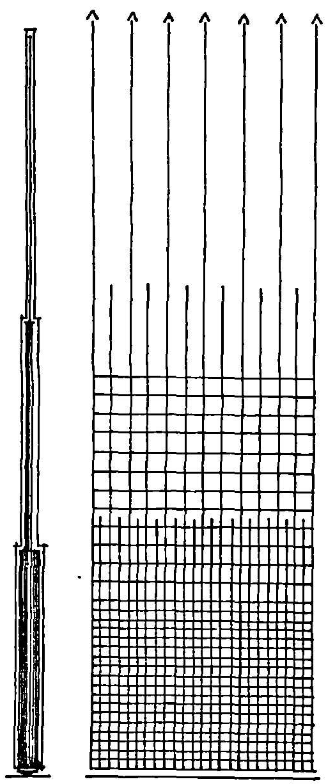
The fountain in Islamic houses exhibits a combination of nature (water) with the geometric transfiguration of surface (marble patterns), Both marble and water reinforce the environmental (physical) aspect of the fountain as well as the sense of coolness (essence).

Figure (5.33) Fountain of the summer sitting room in Beit el-Kredliah (1631-32).

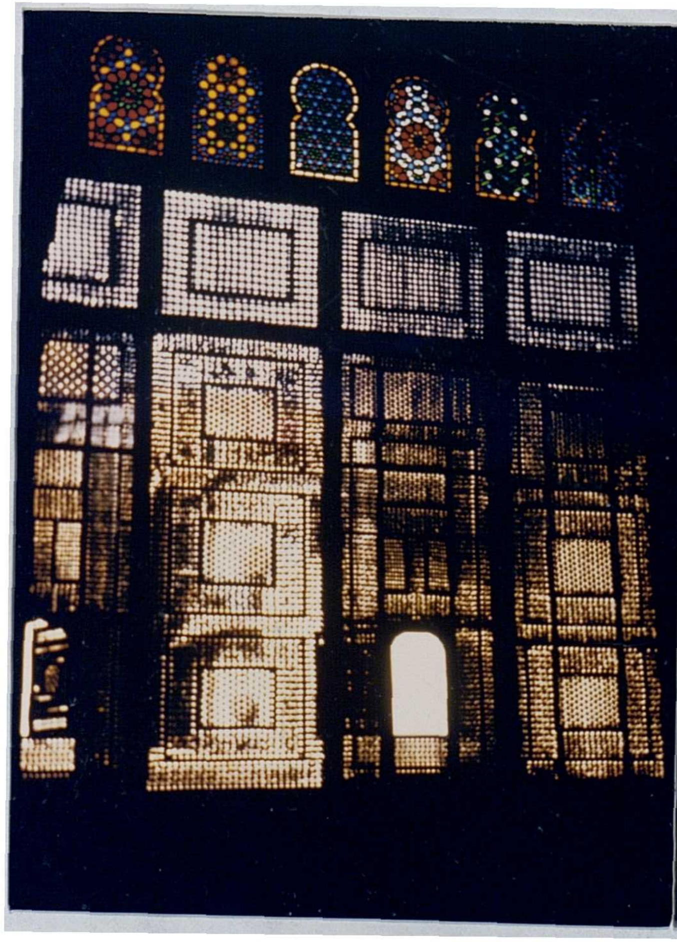
a design criteria of vertical surfaces and emphasizes the vertical ascension of the soul towards the Universal spirit. This is best represented by a unique Islamic house feature, the 'Mashrabieh' figure (5.34). In the interior it is used both as partition and window screen, while on the exterior it is used as a screen.

Ceilings were seen as a reflection of the heavenly vault. The surfaces of the roofs or ceilings, more than any other dimension, related to the concept of shape, figure (5.35). The flat roof expressed a stable form resting unto itself and only gave motion in the horizontal direction. The barrel vault gave the possibility of motion in three dimensional space; its qualities were those of a linear axial space generating vertical movement and symmetrical lines of horizontal movement in two directions. The dome and the intersecting vaults corresponded to maximum mobility and thus expansive and indeterminate shapes capable of generating lines of movement in many directions.

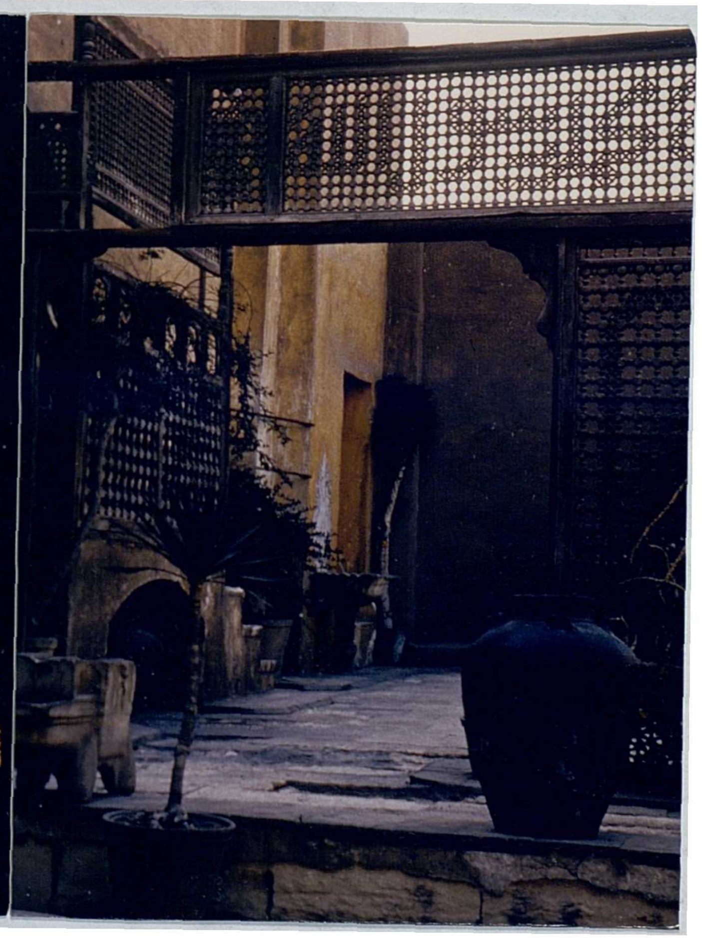
The role of a surface as a container of forms was reinforced by surface patterns which were mainly generated by lines in a geometrical arrangement. These may evolve as simple constructions developed solely on a single level or plane, or as complex constructions developed on many levels. Generally, the concept of geometric patterns was based on the number 'one' and its generation in the universe, where geometric shapes and patterns were bound. Formed of radially symmetrical, regular shapes, the concept of surface patterns related to the cosmic processes, characterized by extension in all directions. Geometrical patterns as a spatial concept required space-filling. To cover a surface with regular shapes leaving no spatial voids neccessitates that the angles lying at any one corner must add up to 360 degrees. Only three regular polygons could satisfy this requirement, the equilateral triangle, the regular hexagon and the square, or their combinations, fig.(5.36).



a) The Mashrabieh as the third dimension of space symbolizing the descending gravity force and the vertical ascending form as the ascension of the soul to the Universal spirit.

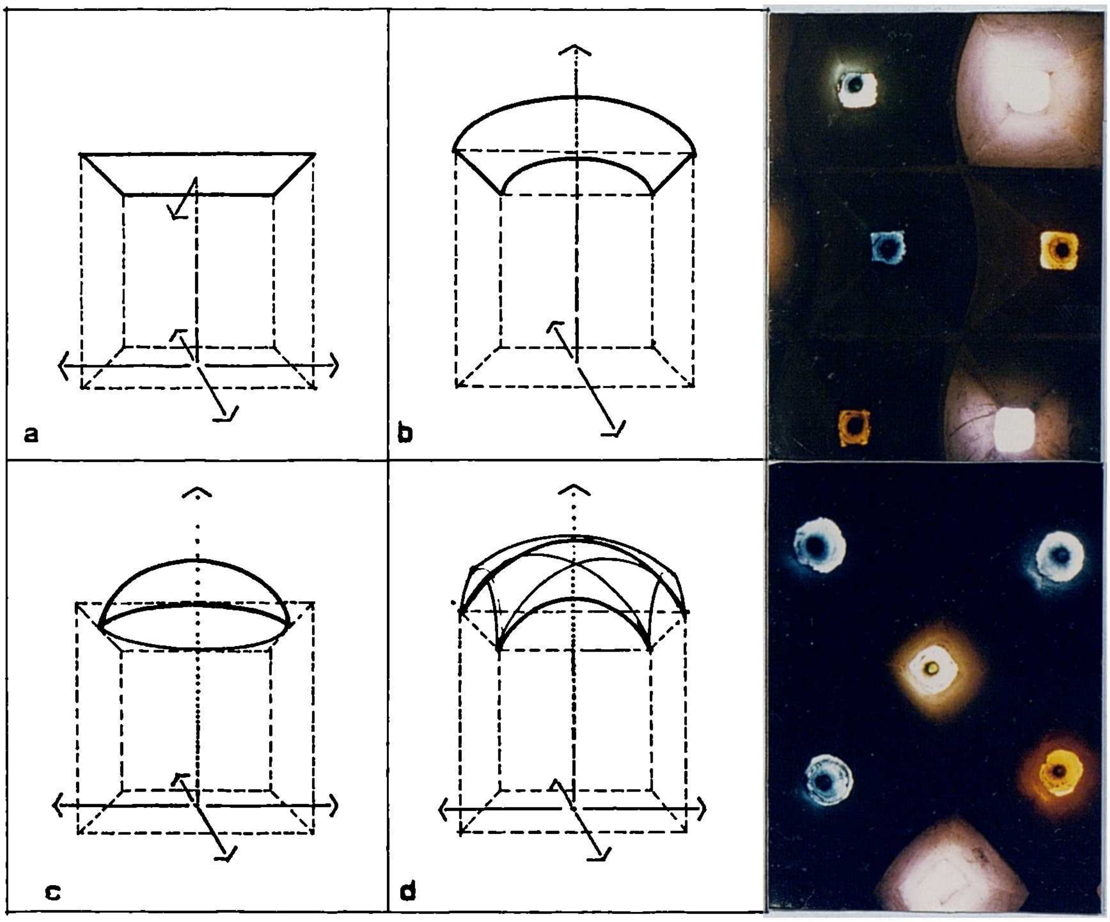


b) Mashrabieh as a window, Beit el-Kredliah.



c) Mashrabieh as partition, roof garden, Beit el-Kredliah.

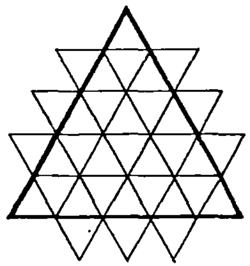
Figure (5.34). The Mashrabieh in Islamic houses.



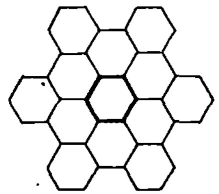
a Flat roof is static in the vertical direction.
b Barrel vault gives motion in three directions only.
c Dome gives maximum motion especially when perforated.
d Intersecting vaults are mobile in many directions.

Openings in the dome reinforcing the motion toward the heavenly sky dome.

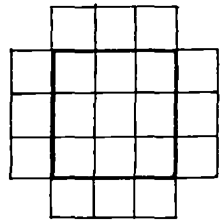
Figure (5.35) Roof types as related to the concept of form.



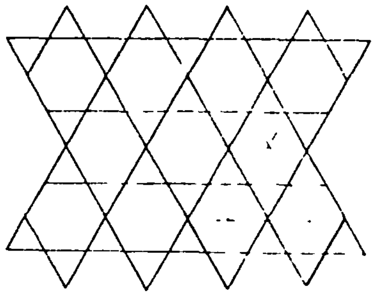
a Equilateral triangles as regular space-filling.



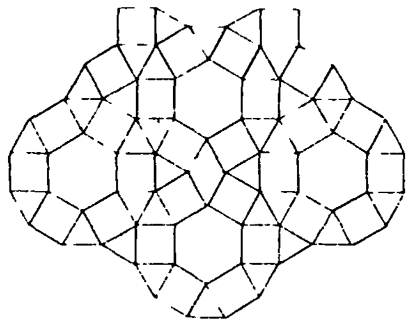
b Regular hexagonals as space-filling patterns.



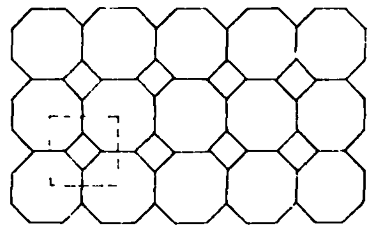
c Squares as a regular space-filling patterns.



d One of 8 possibilities of semi-regular equipartitions whose vertices are similar on each occasion.

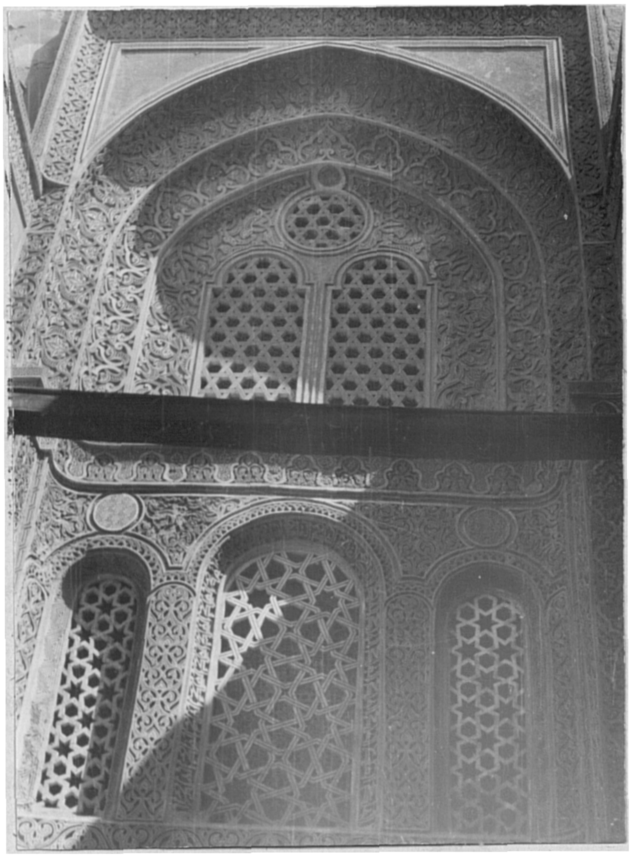


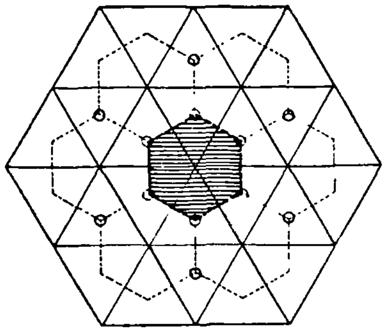
e One of 14 possibilities of demi-regular patterns whose vertices vary.



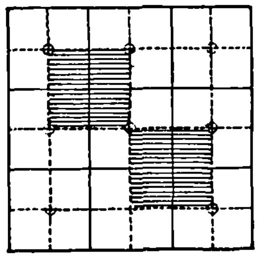
f One of 8 possibilities of semi-regular equipartitions.

Figure (5.36) Geometric patterns; basic regular space-filling patterns.
The equilateral triangle, the regular hexagon and the square (or combinations) are the only three regular polygons to satisfy space-filling of surfaces with no space between the meeting of the vertices (14).

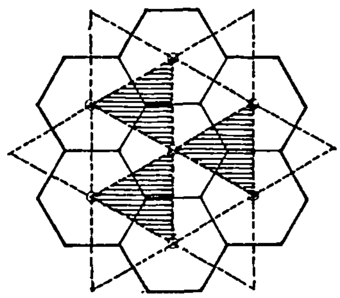




Equilateral triangles generate the regular hexagon



The square complements another square



The regular hexagon complements the equilateral triangle

◇ ◺ The main two components of the design scheme - minimum inventory, maximum diversity

Detailed panel of Sultan Qala'un complex, Cairo (1284 - 5)

Figure (5.37) Geometric patterns, complementary space filling patterns.

Another complementary system of space-filling patterns was formed by taking the centre of a shape as a new vortex, with the complement of the triangle being the hexagon, while that of the square was itself, figure (5.37).

Other decorative patterns were based on calligraphy. Since the Koran was the word of God, calligraphy was considered as the visual body of the divine revelation, sacred in both form and content, and corresponds to iconography in Christianity. The multi-level patterns, figure (5.38), refledted multiple ways of ennobling matter, using motifs of symbolic realities that were indescribable in sensible terms. Arabesques did not fill the totality of surfaces, but enhanced their shapes and lightened their expression in space.

5.3.6 The Islamic House

Two main social characteristics have prevailed since the beginning of the Islamic period and have had major effects on house design and on other buildings. Firstly, the strong emphasis of a traditional society on family unity provided an important sociological reinforcement for the centripetal organization of space. The strong family obligation[1] in Islamic society was reflected in the sizes of the houses. Secondly, the strong emphasis on family privacy introduced a private family section, 'Harameliek', besides the common reception area, 'Salameliek', which affected the arrangement of space usage. These sections corresponded to the daily activities of men and women[2].

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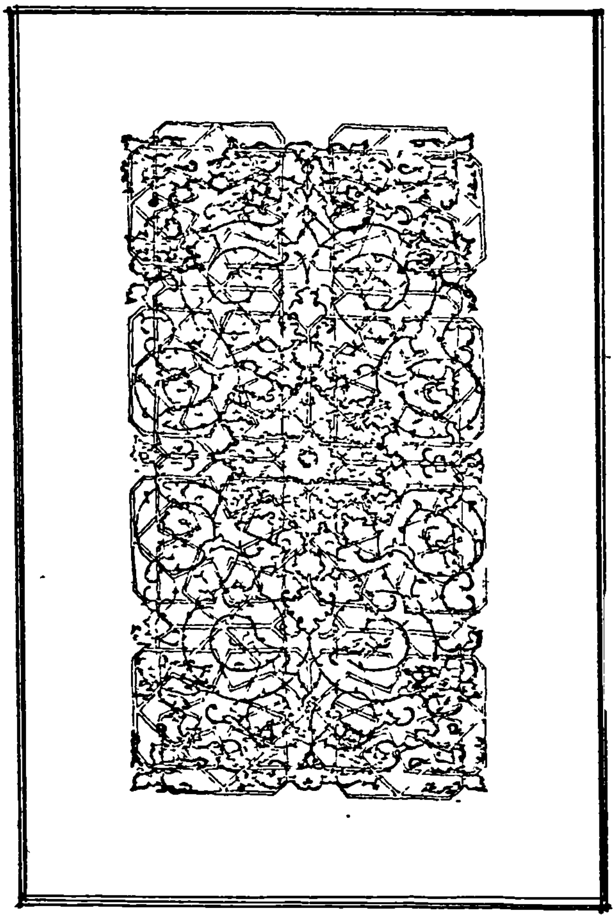
1 In Egyptian society today the family always cares for its old people and orphans, as well as its youth. This may be a marked contrast to the modern west where the old people are frequently placed in public institutions.

2 It is interesting to note that only among nomadic groups did Muslims accept equality between the sexes in public life; within the Touareg groups of North African nomadic societies men are veiled while women are not! (154)



Pattern One - Geometric

Pattern Two - Arabesque
Arabesques do not fill the total surface but act as forms in space set against passive backgrounds.

Pattern Three - Arabesque
Multi-level patterns usually composed of several superimposed ones. Separately they stand on their own but together they can be seen to complement and heighten one another.

Figure (5.38) Multi-level patterns (14).

In most cases the private sections of a family house were on the upper floors, while the public and reception halls were on the ground or the first floor. These were designed in accordance with the fact that man moves through unobstructed spaces more freely than through masses. This provided space continuity and avoided undesirable mass obstruction. Thus, in house design the space concept was created by the enveloping walls which may sometimes have been used for storage or for secondary living spaces, which would have been dependant on the primary ones for their light, ventilation, view and communication with the logos. The primary space may have been open like a courtyard, figure (5.31), or covered like a living hall (Ka'ah).

Fustat[1], figure (5.29b), the new capital of Islamic Egypt, was built by Amer Ibn-el-Aas north of the Roman fortress of Babylon. Most of the Fustat houses were originally single storey, figure (5.39), but in many sections of the capital these developed into multi-storied dwellings reflecting both Encient Egyptian and Coptic influences. Sameh (231) reports on the houses of Fustat, including Amer's house and Abd El-Aziz's house. The latter had a golden dome and was called the Golden Palace. Generally Fustat's houses were constructed with thick brick walls designed around courtyards which had fountains in their centres. The house comprised reception and private sections, and had a bent entrance leading to the courtyard. The arrangement of living spaces around the courtyard usually secured a moderated indoor climate, and provided a thermally controlled, peaceful, open space. The prescence of the fountain helped to humidify the air, reflected

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1 Fedden (106) suggests that Amer's capital was called Fustat because it had been built in the 'lines' (Latin fossa) occupied by the attacking force. Another suggestion was that the name came from the Greek 'fusstum', meaning 'the tent' because the capital was built on the first place on which Amer pitched his tent (231).

the light of the sky in a peaceful, relaxing manner, and provided a perfect place for ablution. Most of the houses discovered contained bathrooms and drainage systems. Amer built his mosque not only as a place of worship, but also as a community centre.

From 660 to 750 AD Egypt was a part of the Umayyad Caliphate of Damascus. In 750 the Caliphate passed to the Abbasid dynasty and Egypt was then ruled from Baghdad. The Abbasid governor Saleh Ibn Ali built a new extension, El-Askar[1] figure (5.29c), north of the Fustat to take advantage of the cool breeze. In later times this became connected by means of gardens and houses to the Fustat, which continued its own existance as the rich and powerful commercial city of Egypt. In 870 the Abbasid governor of Egypt, Ahmed Ibn Tulun, established independence from Baghdad. Finding Fustat and Al-Askar too small for his followers and troops he built a new extension to the North, Al-Qatai[2], fig. (5.29d) He built a palace and a vast square where polo matches were played. His palace had nine doors, one of which opened about 600 metres away from Ibn-Tulun mosque (876 - 9 AD). This mosque was built on piers[3] using pointed arches. The arches were of two centres, one quarter the span apart, and on the line of springing. This was one of the earliest examples in history of the use of the pointed arch.

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1 El-Askar in the Arabic language means 'the soldiers' and this extension took that name because it began as a military camp.

2 Al-Qatai, meaning in Arabic 'the quarters', was so named because it was divided into distinct quarters, each of them allocated to a group of followers.

3 The mosque seemed to have been built on piers as an influence of the earlier Samara mosques (Samara Great Mosque, 836 and Mosque of Abn Duluf, 859), where Ibn Tulun spent some of his childhood, The arch systems and windows, however, resemble Amer Mosque in Fustat. Ibn-Duqmaq and El-Maqrizi suggest that fire safety was the main reason for choosing the Samara construction system, since Fustat was set on fire a few years before.

Behind the south-east Quebla wall[1] of the mosque Ibn Tulun had a rest house called 'Dar El-Imara' (House of the Principality), which was directly connected to the mosque. The Tulunid house comprised a number of spaces arranged around a square courtyard; at one side was the main section of three rooms, a large one (Iwan) covered by a semi-circular vault flanked by the two smaller ones. These rooms were preceded by a covered loggia usually facing the prevailing wind and supported on arches and piers, figure (5.39). On the other side of the courtyard were other Iwans, and in the centre there used to be a fountain, the same as those found in the Fustat houses.

Two courtyards were often employed in the Tulunid houses, besides having the Malkaf. Al-Alfy (39) reports on the air channels of the Malkafs in most of the Tulunid houses and suggests that they are similar to the Fatimid Malkaf found in El-Saleh Mosque. The presence of staircases indicates buildings having more than one storey. These types of houses resembled the Ancient Egyptian houses of the Middle Kingdom; they also reflected the Abbasid residential units within the Ukhidir Palace (778 AD). The Tulunid houses were built of mud bricks employing the same techniques used in the Ibn Tulun Mosque, while the decorations show some similarity to those of Samara which suggests that many of the inhabitants may have been close followers of Ibn Tulun.

Generally speaking, the builders of this period were much more aware of the space dimensions and the significance of the time dimensions in space, than of building forms. The house corresponded both to the human scale and to the

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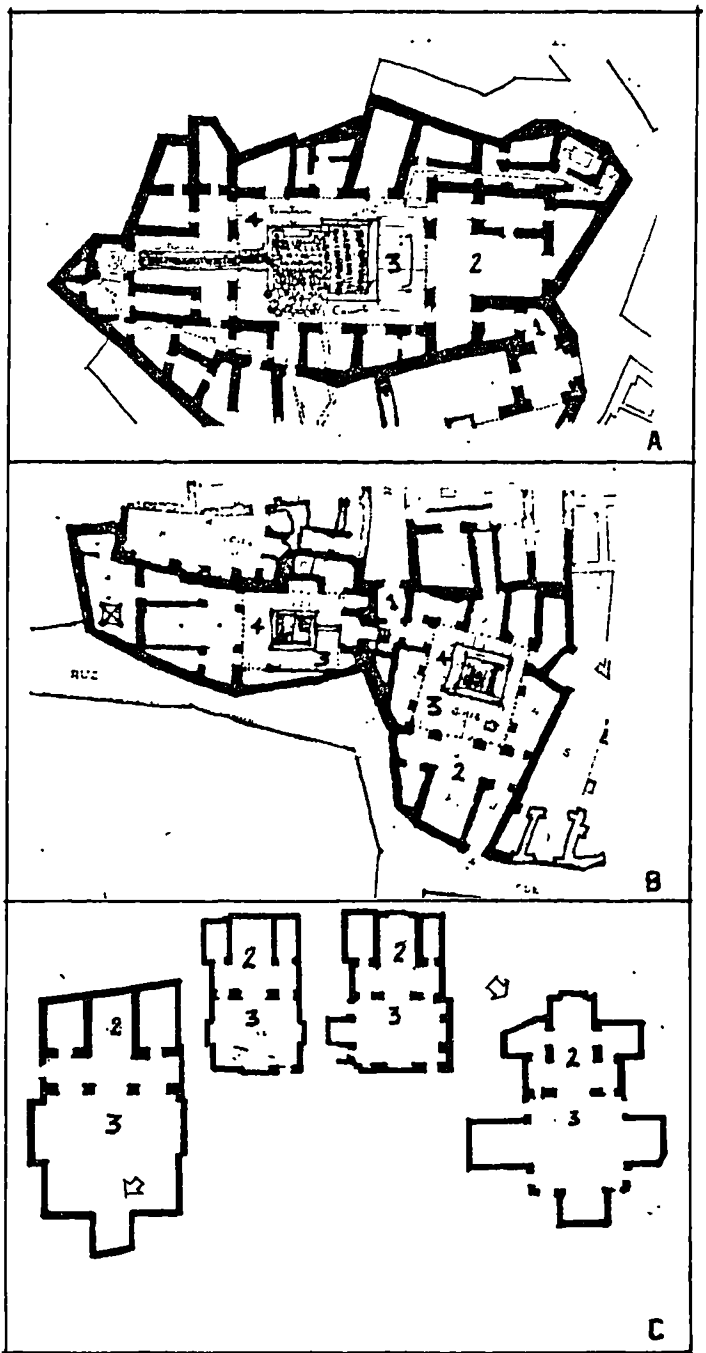
1 Muslims all around the earth face Mecca when they pray and in Cairo that direction is south-east. The Qebla is a niche in that wall indicating the direction for the prayer.



A & B Fustat houses — C Qatai houses

1 entrance
2 reception
3 courtyard
4 fountain

Figure (5.39) House plans discovered at Fustat and Qatai archeological sites (231). The house is generally divided into two sections, reception and private. All spaces are inward-looking onto the thermally controlled court.

surrounding universe, where the courtyard as an enclosed, uncovered, outer space played an important part in relating the house as a microcosm to the universe as a macrocosm. The house reflected the socio-cultural environment of this period where on the outside the house showed nothing but veiled openings, while its interior was divided into two sociopetal sections. Economically, the house expressed eased conditions compared with those of the Coptic period. This allowed a deeper involvement in employing contemporary technology, leading to better internal environmental conditions.

The Fatimids of Morocco, Shia[1] Moslems, advanced into Egypt from the west, conquered it, and by 969 had founded their capital Al Kahira, figure (5.29e), north of Al Qatai. This was a royal quarter, built on a strategic site and fortified with a strong wall, bordered on the west by Fome El-Khalig canal, and protected on the east by the Eastern Desert plain. Within Cairo a wide avenue, 'El-Qasaba', extended from north to south, where the important buildings were situated and from its elegant mosques the Shia teaching was spread. Art trends of this period showed a free style where animal and human figures were extensively used. The prosperous and rich life of the Fatimids was evident from the artistic masterpieces and the reports of many historians like El-Maqrize. Sameh (231) reports that in Cairo the Fatimids built two great palaces overlooking 'El-Qasaba'. The Eastern Palace was built for the first Fatimid to rule Egypt (El-Moaz, 969), and has been reported

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1 In Islam there are two main groups, Shia and Sunni. Both believe that the Koran is the divine word of the Lord God, and perform the same prayers. However, the Sunni follow the example set by Prophet Mohammed in applying the Koranic rules, while the Shia refer only to the Koran. This had clear implications on the form of art and architecture. The Sunni tended to use only abstractions, but the Shia used human and animal figures besides abstractions because there is no clear prohibition of using them in the Koran.

as having four thousand rooms. During the reign of El-Aziz (990) the second palace was built,,and between the two extended a royal square, an area still known today as 'Bain al-Qasrain' - between the two palaces. The two were linked by a tunnel. Naser Khesrow reports scenes from Egyptian life of those days when Fustat was a large city containing houses as high as fourteen floors, and having roof gardens. The Fatimid ruler also owned 20,000 stone houses of five and six storeys which were let. A national park was established on the Nile island of 'El-Rowda'. Al-Hakim and Al-Aqmar mosques were but two examples of the religious buildings of this period; unfortunately none of the residential units of the time have been discovered. However the Fatimid period did have an effect, both positive and negative, on the architecture of the following periods.

El-Naser Salah El-Din (Saladin), acting in the name of the Abbasid, took Al-Kahira in 1171 AD, ending the Fatimid rule and unifying Egypt and Syria. He established the Ayyubid dynasty and changed the Shia sect into Sunni. Cairo was changed into the commercial and cultural capital of Egypt. It became the centre of resistance against foreign invaders. Salah El-Din re-established the Sunni teaching by building the Madrasah[1], a college-mosque for science and religion. Al-Qasaba, the royal Fatimid avenue, became the main commercial and cultural centre of the city which had lost its planned symmetrical character and developed into what we recognize today as the medieval city. He built his citadel and palace on a strategic part of the Mukattam Hills, this remained as the centre of government till the nineteenth centure. In 1250 AD the Ayyubids were replaced by the Mamluks who ruled both Egypt and Syria until 1517 AD, the time of the Ottoman conquest.

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1 The Madrasah Mosque first appeared in Mesopotamia in the second half of the tenth century.

Over the 300 years of Ottoman rule Egypt declined, partly because of the Ottoman mis-rule, and partly because of the discovery of the Cape route to the east. However, the Mamlukes lived on as the powerful feudal lords of Cairo under the Ottoman sultan rule. They maintained their rich and prosperous life style until Napoleon occupied Egypt and defeated them at the Battle of the Pyramids, breaking their long established power. Finally the Mamluke period ended when Mohammed Ali massacred them in Cairo citadel in 1811. It may be said that the Mohammed Ali Mosque (1824 - 1857) was the last gesture of the fading Islamic style.

Though the Mamlukes added no new and imposing quarter to the city, they crowded it with palaces, houses, mosques, mausoleums, hospitals, baths, Khans, wekallas[1] and El-Rab'a[2]. Most of Cairo's Islamic monuments lasting till today were due to the good taste and patronage of the Mamluke sultans and their courts.

The Mamluke houses still existing in Cairo today range between two to four stories high having, in general, one main facade with small openings on the street, fig.(5.40). The openings were regular in shape and filled with mashrabieh screens, while the doorway was of strong construction, artistically decorated. The Mamluke house was designed to satisfy the family's physical, social and spiritual needs, figure (5.41). The entrance door opened onto an entrance

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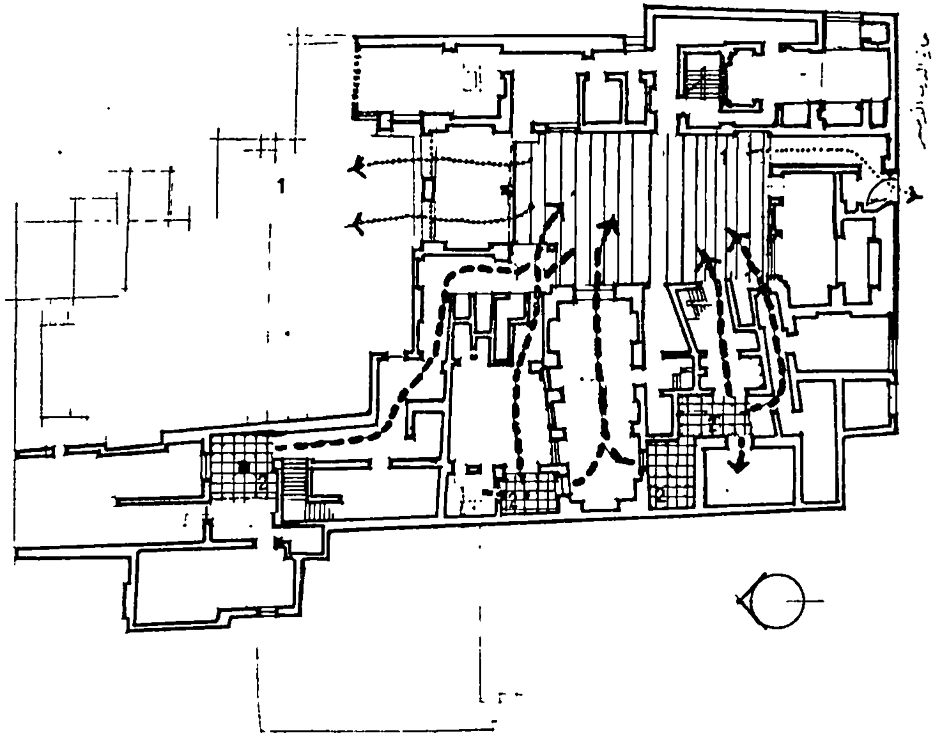
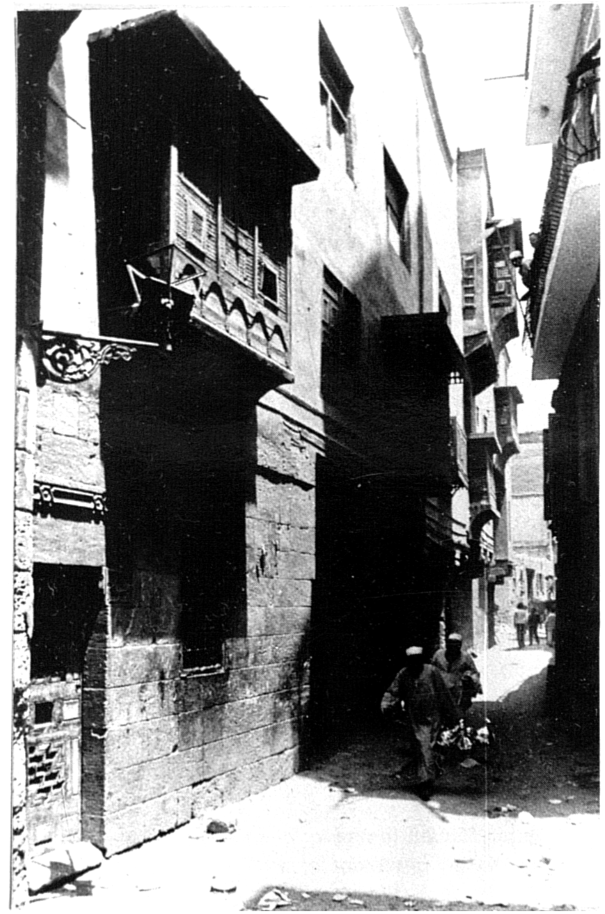
1 Wekalas are a kind of caravansary built round an open court providing shops, lock-ups, stabling for merchandise and beasts, together with accommodation units for the merchants on the upper floors. These types of multistorey residences are believed to be the prototypes of the duplex units built in the twentieth century.

2 El-Rab'a was a type of building serving light industry. It contained workshops and shops on the ground floor and accommodation units similar to those of the wekalas on the upper floors.



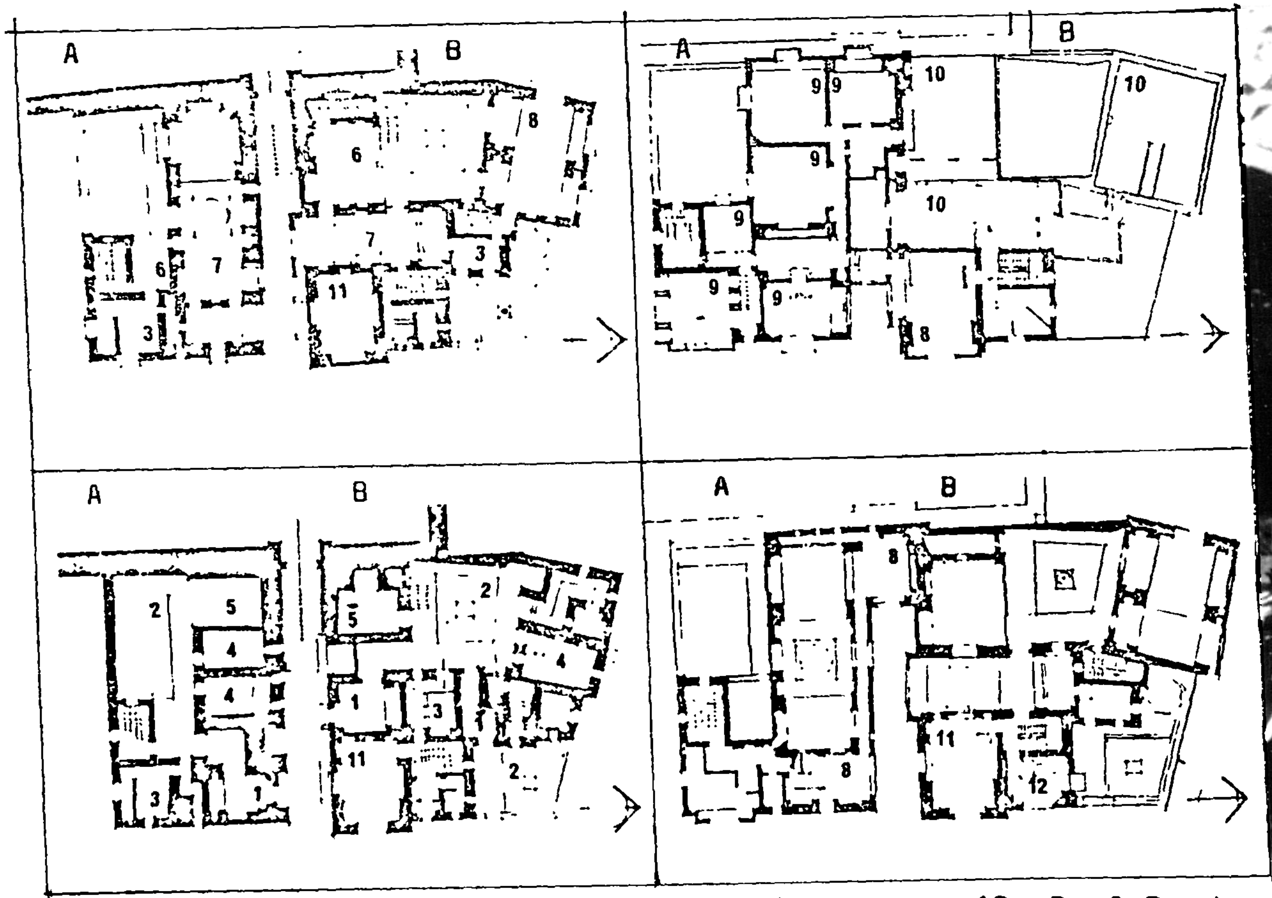
1) Main courtyard 2) Deep courtyard

a) The courtyards as integral ventilation system



b) The south facade

Figure (5.40)´ El-Sehaimi house, Cairo (1648/1796)



1	Entrance	5'	El-Mandara	10	Roof Garden & Terrace
2	Courtyard	6	El-Maka'ad	11	Sabil & Kotab
3	Kitchen	7	Ka'ah	12	Teacher
4	Storage	8	Ka'ah		
5	El-Taktaboush	9	Bedroom		

Beit El-Gazaar courtyard with the fountain as the focal point.

Figure (5.41) Beit El-Kredliah, Cairo 1495/1631 (A Beit Amneh 1495; B Beit El-Gazaar 1631) lobby (1) where one could see nothing but the stone seat (mastabah) of the house keeper. The bent entrance (right angled) secured maximum privacy for the house; when visitors went past it to the courtyard (2) they could see nothing, while they themselves could be observed through the veiled windows. However, the cool breeze drawn from the inner courtyard towards the hot street welcomed them.

The master of the house received his informal visitors in his sitting corner of the courtyard, the 'takhtaboush' (5). Formal visitors could be received either in the 'mandarah' (5̄) or 'El-Maka'ad' (6). Through the maka'ad the visitors were welcomed for parties and study circles held in the main Ka'ah (7), figures (5.41) and (5.45). The house would have had at least two Ka'ahs, one for male and the other for female visitors (8). The Ka'ahs often acted as sitting and dining rooms, and were subdivided into two spaces arranged around a focal point, the fountain. They were serviced from the kitchen (3) or the service room on the same floor. The bedrooms (9) were located on the upper floors and may have been connected to a roof garden (10) as in El-Kredliah house, figure (5.35c). These houses were provided with a secondary entrance (1') for the family whenever possible, and this led to the private part of the house. These different elements of the house - the courtyard, El-Takhtaboush, El-Mandarah, El-Maka'ad and El-Ka'ah illustrate the impact of the spiritual conceptions of Islam as well as the designer's response to the climatic characteristics, be they thermal, visual or acoustic.

Most of the Mamluke houses in Cairo had deeper courtyards than those on common use in the Mediterranean region. Generally, their shapes ranged between the square and the rectangular. They secured a greater amount of shade and shadow to maintain the cool air collected during the night figure (2.12a and b), for a long period of the day. El-Bakry (94) studied El-Sehaimi and El-Kredliah courts using the sunpath diagram at two hour intervals, figure (5.42). The courtyard of El-Sehaimi was over 75% shaded in winter when more sunshine was desirable, while it was just over 45% shaded in summer when complete exclusion of sunshine was desirable. However, the cooling effect of the courtyard in summer was more appreciated than its disadvantage due to the exclusion of solar radiation in winter. Moreover, the exclusion of the strong winter wind was of great importance during the moderate Cairo winter. This can be seen from tables (5.3) and (5.4) where the exclusion of wind by the courtyard moderates winter conditions to satisfy human comfort. A similar study had been carried within El-Kredliah where the courtyard was found to be more efficient as a cooling element because the wall height was greater than the plan dimensions. Evidently then, the deeper the courtyard the more efficient it worked as a cooling element. In most of the Islamic houses in Cairo the height of the courtyard was greater than the plan dimensions, ensuring greater exclusion of direst sunlight and thus a cooler courtyard.

Examining air movements in the courtyard, El-Bakry (94) recorded an air speed of 0·25 m/s on 29th and 30th of March between 10.00 and 13.30. The low air speed recorded reinforces the environmental function of the courtyard as cold air storage having local air movements. Ettouney (98) found that shallow courtyards possess effective sheltering conditions when the wind blows approximately perpendicular to its front, figure (5.43b). A further investigation of air movement in deep courtyards seems of great importance for the full understanding of the Islamic courtyard system. Air movements within a large house like Beit El-Sehaimi should be examined as a complete system of shallow, deep and malkaf features. Air stored in the deeper courtyards would move due to thermal forces theough the spaces of the house towards the main courtyard, figure (5.40). The deep courtyard ranged between 1 and 8 square metres in area,

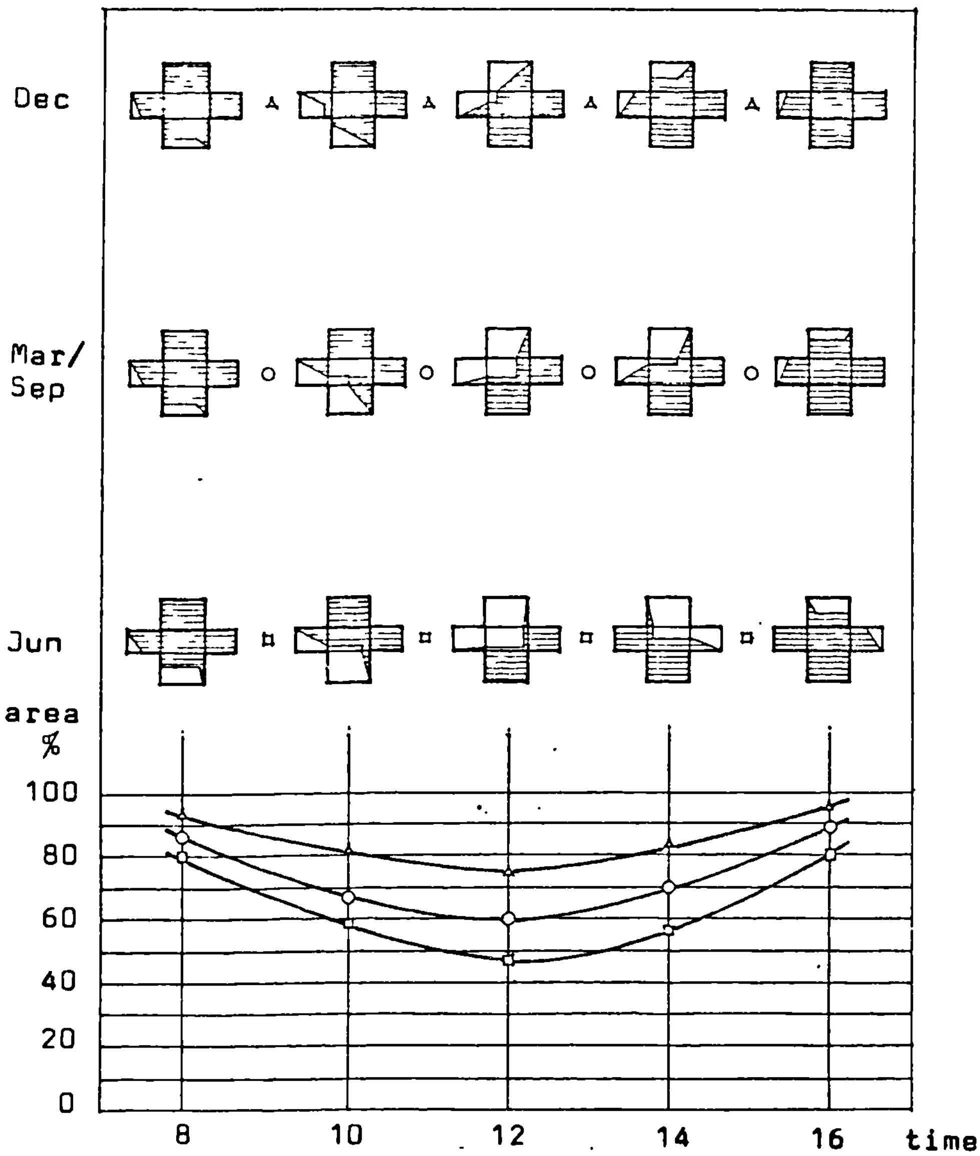
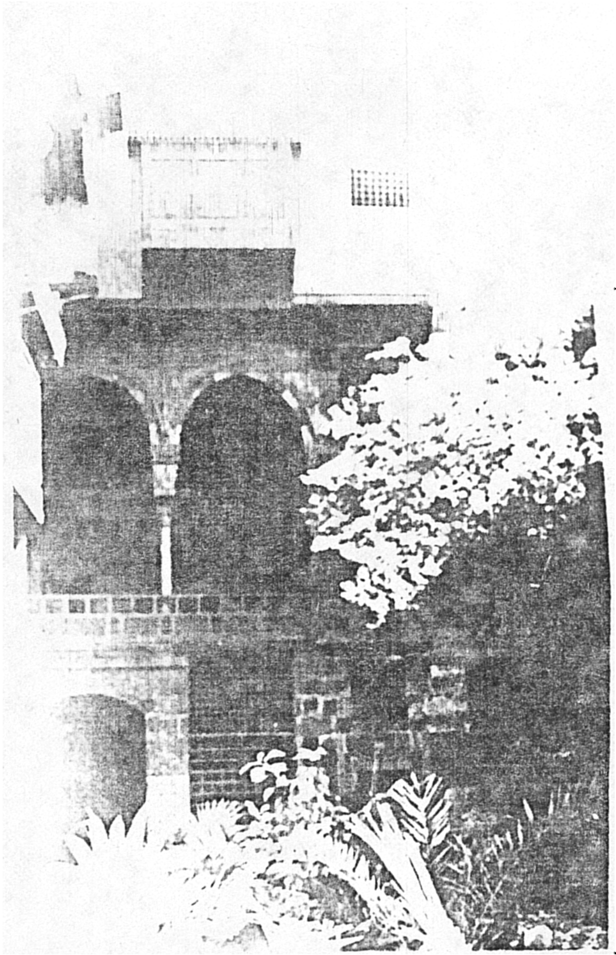
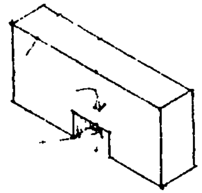
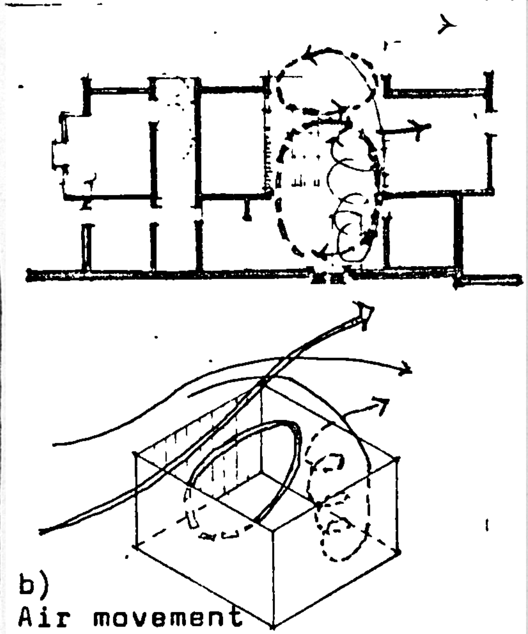


Figure (5.42) Shadow cast in the different seasons at El-Sehaimi house (94).

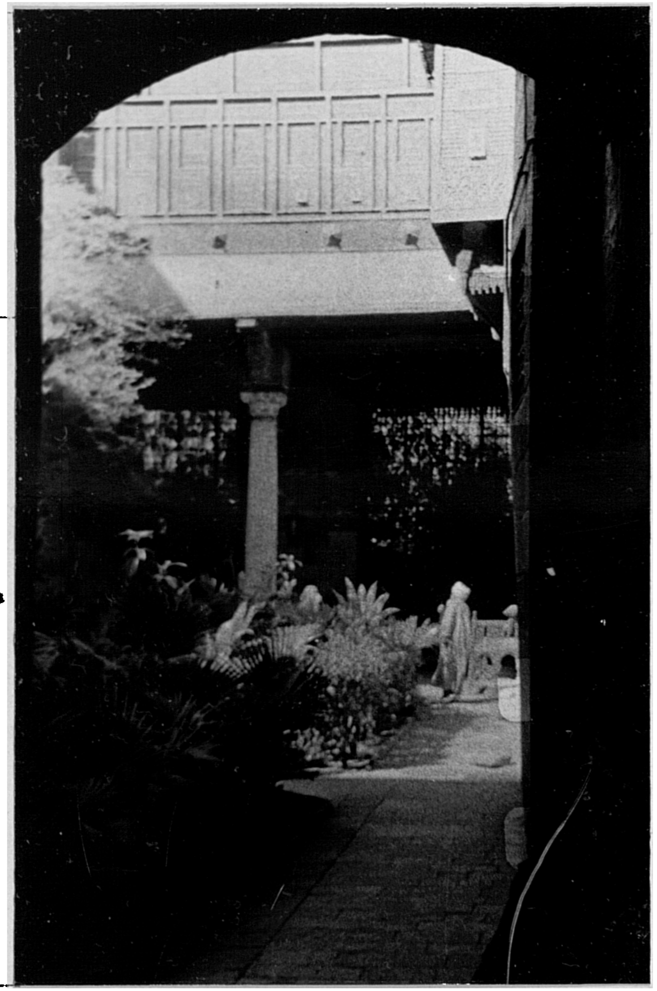




a)
Air movement as expected
in El-Taktaboush



b)
Air movement
in the courtyard



c) El-Maka'ad facing the North,
as seen from the courtyard

d) El-Taktaboush as seen from
the entrance passageway

Figure (5.43) El-Sehaimi house, Cairo (1648/1796).

and from 8 to 28 metres in height. It was usually open to the circulation elements as well as to large halls; these led to the rooms which had windows opening onto the shallower courtyard, thus acting as an air exit. The courtyard's axis was always parallel to the prevailing wind direction. Air temperature within the courtyard ranged between 22 and 27°C, while the relative himidity ranged between 60% and 45%.

Plants in the Islamic courts played a complementary part in modifying the climatic conditions. Besides the aesthetic and symbolic sides, they use a great deal of the incident solar rediation and prevent the solar heat passing to the ground. They raise the relative humidity levels. Plants also reduce the chance of the occurrence of glare in the courtyard, however for a short time around noon glare may occur. The aesthetic qualities of the walls enclosing the courts are best seen with the play of light on the different surfaces surrounding it. The time scale is revealed in a very interesting way even without moving within time. The main colours to be found in courtyards were beige, brown and green. They blended together with a character of their own that was revealed with the movement of the eye over the different courtyard elements. The marble fountain in the centre helped to keep the relative humidity within a comfortable range[1], while its flowing waters added to space aesthetics.

El-Takhtaboush, figure (5.43d), was a square recess raised one or two steps above the level of the courtyard towards which its side was fully open. In the centre of this side was usually found a pillar to carry the floor of the room above. El-Takhtaboush was used as an open reception hall where the men of the house received their intimate friends.

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1 The relative humidity outside the house would be the same as that of El-Ezbekieh zone (5) in Greater Cairo, which is 34%, table (3.16).

It resembled the Iwan of the simpler Fustat and Tulunid houses.

El-Maka'ad was an open loggia facing the prevailing wind and located on the first floor. It could be considered as a continuation of the loggia in the Amarna villas fig.(5.19) and was usually reached by means of a closed staircase. It was mostly used as a summer reception area. The position of the Maka'ad secured shade for all the year round except for a few short hours in the very early morning and late afternoon during May, June and July. As an extension of the courtyard the Maka'ad would store cool air during the night but would be expected to release it more quickly than the courtyard, figure (5.43b). The Maka'ad was more exposed to air movement near the top of the court, however El-Bakry failed to register any air movement within the Maka'ad of El-Sehaimi house on 28th March. The undesirable Khamsin wind blows from the south west, and El-Maka'ad was oriented to avoid it. Air movements in El-Maka'ad should be examined during summer when the prevailing wind may cause appreciable differences. Measurements taken at 11.00 showed the air temperature to have reached $22^{o}C$, about 2^{o} less than the court; relative humidity was 40%, this was 10% less than the court which is of course affected by the fountain in the centre (94).

El-Ka'ah was one of the most interesting spaces in the Mamluke house. Its thermal and visual qualities were but the physical side of its integral environment. El-Ka'ah was designed having at least two Iwans centred around a visual point of interest, the Dar-Ka'ah. With its floor one step lower, and a ceiling two metres higher, than the surroundings, it was the peak of the space hierarchy. It was usually covered by a dome giving spatial ascension toward the greater sky dome. This hierarchy was reinforced by the natural light arrangements and the only furnishing feature of this part of the Ka'ah, the marble fountain. As in the courtyard, the fountain kept the humidity level within the comfort limit. The walls of the Ka'ah resembled a continuous built-in cupboard where all the furniture necessary for the multi-use Ka'ah was stored. Perhaps the most fascinating element of the Ka'ah was its Malkaf, an important part of its ventilation system.

The Malkafs were designed to take advantage of the cool breeze whenever it blew. The air layer moving above the built-up area is usually cleaner, cooler and has higher inertia than that at street level, figure (4.21). Malkafs were oriented to intercept the desirable prevailing wind, hence placed on the top of the roof away from any obstructions. Inside the Malkaf system air moves according to inertia which is a function of the pressure difference between the inlet and the outlet. The outlet would be located in the lowest pressure zone around the building even if this was in one side of the dome, figure (5.44). The inlet was placed at different locations in relation to the Ka'ah and in correspondence to the surrounding buildings. In the Ka'ah of Katkhoda[1], figure (5.46) and in El-Masaferkhana, the malkafs were placed at the northern end of the Ka'ah, opening to the north and to the west at the same time. The incoming air was channelled between the relatively cold internal walls. In Beit El-Sinary the Malkaf was placed to the south side of the Ka'ah, mainly because of the surroundings. The air entering through the Malkaf will escape through the lantern and the mashrabiehs. The influence of the Malkaf can be seen in Persian architecture as well as that of the Gulf area where a special version had been developed to naturally improve the thermal performance of the built environment in that climate. In

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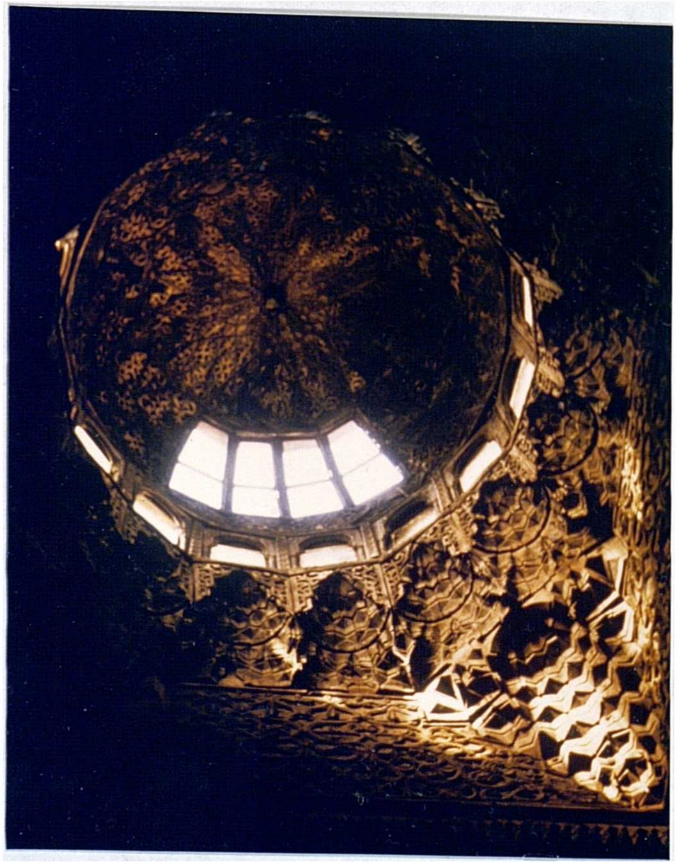
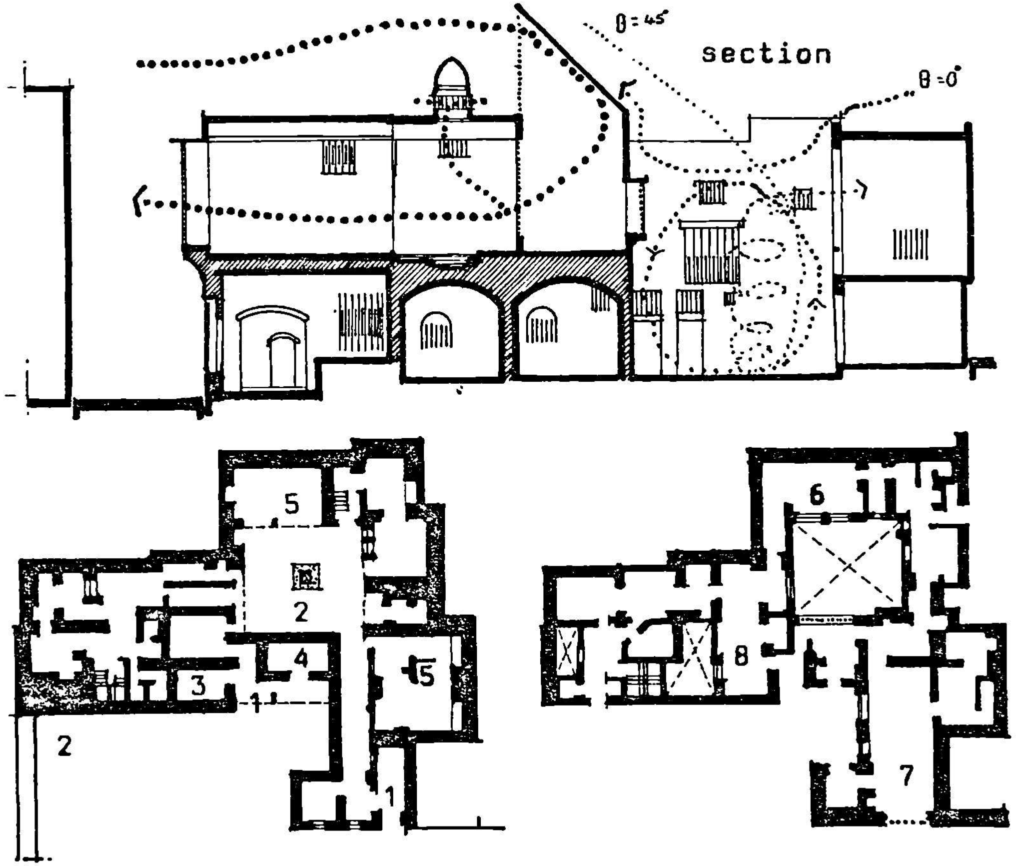
1 This Ka'ah was originally built for Moheb El- Din El-Mowk'a El-Shaf'ai (1545), later owned by the prince Abd El-Rahman Katkhoda (1735) who donated it for public use. Finally in 1837 in a major indiscriminative plan for the westernization of Cairo the house was demolished except for this Ka'ah.



The Dome in the Ka'ah

Figure (5.44) El-Musafirkhana house, Cairo (1779/1788).

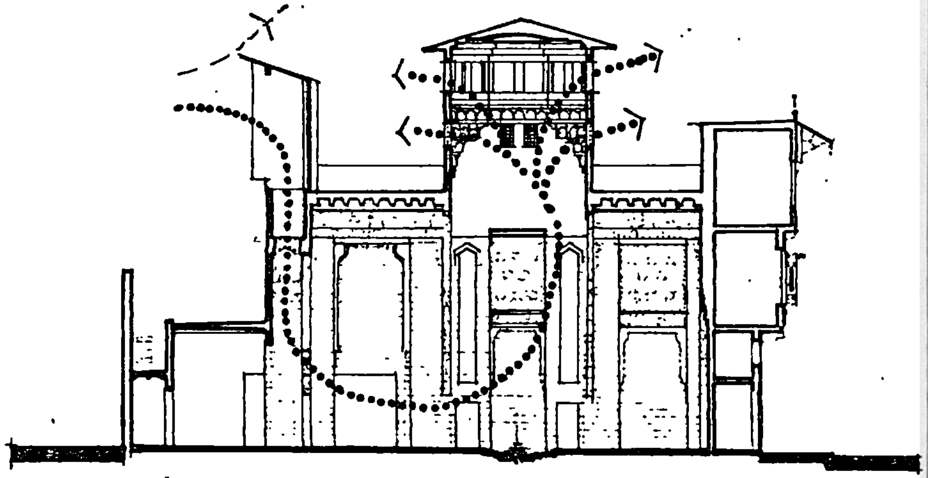


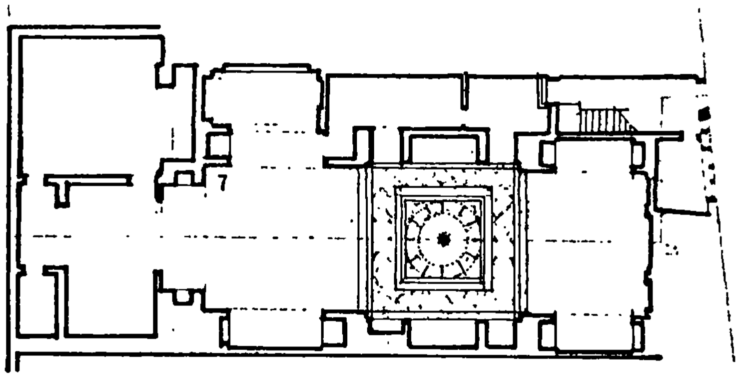
ground floor

first floor

1 Entrance
2 Courtyard
3 Kitchen
4 Storage
5 El-Takhtaboush
6 El-Maka'ad
7 Ka'ah
8 Ka'ah

Figure (5.45) El-Sennary house, Cairo, 1794).


Section through the malkaf


Plan of the Ka'ah

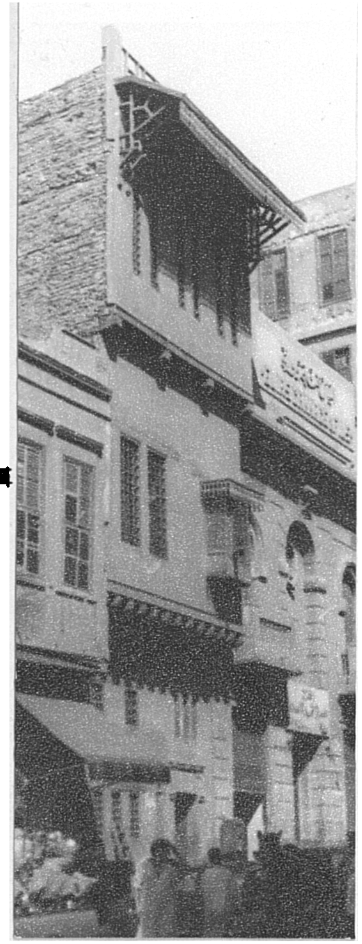

South side facade

Figure (5.46). Ottoman Katkhoda Ka'ah (Moheb El-Din El-Mowka'a El-Shaf'ai) (1350).

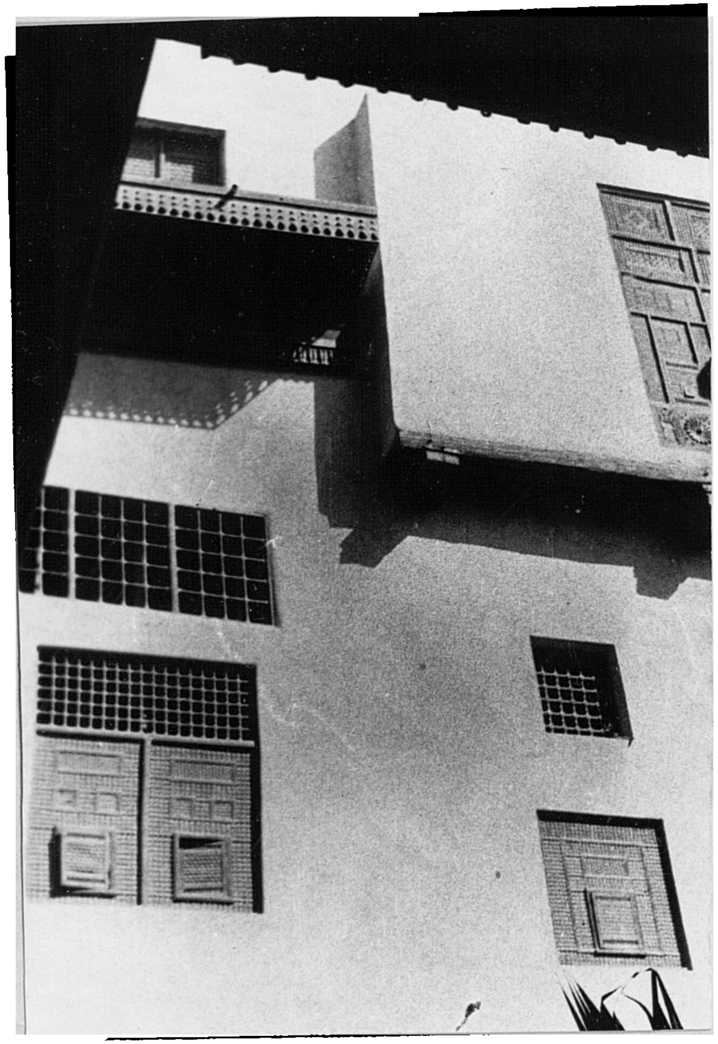
Dubai the houses of El-Bastikeyah district employed the principle of the Malkaf extensively.

El-Bakry (94) failed to record air movements under the malkaf of El-Sehaimi during the beginning of April, a time which coincides with the presence of the Khamsin wind blowing from the south while the desirable wind blows from the north west to north east. Hence, this reflects the effectiveness of the malkaf in excluding the undesirable hot dusty storms. Generally speaking, the architects of the Mamluk houses solved the window problem in complete freedom based on the understanding of human needs. In the Ka'ah the malkaf provided air intake for ventilation, the mashrabieh provided the free view through its lower part, and efficient lighting through its upper part. The malkaf ventilation system contributed to improving the internal conditions and lead to a lowering in temperature of up to 10°C in hot summers. The hot ceiling of the Ka'ah, which was exposed to direct solar radiation, ranged in height between 5 and 7 metres to ward off the radiant heat. The height also ensured air movement through thermal forces whenever inertia forces failed.

A smaller version of the Ka'ah was situated on the ground floor near the entrance and was called El-Mandarah. This used to provide the same function as El-Maka'ad during cold spells.

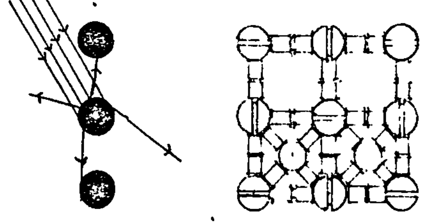
In the Mamluke houses the architect provided for the different window functions, that is, the acoustic, thermal and visual roles, by different means. Acoustically he restricted the openings on the outer, street walls, but opened the house onto a quiet, peaceful core which connected it with the macrocosm. He provided illumination and avoided glare by employing the Mashrabieh; the dense, turned wood components of the lower part (up to head level) figure (5.47), diffused the light rays and avoided glare while allowing a complete visual contact with the outer

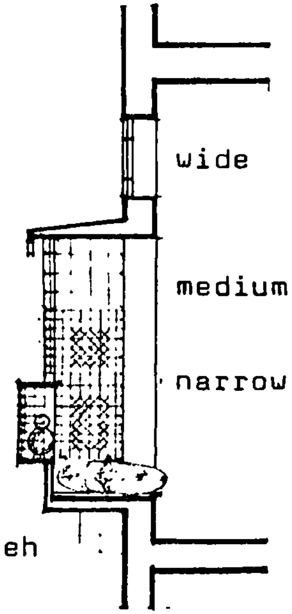
1 The malkaf system is expected to improve the interior thermal conditions by 8 to 12°C.



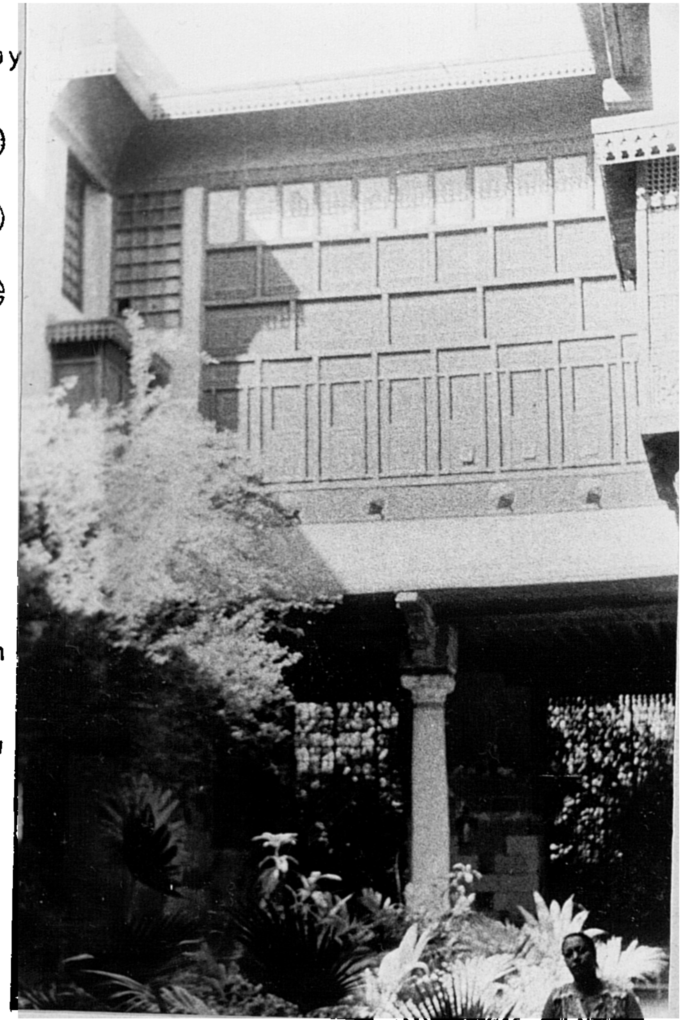
a) Mashrabiehs on the East side of the courtyard

c) Light diffusion by mashrabieh units





b) Mashrabieh detailed section



d) Mashrabiehs on the north side of the courtyard

Figure (5.47) El-Sehaimi House, Cairo (1648/1796).

environment. The distance between the wood components in this section could be as small as ten millimetres. The upper part of the window allowed the light in above the level of the eye. This resulted in a light level approximately uniform within the different parts of the space, conveying visual comfort and a sense of peace. A free flow of ventilation was also allowed by the Mashrabieh. Water jugs would be placed in a projecting part of the Mashrabieh, figure (5.47), where they served a dual purpose humidifying the air which passed over them and cooling the water within. In rooms with only a single opening the Mashrabieh helped to generate air movement, as hot air escaped from the top section to be replaced by fresh, cool air entering through the lower part.

A criticism of the use of the mashrabieh would be the absence of shutters[1], but considering it in the wider context of the integral design of the house it opens onto a completely controlled environment (the courtyard), hence there was no need for such a controlling element. However, the thermal performance of the Mashrabieh during the underheated period should be examined.

The Mamluke houses were built of locally available materials. The lower part of the external walls was built of limestone, not less than 50 cm thickness. Limestone has a high thermal capacity and its time lag is expected to exceed 15 hours. The upper part of the external walls was built of brick, coated with plaster which had high thermal capacity, table (5.1). In structures having high thermal capacity such as these ventilation was of prime importance to keep the inner space cool. The roof was constructed of

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1 In El-Kredlieh house glass shutters have been fixed to keep the exhibits in a good condition and it seems that the exclusion of dust was the precise reason since all the other elements were already eliminated.

palm trunks or wooden beams covered with cement and a layer of mud plus a final layer of stone tiles, in most cases limestone, which reflected the greater part of the incident solar radiation. Mud with its high thermal capacity, coupled with the stone tiles, was expected to have a low U-value and accordingly high thermal resistivity.

In the old quarters of Cairo protection from excessive summer heat dictated the urban pattern. Houses were grouped together seeking defence in volume. The volume of the built area was large with respect to the enclosing surface area, and the buildings were attached horizontally to decrease the surface area exposed to the sun. Streets were irregular[1] having proportions deep and narrow to increase shade and prevent the hot wind from chasing the cool air that had accumulated during the night. The first floor used to overhang the ground floor, and the streets were frequently covered and had gates (182), ensuring shading and keeping out the ground level, hot wind. The sequence of space through time in an old Cairo street is very interesting. Hierarchy of space, variety of views and identity of places reflect high level of consciousness of humane qualities widely ignored in modern architecture and urban design and planning.

The Islamic houses of Cairo are an expression of adaptation to the regional influences coupled with understanding from the architect and the craftsman. The unity of purpose in Islamic architecture is an expression of a faith as a way of life. It is an architecture of enclosures whose main concern is to develop fully the interior spaces as an expression of culture and utility. The principle planning unit was the internal courtyard furnished with colourful tilework, a reflecting pool usually made of marble, plants

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1 The longest straight section of any main street did not exceed 300 metres, and was very much less in the side streets and residential quarters.

and trees. The interior surfaces - floors, walls and ceilings - were brought alive with colour, pattern and texture giving them lightness and conveying the sense of order. Light was carefully controlled by selecting the source which would render the best effect. The use of the malkaf solved the problem of wind orientation. Temperature was regulated by design orientation and the effective use of the mashrabieh. Water was effectively used as a cooling and humidifying agent and its potential exploited to the full. Pointed vaults, domes, arches, minarets, high portals and the horse-shoe-arch are the most apparent exterior features that were extensively used in Islamic architecture (28).

The influence of Islamic architecture had consequences in Europe, particularly in the introduction and development of the pointed arch and vaults, domes and crossed vaults; in various aspects of military architecture; in types and techniques of ornament; and in plan forms such as the cloister. The Mongol invasions in the Thirteenth Century brought the ideas of Islamic designers into Russia and the influence of Islamic architecture can be traced as far as China and Malaysia in the east, and Brighton in Britain in the west. Southward it spread to Nigeria and South-East Africa. Its extension northward was facilitated by the Turkish conquests of the Fifteenth Century which spread up the trade routes to the Baltic and Scandinavia.

5.3.7 The Contemporary Period

The historical events that led to what is known as the Modern Egypt of today started in the early 19th century when the Mohammed Ali dynasty began in 1805 AD, reaching its peak with the completion of the Suez Canal in 1869. This was the beginning of serious European interventions in the internal affairs of Egypt. This period came to an end by the Free Officers Revolution of 1952 deposing the king and proclaiming Egypt as a republic.

Mohammed Ali started an ambitious industrialisation programme trying to make Egypt the industrial centre of the Middle East. However, his descendants who ruled Egypt brought troubles to the country's economy. After Napoleon's invasion Egypt became the subject of competition between the French and the British. The British introduced the railways[1] in 1852, but the French came with the idea of the Suez Canal and succeeded in building it employing Egyptian labour. By the completion of the canal (1859 - 69) the new districts of Cairo were typical copies of those in European cities, a completely imported style. Foreign architects and engineers had been imported to do this work.

Cairo grew outside its old boundaries into the surrounding rural areas. The economic problems had been aggravated by the building of the canal and the accelerated development of the city. The British government of the time took advantage of Egypt's desperate financial situation to buy its controlling shares in the canal (1875 AD). Finally, the British army occupied Egypt to suppress the Egyptian

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1 Egypt was the first country in Africa to have a rail service. The first successful one in the world was built by George Stephenson in 1825, to run between Stockton and Darlington in England.

army revolt of 1882 under Urabi. In 1919 the Egyptians, under the leadership of Saad Zaghlul, revolted against the occupation forces and Egypt was declared an independent kingdom. However, British troops retained their presence under an agreement with the new Kingdom of Egypt until June 1956.

An army movement Known as the Free Officers Revolution led by Nasser took over peacefully in 1952, abolished the monarchy in 1953, and finally brought to an end the presence of British troops in Egypt in 1956. Nasser led Egypt into establishing vast industrial developments which encouraged the urban population to grow at a fast rate. This urban increase, besides the increasing migration from the country-side, figure (5.48) created housing problems in and around the main Egyptian cities, particularly in Cairo. In an attempt to solve the problem the government planned new satellite cities for Cairo in the adjacent desert, Naser city, Muquattam city and others west of the Nile. At the same time Egypt was involved in a long military struggle, from 1948 onward, concerning the right of the Palestinians to a free independant state. The war with Israel in 1967 resulted in the devastation of Sinai and the Suez Canal regions. Destruction of townships, migration from the war zones and the high rate of population growth created a crisis demand on housing, expected to reach 3•1 million residential units by 1985 (61). Since 1975 Egypt has started the reconstruction of the Suez Canal region and the planning of new cities such as 'Tenth of Ramadan' City, Sadat, El Abour and El Amreya cities, figure (5.49).

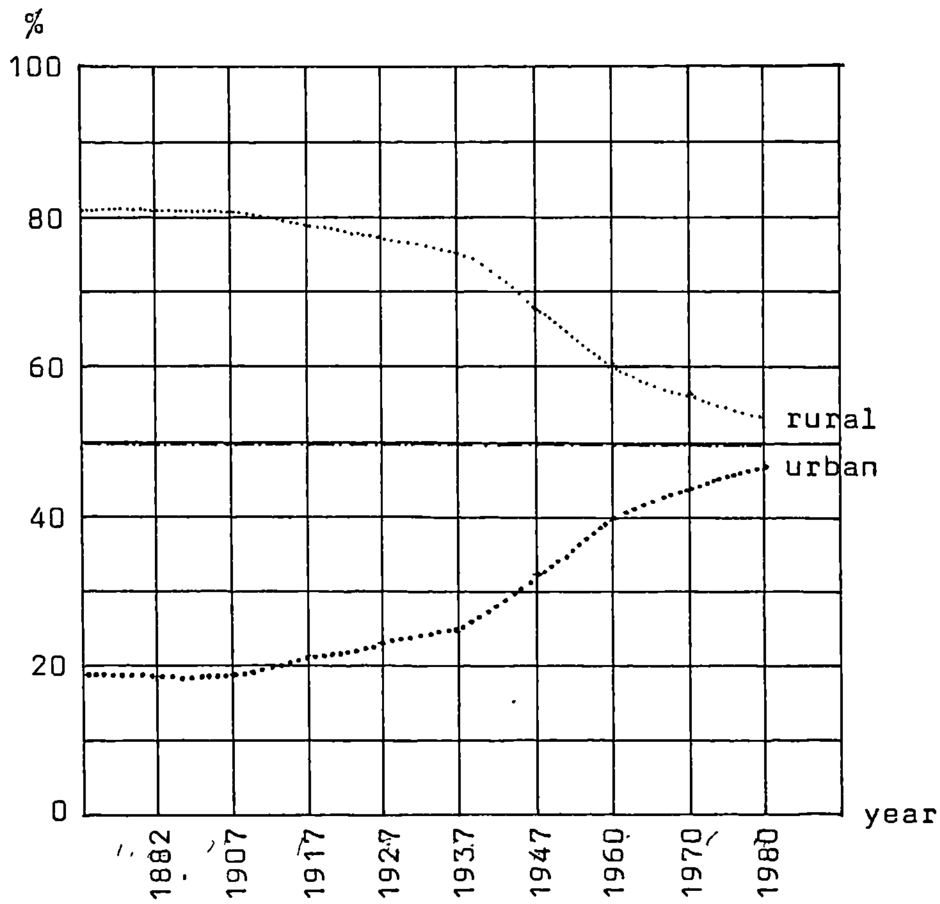
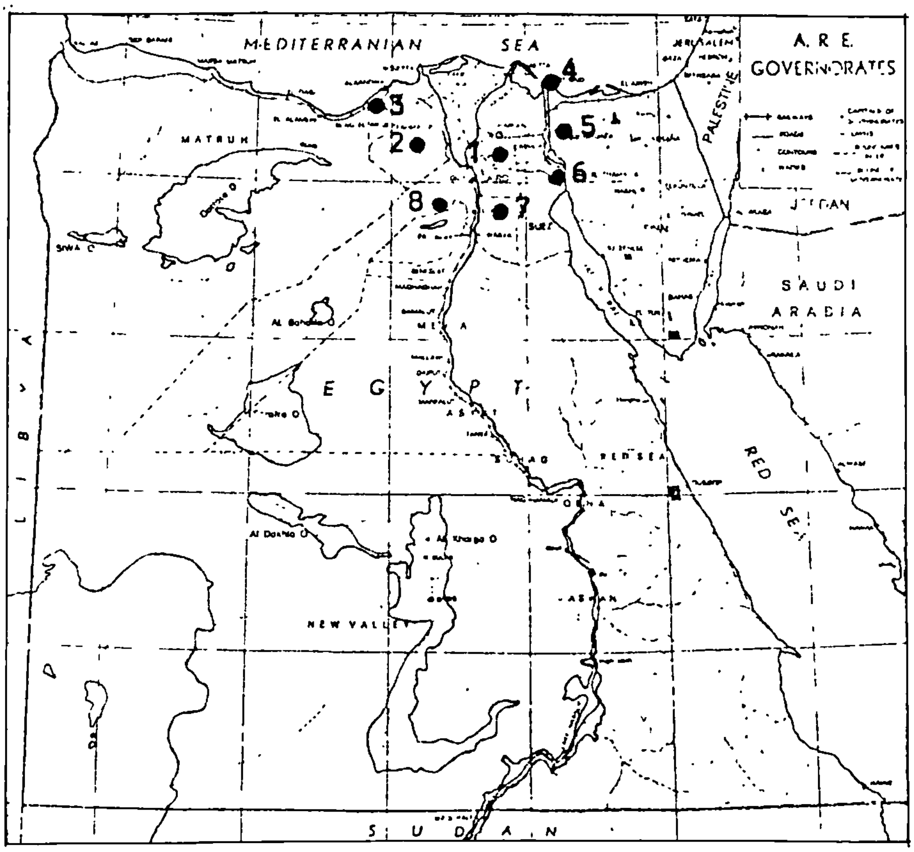


Figure (5.48) Urban and rural population in Egypt (17, 277).



1 10th of Ramadan City
2 Sadat City
3 Amreya
4 Port Said
5 Ismailia
6 Suez
7 Helwan
8 King Khalad

Figure (5.49) New cities and urban developments in Egypt since 1975.

5.3.8 The Contemporary House

During the era of the building of the Suez Canal, the growth of Cairo employed new concepts in town planning such as symmetrical, wide avenues and garden cities. Consequently house concepts which were in use in Europe were adopted and applied with total disregard to the environmental and cultural differences. It is true that Egyptian houses retained their two social parts, Salamliek and Haramliek, but the relation between them had been changed, or at least confused. Moreover, the relation between the house as microcosm and the outer environment as macrocosm, figure (5.30) was completely lost. The main view changed from the inner courtyard to the fashionable street frontage. Instead of the Ka'ah as a multi-purpose space the house acquired a separate room for each of the reception, living, dining and office areas.
However, the house plan kept the requirement of the two entrances, one for the family and services, the other for visitors led to the reception which had access directly to the dining room. The areas of the two main zones were reduced and the house extended vertically to accommodate the newly married sons and daughters.

During the second half of the 19th century the Egyptian house was a detached house. By the turn of the century it had developed into multi-storey apartments with one flat per floor. However, the continuous growth of city populations created a growing demand for cheaper residential units. Multi-storey dwellings with more than one family unit per floor were introduced. Again these followed the European layout. An interesting element which developed during this period and may be related, only in form, to the Islamic house was the light well, 'manwar'. This was a deep courtyard used for lighting and ventilating the service areas, but it was a couse of odour problems in most city dwellings. In these multi-storey developments the unit used to face two sides only and frequently faced only one side. This type of dwelling continued to dominate the Egyptian cities till today, and a substantial section of the Egyptian building regulations was devoted to dealing with this type of building. When the new satellite settlements and new cities were being planned the authority encouraged the same type of housing.

The authority, in attempting to solve the housing problems of the low income sector, sponsored the building of over 30,000 residential units between 1952 and 1960. Since 1960, realising that the housing problem affected almost all income groups, the government started building three different types of housing. These were low cost (economy), middle income (average) and high income (above average), figure (5.50). The standards and norms for these categories were loosely defined, with the strongest emphasis on the living area per person. For the economy units this was 10 m^2 per person, for the average it was 20 m^2, while for the above average it was 30 m^2. Local authorities designed and built many units according to these standards, figure (5.51), with little regard to the actual needs of the inhabitants. They ignored both the socio-cultural and the physiological comfort aspects of design.

Awaida (17) studied the economic residential units built during the sixties in the Greater Cairo area and found that about 50% of the inhabitants were migrants from the rural areas seeking a better standard of living in the city. In the local authority units a common complaint, presented by up to 88% of the dwellers in some models, was about the small size of the units. The use of the living room area for living, studying, dining, and sleeping at night time was common. The inhabitants needed some design modifications[4] to adapt the unit to their needs; rigidity of the design in some models allowed minimal change, while in some other designs 100% of the occupants had made modifications. This highlights the importance of design

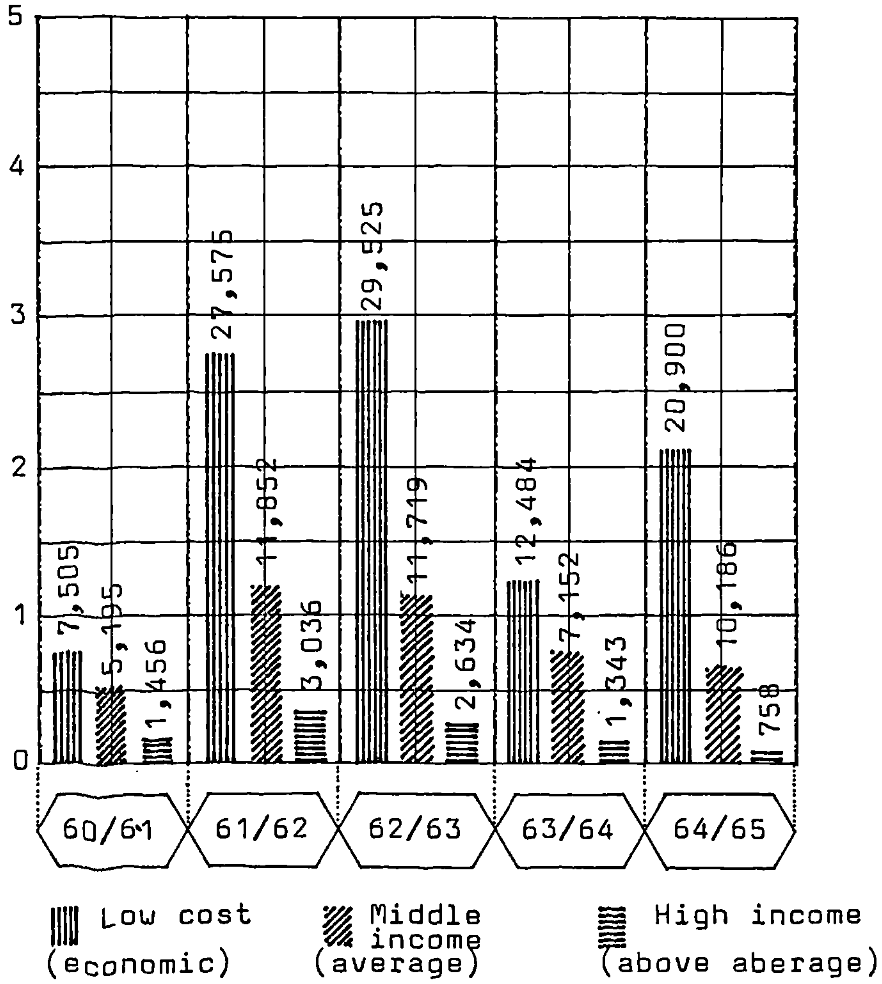
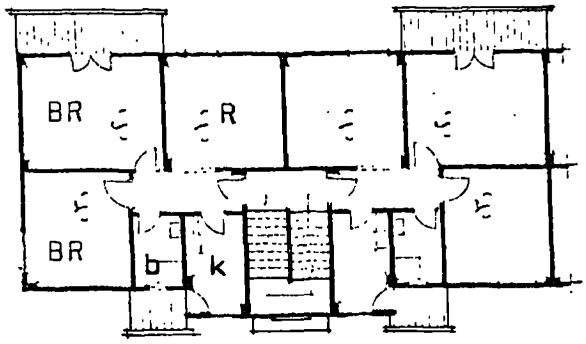
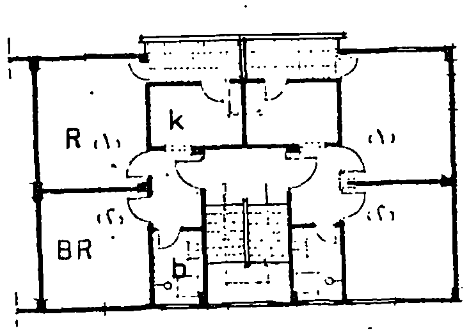


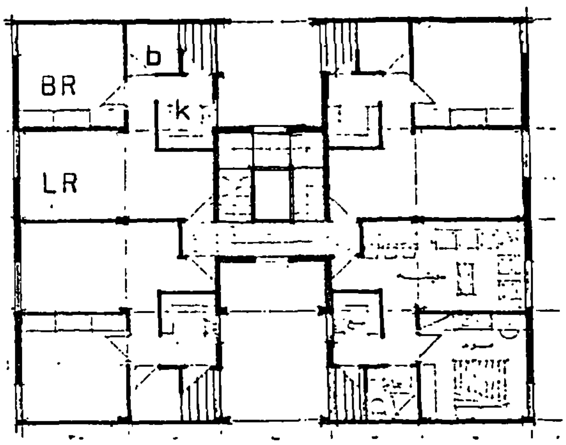
Figure (5.50) Number of units built during the first five year plan (1960 - 65) (17).



3 - room model

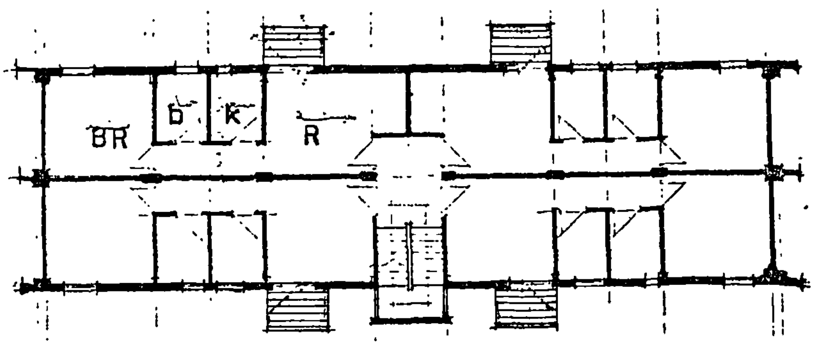


2 - room model



2 - room model

R room
BR bedroom
LR living room
k kitchen
b bath



2 - room model

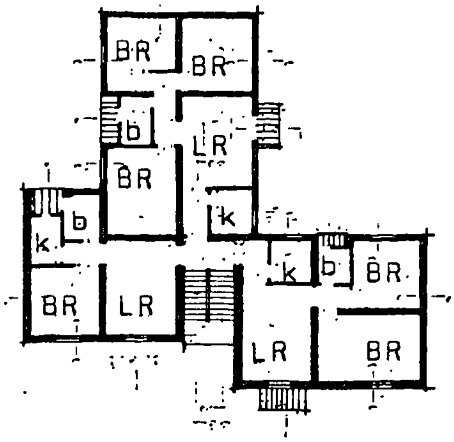
Figure (5.51) Local authority models for low-income (economy) housing.

flexibility needed within the units of the economy housing sector as a consequence of the tight area allocated. The internal privacy aspect within these units ranged between reasonable and poor, while external privacy was poor due to the siting arrangements of the residential blocks. Ventilation within housing units was of a considerably poor quality, and a cause of concern from the thermal comfort and health aspects.

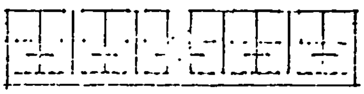
The most common planning layout concept was parallel blocks approximately 10 metres apart. The internal design concept discouraged natural air movement in most of the models where the main entrance door had to be left open, sacrificing privacy for ventilation. Another interesting finding of Awaida was that the two-storey courtyard house was the best model to satisfy the low income needs an it provided a greater flexibility in use and the courtyard helped air movement within the unit.

When the government started the reconstruction of the Suez Canal region in 1974 new housing types were introduced employing the same principles as the previous designs, but encouraging the use of local materials like limestone and sandstone. The use of limestone proved to be more expensive than the traditional brick and concrete frame method of construction because of the lack of experienced labour. Generally both building regulations and planning concepts employed in these most recent developments resulted in housing solutions similar to those in earlier times with scarcely any significant improvements economically, socially or environmentally, figure (5.52) and (5.53).

A characteristic element of the typical residential unit is the external wooden louvre shutters of the window or balcony. The louvres allow air movements and keep glare out. However they also allow in street noises, give inefficient lighting and prevent visual communication with the



LR	living room
BR	bedroom
k	kitchen
b	bathroom



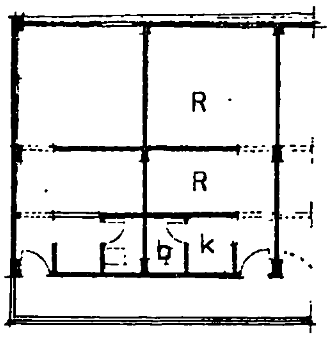


Figure (5.53) Residential units for economic housing projects. Architect H Sahab. Ministry of housing and Reconstruction Cairo.

outside. Some houses are fitted with rolling shutters that with proper adjustment may allow more light and better air movement. This however also allows more noise intrusion. Some houses are fitted with internal venetian blinds or canvas curtains replacing the external louvered shutters. However, during the over-heated period the window glass gives the effect of a greenhouse allowing shortwave radiation to heat the curtain fabric thus trapping the long wave radiation.

Generally speaking, the local authority and governmental housing units have both shown similar characteristics concerning the small size of living area in proportion to the number of inhabitants, and the wasteful use of circulation areas. The units lack any consideration for socio-cultural needs or for privacy requirements. The unit plan does not provide either for storage space or for a courtyard, forcing many inhabitants to divide their terraces between storage and other uses. The houses lacked flexibility, which limited the use of spaces and led to overcrowding in the one room. The monotonous layout of parallel blocks did not allow for local identity or for proper consideration of wind movement around them. The meaningless open spaces combined with a lack of awareness of the climatic impact prevented the inhabitants from making use of their environment most of the time, and lead to accumulation of dirt. The building techniques and materials used did not consider any thermal comfort criteria resulting in the residential units being very hot during the summer, as well as noisy during the day time. Thermal relief could only be expected through natural ventilation, so poor in itself that it was augmented by keeping the doors open. Thus privacy was sacrificed for thermal comfort. The blocks, having long and narrow proportions, allowed a large surface area to volume ratio, resulting in poor thermal performance.

A joint research programme was initiated in December 1976 on the housing and construction industry in Egypt. The project was conducted by Cairo University and Massachusets Institute of Technology, and sponsored by the Technology Adaptation Programme to investigate the housing problem in Egypt. Their recommendations included:

1 Satisfying the demand for housing at the present standards is far beyond the means of the Egyptian economy.
2 Rent control had a depressing effect on housing investment and hurt primarily the poor and the young. It has also caused horizontal inequity aggravated by an almost total lack of turnover.
3 If subsidies are meant to assist the low income group they should be made available directly to the owner rather than on building materials or interest rates.
4 Private contractors should be encouraged to develop their abilities to increase the housing industry's productivity.
5 Classification/Qualification of contractors, and their organization into an association representing their interests are proposed to promote co-operation between firms.
6 Change along managerial, financial and technical lines toward more flexible systems is required at the firm and project level.
7 Knowledge of the organization and operation of construction must be upgraded if proper planning and forecasting are to be done.
8 New materials, and new uses of existing materials have proven to be technically promising for future application in housing construction; reinforcing materials such as reed, burlap and stretched wire mesh as well as gypsum, lightweight concrete, and stabilized earth are among those proven to be most promising. Also the study of the possible production of low-cost cement is important.
9 New techniques of construction, such as surface bonding of brick walls using indigenous material seem promising.

10 Prefabrication factories as they currently exist cannot produce units at a cost low enough for the low income groups. The load bearing brick wall with reinforced concrete slabs is currently the cheapest construction method for building up to five floors.

11 A method of 'support/infill' type of construction should be investigated.

12 Tradeoffs in size, stage of completion, finish, equipment and structural support allow lowering the cost of the final product so it reaches a much lower section of the middle income groups.

13 Use of a simplified series of basic prefab elements to allow 'open systems', along with standardization of subcomponents produced in factories could lower the cost for all construction.

14 The compatability of small locally produced elements (doors, windows, tiles etc) should be stressed and co-ordinated with the prefab designs.

15 Advantage should be taken of the initiative and resources of the low income majority in constructing their own housing.

16 The users should be identified as a function of the housing/family/location cycle in order to determine needs requirements and priorities.

17 The government should redirect its efforts into providing necessary infrastructure and supporting technical and financial assistance and suitable regulations.

18 A basic primary utility infrastructure should be provided with a progressive upgrading correlating to the development of the users' resources.

19 From the standpoint of physical, social, legal tenure, financial, administration and culture, the cluster arrangement is the key to residential development.

20 A simple house should be provided as an initial living space for the users of new isolated developments.

The evaluation of such comprehensive recommendations will have to wait for the appraisal of the pilot projects before wide application is possible. Government housing schemes need continuous evaluation and feedback besides foreward research if human comfort is to be achieved. Apart from reducing costs, research should cover the socio-cultural and physical environmental needs. These studies should be tested and carefully examined in relation to the existing models.

5.4 Lessons From the Historical Precedent

> 'It is not enough to put up slavish imitations of old buildings, Nor is it enough to pretend that old buildings have nothing to say.'
>
> H Fathy (31)

Following the development of Egyptian architecture in house design during the different periods from the Ancient Egyptian, through the Coptic, Islamic and Contemporary periods, it has been shown how each period affected the following one, and how each of the first three related to the thoughts and the socio-cultural environment of its time. The contemporary architects of Egypt, however, seemed to ignore the lessons and experiences learned from their country's heritage. Nevertheless, there is no sense in trying to copy solutions of distant times and applying them to the present. As has been demonstrated, these past solutions were developed according to the functions and requirements of their times, be they cultural, social, religious or technical. Although an understanding of the way our ancestors tackled and solved their problems might help in solving our own, solving a problem is a function of its definition, its constraints and objectives. The main lessons learned from the review of the historical precedent can be summarized as:

- The courtyard had been a common feature from Ancient Egyptian times, figure (5.19), up to the Islamic times. Beside offering an answer to the social conditions of the time it regulated the hot, arid climatic conditions of the region. In the rural areas of contemporary Egypt the courtyard house is the most common type found, offering sound solutions to many problems. The courtyard could be a potential model for the new urban areas where a change of building regulations would have had considerable effect. The survey carried out by Cairo University and MIT showed the courtyard as the main urban tissue of Medieval Cairo, figure (5.54a), having a population density of 1401 persons per hectare, almost the same as that of the most crowded governmental housing scheme, Ain Al-Sira which has 1428 persons per hectare, figure (5.54b).

- The window element in a house should provide for three main functions; to allow internal light; to permit natural ventilation; and to allow communication with the outside. However, noise reduction should also be considered as an important factor. The malkaf, used during the Ancient Egyptian and Islamic periods, had proved to be a successful element. The possibility of re-employing its principles in meeting the ventilation requirements of today should be carefully studied, firstly in relation to the intake position within the air flow patterns of the surrounding area, and secondly in securing effective air outlet which, if ignored, could lead to the failure of the malkaf system. The malkaf is still successfully used to date in rural Egypt, figure (2.1), in Siwa and the western desert, figure (2.32), in Pakistan (226) and in the Persian Gulf (23 , 68).

- The mashrabieh acts as a functional element when it is fitted within the right environment, however it is expensive to manufacture. The three functions of the

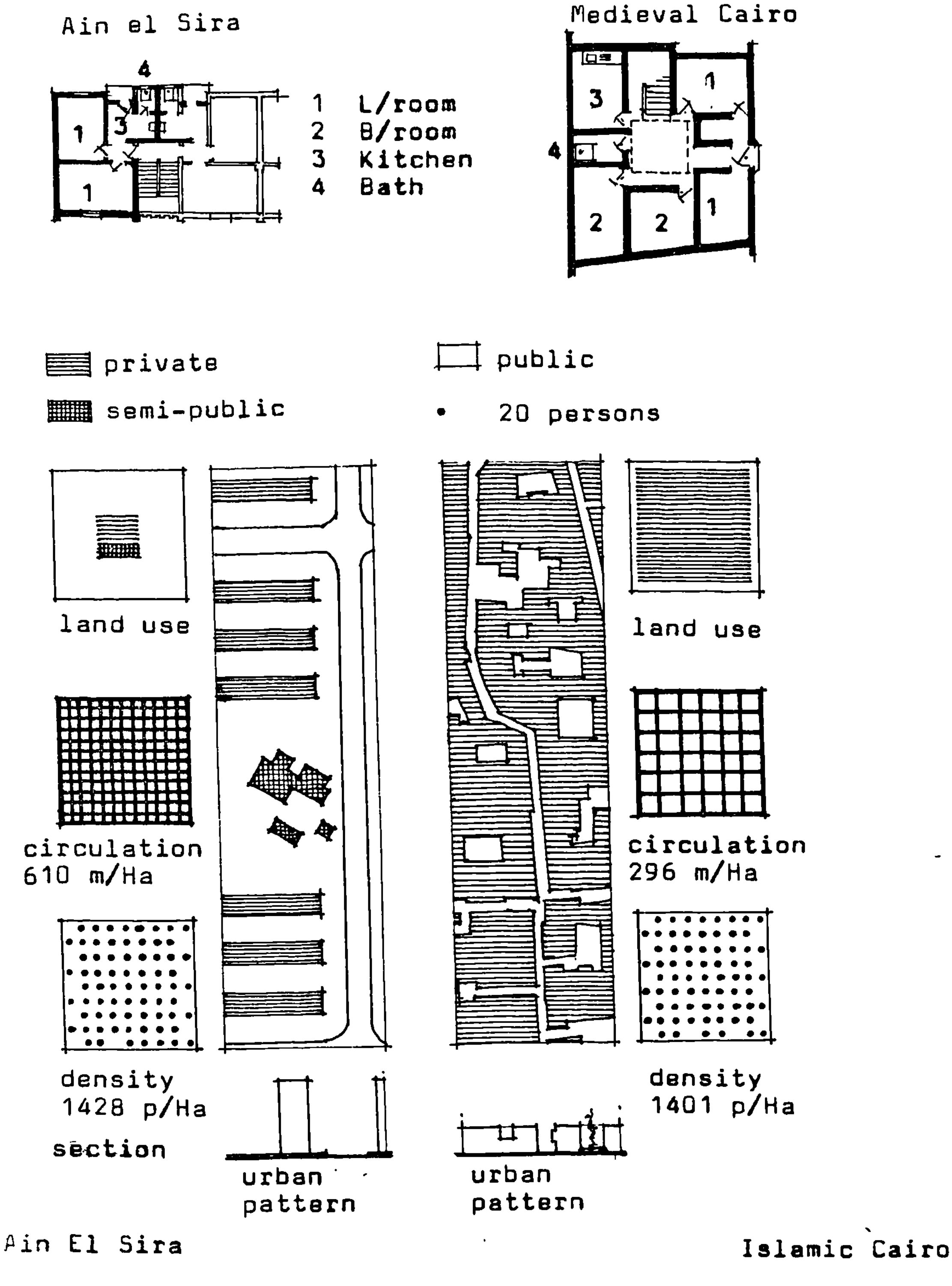


Figure (5.54) Contemporary and Islamic urban tissue in Cairo, (60, 61).

window may be performed economically using simplified prefabricated elements which would be more suitable to our cultural environment. Designing the window should be considered in the context of the ventilation system of the house and as an integral part of the total design process, not just as a window to be added only on aesthetical grounds.

- The high thermal capacity materials used in the past were of great importance in the Ancient Egyptian, Coptic and Islamic periods. It has been suggested that such materials be used in the inner walls of the contemporary house, while constructing the outer shell of good insulating materials, figure (4.4) and (4.5), giving a more sound thermal performance. These proposals need further research and experimental examination before their application.

- Economic factors should be considered, not only from the actual money value, but from the total energy analysis point of view. Money values provide only a limited comparative index at the time of consideration while total energy in its abstract meaning can be valued over a considerable timespan. During both the Ancient Egyptian and the Islamic periods the prosperous conditions may have relieved architects from economic pressures. However, during the Coptic period the Egyptian builders were more aware of financial restraints. This was illustrated in the construction methods used, especially those employed in staircases, and in the limitations imposed on space dimensions, openings standards, and the compact design of housing units.

- Privacy was an important feature which is now lacking in contemporary housing. Throughout the history of the Egyptian house many lessons could be learned from the way design for privacy was done to satisfy the social and cultural needs of the inhabitants.

Chapter 6 : THE PREDICTION OF AIR FLOW : Wind Tunnel Experiments

6.1 Introduction

Wind configuration in and around buildings is considered under the topic 'Architectural Aerodynamics' which includes both the structural and the environmental aspects. The structural aspect considers mainly the wind loading on buildings and structures, while the environmental aspect considers natural ventilation, effluent disposal, wind impact on building services, pedestrian comfort and wind generated noise. Although environmental aerodynamics is a new[1] subject, concern for wind movements within and without buildings can be observed in many ancient houses, figure (4.20), and towns. In El-Lahun, 1900 BC, both houses, figure (5.19b), and town plan reveal an awareness of the beneficial wind. Cairo houses of the Islamic period show very sophisticated techniques in employing wind as a thermal relieving force within the inner environment. The environmental effects of wind on thermal comfort were considered in Sections 2.4, 3.5 and 4.2.2, the configuration of wind around buildings and air flow within them were discussed in Sections 4.4 and 4.5, while wind considerations in the house design process was investigated in Sections 5.3, 5.4 and 5.5.

Air flow around and within buildings may be investigated through records taken in full scale models and buildings.

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1 In 1903 Napier Shaw gave laws of ventilation using electric circuit analogies; between 1924 and 1933 the American Society of Heating and Ventilating Engineers published a report on a research project for the infiltration rates with reference to pressure difference. By 1950 BRE in England published an account of their studies in infiltration (18).

Although this is the most accurate way of flow pattern investigation, it is time consuming, costly and may not allow examination until the building is completed. Moreover, modifications and alterations of wind characteristics are considerably difficult and any design modifications would be costly to execute. Second to full scale testing is the wind tunnel investigation[1] which allows air configuration with buildings to be simulated provided that the prevailing wind conditions are known and building modelling techniques allow accurate simulation of the expected environment. Wind tunnel testing allows the duplication of the flow pattern, allowing any necessary modifications to be done during the different design stages, whenever required. It also allows for obtaining accurate data concerning wind loading, ventilation and environmental comfort.

In Section 4.3 the physical mechanism of natural ventilation has been discussed and the resultant ventilation[2] has been assumed to be dominated by wind forces. The wind in its configuration with building forms changes both its direction and speed, hence air movements past the building surface result in different flow patterns within the typical residential unit located at different stories of the single block of flats, figure (4.37). This highlights the importance of investigating air flow across the building faces in relation to its flow within the built environment.

Air movement within the built environment first tends to follow the initial entry direction until it loses inertia

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1 Other techniques of simulating air flow around buildings such as the water tunnel, electrical analogies and mathematical models, are expected to give less accurate results because of the many parameters concerning both wind characteristics and the wind configuration with physical forms. The integral effect results from them interacting instantaneously.

2 In this Section natural ventilation of typical multi-storey flats is considered during the overheated period.

due to friction, obstruction or being dominated by other forces. When the inertia forces are diminished, or the forces generated by the difference in pressure are greater, the flow pattern will be governed by the magnitude of that pressure difference as well as the direction of the flow past the building's leeward face.

Throughout this Chapter the experimental investigations are conducted in two sets. The first will be aimed toward a qualitative answer only, rather than achieving a pre-determined quantitative goal. The investigation at this stage will consider the parameters which are likely to affect the second stage, in which quantitative as well as qualitative answers will be aimed for. In the course of these investigations consideration will also be given to the prevailing wind direction as well as the basic standards for contemporary low cost housing units in Egypt.

In the first set of experiments air flow patterns around a single block, groups of blocks, and within single courtyard blocks will be examined. The main regions of flow along the surface of the building and in its vicinity which are likely to affect the flow inside the built environment, and the ways they would alter the flow pattern in a typical single cell as well as combinations of connected cells will also be examined, and their parameters specified. In the second experimental set air flow will be monitored and recorded, providing both qualitative and quantitative data. The parameters to be examined include the effects of inlet/outlet distance, inlet/outlet area, and the arrangements of internal partitions. These are considered for angles of incidence[1] θ between $-45^{\circ} < \theta < 90^{\circ}$, with a constant, smooth wind flow at a speed of 1 m/s being adopted throughout the experiments.

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1 The choice of θ values is expected to cover the possible wind configurations for the models examined.

6.2 Experimental Arrangements

The experiments have been conducted in the low speed wind tunnel of the Department of Architecture and Building Science, figure (6.1), which has a working cross-section of one square metre. The wind tunnel has been examined and the necessary modifications and preparations preceded the experiments. These included erecting a screen on one side of the tunnel, modifying the lighting system, improving the smoke generator performance, figure (A4.4a), and upgrading the electronic anemometry systems, figure (A4.4b). Appendix A4 Section A4.1 includes detailed illustrations of the wind tunnel description, performance, instrumentation, testing, modifications and the preparation process.

Flow visualization was possible using evaporated oil smoke as the tracing medium for air flow patterns around buildings. Smoke puffs were used to draw the lines of the flow, but when air flow within enclosed spaces was of interest this technique allowed only low intensity smoke with poor traces. Another technique had to be employed where the space was first flooded with smoke, then air was allowed to infiltrate drawing the flow patterns as black lines in the white smoke. The models were places with their centres aligned with that of the turntable so that it was possible to rotate them and consequently change the angle of incidence of the flow, figures (6.2) and (6.3).

Flow documentation[1] was made possible using photographic techniques accompanied by close observation. Speed measurements were taken occaisionally to illuminate the visualization interpretation and give indications of the deviation

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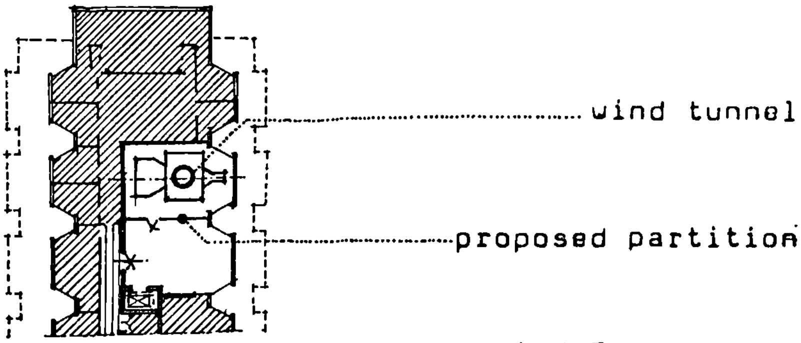
1 A sample of the flow visualization photos is included in Appendix A5.



Wind Tunnel Layout

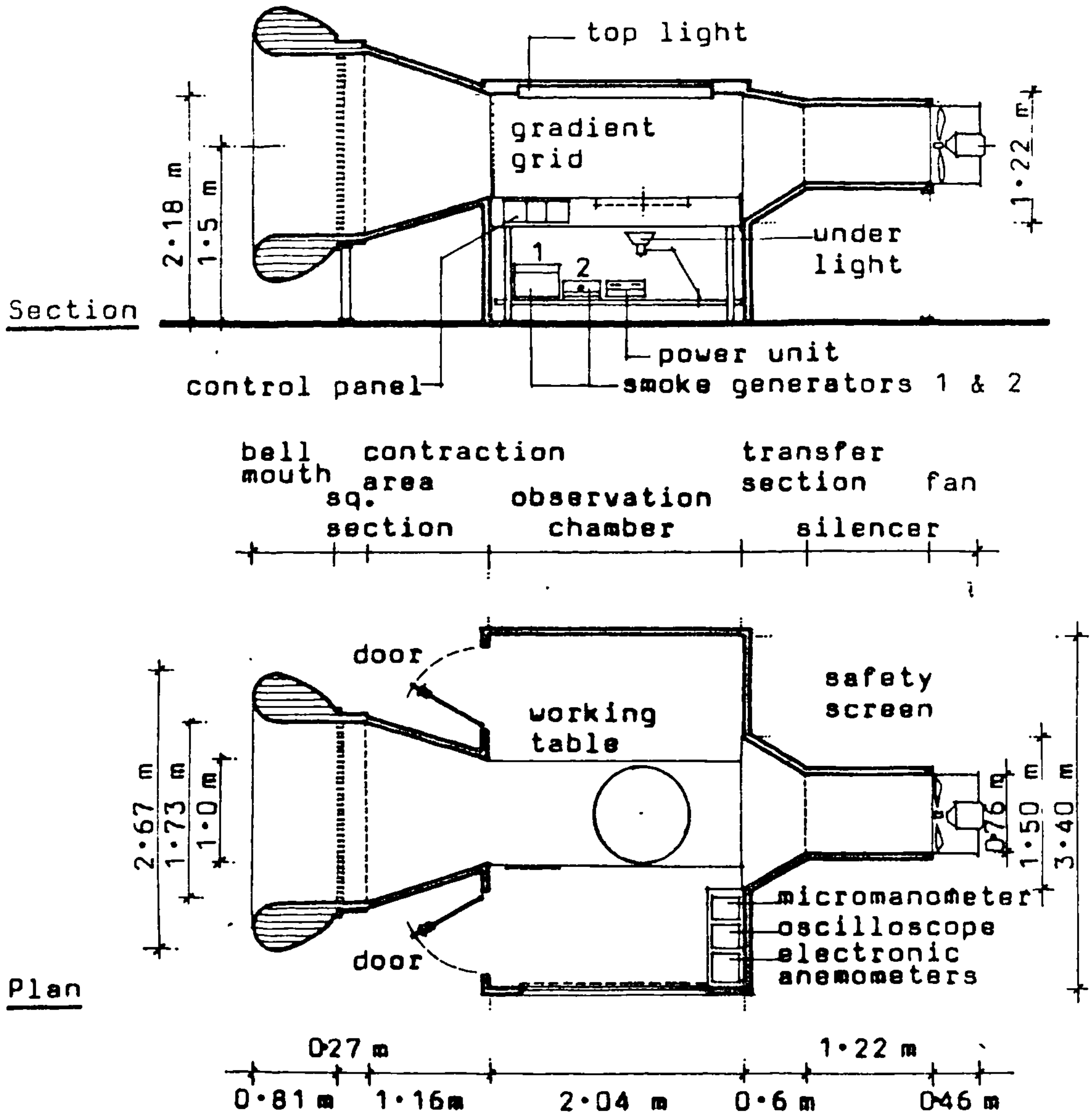
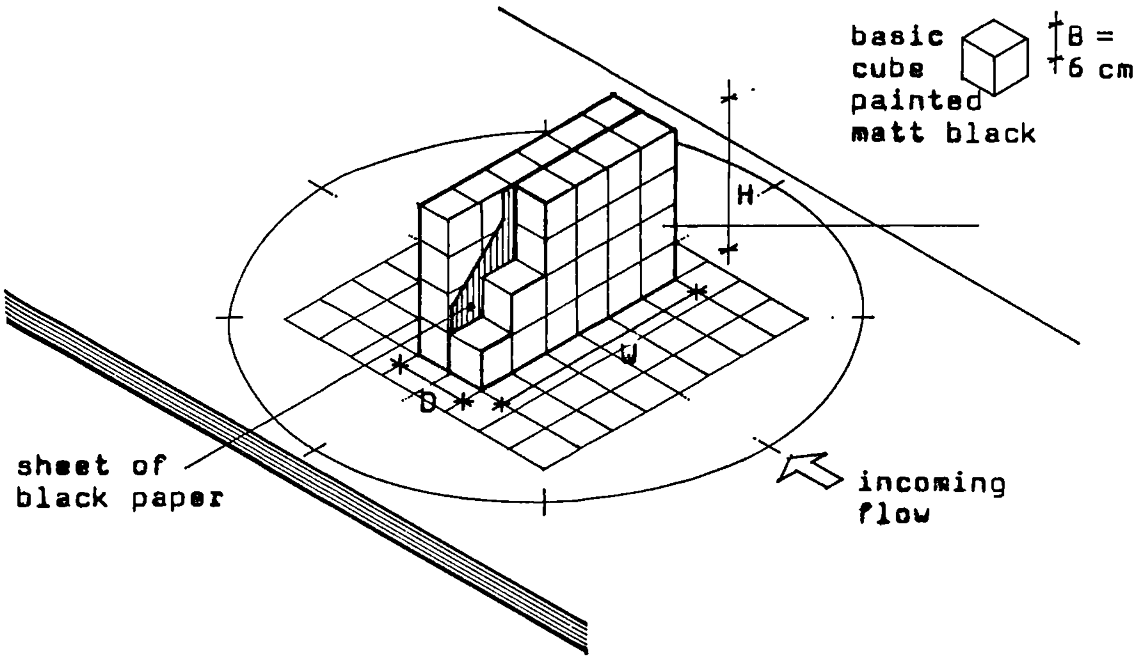
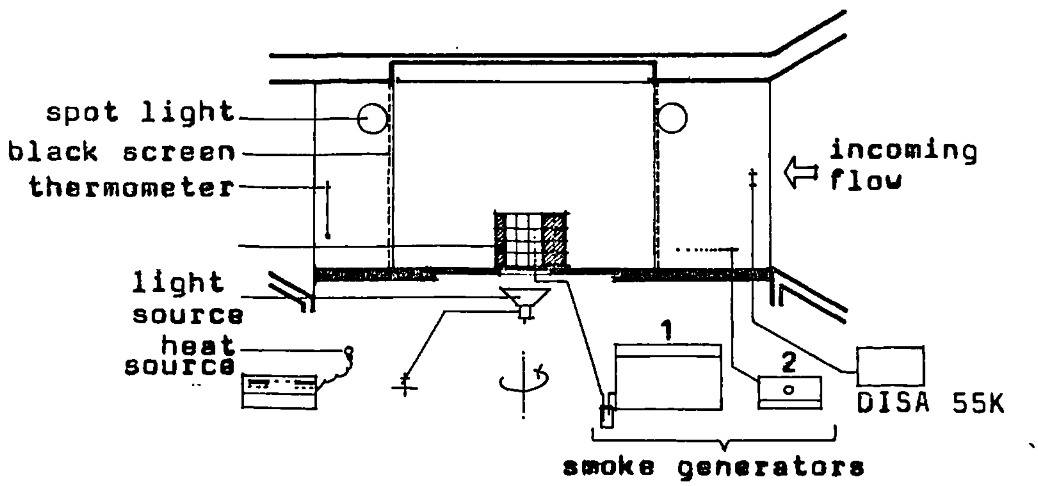


Figure (6.1) The wind tunnel of the Department of Architecture and Building Science (A Abdin)

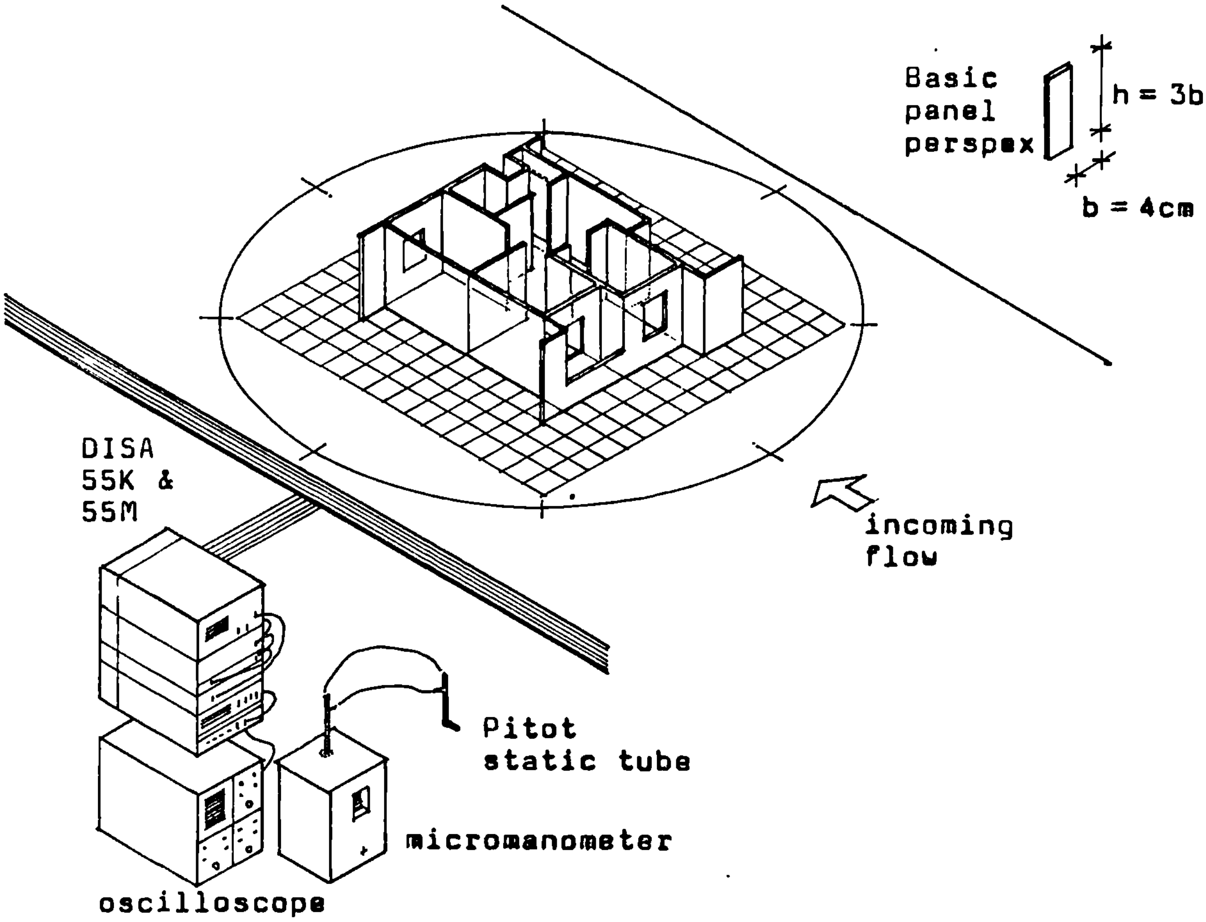


a) Details of the external flow model structure

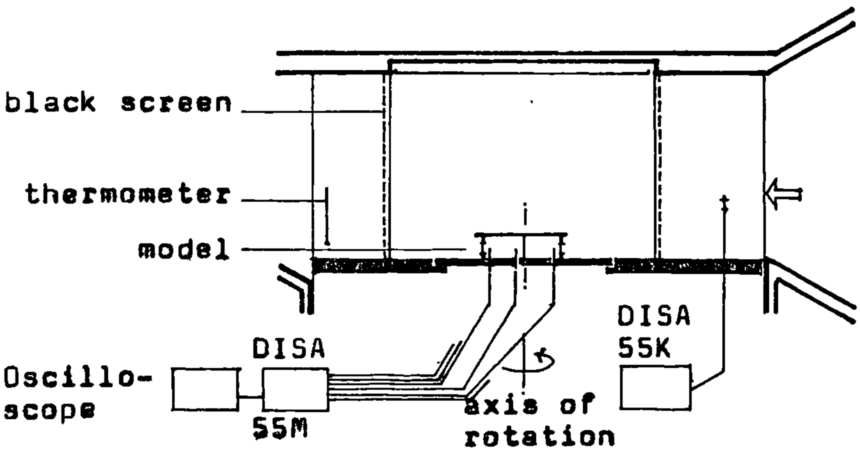


b) Details of the model mounting system as set in the observation chamber

Figure (6.2) External flow model



a) Details of the internal flow model and instruments set up



b) Details of the model mounting system as set in the observation chamber

Figure (6.3) Internal flow model

in magnitude from the free stream. The experimental setting examining each set of parameters was repeated three times[1] for the purpose of checking the findings. Air velocity in the free stream was kept constant at 1 m/s, monitored by the DISA 55K anemometry system while dry bulb temperature was recorded using a mercury thermometer. The set up and mounting system of the external flow model is illustrated in figure (6.2), while detailed description of the flow visualization, flow documentation and instrumentation are illustrated in Appendix 4, Section A4.1.4.

Air speeds within enclosed spaces were measured by two DISA anemometry systems. The DISA 55K system incorporating 55 K 14 wide range adaptor was used to monitor the free stream velocity[2] while the DISA 55M system including the 55 D 65 probe selector was used for recording air velocity within models of single and multi-cells, figure (6.3). Air velocity was measured at 6 cm above the model floor and in the centre of the openings through which the air flowed from one cell to another, or between the inside and the outside of the model. The flow speed measured at each point of interest was taken in three sets of 15 readings each, giving a total of 45 readings for every point. These readings[3] were taken at two second intervals and the final was their arithmetic mean. These readings were recorded as voltages then converted to metres per second using the calibration charts. The results were then expressed as a percentage of the outdoor air speed, $C_{v\hat{n}}$ to be employed in equation (4-13):

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1 The experiments were repeated seven times, five times, and three times, and little difference was found between them. Hence, three settings was considered adequate.
2 In the context of this Section the free stream velocity is equal to the air speed at window level.
3 A sample of the speed measurements is given in Appendix A6.

$$V_n = C_{vn} \bar{V}$$

where

V_n = air speed expected at the point of interest

C_{vn} = velocity coefficient

$\vec{V}$ = outdoor air speed

The results of the 41 models examined are summarized in Appendix A7. These, as in the external flow model, were placed on the turntable to allow for changes in the flow angle of incidence (θ) in relation to each model. Smoke visualizations were carried out occaisionally to clarify flow direction and details of the flow pattern.

The models used were intended only to represent the parameters to be examined and not to be of actual buildings with their varying architectural articulations. Accordingly as the cube is the most commonly used space form in the low cost residential units, the external flow model was designed as a set of cubes of 6 cm side, to represent the main building modelling component. These were assembled into models of scales 1 : 50 or 1 : 100. Infiltration between the cubes was eliminated by using vertical sheets of hard paper behind the first row of cubes, figure (6.2a). The internal flow models were built to 1 : 25 scale corresponding with the external flow models and representing the morphology of residential spaces. They were made of panels 4 x 12 cm, representing the full-scale 1 x 3 m panel, and were of transparent perspex. They were fixed to each other and to the base with both double-sided and single-sided tranparent tape, allowing air to infiltrate only where intended.

Details of air flow patterns depend on building geometry and upon characteristics of the wind to which that building is exposed. In wind tunnel simulation the ideal conditions require the same Reynolds Number (R) for the model as would exist in the full scale structure where:

$$\text{Reynolds Number}^{1}\ (R) = \frac{\text{inertia forces}}{\text{viscous forces}} = \frac{(\text{velocity} \times \text{size})}{\text{kinematic viscosity}}$$

Since air is used to simulate wind flow around buildings and has the same atmospheric pressure, the kinematic viscosity will be the same for the model as it is for the full scale structure. Therefore, Reynolds number will depend on the velocity and the size. If the size is decreased the speed must be increased to achieve the same R. The models tested in wind tunnels are usually smaller in size by hundreds of times than that of the real structure, making it impossible to achieve the same R by means of increasing the air speed alone. However, in the case of a sharp edged body the drag coefficient is almost constant for Reynolds number ranging between 10^4 to 10^7. Hence for sharp edged bluff bodies Reynolds number is of little importance and thus the wind speed in the tunnel, as well as the size of the model, is of little importance.

This is not the case for curved bodies where the results may not be relevant to the actual flow and the test is likely to be conducted in the region of the critical[2] Reynolds Number (R_{crit}). Moreover, any part of the model which has a small dimension may cause R for this part to fall below R_{crit} producing false results. Therefore, the

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1 Reynolds Number (R) was discovered by Osborne Reynolds (1842 - 1912). Generally it is the ratio of inertia to viscous forces.

2 The Critical Reynolds Number (R_{crit}) is that where the model's drag coefficient suddenly changes its value. For curved surfaces R_{crit} occurs when $R = 2{\cdot}8 \times 10^5$ which is likely to occur during the test. Sharp edged bodies have an almost constant drag coefficient for values of R from 10^4 to 10^7, covering a wide range of speeds and model sizes (115).

architectural surface details may be affected in this way and wind tunnel models may ignore these details with little effect on the overall results. The nature of the relative importance of Reynolds number is a result of the fact that the flow always separates from the surfaces of the sharp edged bodies at these edges, while on a curved surface the separation place will depend on the conditions of the boundary layer on the block surface (115). In the present work Reynolds number was ignored on the grounds that the external flow models were sharp edged with no architectural surface details[1].

The difference in air speed between the free atmosphere and the flow near the ground is considerable as a result of surface friction, figure (4.21). Human discomfort, from wind impact, is generated by the deflection of higher wind speeds in the free atmosphere down to the pedestrian level. Wind behaviour in the boundary layer and the modifications necessary to bring its magnitude down to the likely value at window level, figure (4.23), have been considered in Section 4.4.1. However, simulation of the boundary layer velocity gradient in wind tunnel is applicable when the wind is stronger than 10 m/s, which is the case for wind loading and environmental safety studies. In the case of natural ventilation during the overheated periods and effluent dispersal studies, wind velocities less than 10 m/s are more common. Accordingly the critical test is shifted from the top speed to the lower speeds. Hence, the speed gradient is weak and may be ignored, as recommended by Cook (69). The velocity gradient assumption would stand for a single building or buildings higher than their surroundings. In these experiments the velocity gradient will not be considered on the grounds that only

1 The model examined has a Reynolds number of approximately 4×10^5.

air speeds less than 6 m/s and in most cases equivalent to 1 m/s are involved. Moreover, low cost housing projects in Egypt usually consist of one building height only, and within the densely built-up areas the lower part of the boundary layer, known as the surface layer[1], extends up to 20 metres.

In the residential units to be examined the flow which is affected by the building's surface flow depends on the location of the unit in relation to the whole block. Physical examination of the unit within the block was not possible due to limitations in both the working cross-section of the wind tunnel and the instruments available. Instead the experiments were conducted in two stages. The first stage was to investigate air flow patterns around buildings with respect to the block proportions and the grouping patterns. Air flow patterns within courtyards with respect to area, depth and proportions were also examined. The second stage was to examine air flow patterns within both single and multi-cells. The effects of inlet/outlet distance and relative areas were also investigated, and the effect of space dividing elements was examined.

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1 In the surface layer air speed does not have gradient but an almost constant speed, and this layer has been referred to in detail in Section.4.4.1.

6.3 Air Flow Patterns Around Buildings

A solid prizm has only three physical dimensions, height H, width W and depth D, that can affect its configuration with wind. It is possible to relate these parameters using dimensionless variables indicating the change in the block proportions. Considering the model to be examined of the type shown in figure (6.2a) its dimensions can be related to each other as follows:

$$\text{Let} \quad \alpha = W/H$$
$$\beta = D/W$$
$$\text{Hence} \quad D = \beta W = \alpha \beta H$$

where α and β are dimensionless variables expressing the relationship between these parameters.

These relationships were investigated with special emphasis on both block proportions and size. Firstly, the depth D was kept constant while both the height H and the width W were changed between $\frac{1}{3} < \alpha < 3$. Secondly, the width W was kept constant while the height H and the depth D varied between $\frac{1}{3} < \alpha\beta < 3$. Finally, the height H was kept constant with both the width W and the depth D changing between $\frac{1}{3} < \beta < 3$, figure (6.4). The initial air flow was kept smooth with a constant velocity of one metre per second while the angle of incidence 0 changed between $-90 < \theta < 90^{\circ}$ at 45° intervals. Changes in block size[1] were considered for various values of α, $\alpha\beta$ and β up to unity.

---

1 The change in size is expected to have little effect on the flow pattern; the size as stated in Section 6.2 is ignorable. The change in size may however indicate the possibility of extending the results to cover block sizes with blockage ratio higher than those examined.

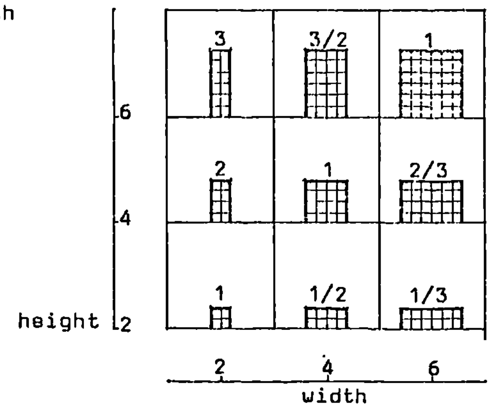
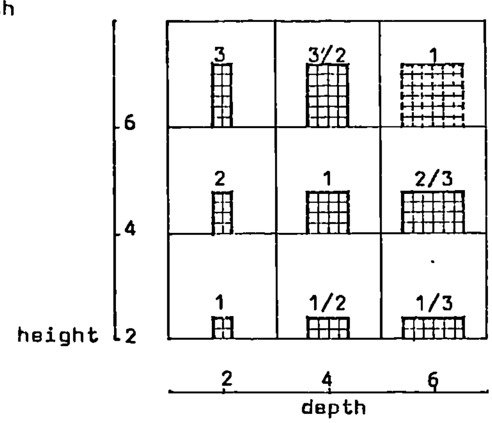
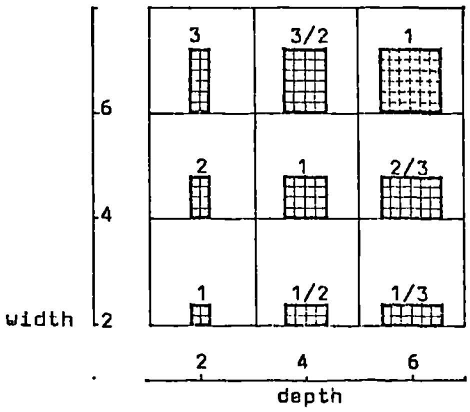
Parameter	Proportions	Properties
1 : height/width H/W		$W = \alpha H$ $1/3 < \alpha < 3$ D is constant
2 height/depth H/D		$D = \alpha\beta H$ $1/3 < \alpha\beta < 3$ W is constant
3 width/depth W/D		$D = \beta W$ $1/3 < \beta < 3$ H is constant

Figure (6.4) Parameters considered for flow patterns around buildings

6.3.1 The Effect of Block Proportions: α, $\alpha\beta$ and β

A - the parameter α

The dimensionless parameter α was examined to determine the effect of the height/width proportions on the main characteristics of the flow. When the block was positioned perpendicular to the wind flow, ie angle of incidence $\theta = 0^o$ the air separated on the front face edges generating a shear layer in between the free stream and the wake flow, figure (6.5). In front of the block the flow formed a standing vortex which was as high as the stagnation point[1]. On the windward face of the block the flow pattern was governed by the position of the stagnation point. Air speeds build up from this point towards the edges and the floor of the block. This point fell on the vertical centre-line of that face, while its height[2] h was inversely proportional to the dimensionless parameter α, figure (6.6). When α was equal to 1/3 the stagnation point was at 3/4 H, and at 1/4 H when was equal to three. Near the floor of the model the standing vortex curled into a more dynamic vortex moving towards the edge, figure (6.7a). This movement reinforced, and was reinforced by, air moving on the lower part of the block's windward face, figure (6.8), and continued to form a strong vortex in the lower section of the corner stream.

The roof flow was a result of the separation at the top edge of the block and was dominated by the shear layer over which the flow speed was greater than that of the free stream. This could be as high as 1·3 times the speed of the free stream. The flow under the shear layer formed a large eddy, the bottom of which was adjacent to the roof,

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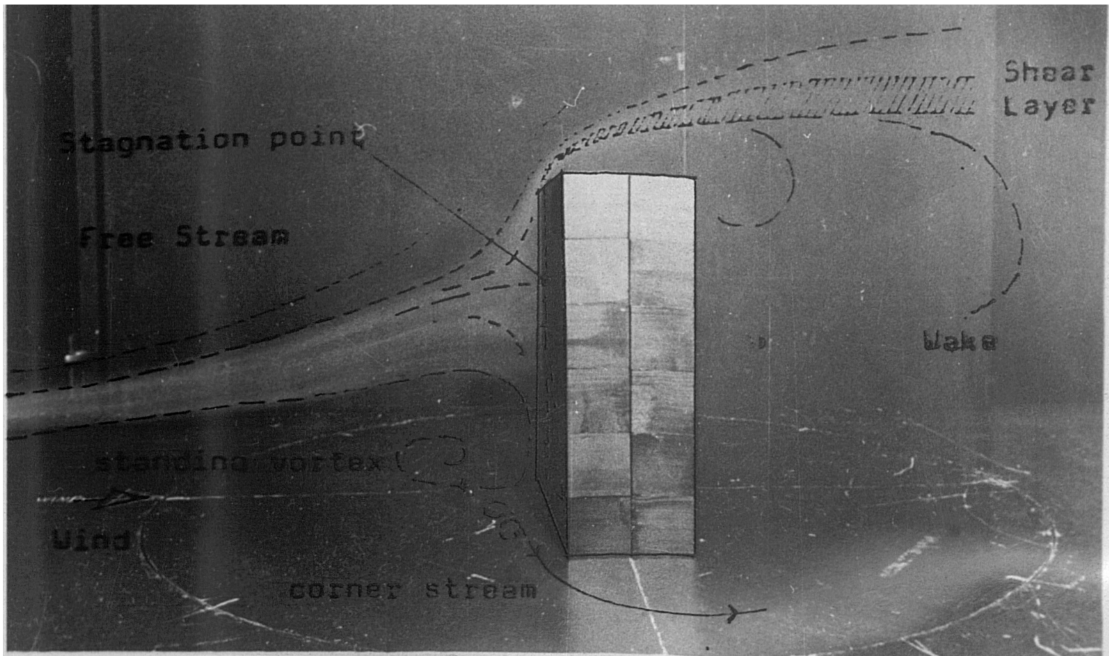
1 The stagnation point is a point on the windward face where the air comes to zero motion, ie stagnant.
2 The stagnation point height h is considered in relation to the total block height H, ie h/H.



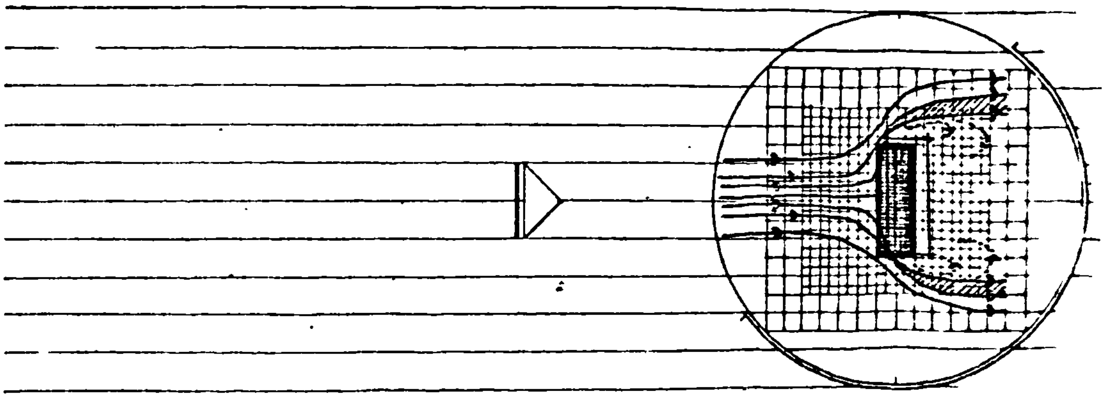


Figure (6 . 5) Air flow regions round a simple building

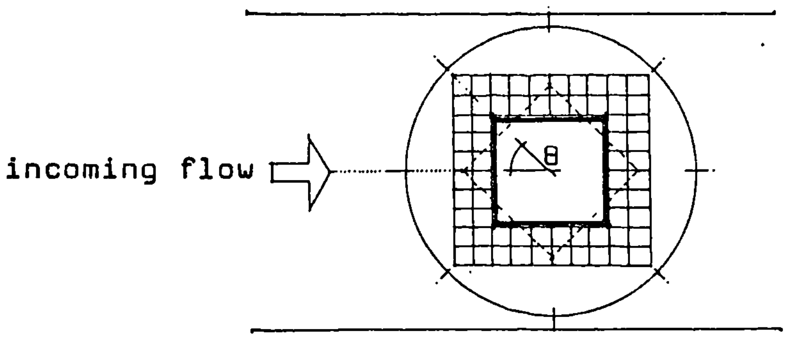


Figure (6.6a) The angle of incidence θ in relation to the model block.

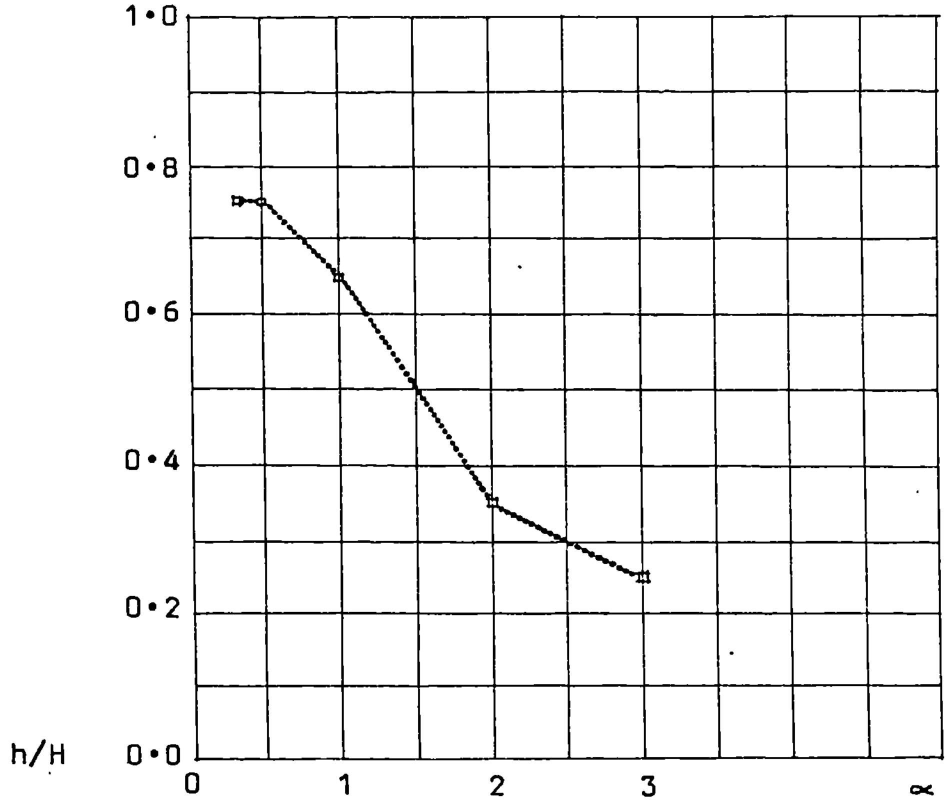


Figure (6.6b) The height of the stagnation point as a function of ∝.

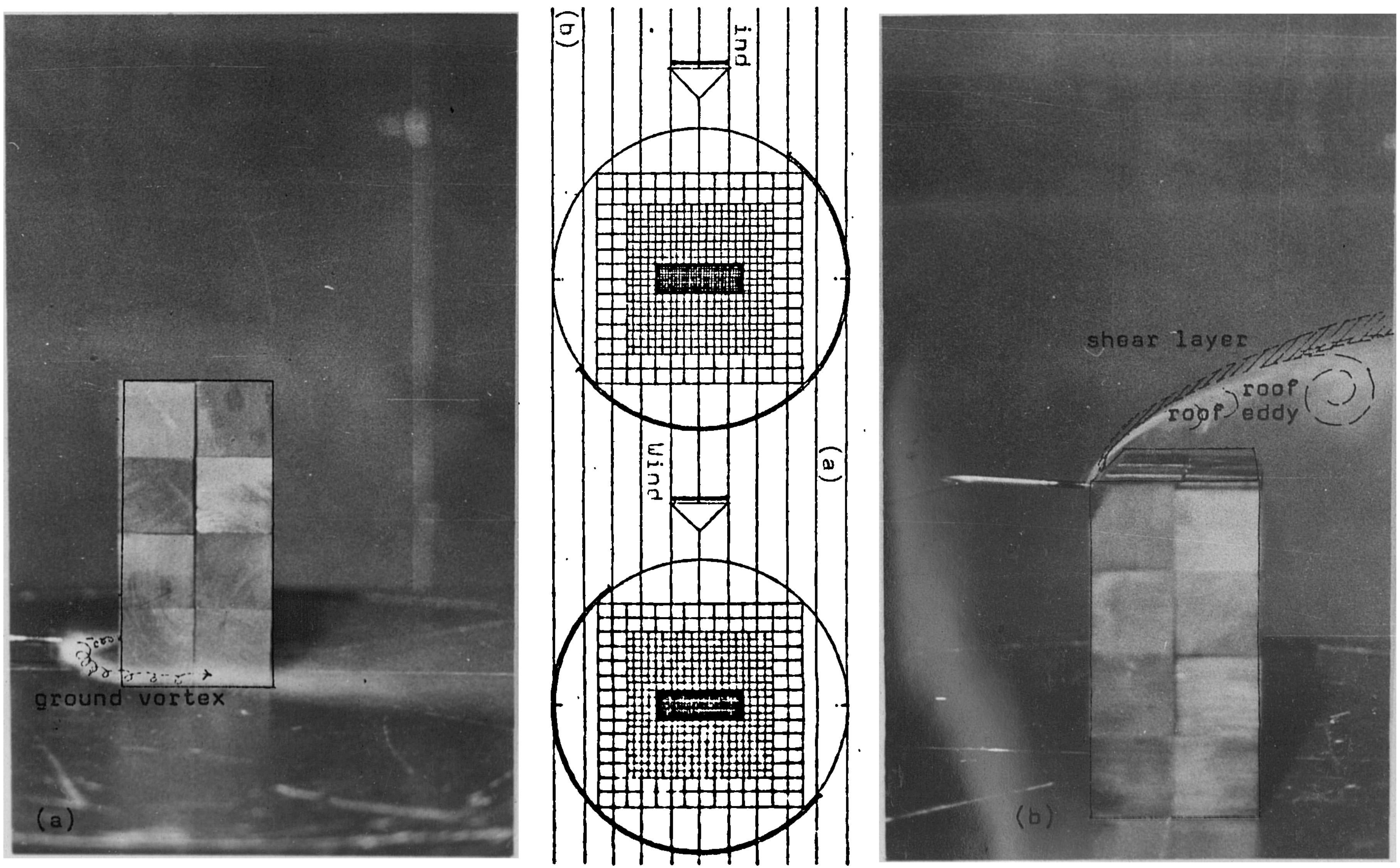


Figure (6.7) Details of regions in the flow pattern around a simple block.

and flowed in the opposite direction to the free stream. At the leeward edge the up-flow from the leeward face of the block generated a small eddy compared to the main roof eddy, figure (6.9). However, the depth of the leeward edge eddy seemed to be a function of α consistantly in all cases examined, and was strongest when α was equal to 3. Although flow reattachment did not occur on the roof, the lower part of the shear layer had small vortices oscillating with both the eddies on the roof and the flow upward from the leeward face, figures (6.7b) and (6.8).

The corner stream to the side of the block and near to the floor was dominated by the side flow of the ground eddy moving from the windward side and penetrating deep into the wake. Near the windward edge air speeds as high as 1·35 times the free stream speed were observed. Inside from the eddy, and adjacent to the block side, air movements followed a pattern similar to that of the roof flow.

The wake flow took the form of a big eddy behind the block. Near the floor the flow took the opposite direction to the free stream, while on the leeward face of the block the wake resulted in an upward flow. This caused the small eddy penetrating into the roof flow.

In the course of this investigation three block sizes, having α values equal to one, were examined showing no marked differences in their flow patterns.

When the angle of incidence θ was changed to $\theta = \pm 45^{o}$ the flow patterns showed considerable variation from that examined above. On the windward face air moved in a plane tangential to that face. Above 1/4 H the upward movement towards the roof and the far edges was dominant but below that height the air movement inclined towards the floor dominated (the air moving upward seemed to be a function of α; when $\alpha < 1$ the air moved upward above 1/4 H, when

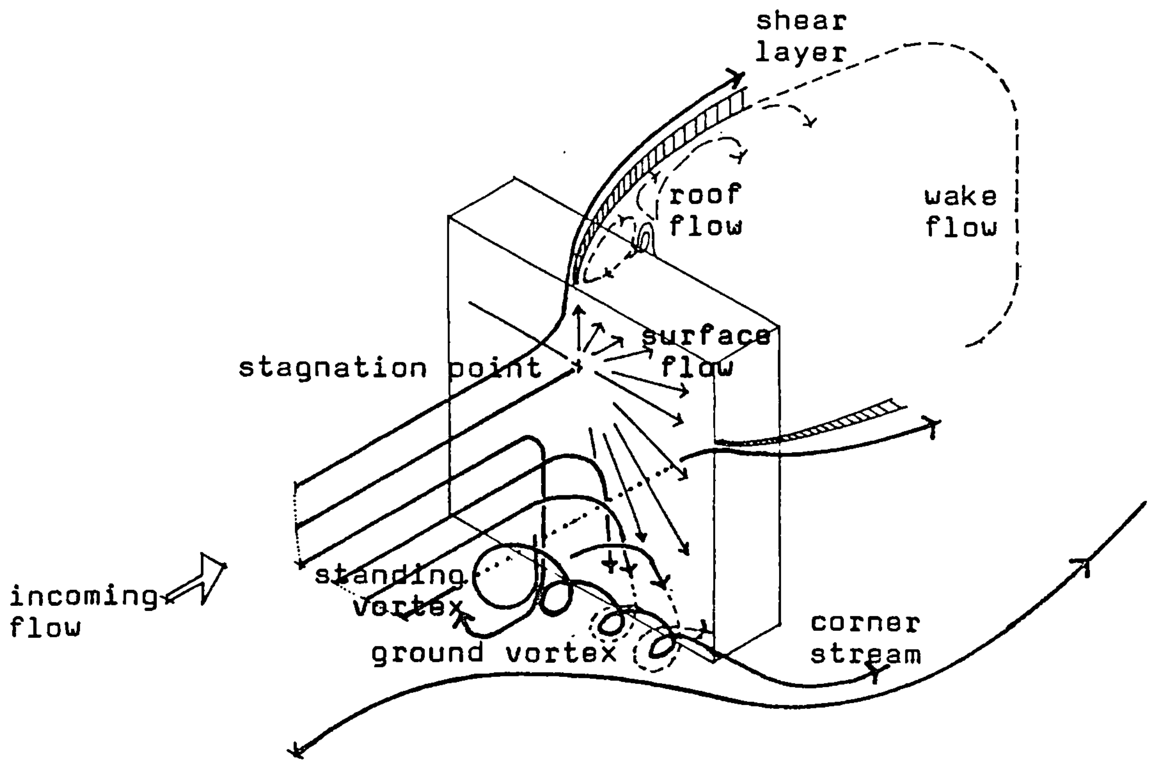


Figure (6.8) Diagram of the main regions in the observed flow around a simple block (angle of incidence $\theta = 0^{o}$).

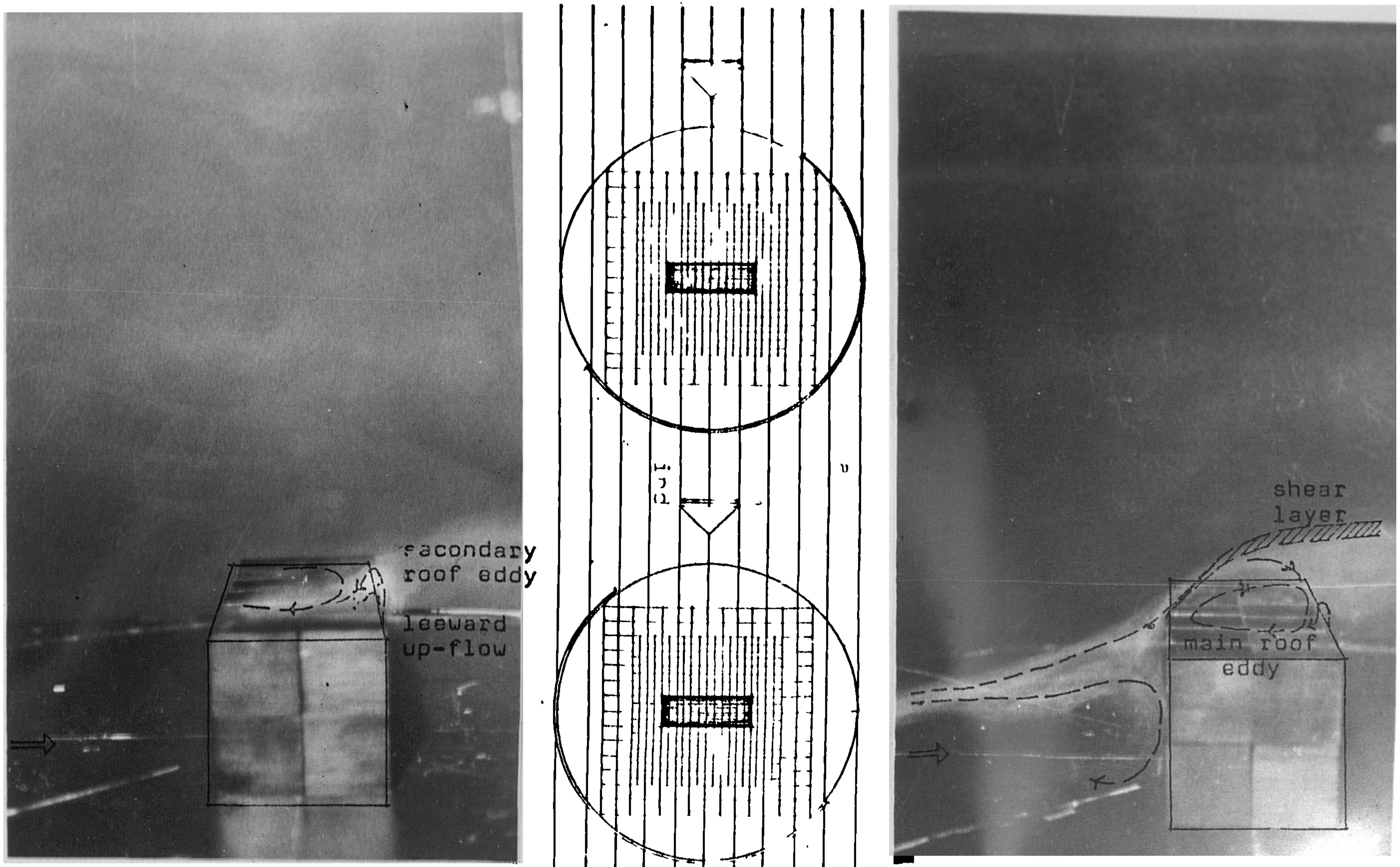


Figure (6.9) Details of regions in the flow pattern around a simple block.

$\alpha = 3$ the upward movement started at 1/6 H). This movement reinforced and was reinforced by the vortex moving in front of the block and towards the far corner, figure (6.10).

On the roof the flow sprang from the windward corner and reattached diagonally. The reattached flow was characterized by high speeds reaching 1·6 times the free stream speed. The roof was divided into two triangular areas, which were identical in the case of a cube with $\alpha = 1$. Over each section the roof had a conical vortex with the apex in the windward corner, figure (6.11). Also the shear layer was observable over the 45° line from the corner. The roof vortices governed the nature of the leeward flow pattern. The upward flow on the leeward face affected only the flow over the far section of the roof, but this upward flow was suppressed nearer to the windward section. When $\alpha = 1/3$ the upward flow was suppressed in the first 1 H of the leeward roof width, with little difference as the value of α changed. That configuration was not a function of the front proportions but seemed to be a function of the plan proportions, ie β.

The wake flow was considerably turbulent with greater shadow than that of $\theta = 0^{\circ}$. The wake eddy was more dynamic with its axis inclined to the horizontal. The flow near the floor in the shadow of the block was opposite in direction to that of the free stream. On the leeward surface the upward flow dominated the flow pattern and penetration into the roof flow occurred near the leeward corner. The upward flow at the other corner was forced to flow near the horizontal.

The angle of incidence θ was altered to values of $\pm 90^{\circ}$ respectively. On the windward side the standing vortex was always equal to 1/4 H. It was very difficult to pinpoint the stagnation point, however it was found to fall between 1/4 H and 3/4 H. At these heights the side flow

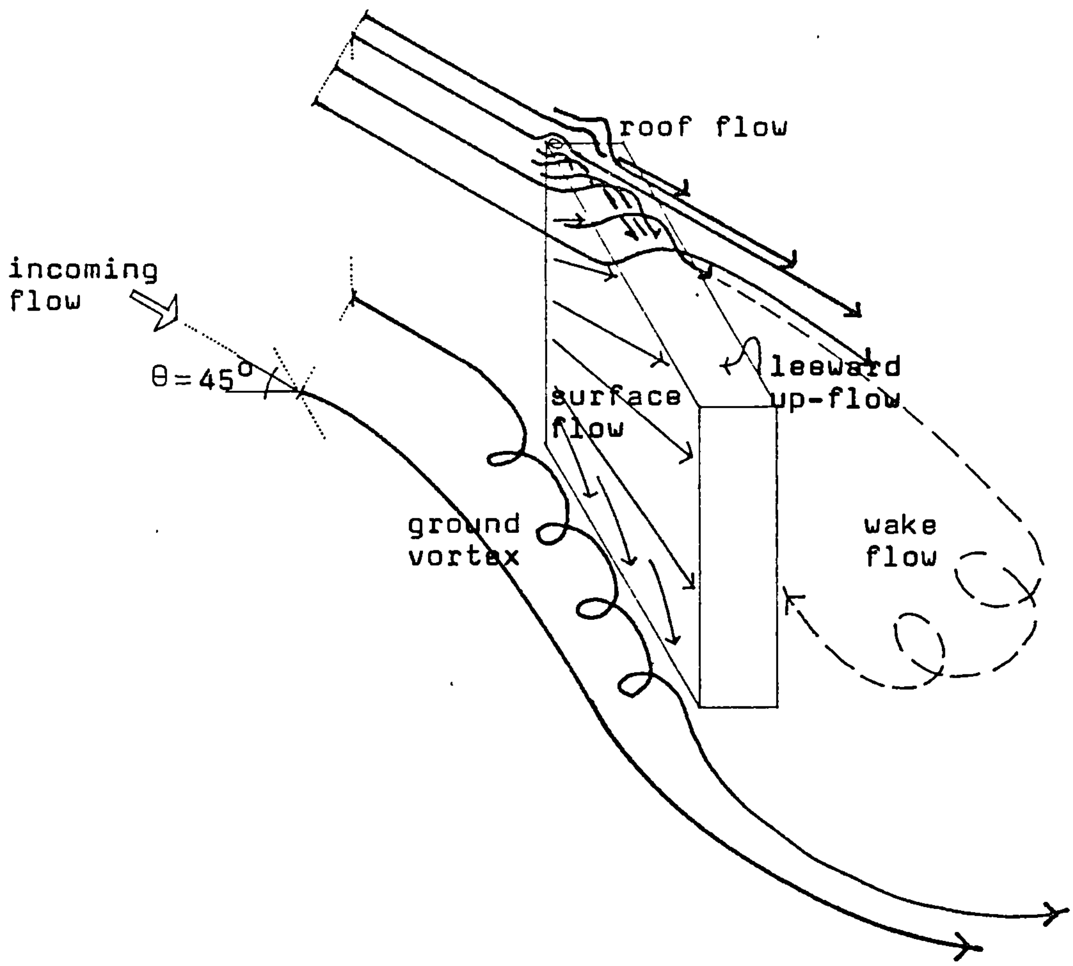


Figure (6.10) Diagram of the main regions in the observed flow around a simple block (angle of incidence $\theta = \pm 45^{o}$).

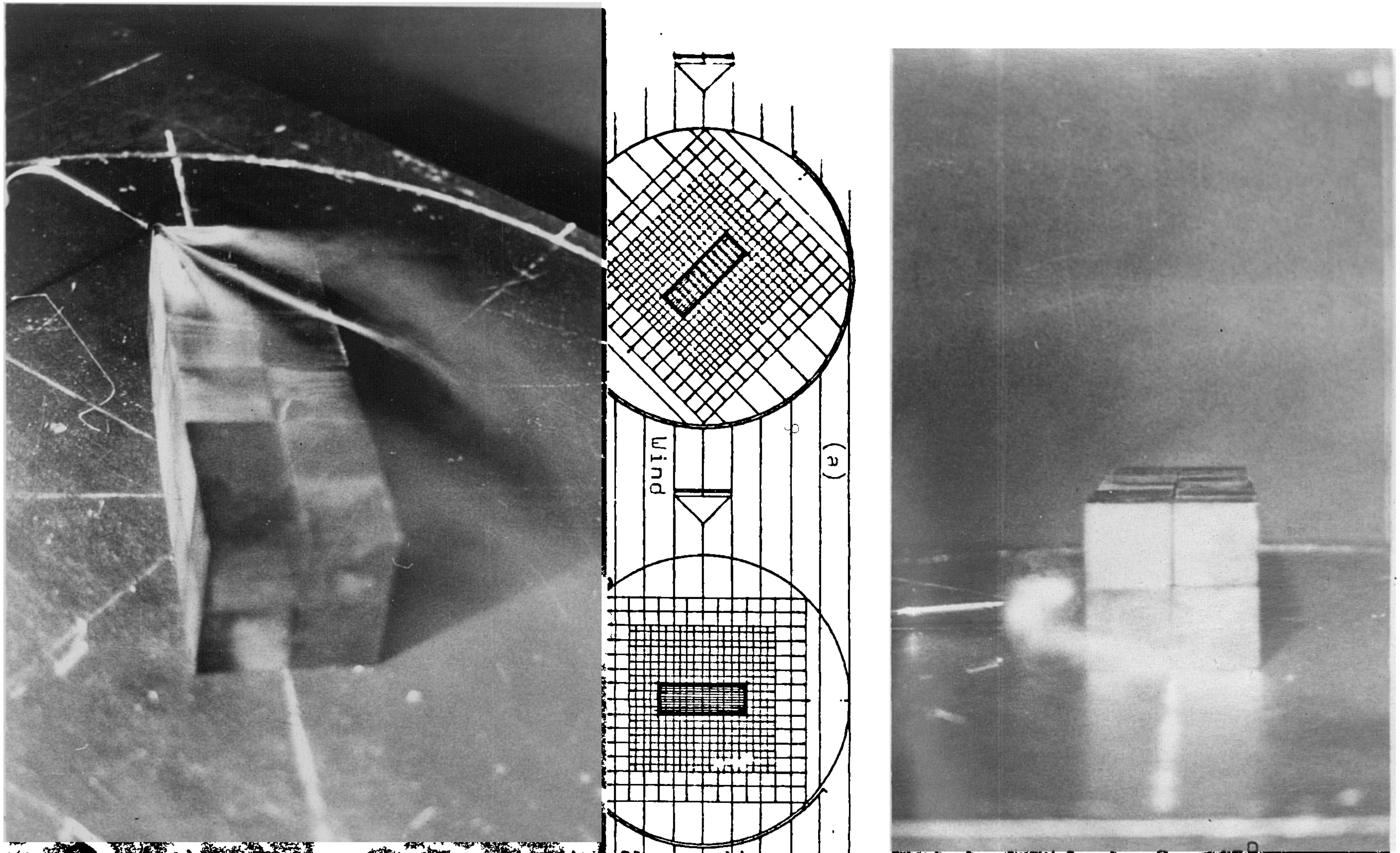


Figure (6.11) Details of regions in the flow pattern around a simple block, $\theta = 45^{\circ}$.

dominated the pattern of the flow, with no up-flow identifiable below 3/4 H.

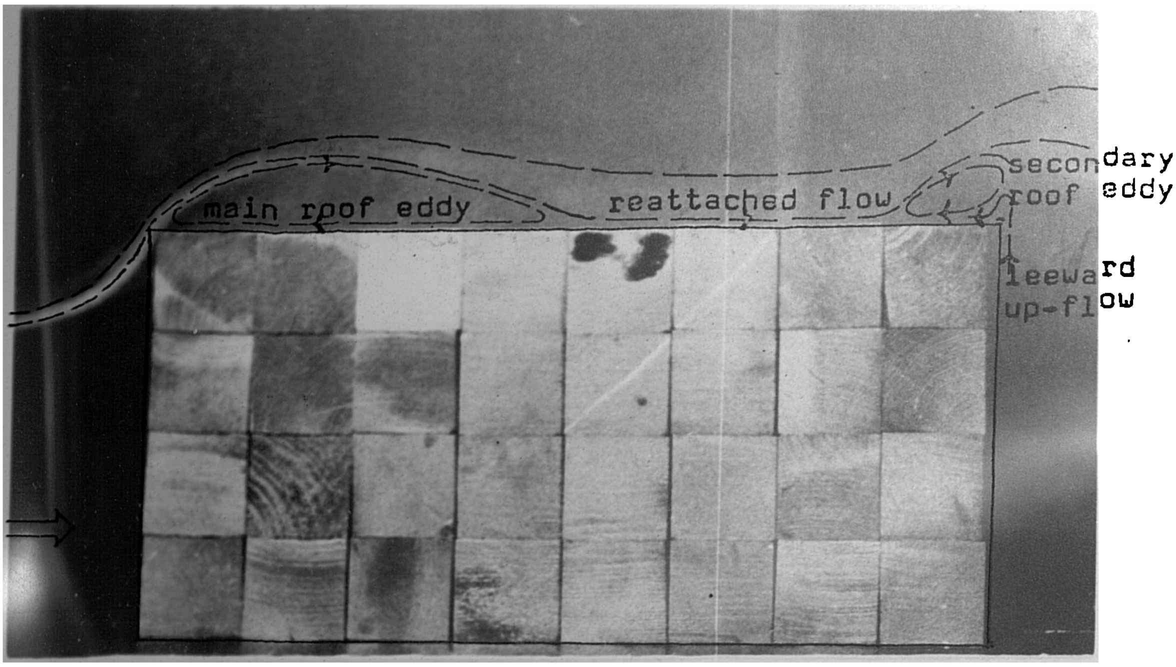
The flow separated at the edges of the windward face and with $\alpha > 1$ it followed a pattern similar to that of an angle of incidence $\theta = 0^o$, with the shear layer between the free stream and the roof eddies well established. When α was less than 1 the flow reattached to the roof. The roof had two eddies; nearer to the windward edge a large eddy similar to that formed when $\theta = 0^o$ was observed; at the leeward edge the eddy coused by the upward flow from the leeward face was more pronounced than for $\theta = 0^o$. This eddy resulted in a smooth separation of the flow near that edge, figure (6.12). The corner stream was similar to the roof flow but with a ground vortex dominating the flow near the floor.

The height/width proportion α had a considerable effect on the position of the stagnation point and consequently the flow on the windward face. To a lesser extent, α affected the roof flow, the configuration of the upward flow from the leeward face with the roof flow, and the roof reattachment.

B - The parameter α/β

This parameter was examined to determine the effect of height/depth H/D on the main characteristics of the flow pattern.

For angle of incidence $\theta = 0^o$, ie blocks perpendicular to the main flow, the flow pattern in front of the windward face, as well as that across this face, followed the same pattern as that examined above for the parameter α at $\theta = 0^o$. The height of both the standing vortex and the stagnation point was a function of the height/width proportion, ie α alone, rather than the height/depth, α/β. Above the roof



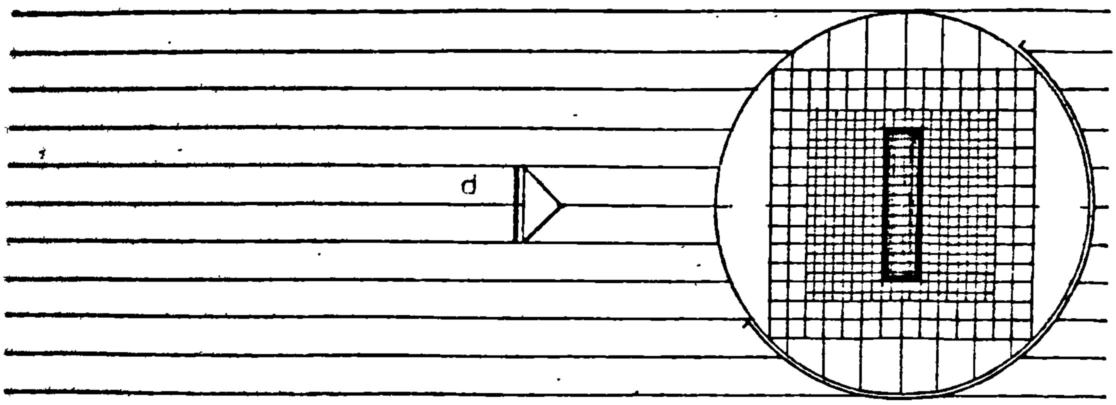


Figure (6.12) Detail of the roof flow of a simple block for $\alpha > 1$, $\theta = 90^{\circ}$.

the shear layer resulted from the flow separation at the top edge of the block. Within this layer air speed reached 1·4 times that in the free stream. The flow under the shear layer formed a main eddy with the air adjacent to the roof and flowing opposite in direction to that of the free stream. The upflow from the leeward side generated a small eddy which penetrated as far as 1/4 D on the roof in most cases. This may indicate that this eddy was a function of $\alpha\beta$. The flow did not reattach for $\alpha\beta > 1$, but when $\alpha\beta < 1$ it reattached to the roof and this was most clear at $\alpha\beta = 1/3$. The flow separation was smoother than that occurring at the windward edge and was observed at 1/4 H from the leeward edge. The eddy was more pronounced than that observed for α. Air moved in an upward direction on the leeward face of the block with a speed 0·12 times the free stream near the floor, increasing to 0·40 near the roof edge. The corner stream observed was similar to that of the roof with the floor vortex dominating the lowest layer (1/6 H) of the flow.

When the angle of incidence θ was changed to 45^{o} the flow followed the same pattern as that observed when the effect of α was investigated.

C - The parameter β

The width/depth (W/D) β and its effect on the main characteristics was investigated following a similar approach to that used for α and $\alpha\beta$. When the angle of incidence $\theta = 0^{o}$ the standing vortex and consequently the stagnation point height h showed a slight increase with the increase from $\beta = 1$ to $\beta = 3$, ie increasing the width of the block will increase the height of the stagnation point. Comparing this with α's relationship to the stagnation point, figure (6.6) illustrated that the effects of α and β were inversely proportional. The flow separated on the roof edge having a higher speed than that experienced in the first two stages

(α and β), and showing a moderate increase with increase in β value. For β = 1 air speed in the shear layer was 1·30 times the free stream, this increased to reach 1·50 when β = 3. Beneath the shear layer the air formed an eddy similar to that experienced in the examination of α. The air reattached to the roof only at $\beta > 1$. The upflow from the leeward face formed a small eddy near the leeward edge of the roof similar to that observed for α and $\alpha\beta$. This caused the roof flow to separate after reattachment. The flow up the leeward side was weakest when β = 3, and strongest at β = 1/3 where air speed increased from 0·12 near the floor to 0·35 times the free stream near the roof edge. The corner stream was similar to that of the roof flow with air speed ranging from 1·3 times the free stream for β = 1/3 to 1·45 for β = 3.

When the angle of incidence θ was changed to 45^o, the flow across the windward face followed the same pattern as that observed when the α effect was investigated. Also the flow over the roof when $\beta > 1$ and $\beta < 1$ was similar to that for α. The flow in the wake as well as that across the leeward face, was similar to that of α but when β = 1 the air seemed to move slowly downward. Around the corners the flow did not separate and consequently did not have a shear layer. Instead the air moved in a dynamic vortex with a speed lower than that experienced when the angle of incidence $\theta = 0^o$.

<u>In general</u>: the flow pattern around a block showed little change with variations in the block proportions. This fact affected perceptions of the relationship between internal and external flow patterns; flow inside buildings was usually thought to be solely a function of the flow around buildings. However, this underestimated the important effect of the flow across the surfaces. The flow on these surfaces corresponded in a more pronounced way to changes in the building's proportions. Consequently this

affects the flow within the built spaces inside the block.

From the above investigation the following points may be considered:

1 The stagnation point is proportional to β and inversely proportional to α. Hence estimating flow inside buildings should take into consideration air flow radiating from this point.

2 The flow in the lowest 1/4 H on the windward face is a function of the dynamic vortex generated in front of the building and it will move in an inclined direction towards the floor and the nearest side edge.

3 The roof flow is a function of β and reattachment occurs only when $\beta < 1$. However, the flow separates again at at 1/4 H from the leeward end.

4 The roof flow has two eddies; the first, which is near the windward edge, is as large as H; the second is near the leeward end and has a length equal to 1/4 H. The roof flow should be carefully considered when placing exhausts such as chimneys and air conditioning outlets.

5 In many respects the corner flow is similar to that of the roof, and needs similar care in the placing of any opening.

6 Air flows on the leeward face towards the roof edge, while its speed is inversely proportional to β.

7 When the angle of incidence θ is altered to 45^o the air on the windward faces flows toward the leeward edges but is inclined to the vertical. However, in the lowest 1/4 H the movement inclines towards the floor.

8 In general, air flow on the roof is inclined at 45^o and towards the windward edges.

9 When $\theta = 0^o$ the air flow pattern around an isolated cube agrees with that reported by Soliman (245), Penwarden and Wise (216) and Maccabee (174), while at $\theta = 45^o$ flow pattern agrees with that reported by Cermak (64).

6.3.2 The Effect of Some Grouping Patterns

Air flow around buildings is modified due to the presence of other buildings in the vicinity. Three flow patterns, isolated roughness flow, skimming flow and wake interference (245), have been suggested in Chapter 4, figure (4.34). These flow patterns were established for simple cubes placed at equal distance. In architectural practice it is seldom found that a community has been designed comprising only cubical forms placed at equal distances from each other. The presence of irregular forms at different distances is more common and this will modify the three suggested regimes.

At this point in the research the groups to be examined do not cover all the possible grouping patterns employed in housing, but they do investigate some of the more common groupings employed on governmental housing schemes in Egypt to illustrate the possible modifications in the flow patterns to be expected when designing building groups, figure (6.13).

The model had a scale of 1/100 and it was composed of blocks emulating buildings 4 stories high. The flow was kept smooth with constant air speed of 1 m/s, and angle of incidence varied between $-90^{o} < \theta < 90^{o}$.

In most of the groups examined the flow around the windward blocks, for angle of incidence $\theta = 0^{o}$, agreed with that of the isolated block. To the leeward side of them a shadow covering all the group was established where air speed suffered considerable reduction. The flow did not reattach within the group. The flow between the blocks of the group was of the wake interference type.

In the first grouping the distance between the blocks was 2·5 H. The wake of the first block interacted with the

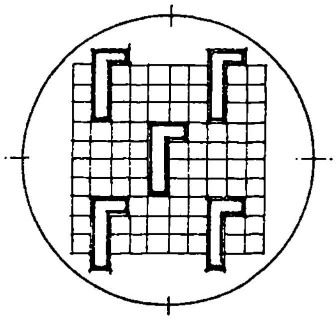
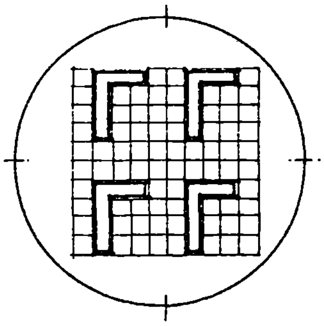
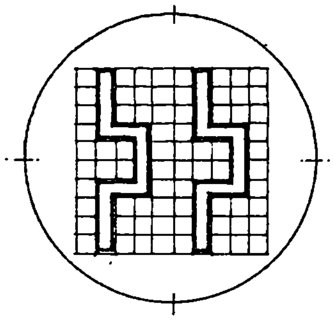
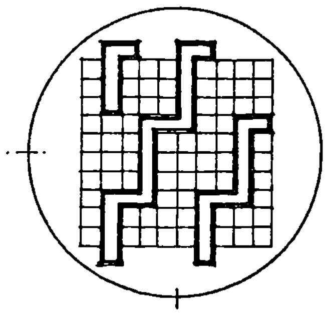
Parameter	Grouping pattern	Properties
Group of L-shaped blocks (1)		H = 4B $-90^{o} < \theta < 90^{o}$
Group of L-shaped blocks (2)		H = 4B $-90^{o} < \theta < 90^{o}$
Continuous block		H = 4B $-90^{o} < \theta < 90^{o}$
Zigzag block		H = 4B $-90^{o} < \theta < 90^{o}$

Figure (6.13) Parameters considered for flow patterns around groups of buildings.

standing vortex of the second, which was approximately 7/8 H high, figure (6.14a). This could be due to the air flowing down the windward face below that height. When the distance between the blocks was reduced to 2 H, these two vortices formed a single integral vortex while the stagnation point remained at the same height, fig.(6.14b).

When the angle of incidence θ was changed to 45° the flow over the first block became a function of its proportions with respect to the parameter α/β. For $\alpha/\beta > 2$ the shelter effect was less established than for $\alpha/\beta = 1$. In the latter case the shelter was as effective as that when $\theta = 0^{\circ}$, figure (6.14c & d). For angle of incidence $\theta = \pm 90^{\circ}$ the flow around the first block was similar to that of the isolated block, but around the second row the flow resembled that of the wake interference.

The air flow pattern around groups of buildings was affected by two main factors:

1 The angle of incidence, which affected the first row, and the flow could be considered of the isolated roughness type.
2 The shadow forming behind the first row, inside which the flow direction had little effect; the distance between the blocks had a more pronounced effect on the flow pattern. The flow could be either a skimming flow regime or a wake interference flow regime. The stagnation point on the windward face would be at approximately 7/8 H with air flowing upwards on the leeward faces.

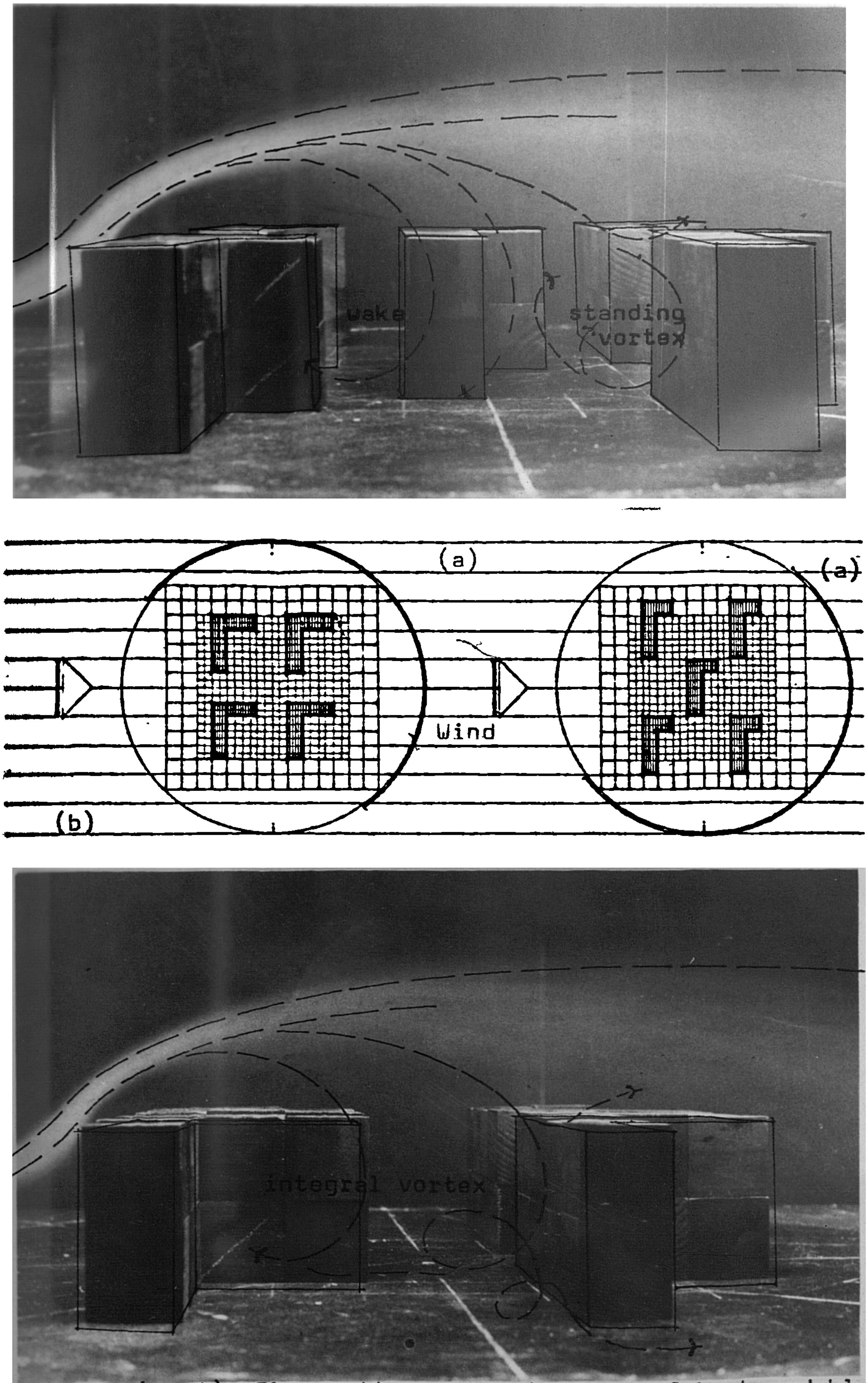


Figure (6.14) Flow pattern around groups of L-shaped blocks, $\theta = 0^{o}$.

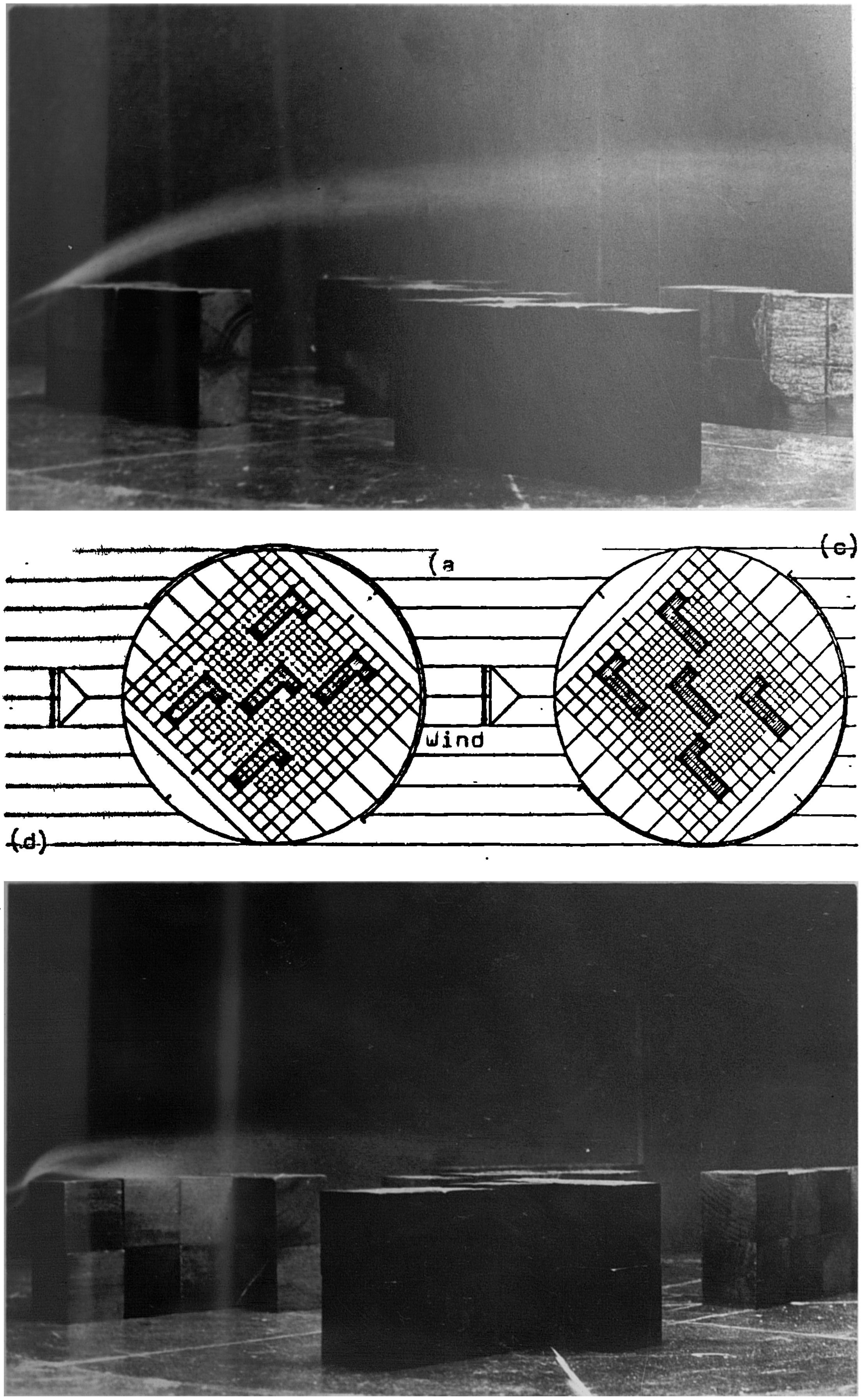
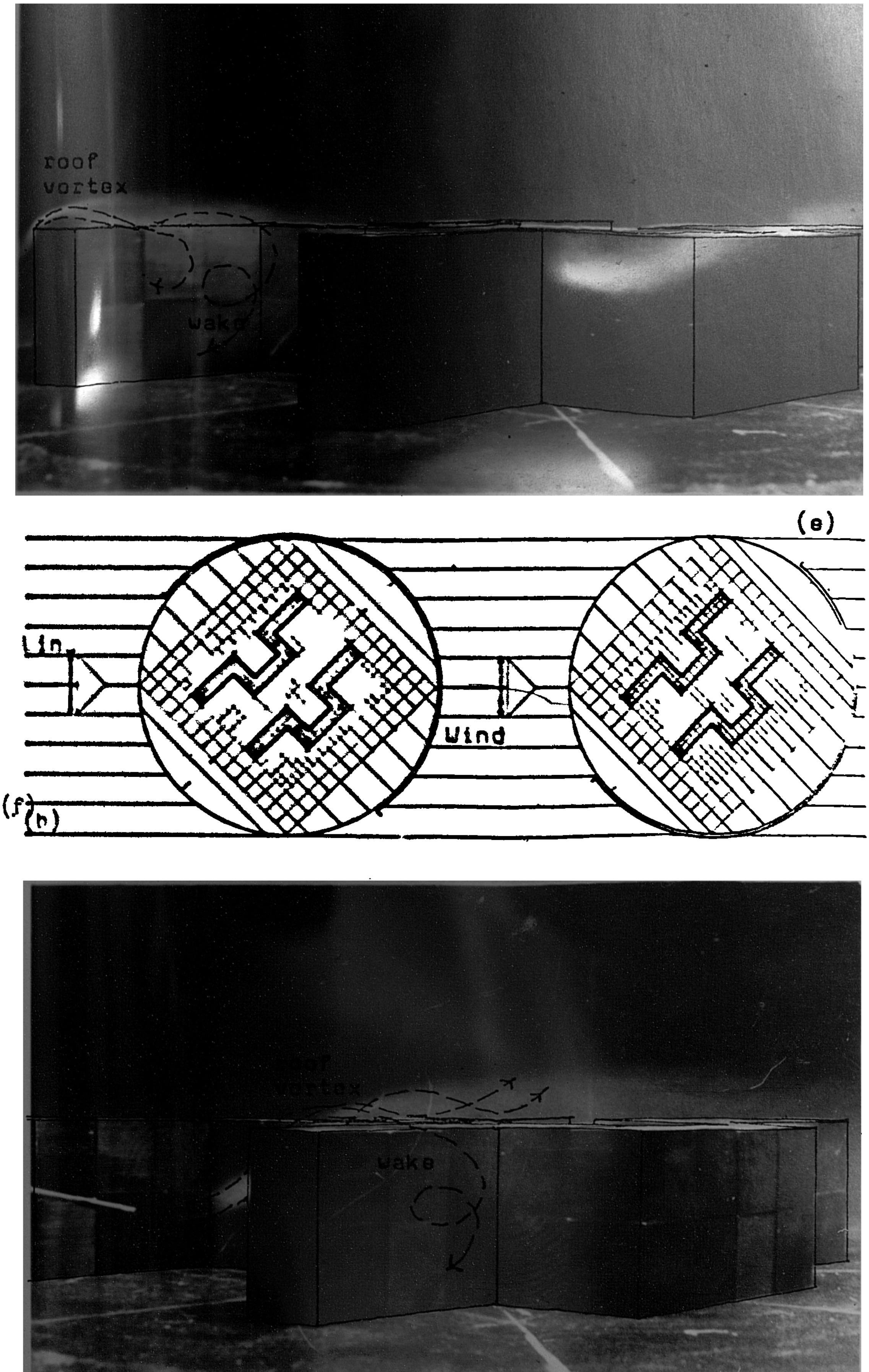


Figure (6.14) Flow pattern around groups of L-shaped blocks, $\theta = 45^{o}$.



igure (6.14) Flow pattern around groups of continuous blocks, θ = 45°.

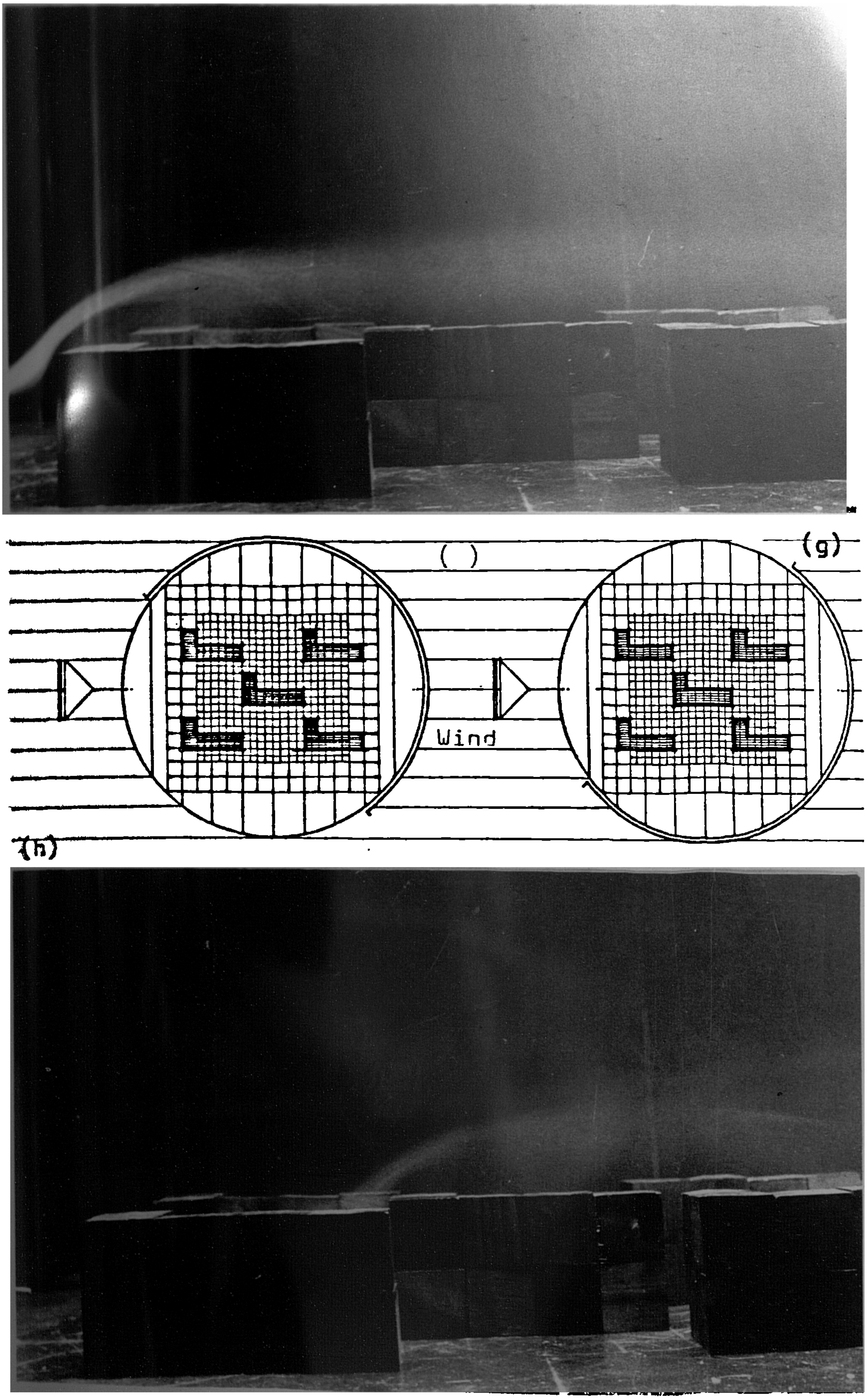
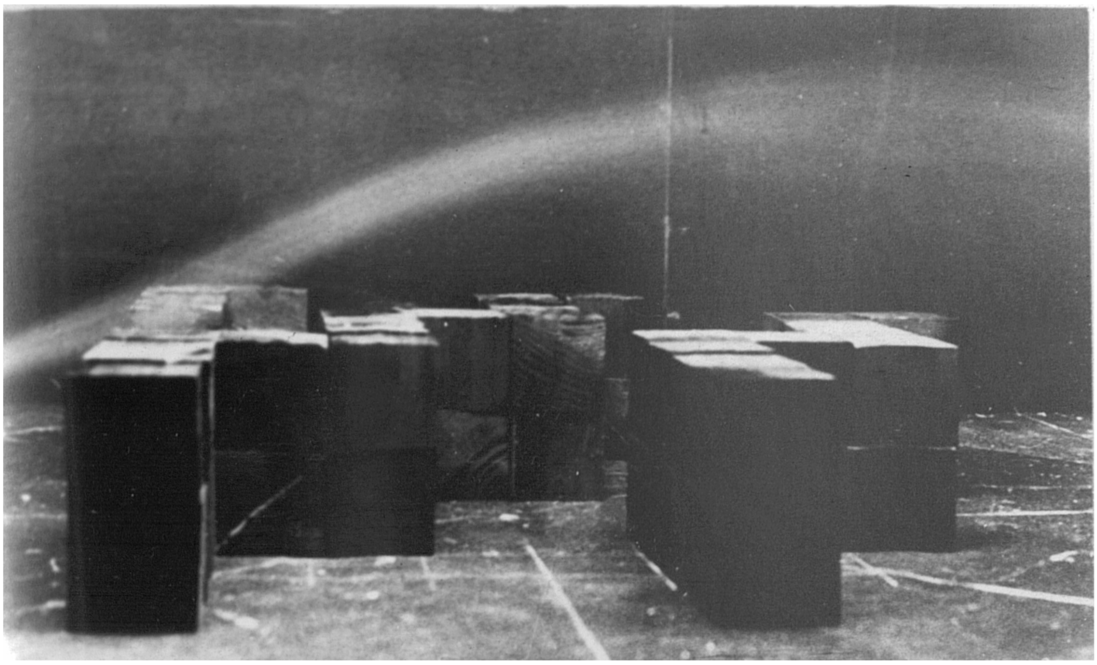
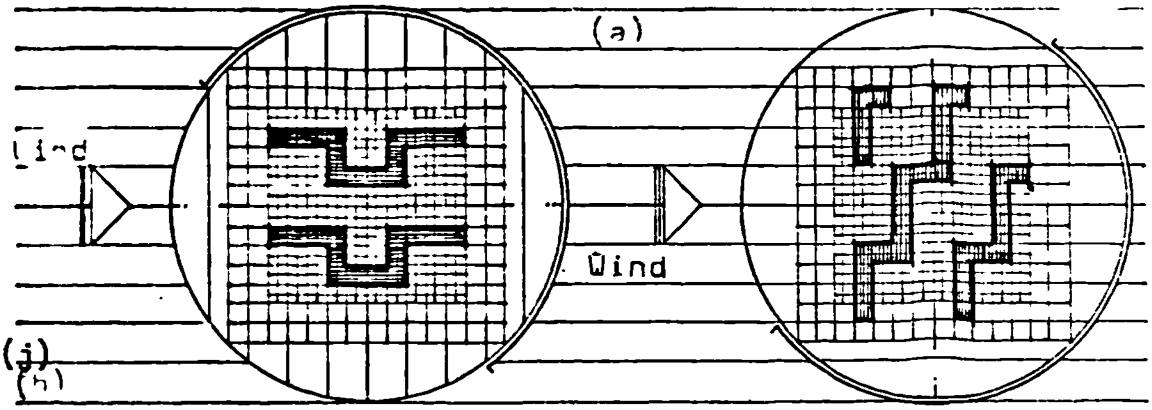


Figure (6.14) Flow pattern around groups of L-shaped blocks, $\theta = 90^{o}$.



(i)



(j)

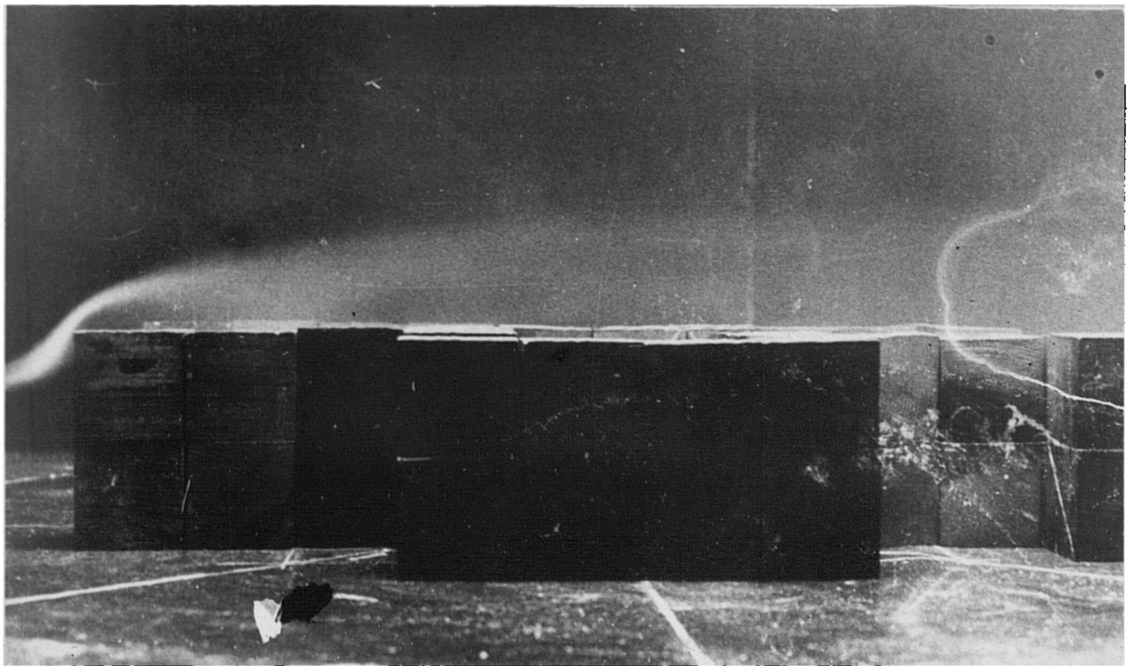


Figure (6.14) Flow pattern around continuous blocks, θ = 90°, and zigzag blocks, θ = 0°.

6.4 Air Flow Patterns Within Courtyards

Air flow inside a courtyard is generated by inertia forces or thermal forces. Thermal forces will dominate the movement if the courtyard has a heat source near its ground surface, or its surfaces are hotter than the outside. A chimney may be considered as a deep courtyard with a heat source inside and consequently the thermal forces dominate air movement. If there is no heat source, the inversion phenomenon will offset the upward flow, figure (2.12). Inertia forces dominated by wind are the main concern of this Section.

A courtyard is a part of the building form and consequently the air flow within it is a function of the flow pattern around the building in general, and the roof in particular. Beside the main parameters affecting the building proportions examined in Section 6.3, the flow will be affected by the courtyard proportions, its position with respect to the building block and the angle of the incident flow, θ.

The aim of this section was to investigate the qualitative aspects of the flow within a square courtyard. The parameters examined include the height (H), the area (A) and the size (H x A). The courtyard was limited to a square plan to correspond with the main block form, and to eliminate the effect of the building form the block plan was limited to a square of 6 units. Also the upwind wall was kept constant so that wind configuration with the block would follow the same pattern in all cases examined.

Considering any courtyard of width W, depth D and height H its dimensions can be related to each other as those of the solid block, ie:

$$\alpha = W/H$$

$$\beta = D/W$$

$$D = \beta W = \alpha \beta H$$

However, as the courtyard under investigation was square, then:

$$D = W \text{ and } \beta = 1$$

and,

$$D = W = \alpha H$$

Also area $A = DW = \alpha^2 H^2$

The height/area proportion $= \Omega = H/A$

$$= H/\alpha^2 H^2$$

$$\doteq 1/\alpha^2 H$$

The relationship between the height/plan area will be examined in the range of $1/3 < \Omega < 6$, as illustrated in figure (6.16), while the angle of incidence θ will be changed between $-90^{\circ} < \theta < 90^{\circ}$ at 45° intervals.

Because of the low intensity of the tracing medium the flow visualization technique had to be reversed, ie the courtyard space was flooded with smoke then air allowed to penetrate drawing the flow pattern as dark lines within the white smoke.

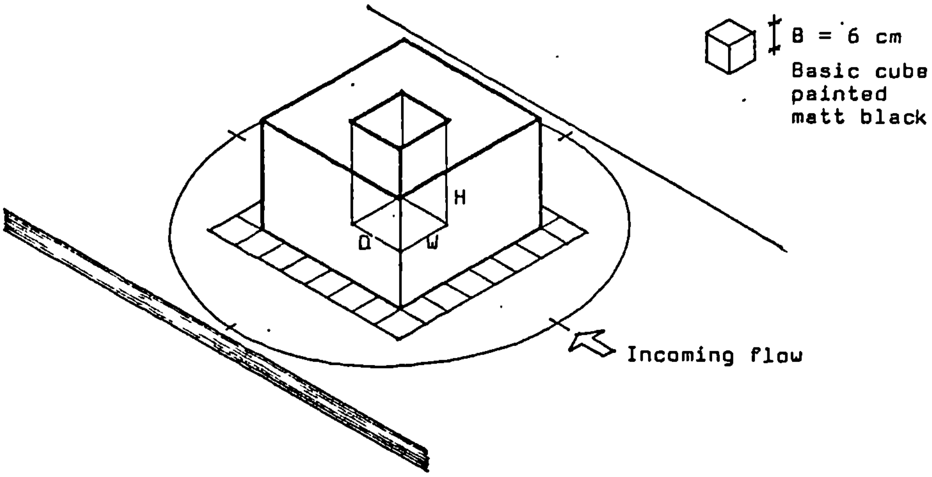
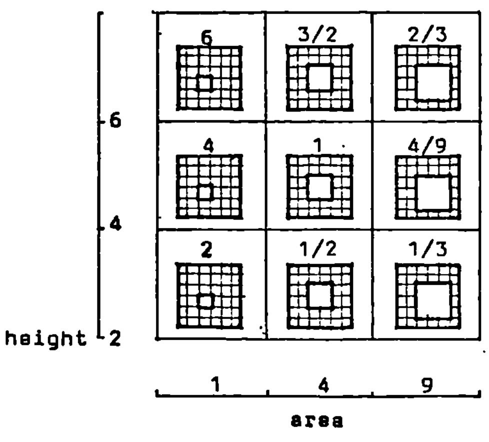


Figure (6.15a) Detail of the courtyard model.

Parameter — **Dimensions** — **Properties**

height/area
H/A



$6 > \Omega > \frac{1}{3}$

$\Omega = H/A$

$= 1/\alpha^2 H$

Figure (6.15b) Parameters considered for flow patterns inside courtyards.

6.4.1 The Effect of Courtyard Proportions

The effect of height/area, H/A, ratio (Ω) was examined to determine the flow pattern inside the courtyard. First the angle of incidence θ was kept at 0^{o}, consequently the flow around the block followed the same pattern as that reported in Section 6.3.1 for a similar block. Inside the courtyard the persisting characteristicis the air flow moving in a plane parallel to the main stream and the side walls. The main roof eddy was the primary source of energy for the flow inside the courtyard. When $\Omega < 1/2$ the roof eddy dominated the flow and extended to cover the full height of the courtyard. Air flowed upward on the windward wall of the courtyard, also a small vortex was observed near the floor. On the opposite wall the flow was directed downward, figure (6.16). These observations agree with those reported by Ettoney (98) and Smith et al (244) for a courtyard with $\Omega < 1/2$.

As the area was reduced with respect to the height, ie Ω value increased, a new flow regime was clearly observed. The roof eddy penetrated to cover only the top layer of the courtyard, approximately 1/4 H, below which a second eddy was observable. This new eddy was parallel to the roof eddy but with the air flowing in the opposite direction, figure (6.17). The development of the bottom eddy may be explained as being a counterbalance to the roof eddy, and this could be why it does not penetrate to a lower level. Thus, the length of bottom eddy penetration into a deep courtyard is expected to be a function of the building's proportions and the siting of the courtyard in relation to the plan, as well as the courtyard's own proportions. The transformation from the single eddy to the double eddy regime seemed to occur at $\Omega = 4/9$ where the height/depth ratio of the courtyard was approximately 3/2. Within Ω ranging between $4/9 < \Omega < 6$ this regime was evident. Also with the increase of Ω values the eddies

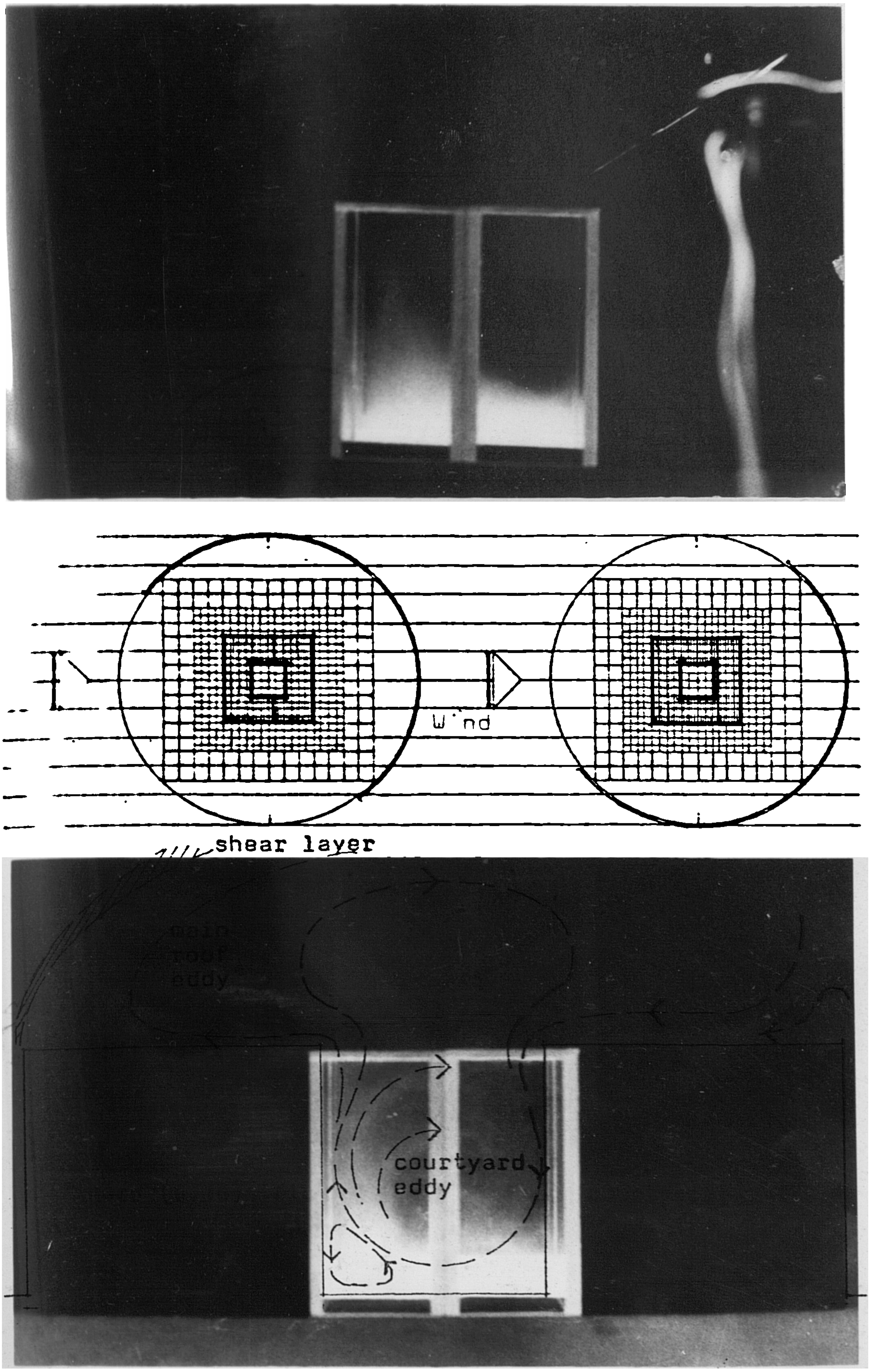


Figure (6.16) Flow pattern inside a courtyard, $\Omega = 1/2$ and $\theta = 0^{o}$.

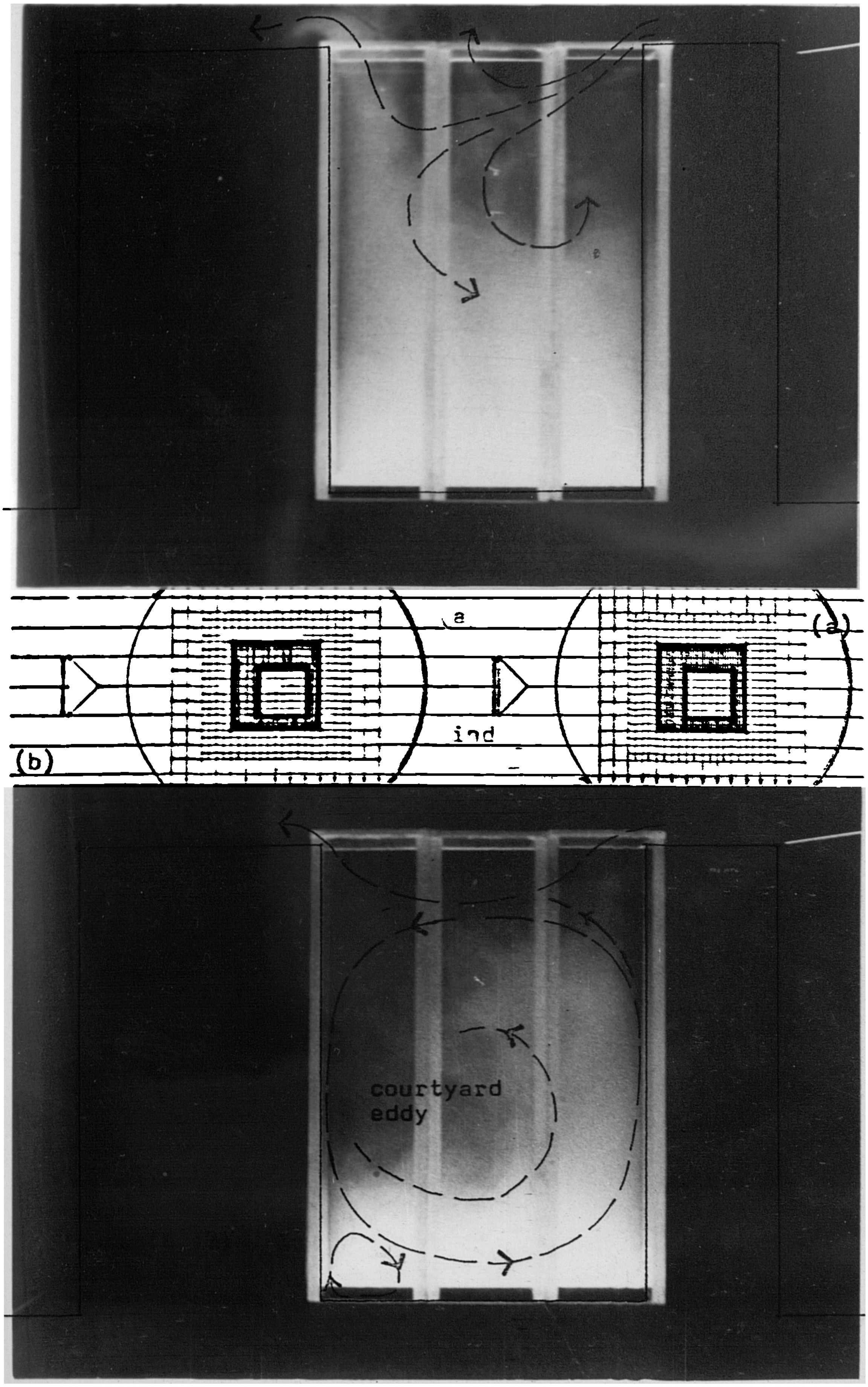


Figure (6.17) Flow pattern inside a courtyard, = 1/2 and $\theta = 0^{o}$.

showed little change, and the air below them was stagnant, figure (6.18a & b). The penetration into the courtyard of the double eddy regime was consistant and showed some correlation to Ω values. It also illustrated a more sound relation with the depth (D) of the courtyard, table (6.1).

$$\text{pentration depth } h = 3/2D$$

When the angle of incidence θ was changed to θ = 45^{o}, marked differences were observed in the flow, which was characterised by a vigorous downward movement resulting from the roof reattached flow. The air flow at each side of the courtyard and at the windward corner have vortices with their axes perpendicular to the floor. Each vortex penetrated as far as the courtyard floor then rose upward to the leeward corner. The movement was extremely turbulent and was characterised by a high air speed with no stagnant zone.

Table (6.1) The relationship at the two eddies regime penetration depth to the area (A) and the depth (D).

Ω	h/A	h/D
2/3	4/9	4/3
1	3/4	3/2
3/2	3/4	3/2
4	3/2	3/2
6	3/2	3/2

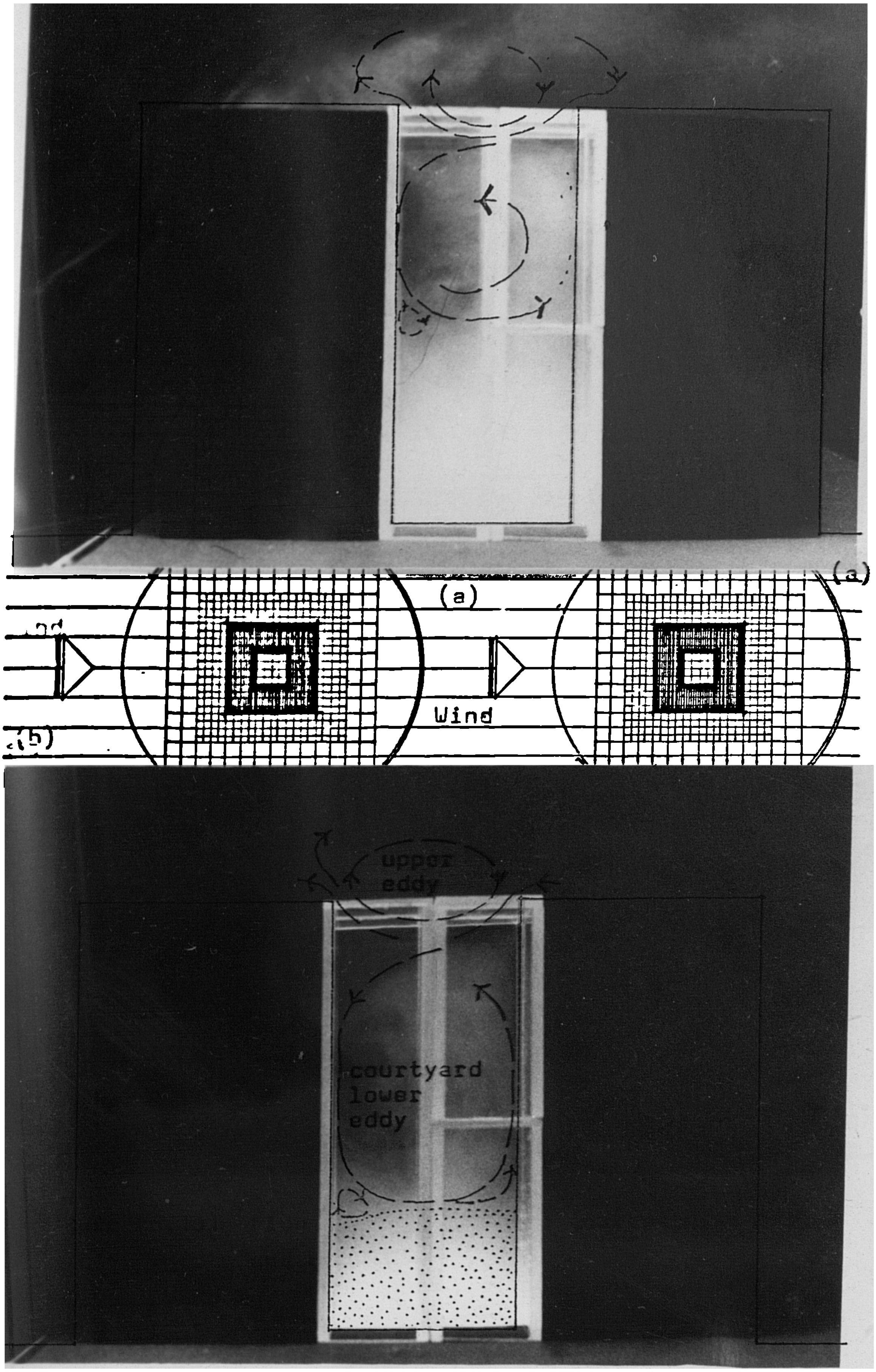


figure (6.18) Flow pattern inside a courtyard, Ω = 1 and $\theta = 0^{o}$.

6.5 Air Flow Patterns Within Single Cell

The forces affecting air flow within the single cell are inertia and pressure difference. Air will follow its original entry direction until the inertia forces diminish or are dominated by the pressure difference between the inside and the outside. At this stage air flow will be affected by the force resulting from both pressure difference and the flow outside the outlet. The latter will have a more pronounced effect on the direction of flow.

In Sections 6.3 and 6.4 the flow around buildings and inside deep courtyards have been investigated and the following characteristics were observed:

1 Air movement across the surface of the block was a result of the flow around it. This was likely to have a significant effect on the air flow direction inside the building.

2 When the angle of incidence $\theta = 0^o$ the stagnation point on the windward face governed the flow across that face. The stagnation point could be as low as 40% of the height for narrow buildings, ie $\alpha > 2$, and up to 70% for buildings with square and horizontal frontal proportions, ie $\alpha \ngtr 1$. The flow across the building's face radiated from this point. The positioning of the inlet on this face should take into account the fact that air entering openings above this point will tend to move towards the ceiling, while that entering through openings below it will tend to move nearer to the floor.

3 In a multi-storey building the air flow pattern would be affected by the distance between the inlet and the stagnation point. High ceilings in floors above the stagnation point could reduce the desirable effect of air movement by allowing the air to flow away from the living level.

4 The roof flow regime consisted of two eddies; the larger one was near the windward edge and resulted from the separation on that edge. The smaller one was near the leeward edge. The roof flow was a function of the height/depth proportion (β) and reattachment to the roof occurres at approximately $\beta > 1$. The flow separated again at 1/4 H from the leeward edge. Thus, positioning of roof openings should consider the above characteristics.

5 Air flowed up the leeward face, forcing air inside the building to flow near the roof if the outlet was located on this face.

6 The porosity of the building would affect the magnitude of the air speed, and consequently the extent of air deflection. This factor has been briefly examined and it showed that the flow near the outlet was deflected upward to conform with air moving past the leeward face, figure (6.19a & b).

7 When angle of incidence θ was altered to 45^{0} the air flow across the windward faces was inclined towards the roof and the far edge. At 1/4 H the wind flowed towards the floor as a result of the ground vortex.

8 The roof flow formed two vigorous eddies with the flow adjacent to the roof paralled to the incident flow

9 The flow around groups of buildings followed one of three regimes - isolated roughness, wake interference or skimming flow. The main stream direction affected the first row where the flow could be considered as of the isolated roughness category. In the shadow behind the first row the flow direction had a less pronounced effect, and the distance between the blocks a more pronounced effect. The flow was one of the three categories mentioned above. The stagnation point could be as high as 80% H and air flowed up the leeward face.

10 At angle of incidence $\theta = 0^{0}$ air movement within the courtyard was energised by the roof eddies. For a courtyard with $H/D < 1$ the air flowed downward on the far face and upward on the face near to the windward

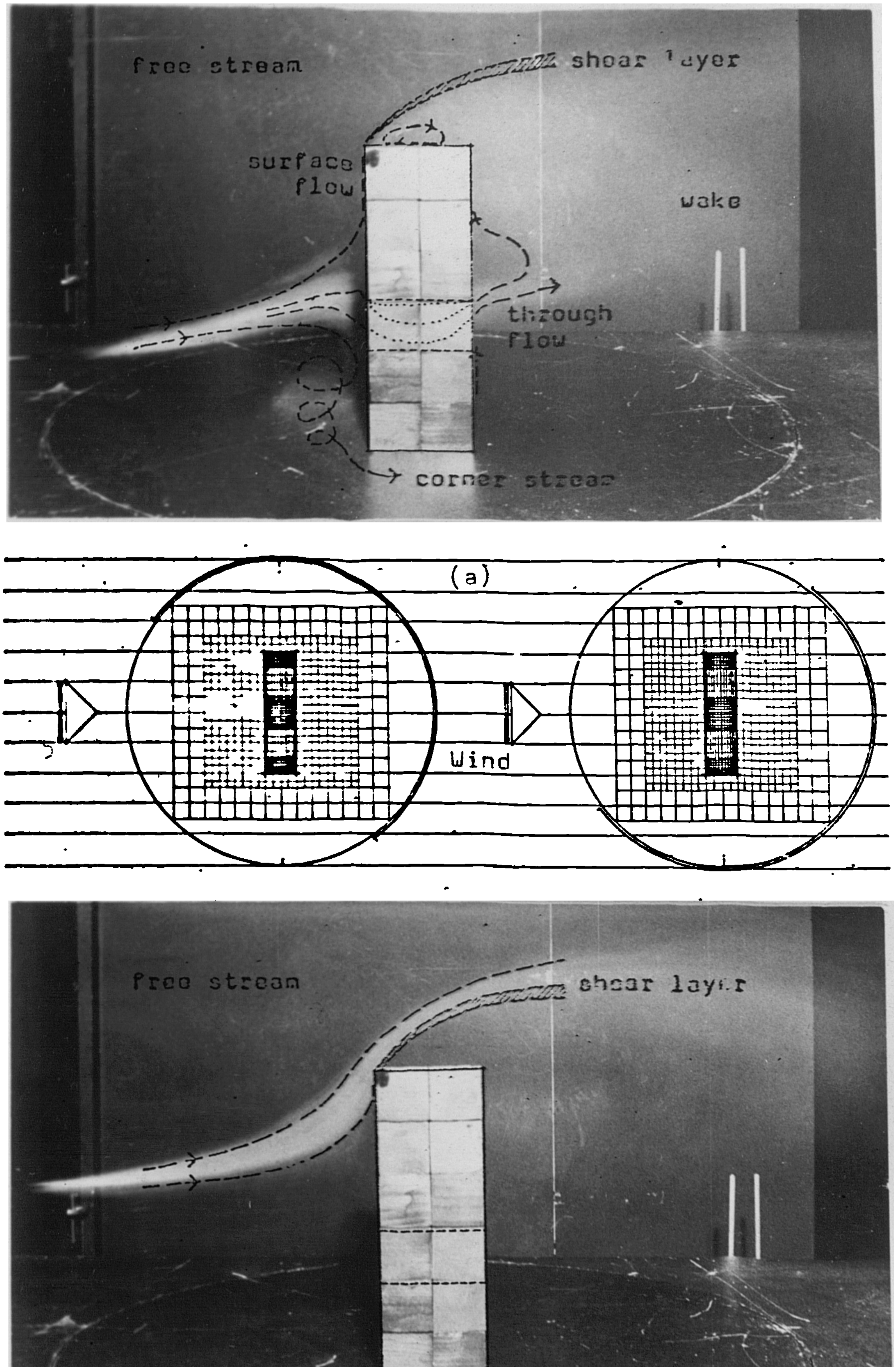


Figure (6.) Air flow regions round a perforated building.

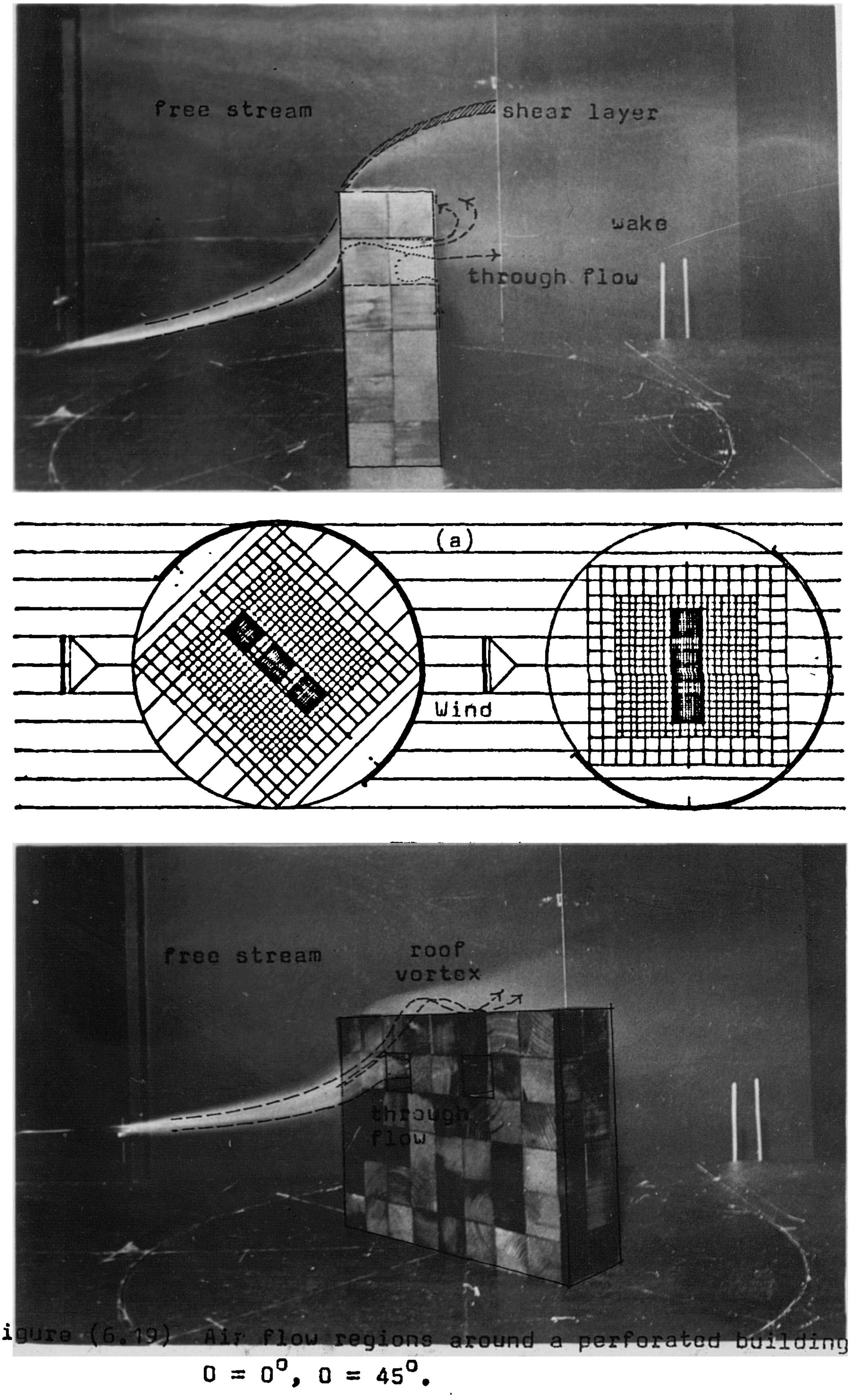


Figure (6.19) Air flow regions around a perforated building,
$\theta = 0^{o}$, $\theta = 45^{o}$.

side of the building. Only air within 0·2 D of the height will follow the above mentioned pattern when $H/D \geqslant 1$, but for the lower 1·4 D of the height the air moved upward on the far face and downward on the near face. Below 1·4 D of the height the air was almost stagnant. At oblique angles of incidence, eg 45^o, the stagnation zone diminished with air moving downward at the windward corner and upward at the leeward corner.

Considering the forces generating the flow, and the modifications expected in the flow pattern due to building forms, the parameters examined in this Section included:

1 The effect of inlet/outlet area.
2 The effect of internal partitions.
3 The effect of the inlet/outlet relative positions.

The points at which air speeds were recorded were the inlet, the outlet, where a change in the space occurred, and selected points near the corners. These were chosen on the grounds that they would give the best indication of the changes in the magnitude and pattern of the flow in relation to the parameters examined[1]. The structure of the model is discussed in Section A4.2.3. The arrangements of the cells were designed to correspond to the parameters examined, bearing in mind the main characteristics of residential units in Egypt.

The single cell considered at this stage had height H, width W and depth D, as that shown in figure (6.20). It had two windows of height h, and width w, on opposite sides. Assuming that the window in the windward face had height h_1 width w_1 and area a_1, and that in the leeward side had height h_2, width w_2 and area a_2, for the single cell model these dimensions can be related as follows:

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1 These allowed monitoring of both air speed and air changes within the model.

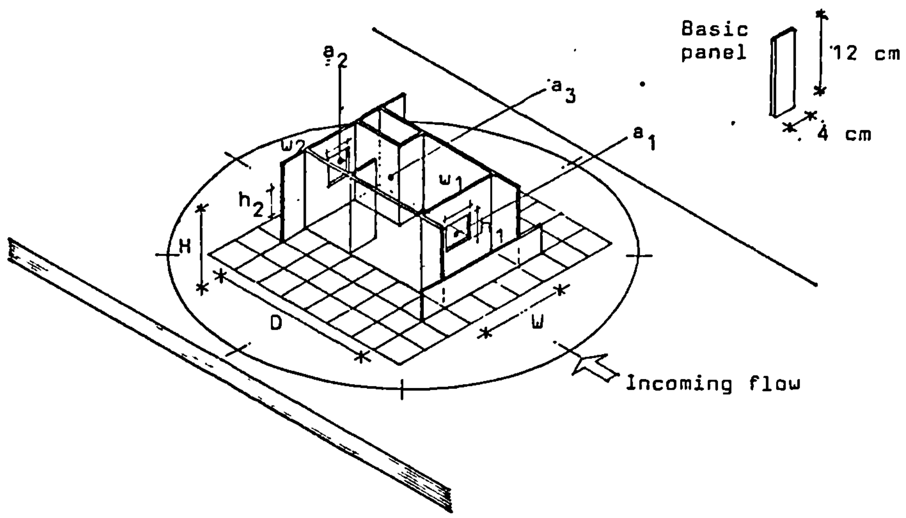


Figure (6.20) Detail of the internal flow model (single cell).

model	inlet width w_1	inlet height h_1	inlet area a_1	outlet width w_o	outlet height h_o	outlet area a_o	inlet/outlet area λ
A/1	1/3	1/3	1/9	2/3	1/3	2/9	1/2
A/2	1/3	1/3	1/9	1/3	1/3	1/9	1/1
A/3	1/3	1/3	1/9	1/3	1/3	1/9	1/1
A/4	1/3	1/3	1/9	1/3	1/3	1/9	1/1
A/5	2/3	1/3	2/9	1/3	1/3	1/9	2/1
A/6	3/3	1/3	3/9	1/3	1/3	1/9	3/1
A/7	1/3	1/3	1/9	1/3	1/3	1/9	1/1
A/8	1/3	1/3	1/9	1/3	1/3	1/9	1/1
A/9	1/3	1/3	1/9	1/3	1/3	1/9	1/1

Table (6.2) Openings considered in models A

$$w = \lambda h$$
$$h_1 = h_2 = 1/3\ H$$
$$w_1 = 1/3\ \lambda_1 H$$
$$w_2 = 1/3\ \lambda_2 H$$
$$a_1 = 1/9\ \lambda_1 H^2$$
$$a_2 = 1/9\ \lambda_2 H^2$$
$$\lambda = a_1/a_2$$
$$= \lambda_1/\lambda_2$$

where λ_1, λ_2 and λ are dimensionless variables expressing the relationships between the above mentioned parameters. For these experiments λ ranged between $1/2 < \lambda < 3/1$, table (6.2).

6.5.1 The Effect of Inlet/Outlet Area

The effect of the change in inlet/outlet relative area (λ) on the general flow pattern, as well as local speed magnitude was investigated in four models, A/1, A/2, A/5 and A/6, which had $\lambda = 1/2$, $\lambda = 1/1$, $\lambda = 2/1$ and $\lambda = 3/1$ respectively. In this Section the internal air speed magnitudes were expressed as a percentage of the outdoor air speed, and referred to as 'C_{vn}'. These models were first positioned so that the angle of incidence $0 = 0^o$. In model A/1 where the outlet was double the size of the inlet ($\lambda = 1/2$), the speed at the inlet (C_{vn}) was 88% while air in the windward corners was almost stagnant, figure (6.21a & b). The air flow was characterised by a high speed, C_{vn} reaching 49% at the centre of the partition opening then 41% at the middle outlet and 54% at the side outlet, figure (6.22). Air speed was considerably high throughout the space reaching 30% at the corner. The high speed within the space was evidence that a Venturi effect dominated the flow pattern when $\lambda = 1/2$.

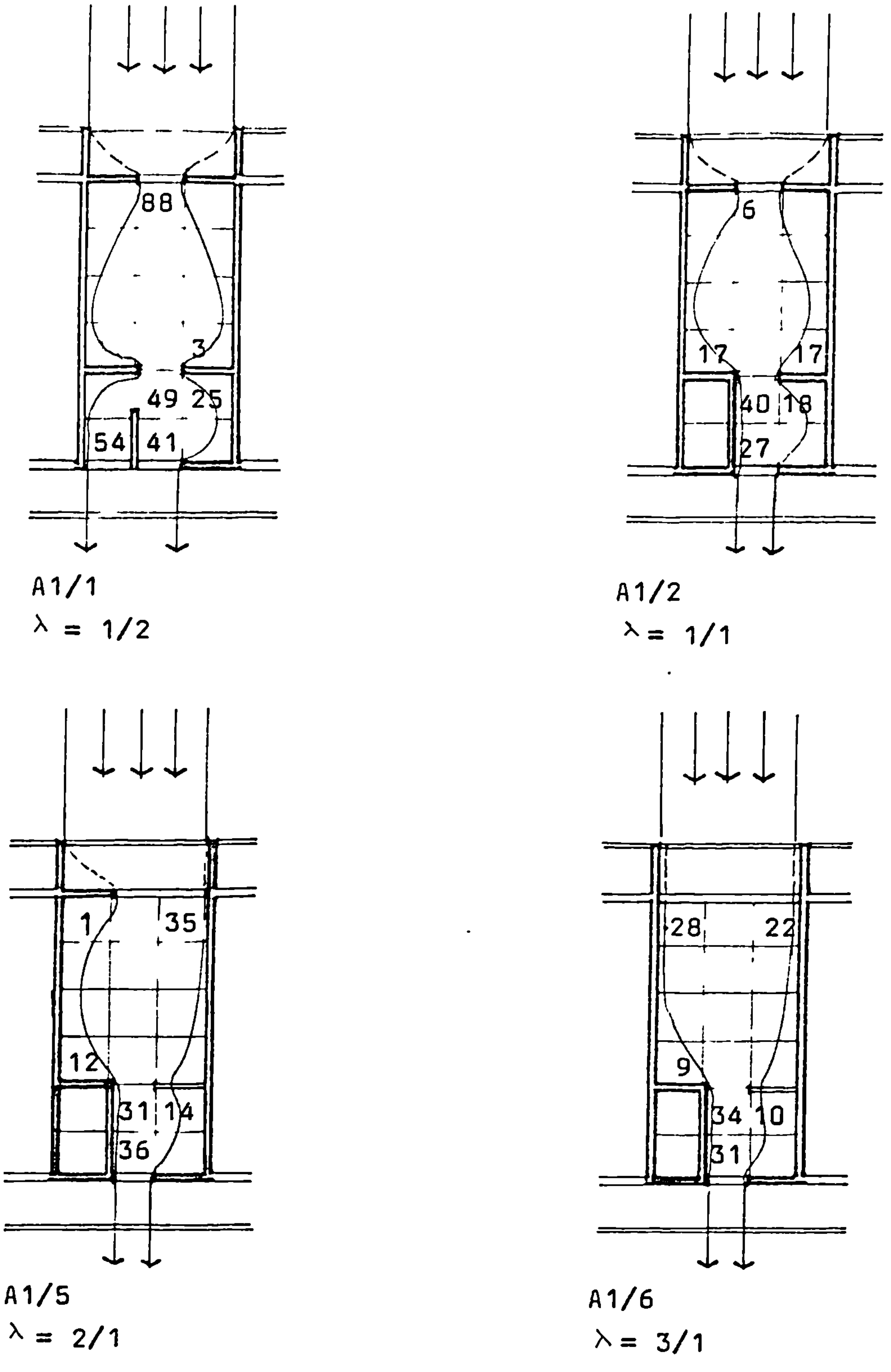


Figure (6.21a) The effect of inlet/outlet area (λ) on the flow within single cell (angle of incidence $\theta = 0^{o}$).

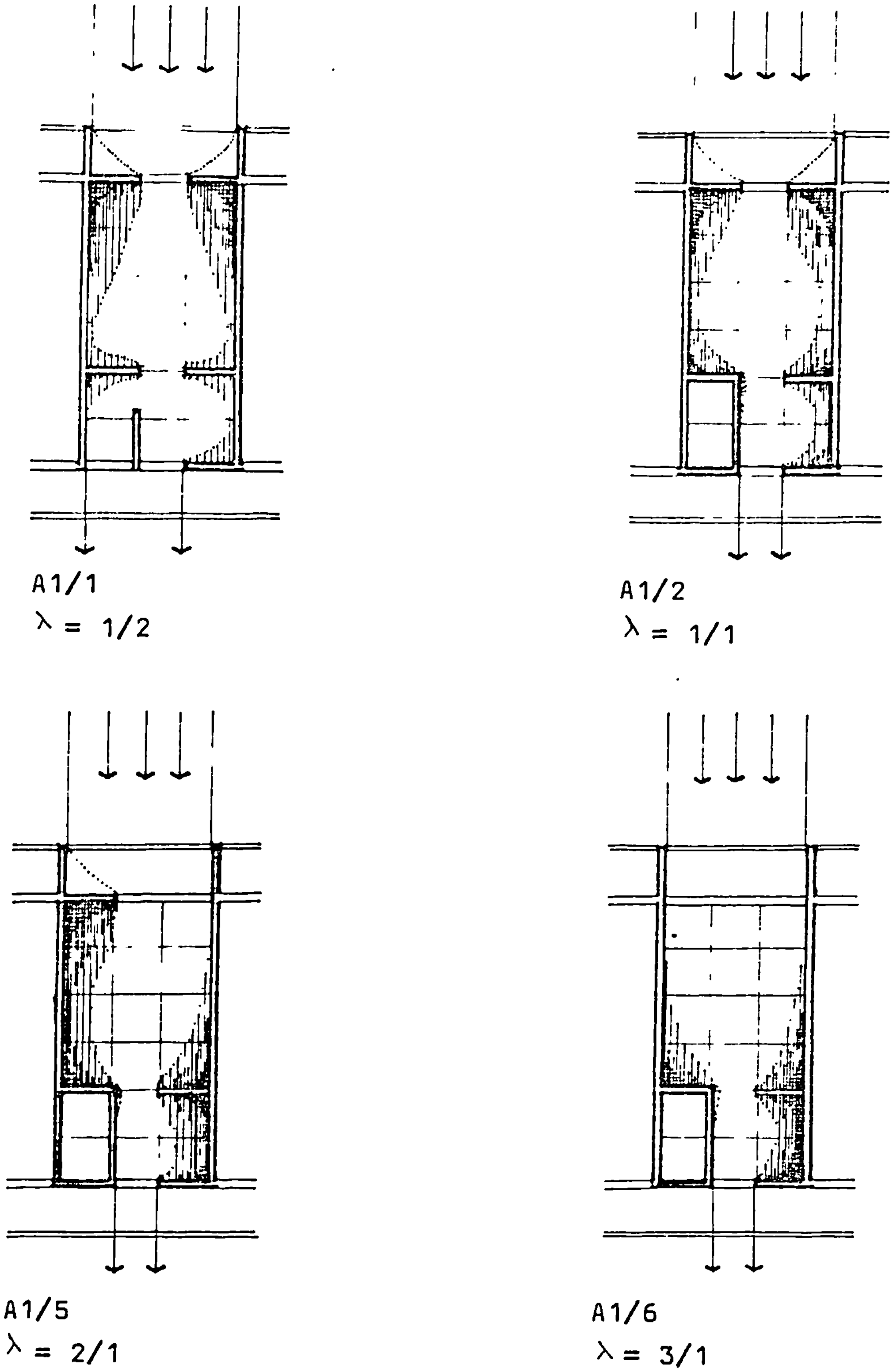


Figure (6.21b) The effect of inlet/outlet area (λ) on the flow pattern within the single cell for angle of incidence $\theta = 0^o$.

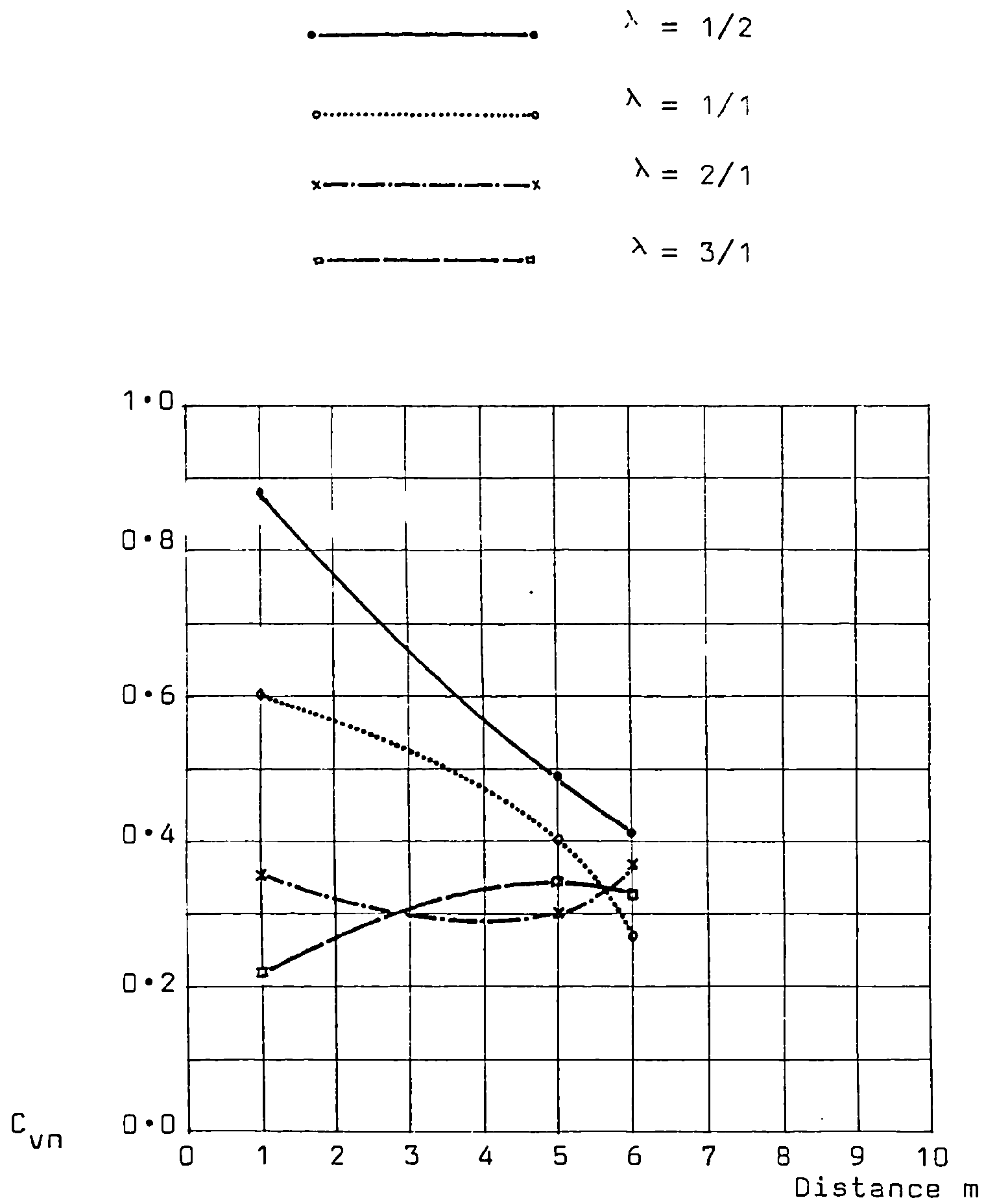


Figure (6.22) The change in C_{vn} in relation to inlet/outlet distance. (angle of incidence $\theta = 0^o$).

In model A/2 the inlet/outlet relative area (λ) was 1/1. A marked decrease in air speed near the inlet was observed with air speed at 60%. On the centre line linking the inlet and outlet the air speed was considerably high reaching 40% at the partition opening. At the corners air speeds were lower than those observed when $\lambda = 1/2$, also at the middle of the outlet the air speed was 27%.

Inside model A/5 where the inlet/outlet relative area (λ) was 2/1, a further reduction in the incoming air speed was observed and $C_{vn} = 35\%$. At the sheltered corners air speed ranged from 1% at the windward corner to 12% at the leeward corner of the windward space. On the leeward side of the partition high speed air movement was limited to the centre line between the partition opening and the outlet.

Inside model A/6 with $\lambda = 3/1$, air speed at the inlet suffered a further reduction ranging between $C_{vn} = 22\%$ and $C_{vn} = 28\%$. At the partition air speed was increased to reach 34%, then showed a slight decrease to $C_{vn} = 31\%$.

The trends observed at angle of incidence $0 = 0^o$ can be summarized as follows:

1 The inlet/outlet relative area λ was inversely proportional to air speed magnitude near the inlet. This conforms with Venturi effect.

2 When $\lambda = 1/2$ the air flow shows a more dynamic pattern than that for $\lambda = 3/1$.

3 The inertia forces dominated the part of the space on the windward side of the partition while suction dominated the leeward side.

4 Air speed in the corners of the leeward side of the partition decreased with the increase in λ value, figure (6.22). Between $1/2 < \lambda < 2/1$ air speed decreased with distance and this seemed to be a function of λ. The higher the λ value the smaller the decrease.

The decrease was reversed when $\lambda = 3/1$. This phenomenon was clearly observed when inspecting air speed near the partition in figures (6.27) to (6.30), for angle of incidence $\theta = 0^o$.

When the angle of incidence θ was changed to $\theta = 45^o$ air flow patterns within these models showed marked changes, figure (6.23). Near the inlet of model A/1, with $\lambda = 1/2$, air speed C_{vn} was as high as 48% while near the outlet it ranged between 8% and 21%. When $\lambda = 1/1$ air speed at both the inlet and the outlet was lower than for the previous model, but the flow gradient on the centre line of the space was similar, figure (6.24). This may be interpreted as the existance of a Venturi effect at angle of incidence $\theta = 45^o$. Air speed at the inlet was increased to $C_{vn} = 44\%$ for $\lambda = 2/1$, but decreased again to $C_{vn} = 40\%$ at $\lambda = 3/1$. Near the outlet air speed was highest at $\lambda = 2/1$ when $C_{vn} = 32\%$ and reduced to $C_{vn} = 24\%$ at $\lambda = 3/1$. Despite the high speed near the inlet of the model for $\lambda = 1/2$, air speed both near the corners and inside the leeward space was considerably low. In all cases observed, when $\lambda > 1/1$ the flow was more turbulent than that when $\theta = 0^o$.

When the angle of incidence was changed to $\theta = 90^o$ the flow was characterized by low speeds. At this angle the least air movrment was observed when $\lambda = 1/1$, fig.(6.25). When $\lambda = 1/2$ there was little evidence of cross ventilation but air moved near the outlet. When $\lambda > 2/1$ the air seemed to move across the space with relatively low speed near the outlet, figures (6.25) and (6.26). The flow within the space showed some correlation with both the width of the opening and the depth of the space near the bigger opening. This may be explained by referring to the nature of the forces inducing the air movement. In the last case inertia was the dominating force while pressure difference was almost negligible. When the partition was placed near to the larger opening it offered a higher

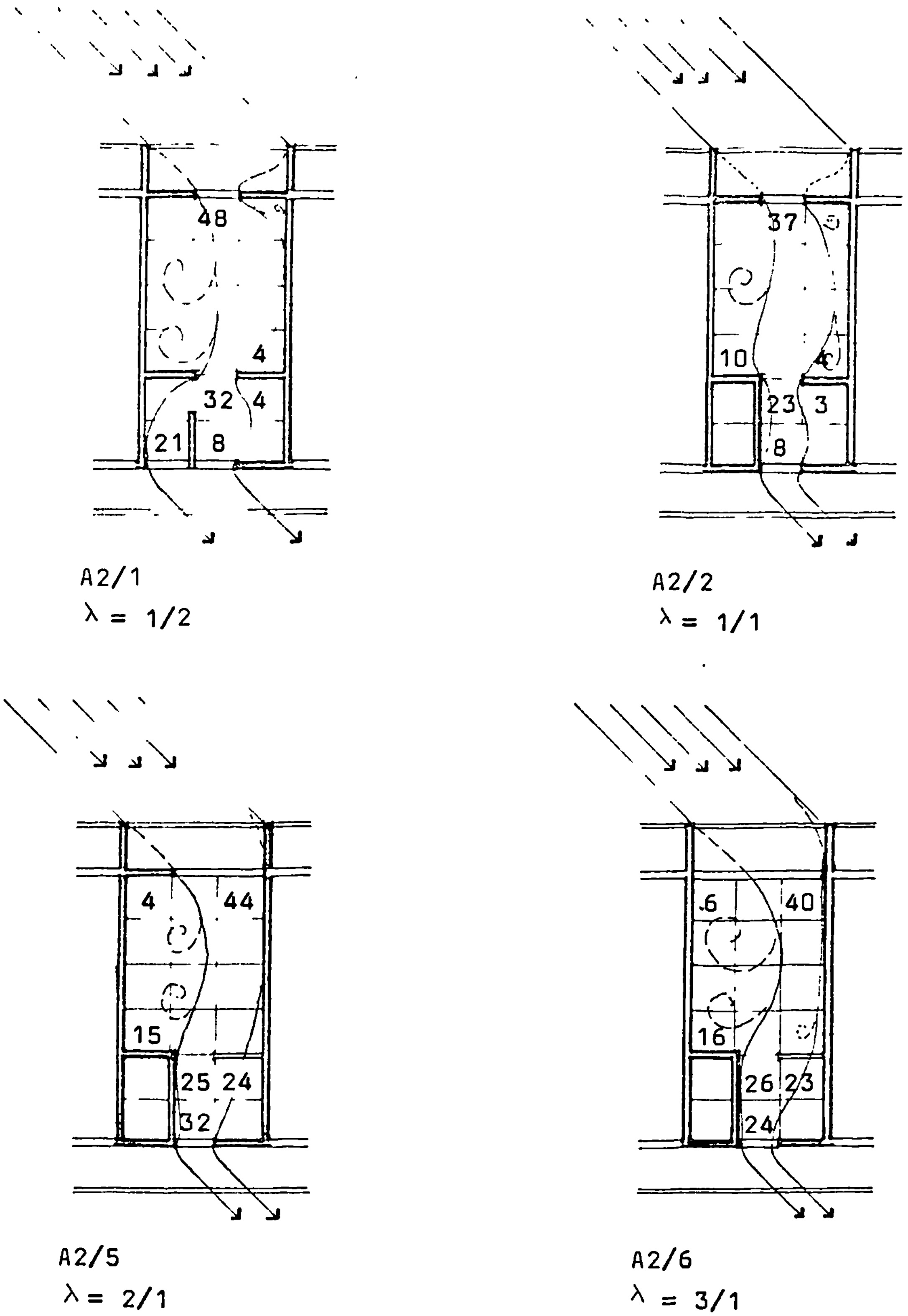


Figure (6.23) The effect of inlet/outlet area (λ) on the flow within single cell (angle of incidence $\theta = 45^o$).

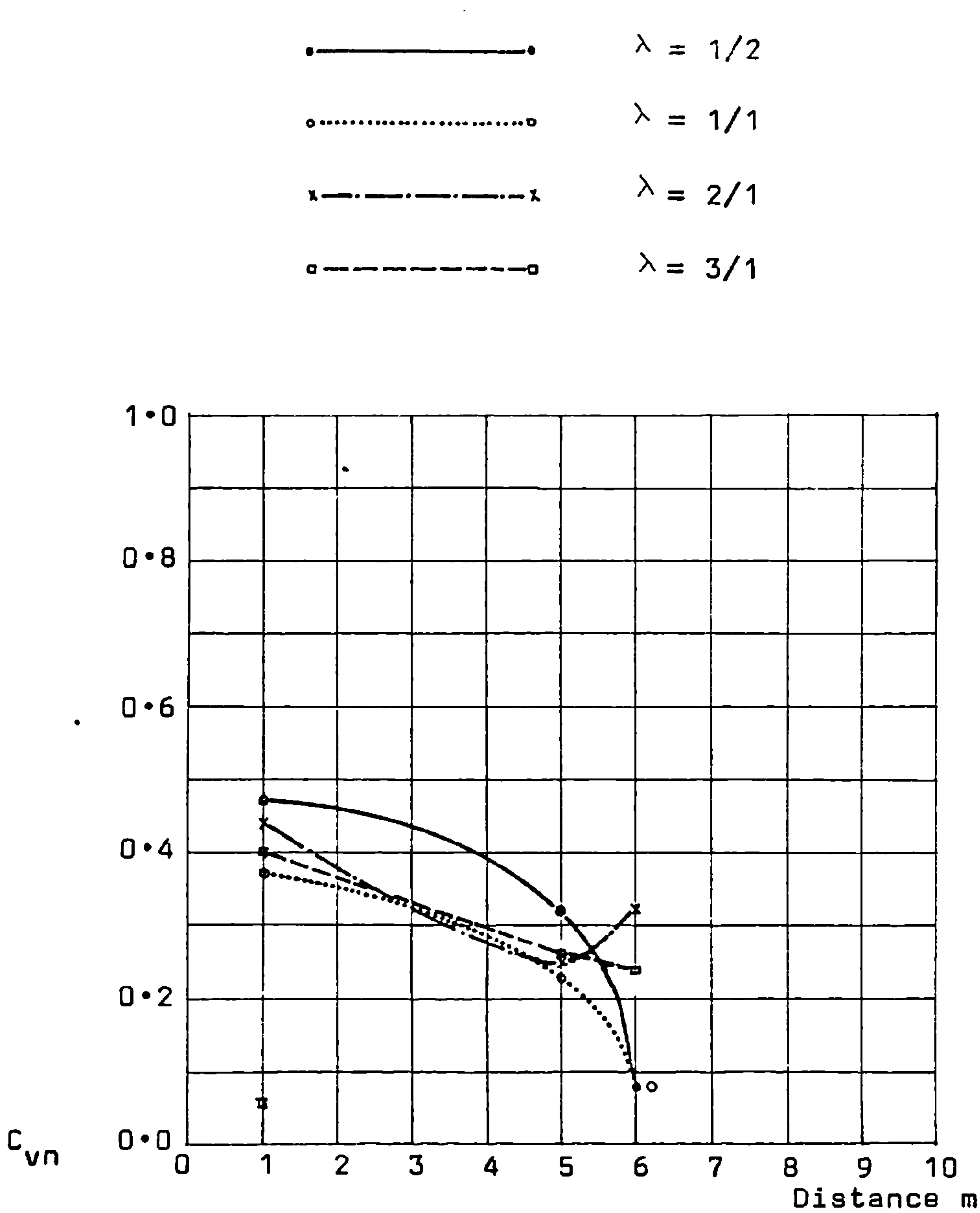
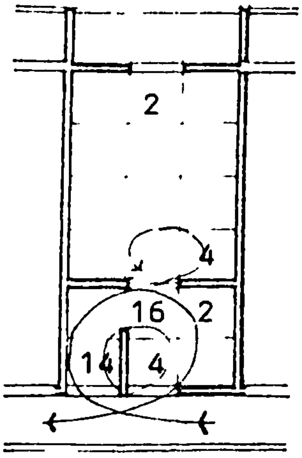
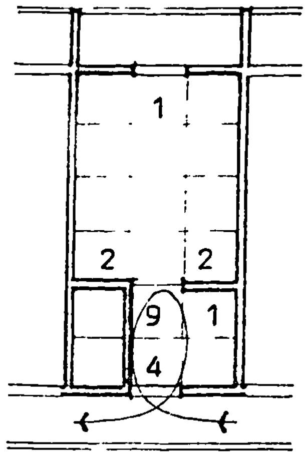


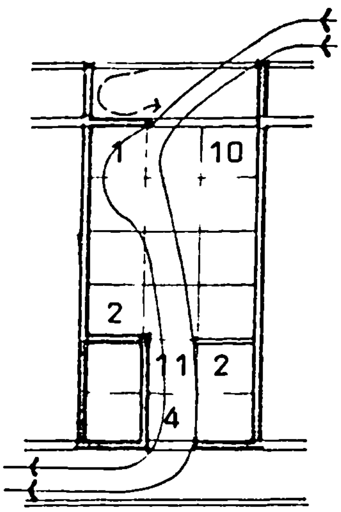
Figure (6.24) The change in C_{vn} in relation to inlet/outlet distance (angle of incidence θ = 45°, 1/2 < λ < 3/1).



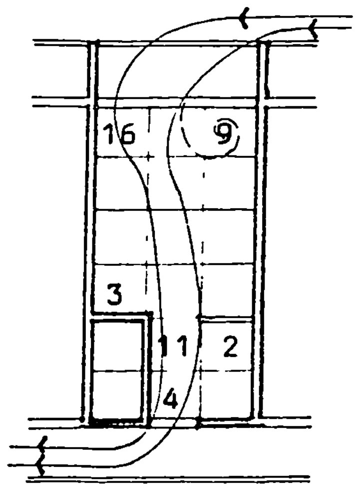
A4/1
λ = 1/2



A4/2
λ = 1/1



A4/5
λ = 2/1



A4/6
λ = 3/1

Figure (6.25) The effect of inlet/outlet area (λ) on the flow within single cell (angle of incidence $\theta = 90^o$).

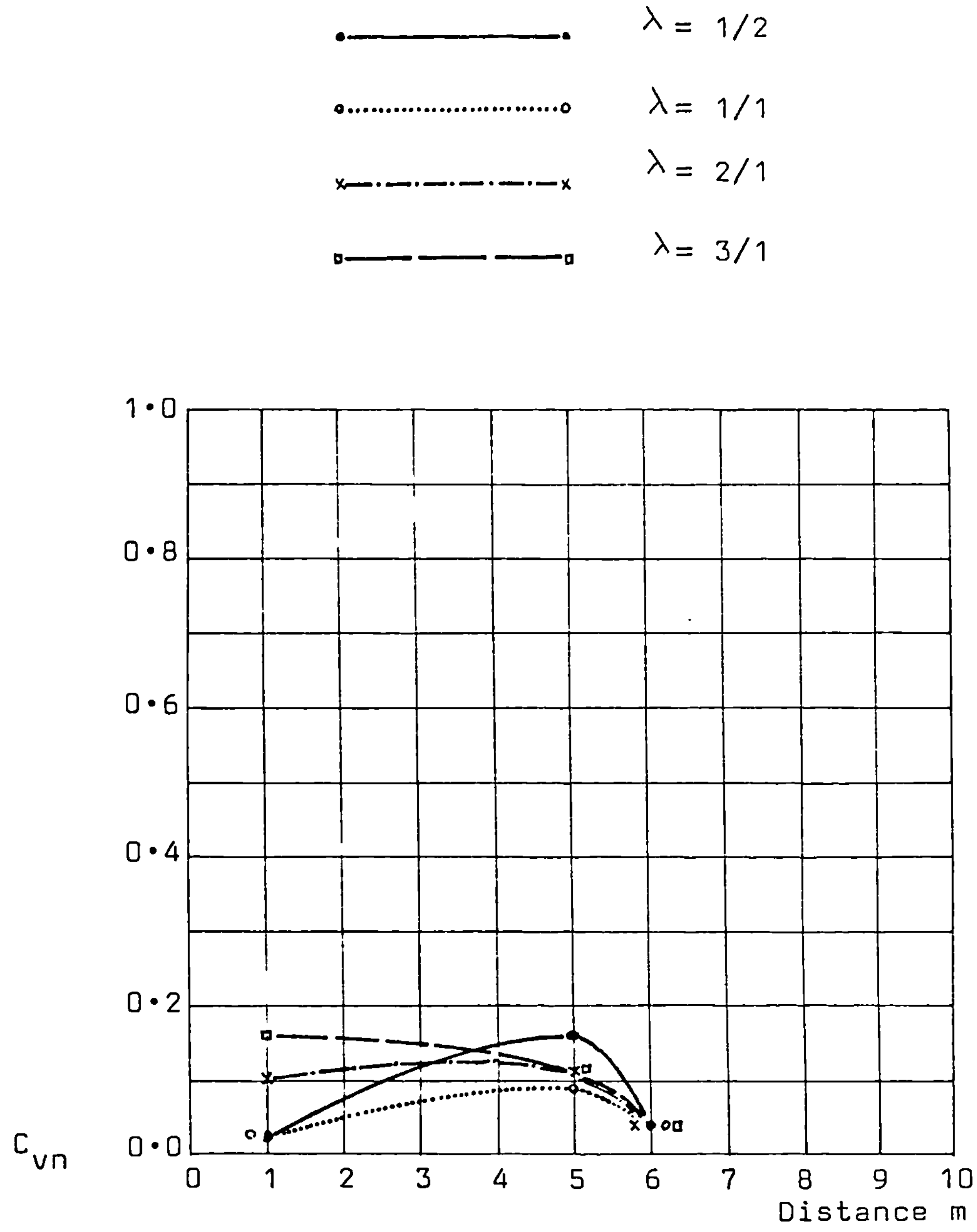


Figure (6.25) The change in C_{vn} in relation to inlet/outlet distance (angle of incidence θ = 90°).

resistance cousing the air to lose its kinetic energy and resulting in little penetration into the adjacent space. With the larger opening to the greater space the air penetrated to reach the outlet in the opposite wall, but when both openings were small, ie 1/3 of the wall's width. little air movement occurred.

The change in the angle of incidence 0 caused considerable reduction in air speed, not only near the inlet but also deep inside the space. Figures (6.27) and (6.28) illustrate air speed in relation to the angle of incidence for inlet/outlet relative area $\lambda = 1/2$ and $\lambda = 1/1$ respectively. For angles of incidence $\theta = -45^{\circ}$ and $\theta = +45^{\circ}$ the reduction in air speed from that at $\theta = 0^{\circ}$ showed a similar pattern, with little difference in the speed magnitude between $\theta = -45^{\circ}$ and $\theta = +45^{\circ}$. When $\lambda = 2/1$ and $\lambda = 3/1$ air speed near the inlet showed a considerable increase for $\theta = -45^{\circ}$ compared to $\theta = 0^{\circ}$ but decreased at $\theta = +45^{\circ}$, figs.(6.29) and (6.30). This was a result of the asymmetry of the space arrangement with respect to the inlet which had the most pronounced effect when $\lambda > 2/1$. This phenomenon will be further examined in the case of the multi-cell models.

Air speed at the partition showed an increase and decrease similar to those of the outlet, even with the change in the angle of incidence θ. This gave evidence that introducing a partition in a single cell would cause air speed to the leeward side of it to follow that of the outlet, ie the nearest opening. This phenomenon will be examined further for the case of the multi-cell.

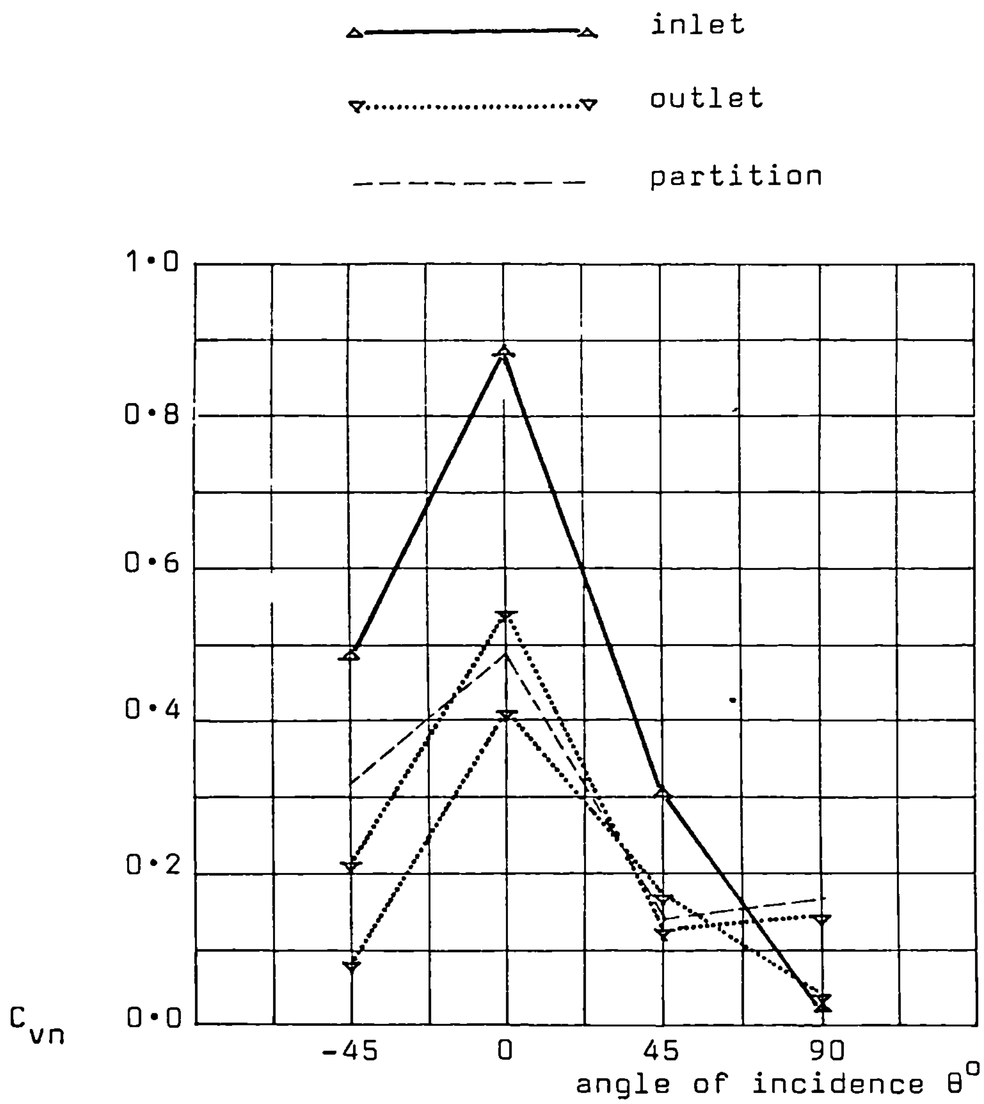


Figure (6.27) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 1/2.

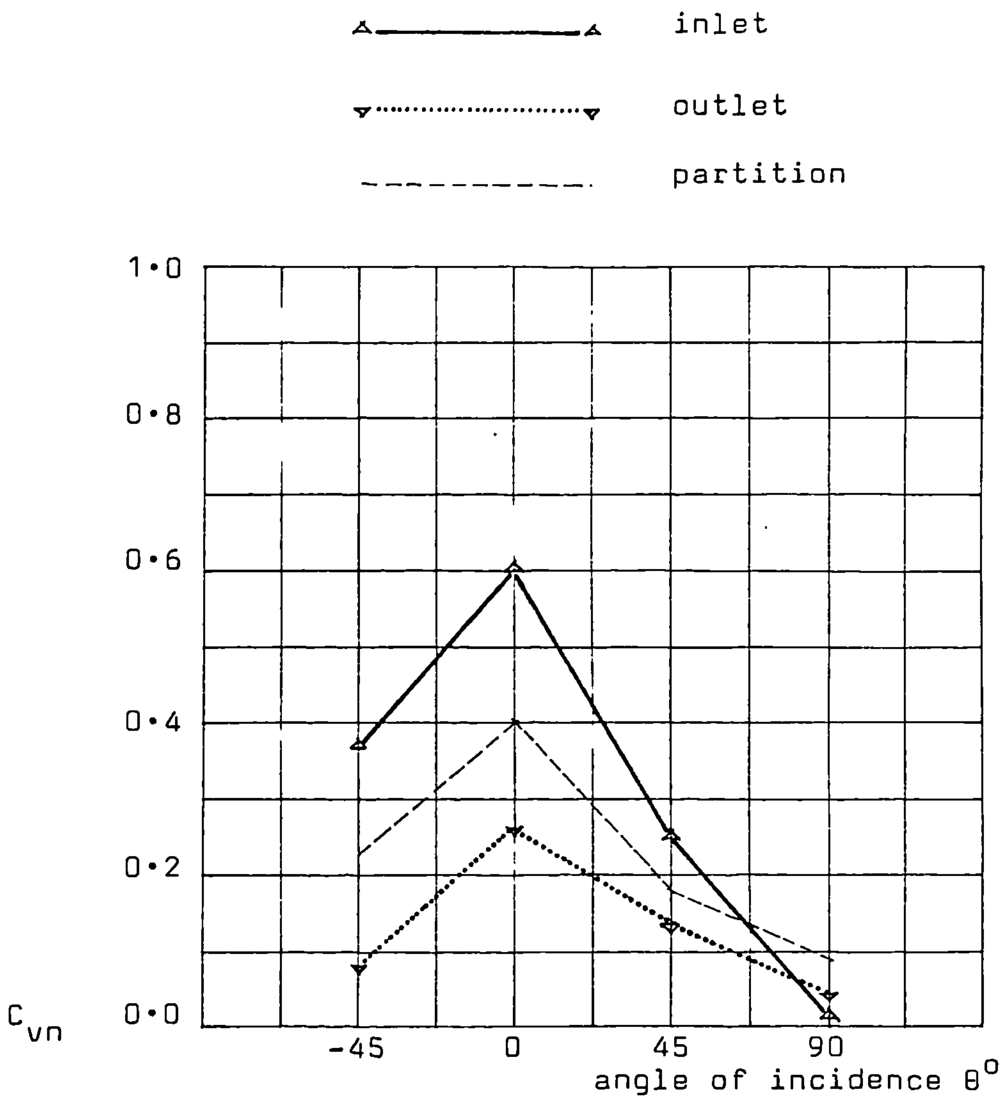


Figure (6.28) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 1/1.

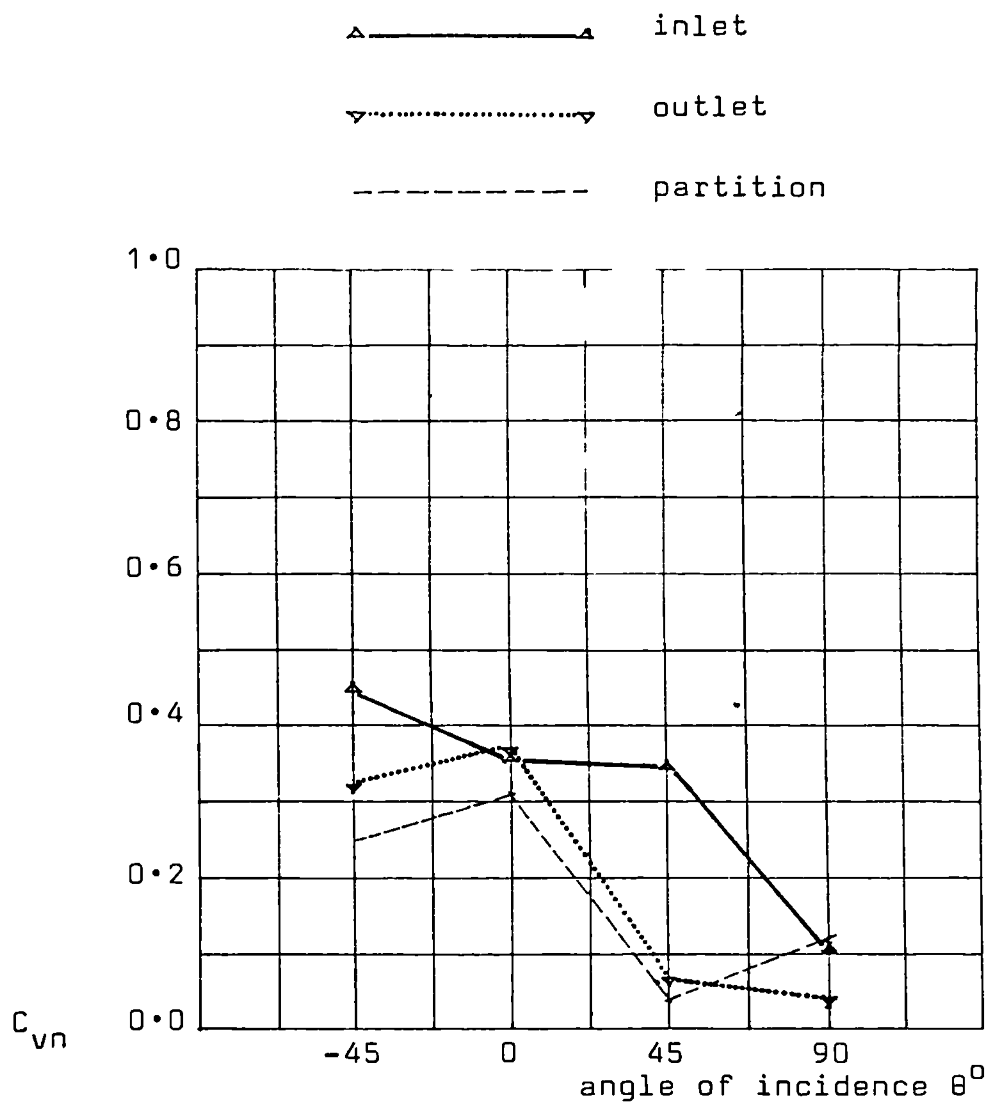


Figure (6.29) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 2/1.

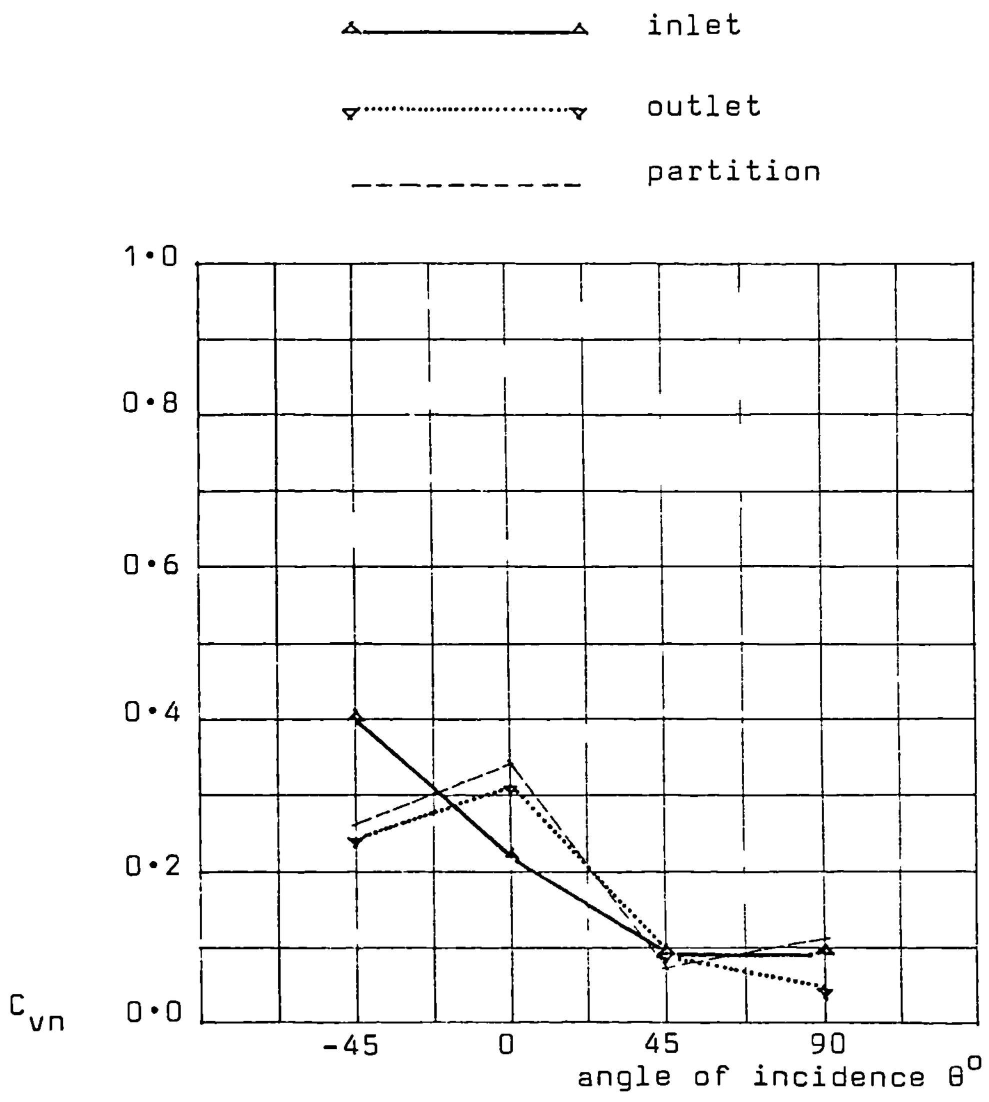


Figure (6.30) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 3/1.

6.5.2 The Effect of Internal Partitions

The presence of a partition within a single cell affected the air flow pattern. Models A/2, A/3 and A/4 had equal sized inlets and outlets, but they had differing partition opening area a_3 of 1/3, 4/9 and 5/9 respectively. Air speeds within these models showed marked differences, figure (6.31). For $a_3 = 1/3$ air speed, C_{vn}, at the inlet was 60% compared with 63% for $a_3 = 4/9$, and 66% for $a_3 = 5/9$. The increase in speed was a result of Venturi effect. The speed decreased at the partition to $C_{vn} = 40\%$, 31% and 24%, while near the outlet the speeds were 27%, 25% and 30% for $a_3 = 1/3$, $a_3 = 4/9$ and $a_3 = 5/9$ respectively. Despite the decrease in speed at the partition with the increase in a_3 area, the general distribution of air speed over the space was higher for higher a_3 values, fig.(6.32). For $a_3 = 5/9$ the air speed behind the partition was higher and more uniform than for $a_3 = 1/3$.

At angle of incidence $\theta = 45^{o}$ the flow near the inlet was a function of the partition area, also the air speed inside the space and near the corners indreased in magnitude with the increase in the partition opening area a_3.

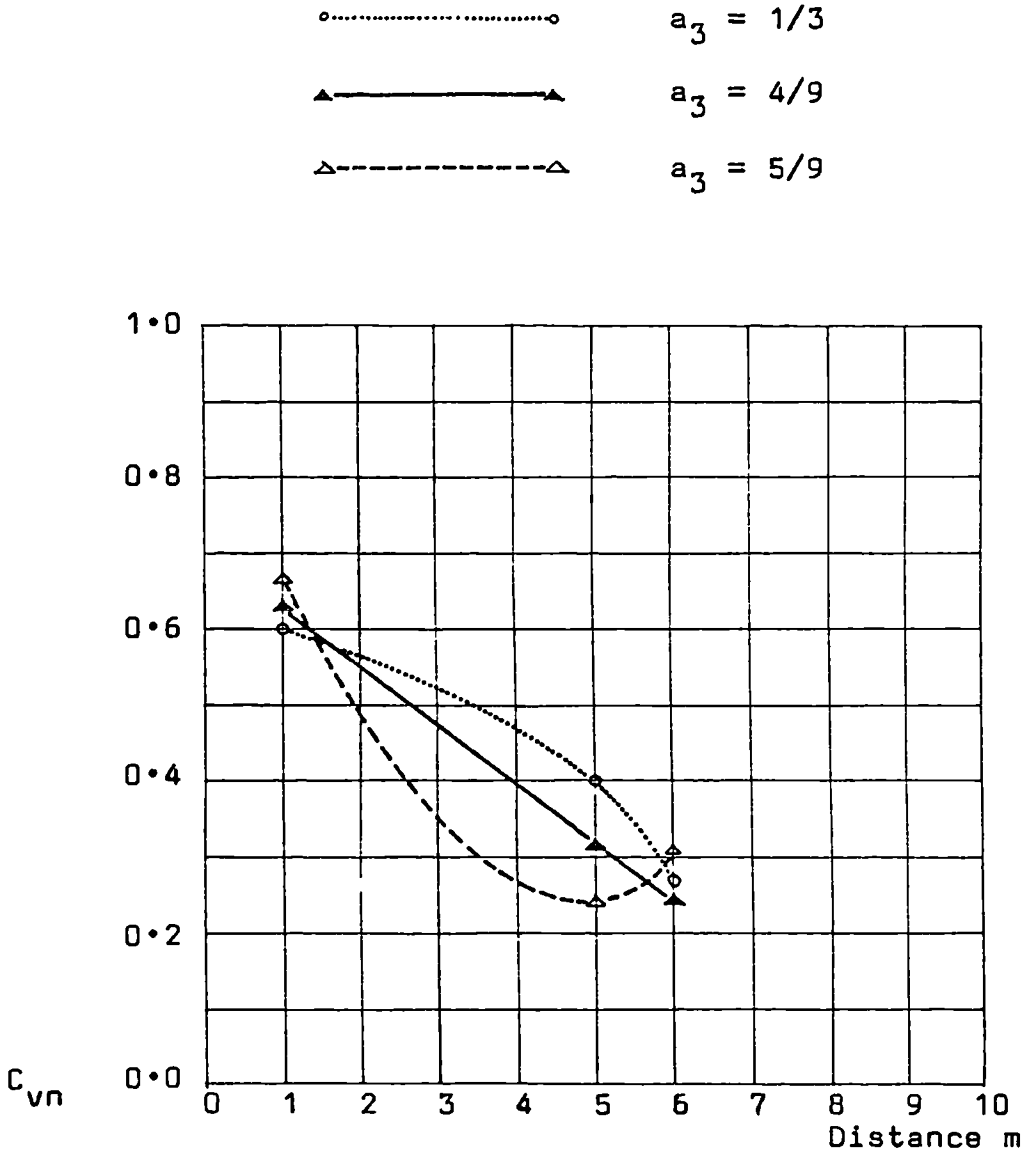
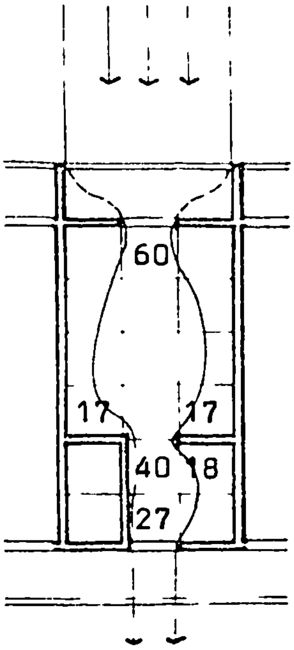
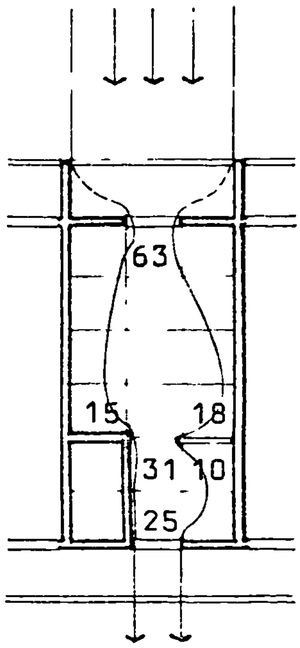


Figure (6.31) The change in C_{vn} in relation to the internal partition area a_3 (angle of incidence $\theta = 0^o$).



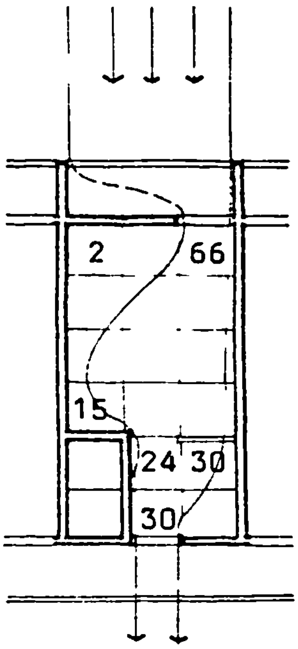
A1/ 2

a_3 = 1/3



A1/ 3

a_3 = 4/9



A1/4

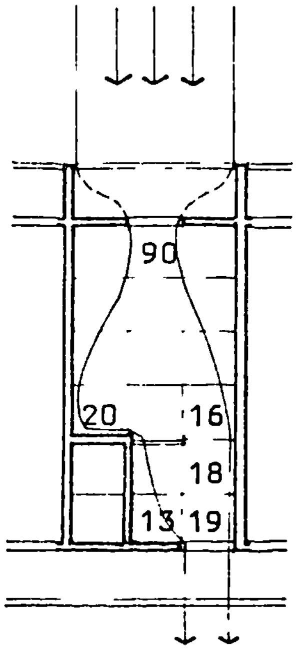
a_3 = 5/9

Figure (6.32) The effect of the internal partition area a_3 on the flow within single cell (angle of incidence $\theta = 0^o$).

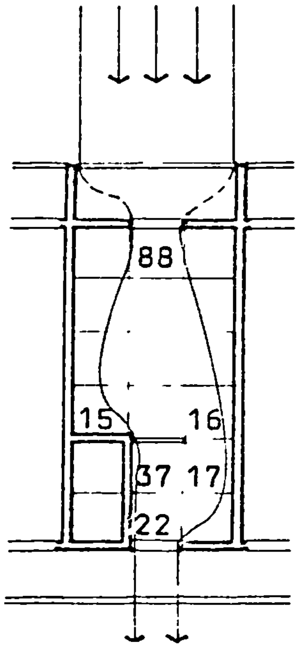
6.5.3 The Effect of Inlet/Outlet Relative Position

The effect of the inlet/outlet relative position was investigated in models A/7, A/8 and A/9. These models were characterized by similar inlet/outlet area, ie $\lambda = 1/1$, also they had equal partition opening area of $a_3 = 5/9$. The inlet was always at the centre-line of the windward wall while both the outlet and the partition changed their positions. In this case the partition opening acted as a mid-distance opening. Air speed, C_{vn}, at both the inlet and the outlet showed little variation with the change in the position of the outlet, figure (6.33). Air speed near the inlet was C_{vn} = 90%, 88% and 86% for A/7, A/8 and A/9 respectively, while it was 19%, 22% and 23% near the outlet, figure (6.34). The trend was for the higher inlet speed to accompany the lower outlet speed. The flow inside the model showed more pronounced variations than near the openings. On the windward side of the partition the air was more dynamic in A/7 where air speed at corners was as high as C_{vn} = 20% compared with 15% and 16% for A/8 and A/9. In the leeward space air speed was highest, C_{vn} = 37% at the centre line connecting the inlet to the outlet of model A/8, but it was considerably lower away from that.

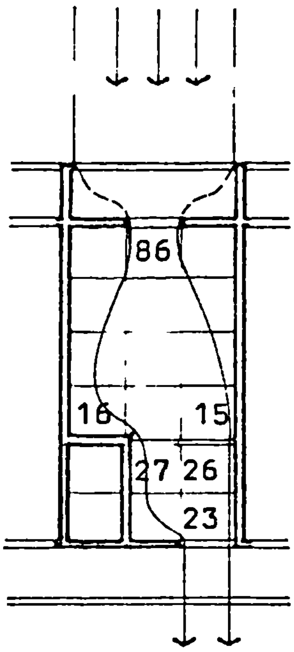
Speed was more uniform when the outlet was placed at an angle to the inlet; this forced the air to change direction and air speed was more uniform compared with that of A/7. When $\theta = \pm 45^o$ the only difference between the three models examined was the speed at the inlet where it was highest, C_{vn} = 46%, for model A/8, but almost the same for A/7 and A/9 at 39% amd 38%. At angle of incidence $\theta = 90^o$ the air speed was considerably lower.



A1/7
λ = 1/1



A1/8
λ = 1/1



A1/9
λ = 1/1

Figure (6.33) The effect of inlet/outlet relative position on the flow within single cell (angle of incidence $\theta = 0^{o}$).

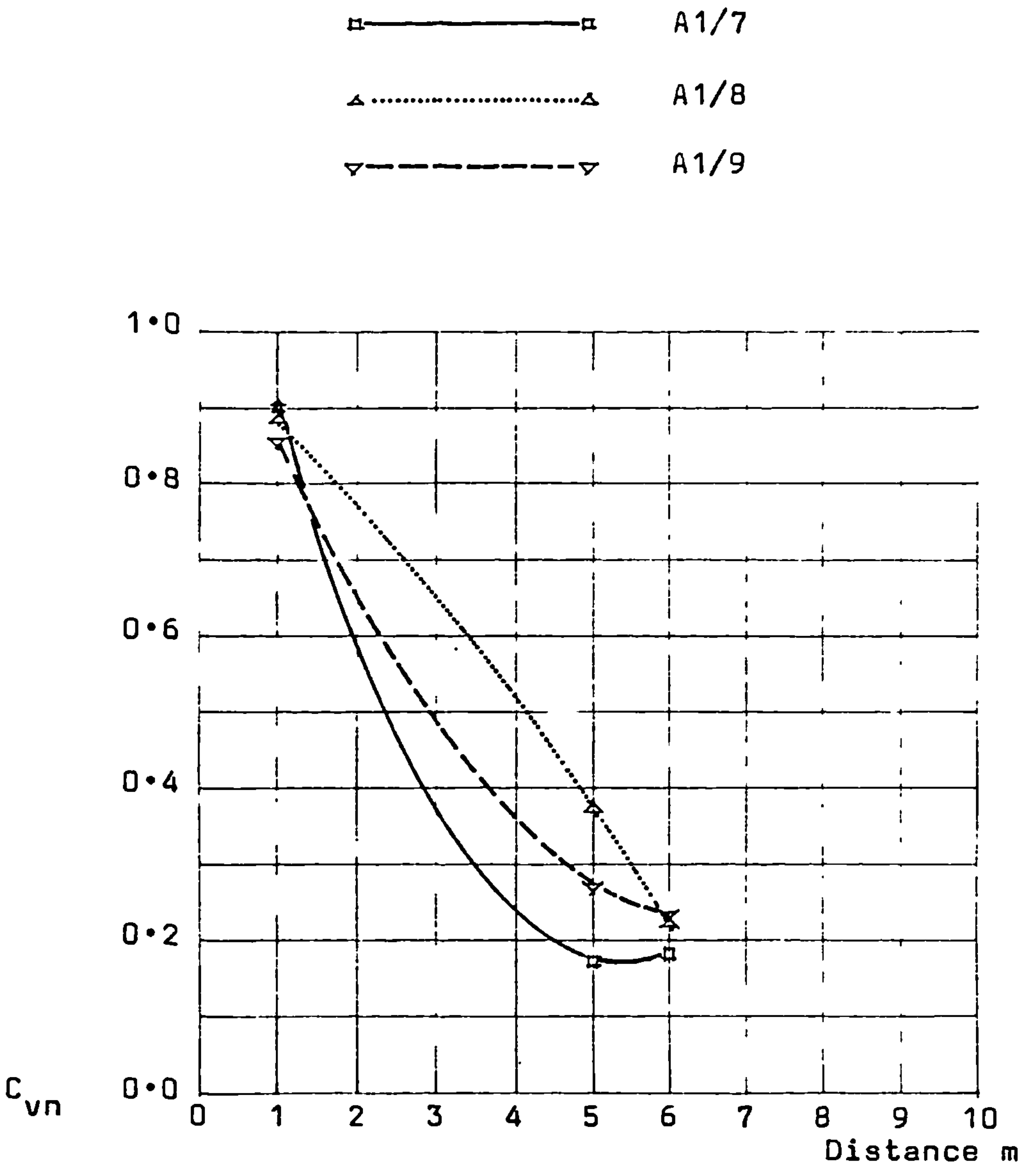


Figure (6.34) The change in C_{vn} in relation to the inlet/outlet relative positions (angle of incidence $\theta = 0^{o}$).

6.6 Air Flow Within Multi-cells

In this Section the effects of inlet/outlet relative area λ, internal partition area a_3 and inlet/outlet relative position were examined in three categories of multi-cell models, B, C and D. These models were similar in construction to the single cell model examined in the previous Section, and illustrated in detail in Appendix A4.2.3. As in model A, air speeds were recorded at the inlets, the outlets, selected points near the corners and where a change in the space occurred.

The inlet/outlet relative area λ for the multi-cell models, which had at least two inlets, were related to each other using similar dimensional analysis to that of the single cell models in Section 6.5. Hence, the dimensionless parameter λ expressed the ratio of the inlets' total area to the outlets' total area, figure (6.35), and tables (6.3), (6.4) and (6.5). The parameter λ ranged between $1/1 < \lambda < 2/1$ for catefory B, $2/3 < \lambda < 3/1$ for category C and $1/2 < \lambda < 3/1$ for D, while the angle of incidence θ varied between $-45^{\circ} < \theta < 90^{\circ}$. The partition opening area was for the middle partition only. To neutralize the effect of the other partitions their opening areas were kept constant.

6.6.1 The Effect of Inlet/Outlet Area

The effect of the inlet/outlet relative area (λ) was examined in the three model categories B, C and D. First it was investigated in models of category B - B/2, B/1 and B/8, having λ values of $\lambda = 1/1$, $\lambda = 3/2$ and $\lambda = 2/1$ respectively, figure (6.36a & b). With angle of incidence $\theta = 0^{\circ}$, and within the right hand section of the model, the speed near the inlet of B/2 was $C_{vn} = 71\%$ compared with 54% and 53% for B/1 and B/8 respectively. Near the outlet

model	inlet area a_1	outlet area a_2	partition area a_3	inlet/outlet area
B1	3/9	2/9	1/3	3/2
B2	2/9	2/9	1/3	2/2
B3	2/9	2/9	2/3	2/2
B4	2/9	2/9	1/3	2/2
B5	2/9	2/9	2/3	2/2
B6	3/9	2/9	4/9	3/2
B7	2/9	2/9	4/9	2/2
B8	2/9	1/9	2/3	2/1
B9	2/9	2/9	4/9	2/2

Table (6.3) Openings considered in models B.

model	inlet area a_1	outlet area a_2	partition area a_3	inlet/outlet area
C1	2/9	3/9	1/3	2/3
C2	2/9	2/9	1/3	2/2
C3	2/9	2/9	5/9	2/2
C4	2/9	2/9	1/3	2/2
C5	2/9	2/9	1/3	2/2
C6	2/9	2/9	1/3	2/2
C7	4/9	2/9	1/3	4/2
C8	6/9	2/9	1/3	6/2
C9	2/9	2/9	1/3	2/2
C10	2/9	2/9	1/3	2/2
C11	2/9	2/9	1/3	2/2

Table (6.4) Openings considered in models C.

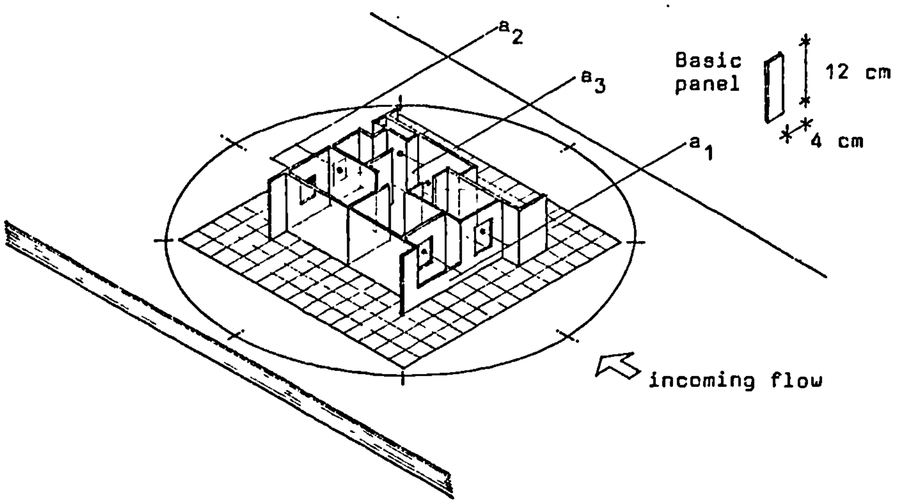
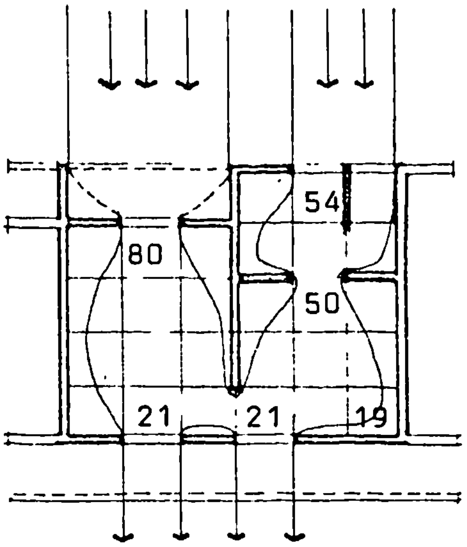


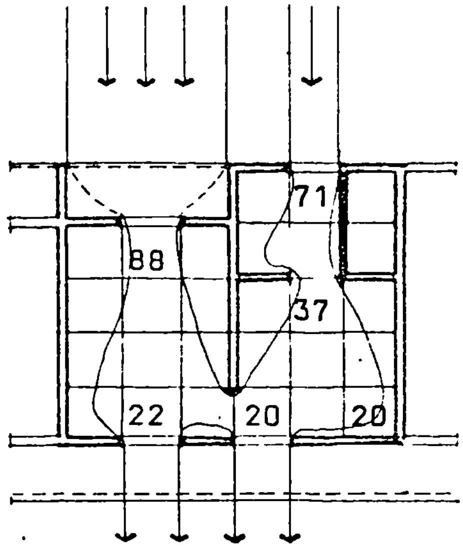
Figure (6.35) Detail of the internal flow model (multi cell, D).

model	inlet area a_1	outlet area a_2	partition area a_3	inlet/outlet area
D1	2/9	4/9	1/3	2/4
D2	2/9	3/9	4/9	2/3
D3	2/9	2/9	1/3	2/2
D4	2/9	2/9	1/3	2/2
D5	3/9	2/9	1/3	3/2
D6	4/9	2/9	1/3	4/2
D7	3/9	3/9	1/3	3/3
D8	2/9	3/9	1/3	2/3
D9	2/9	4/9	1/3	2/4
D10	2/9	2/9	1/3	2/2
D11	2/9	2/9	4/9	2/2
D12	4/9	3/9	1/3	4/3

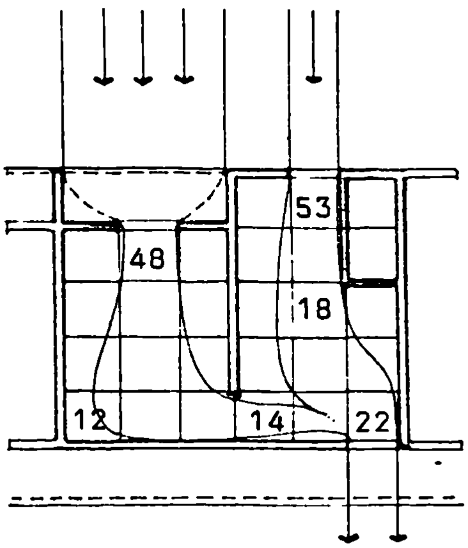
Table (6.5) Openings considered in models D.



B1/1
λ = 3/2

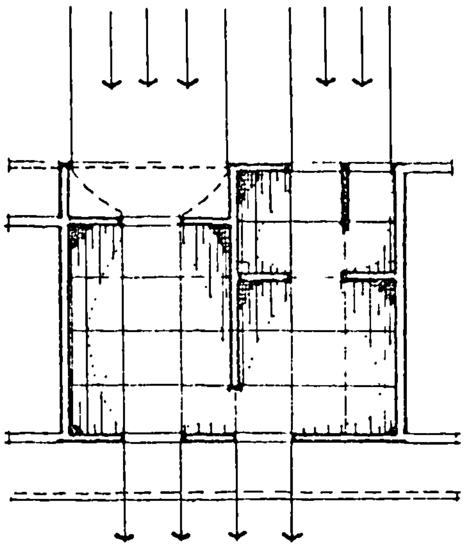


B1/2
λ = 1/1

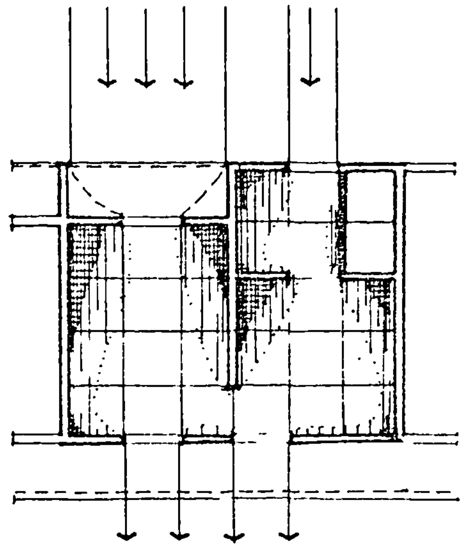


B1/8
λ = 2/1

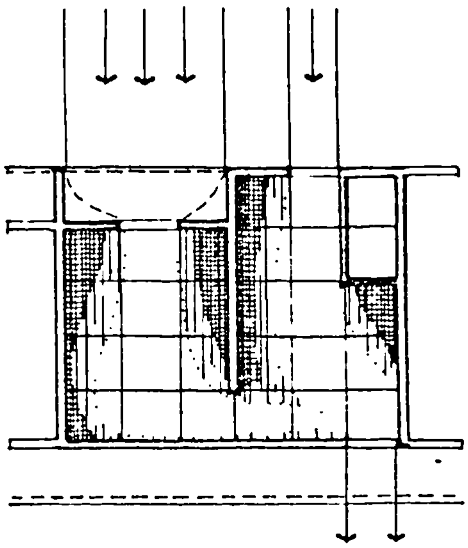
Figure (6.36a) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model B1 (angle of incidence $\theta = 0^{o}$).



B1/1
λ = 3/2



B1/2
λ = 1/1



B1/8
λ = 2/1

Figure (6.36b) The effect of inlet/outlet area (λ) on the flow pattern within multi-cell, Model B1 (angle of incidence $\theta = 0^o$).

air speed showed little variation from one model to another, C_{vn} = 20%, 21% and 22%. Near the corners of the right hand section of the models air speed observed was a function of λ with the most dynamic movements occurring in B/2 and the least dynamic in B/8, figure (6.37). Air speeds both near the inlet and across the space were higher for the smaller λ values than for the bigger λ values, indicating that a Venturi effect existed in a space comprising two adjacent cells as it did in a single cell space. Moreover, in the left hand cell of the models which were identical in B/2 and B/1, air speed near the inlet of B/2 had a value of C_{vn} = 88% while in B/1 it was only 80%, figure (6.37). This illustrated the effect that one cell can have on another even when both are open to the outside at either end. If the air movement had been estimated using equation (4-12) of the pressure coefficient method, reported in Chapter 4 Section 4.3.2, the effect of this phenomenon would have been ignored.

The inlet/outlet relative area (λ) was examined for models of category C comprised of four adjacent cells. Models C/1, C/2, C/7 and C/8 had λ values of 2/3, 1/1, 2/1 and 3/1 respectively, figure (6.38a & b). Firstly the models were set so that the angle of incidence had the value of $0 = 0^o$. Air speed near the inlet showed a similar relationship to λ as that observed in the first two model categories, indicating that the Venturi effect extended to cover this model category, figure (6.38a). The speed near the inlet of the left hand space had values of C_{vn} = 88%, 66%, 41% and 36% for the models having λ values 2/3, 1/1, 2/1 and 3/1, while the outlet speeds were C_{vn} = 20%, 25%, 30% and 31% respectively, figure (6.39). Air speed near the partition was higher for λ = 2/3 (C_{vn} = 37%) than for λ= 1/1 (C_{vn} = 32%) indicating a more dynamic air flow. Air speeds for λ= 2/1 and 3/1 within the leeward space were higher than those observed in the first two models of category C.

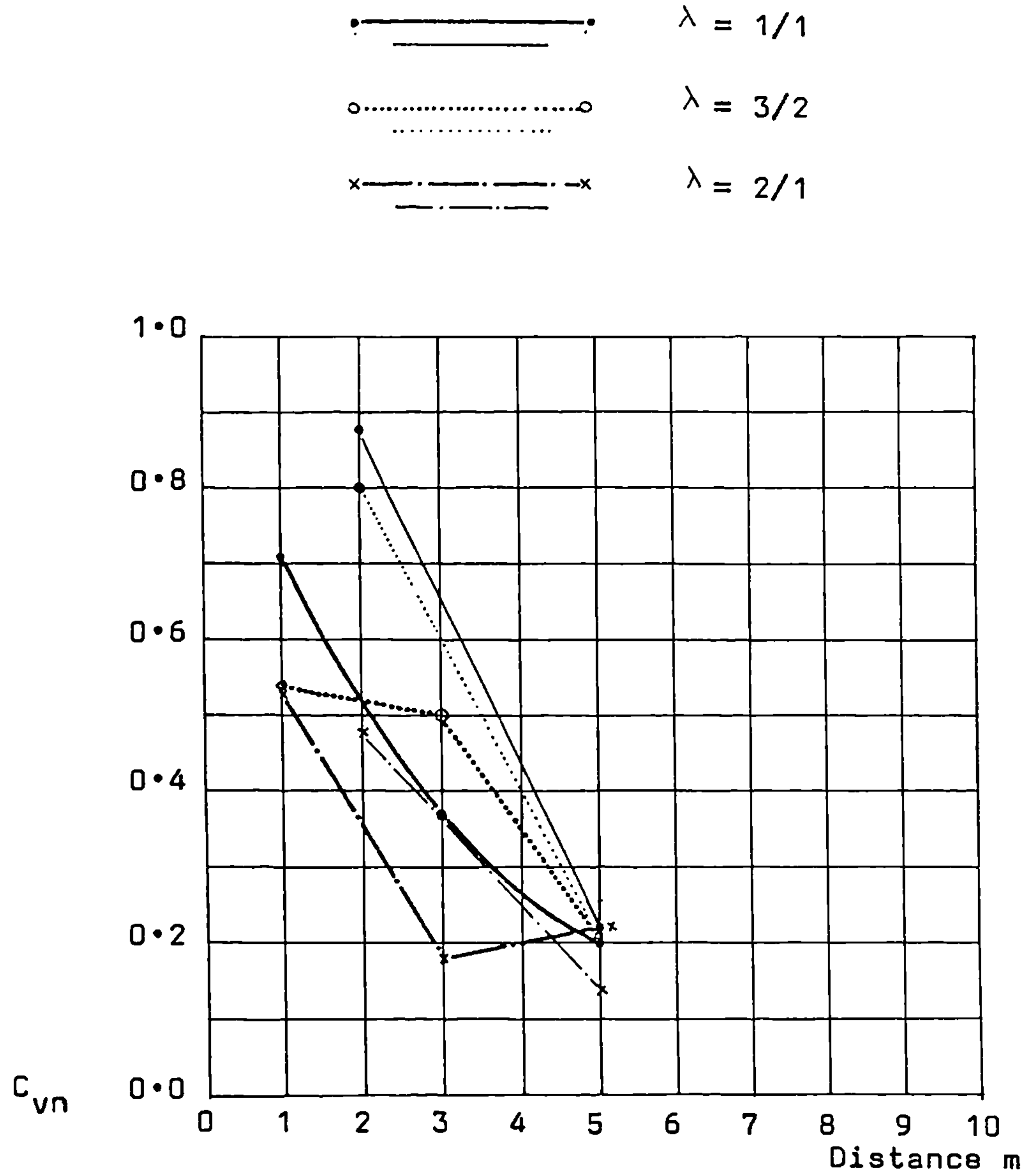


Figure (6.37) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell Model B1 (angle of incidence θ = 0^o).

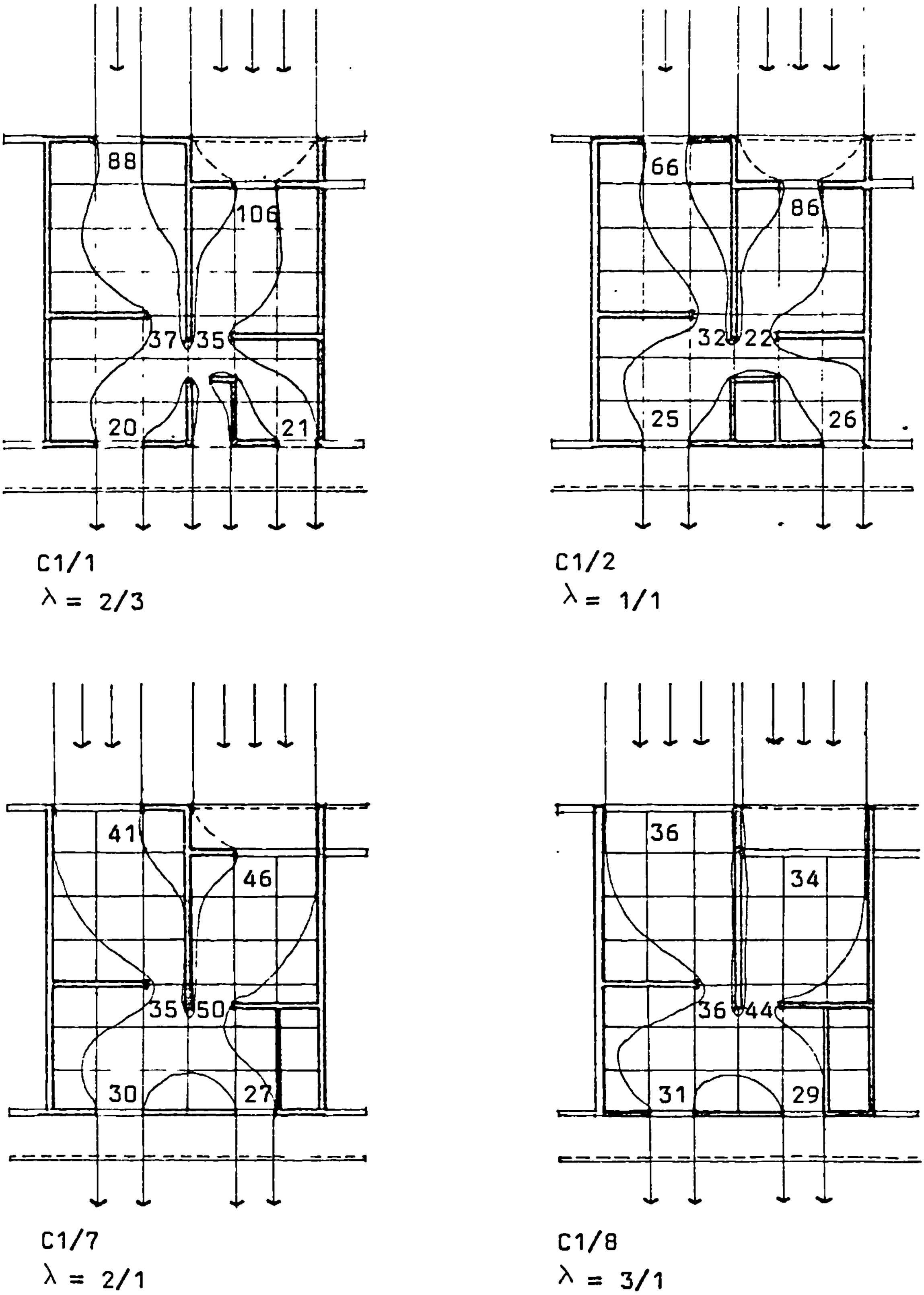
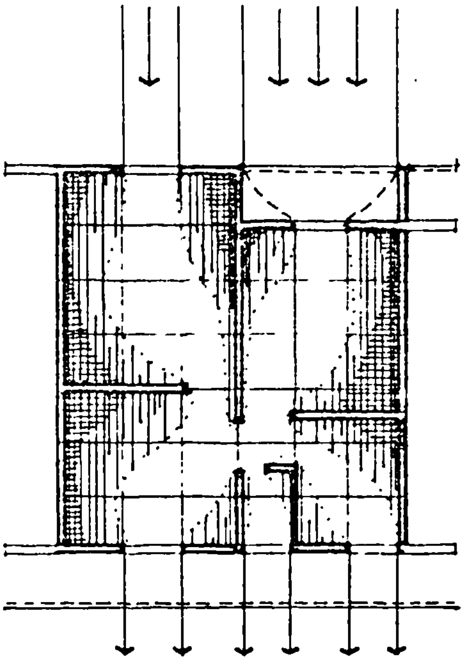
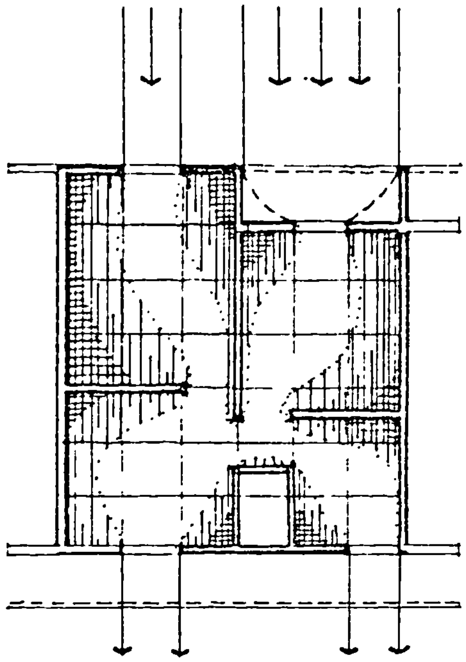


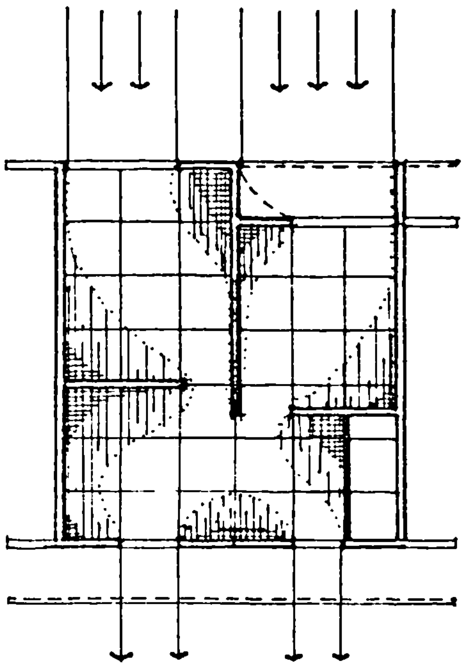
Figure (6.38 a) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model C1 (angle of incidence $\theta = 0^{o}$).



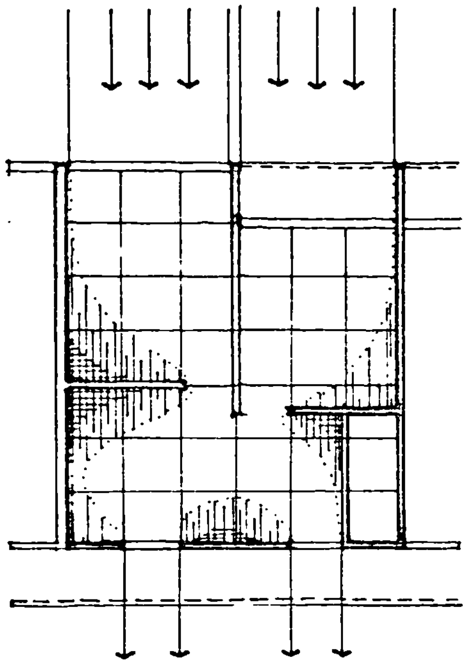
C1/1
λ = 2/3



C1/2
λ = 1/1



C1/7
λ = 2/1



C1/8
λ = 3/1

Figure (6.38b) The effect of inlet/outlet area on the flow pattern within mlti-cell, Model C1 (angle of incidence $\theta = 0^{o}$).

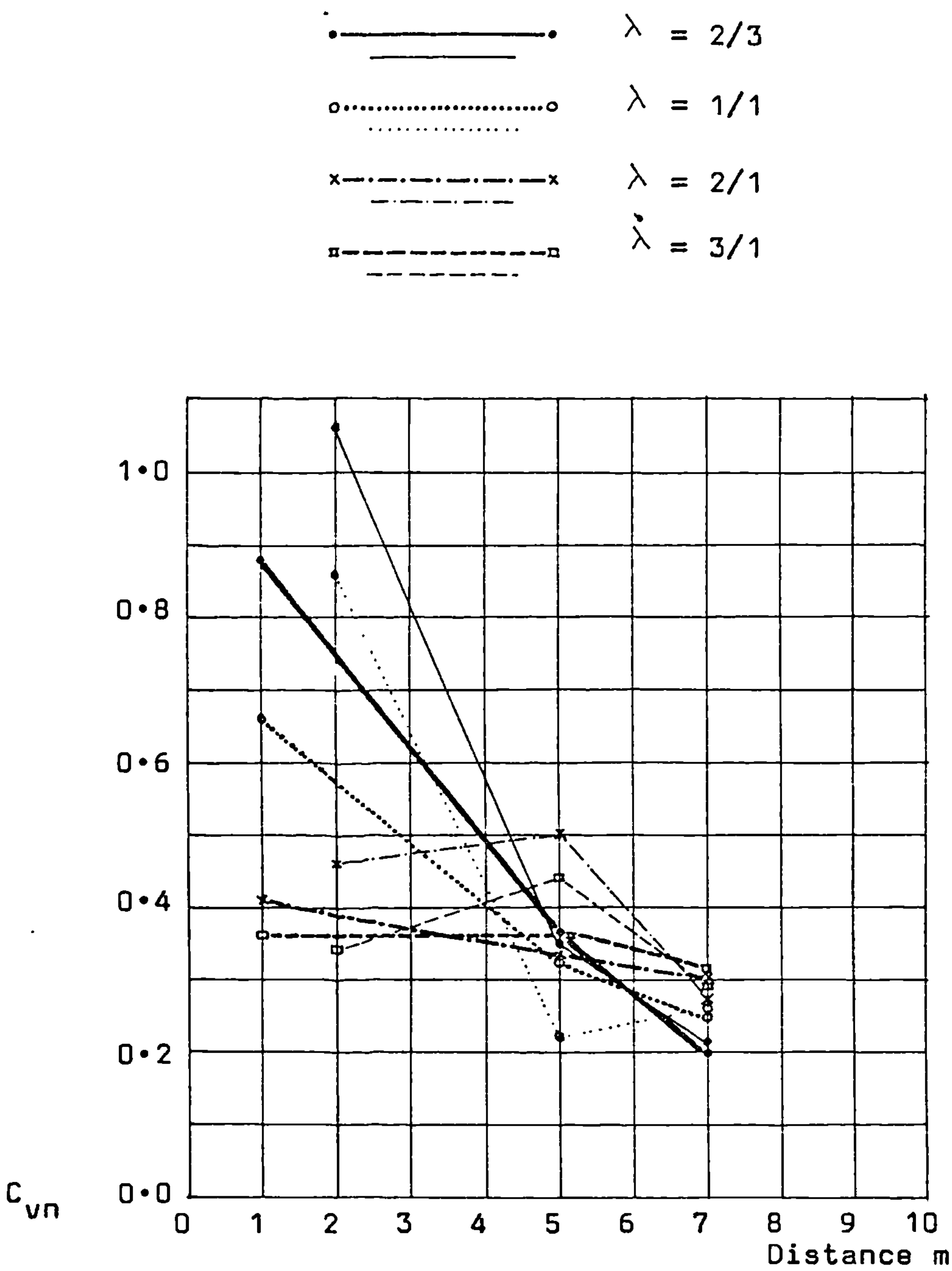
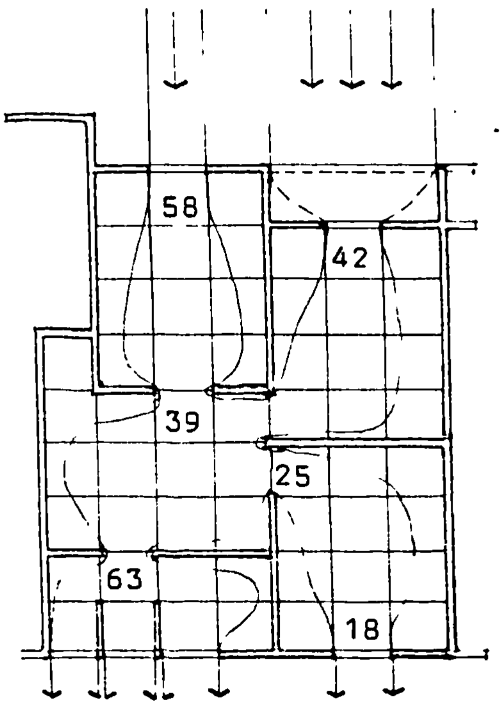


Figure (6.39) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell Model C1 (angle of incidence $\theta = 0^{o}$).

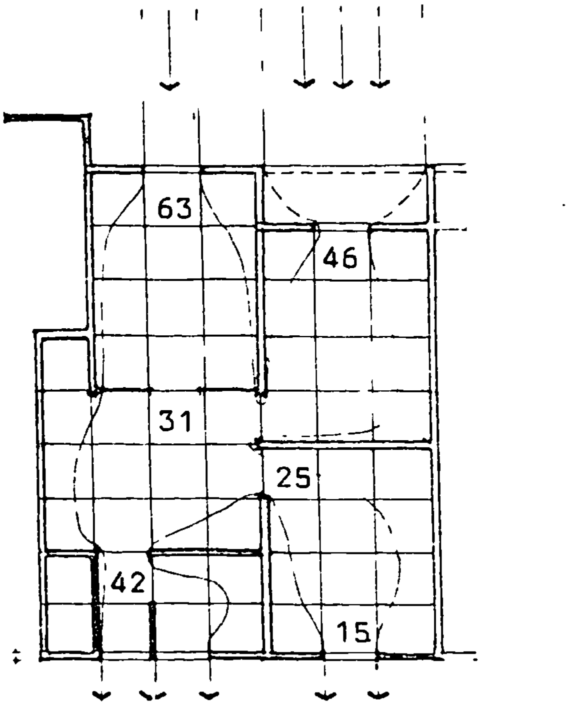
The change in the inlet/outlet relative area (λ) effect on the flow within models of category D was investigated in models D/1, D/2, D/3, D/5, D/6 and D/12 which had λ = 1/2, 2/3, 1/1, 3/2, 2/1 and 4/3 respectively, figure (6.40a to d). Air flow within the left hand section of the model was highest at the inlet, then suffered considerable reduction at the partition opening of the first space, followed by a marked increase in speed near the outlet. The magnitude of the air speed fluctuated with the change in λ.

For values of ranging between $1/2 < \lambda < 1/1$ the air speed near the inlet showed little change, but near the partition as well as near the outlet air speed was inversely proportional to λ, figure (6.40a & c), When the inlet/outlet relative area λ was further changed between $4/3 < \lambda < 2/1$ air speed near the inlet as well as that near the partition and the outlet, was inversely proportional to λ, figure (6.40b & d). In the right hand section of the model air speed was lower than that observed in the left, but showed a strong correlation to it as it fluctuated. It is note-worthy that the Venturi effect was less pronounced within this category of space arrangement and this may be due to two main reasons; first, thd distance between the inlet and the outlet which was approximately double that of the models of category B; second, the presence of the many partitions obstructing the flow, figure (6.41). Inertia forces dominated the windward space, while suction dominated movement in the leeward space. Within the centre space, air speed near the windward opening was always lower than that of the leeward opening. The magnitude of the air speed at the leeward opening of this space fluctuated in a similar manner to that of the outlet, indicating the strong effect of the outlet flow.

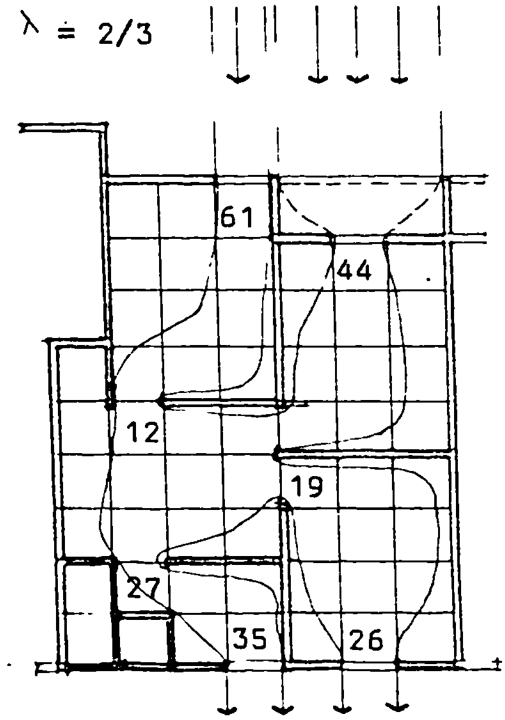
When angle of incidence θ was altered to $\theta = 45^{o}$ changes were observed in both the speed magnitude and flow direction within the models. Inside model category B the air



D1/1
λ = 1/2



D1/2
λ = 2/3



D1/3
λ = 1/1

Figure (6.40a) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model D1 (angle of incidence $\theta = 0^o$).

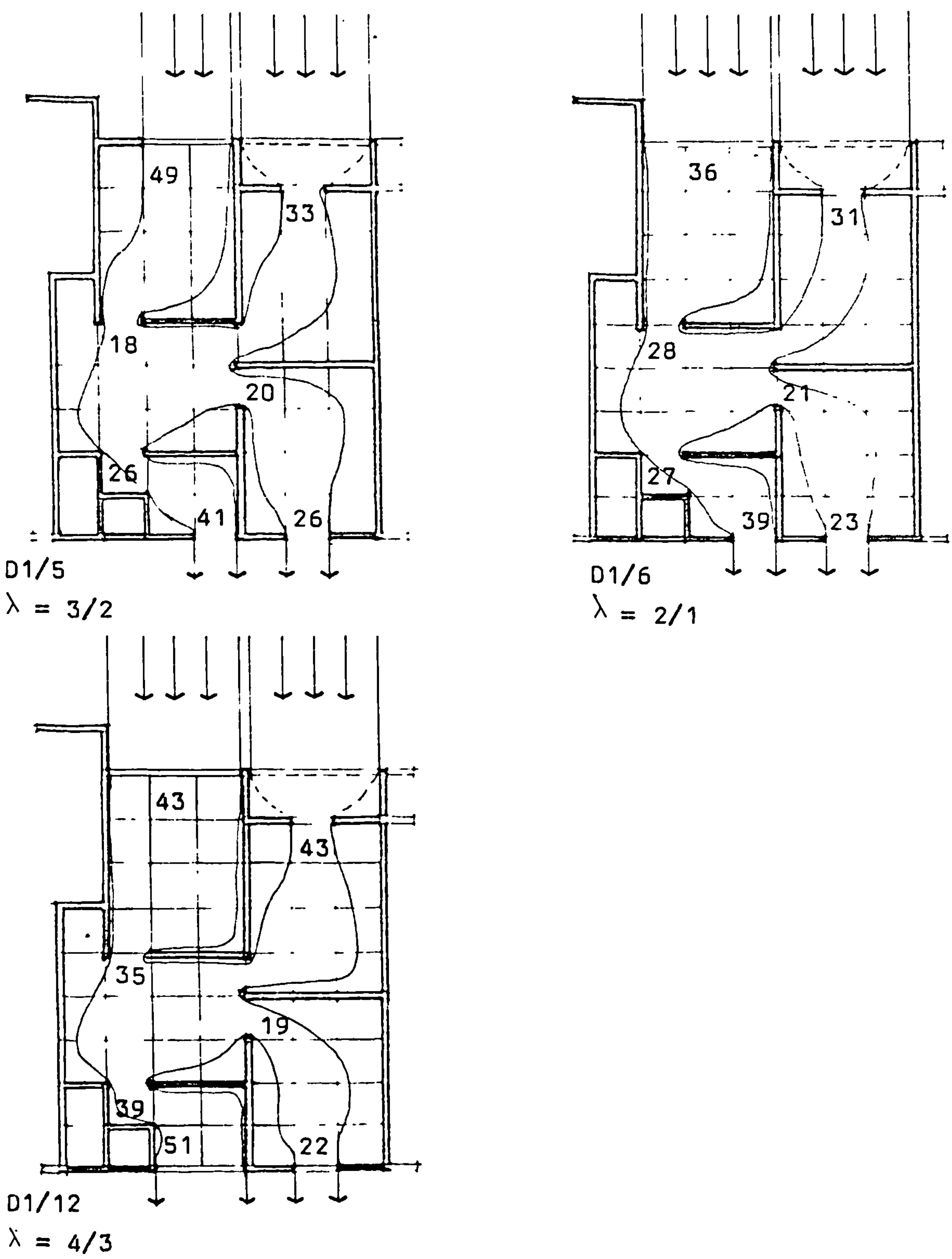
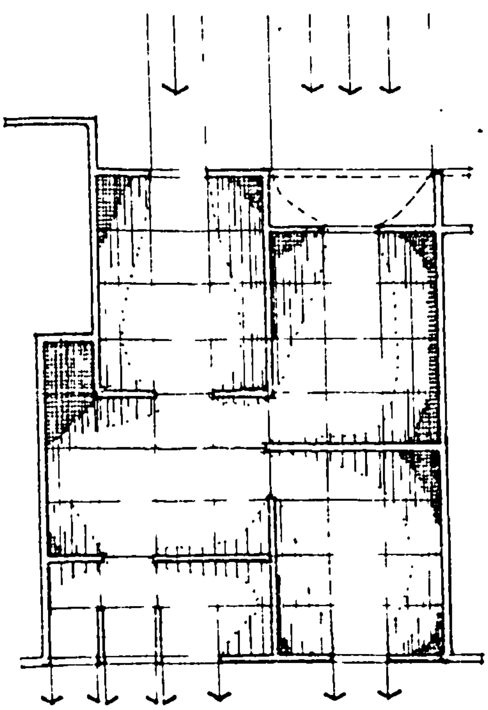
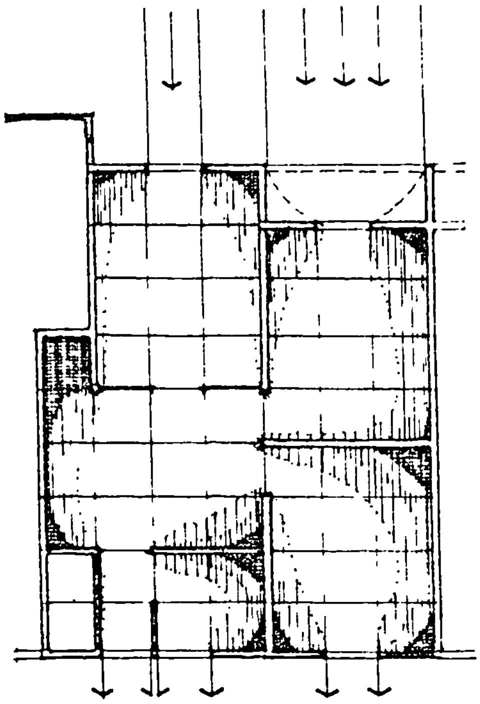


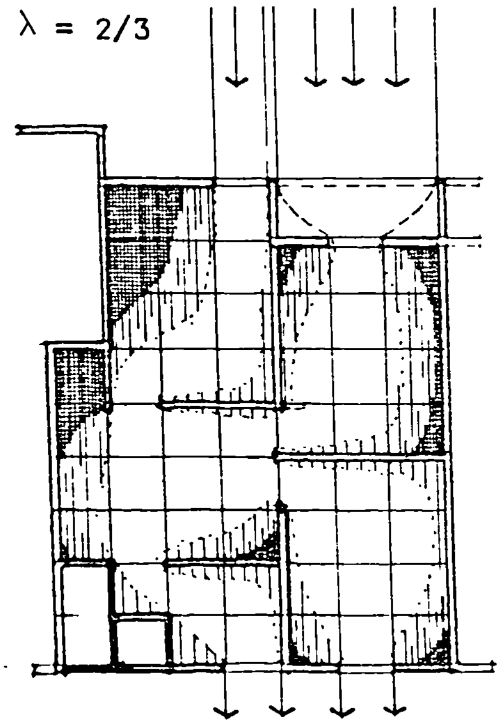
Figure (6.40b) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model D1 (angle of incidence $\theta = 0^{\circ}$).



D1/1
λ = 1/2



D1/2
λ = 2/3



D1/3
λ = 1/1

Figure (6.40 c) The effect of inlet/outlet area (λ) on the flow patterns within multi-cell, Model D1 (angle of incidence $\theta = 0^{o}$).

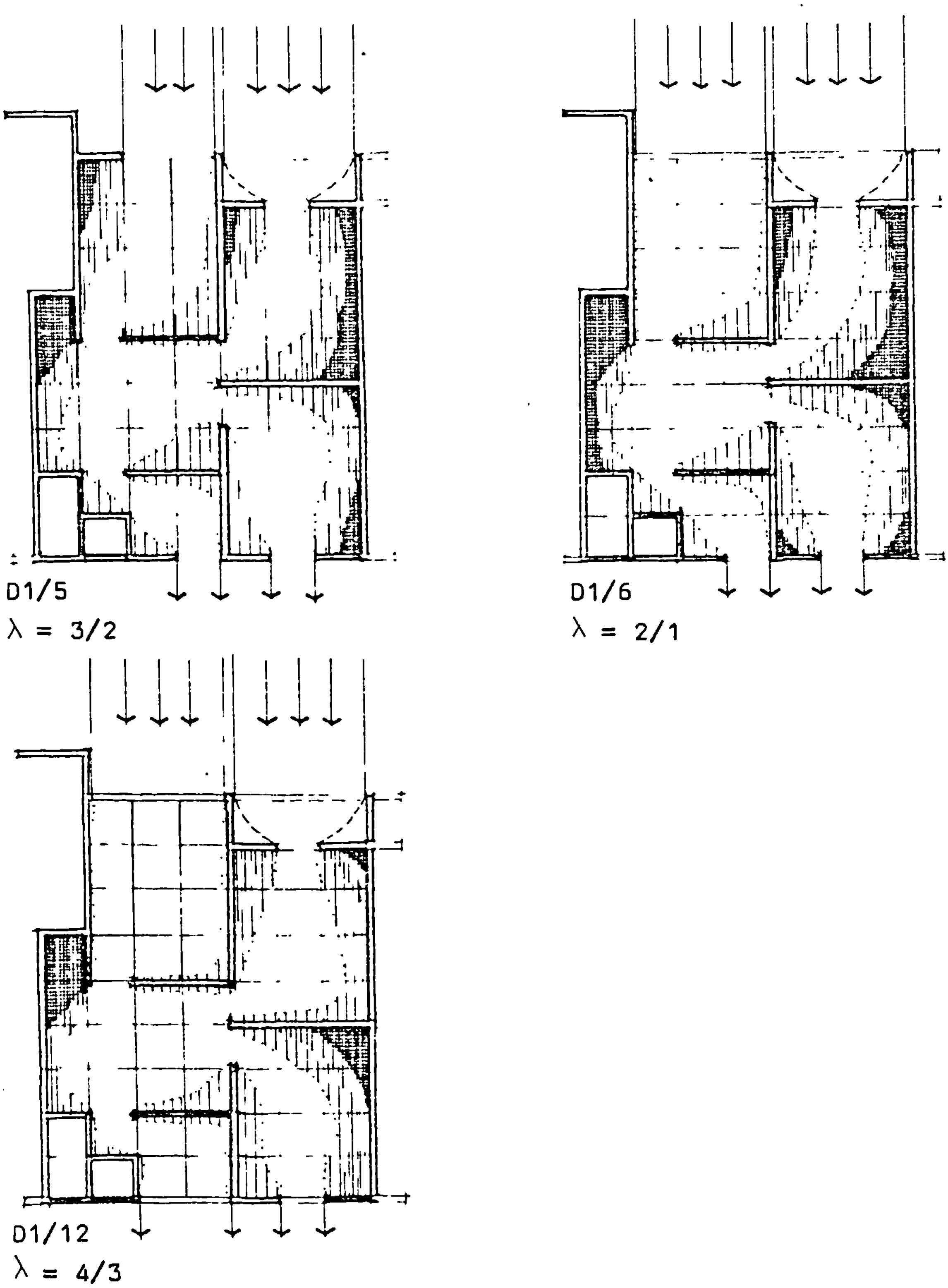


Figure (6.40d) The effect of inlet/outlet area (λ) on the flow pattern within multi-cell, Model D1 (angle of incidence $\theta = 0^o$).

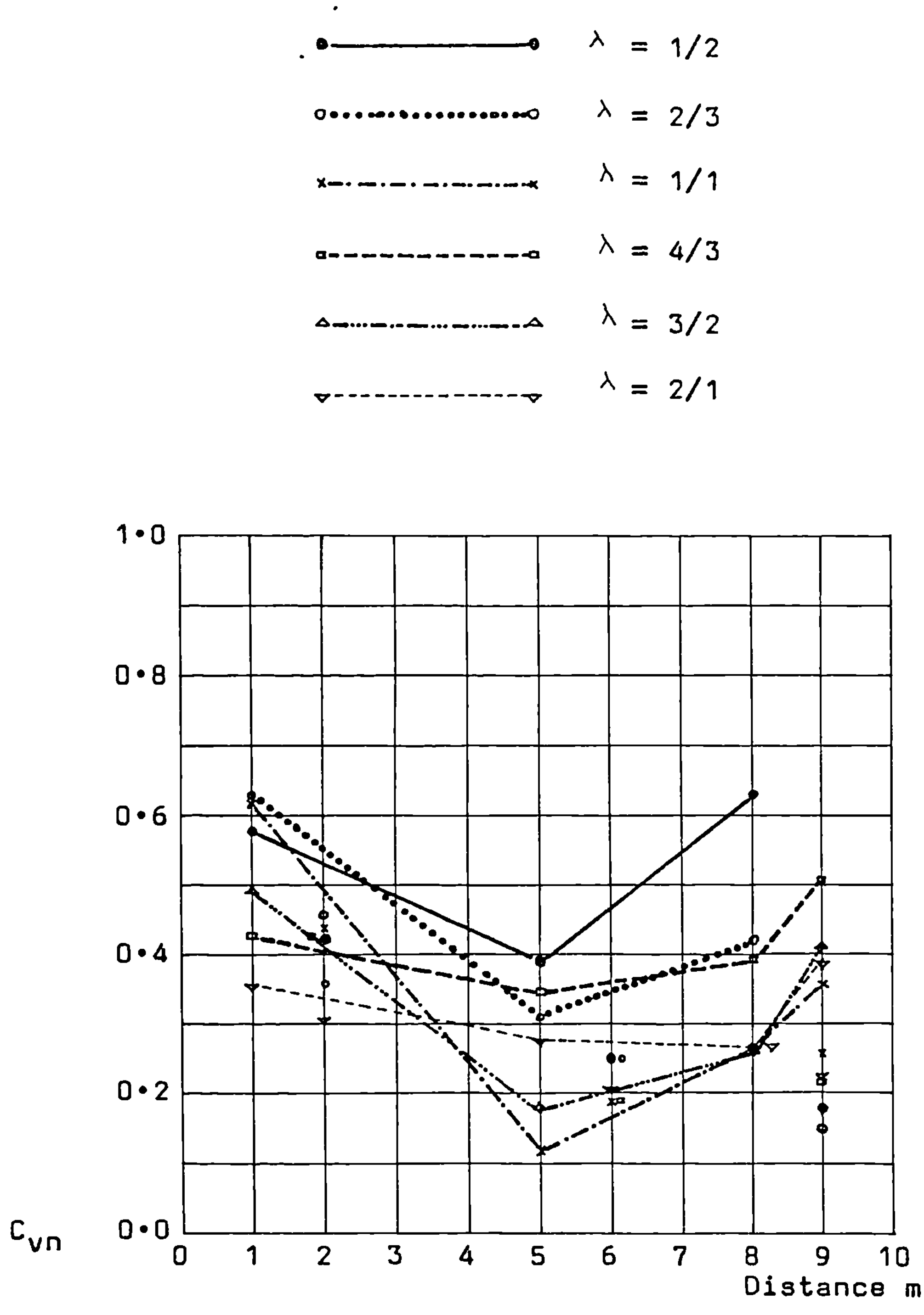


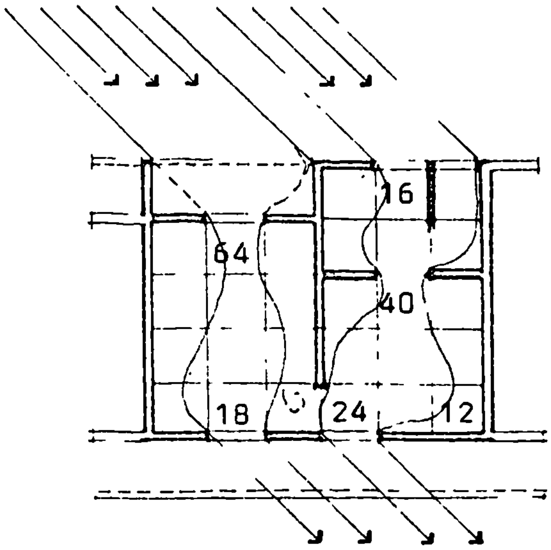
Figure (6.41) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell Model D1 (angle of incidence θ = 0°).

speed near the inlet was highest for λ = 1/1 where C_{vn} = 23% and lowest for λ = 2/1, C_{vn} = 7%, figure (6.42). This trend was also observed in the left hand section of the space. Near the outlet air speed was proportional to λ, C_{vn} was as high as 30% when λ = 2/1, 24% for λ = 3/2, and 15% for λ = 1/1, figure (6.43). These observations agreed with the trends observed in the single cell.

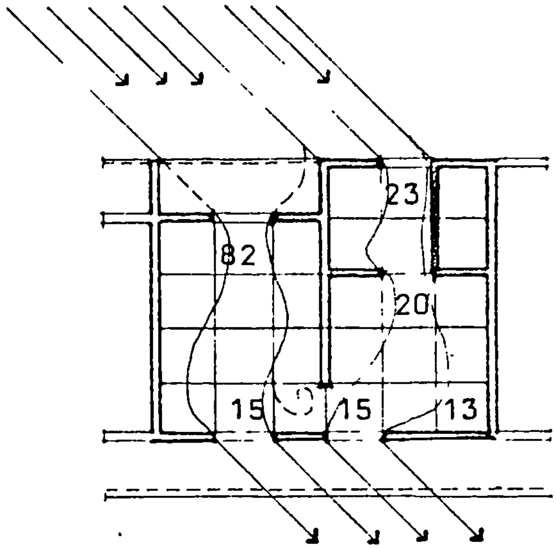
Inside the models of category C air speed followed a similar trend to that observed in model A for similar angles of incidence, figure (6.44). The air speed near the inlet was higher for λ = 2/3 than for λ = 1/1, indicating the existance of Venturi effect between $2/3 < \lambda < 1/1$. The air speed increased to 14% when λ = 2/1, and increased further for λ = 3/1 to 32%, figure (6.45). Near the outlet the air flow was proportional to λ showing similar behaviour to the previous models.

In model category D marked changes in the air flow were observed at angle of incidence $\theta = 45^o$. Within the left hand section of the model air speed near the inlet as well as the outlet was inversely proportional to λ; when λ ranged between $1/2 < \lambda < 1/1$, C_{vn} value varied between $29\% > C_{vn} > 10\%$ respectively. Near the inlet there was a considerable increase in C_{vn} value when λ = 3/2 to 56% and a decrease to 33% for λ = 2/1, figures (6.46a & b) and (6.47).

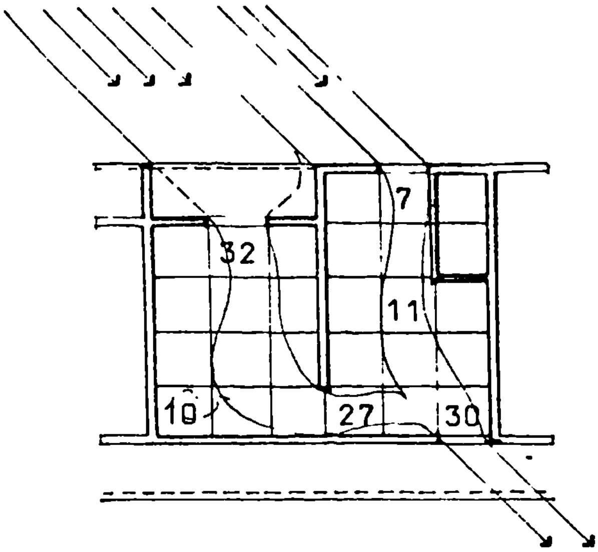
When angle of incidence θ was further changed to $\theta = 90^o$ the flow in model category B had relatively low speed, though higher than that observed for the single cell space having a similar inlet/outlet relative area (λ), fig.(6.48). In most of the models examined the speed distribution suggested that air flowed from one opening in a wall to the other in the opposite wall, figure (6.49). The fact that the inlet/outlet distance in model category B was less than that of the single cell may have contributed in



B2/1
$\lambda = 3/2$



B2/2
$\lambda = 1/1$



B2/8
$\lambda = 2/1$

Figure (6.42) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model B2 (angle of incidence $\theta = 45^{o}$).

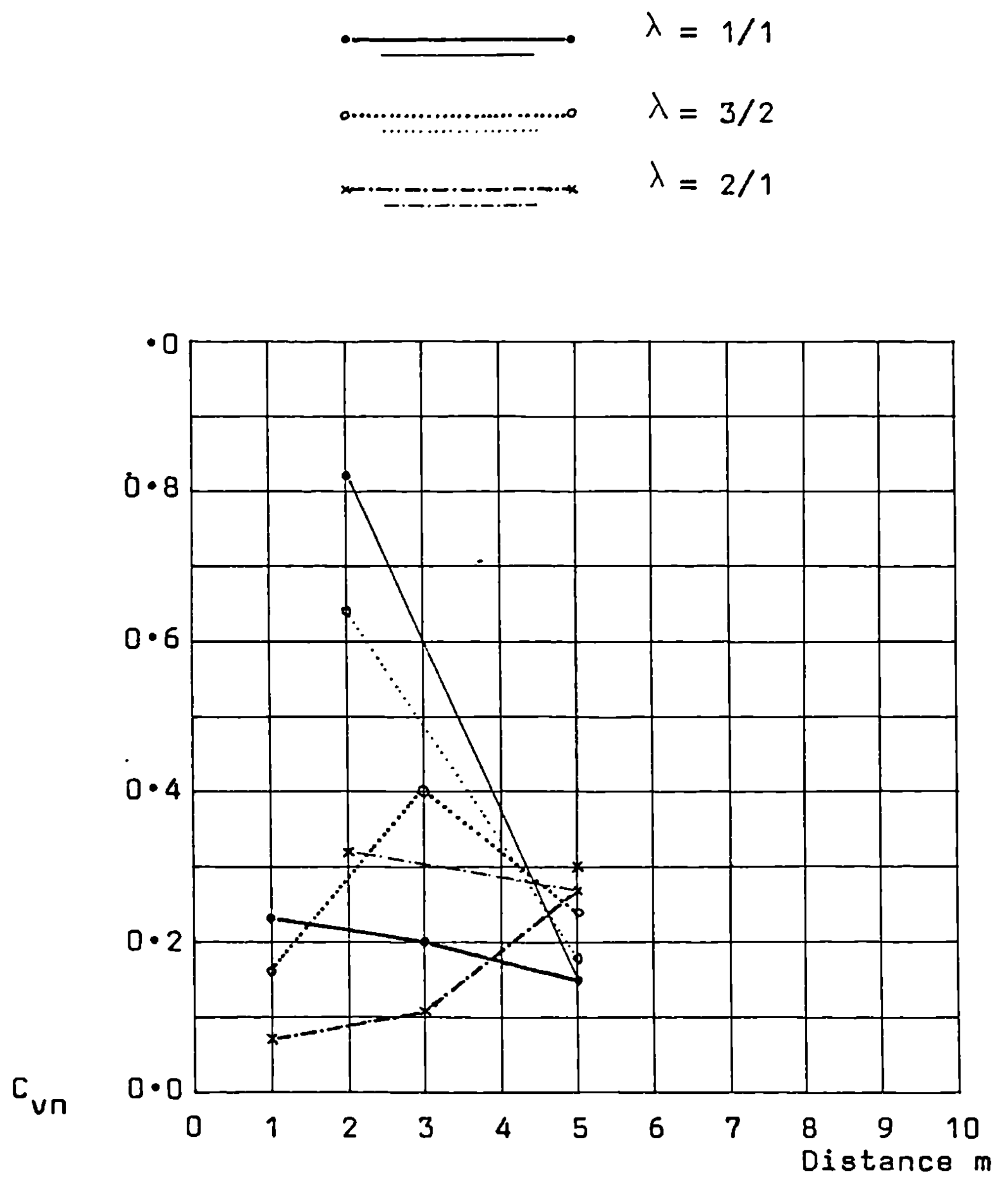


Figure (6.43) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell, Model B2 (angle of incidence θ = 45°).

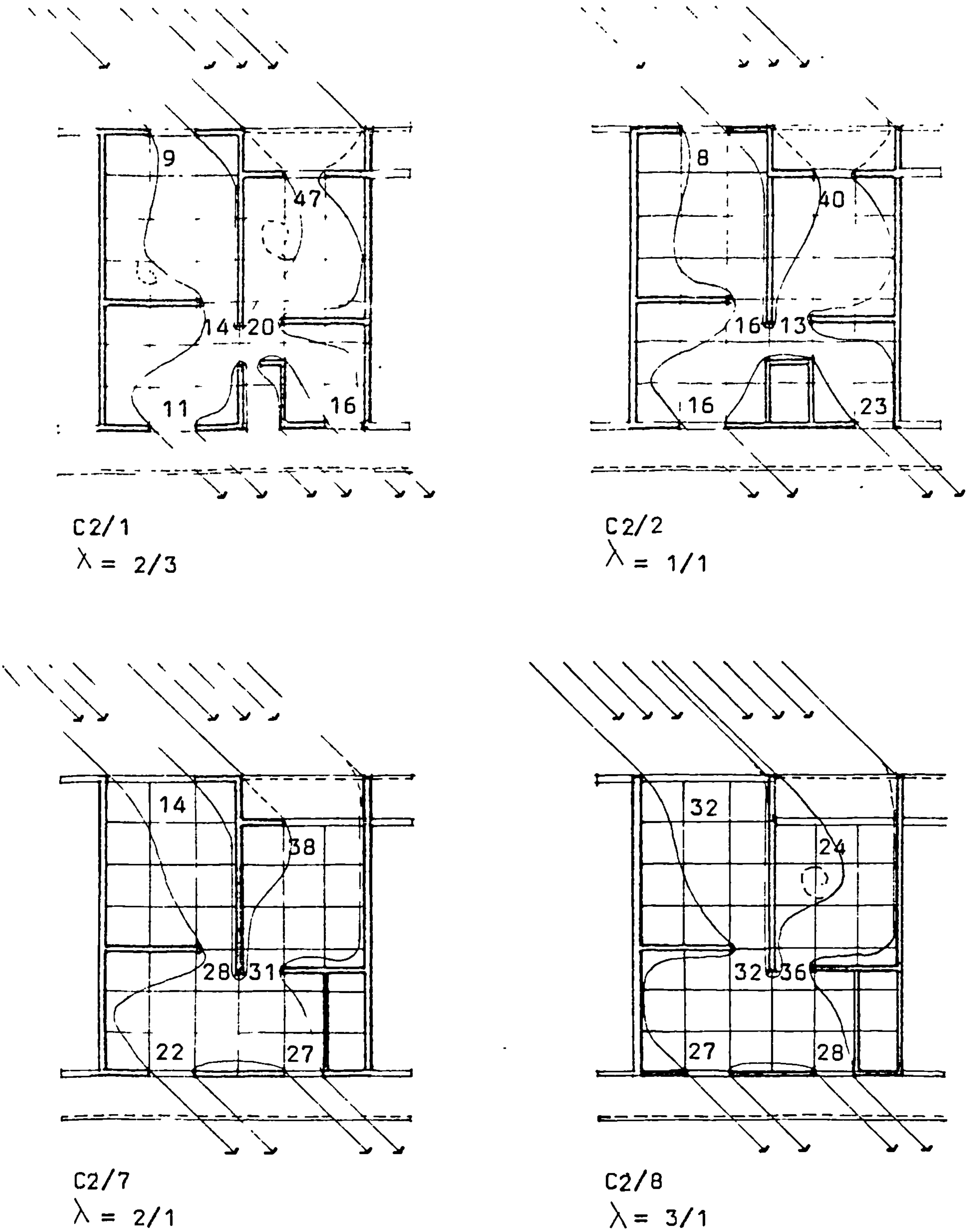


Figure (6.44) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model C2 (angle of incidence θ = 45°).

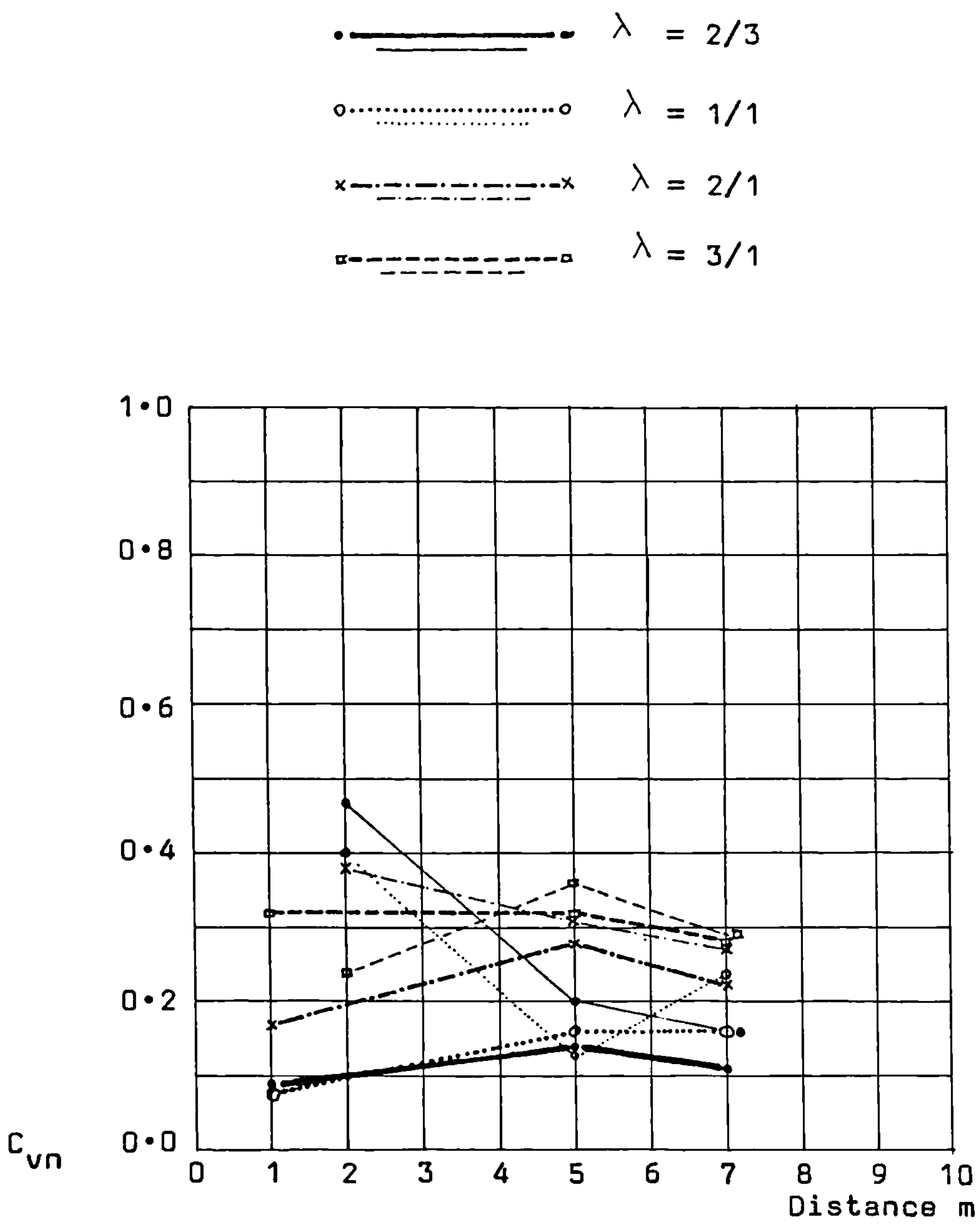


Figure (6.45) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell Model C2 (angle of incidence θ = 45°).

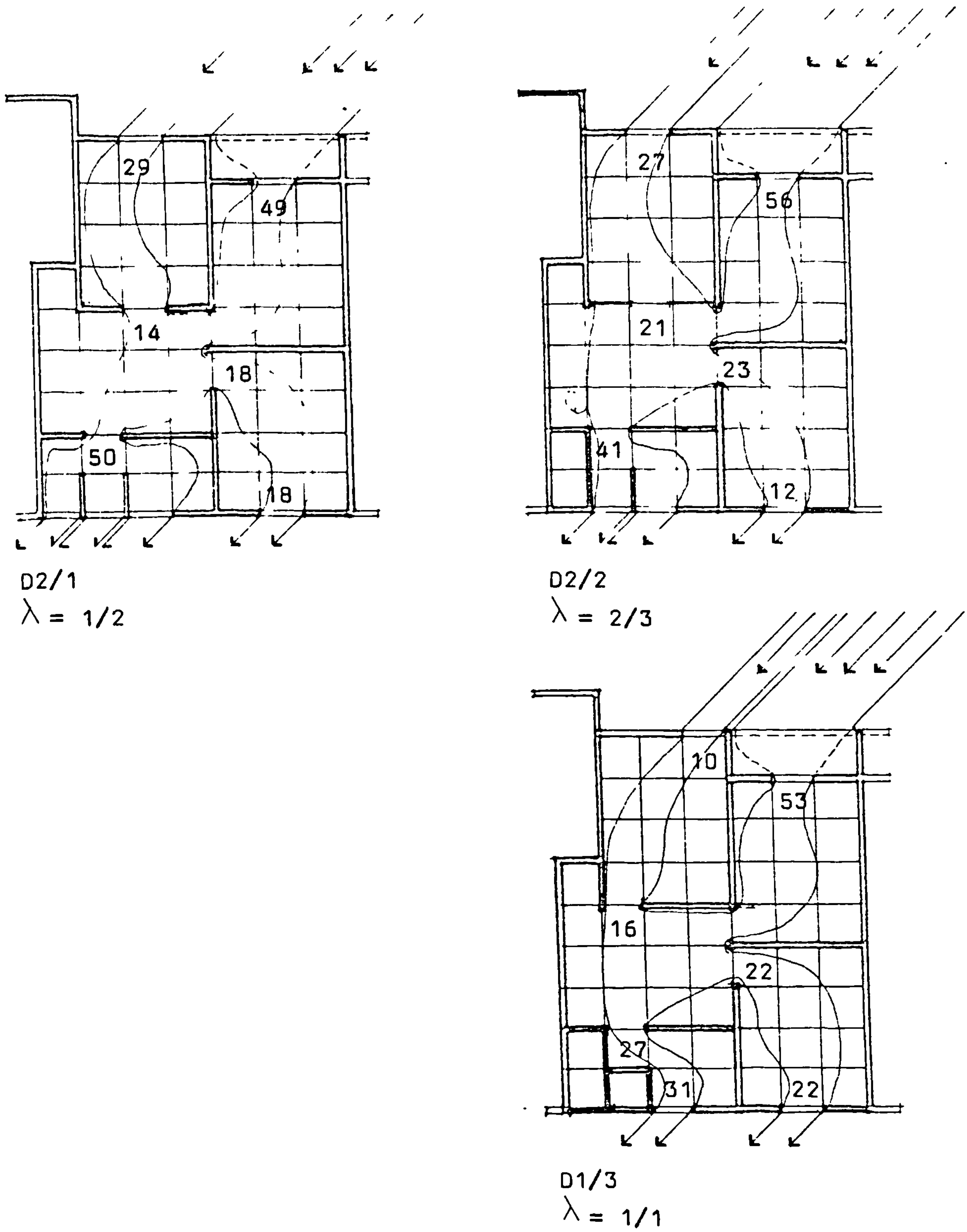
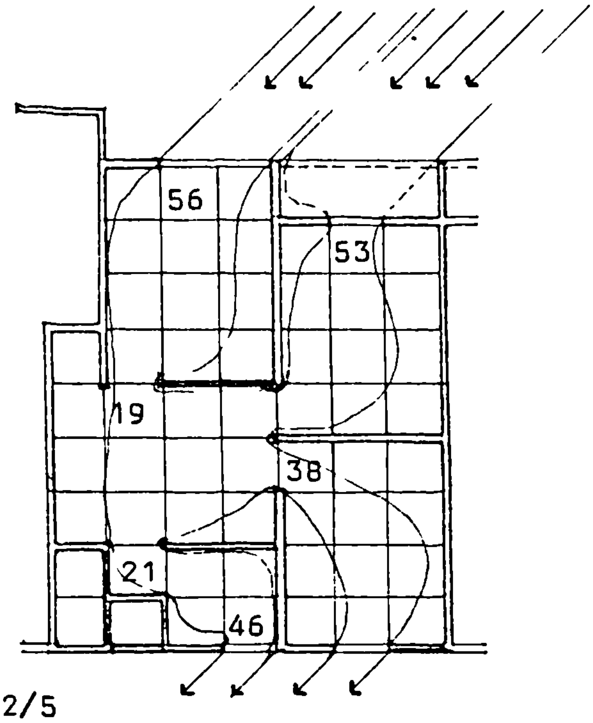
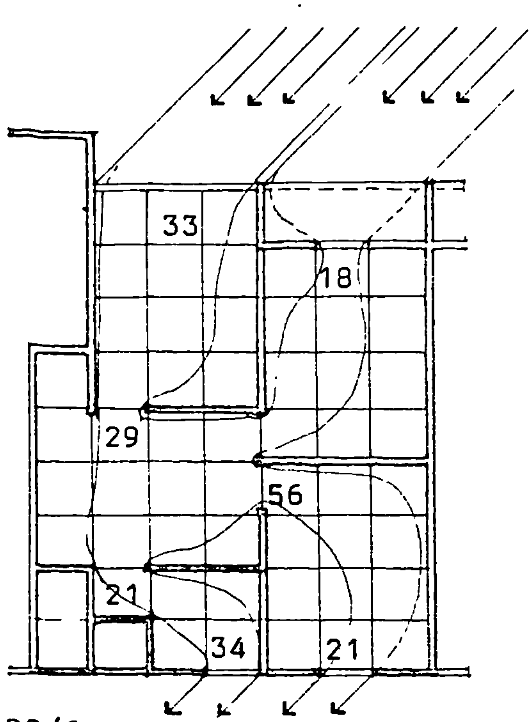


Figure (6.46a) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model D2 (angle of incidence $\theta = 45^{o}$).



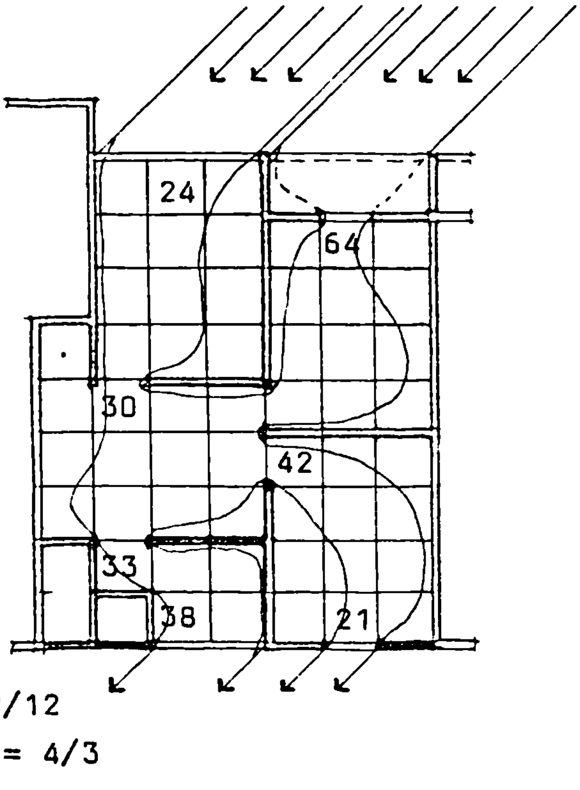
D2/5

$\lambda = 3/2$



D2/6

$\lambda = 2/1$



D2/12

$\lambda = 4/3$

Figure (6.46b) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model D2 (angle of incidence $\theta = 45^{o}$).

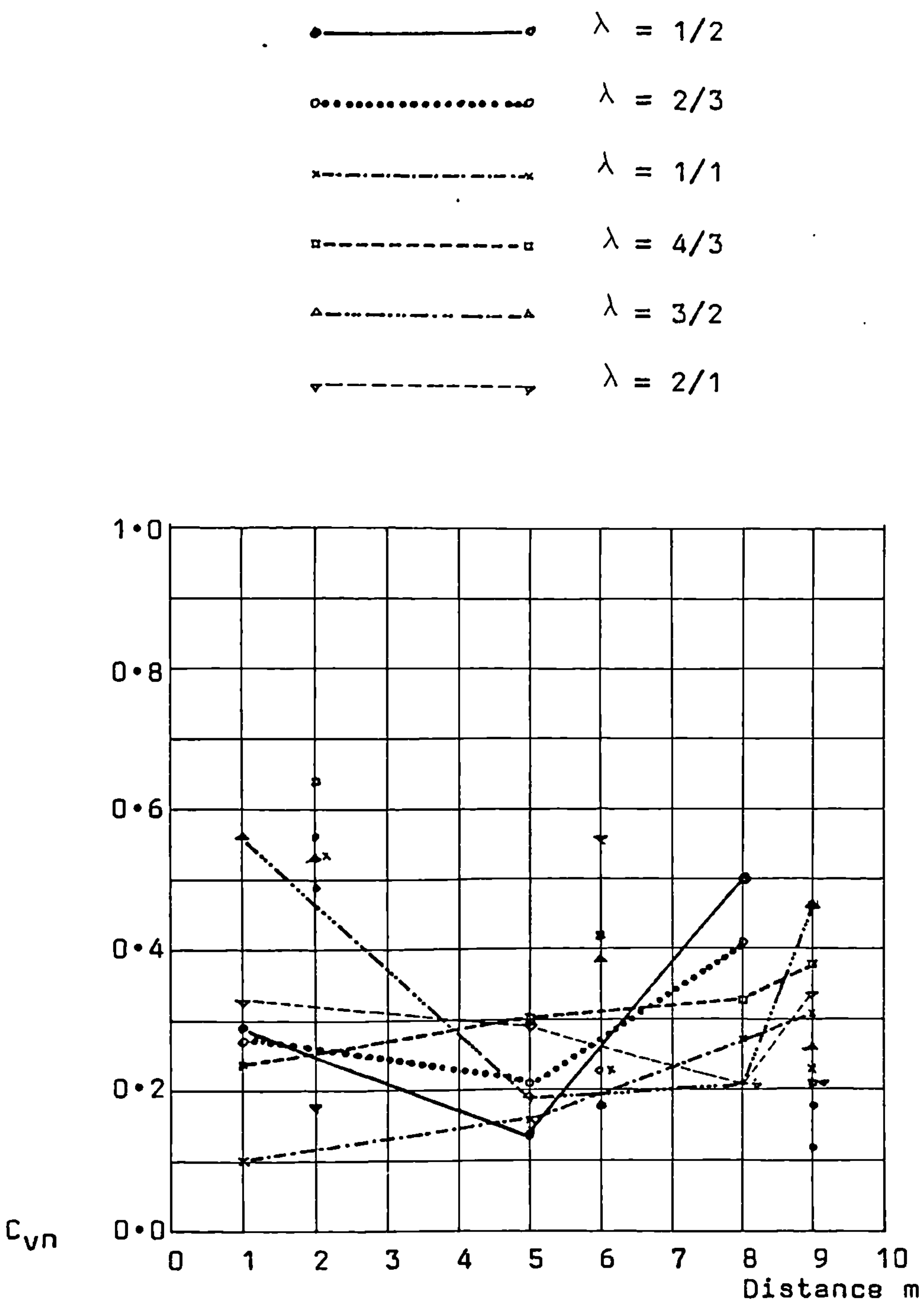
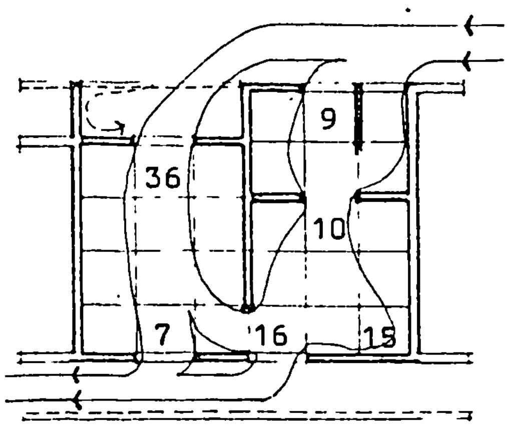
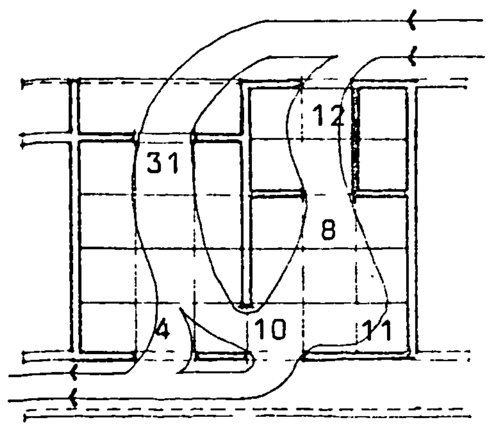


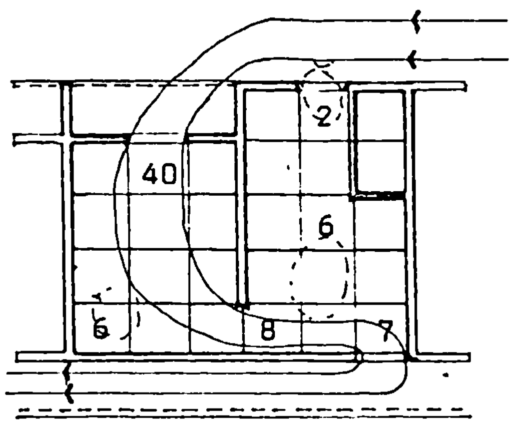
Figure (6.47) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell Model D2 (angle of incidence θ = 45°).



B4/1
λ = 3/2



B4/2
λ = 1/1



B4/8
λ = 2/1

Figure (6.48) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model B4 (angle of incidence $\theta = 90^{o}$).

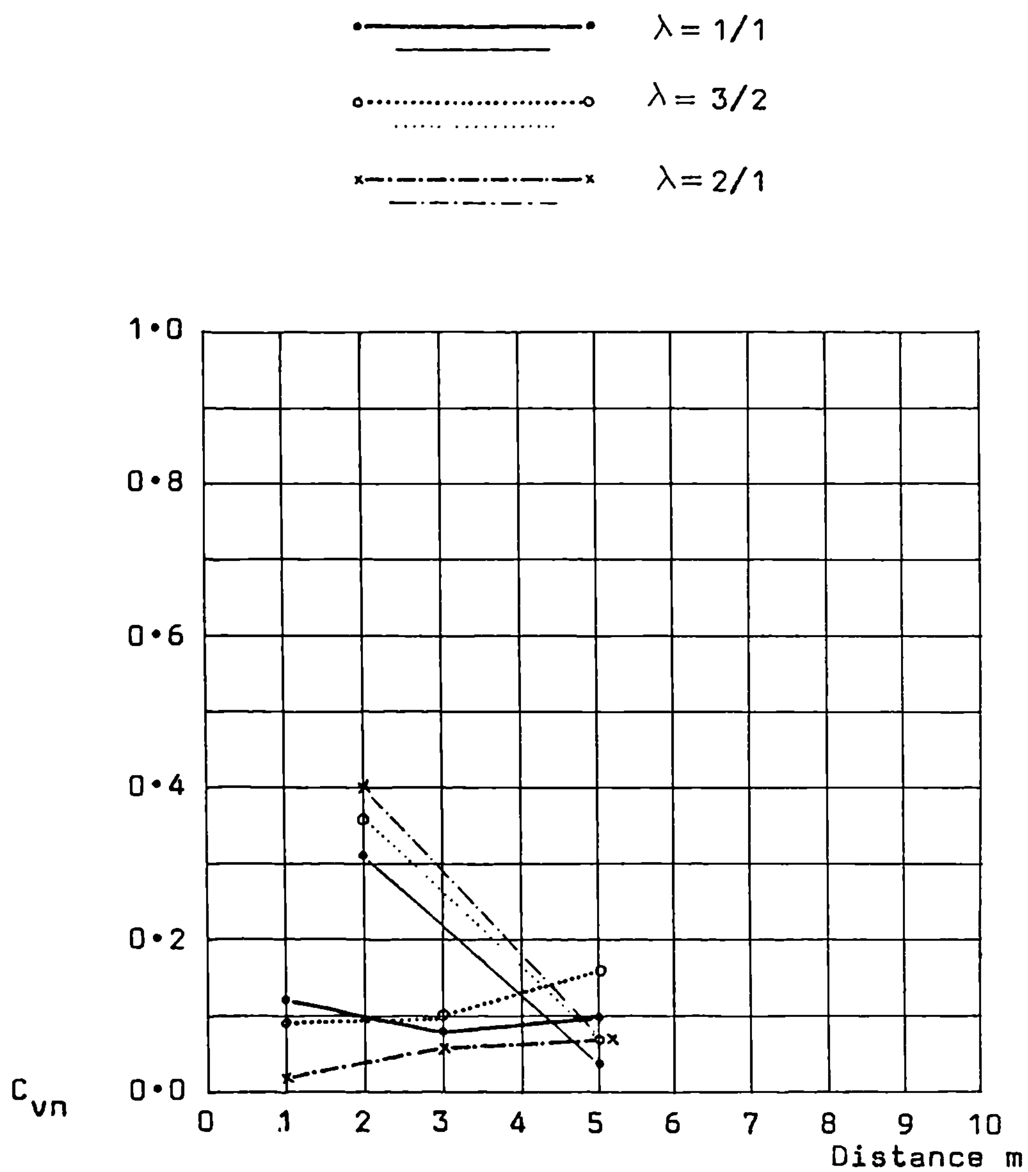


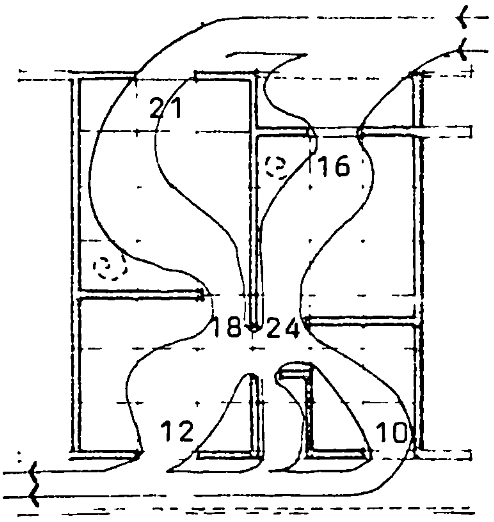
Figure (6.49) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell, Model B4 (angle of incidence $\theta = 90^{o}$).

producing higher speeds, since the speed was a function of its generating forces. Also the presence of a large face with two inlets and outlets may have reinforced this trend.

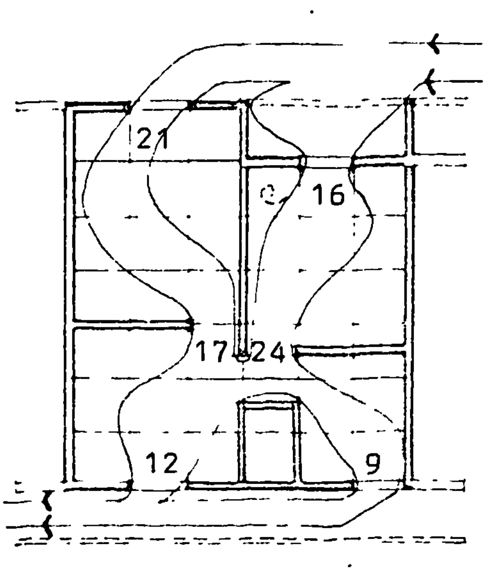
Within models of category C the air speed observed for $\theta = 90^{o}$ was lower than those for $\theta = 0^{o}$ and $\theta = 45^{o}$, but was more dynamic than those for models A and B with similar λ values, figure (6.50). Air speeds recorded near the openings between the consecutive spaces were fairly high, figure (6.51), compared with speeds at the external openings. This indicated a high rate of air flow between the two spaces. The speeds were higher for the higher λ values.

In models of category D the flow was more dynamic than that in any of the previously examined models for the different space categories. The speed near both the inlet and the outlet was inversely proportional to λ value for models with λ varying between $1/2 < \lambda < 1/1$, figures (6.52a) and (6.53). Air speed near the inlet showed a remarkable increase, from C_{vn} = 34% for $\lambda = 1/2$, to C_{vn} = 70% for $\lambda = 3/2$, then decreased to C_{vn} = 32% for $\lambda = 2/1$, figure (6.52b). At the outlet air speed continued to decrease even with the increase in speed at the inlet. Air speed at the windward opening of the middle space showed considerable increase with increase in λ value. Near the outlet air speed was inversely proportional to λ in all cases. The air inside a multi-cell of this category showed a dynamic flow which decreased slightly with an increase in the distance from the inlet.

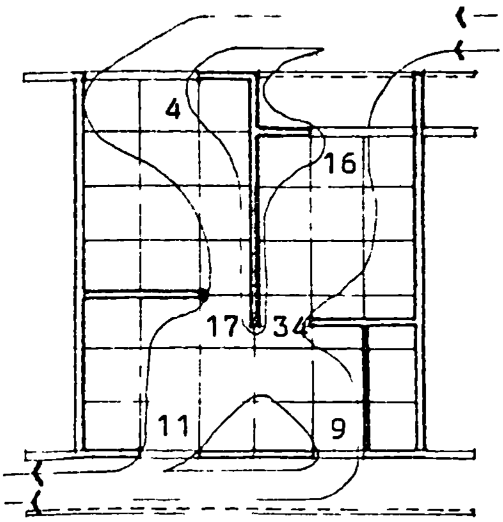
The change in the angle of incidence produced differences in the flow pattern within the space, similar to those observed near both the inlet and the outlet. Within model category B marked changes were observed. When angle of incidence was $\theta = -45^{o}$ air speed near the partition was higher than that near the outlet, which was in turn higher than that recorded at the inlet, figures (6.54) to (6.56).



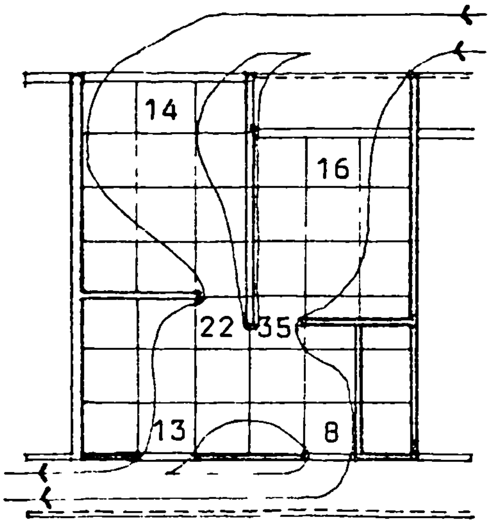
C1/1
$\lambda = 2/3$



C1/2
$\lambda = 1/1$



C1/7
$\lambda = 2/1$



C1/8
$\lambda = 3/1$

Figure (6.50) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model C1 (angle of incidence $\theta = 90^{\circ}$).

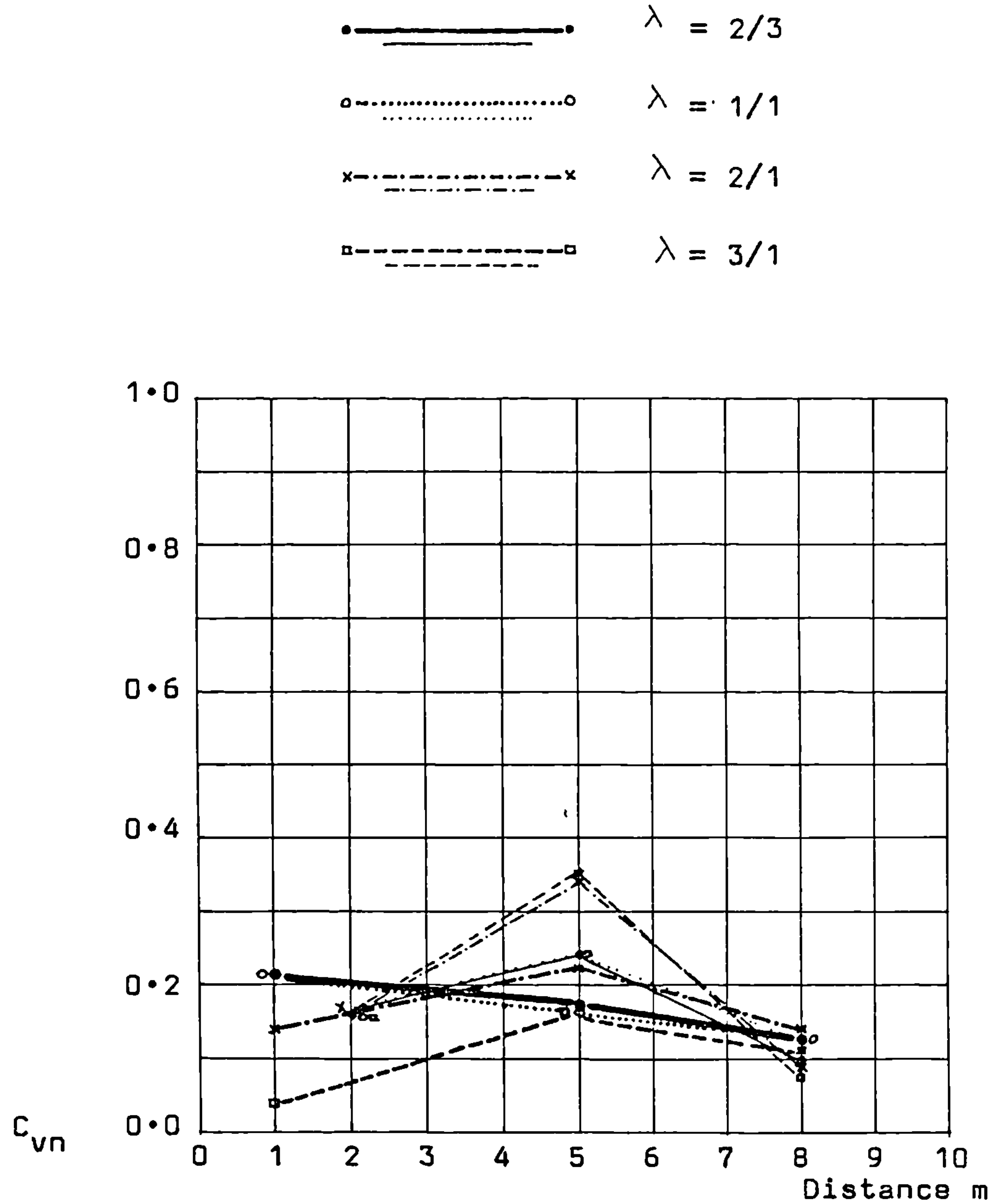
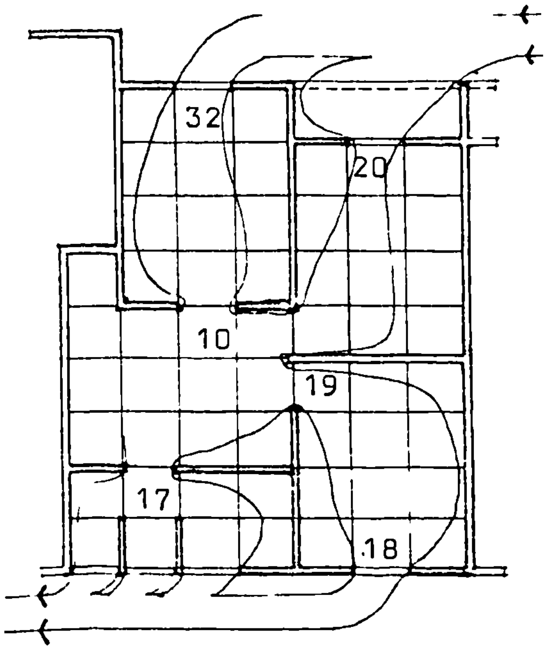
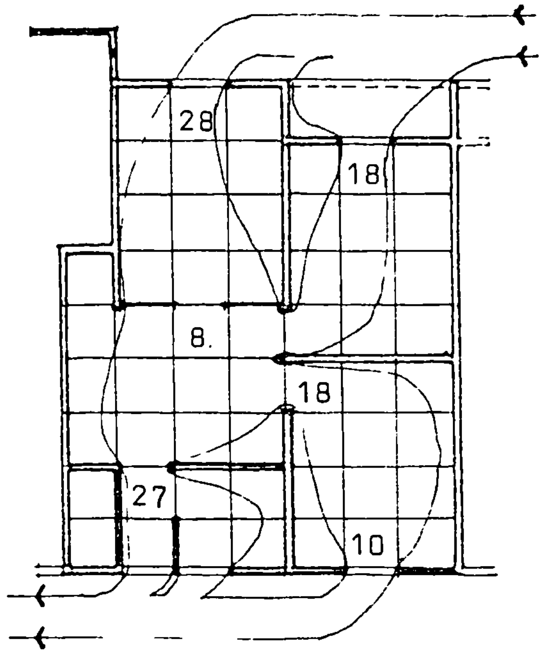


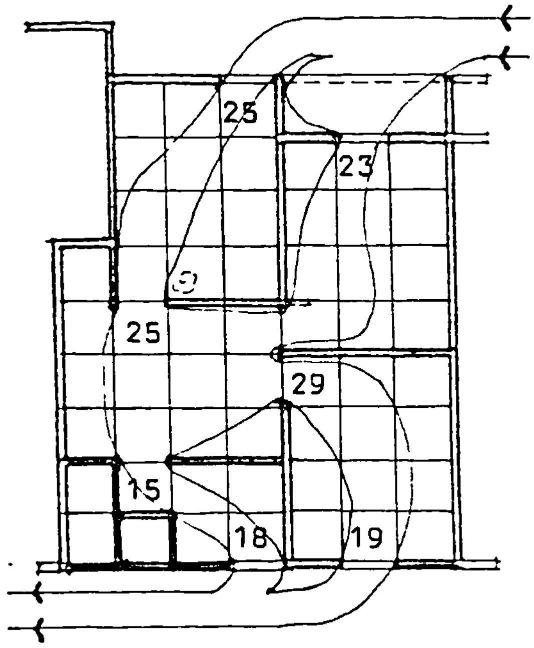
Figure (6.51) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell Model C4 (angle of incidence θ = 90°).



D4/1
λ = 1/2

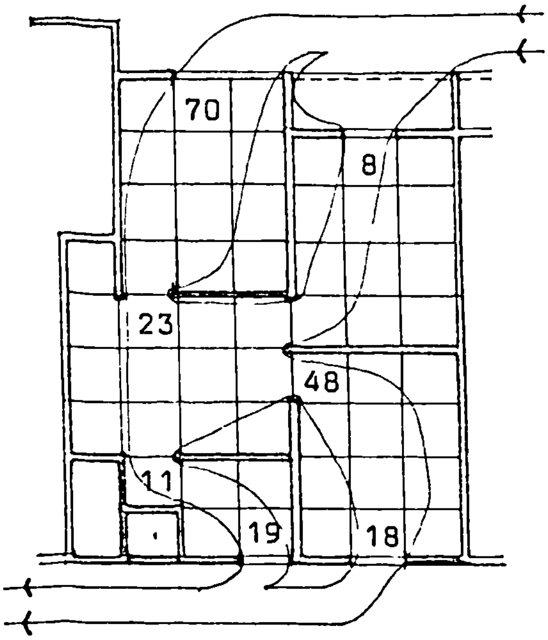


D4/2
λ = 2/3

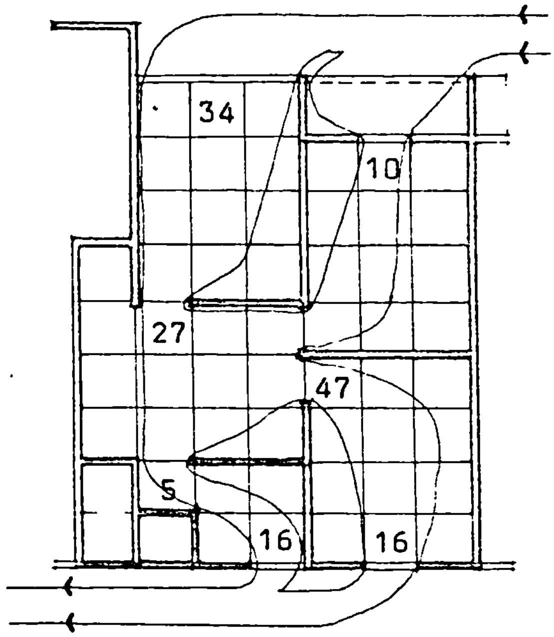


D4/3
λ = 1/1

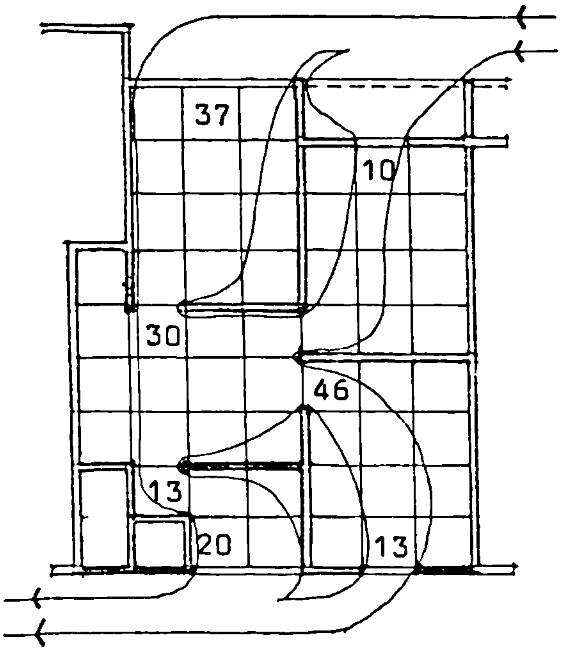
Figure (6.52a) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model D4 (angle of incidence $\theta = 90^{0}$).



D4/5
$\lambda = 3/2$



D4/6
$\lambda = 2/1$



D4/12
$\lambda = 4/3$

Figure (6.52b) The effect of inlet/outlet area (λ) on the flow within multi-cell, Model D4 (angle of incidence $\theta = 90^{\circ}$).

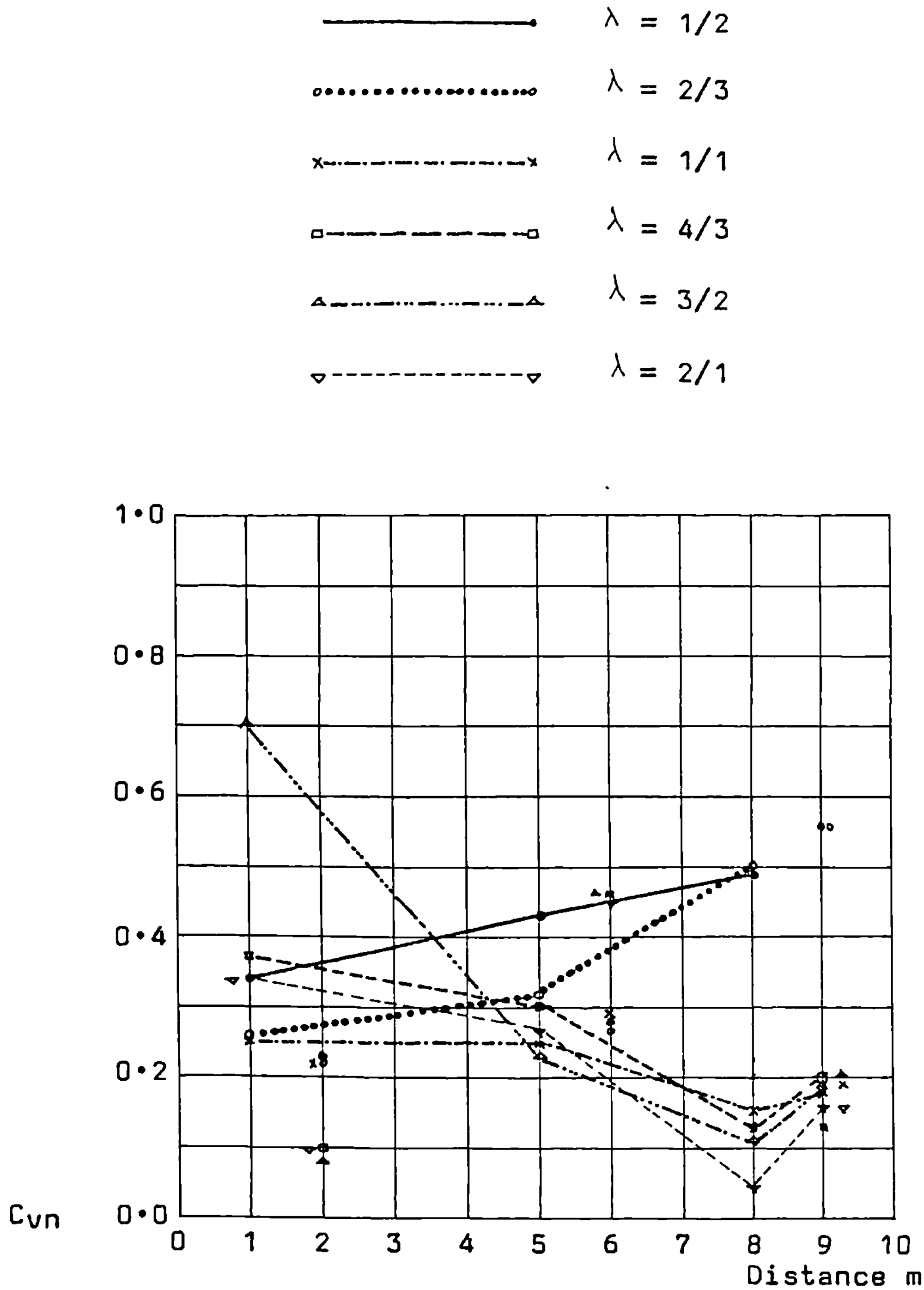


Figure (6.53) The change in C_{vn} in relation to inlet/outlet distance and λ for multi-cell Model D4 (angle of incidence θ = 90^0).

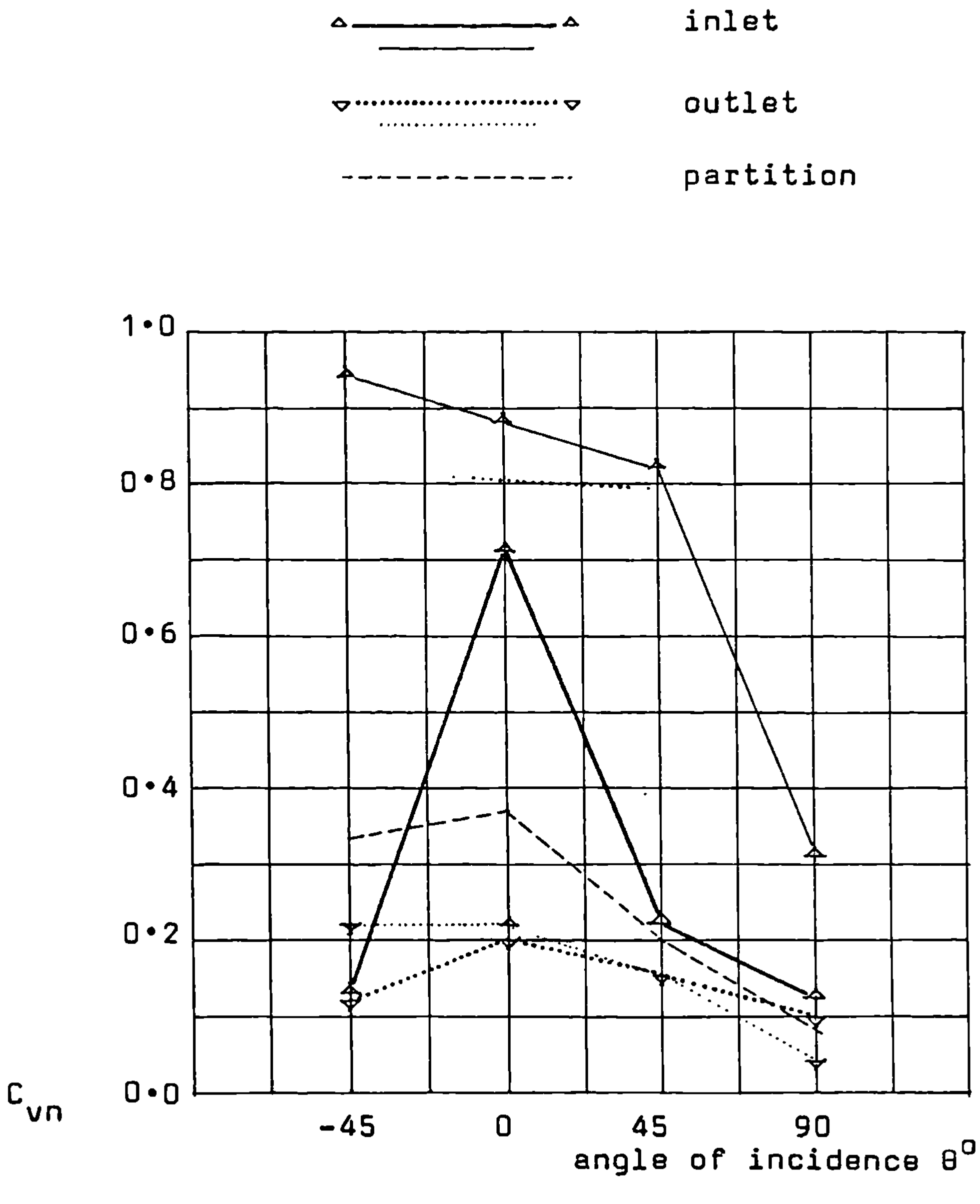


Figure (6.54) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 1/1, for multi-cell Model B1/2.

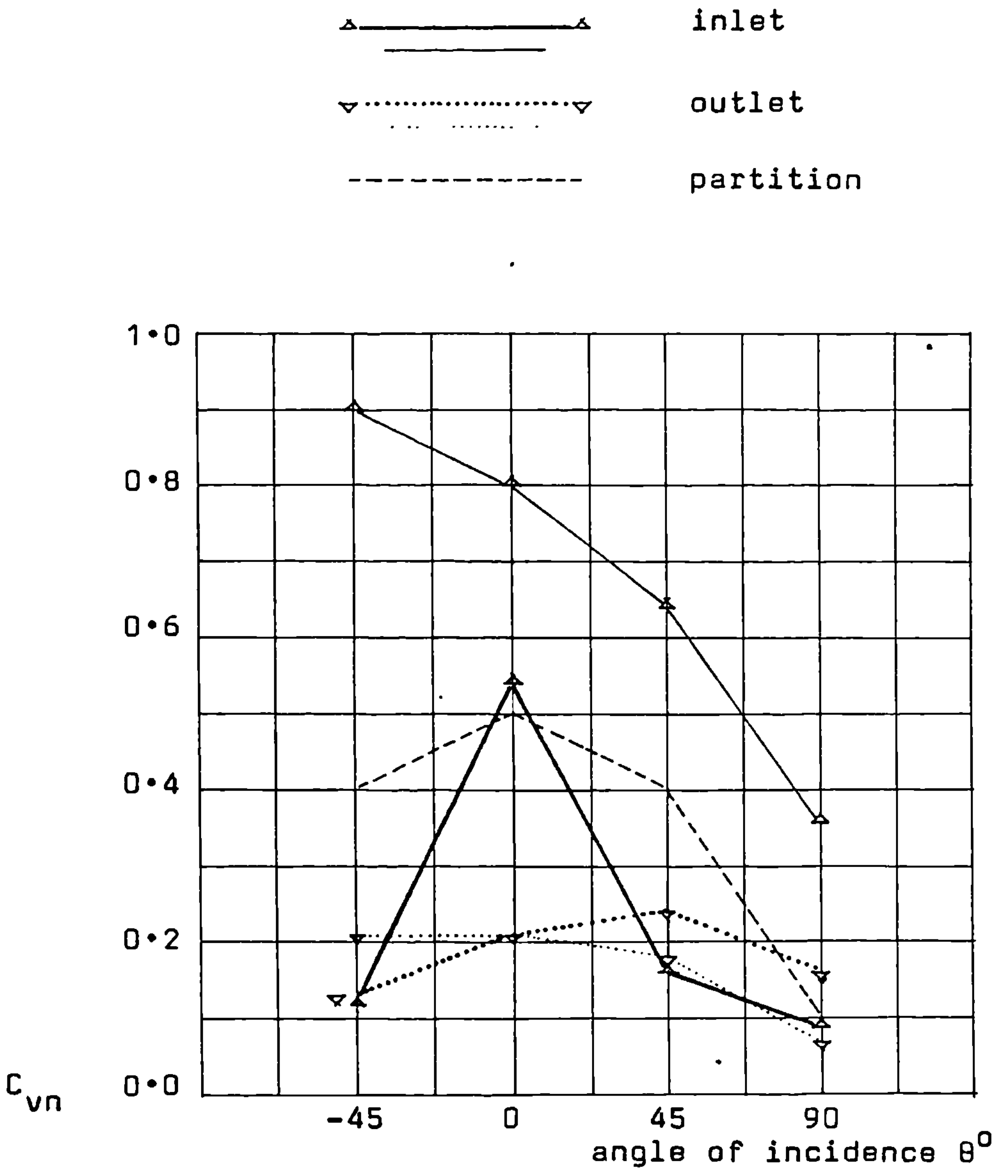


Figure (6.55) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 3/2, for multi-cell Model B1/1.

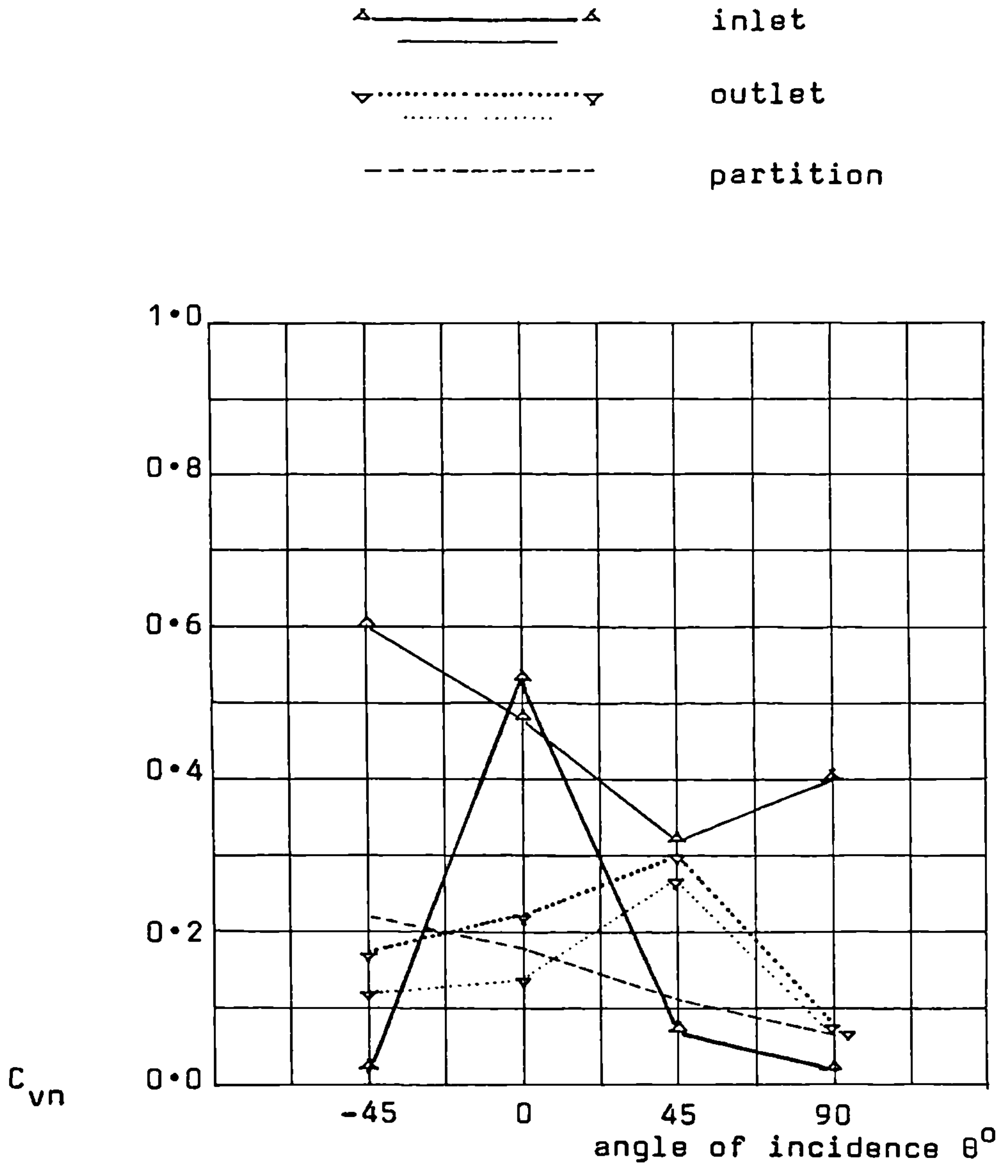


Figure (6.56) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 2/1, for multi-cell Model B1/8.

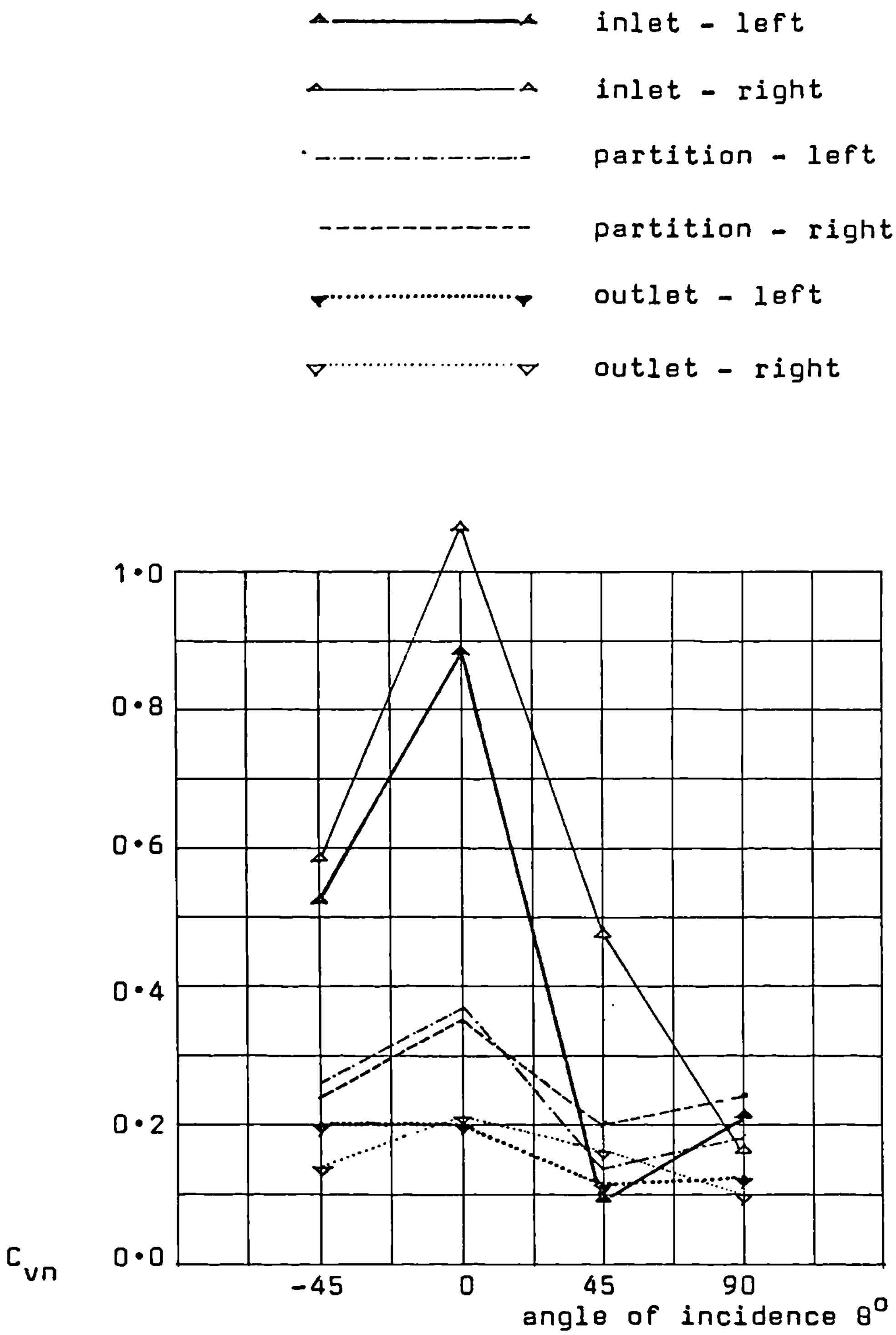


Figure (6.57) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 2/3, for multi-cell Model C1/1.

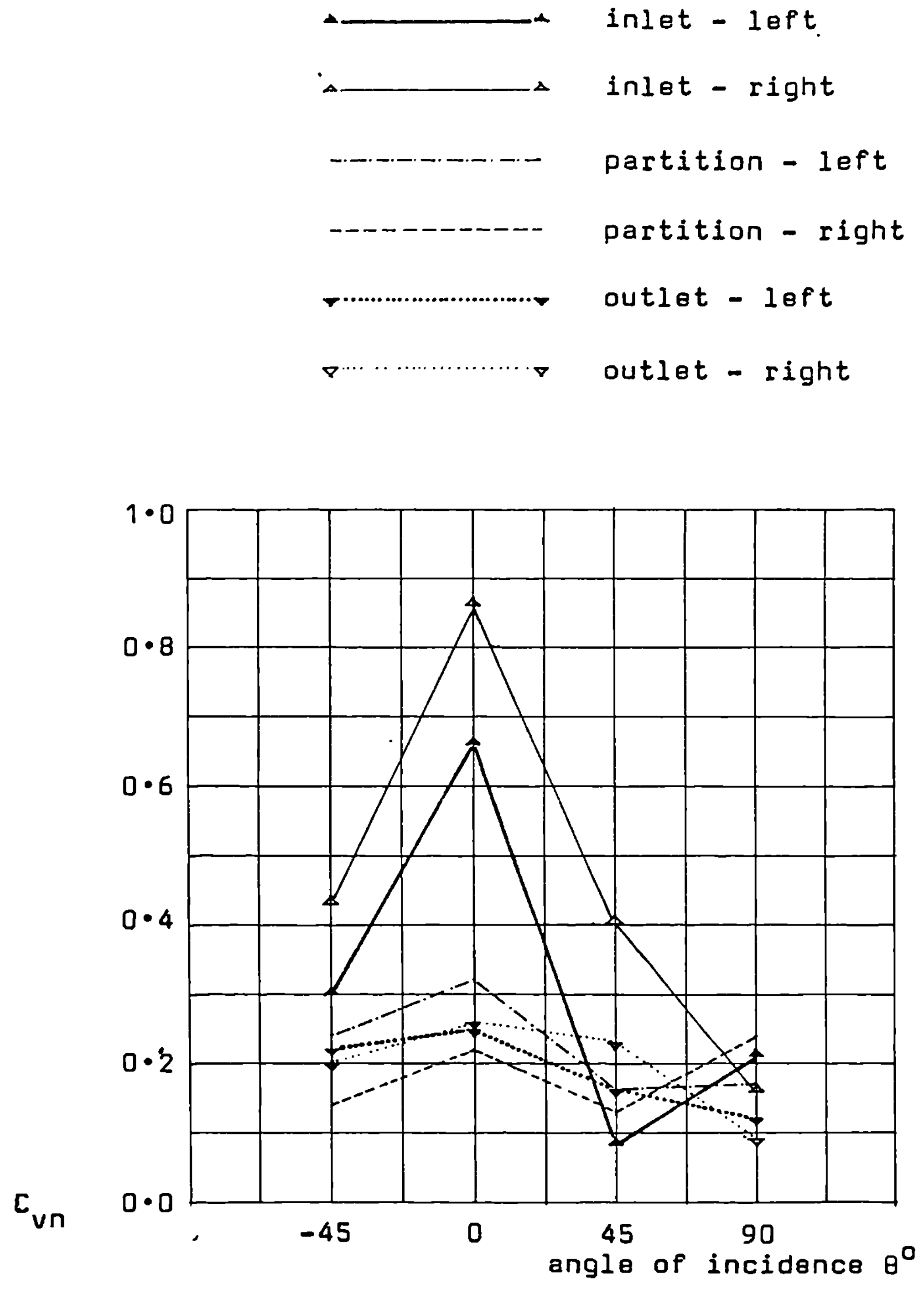


Figure (6.58) The change in C_{vn} in relation to θ for inlet/outlet (λ) =1/1, for multi-cell Model C1/2.

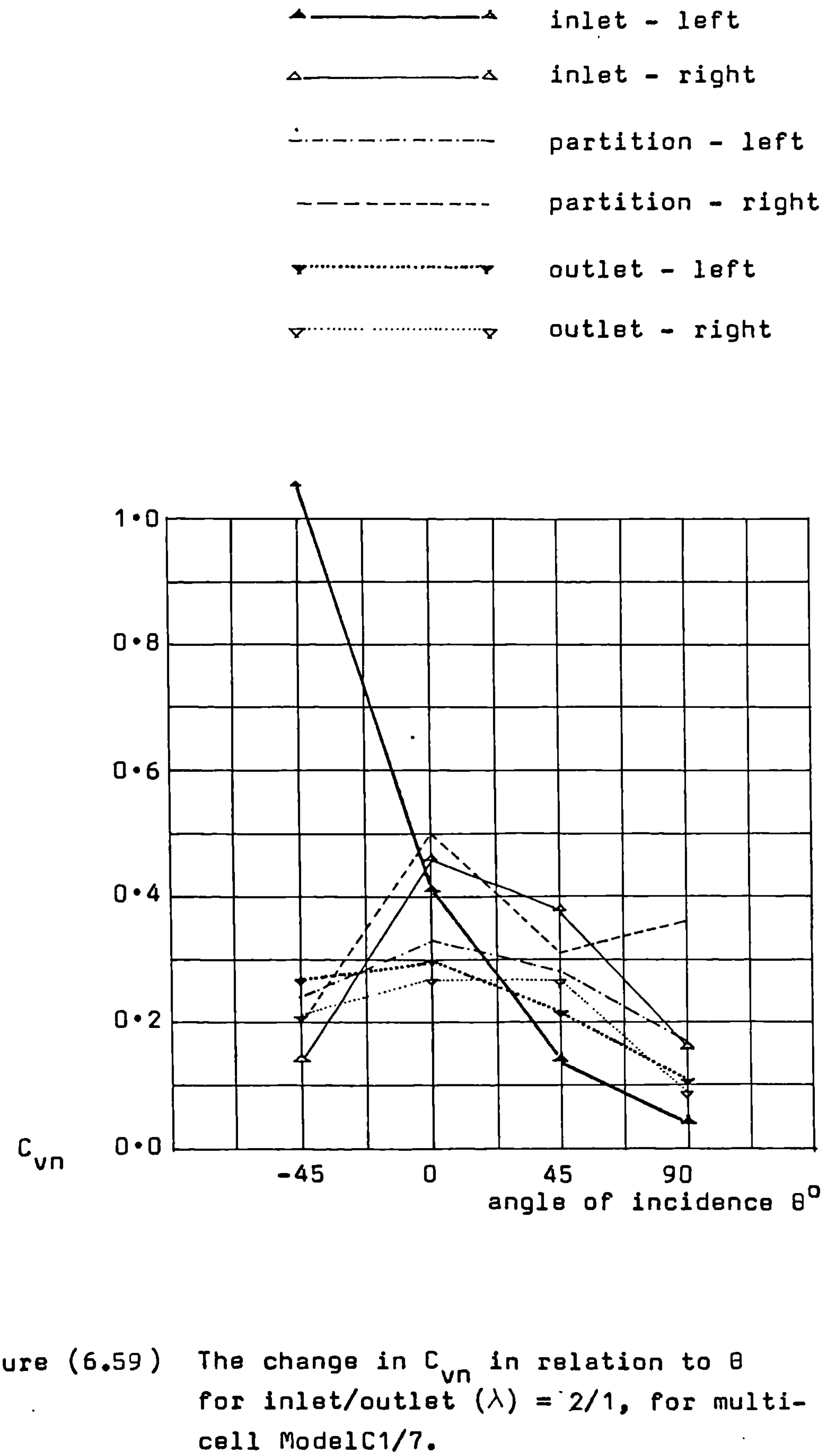


Figure (6.59) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 2/1, for multi-cell ModelC1/7.

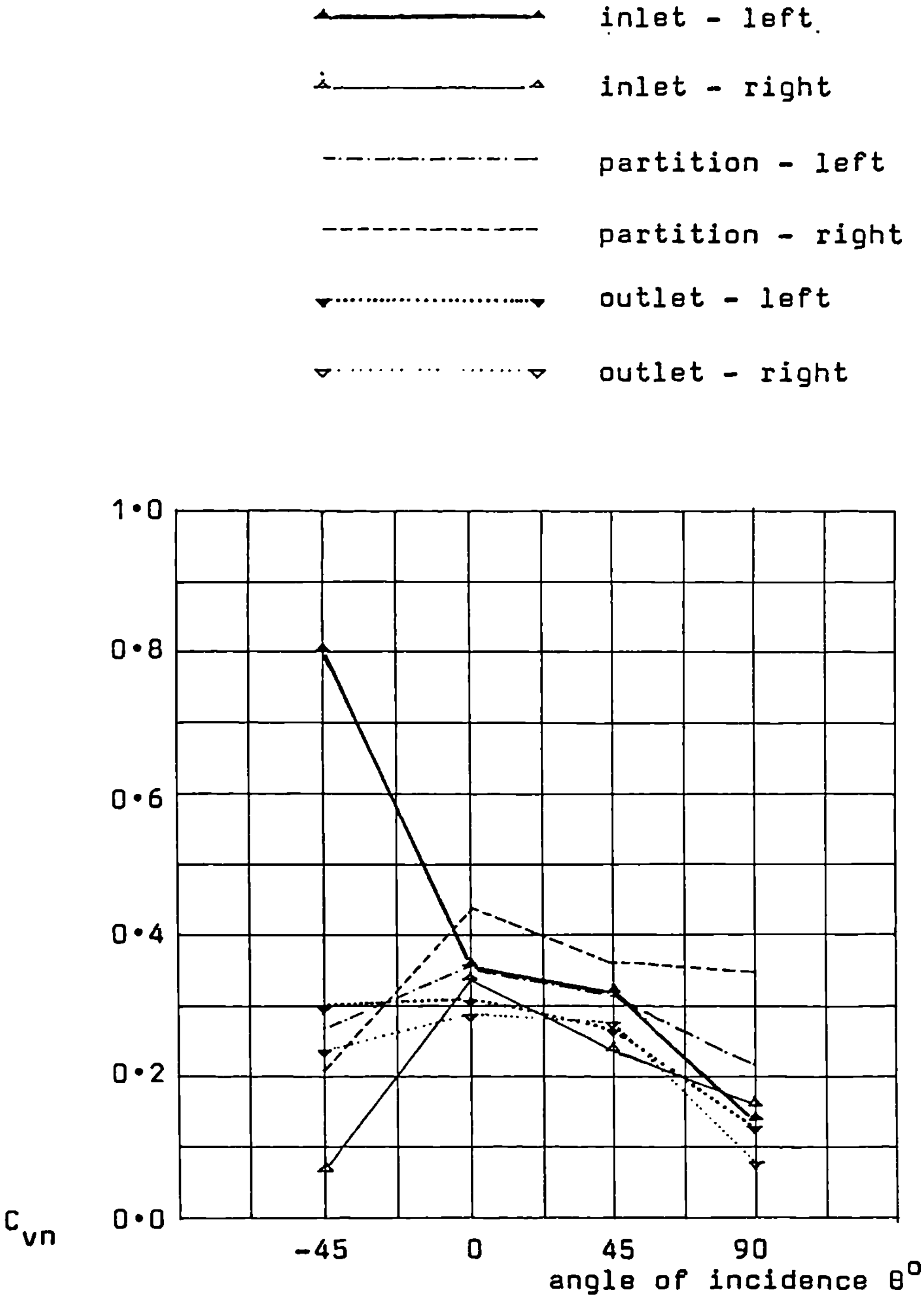


Figure (6.60) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 3/1, for multi-cell Model C1/8.

When the angle of incidence was $\theta = 45^o$ the outlet speed was higher than the inlet for $\lambda > 3/2$. The difference in the flow pattern between $\theta = -45^o$ and $\theta = +45^o$ was due to the nature of the two cell connection and the asymmetry of the space with respect to the inlet and the outlet. It was also observable that air speed inside the space did not correspond with either the inlet or the outlet. This was because of the dynamic nature of the interaction between the flow in both the right and the left hand sections of the models.

In models of category C the degree of variation differed from one opening arrangement to another. Air speed near the inlet showed a considerably greater reduction for $\theta = 45^o$ than that observed for $\theta = 0^o$, but when $\lambda \geqslant 2/1$ air speeds for $\theta = -45^o$ showed a substantial increase, C_{vn} = 106% and 80% for $\lambda = 2/1$ and 3/1 respectively, figures (6.57) to (6.60). Near the outlet air speed was highest at angle of incidence $\theta = 0^o$ for all models. The outlet speed was also higher than that near the outlet for $\lambda < 3/1$. The fluctuation in air speed near the partition showed some correlation to that of the outlet, which could be a result of the shorter distance between the partition and the outlet than between the partition and the inlet.

Figures (6.61) to (6.66) illustrate the change in air speed magnitude with varying values of θ occurring within the different parts of the space for category D models. The flow near the inlet showed a marked change in magnitude with changes in the values of both λ and θ. Lower C_{vn} values were observed for $\theta = 45^o$ than for $\theta = -45^o$ for $1/2 < \lambda < 4/3$. For $\lambda > 4/3$ air speed at $\theta = 45^o$ was greater than that at $\theta = -45^o$. The air flow near the inlet of the right hand section followed closely that of the left hand section for angles of incidence $\theta = -45^o$, 0^o and 90^o when λ ranged between $1/2 < \lambda < 1/1$. For $\lambda > 1/1$ air flow near the inlet of the right hand section and at angle of incidence $\theta = -45^o$ was considerably greater than the left hand

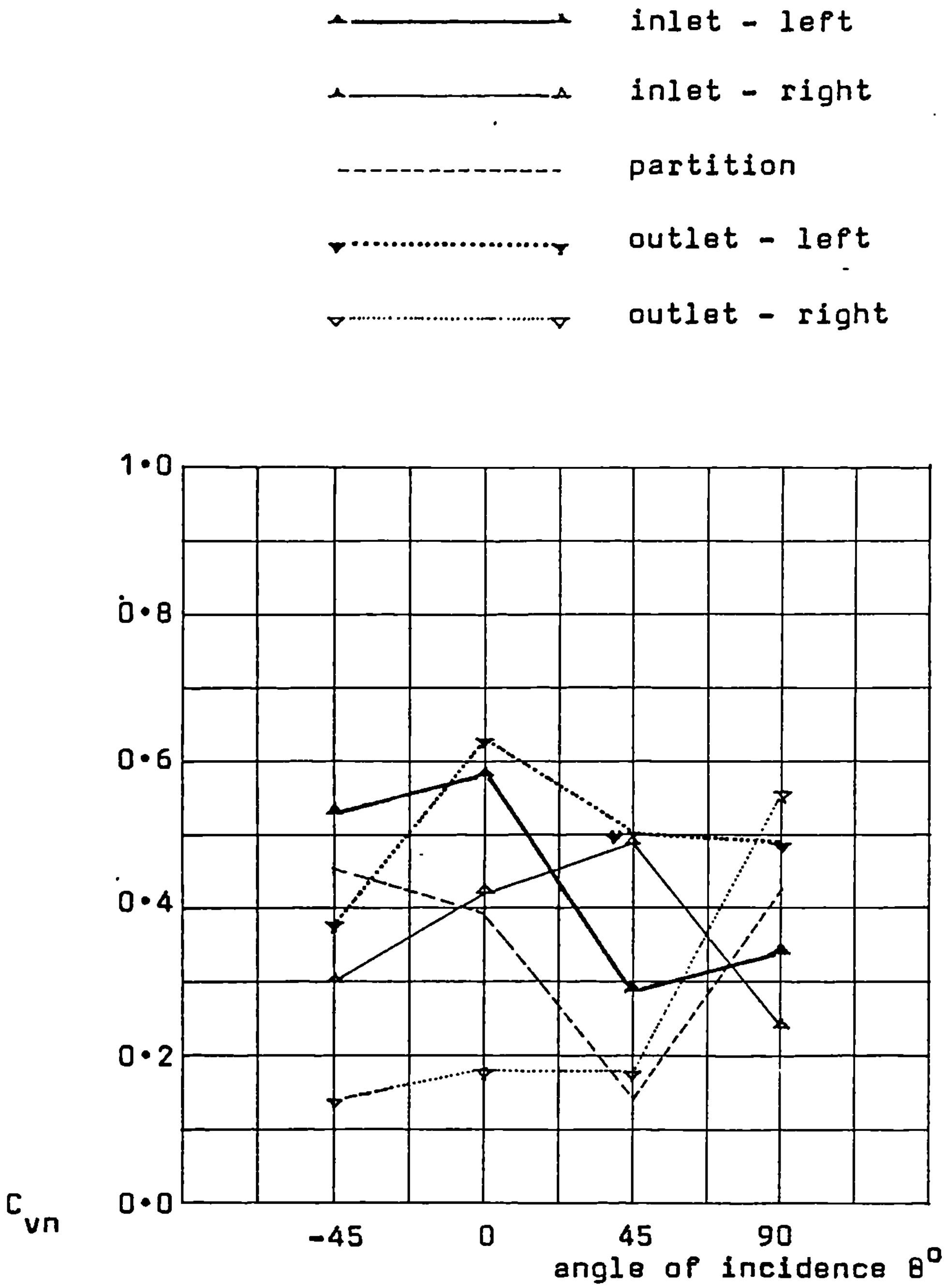


Figure (6.61) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 1/2, for multi cell Model D1/1.

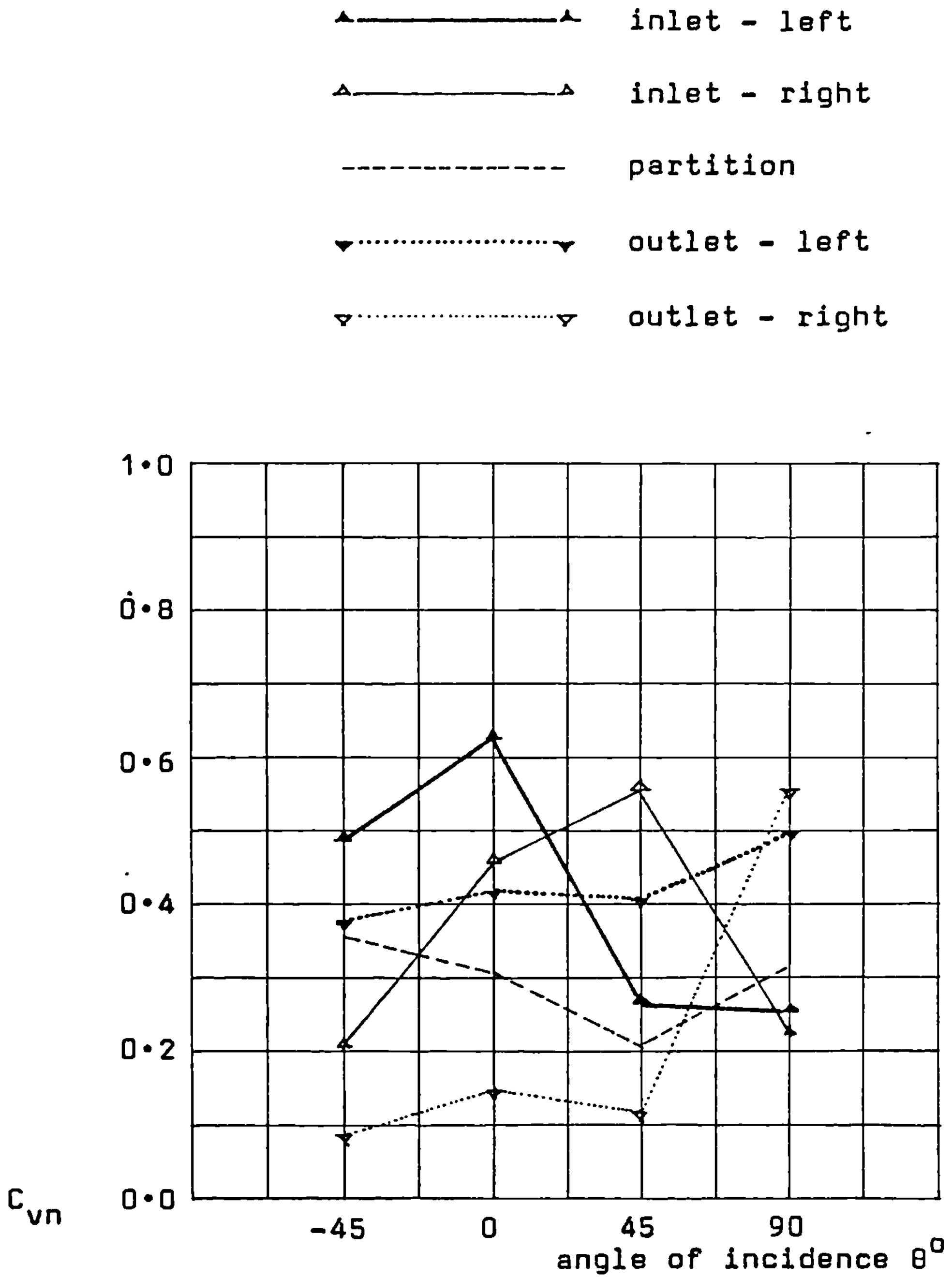


Figure (6.62) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 2/3, for multi-cell Model D1/2.

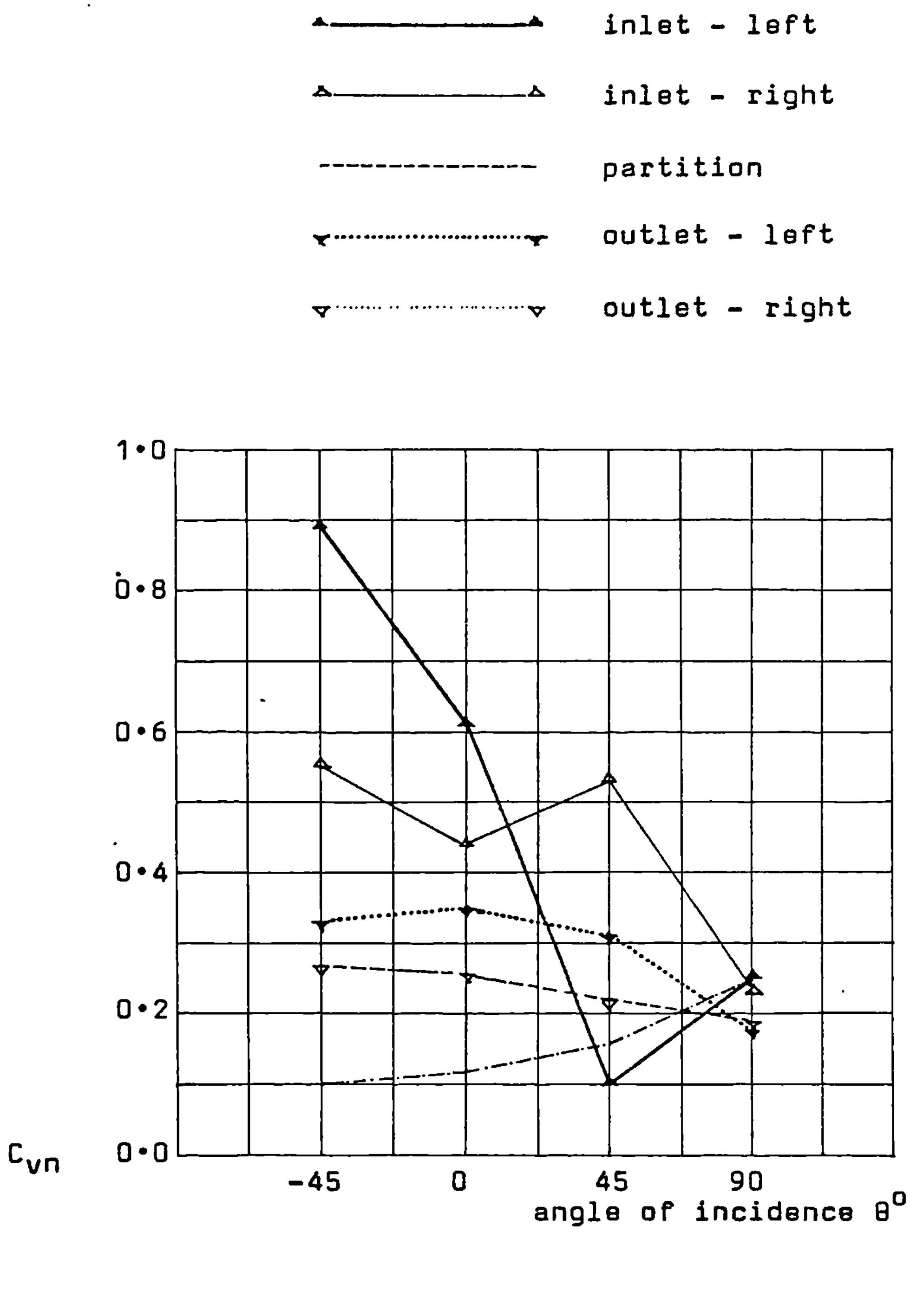


Figure (6.63) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 1/1, for multi-cell Model D1/3.

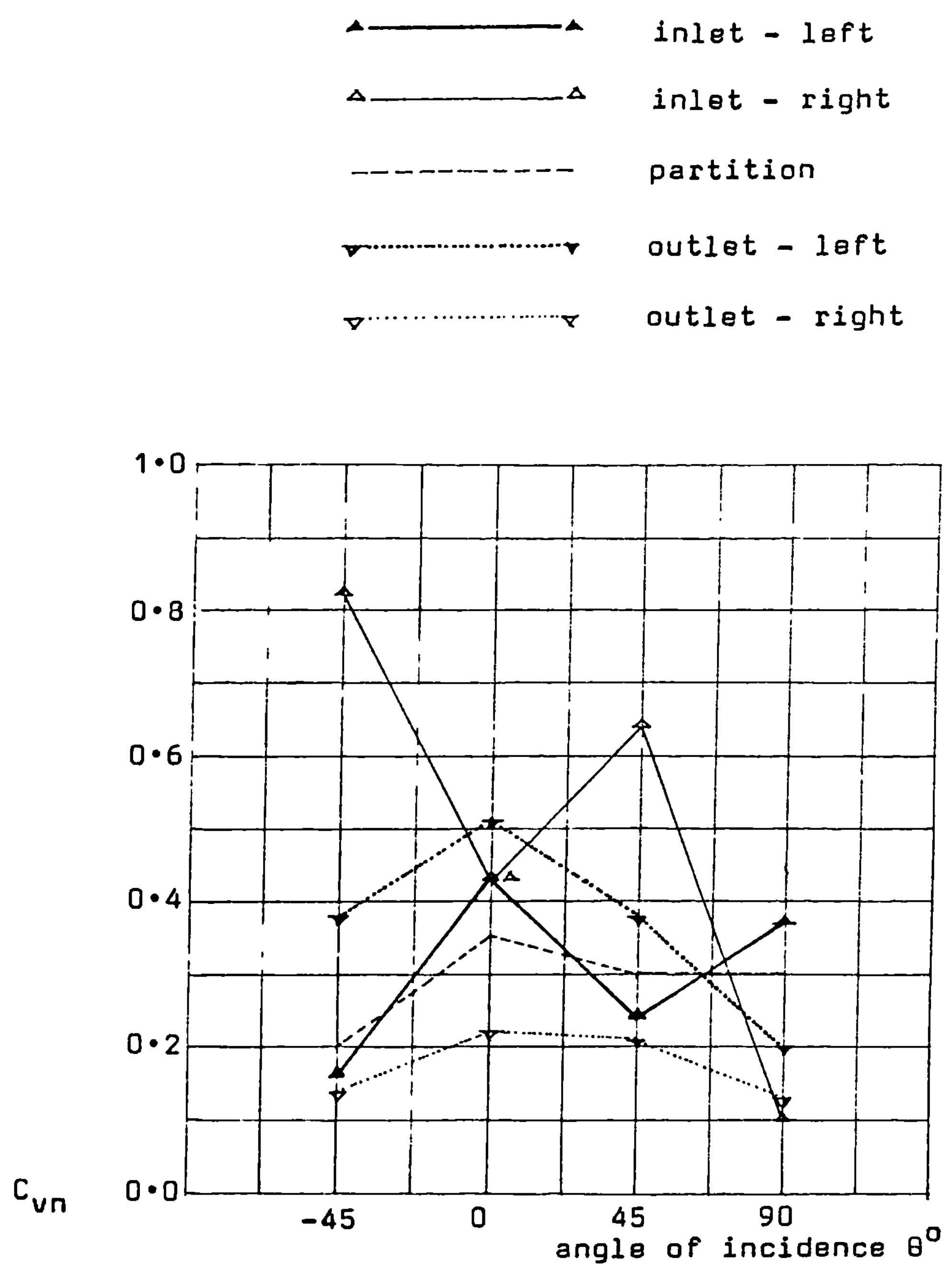


Figure (6.64) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 4/3, for multi-cell Model D1/12.

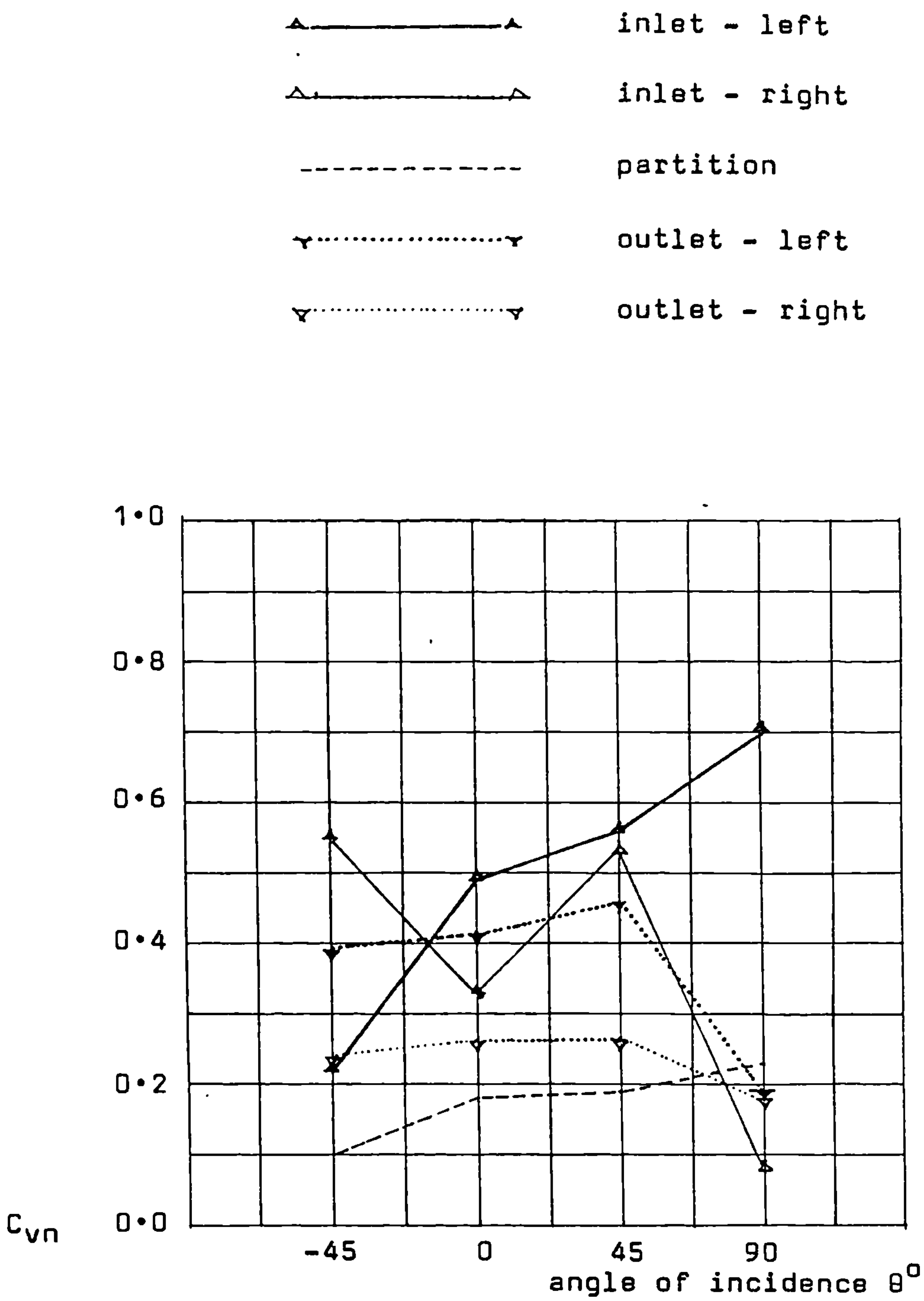


Figure (6.65) The change in C_{vn} in relation to θ for inlet/outlet (λ) =.3/2, for multi-cell Model D1/5.

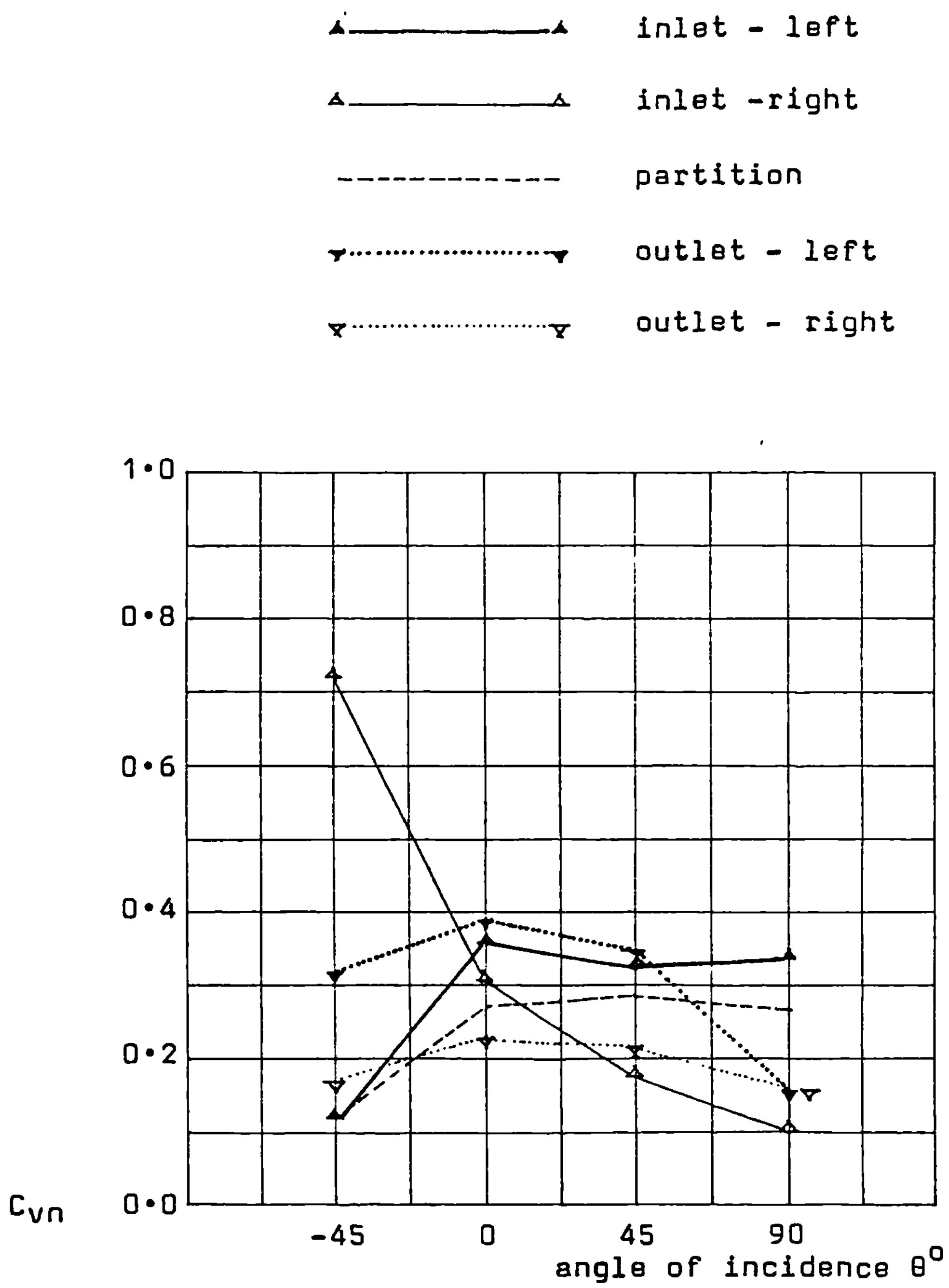


Figure (6.66) The change in C_{vn} in relation to θ for inlet/outlet (λ) = 2/1, for multi-cell Model D1/6.

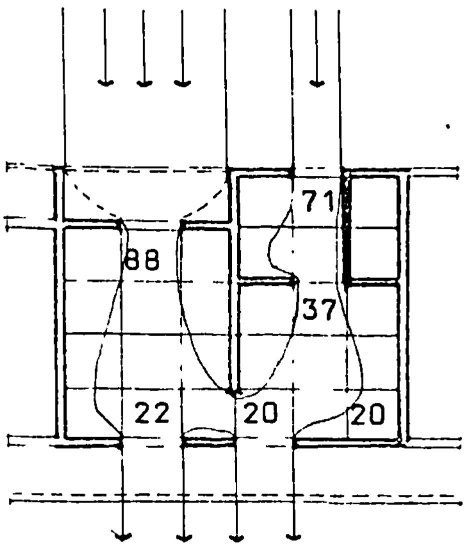
section. Beside the effect of λ, the asymmetry of the space arrangements in relation to the inlets and outlets contributed to these changes. The trend of air speed fulctuation at the windward opening of the central space followed that of the left hand windward section (nearest inlet). but was of lower magnitude.

6.6.2 The Effect of Internal Partitions

Air flow is as much a function of the moving forces as of the resistance of the space elements. The presence of partitions within the space will result in a deviation in air speed and direction from that in a typical unobstructed space. In this Section the effect of internal partitions within three multi-cell model categories is investigated.

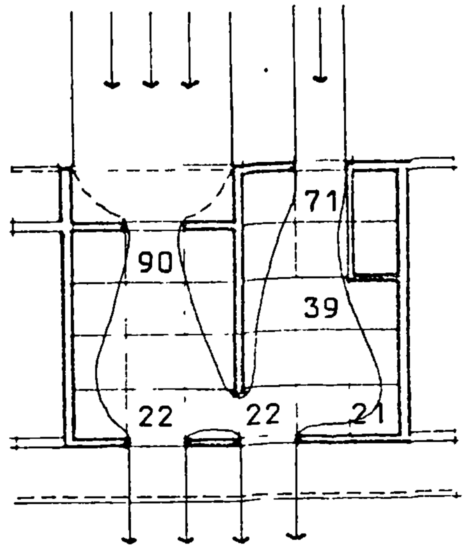
Firstly, three models, B/2, B/3 and B/9, having partition opening areas a_3 = 1/3, 2/3 and 4/9 respectively, were examined, figure (6.67), to determine the effect of this parameter on the flow pattern. When the angle of incidence had the value $\theta = 0^o$ the speeds near the inlet and outlet showed considerable differences. Near the inlet air speed was C_{vn} = 71% for both a_3 = 1/3 and 2/3. When a_3 = 4/9, and the partition was positioned near the inlet , air speed near this inlet was as low as C_{vn} = 58%, figure (6.68). However, air speed across the space and near the outlet was considerably higher, indicating better ventilation conditions than the first two models. In the left hand space, which was identical in all the models, air speeds near the inlet were C_{vn} = 88%, 90% and 69% for a_3 = 1/3, 2/3 and 4/9 respectively. Near the outlet of this section C_{vn} was 22% for the first two models and 32% for the third. This illustrated that the relationship between the two spaces was a strong one, and design considerations for ventilation should view the multi-cell as an integral unit.

At angle of incidence $\theta = 45^o$ air speed near the inlet



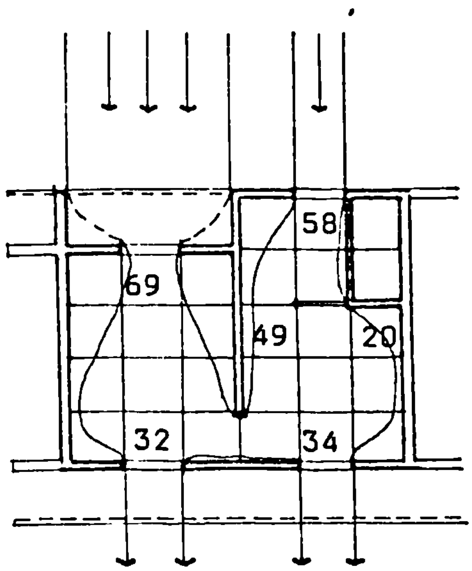
B1/2

$a_3 = 1/3$



B1/3

$a_3 = 2/3$



B1/9

$a_3 = 4/9$

Figure (6.67) The effect of the internal partition area a_3 on the flow within multi-cell, Model B1 (angle of incidence $\theta = 0^o$).

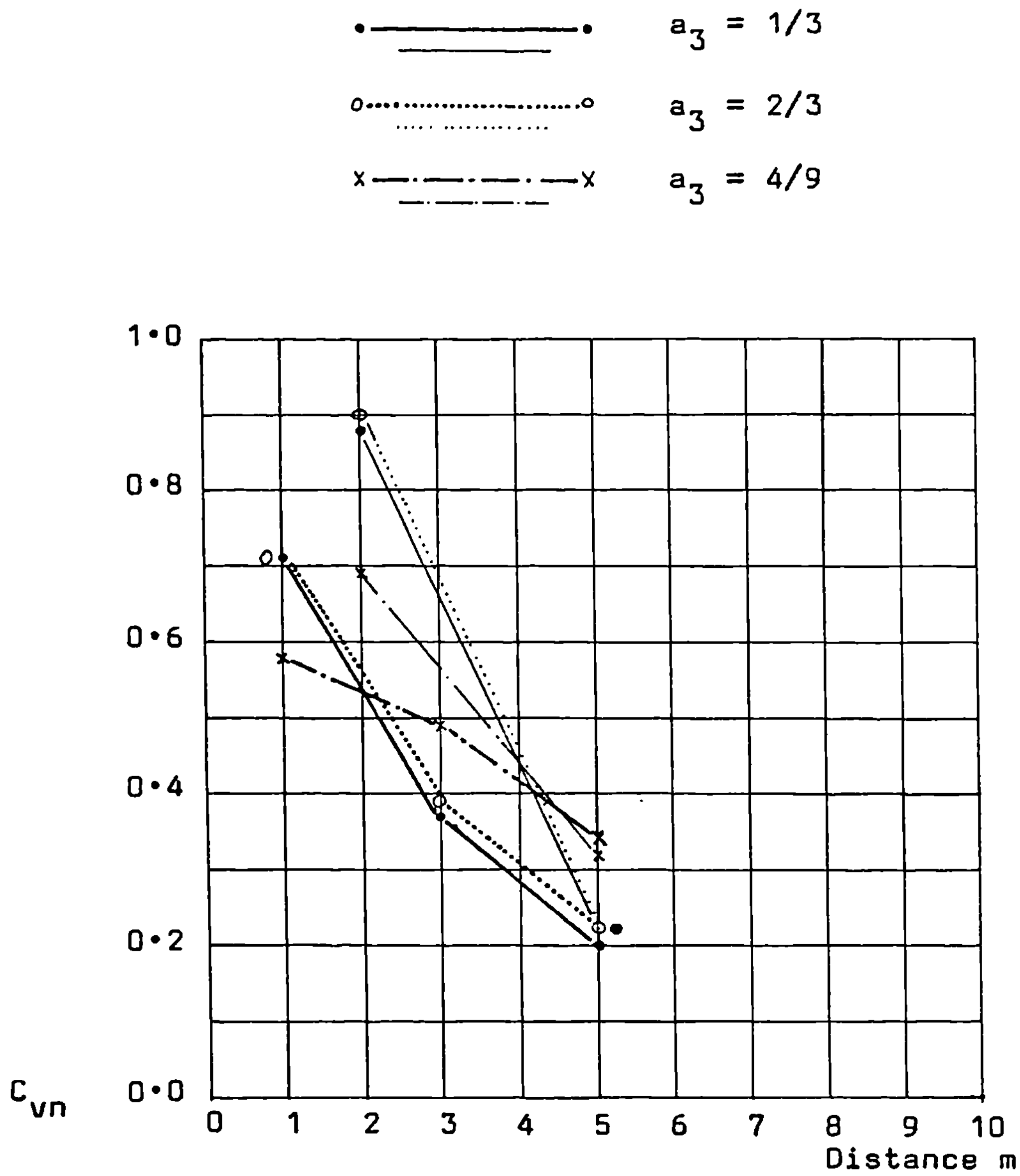
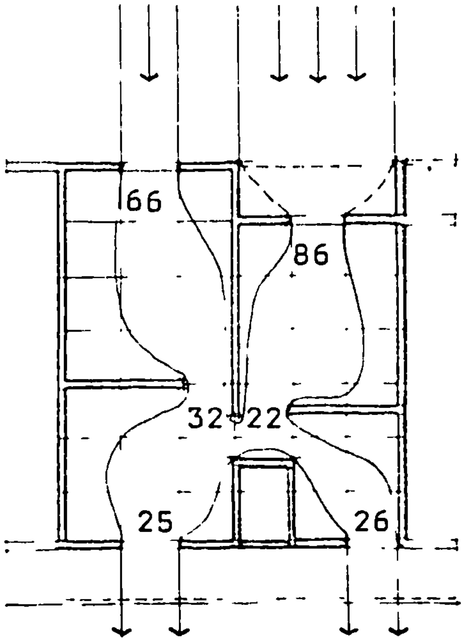


Figure (6.68) The change in C_{vn} in relation to the internal partition area a_3 within multi-cell, Model B1 (angle of incidence $\theta = 0^o$).

showed a marked reduction but this was less pronounced both near the outlet and inside the spaces. Air speeds near the openings and across the space suffered further reduction with the change of the angle of incidence to $\theta = 90^o$.

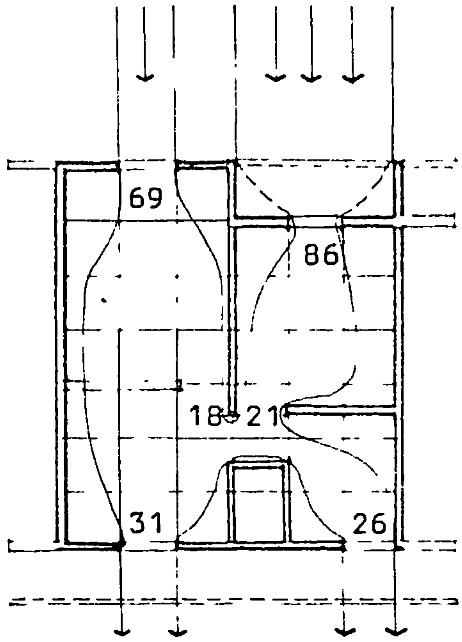
Secondly, models C/2, C/3 and C/4 had equal λ values of $\lambda = 1/1$, but varying partition opening areas of $a_3 = 1/3$, 5/9 and 1/3 respectively. Models C/2 and C/4 had similar a_3 but with different space arrangements, figure (6.69). Air speed near the inlet of the left hand space showed an increase of 3% when a_3 increased from 1/3 to 5/9. Near the outlet air speed showed a more pronounced effect with C_{vn} increasing from 25% to 31%. At the partition opening the speed for $a_3 = 1/3$ was $C_{vn} = 32\%$ compared with $C_{vn} = 18\%$ for $a_3 = 5/9$. The air speed distribution in this second case indicated that air flowed over the low partition as well as through the original opening, showing a more uniform flow for this arrangement than for $a_3 = 1/3$. Air flow through the right hand section was identical in both cases, figure (6.70). In C/4 the change of the leeward spaces into an open plan space had a marked effect on the flow across the whole model. The moving air in the windward section did not lose as much kinetic energy as in the two previous cases. This conserved energy was lost in the leeward section, resulting in more dynamic movement but a lower air speed near the outlet. At angle of incidence $\theta = 45^o$ air speed near the inlet was reduced to approximately half the value of the speed at $\theta = 0^o$. Near the outlet the reduction experienced in air speed was less pronounced in all models. At angle of incidence $\theta = 90^o$ the air speed suffered further reduction, although the air flow showed similar pattern for all models.

Thirdly, four models D/2, D/3, D/10 and D/11 were investigated to determine the effect of varying the relative positions of inlet and partition openings on the air flow. The models were grouped in two arrangements, first D/2 and D/10 and second D/3 and D/11. In the first group the



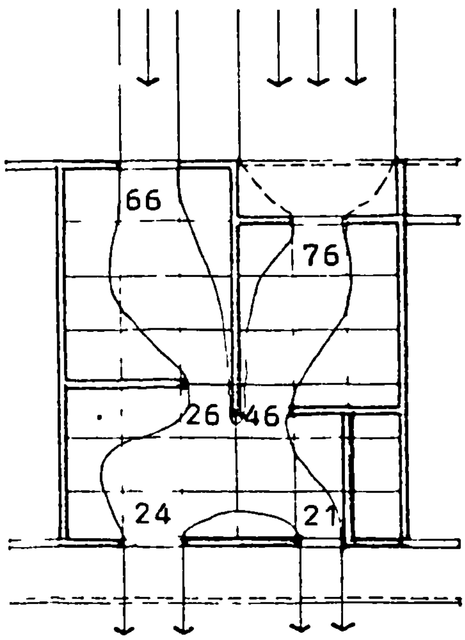
C1/2

a_3 = /3



C1/3

$a_3 = 5/9$



C1/4

a_3 = /3

Figure (6.69) The effect of the internal partition area a_3 on the flow within multi-cell, Model C1 (angle of incidence $\theta = 0^o$).

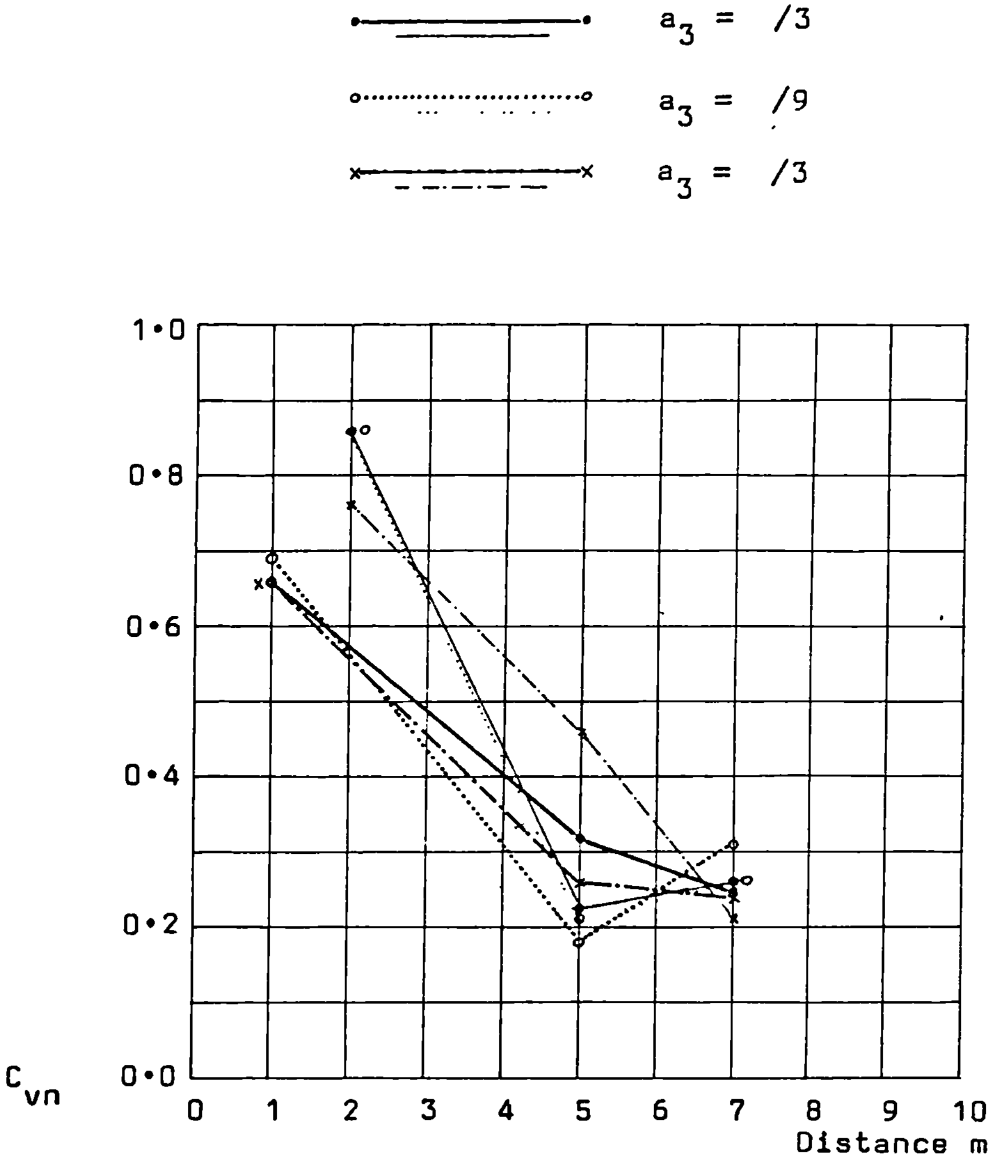


Figure (6.70) The change in C_{vn} in relation to the internal partition area a_3 within multi-cell, Model C1 (angle of incidence $\theta = 0^o$).

inlets of the left hand section and the partition were in the middle, while in the second they were shifted to one side. When angle of incidence was $\theta = 0^{o}$ the main trend observed was as follows - air speed near the inlet, the partition and the outlet of the left hand section increased with the decrease in the partition area, indicating more dynamic flow. At angle of incidence $\theta = 45^{o}$ air speed near the inlet, the middle space and the outlet of the left hand sections of D/2 and D/10 showed considerable reduction with the decrease in a_3, however, near the outlet of the right hand section it showed an increas with the decrease in a_3. This trend was less pronounced in models D/3 and D/11 with the partition opening shifted to the corners. At angle of incidence $\theta = 90^{o}$ a variation similar to that observed for $\theta = 45^{o}$ was evident, figures (6.71) to (6.72).

6.3.3 The Effect of Inlet/Outlet Relative Position

The inlet/outlet relative position was expected to have a marked effect on air flow pattern due to the changes in their positions relative to the different parameters within the space. This was investigated in the three categories of the multi-cell mentioned above. For category B, models B/4, B/5 and B/7 had similar inlet/outlet relative areas, $\lambda = 1/1$. In models B/4 and B/5 the inlet positions were changed, while in B/7 the outlet position was changed. Where the inlet was shifted to the left corner of both spaces, as in B/4, air speed was C_{vn} = 80% and 88% near the inlet, values which were higher than those for the openings at the right hand corner, C_{vn} = 73% and 74%. However, air speed near the outlet was slightly higher for the second case, figures (6.73) and (6.74). In B/7 where the outlet position was changed to the far corner, air speed near the inlet, C_{vn} = 68%, was lower than that observed in the first two models. Despite this reduction air speed observed across the whole space was higher than in the first two models. The main trend was for speed distribution across

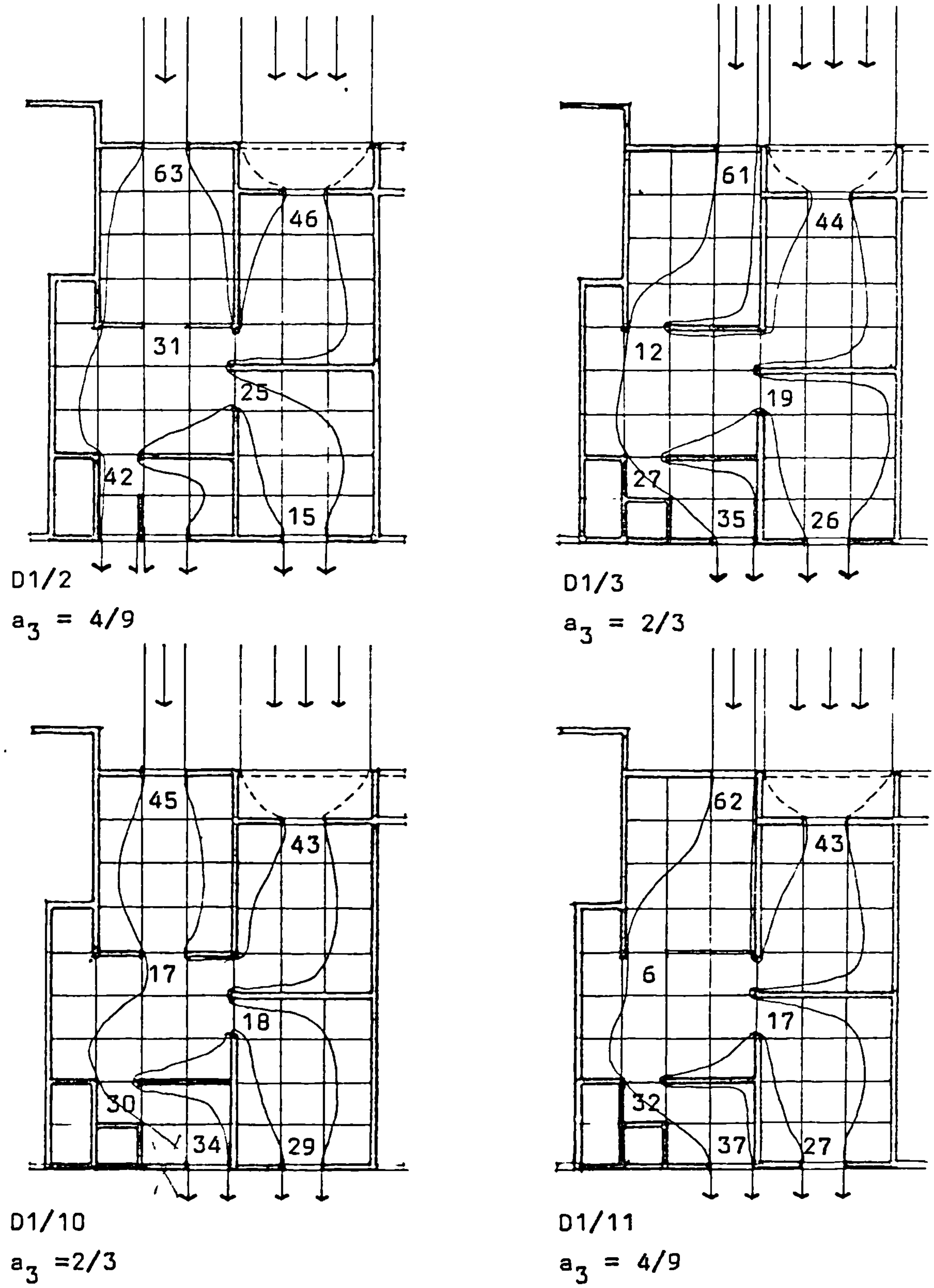


Figure (6.71) The effect of the internal partition area a_3 on the flow within multi-cell, Model D1 (angle of incidence $\theta = 0^o$).

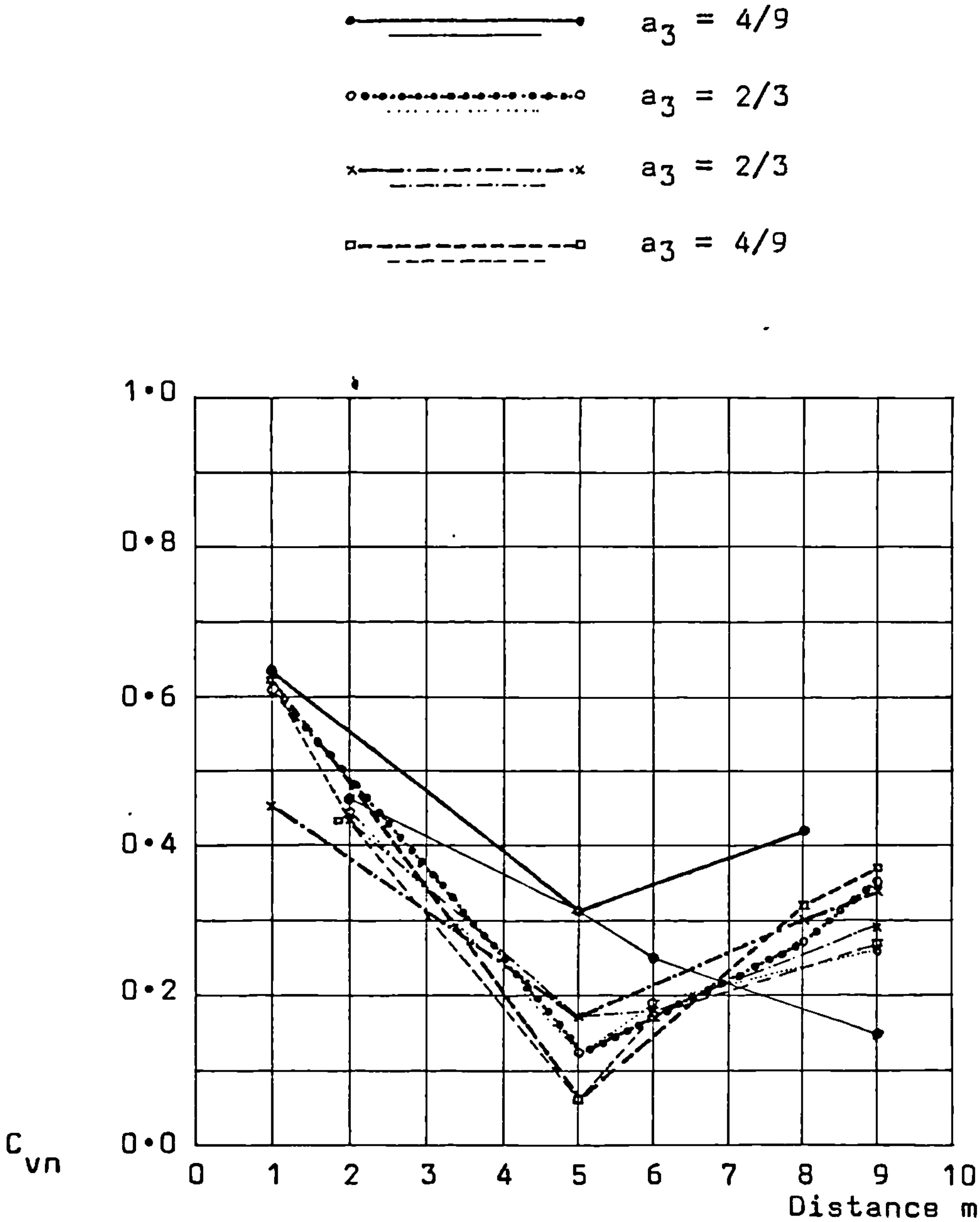
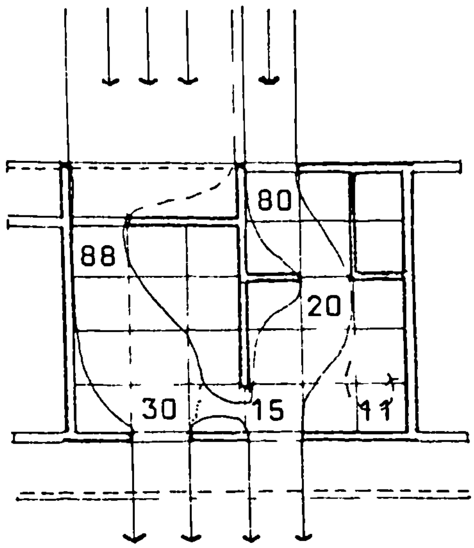
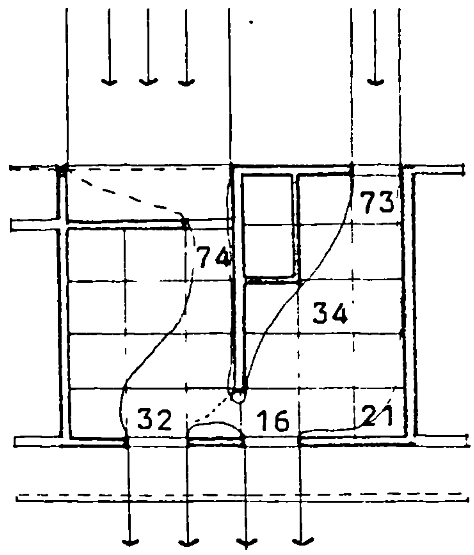


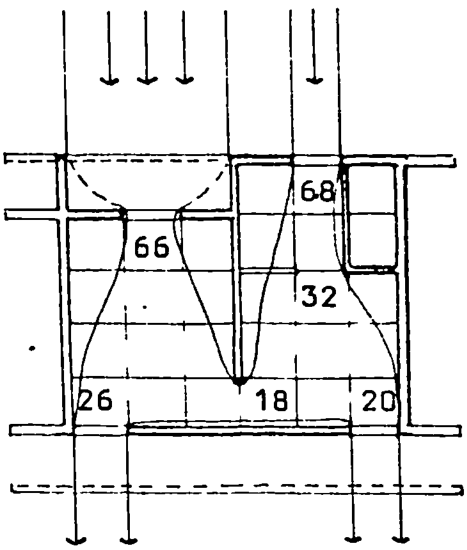
Figure (6.72) The change in C_{vn} in relation to the internal partition area a_3 within multi-cell, Model D1 (angle of incidence $\theta = 0^o$).



B1/4
λ = 1/1



B1/5
λ = 1/1



B1/7
λ = 1/1

Figure (6.73) The effect of inlet/outlet relative position on the flow within multi-cell, Model B1 (angle of incidence $\theta = 0^{o}$).

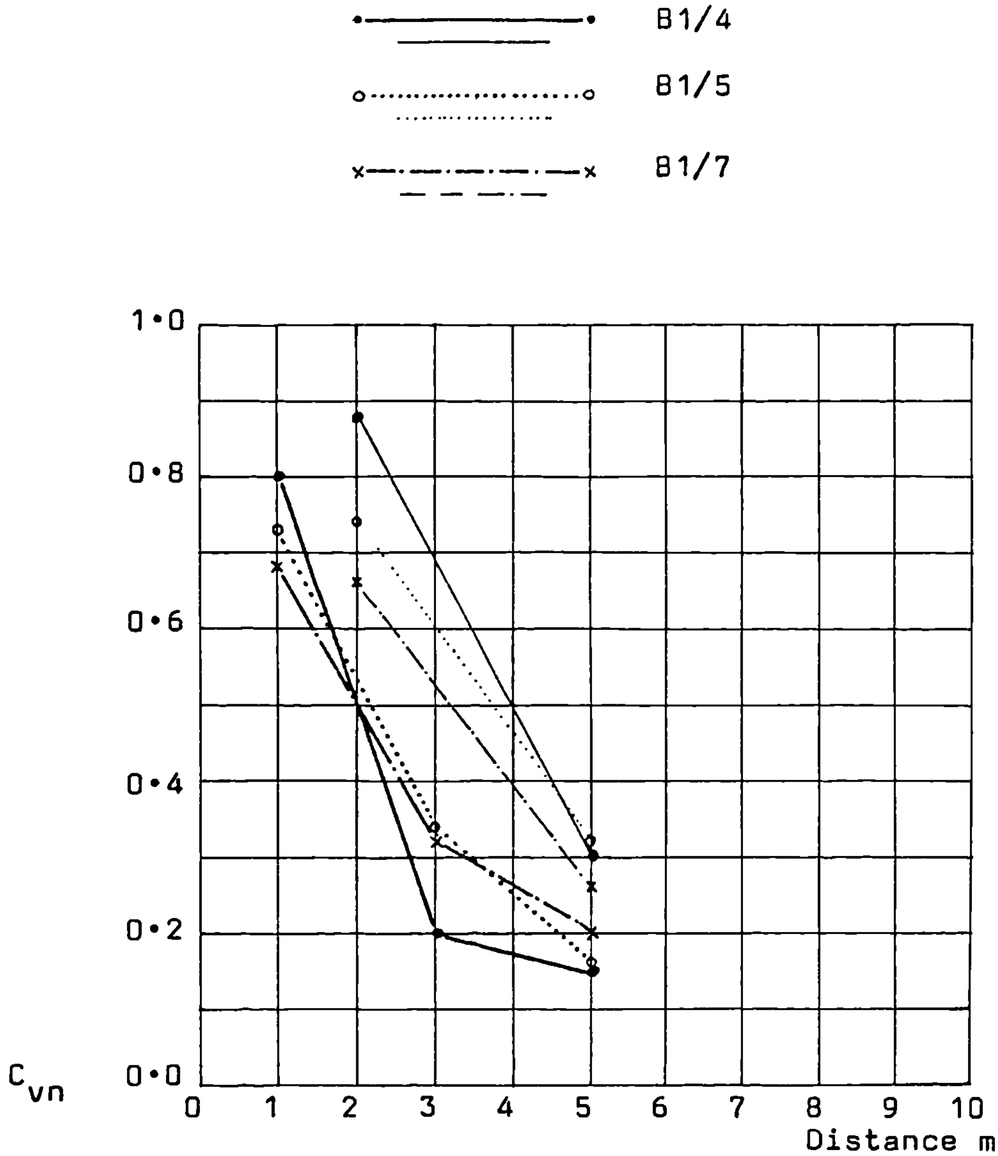
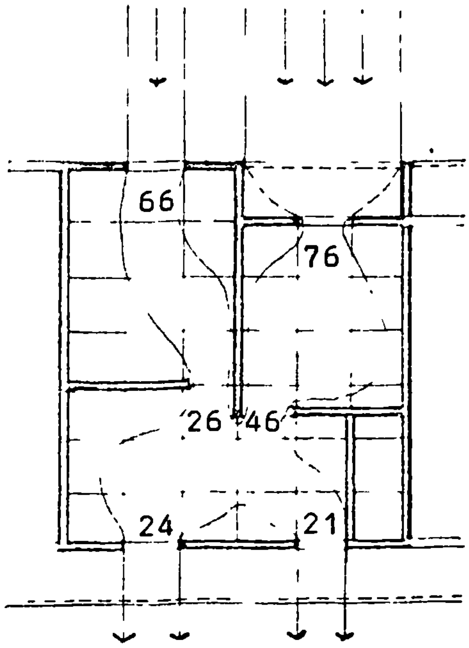


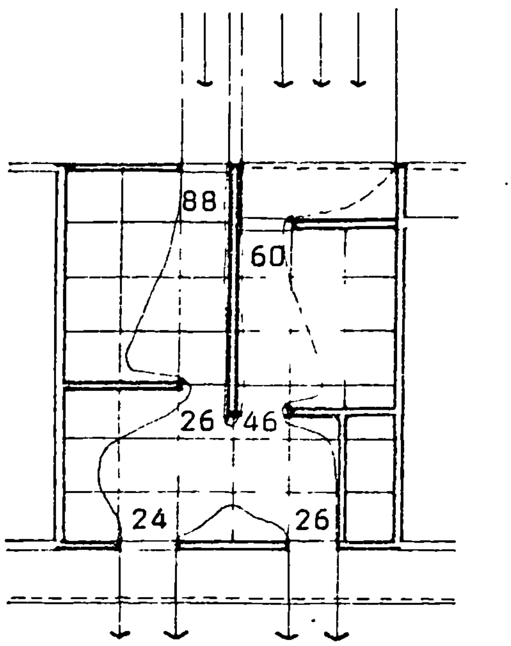
Figure (6.74) The change in C_{vn} in relation to inlet/outlet relative position within multi-cell, Model B1 (angle of incidence $\theta = 0^{o}$).

the space to be higher and more uniform when the outlet was non-aligned with the inlet, while the best distribution occurred when the outlets were furthest away from each other. When the angle of incidence θ was changed to $\theta = 45^{o}$ air speeds near the inlet of the right hand section were low, C_{vn} = 4% and 6%, compared with that of B/7, C_{vn} = 15%, which showed a better speed distribution across the whole space. Air speed in the left side space was considerably high in all three models. At angle of incidence $\theta = 90^{o}$ the air speed was low in all the models examined.

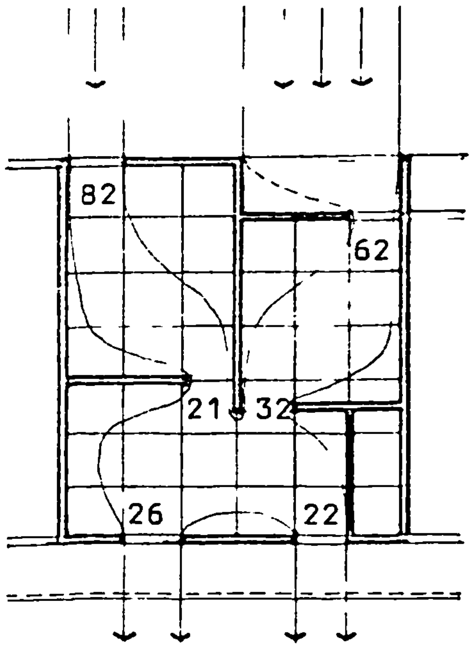
Models C/4, C/5, C/6, C/9, C/10 and C/11, all of which had inlet/outlet area $\lambda = 1/1$ and $a_3 = 1/3$, were also examined. In the first three models the inlet positions were varied with the outlets positioned in the centre line of each section. In the last two models the inlets were positioned in the middle of the windward walls while the outlet positions were varied. Near the inlet air speed showed marked changes with changing inlet positions, in the order of C_{vn} = 66%, 88% and 82% near the left inlets and C_{vn} = 76%, 60% and 62% for the right inlets of models C/4, C/5 and C/6 respectively, figures (6.75) and (6.76). The trend in the left hand space was to higher speeds for the corner inlets with the lowest when the inlet was in the centre; this trend was reversed in the left side. Air speeds at the partition opening were identical in C/4 and C/5, but in C/6 where the inlets were located at the far corners air flow through the partition opening had lower speed C_{vn} = 21% and 32% in the left and right hand sections respectively, compared with that previously observed. Near the outlets speed variation was limited, $21\% < C_{vn} < 26\%$. When the outlet position was varied the air speed near the inlet showed considerable changes. In model C/10 where the outlets were adjacent forming a large opening in the centre, air speed near the left hand section inlet was highest, C_{vn} = 94% while near the right section inlet C_{vn} = 91%. Slightly lower air speeds were recorded in C/11 where the



C1/4
λ = 1/1



C1/5
λ = 1/1



C1/6
λ = 1/1

Figure (6.75) The effect of inlet/outlet relative position on the flow within multi-cell, Model C1 angle of incidence $\theta = 0^{o}$).

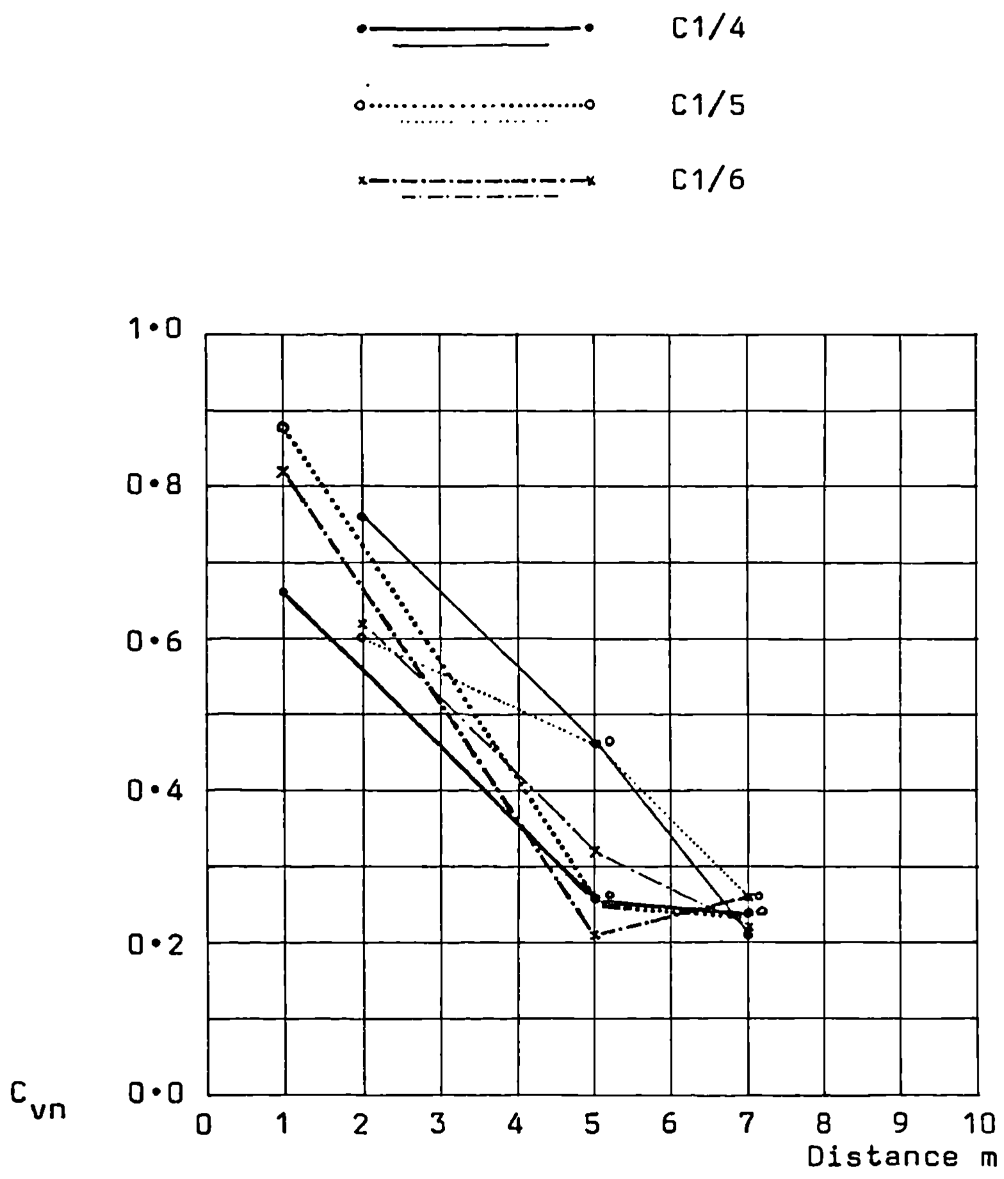


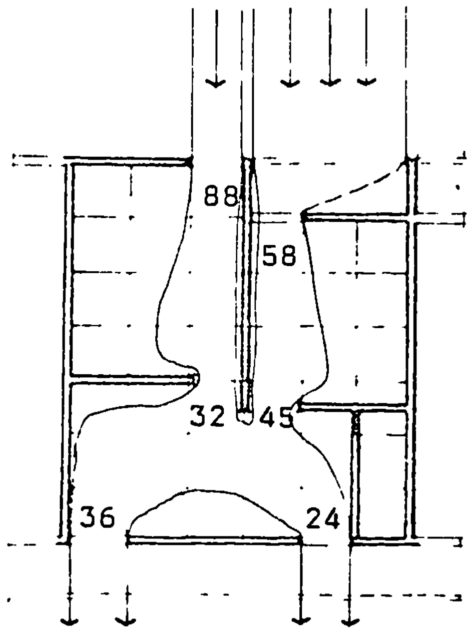
Figure (6.76) The change in C_{vn} in relation to inlet/ outlet relative position within multi-cell, Model C1 (angle of incidence $\theta = 0^{o}$).

outlets were located at the far corners, figs.(6.77) & (6.78).

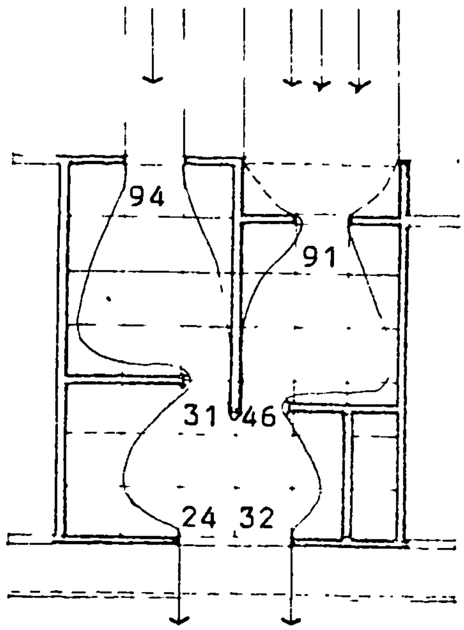
In conclusion, air speeds within a multi-cell of category C will improve substantially with the changes in the relative positions with the outlets joined to form one big opening resulting in the highest speeds near the inlets, and the outlet at the far corners, providing the best speed distribution within the leeward space. When angle of incidence θ was changed to $\theta = 45^{o}$ a marked reduction in air speed was experienced in the windward spaces but the leeward space showed less reduction in most of the models examined. At angle of incidence $\theta = 90^{o}$ the air speed suffered further reduction in models C/6 and C/11 which had their inlets and outlets furthest away from each other, securing highest air movements across the whole space.

The effect of the inlet/outlet relative position was investigated in models D/3, D/4 and D/10, figure (6.79), which had similar λ values of $\lambda = 1/1$ as well as $a_3 = 1/3$. Models D/3 and D/4 had similar inlet position but different outlets, while D/3 and D/10 had similar outlet but different inlet positions. At angle of incidence $\theta = 0^{o}$ air speed within the left hand side of model D/3 was $C_{vn} = 61\%$ at the inlet, but suffered a considerable reduction near the partition, $C_{vn} = 12\%$, then regained some speed near the outlet, $C_{vn} = 35\%$. In the right hand side air speed was as high as $C_{vn} = 44\%$ at the inlet and 26% at the outlet. Comparing the flow within D/4 with that in D/3 air speed at the inlet was $C_{vn} = 60\%$ and 33% at the left and right hand sections respectively, while at the partition C_{vn} values were as high as 17%. These increased near the outlets, $C_{vn} = 30\%$ at the left, and 21% at the right side.

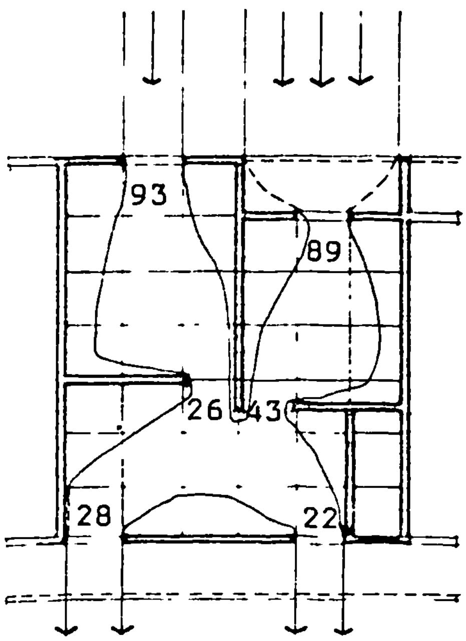
The air speed magnitude varied from those of model D/3 by an average of 5% decrease in the flow near the openings. When the left inlets as well as the partition opening position were changed, as in model D/10, from that of model



C1/9
λ = 1/1



C1/10
λ = 1/1



C1/11
λ = 1/1

Figure (6.77) The effect of inlet/outlet relative position on the flow within multi-cell, Model C1 (angle of incidence $\theta = 0^{o}$).

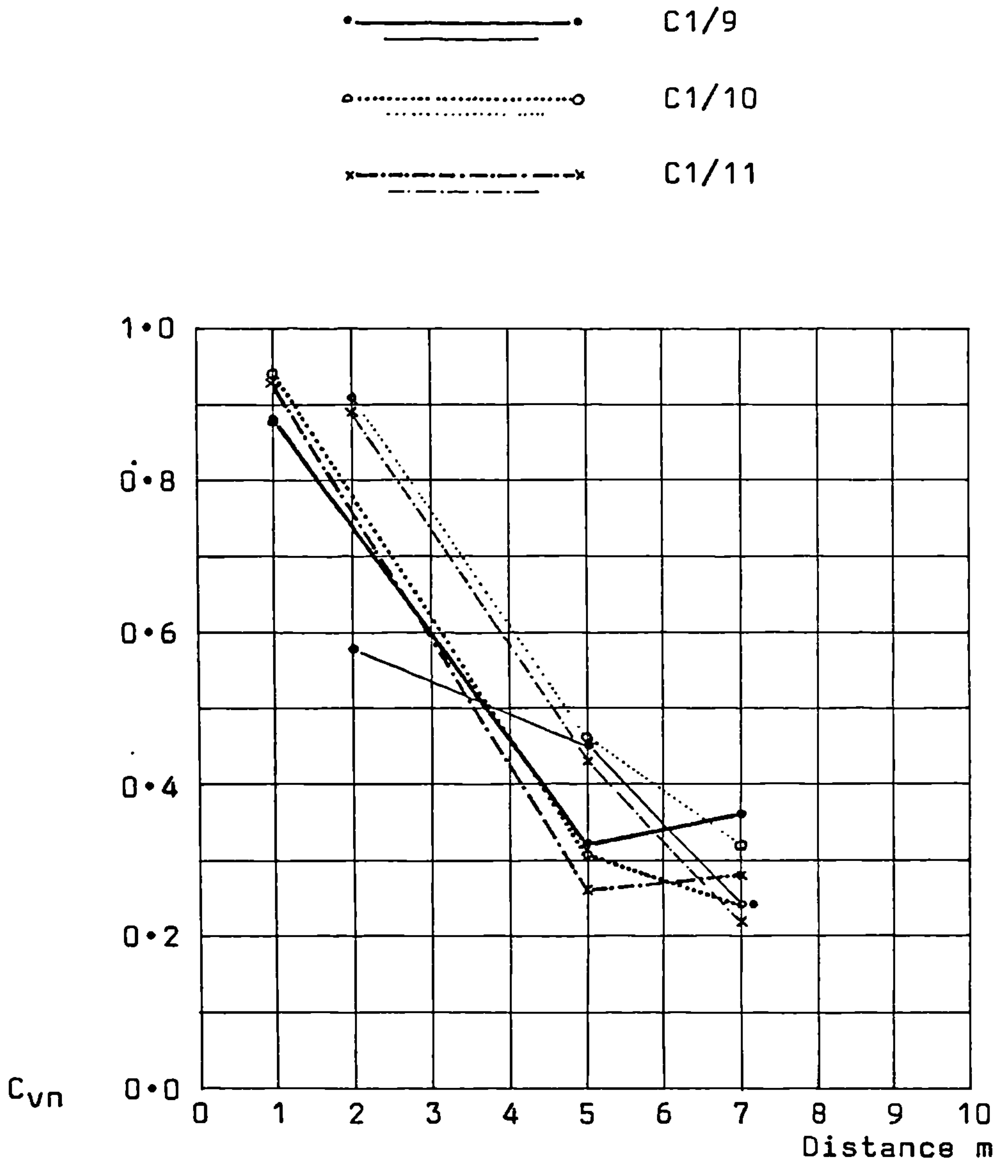
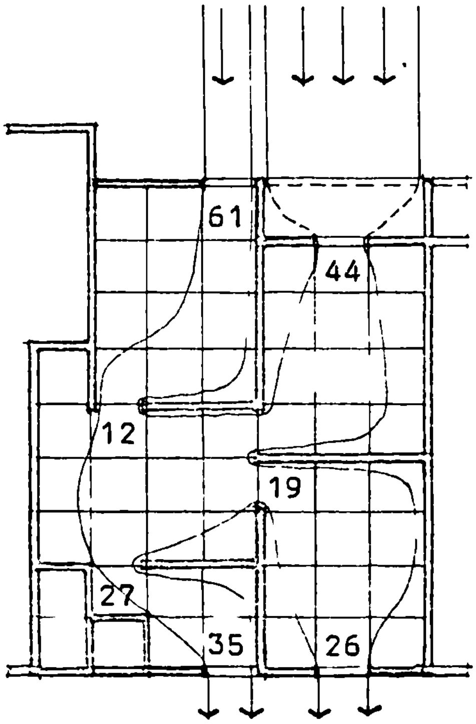
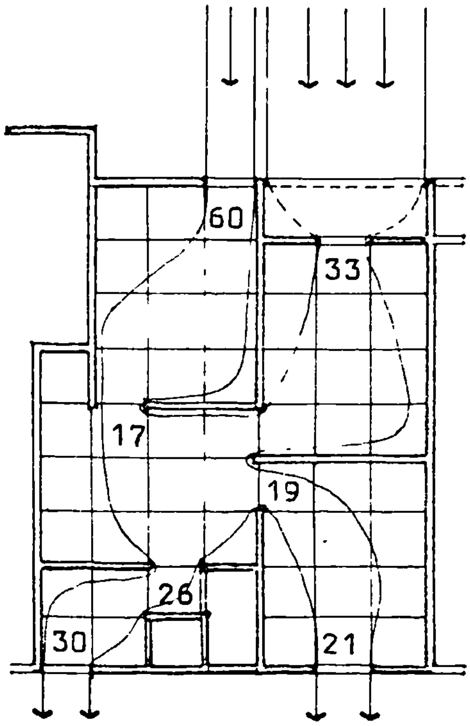


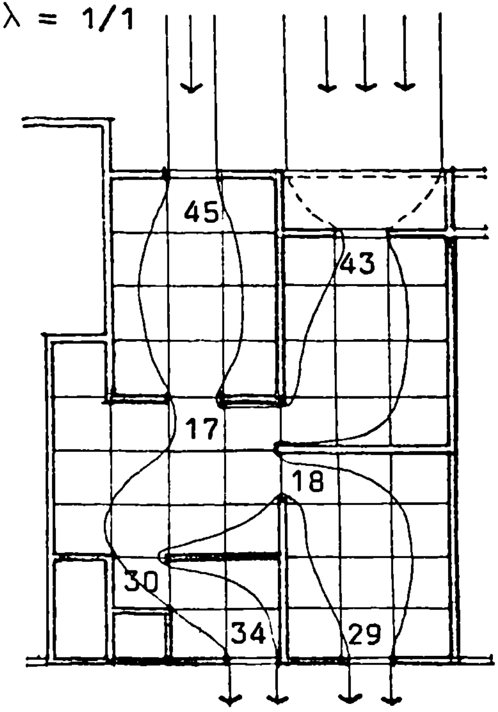
Figure (6.78) The change in C_{vn} in relation to inlet/outlet relative position within multi-cell, Model C1 (angle of incidence $\theta = 0^{o}$).



D1/3
λ = 1/1



D1/4
λ = 1/1



D1/10
λ = 1/1

Figure (6.79) The effect of inlet/outlet relative position on the flow within multi-cell, Model D1 (angle of incidence $\theta = 0^{o}$).

D/3, the decrease in air speed magnitude was in the order of 16% near the inlet where C_{vn} = 45%, while the increase near the partition was 5% where C_{vn} = 17%. Air flow near the outlet and within the right section showed slight changes, figure (6.80).

When angle of incidence θ was altered to θ = 45° air flow within D/3 showed an increase in speed near the outlet, C_{vn} = 89% (left) and 55% (right), while across the space the flow showed little difference in air speed magnitude. In D/4 the flow suffered a decrease in speed near the left inlet but increased near the outlet, C_{vn} = 36%. In the left section a slight change in air speed magnitude near the openings was observed. In model D/10 the main change observed was near the inlets, where C_{vn} = 40% for the left and 66% for the right, with C_{vn} = 8% near the partition. Near the outlets the change was less pronounced, 32% for left and 23% for the right. When the angle of incidence was changed to θ = 45° air speed showed considerable decrease near the left inlet but increased near the right, while the outlets showed little decrease. At angle of incidence θ = 90° a considerable reduction was observable in all cases, but a marked increase in air speed magnitude was evident within the central space.

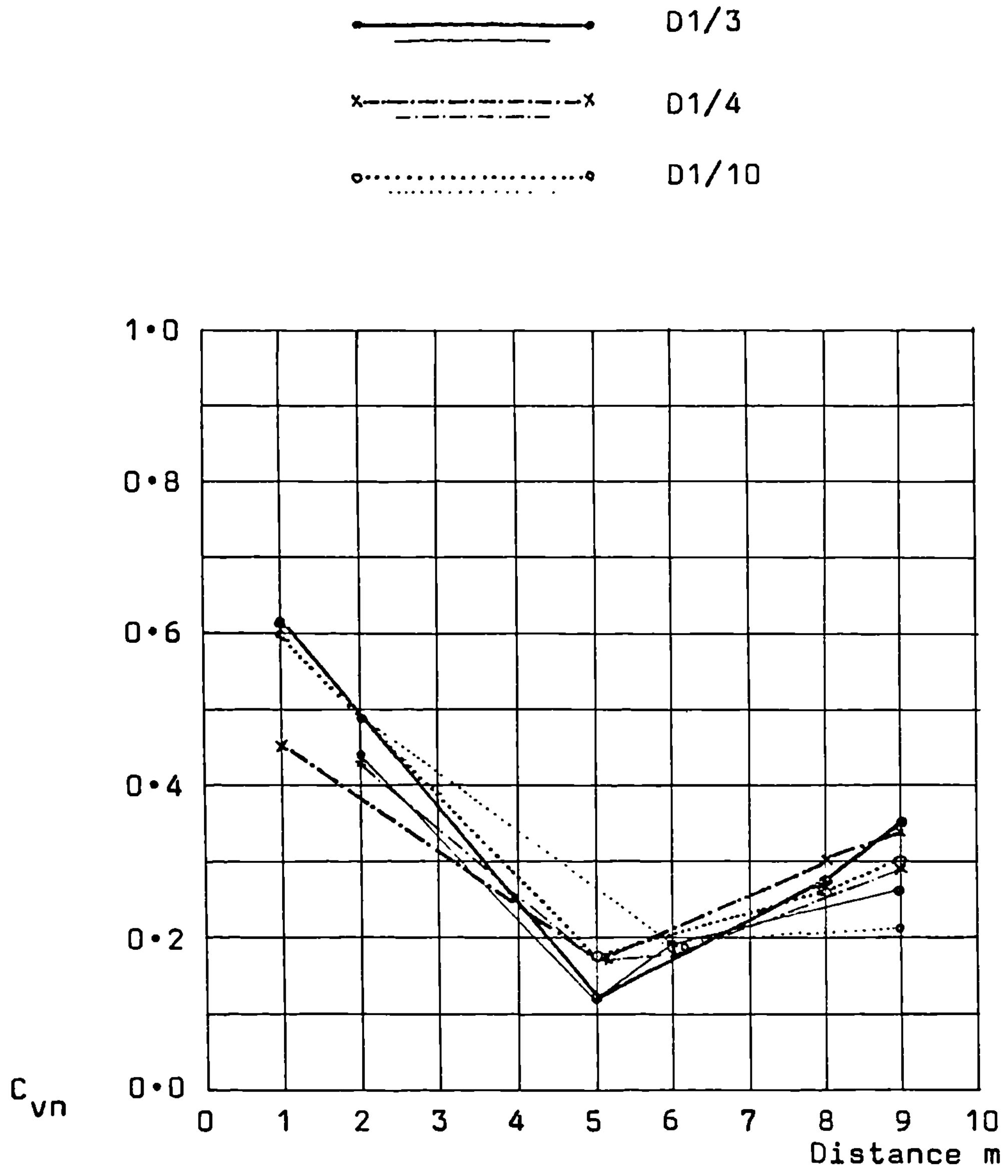


Figure (6.80) The change in C_{vn} in relation to inlet/ outlet relative position within multi-cell, Model D1 (angle of incidence $\theta = 0^{o}$).

6.7 Validation of Results

In the course of the above investigation air flow within the single cell model of category A has been examined. The findings concerned both the qualitative and the quantitative aspects of the flow.

At angle of incidence $\theta = 0^o$, and when $1 > \lambda > 1/2$, high air speed covered most of the space and the Venturi effect dominated the flow pattern. This high speed was due to the fact that openings arrangements secured minimum energy loss, ie minimum kinetic energy converted into pressure. With $\lambda > 1/1$ a remarkable reduction in air speed at the inlet, the outlet and the corners of the space was observable. These observations agree with those reported by Straaten (249) where he stated that a small opening downstream reduced the air speed. They also agree with Olgyay's observations (206).

The change in air speed, ie C_{vn}, in relation to variations in the inlet/outlet relative area (λ) are illustrated in figures (6.81) and (6.82). Givoni (119, 120, 121, 122) conducted a series of investigations of air flow patterns within a simple single cell model of 65 x 65 x 50 cm. These models occupied 27% of the wind tunnel working cross section, 80 x 150 cm. For a model of this nature the recommended maximum blockage[1] is 7½%. The accuracy of the results Givoni obtained are questionable because of the large blockage ratio of his models which would have caused higher pressure values around them, resulting in higher air speeds in many cases and exaggerated the resistance of walls to air flow in others. Bearing in mind the above

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1 The effect, and the recommended blockage are discussed in detail in Appendix A4.

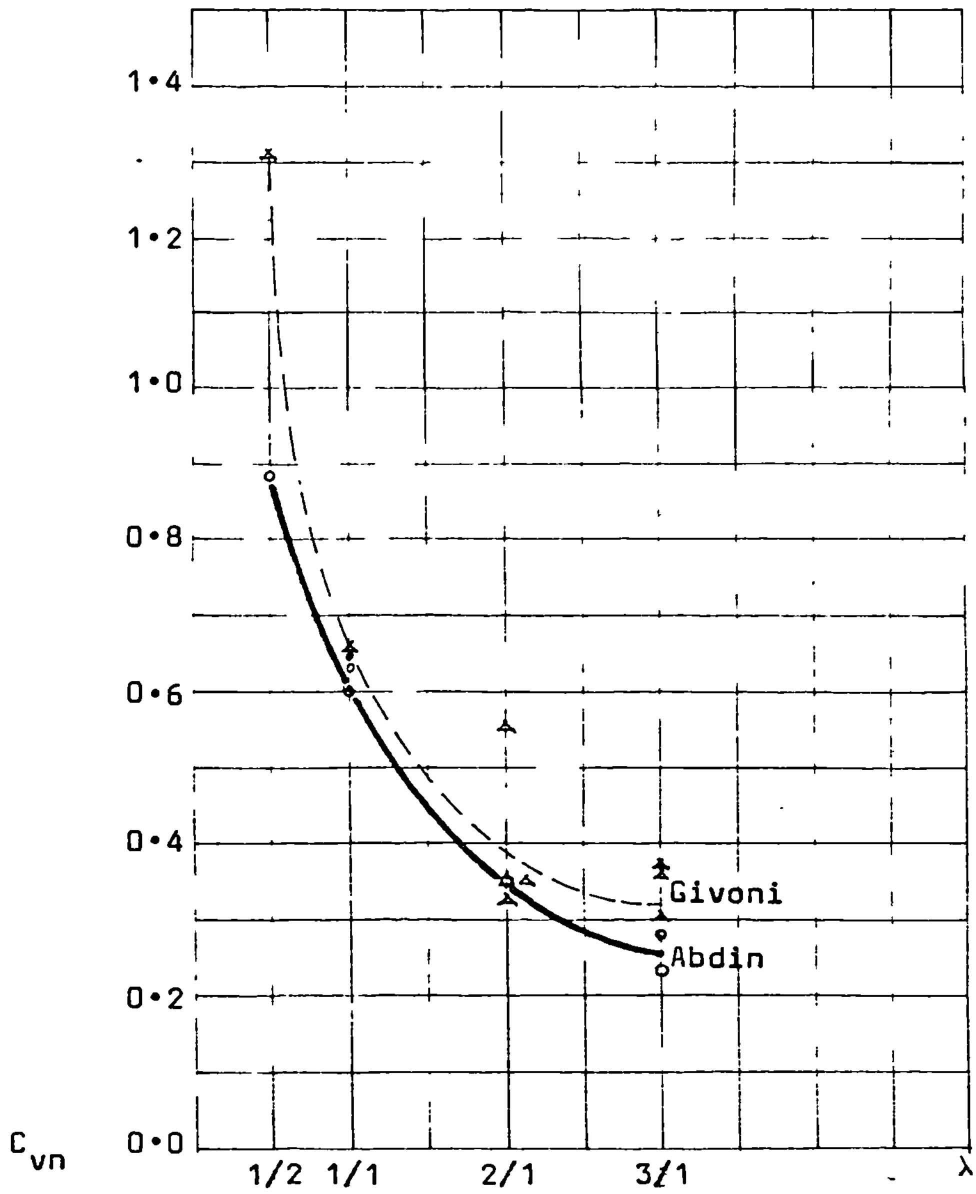


Figure (6.81) The change in C_{vn} in relation to variation in λ, showing comparison between results for the present investigation and those of Givoni (119,120,121,122) angle of incidence θ = 0°), inlet values.

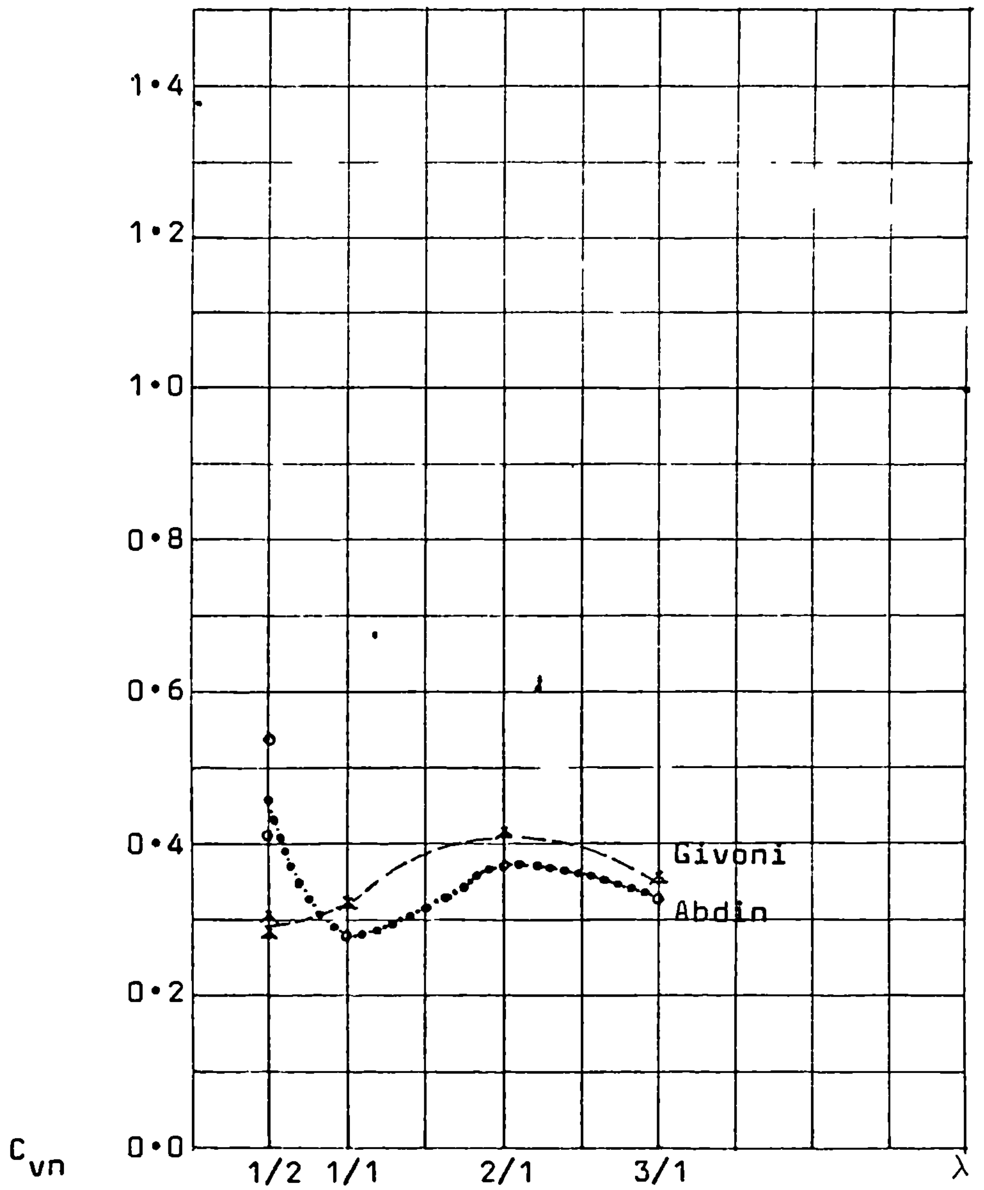


Figure (6.82) The change in C_{vn} in relation to variation in λ, showing comparison between results for the present investigation and those of Givoni (119,120,121,122)(angle of incidence θ = 0°), outlet values reservations, Givoni's results for the single cell model with similar opening arrangements have been considered on the same basis as the author's results and are illustrated in figure (6.81) for the inlet and figure (6.82) for the outlet. Givoni's results show a similar pattern, but with higher speeds as expected.

Air speed at the outlet was highest when $\lambda = 1/2$, decreased when $\lambda = 1$, then increased again when $\lambda = 2/1$, to a value higher than that near the inlet of the same model. This was to be expected because of the change of the pressure, ie the potential energy, of the incoming air into kinetic energy which reinforced the suction at the outlet. The low air speed Givoni obtained for the model with $\lambda = 1/2$ was a result of the exaggerated wall resistance expected in a model having inlet/outlet relative area (λ) of this order. However, the general pattern at the outlet produced from Givoni's results agrees with the present work exept for $\lambda = 1/2$ where the large blockage effect is most evident figure (6.82).

When the angle of incidence was 45^o the Venturi effect prevailed at $\lambda < 1$, but with less pronounced difference between $\lambda = 1/2$ and $\lambda = 1$. Air speed near the outlet rose again at $\lambda = 2/1$, then fell sharply at $\lambda = 3$, figure (6.83). The fluctuation in air speed in relation to λ observed during the present work corresponded with those reported in Givoni's work but the air speed magnitude showed marked differences. Also, it is interesting to note that the flow near the inlet for this angle of incidence shows a similar pattern to that near the outlet for angle of incidence $\theta = 0^o$. Moreover, at inlet/outlet relative area $\lambda = 2/1$ the air speed shows little change between the inlet and the outlet due to the change in the angle of incidence.

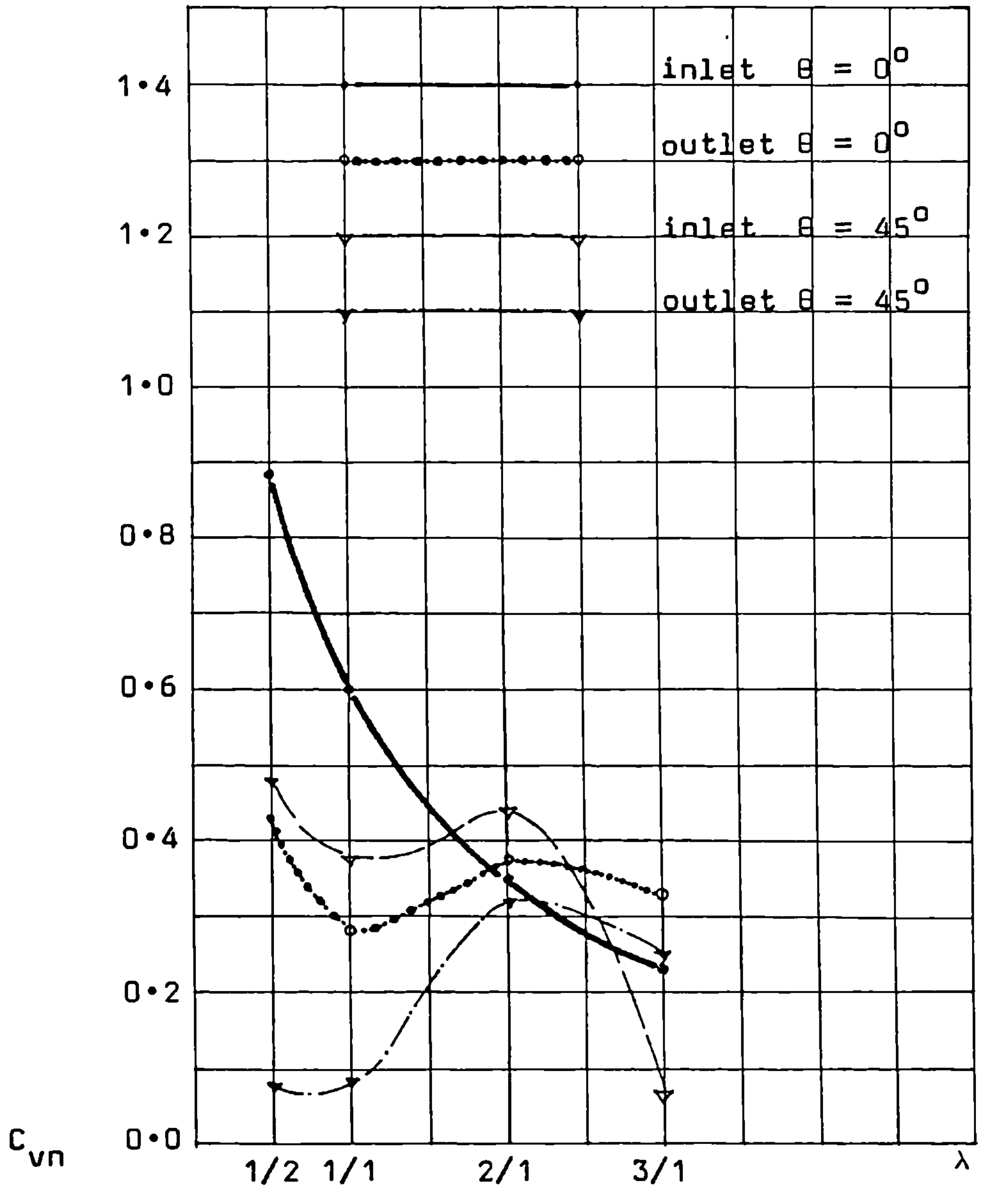


Figure (6.83) The change in C_{vn} in relation to variation in λ for both inlet and outlet at angles of incidence $\theta = 0^{\circ}$ and $\theta = 45^{\circ}$.

6.8 Design Considerations

During this investigation two kinds of observations have been made, a qualitative one and a quantitative one. The qualitative observations concerned the pattern of air flow and the quality of ventilation in the whole space as well as the air movements in the corners where it seemed to be stagnant in some cases. They also considered air speeds in different parts of the space in relation to the speeds at the inlet and the outlet. This will help to indicate the ways in which change may occur in the flow. It was decided to illustrate this information in a qualitative manner on the grounds that these changes are dependent on the complex parameters governing space design, of which ventilation is only one. It was also thought that it would be desirable to impose minimum restrictions and give maximum flexibility to designers by describing the broad lines of the effect space arrangements have on air flow patterns hoping that this will be of value to their decision making processes during the early design stages.

The quantitative observations conserned the magnitude of changes in air flow within the space. On the one hand a comprehensive program covering all the possible changes in air flow within the built environment will need monitoring the flow with greater numbers of probes and recording equipment than that available for this study. On the other, the knowledge of air speed at the opening will help in predicting air flow patterns, the speed gradient at least within the vicinity, and hopefully across the whole space, This would also allow more accurate estimation of the number of air changes due to wind ventilation whenever needed.

In Sections 6.5 and 6.6 air speeds at the openings in models of categories A, B, C and D have been monitored and the following are the prevalent trends observed during this investigation:

1. At angle of incidence $0 = 0^o$ the partition area across the space will cause changes in air speed within the single cell model of category A at both the inlet and the outlet in the order of 6% and 5% respectively. For a multi-cell model of category B the change in air speed near the inlet and the outlet is in the order of C_{vn} = 13% and 14% respectively, while the order of change is 3% and 7% respectively in a multi-cell model of category C. In model categoru D the change is in the order of 6% near both inlet and outlet.
2. The smaller the partition area the smaller will be the air speed magnitude at its opening and the higher the average speed leading to more uniform ventilation conditions. However, the presence of a partition near the inlet will result in reducing air speed at the inlet, but increasing the outlet air speed.
3. At angle of incidence $0 = 45^o$ space arrangements show considerable impact on the air flow near the inlet but less effect on air flow near the outlet. In the case of a single cell model of category A this impact is most pronounced for models having $\lambda > 2/1$. In multi-cell models of category D air speed near the partition suffer a marked reduction with the reduction in a_3.
4. Whenever there is a partition near the outlet, air flow within the leeward space will be a function of the outlet air movement.
5. In the case of three consecutive cells, as in model category D, air speed is proportional to the depth of the space. Air speed decreases near the first partition then increases near the outlet. Within the middle space air speed near the windward opening fluctuates in concordance with the fluctuation of air

speed near the inlet. Air speed near the leeward opening of the middle space fluctuates with that near the outlet

6 With the change in the inlet/outlet relative position within a single cell, air speed will show little change near the opening. The major change will occur in the flow pattern inside the space where a shifted inlet/outlet position will cause higher air speed over wider area than that when the inlet and the outlet are positioned at the same line, parallel to the outside flow. Within a multi-cell of categories B and C the change in the inlet/outlet relative positions will have a more pronounced effect on both the inlet and the outlet air speeds, figure (6.73), than that observed in the single cell model with the lowest air speed at the inlet, but the most dynamic flow across the whole space, which is observed when the openings are furthest apart. This results in the air changing direction within the space, hence increasing the area of the space it flows over.

7 In a multi-cell of three consecutive spaces, ie of category D, air speed near the inlet is highest when inlet is positioned diagonally from the partition opening, with the highest speed at the partition occurring when the outlet is positioned diagonally from the inlet. This arrangement will secure an increase in air speed at the windward side of the middle space in the order of 5% beside higher air speed in the windward spaces. Air speed near the outlet shows changes the reverse of those at the partition, figure (6.79). It is necessary to aknowledge the fact that the above observations are a simplified picture of the flow which is affected by the infinite parameters of a space of this nature.

8 The change in the angle of incidence O to $O = 45^{o}$ will result in the reduction of air speed in all models, In the single cell model with one opening in each side

the best speed distribution occurs when the openings are aligned. In multi-cell models with two inlets and two outlets the most uniform speed distribution exists when the openings, either inlets or outlets, are positioned furthest apart. The flow in most cases is considerably dynamic at the central space of the model of category D. In the more complicated spaces the asymmetry of the space arrangements may result in marked differences between $\theta = -45^{\circ}$ and $\theta = +45^{\circ}$.

9 At angle of incidence $O = 0^{\circ}$ air speed near the inlet and the outlet is a function of the inlet/outlet relative area λ. When the value of λ ranges between $1/2 < \lambda < 1/1$ air flow is characterized by high speed over most of the space. Air speed near the inlet is inversely proportional to λ. The change in C_{vn} with respect to λ is illustrated in figures (6.84) to (6.86) for model categories B, C and D respectively. The distance between the inlet and the outlet seems to have a considerable impact on the variation in C_{vn} in relation to λ. This is to be investigated further in Chapter 7.

10 Air speed at the outlet is inversely proportional tp λ values. However, in model categories A and D, when $\lambda < 1/1$ the strong Venturi effect reverses this relation.

11. When the angle of incidence is 0° the effect of the Venturi phenomenon on the flow at $\lambda < 1/1$ is observable and it is also evident at angle of incidence $O = 45^{\circ}$.

12 The ventilation coefficient C_{vn} near the inlet, the outlet and within the space gives direct indication of the expected air speed within the space, hence it can be used as an index for the ventilation performance in the early design stages.

Therefore, knowing the angle of incidence O and the inlet/outlet relative area λ it would be possible for a designer to determine the value of C_{vn} from figures (6.83) to (6.86) and hence predict the value of the air speed at the inlet,

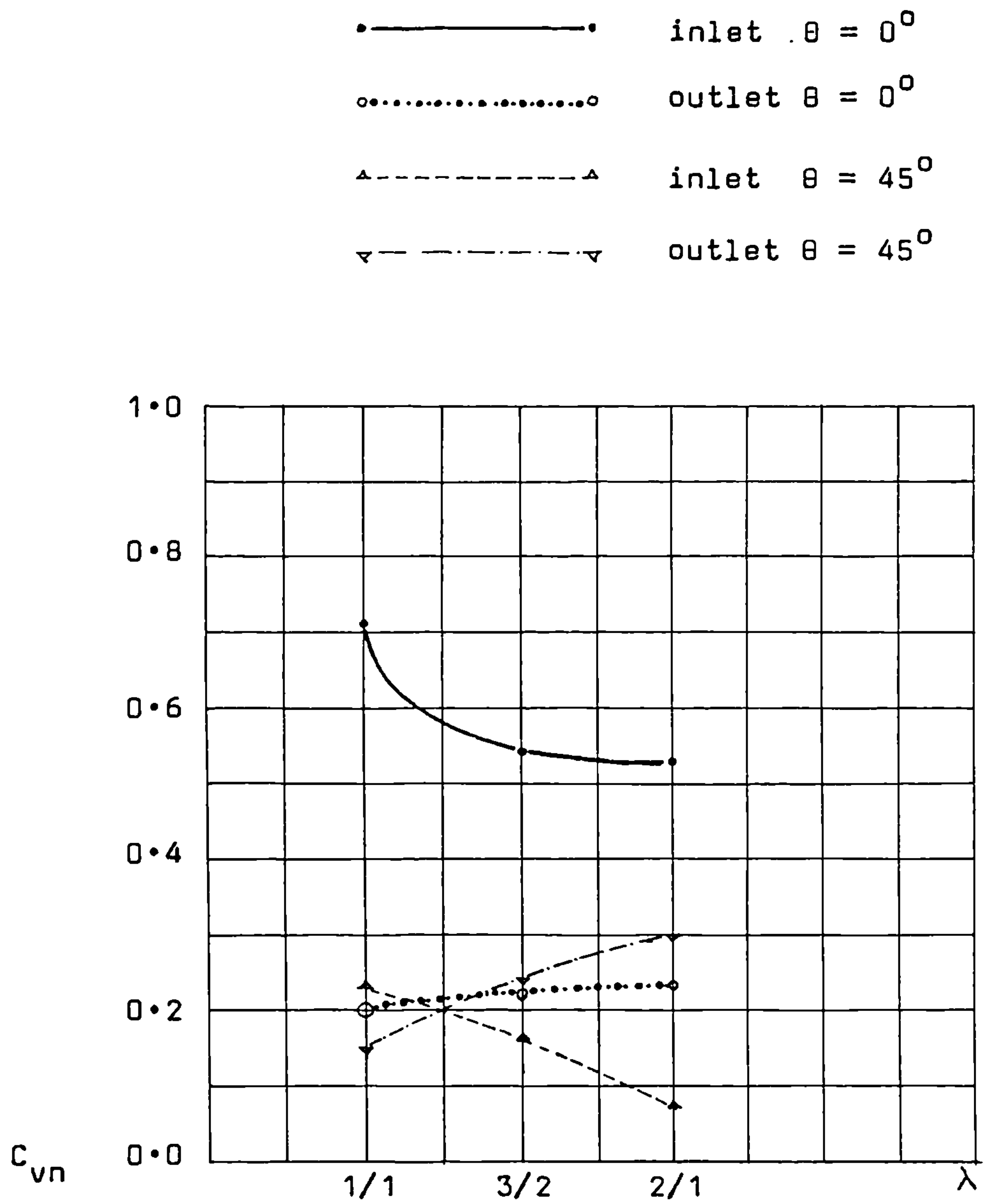


Figure (6.84) The change in C_{vn} in relation to variation in λ for both inlet and outlet within multi-cell Model B at angles of incidence $\theta = 0^o$ and $\theta = 45^o$.

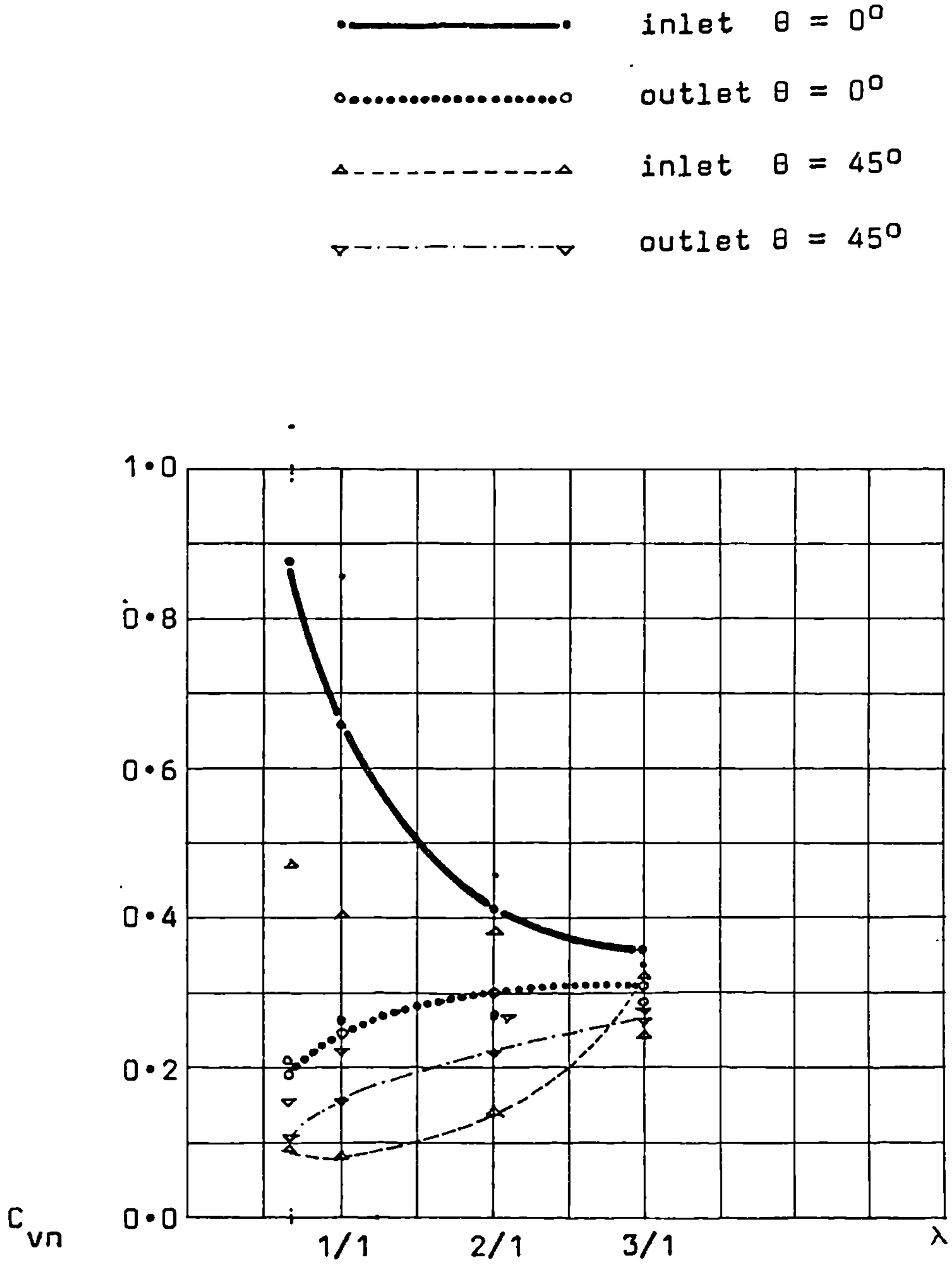


Figure (6.85) The change in C_{vn} in relation to variation in λ for both inlet and outlet within multi-cell Model C at angles of incidence θ = 0° and θ = 45°.

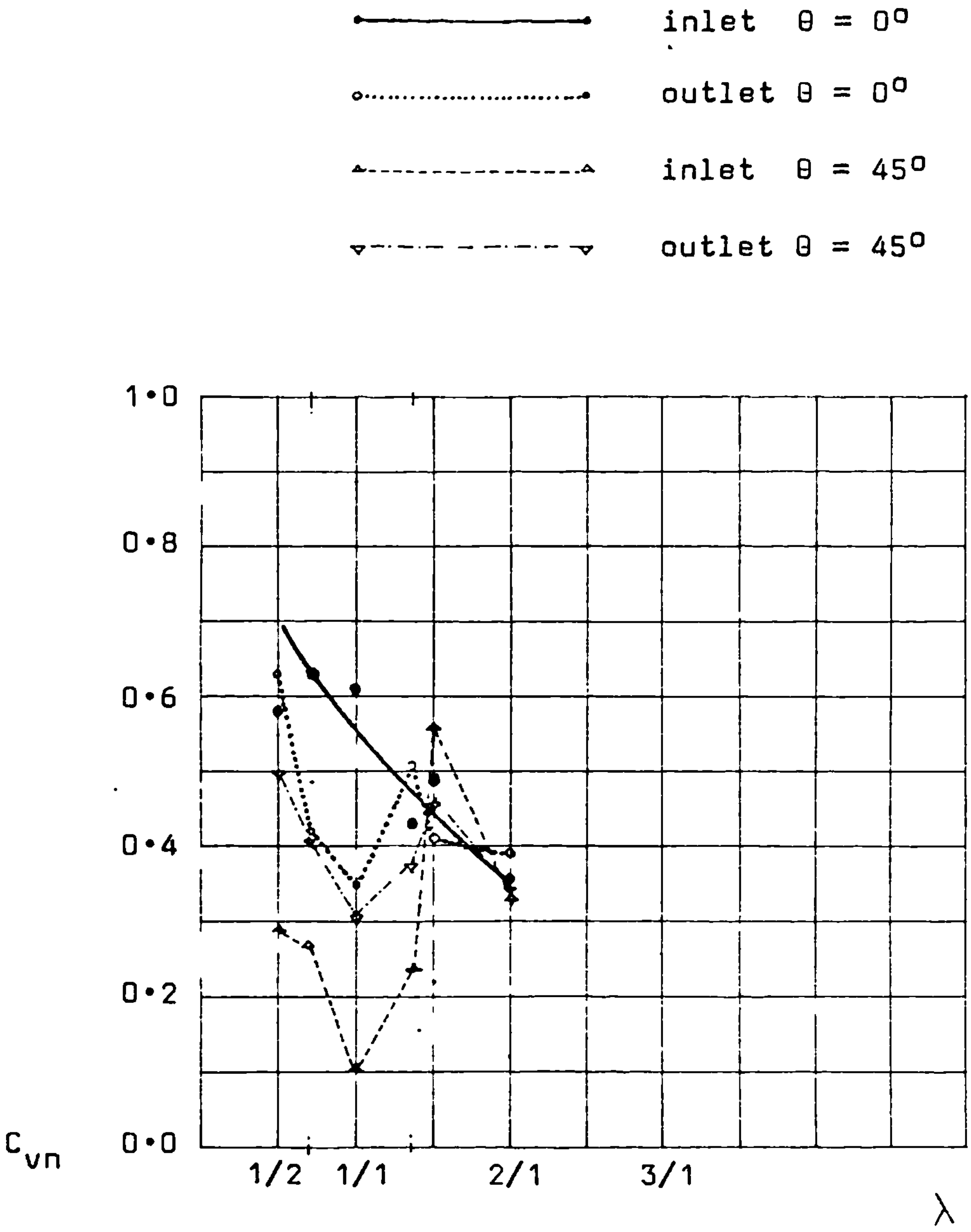


Figure (6.86) The change in C_{vn} in relation to variation in λ for both inlet and outlet within multi-cell Model D at angles of incidence $\theta = 0^o$ and $\theta = 45^o$.

outlet or inside a similar space. Relating air speed at the opening to that outside (meteorological wind speed) and to the air speed inside the space would help a designer in predicting accurately the ventilation performance of the building being designed, and would enable him to achieve human comfort through natural ventilation. This will be further investigated in Chapter 7.

Chapter 7 : A BIOCLIMATIC APPROACH TO HOUSE DESIGN

7.1 The Bioclimatic Approach

Architectural design is a practical profession where the value of a principle lies in its applicability to the design problem. The main responsibility of the architect is to satisfy the physiological (function, flexibility, comfort), psychological (aesthetics, safety) and sociological (cultural, economic) needs of the people who are going to use his buildings. The importance of these needs varies according to the variation in the environmental forces, without knowledge of which it is impossible to design for them. In hot and semi-desert climates the physiological needs assume considerable importance and the architect is required to control the built environment by all available means. Extending the benefits of environmental control to the low income housing will necessitate employing natural techniques. It is an essential condition of economy in house design to start with the consideration of climate because, unless the design is fundamentally correct in this aspect, it is expensive, and sometimes impossible, to make the building function satisfactorily. In low income housing the occupants can afford neither the initial nor the running costs of mechanical means to control their environment. Also, it must be realized that the climate aspect is but one side of a many sided problem. If the aim is to enable the architect to produce houses that are climatically sound he must be offered a means of achieving this aim within the time available at each design stage. The design approach should start from the earliest analysis leading to the initial decisions being made at the beginning of the design process, where most of the important strategic decisions are made.

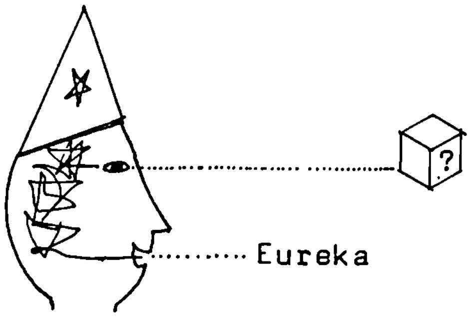
The convential method, starting by first assuming the important features of the project then calculating the climatic performance of the building to a fraction of a millimetre of fabric thickness, falls short of satisfying the architect's needs at the most crucial decision making stage. A method that gives the architect a ready-made decision however, will limit his initiative and inventiveness in solving his unique local problem. Both approaches are far from satisfying the architect's needs for a flexible approach to the design process and thus a bio-climatic approach is to be considered in the next Section.

Climatic effects should be considered when deciding on the overall concept of a project, on the orientation, the shape and character of the structure, and on the enclosed and open spaces. Air temperature, humidity, radiation and air movement are not the only climatic characteristics affecting human comfort, but they are the dominant ones. The level of activity and type of clothing are the dominant factors affecting the human physiological reaction to climate. The designer would need the climatic conditions to be classified according to the simultaneous effects of the above mentioned six factors. In doing so, it would be necessary to assess the length and intensity of various seasons and to study the detailed features of their extreme conditions to establish the climatic design limits for each season. These should be followed by determining the effect that alteration of each element could have on physiological comfort, giving indications of the possible directions of modifications available. Knowing the forces behind these modifications, the designer will acquire a flexible design tool aiding him in making the right strategic as well as tactical decisions at any step, directed towards producing a coherent solution. These are necessary for generating a design integrated with its climate. As the designer advances through the design process the need for accuracy increases. At all stages the degree of accuracy as well as the nature of the information should be related to the characteristics of the climatic and physiological data, and to the materials and techniques that are available.

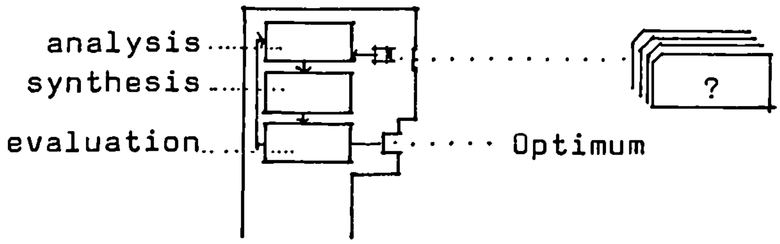
Research workers in the field of design methodology perceive the designer as approaching the design problem mainly in one of three modes, as a black box, a glass box or a self-organizing system, figure (7.1). The evaluation of the theoretical background and the practical feasibility of these design methods is out of the scope of this Section. The 'designer as a glass box' system, conscious of the development of the design process in three main stages, analysis, synthesis and evaluation, is to be adopted in the course of this Section. Considering the plan of work of an architectural team (223), the climate may influence the design process in three stages:

a The Bioclimatic Analysis stage, which should start with the inception, and develop in the course of, the feasibility studies. As the main aims of these sub-stages are to prepare a general outline of requirements and to examine the functional, technical and financial feasibility of the design it is essential to consider the potentials of the climatic modifications on the design. The bioclimatic analysis should include the main climatic factors, their design limits and their simultaneous impact on human physiological comfort. The potential modifications of the prevailing climate as a function of human comfort should also be considered in the context of the local site characteristics, as well as the socio-economical and psychological needs of the users. Collecting and processing the climatic data, obtaining the design limits and determining the physiological comfort level under the prevailing conditions can be achieved by employing the techniques applied in Chapter 3 to the Egyptian climate.

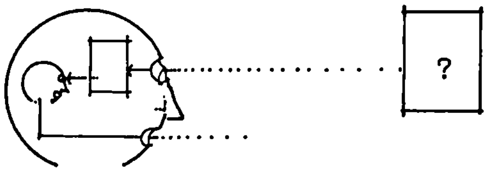
b Spatial Design Stage, which covers both the outline proposal and the scheme design activities. This stage



Designer as a black box.



Designer as a glass box.



Designer as a self-organizing system.

Figure (7.1) Modes of design. After J C Jones, 1969.

can be considered as a design loop within the main design process, hence it may include further analysis, synthesis and evaluation. During this stage the general approach to layout, space concept and construction is to be determined. Then the planning arrangement, space design, environmental control techniques, services to be involved, construction, outline specifications and costs are to be decided. Therefore, full account should be taken of the bioclimatic analysis as well as other types of analysis before the final project concept is concluded and decisions made. In Chapter 4 wind impact on buildings, health ventilation, potential thermal relief and physical mechanism of air movement around and within buildings were considered, also current knowledge related to air flow was examined. In Chapter 5 thermal stress on building form and the design orders related to socio-cultural and climatic factors in the Egyptian examples of houses throughout history were considered. These gave indicators of the changes to the environmental forces which are possible as a result of employing diverse techniques, some of which could help in generating solutions to the design problems of today.. The first phase of the experimental programme, illustrated in Chapter 6, examined the effect of building forms and groupings on air flow outside, while the second phase examined the ways space design could alter air flow within the built environment and the possible trends of modifying air flow within the unit. Knowing the nature of the forces affecting the environment, as well as the possible modification trends, the architect will have a flexible design tool providing him with maximum aid and minimum restriction to his initiative and inventiveness.

c Detail Design Stage, this stage will involve further analysis, synthesis and re-evaluation of all elements contributing to the agreed design. Each element will designed in the context of the overall design. At this stage the aim is to finalize all the details of the design, and prepare working drawings necessary for the execution stage. This includes matters such as window design, environmental control systems, final design of every part and component of the building and the final evaluation of the expected performance of each item. To achieve these objectives the designer will require information at the highest possible level of accuracy. During the second phase of the experimental work (Sections 6.6, 6.7 and 6.8) air flow within the multi-cell showed a clear correlation to the angle of incidence 0, the area of the partition a_3, and the inlet/outlet relative position. Inlet/outlet relative area showed a strong correlation to the flow pattern and the magnitude of flow. Thus, as concluded in Chapter 6, it would be possible to predict the magnitude of air flow using the velocity coefficient C_{vn}. This will provide the architect with a means to design the window system necessary to satisfy human comfort requirements during the overheated periods, which should result in a more sound ventilation system and consequently a more acceptable thermal environment within residential units under a given set of conditions.

The three stages (summarized above and detailed in the following Section) in which the climate will affect the design process should be followed by preparing the experience gained so it can be fed into the next project to be designed.

7.2 Bioclimatic Analysis

The bioclimatic analysis should start with the collection of relevant information and establishing a coherent base of climatic data[1]. In most places these data could include air temperature, relative humidity, hours of bright sunshine or intensity of solar radiation, wind speed and direction, rainfall and altitude. In hot and semi-desert climates the first four are the dominant elements affecting both human comfort and building design. The two human factors, metabolic rate and clothing, should be decided. The nature and magnitude of each climatic element, as well as the human response mechanism has been investigated in detail in Sections 2.2 and 2.4 respectively. Classification of climate was examined in Section 2.3 and the architect's need for a new climatic classification was recognized. A climatic classification based on the human physiological response seemed possible only when a thermal index considering most of the outdoor climatic elements was developed to include the direct solar radiation. A computer program has been developed, Appendix A2, to predict the intensity of solar radiation as well as its sensory effect on human comfort for different latitudes and land cover. This allowed the use of the Standard Effective Temperature (SET), illustrated in Appendix A3, as a base for the bioclimatic analysis conducted in Chapter 3 for both Egypt and Cairo. If the two human factors are to be standardized, a world climatic classification based on human comfort would be possible, employing the same technique used for the Egyptian climatic regions. Such a

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1 The climatic data from the nearest meteorological station should be accepted. However, if there is a site observatory which has kept records for at least one year its data should be considered instead. Major site features can be recognized and allowed for.

classification could be of significant value to the architectural profession. However, this is out of the scope of the present study. This Section is concerned with the formulation of the Egyptian regionsl climatic characteristics.

The climatic elements of the Egyptian regions are illustrated in table (3.10); the climatic data of any location may be recorded in a similar manner to that of table (7.1). It was possible to detect the simultaneous effect of the climatic elements using the Standard Effective Temperature (SET) in Appendix 3. The DISC value of each month was compared with the optimum comfort limit (OCL) which ranges between $-0{\cdot}5$ DISC $<$ OCL $<$ $+0{\cdot}5$ DISC. Then the daytime DISC value is less than $-0{\cdot}5$ DISC the monthly climatic conditions will be considered as underheated period U, winter, and when it is more than $+0{\cdot}5$ DISC it will be considered as overheated period O, summer.

Having determined the hottest and coldest months it is possible to determine the upper and lower design limits for each region. The instantaneous impact of the climatic elements has been statistically analized on an hourly basis and the upper and lower design limits have been determined in Section 3.3, and illustrated in the map of Egypt in figure (7.2). The overheated and underheated seasons, as well as comfort design limits for each of the Egyptian regions are illustrated in the map in figure (7.3). The designer will be more concerned with the design limits rather than systematic data. In any of these regions the designer can extract the design limits directly from these maps. The small differences between meteorological stations records within these regions may be ignored, though the designer should consider the effect of any significant changes in landcover, topography or other local factors which may cause large deviations from the regional conditions and results in the micro-climate within the region.

Table (7.1) The climatic data, physiological human comfort, seasons, hottest and coldest months in Cairo region: Lat 30^{0} 8' N, Long 31^{0} 34' E, Altitude 75•5m.

		J	F	M	A	M	J	J	A	S	O	N	D	max / min	AMR / DMR
Air Temp	day	19.	20.5	23.5	2.8	32.5	34.5	35.5	35	32.5	30	25	20.5	35•5	27
	night	8•5	9	11.5	14	17.5	20.0	21.5	21.5	20.0	18.0	14.0	10.5	8•5	15
RH	day	43	38	32	27	24	25	31	34	35	35	41	45	24	56
	night	70	68	69	66	64	70	76	79	80	78	76	71	80	45
Wind	m/s	3•4	3•6	3•8	4•0	3•9	3•5	2•5	2•6	2•9	3•1	3•0	3•0	4•0	
	Dir	NE	NW	SW	NW	N	NW	SW	SW	NW	NW	NW	NW	NW	
SR	oC	2•4	4	5•4	6•2	6•6	6•6	6•6	6•3	5•2	3•3	2	1•7	6•6	4•9
	W/m^2	186	258	553	696	795	787	798	726	518	273	147	136	798	662
Comfort level	day	-1.0	-0.3	0.3	0.6	1.1	1.9	2.0	2.2	1.6	0.8	0.1	-0.8	2•2	6•2
	night	-4.0	-3.9	-3.5	-3.1	-2.6	-1.4	-1.0	-0.9	-1.3	-1.8	-2.9	-3.7	-4•0	4•5
Seasons	day	U			O	O	O	O	O	O	O		U	Jan	Aug
	night	U	U	U	U	U	U	U	U	U	U	U	U		
		J	F	M	A	M	J	J	A	S	O	N	D	C	H

U = Underheated period
O = Overheated period
C = Coldest month
H = Hottest month

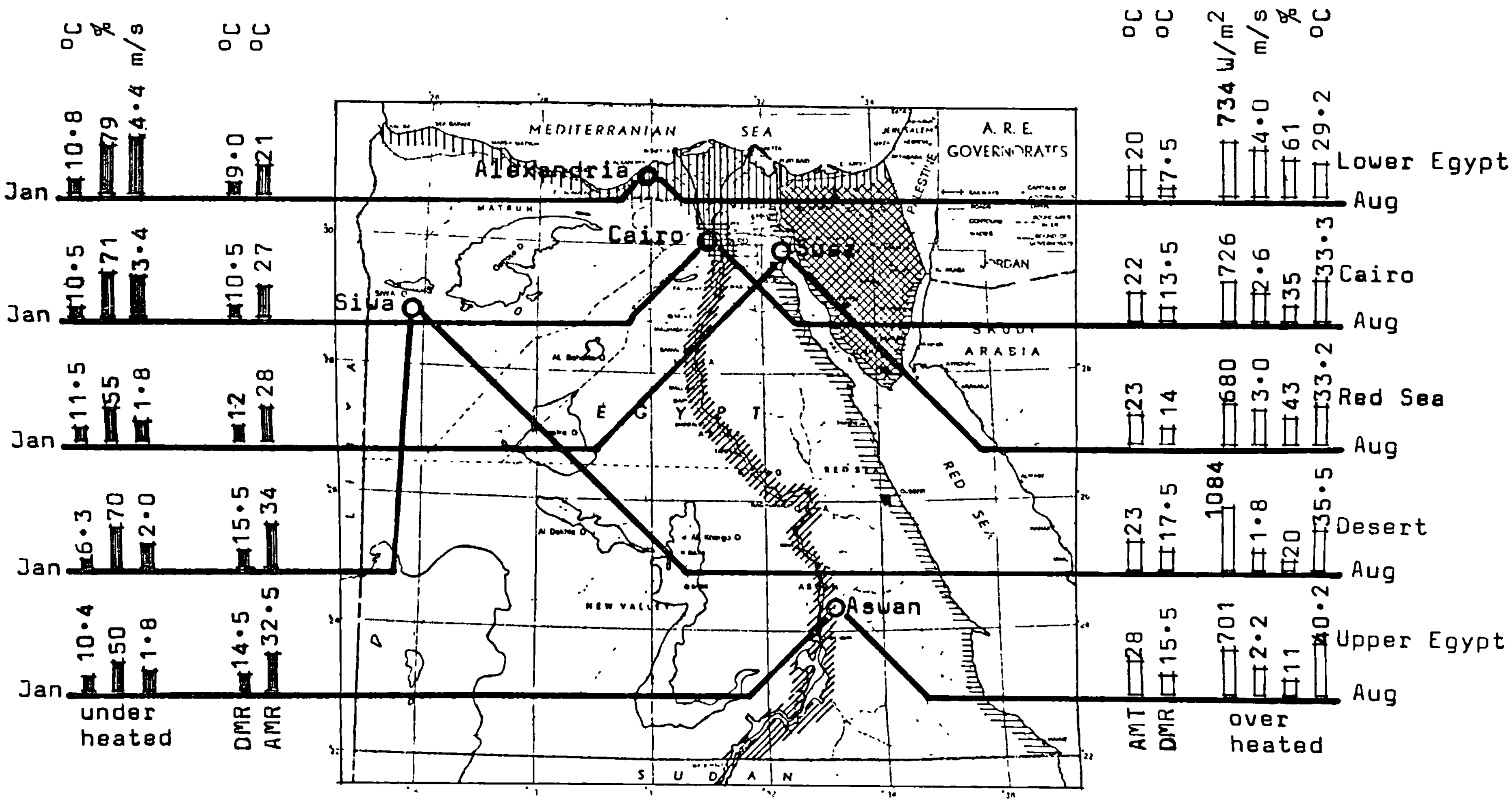

Figure (7.2) The design limits for the five Egyptian regions during underheated and overheated seasons (metabolic rate = 1 Met; clothing = 0·9 clo).

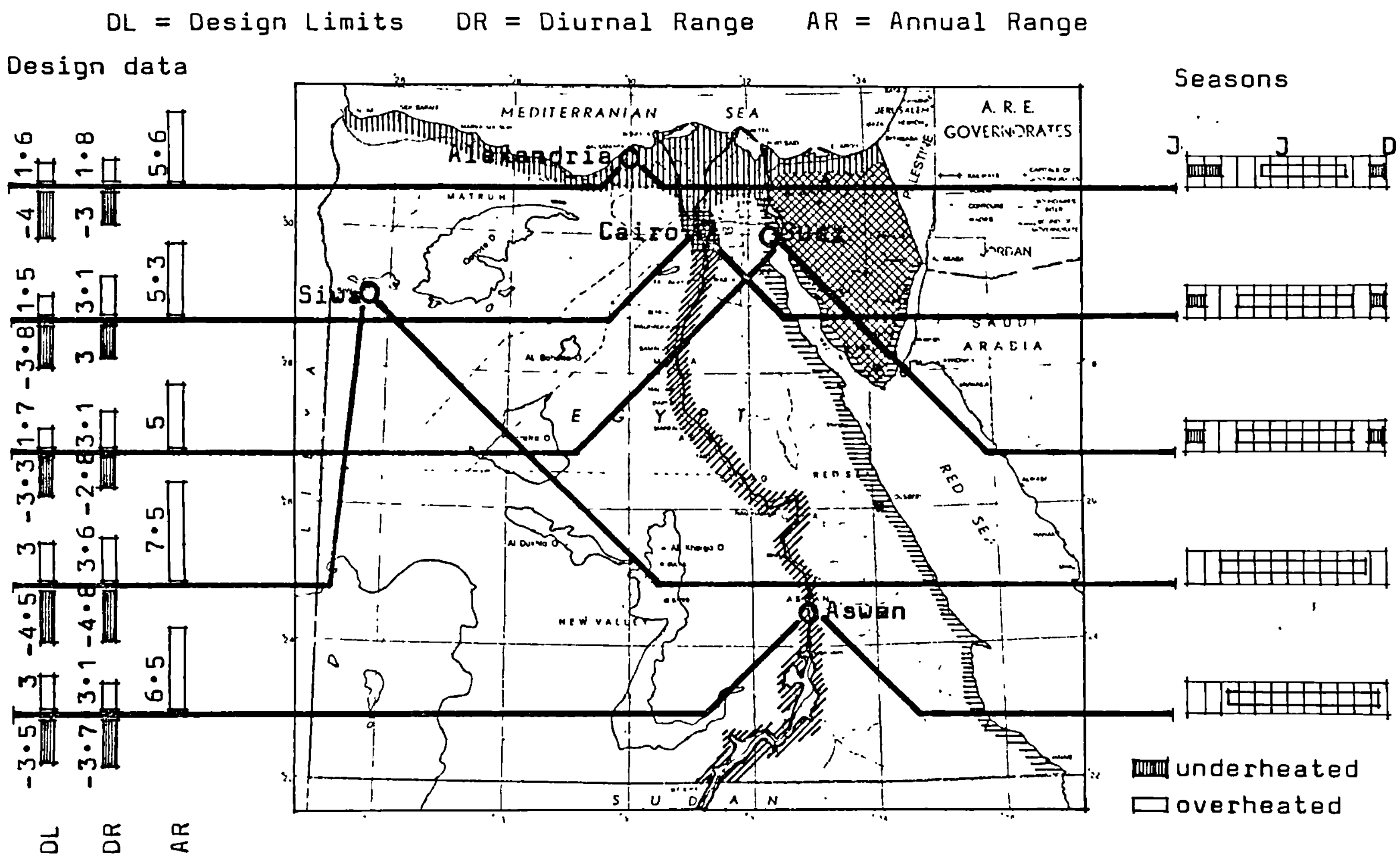

Figure (7.3) Comfort design limits, daily range, annual range and the seasons of the Egyptian regions expressed in units DISC.

The comfort analysis conveys more information about human physiological response to climate than just climatic element analysis. It diagnoses the architectural requirements in terms of human comfort derived from the instantaneous effect of the four[1] climatic and the two human elements. The comfort analysis points towards possible techniques for improving the climatic conditions. It would not take decisions for the architect, but rather points out the consequences of his decisions on modifying the climatic conditions.

The comfort limits in the Egyptian regions have been computed and are illustrated in figure (7.4) where the duration of the different seasons and the magnitude of heat stress have been charted. In Chapter 3 ventilation due to wind forces formed the variation between the climatic regions where it was the key factor for improving environmental qualities. In all regions the dominant problem is the excessive heat stress and bright sunshine for a considerable length of the day, and extending over a substantial period of the year. Cold conditions prevail mainly during the nights of the short winter. In Lower Egypt the overheated period prevails for five months while the underheated period lasts for only three months. In Cairo and the Red Sea regions the overheated period extends to seven months and the underheated period is only two months. In Upper Egypt and the Desert regions the overheated period extends to approximately nine months, while the underheated period covers only a short period of the short moderate season.

The architect aims to reduce the deviation of the prevailing climatic conditions from those required for comfort. In doing so he would have to reinforce and amplify the positive

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1 Some methods diagnose the thermal stress employing only air temperature and relative humidity (158, 259). These seem to underestimate the importance of solar radiation and wind.

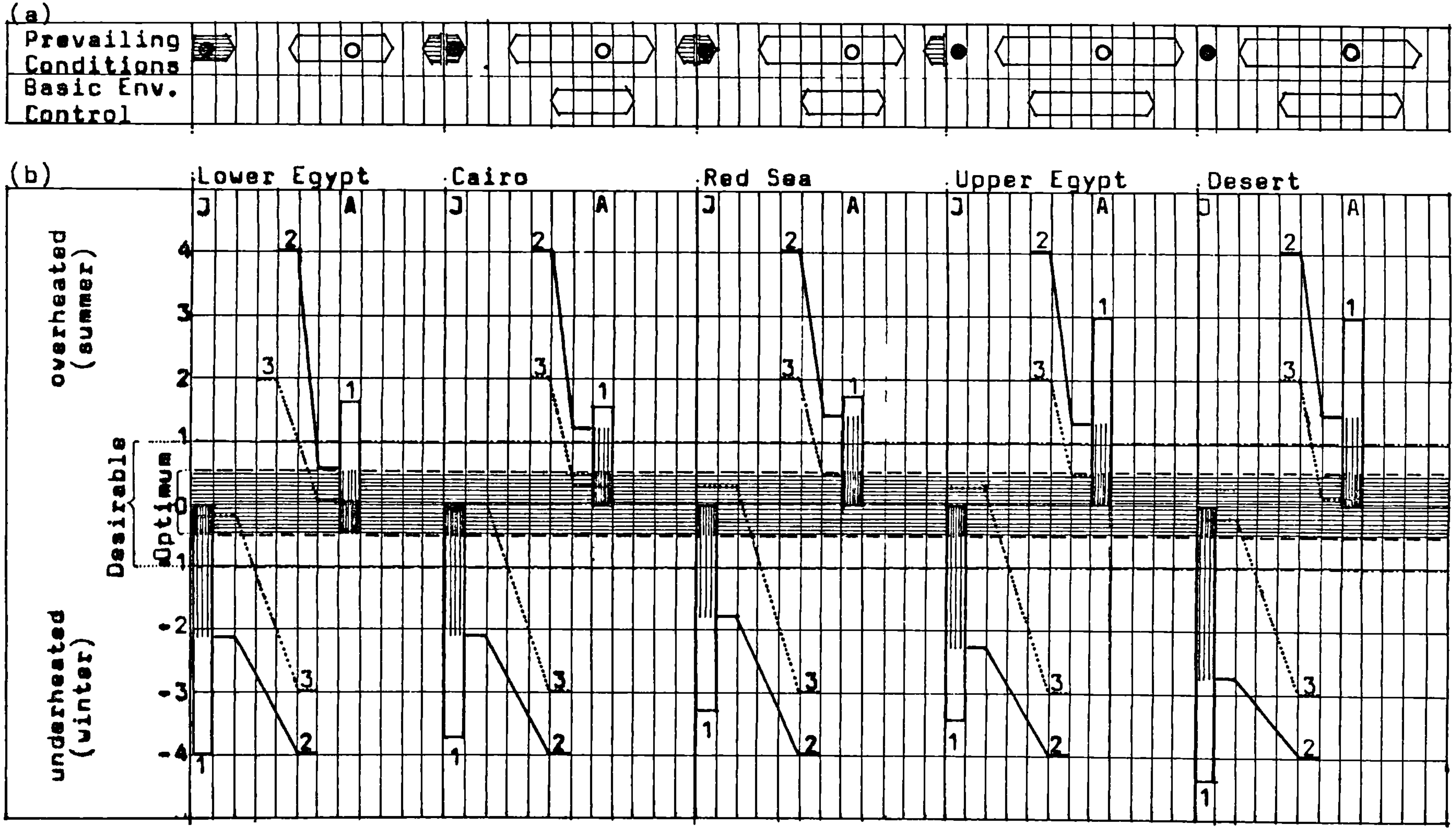

Figure (7.4) Possible modifications to the prevailing climatic conditions[1] due to shading[2], cross ventilation, microclimatology and building fabric[3] as seen in the different climatic regions in Egypt.

climatic elements and eliminate the negative ones. The effect of excluding solar radiation is illustrated in table (5.2). However, during the underheated periods the architect will require as much radiant heat as possible, table (5.3), and will need to eliminate the cold winds, table (5.4). The way in which the basic environmental control techniques will modify thermal stress during different seasons of the Egyptian regions is illustrated in chart(a) of figure (7.4). In Lower Egypt it is possible to arrive at a full year of comfort conditions employing basic environmental control techniques while in Cairo, Red Sea, Upper Egypt and desert regions it is possible to exclude the underheated season and shorten the overheated season by at least three months. Eliminating wind, changing the type of clothing as well as the provision of a thermally insulated outer shell will be needed during the underheated season, while providing shade, reinforcing air movement and high thermal capacity building elements are needed to balance the hot day with the cool night. A happy compromise for the two seasons would be a well insulated outer shell with high thermal capacity inner structure. A selection of building materials in current use in Egypt and many of the hot climate regions is listed in table (5.1).

Generally the main emphasis on the physical aspects of design should be as follows:

1. Compact building forms are advantageous with respect to heat transfer. The surface area/volume ratio should be as small as possible.
2. The long face of the building should face north - south to avoid maximum heat load due to solar radiation.
3. Building around a courtyard system consisting of at least two courts, figure (2.12), is advantageous because of the shelter nature of courtyards. This is examined in detail in Section (6.4).
4. Building groups should allow for maximum air movement

during the overheated periods and provide shelter from wind in the underheated periods.

5 Openings for inlets should be located in high pressure zones while outlets should be placed in low pressure zones.

6 The opening should be able to provide air movement at the living level, an important factor in the design of high rise flats, as well as when deciding on the roof height. This effect is illustrated in figure (6.19a & b).

7 A well insulated outer shell with a high thermal capacity inner core will perform well during both the under- and over-heated periods. This suggestion was considered in more detail in Section 4.2.3.

8 Large, shaded outdoor loggias and shaded areas in front of the openings of the ground floor will provide cool air supply during the overheated periods.

9 Outdoor sleeping should be examined in the socio-cultural context where privacy and security may be highly valued.

10 Reflective colours on building surfaces are advantageous to minimize radiant heat gain. Measures to prevent glare should be considered when disigning openings facing reflective surfaces.

7.3 Spatial Design

This stage aims at laying down the main space concept, taking into account the recommendations arrived at during the previous stage, as well as the analysis of other factors. This gives an indication of the required space, lay-out, environmental control system, services, construction, specifications and estimating the cost of the project. Decisions should be made on the dimensions and proportions of rooms, space composition with respect to form and function, wall fabrics, roof shape and fabrics, size of openings and their distribution to satisfy their three functions, view, light and ventilation. Outdoor spaces and thermal properties of building fabrics. All these factors are influenced by the prevailing climatic conditions. The difference in the land cover between the meteorological stations and the site should be considered if they are great enough to cause variations.

A large diurnal mean range, DMR, is indicative of dry weather and clear skies while a small DMR indicates overcast skies and humid climate. An outer shell well insulated and of high thermal capacity will be advantageous in the first case, while a well ventilated light-weight shell will be more suitable in the second.

The typical activity pattern for urban life in Egypt was considered in Section 3.1 while the monthly and hourly data were analysed in Section 3.4, with consideration of the daily activity pattern. The designer's objective should be to co-ordinate the activity pattern[1] with the most suitable climatic conditions prevailing at the time. On

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1 Activity pattern should be related to the physiological comfort conditions generated from the prevailing climatic conditions rather than air temperature alone.

the one hand the designer's objective during the underheated period will be to minimize ventilation coupled with maximizing radiation and providing sufficient insulation, and on the other he aims to maximize shade in the late morning and afternoon coupled with maximizing humidity and air movement during the overheated period.

The overheated period needs special attention during the design process, and consideration should be taken of the following:

1. The urban tissue should be compact to produce maximum shading for outdoor spaces.
2. Vegetation should be promoted to absorb radiation and provide evaporative cooling.
3. Walk-ways should be shaded and kept as short as possible.
4. Courtyard houses are most advantageous, and housing groups should attempt to create similar patterns to control the environment.
5. Heat loss should be promoted possibly by structural ventilation, night time outgoing radiation losses and evaporative cooling.
6. Heat gain should be minimized by small surface area/volume ratio and north - south facing blocks.
7. Deep room proportions, and the use of low emissivity colours for the interiors and highly reflecting colours for the exteriors are advantageous.
8. Ventilation should be promoted by considering the deep windward space and shallower leeward spaces with inlet/outlet area (λ) less than 1 (subject to temp.& RH).
9. Openings should direct air flow over the whole living space, and at body level.
10. Evaporation is most advantageous both in the interior and the exterior. A small fountain will have a significant psychological effect besides its physical value.

Traditional solutions have been studied in Chapter 5 with the emphasis on their development under economical, cutural and social conditions that have ceased to exist. Thus, the designer must not copy them but rather understand the factors and the philosophy of their development, and the way they performed during their era. Then he can master the creative instincts behind these environmental techniques and develop suitable solutions for his unique local design problems. Merely copying from the solutions of similar problems which are distant in either time or space will result in many cases in designs irrelevant to the problem under consideration. An illustrative example of this is the way ventilation forces act against each other in contemporary houses employing a single courtyard and opening to the outside to face the oncoming wind, resulting in great loss of natural energy and consequently low performance. In the Islamic houses of Cairo's old quarter these forces are carefully utilizes to enhance each other, thus conserving natural energy and resulting in a high ventilation performance. The consistency of space design, and the harmony of its elements, is another lesson to be learned from this historical period which has been examined in Chapter 5. The main lessons learned from the historical precedent may be summarized as follows:

1 The courtyard system composed of more than one court was a common success of the urban tissue. It has its contemporary counterpart, the 'Manwar', however its application is contradictive to the desired function and consequently it became a design failure instead of an advantage.
2 The window functions, illumination, ventilation and communication, were successfully provided for by using different elements, sometimes dividing the window to achieve this separation. It is possible to achieve this performance by employing modern economic techniques.
3 The Malkaf is a sound ventilation aid which has been employed successfully in contemporary buildings.

However, its application should take into account the other openings, as they all function in one integral system.

Those manuals and design guides which recommend both night-time ventilation and sleeping outdoors for hot climates impose highly restrictive measures on the occupants. They underestimate the importance of both privacy and security. Also, the recommendation for restricting day time ventilation considers only one function of the three performed by modern design of openings, particularly in urban areas, ie illumination, communication, plus ventilation.

Ventilation can be employed for thermal relief even when air temperature is a few degrees higher than skin temperature, because of the cooling effect of sweat evaporation resulting from air movement. Also, on the top floor where the heat radiating from the ceiling is of considerable magnitude, movement of air near the ceiling will result in cooling it by convection.

7.4 Detail Design

Having agreed on the min design, the form and dimension of each element should be framed in the context of the overall design, aiming at optimizing the climatic performance of the building. For the overheated season the design consideration can be summarized as follows:

1 The choice of building material should consider the mode of heat transfer. Building fabrics of day time spaces can be of high thermal capacity materials with time lag of at least 10 hours, while night time spaces should be of low heat capacity material which is beneficial to radiative cooling to the sky at night.

2 If the building is of a limited number of spaces, that is, every space is to be used 24 hours a day, high insulation fabrics are to be used in the outer shell; however, high thermal capacity fabrics (10 hour) can be used in outer shells if insulating techniques are not economically feasible.

3 Shaded ventilated roofs or curved form are advantageous in reducing the solar radiation gain. Evaporative cooling has a welcomed effect. If high thermal capacity is to be used it is required to have a 12 hour time lag.

4 Shading devices are necessary in all windows exposed to radiation. They should be structurally separated.

5 It is worthwhile to employ passive energy techniques using solar cooling to utilize the high solar insolation as an energy source, at the same time relieving the house of this unwanted energy.

6 Openings should be shaded from direct solar radiation and located in north or south faces.

7 The area of window needed for ventilation is larger than that needed for illumination, hence it is possible to use techniques similar to the 'Mashrabieh' and 'Malkafs'.

7.5 Optimization of Natural Ventilation

Analysis is made for the design limit securing a high level of accuracy at all design stages, however, further verification is needed of the effect of each design element of the building. This will be necessary for instance in designing for ventilation. In this Section ventilation and space design will be closely considered.

The architectural approach to ventilation in overheated seasons should differ from the engineering approach to the underheated period. In Chapter 4 methods of natural ventilation calculation were investigated. Natural ventilation during the overheated season is calculated using the method[1] which is dependent on the pressure difference across the building. The main assumptions to estimating the difference in pressure across a building oversimplify the effect of the building form and the properties of the prevailing wind, and ignore the effect of space parameters. Moreover, this ignores the physical mechanism of the human sensory system which is a function of air speed rather than air pressure.

From the review of the relevant literature on natural ventilation (Chapter 4) no general relationship has been found to be available which relates space design parameters of the built environment to flow through a single cell with space dividing element, or for multi-cells. Furthermore, the slim body of data available needs updating; this is necessary to take advantage of the more accurate measuring equipment and to allow for the experimental restrictions found in previous data.

It has been shown in Sections 6.3 and 6.4 that air flow

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1 This method (the 'crack method') is discussed in Section 4.3.2, also in ASHRAE (12).

around buildings depends on the individual building form, the grouping pattern, the plan porosity and the frontal porosity. It is also stated that air flow within buildings is a function of the flow past the building's surface as well as the space arrangements.

The present work has clearly illustrated that there is a strong correlation between the inlet/outlet relative area (λ), the space composition, the space depth, the angle of incidence, and the magnitude of air speed expressed as a percentage of the outdoor air speed. Air speed near the inlet as observed within a variety of multi-cells is plotted against the C_{vn} in figure (7.5). This shows a clear correlation between λ and C_{vn} for each model arrangement as well as a similar trend for all of the models. This may suggest that in Model B of the two adjacent cells and D of the four cells the relationship between λ and C_{vn} for $\lambda = 1/2$ and $\lambda = 3/1$ will have a strong correlation to the pattern observed in Models A and C.

When the air flow near the outlet of the space is considered air flow for each inlet/outlet relative area (λ) value shows a similar pattern but with difference in magnitude, figure (7.6). Air flow at angle of incidence $0 = 0^{o}$ shows a clear correlation for the change in air speed magnitude C_{vn} with the change in the unit depth, figure (7.7).

In order to identify the reduction expected in the outdoor air speed from that of the meteorological wind speed it is possible to employ the method suggested in Chapter 4. In Section 4.4.1 it has been stated that the meteorological data are recorded for open terrain with scattered obstructions, such as airports or open park land with isolated structures, and is referred to as the speed over the reference terrain. In architectural practice other terrains are to be encountered, table (4.11). Velocity gradient over other types can be expressed in terms of this reference terrain using the relationship derived by Handa (133).

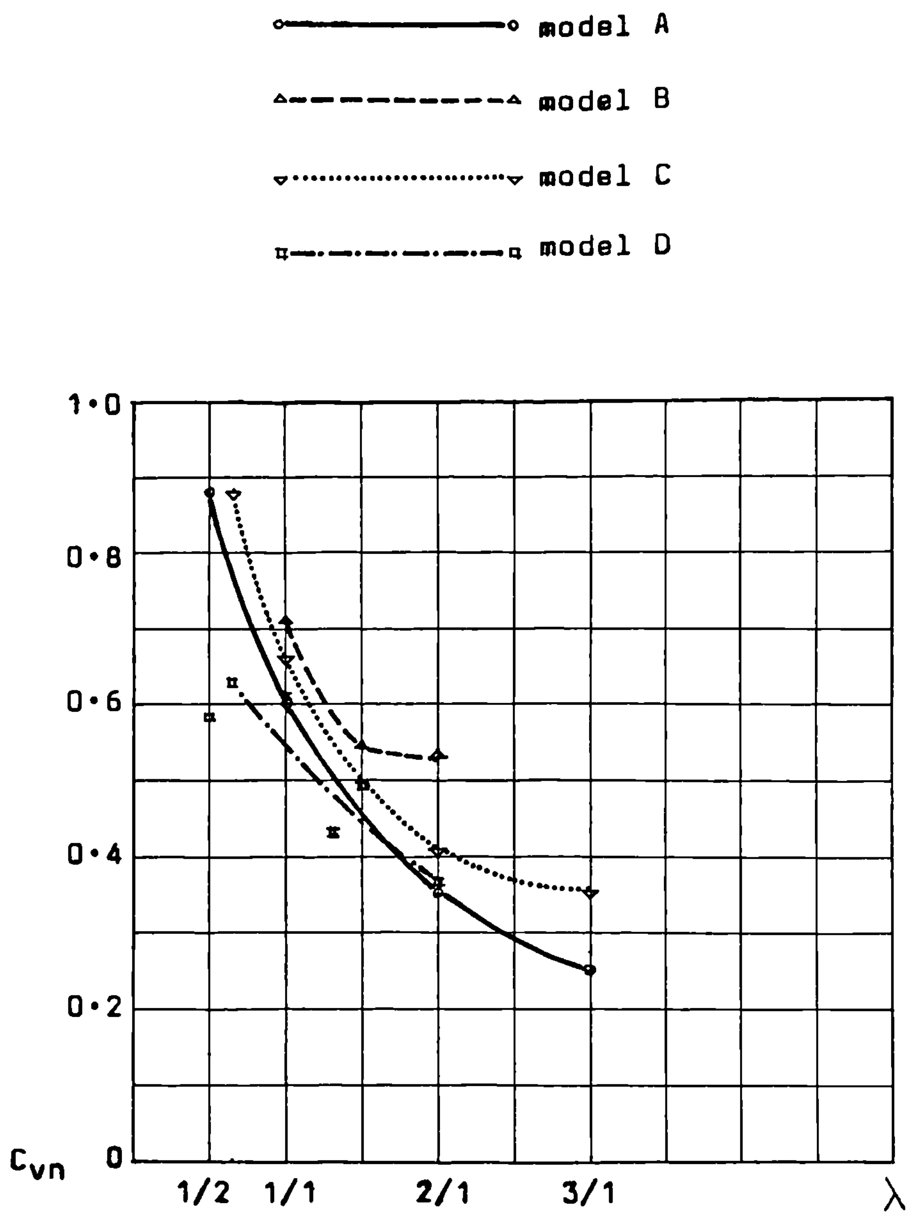

Figure (7.5) The change in C_{vn} in relation to variation in λ for inlets, angle of incidence $\theta = 0^{0}$.

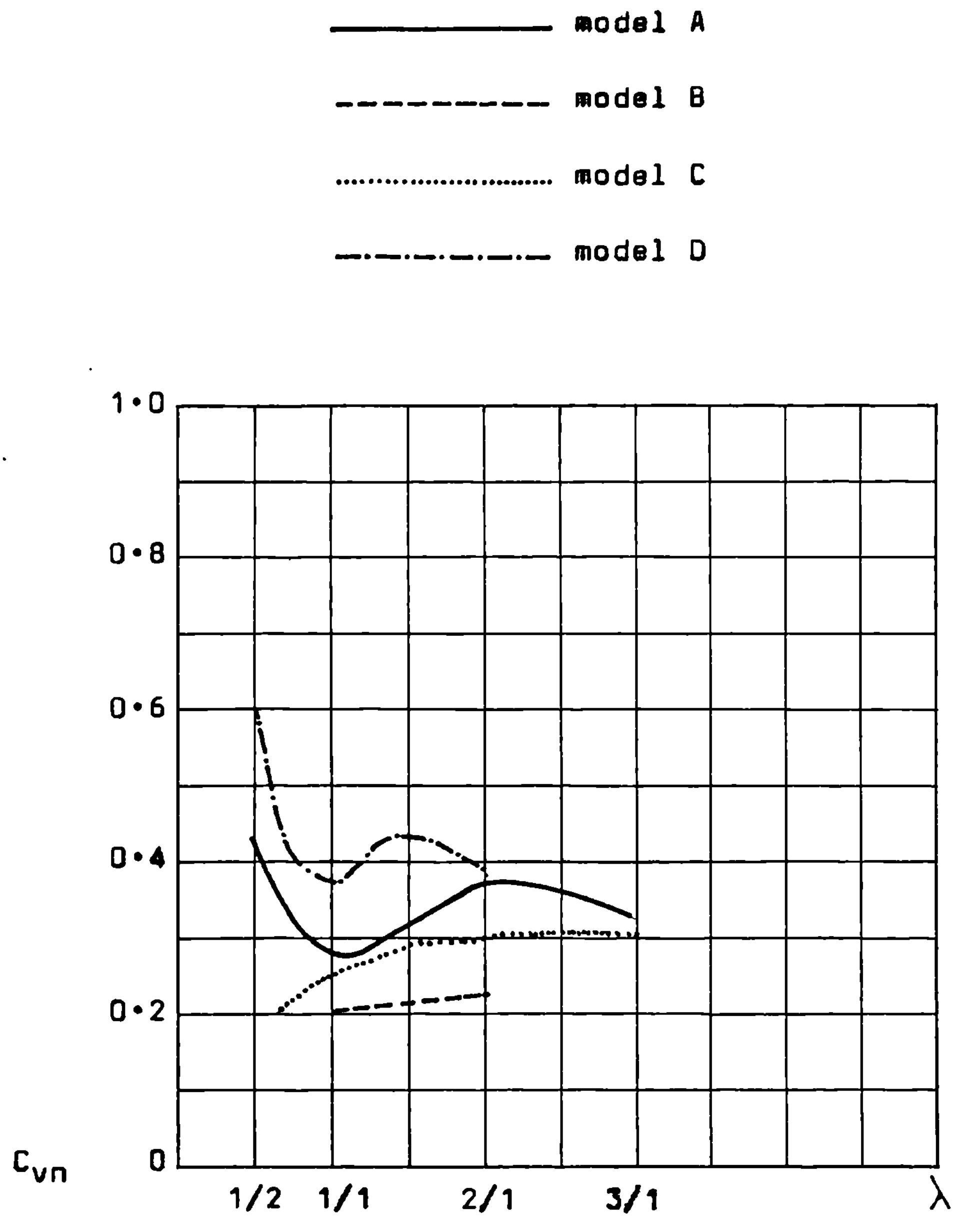

Figure (7.6) The change in C_{vn} in relation to variation in λ for outlets, angle of incidence $\theta = 0^{o}$.

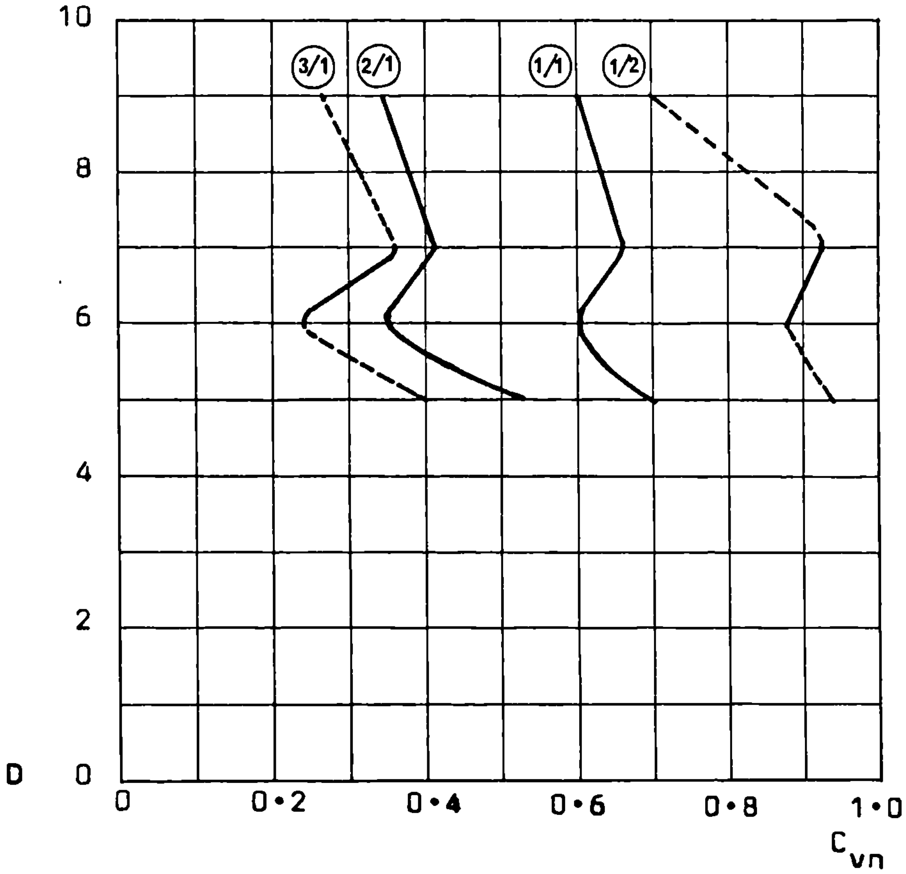

Figure (7.7) The change in C_{vn} in relation to variation in space depth D for inlets, angle of incidence $\theta = 0^{o}$ and $1/2 < \lambda < 3/1$.

$$\overline{V}_{AH} = C_{AH} \times \overline{V}_{R10} \qquad (4\text{-}12)$$

$$C_{AH} = 1{\cdot}13 \times (H/5)^{0{\cdot}1}$$

$$\overline{V}_{BH} = C_{BH} \times \overline{V}_{R10} \qquad (4\text{-}18)$$

$$C_{BH} = 0{\cdot}83 \times (H/15)^{0{\cdot}22}$$

$$\overline{V}_{CH} = C_{CH} \times \overline{V}_{R10} \qquad (4\text{-}19)$$

$$C_{CH} = 0{\cdot}68 \times (H/20)^{0{\cdot}3}$$

Also, the speed coefficients C_{AH}, C_{BH} and C_{CH} are plotted against height and illustrated in figure (7.8), from which the direct values of the speed coefficient can be obtained at the window height.

In order to predict the probable value of C_{vn} information will be needed about the inlet/outlet relative area and the depth of the unit. It is possible to determine the appropriate C_{vn} for the building being designed using fig.(7.7) for the inlet, fig.(7.9) for the outlet and fig.(7.10) for the partition. Similar charts may be produced for any other point of interest within the space employing the same basis of this analysis.

Having arrived at a means of determining the value of C_{vn} for a systematic variation in the parameters governing air flow within the built environment, it is possible to devise the prediction procedure. The prevailing wind speed in the climatic region of the building to be designed is obtainable as a meteorological wind speed. In urban areas this will be modified due to the presence of man-made obstructions such as buildings. The modification at the window sill height needs to be included as a part of any serious attempt to predict air speeds within the built environment. The speed coefficient is the parameter governing the relationship between the meteorological wind speed and air speed at

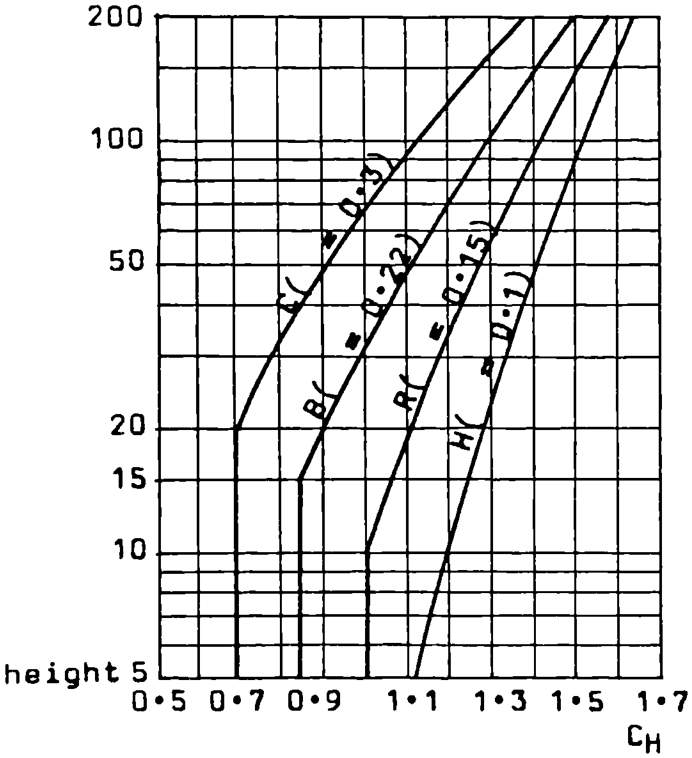

Figure (7·8) Velocity gradient coefficient C_H for different surface roughness, (133).

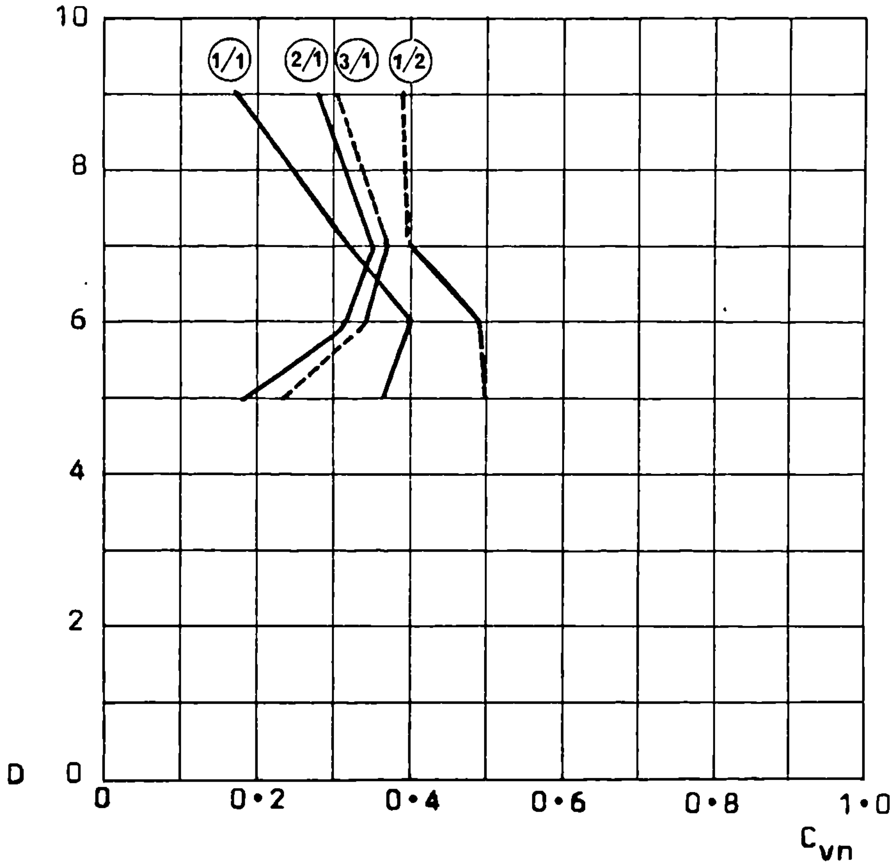

Figure (7.9) The change in C_{vn} in relation to variation in space depth D for partitions, angle of incidence $\theta = 0^{o}$ and $1/2 < \lambda < 3/1$.

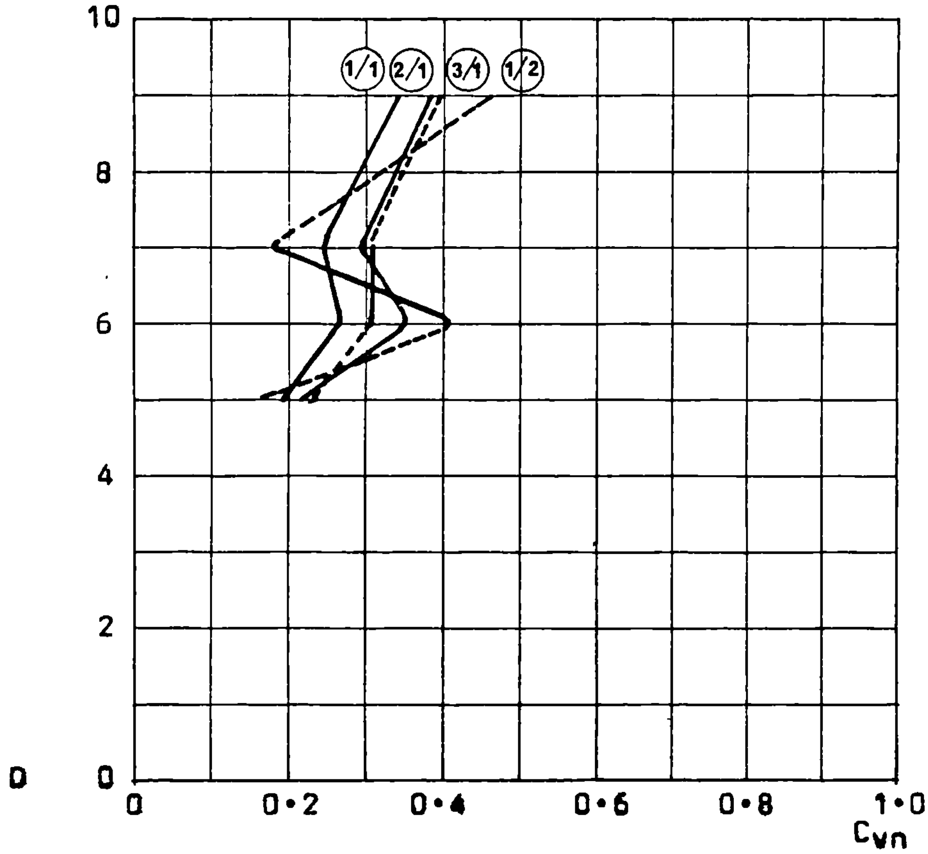

Figure (7.10) The change in C_{vn} in relation to variation in space depth D for outlets, angle of incidence $\theta = 0^o$ and $1/2 < \lambda < 3/1$.

a required height in the boundary layer. The speed coefficient, illustrated in figure (7.8), gives the relationship between the velocity coefficient and the height, and illustrates that in urban areas the belocity gradient coefficient C_H is constant in the lowest 20 metres of the boundary layer, known as the surface layer. Knowing the speed coefficient it is possible to estimate air speed at the window sill height employing equation (4-19) as follows:

$$\overline{V}_{CH} = C_{CH}\overline{V}_{R10}$$

where

$\overline{V}_{CH}$ = mean air speed estimated at height H

C_{CH} = speed coefficient for urban areas

$\overline{V}_{R10}$ = meteorological wind speed record

Air flow within the built environment will be modified from that entering it. The parameters governing this are the inlet/outlet relative area and the unit depth, and to a lesser extent the number of units within the space.

The design curves for the velocity coefficient are illustrated in figure (7.11) at the point required. After computing the velocity coefficient it is possible to predict air velocity at this point as follows:

$$\overline{V}_n = C_{vn}\overline{V}_{CH}$$
$$= C_{vn}C_{CH}\overline{V}_{R10} \qquad (7\text{-}1)$$

If the number of air changes is required the predicted air speed at the outlet can be multiplied by the outlet effective area, however, if the rate of air change is required the number of air changes can be divided by the space volume. The design curves illustrated above employ the

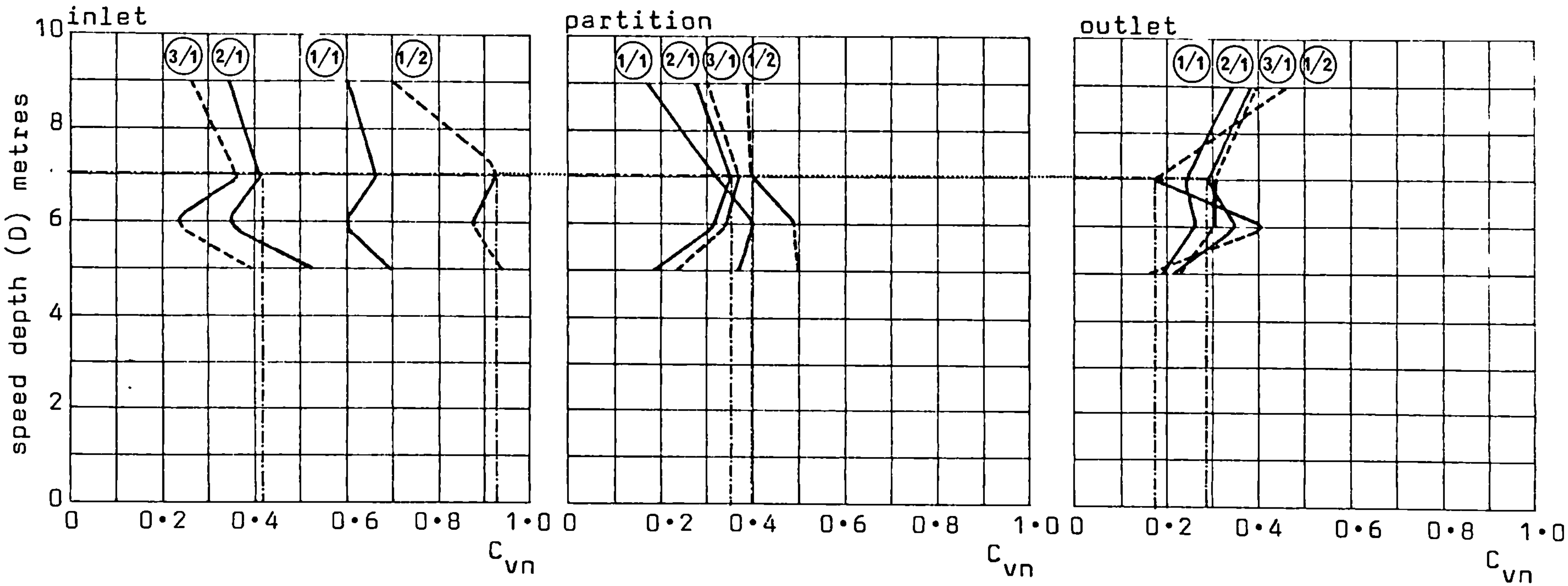

Figure (7.11) Ventilation optimization chart, the relationship between velocity coefficient C_{vn} at the centre of the opening and the total space depth for angle of incidence $\theta = 0^{o}$ and λ ranging between $1/2 < \lambda < 3/1$.

effect of λ values between $1/2 < \lambda < 3/1$ and distance D of $5 < D < 9$ metres. To take account of λ and D values other than those already considered, other charts need to be produced. However, in housing there is little possibility that either λ or D will exceed these values. Also, it is noteworthy that this procedure, like many others, is theoretically based, backed by physical modelling, however it needs to be verified against actual size physical modelling which is a possibility for future research. The simplicity of the procedure is aimed at allowing the architect to use it during the different design stages. The design curves illustrated in figure (7.11) can be used in the scheme design to decide on the size of opening to be employed and the depth of the unit and consequently the building form, comparing the different proposed designs. It can also be used to evaluate the ventilation performance of existing buildings and hence improve their natural ventilation potential.

In figure (7.11) the flow due to two arrangements of openings, $\lambda = 1/2$ and $\lambda = 2/1$, for identical spaces shows that air speed at the inlet and the partition of the first arrangement will be considerably higher than the second, while at the outlet it is higher for the second arrangement.

Chapter 8 : CONCLUSION AND RECOMMENDATIONS

8.1 Conclusions

Man's control of his environment and mastery over its resources is an indicator of civilization and the level of mankind's progress through the ages. Climate is the most pronounced environmental factor to influence man's life; the house is but an attempt to control the prevailing climate in order to achieve a more comfortable environment.

In hot climates the designer is faced with problems which differ from those of the cold and temperate climates. Two main differences exist, the first concerns the dominant climatic parameters affecting the design process, the second concerns the human physiological response to the surrounding conditions. Hence, from the environmental design point of view, the approach to building design in hot climates should differ from that of the cold and temperate zones. Applying a bioclimatic approach to the design problems of hot climates is essential if an economical and environmentally sound building is required. This will extend the benefits of environmental control to the low-income housing.

To understand the climate of any region its causes need to be investigated. Examination of the climatic elements allows a clear understanding of the climate mechanism, thus determining the nature of the dominant elements of the semi-desert and hot climates. It is essential to determine the forces generating these elements, consequently allowing a better understanding of the methods by which they can be altered. The radiant heat affecting human habitation can be direct shortwave radiation from the sun, diffused short wave radiation from the sky, or both short and long wave radiation from the surrounding environment. The building as a part of the environment will exchange long wave radiation with its surroundings. Annual and diurnal air temperature patterns depend mainly on the sun's relation to the Earth, and variations in the adjacent surface temperature. In semi-desert and hot climates surface inversion is utilized by providing outer living spaces which are sheltered from wind. The courtyard system of the Islamic house is a further development of the way in which early civilizations utilized the surface inversion phenomenon, figure (2.12a & b). Wind movement is due to pressure difference; it is also affected by the rotation of the Earth and the distribution of land and water masses. These forces govern regional wind patterns as well as the global ones. Precipitation level affects the roof shape. Moisture content, measured either as relative humidity or as vapour pressure, is one of the most important climatic factors affecting human physiological comfort and consequently building design.

The available global climatic classifications have definite limitations from the architectural design point of view. They were established with consideration to one or two climatic elements only, and based on the global vegetation pattern. There is no global climatic classification available which is directly related to human physiological comfort. Such a classification should offer the information needed for design for climate. Microclimatic studies are therefore necessary to provide information on the local climatic characteristics. Both the climatic classification and the microclimatic analysis should be based on a thermal index which takes into account the human physiological comfort.

Man's interaction with his thermal environment depends mainly on air temperature, relative humidity, wind, solar radiation, clothing and activity level. Heat exchange in the environment occurs in one of four modes, radiation, conduction, convection and latent heat loss or gain (evaporation). The designer should identify the mode of heat transfer then apply the appropriate treatment. Human physiological comfort is a function of the simultaneous effect of all the environmental factors. Comparing the thermal indices on the basis of their approach to the thermal environment, the units used and the range of their application resulted in selecting the Standard Effective Temperature (SET) as a possible index for the bioclimatic analysis. The range of this index has been extended to include the external radiant heat load by means of the computer program reproduced in Appendix A2.

The built environment should be considered as a part of a total system extending from the body core to the surrounding environment. It is necessary to determine the degree of discomfort due to the prevailing climatic conditions in order to decide the appropriate control techniques for improving the environment. The Standard Effective Temperature allows estimation of the degree of discomfort on its DISC value. Human activity pattern is often ignored, this factor determines the time, form and place of different spaces. Hence it is important to consider it in the design process to synchronise activity with the appropriate space from the climatic point of view.

The hot dry and semi-desert climates require a built environment capable of excluding radiant heat while allowing carefully controlled ventilation. The urban tissue should provide shaded outer spaces, sheltered from the hot dusty wind but still allowing cool breezes to penetrate. Air humidifiers are of special importance in these regions.

The Egyptian regional climate is considered as comprising six divisions, figure (3.5). The climatic analysis of the

Egyptian regions was based on the instantaneous effect of the dominant climatic elements, coupled with the metabolic rate and the type of clothing. However, analysis of each climatic element illustrated the differences between the regions. Air temperature differed not only in magnitude but also in the time of occurrance. The humidity level affects the evaporative capacity of air and hence the efficiency of the sweat cooling mechanism. Air movement can counterbalance the evaporative effect of humidity as well as assisting the convective heat transfer. When the air temperature is lower than skin temperature the result is a cooling sensation on the body. Otherwise the two may work in different directions; if air temperature is higher than skin temperature it must be cooled down before allowing it into the built environment. The presence of vegetation and latent heat loss by evaporation are of advantage for cooling the air in hot dry climates.

The thermal effect of solar radiation is desirable during the underheated periods, but it should be excluded during overheated periods. In many parts of the world sunshine records are much more common than solar radiation, so a computer program has been designed to compute solar insolation with respect to latitude, longitude and type of terrain. This program should be replaced by the actual records wherever they are available. In hot dry and semi-desert climated solar radiation is a potential energy source which is relatively high throughout the year, and should be utilized much more than it is at present.

The seasonal pattern in Egypt differs from one region to another. In Lower Egypt winter starts by the beginning of December and finishes by the end of February, while summer extends from the middle of May to the middle of October. In Greater Cairo winter extends from December to February, and summer from April till October. In the Red Sea region winter starts by the second week of December and ends by the first week of February while summer is evident from the end of March till the end of October. Upper Egypt has two seasons, a short spring from the second week of December to the first week of March and a long summer. The hottest region is the Desert with two seasons only, a short spring from the last week of November ending by the end of February, and a long hot summer.

Bearing in mind the Egyptian way of life, the lower and upper design limits in the Egyptian regions were determined as the conditions that prevail for 90% of a typical day during the coldest and hottest months. On these grounds the prevailing conditions in all the climatic regions during January and August were taken as the lower and upper design limits, although the magnitude of these limits differs from one region to another, tables (3.11) to (3.15). Within each region the climatic conditions will vary according to the surrounding topography, exposure, obstructions (including buildings and the existing natural cover). In Cairo wind is the main pronounced climatic element which differs from one microzone to another.

Ventilation should satisfy three main requirements:

- Health ventilation which should be satisfied under all climatic and environmental conditions. The most pressing requirement under this category is removal of smoke and odours.
- Ventilation for comfort, which should assure body cooling in hot climates and is essential during hot humid conditions.
- Ventilation for structural cooling, essential in hot dry climates when the outside air is cooler than that inside.

The desirable rate of fresh air supply depends upon the purpose for which the internal space is utilized, the number of occupants and their individual activities. Unless the ventilation aspect is considered within the overall design concept, unnecessary and often expensive and less satisfactory remedial solutions will have to be resorted to.

The production and evaporation of sweat is the body's most powerful temperature control mechanism. Heat loss will depend on the evaporation rate which is a function of ambient air temperature, radiant heat, humidity and air movement. When both air temperature and humidity are high air movement becomes of greatest importance.

In hot climates structural cooling is necessary when outside air is cooler than the inside air. Unventilated heavy structures will have a long time lag, heat gained during the day time will reach the inside surface during night time. In traditional buildings of the hot dry climates natural ventilation is sometimes employed for structural cooling during night time. For night ventilation the structural shell should be of small thermal capacity and high thermal resistance to damp the sharp rise in temperature observed in the early hours of the morning. The core of the building should be of high thermal capacity so that it can absorb the day time heat produced in the living process then re-emit it during night time to the ventilating air.

Ventilation is also necessary for humidity control and to prevent condensation on the structure's inner surface and allow any condensation to evaporate befor the growth of lichens, moulds and similar organisms. The removal of moisture-laden air at a point near the source will help in controlling humidity level inside the building, but humidifying the air near the inlet improves the dry conditions of hot dry climates. In these climates air flow should be directed at the living (sitting) level, and within that part of the space most likely to be occupied by residents. Adjustable louvers, screens and vegetation can be used to control the direction of air flow.

Air flow is mainly due to thermal forces, inertia forces or the combined effect of these two. The maximum flow will be expected when the two forces act in the same direction. Air moves from high pressure zones, ie cold air masses, to low pressure zones, ie hot air masses. Cold air moves seeking the lowest level. In the naturally ventilated buildings in hot climates temperature difference between indoors and outdoors is not significant, however a system of narrow and wide courtyards is expected to produce a pressure difference between them and air will flow from the narrow yard, through the built space, to the shallow yard due to the difference in pressure.

To achieve maximum wind ventilation in a building its form, orientation and exposure must be such that the pressure differences between the inlet and the outlet locations are maximized with respect to local wind characteristics. The small temperature difference between inside and outside, and the very small pressure head does not allow stack effect to develop enough to dominate the ventilation process. Hence, inertia is likely to be the generating force for ventilating the low income multi-storey housing in hot climates.

Temperature extremes tend to press buildings into compact forms while heavy radiation impact tends to elongate the shapes in the east-west axis. In all latitudes of the northern hemisphere the northern side receives only a small amount of radiation during summer. On the west side high temperature impact is amplified by the afternoon radiation effects. The amount of radiation received on a horizontal roof during the summer exceeds the total amount received on all the other sides.

There are two forms in which heat may be manifest in a body - 'sensible' and 'latent'. Heat is usually transferred from warmer to cooler bodies or parts of the same body. The mode of heat transfer may change during its flow through a building element in accordance with the nature of the structural element, as well as differences between the internal and external thermal conditions. The selection of building materials should be made with consideration to their thermal properties, it should be a function of the mode of heat transfer and aim at minimizing the heat gain. The compact building form is also advantageous with respect to minimizing heat transfer. The volume effect can be utilized architecturally where early design decisions concerning the formation of the structure may have great influence on the building's thermal behaviour.

Architecture as a work of man is continuous and humane, and contemporary designers should consider history as experimental evidence demonstrating both the advantages and the disadvantages of its architecture. The space defining factors consist of simple configurations of linear and planar elements that define the basic volumes of space. In combining form and space into a single essence, architecture not only fulfils a basic purpose but also communicates meaning. Movement through the sequence of spaces in a building is organized by the circulation paths. These can be conceived as the perceptual thread that links all spaces together. The appreciation of a space will involve the consideration of its four dimensions, length, width, height and time. These are related to each other to generate the proportions. Relating the product of dimensions to man will involve the scale; in architectural spaces man is concerned with two main scales, the human and the grand scale.

In architectural perception our reactions to space are governed not by what is actually there in terms of dimension, but by what appears to be there. The perception of forms in space occurs due to two main factors. Firstly, we perceive the edges of the various surfaces of the object and secondly, we are aided in our perception of form by patterns of light and shade on an object which identify its geometrical characteristics (shape and size). These geometrical and perceptual aspects of space properties can be employed as means of improving the impression of space proportions. Architectural space can excite and encourage the desired behaviour pattern (as sociopetal space) and at the same time can discourage undesirable behaviour (as sociofugal space). A space can easily be transformed from sociopetal to sociofugal by executing minor changes such as rearrangement of furniture or change in the lighting qualities.

The Ancient Egyptian house plan was modular in system, harmonious in space relation and compact in form, securing the minimum surface area to volume ratio. This period of history marked the beginning of architecture based on geometry and mathematics. The unit of measurement upon which all proportions were based was the hand, that part of the body that transfers thoughts into objects. From the outstretched hand and arm was derived the decisive linear measurement, the 'Cubit', which has been in use in present-day Egypt right up to the fifties. This measurement system was older than the oldest stone monument in Egypt, Zoser complex, 2780 BC. In contrast to the metre the cubit is a human measurement originating in the proportions of the body itself.

The house always had at least two sections, a living area comprising a hypostyle hall, and a private area including the bedrooms, kitchen and bathrooms. Bricks of mud mixed with chaff or sand were used to build the thick, massive walls, the true arches and ribbed vaults. The high thermal capacity of this material, with a time lag of approximately 8 hours, helped in modifying the indoor climate to a more comfortable level. The cool breeze was considered in space design and orientation. When there was an open courtyard the loggia was located on the south side in order to receive the north breeze, but if the house had no courtyards a first floor loggia facing the north was introduced. The roof ventilators were usually positioned to face the most desirable wind direction. Both the loggia (Maka'ad) and the roof ventilators (Malkaf) had been a cornerstone in house design from the Ancient Egyptian time till the end of the last century.

In the Coptic house arched doorways and staircases were remarkably narrow and the staircases themselves very steep. This reflects the economic forces and security needs of that period. Their multi-storey houses had small surface area compared to that of single storey houses of equal volume.

Islamic architecture was based on the interpretation of Islamic philosophy as seen by both formal science and art. Space and form were related closely to mathematics and were seen as a manifestation of the unity of creation. The house corresponded both to the human scale and to the surrounding universe. The size of the house and the type of internal space resulted from the strong sense of family unity. The emphasis on family privacy introduced two strictly separated sections, the reception area 'Salamleik' and the family area 'Haramleik'. In each section the space continuity was the main feature. Walls enclosing multipurpose spaces (Ka'ah) often incorporated built-in store cupboards.

The different elements of the Mamluke house, the courtyard, El-Takhtaboush, El-Mandarah, El-Maka'ad and El-Ka'ah illustrate the impact of the spiritual conceptions of Islam as well as the designer's response to the climatic characteristics, be they thermal, visual or acoustic. The main entrance was right angled through the lobby so that visitors could see nothing but the housekeeper's seat, however the cool breeze drawn from the courtyard welcomed them. The Islamic house of this period was designed as a naturally air-conditioned environment. The ventilation system was composed of inlets, air storages, humidifiers and outlets. The cool air storages were the many deep courtyards which included openings solely for ventilation. The malkaf was another inlet used to catch air high above the ground where it is cooler and has a higher inertia. These air inlets were generally located to channel air into the circulation elements, ie corridors and staircases, then allowing it to the living spaces. The openings from the living spaces were either onto the main courtyard or onto the street where the air was discharged.

This courtyard system differed basically from those of southern Europe, where only one courtyard existed. The integration of inertia energized elements (malkafs) with the thermally energized system (courts) illustrates the architect's consciousness of the moving forces of the ventilation system. In meeting the ventilation requirements of today the principles of the malkaf should be carefully examined, firstly in relation to its intake position, and secondly in securing effective outlets, which if ignored could result in the failure of the malkaf system.

The architect of the Mamluk house solved the window problem in complete freedom based on an understanding of human needs. The different window functions, illunimation, ventilation and communication, were provided for by different means. Acoustically he restricted the openings on the outer, street walls, but opened the house onto a quiet, peaceful core which connected it with the macrocosm. He provided illumination and avoided glare by employing the Mashrabieh, the dense turned wood components of the lower part (up to head level) diffused the light rays and avoided glare while allowing a complete visual contact with the external environment. The upper part of the window allowed the strong light in above the level of the eye and covering the whole space with a uniform level of lighting. This conveys visual comfort and a sense of peace. A free flow of ventilation was secured by the Mashrabieh, water jugs placed within the lower part serving the dual purpose of humidifying the air while cooling the water within the jug. In rooms with only a single opening the Mashrabieh helped in generating air flow. As hot air escaped from the top section to be replaced by fresh cool air entering through the lower part. The design of the window should be considered in the context of the ventilation system and as an integral part of the total design process, and not simply on aesthetic grounds. The Mashrabieh acts as a functional element when it is fitted within the right environment, however, it is expensive to manufacture. The three functions of the window may be performed economically using simplified prefabricated elements which would be more suitable for our cultural environment.

The urban pattern of Cairo's old quarter was dictated by the excessive heat of summer. The volume of the built area was large with respect to the enclosing surface area, and the buildings were attached horizontally to decrease the surface area exposed to the sun. Streets were irregular having their proportions deep and narrow to increase shade and shelter cool air accumulated during the night. The first floor used to overhang the ground floor and streets were frequently covered and had gates. In Cairo's old streets the hierarchy of spaces, variety of views and identity of places reflect a high level of consciousness of human qualities widely ignored in modern architecture, urban and town planning.

In the contemporary house in general, and the low-income residential units in particular, there is a lack of any consideration for socio-cultural needs. Living areas are small in proportion to the number of inhabitants while considerable areas are wasted as circulation. The unit plan does not provide storage space or outdoor activity space, forcing the inhabitants to divide their terraces between storage and other uses. The houses lack flexibility thus limiting the use of spaces and encouraging overcrowding in the one room. The monotonous layout of parallel blocks do not allow for local identity nor for proper consideration of wind movement. The unfunctional open spaces lead to accumulation of dirt. The building techniques and materials did not consider the thermal comfort criteria. Thermal relief which could have been achieved through natural ventilation was not considered, and the occupants often sacrificed privacy to achieve thermal comfort. The blocks, with their long, narrow proportions, allowed a large surface area to volume ratio resulting in poor thermal performance.

The building codes were developed due to imported concepts, irrelevant to the Egyptian environment and climate. This reinforced an urban tissue pattern and house elements which lacked appropriate consideration to the climatic conditions and the sociocultural needs. The courtyard house of the thirteenth century is still a sound solution for high density residential areas. The survey carried out by Cairo University and MIT showed the courtyard as the main urban tissue of Medieval Cairo having a density of 1401 persons per hectare compared to the most crowded governmental housing scheme, Ain Al-Sira, which has 1428 persons per hectare.

Economic evaluation of any building system should be considered not only from actual money value, but also from the total energy point of view. Money values provide only a limited unstable index, applicable for a limited time compared with that of the total energy cost analysis, which would give a meaningful evaluation over a considerable time period. Some traditional building construction techniques can be standardized and developed to include energy saving prefabrication techniques.

A bioclimatic approach is essential to enable the architect to produce buildings that correspond to their climate. It should offer him a means of achieving this aim within the time available at each stage. Starting from the earliest analysis, the design approach helps the architect to make the right decision at the time where most of the strategic decisions are made according to the plan of work of an architectural team. Climate may influence the design process at three stages - the bioclimatic analysis, the spatial design synthesis, and the detail design appraisal.

Bioclimatic analysis should start with the collection of climatic and human data relevant to both the location and the nature of the design problem. The simultaneous impact of the climatic factors on human physiological comfort should be assessed to establish the climatic design limits which would then be examined in the context of the socio-economic and psychological environment. The analysis should first assess the length and intensity of the various seasons then the detailed features of the extreme conditions should be considered to establish the climatic design limits for each season. This should be followed by analysis of the physiological effect of the possible change in each element which can give an indication towards the direction of modifications available. A knowledge of the forces generating these modifications will provide the architect with a flexible design tool aiding him in making the right strategic as well as tactical decisions during the design process, leading to an environment designed to integrate with its climate.

The design limits should be presented as comfort limits on an analytical map of the different regions. Thus, the task of the designer would be eased as he is more concerned with the design limits than the systematic climatic data. The comfort analysis conveys more information about human physiological response to climate than the climatic data itself.

It helps in diagnosing architectural requirements in terms of human comfort. It would not take decisions for the architect, rather it points out the consequences of his decisions on modifying the climatic conditions. The architect aims to reduce the deviation of the prevailing climatic conditions from the required comfort conditions. He should reinforce and amplify the effects of the positive climatic elements, and minimize or eleminate the negative ones.

The first response of inhabitants to variations in climate is usually to change the type of clothing worn. Eliminating wind (draught) and a thermally insulated outer shell will be needed during the underheated season, while providing shade, reinforcing air movement, thermally insulated outer shell as well as high thermal capacity building elements are needed to balance the hot days with cool nights. Plans for building groups should allow for maximum air movement of the cool wind during the overheated periods, but provide shelter from cold wind in the underheated periods. Where possible, building groups should be arranged to create a pattern similar to that of the courtyard house, thus constructing a useful cold air storage. The use of reflective colours on building surfaces can be advantageous in minimizing radiant heat gain, however, provisions for avoiding glare must be considered when designing openings facing a reflective surface.

Compact building forms are advantageous with respect to heat transfer, with surface area to volume ratio as small as possible. The long faces of the building should face north-south to avoid excessive heat load due to solar radiation. Openings should provide air movement at the desired living level, figure (6.19), and their location should take account of air movement outside, and the nature of the inducing forces along with the aesthetic consideration. Large, shaded outdoor loggias and shaded areas in front of the ground floor openings will provide cool air supply during overheated periods. Terraces in multi-storey buildings serve the same function. Building around a courtyard system consisting of shallow and deep courts is also advantageous, figure (2.12).

The spatial design stage covers both the outline proposal and the scheme design. Full account should be taken of the bioclimatic analysis as well as other types of analysis and recommendations before deciding the final concept. The designer's objective should be to co-ordinate the activity pattern with the most suitable climatic conditions prevailing at the time.

The urban tissue should be compact to produce maximum shading for outdoor spaces. Heat loss should be promoted by structural ventilation, night time outgoing radiation and evaporative cooling, while heat gain should be minimized. Areas of vegetation will be advantageous in that they absorb radiation and promote evaporative cooling. Deep room proportions and the use of low emissivity colours for the interiors and high reflectivity colours for exteriors will minimize radiant heat gain. Deep spaces on the windward side and shallower ones on the leeward face, as well as inlet/outlet relative area less than one will promote ventilation. The openings should be designed to direct air flow over the whole living space and at body level for thermal comfort, or at the structural surface for structural cooling. Evaporation is most advantageous both in the interior and the exterior. The physical effect of a fountain is reinforced by its psychological impact.

At the detail design stage the designer requires information at the highest possible level of accuracy. Having agreed on the main design concept his aim should be to optimize the design and prepare the working drawing necessary for the execution stage. This stage includes matters such as window design, environmental control system, final design of every part and component of the building and a final evaluation of the expected performance of each item.

The choice of material for each element of the structural shell should consider the mode of heat transfer and aim towards excluding or delaying it. Building fabric of day time spaces can be of high thermal capacity with time lag of 10 hours, while night time spaces should be of low heat capacity material which is beneficial to radiative cooling to the sky at night. If the space is to be used 24 hours high insulation fabric should be used in the outer shell and ventilation should be promoted. High thermal capacity should be used if insulating techniques are not economically feasible.

The ventilated double roof, shaded roof and curved roof forms are advantageous in reducing excessive radiant heat impact due to solar radiation. If high thermal capacity material is used it should have a 12 hour time lag. Windows exposed to solar radiation should be sufficiently shaded and shading devices should be separated structurally from the building. Passive solar energy techniques can also be advantageous, both as a source of energy and as a thermal relieving element. It is possible to use techniques based on the main concepts of the courtyard, the Malkaf and the Mashrabieh to provide for the different functions of the window (ventilation, communication and illumination).

Natural ventilation is not the only thermal relieving mechanism available but it is of great importance during the overheated periods, and essential for environmental control in hot climates. It is also required for structural cooling and body cooling. Maximum ventilation is required during this period, it is possible to involve 20 to 50 air changes[1]

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1 It has been suggested that 1·5 m/s air speed is equivalent to 100 air changes per hour.

per hour. Ventilation is induced by inertia forces as well as thermal forces, and since the human body needs to lose considerable amounts of heat, air movement is of great importance in maximizing heat loss by both evaporation and convection; body cooling is a function of air movement past the skin.

During the underheated periods minimum ventilation is required. This is not likely to involve more than 2 air changes per hour in a residential space[1]. Air change is induced by thermal forces and occurs mainly due to infiltration through window cracks. Since the human body needs to lose little heat at these times air movements should be kept to a minimum to reduce heat loss by evaporation and convection. Natural ventilation is still needed, however, for changing the air vitiated in the process of living inside the space.

The architectural approach to ventilation during overheated periods should differ from the engineering approach to the underheated period ventilation. The engineering approach to calculation of natural ventilation during the overheated period is based on the crack method which is dependent on pressure difference across the building. Estimating the pressure difference oversimplifies the effect of building form, and the characteristics of the prevailing wind, while ignoring the effect of the space parameters. Moreover, this ignores the physical mechanism of the human sensory system during the overheated period. Human comfort under these conditions is a function of air speed rather than air pressure.

Reviewing the literature on natural ventilation showed no general relationship to be available which relates the space parameters to the flow within a multi-cess space. Moreover, the slim body of data available on the single cell needs

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1 Cells in police stations require 5 air changes per hour.

updating to allow for the experimental restrictions found in this data.

From the analysis of the residential units it was concluded that a single cell with no partition is an oversimplification of the nature of residential spaces. They are more likely to comprise a single cell with a space dividing element, a double cell, or a multi-cell of 3 consecutive cells.

Understanding natural wind characteristics and wind configuration with buildings is essential for accurate prediction of natural ventilation performance. The velocity of wind flow over the Earth's surface will be reduced due to frictional forces. The magnitude of this reduction will differ with height, and from one kind of terrain to another. This phenomenon should be accounted for when computing the likely ventilation performance.

Air flow fields around buildings can be simplified as three regions, free stream, shear layers and wake flow, while near the ground three regions of increased speed are generated, vortex flow, cornerstream and through flow. Air flow across the face of a building will be a function of the pressure distribution across that face. Around buildings the flow is influenced by the difference between the high windward pressure and the lower pressure of the wake depression. Where buildings are arranged in groups the flow will follow one of three regimes, isolated roughness, wake interference and skimming flow.

Investigating the flow pattern for a simple block showed changes related to variations in the block proportions. The flow on the erfaces of the block correspended in a more pronounced way to changes in its proportions. This had a significant effect on the direction of the air flow entering the building.

The relative height of the stagnation point is proportional to the width/depth ratio (β), and inversely proportional to the height/width ratio (α). The height of this point varies from 40% for a narrow building up to 75% for horizontal proportions. The flow across the building's face radiates from this point, and air will tend to be deflected away to the far side of it. The flow on the lowest 1/4H of the windward face is a function of the dynamic vortex generated in front of the building and air will flow inclined towards both the floor and the nearest edge.

The general belief that high inlets deflect incoming air towards the ceiling, and low inlets will deflect the flow towards the floor stands only for single storey buildings. In multi-storey buildings the flow direction in the vertical plane will depend on the location of the opening in the windward face. The air flow pattern may be considered as a function of the distance between the opening and the stagnation point (at appro imately 3/4H). High ceilings in the levels above the stagnation zone may substantially reduce the desirable effect of ventilation by allowing air to flow away from the living level. Architectural features and projections on the facade can affect the air flow and the pressure distribution across the faces of a building, particularly the windward face, and designers should consider this.

The roof flow was a function of the width/depth ratio (β), and reattachment occurred only when $\beta > 1$, though it seperated again at 1/4H from the leeward end. The roof flow should be carefully considered when placing inlets such as air conditioning intakes and malkafs. It should also be considered when placing exhausts such as chimneys and air conditioning outlets. Inlets and outlets on the corners would need similar care to those of the roof.

On the leeward face air flows towards the roof edge forcing the air inside the building and near this side to flow near the roof. At angle of incidence $\theta = 45^{o}$ the air flow inclined towards the roof and the leeward edges. In the lowest 1/4H the flow was inclined towards the floor, and on the roof the flow inclined at an angle of 45^{o}.

In the examination of air flow around groups of buildings the first row of buildings was affected by the angle of incidence of the oncoming wind. In the shadow of the first row the flow could be either skimming flow regime or wake interference. The stagnation point on the windward face would be at approcimately 7/8H, with air flowing up the leeward face.

The roof flow is the main source of energy to the flow within the courtyard when the height/area ratio $\Omega < 1/2$. The roof eddy extended to cover the full height of the courtyard, with air flowing upward on the windward walls and downward on the leeward walls. As the height/area ratio increased the roof eddy only penetrated to cover the top layer, and a new eddy developed under it. This new regime penetrated to a depth of 3/2 of the depth D of the courtyard. Below 3/2D the air was stagnant, showing no significant movement. At oblique angles of incidence ($\theta = \pm 45^{o}$) the stagnation zone diminished with air moving downward at the windward corner, and upward at the leeward corner.

Air flow within the built environment is governed by two main forces. It will tend to follow its original direction and will be governed by its inertia forces until they are lost due to friction or obstruction, or being overcome by other forces. When the inertia force diminishes, or is less than the force generated by pressure difference, air flow direction will be controlled by the outlet. The first force can be modified due to building grouping, window detail, and proportions of the windward space, while the second will depend mainly on space design and outlet position. The resulting ventilation system will depend mainly on designer's mastery of space detail design, and the openings system.

Air flow inside the built environment is as much a function of the moving forces as of the resistance of the space elements. The size and position of openings, as well as the presence of partitions within the space, will result in a deviation on air speed and direction from that outside the space.

At angle of incidence $\theta = 0^o$ the change in the partition area across the space will cause changes in air speed proportional to the relative area of the partition opening as well as to the depth of the space. The change is less pronounced with the increase in depth, in the order of 14% for a space of 5 metre depth, but 6% for a space of 9 metre depth. The greater the partition opening area the smaller will be the air speed magnitude at this opening, but the higher the average speed leading to more uniform ventilation conditions. Inertia forces dominated the part of the space on the windward side of the partition while suction dominated that on the leeward side. The presence of a partition close to the inlet reduced the air speed at the inlet, and consequently air speed at the outlet increased. Deep spaces on the windward side secure high wind speed on that space. It seems that there is an optimum distribution to the relation between the ventilation inducing forces, and that could be a function of the space depth.

At angle of incidence $\theta = 45^o$ space arrangements influence air flow near the inlet. This effect is also proportional to the depth. The nearer the partition to the outlet, the more pronounced the outlet effect, and air flow within the leeward space will be a function of the outlet air movement. Air speed magnitude changes as it flows through three consecutive cells. The speed decreases near the first partition then increases near the outlet. Within the middle space air speed near the windward opening fluctuates in accordance with the fluctuation of air speed near the outlet.

At angle of incidence $\theta = 90^{\circ}$, and as the partition was placed near to the larger opening it offered higher resistance causing the air to lose its kinetic energy and resulting in minimal penetration into the adjacent space. With the larger opening to the greater space the air penetrated to reach the outlet in the opposite wall.

The change in inlet/outlet relative position from aligned to diagonal, for $\theta = 0^{\circ}$, had little impact on air speed magnitude near the openings. Inside the space a shifted inlet/outlet position will cause higher air speed over a wider area. This is a result of the air changing direction within the space, and increasing the area over which it flows.

A change in the angle of incidence from 0° to 45° resulted in decreasing air speed in all models. In the single cell model with one opening in each side uniform speed distribution occurs when the openings are aligned. In multi-cell models with two outlets the openings should be positioned furthest apart to allow uniform speed distribution. The asymmetry of the space arrangements resulted in different air speeds for $\theta = -45^{\circ}$ and $\theta = +45^{\circ}$.

At angle of incidence $\theta = 0^{\circ}$ air speed is a function of the inlet/outlet relative area λ. When $\lambda < 1/1$ air flow was characterized by high speed over most of the space and it was inversely proportional to λ. This was a result of the strong Venturi effect.

The ventilation coefficient C_{vn} near the inlet, the outlet and within the space gives a clear indication of the expected air speed inside the space, hence it can be used as an index for the ventilation performance in the early design stages. There is a clear correlation between λ and C_{vn} for each space arrangement and a similar trend existed in all the cases examined. The unit depth is an important parameter governing this relationship.

A systematic procedure for predicting air speed within the built environment allowed the prediction of the ventilation performance of the dèsign being evaluated. This procedure consisted of two parts; the first concerns the modification of the prevailing wind speed to that expected outside the building and at the window sill height. This modification corresponds to the type of terrain which governs the velocity gradient. The second step is to modify this outside speed entering the space to that expected at the points of interest. Using the velocity coefficient as indicated in equation (7-1) information will be needed regarding the inlet/outlet relative area and the depth of the unit, figure (7.11). From a knowledge of the air speeds at the openings and the space volume, it is possible to compute the ventilation rate and the number of air changes.

8.2 Recommendations

A synthesis of the findings of this research makes possible the following recommendations:

1 HISTORY SHOULD BE CONSIDERED AS EXPERIMENTAL EVIDENCE DEMONSTRATING THE ADVANTAGES AND DISADVANTAGES OF AN ARCHITECTURE which was developed according to the socio-economic, cultural and technological factors prevailing at the time. Hence, applying solutions and borrowing (house) elements of different times may not fit todays socio-economic, cultural and technological conditions. However, investigating the approach and the methodology that our ancestors applied to their environmental problems will help us in developing suitable solutions to our problems (and in avoiding unnecessary mistakes).

2 ARCHITECTURAL DESIGN SHOULD ACCOMMODATE THE WAY OF LIFE OF THE INHABITANTS AND BE CONDUCIVE TO THEIR SENSE OF IDENTITY. The future inhabitants of the proposed housing project should be invited to participate in designing their future dwellings rather than allowing the professional exclusively to set housing standards. The inhabitants must be consulted about their priorities and needs instead of applying preconceived notions which may be contrary to their cultural environment.

3 A STREET PATTERN WHICH EMBODIES A HIERARCHY OF STREET SIZE CORRESPONDING TO THEIR FUNCTIONS IS NEEDED. This should allow for high intensity transportation in a super-grid of wide streets, and small residential streets to provide pedestrian access, services and safety. This pattern would be more relevant to the needs of the Egyptian urban centres and similar societies, and will encourage the growth of an urban tissue

more relevant to the socio-cultural and bioclimatological conditions than the street patterns in the contemporary residential areas. Egyptian contemporary dwellings are built to satisfy the image of a motorcar city which is irrelevant to the environmental, socio-economic and psychological needs.

4 THE PRESENT PLANNING REGULATIONS FOR HOUSING IN THE SUBURBS OF CAIRO AND OTHER MAJOR URBAN CENTRES NEED TO BE REVISED. Arbitrary limitations such as surrounding the house with large, meaningless spaces, providing wide streets for motorcars, deprives the residential units of privacy, environmental control, social and psychological needs.

5 IT IS NOT ENOUGH TO PROVIDE OPENINGS FOR VENTILATION; CONSIDERING THE AIR FLOW BETWEEN INLETS AND OUTLETS IS ESSENTIAL. This should be based on the knowledge of the relationship between the inducing forces of the ventilation system, which is possible using the procedure developed in this thesis and illustrated in Section (7.5). Air movements should be directed at the living level and cover the parts likely to be occupied.

6 THE CONCEPT OF DEEP COURTYARDS AS THE COOL AIR STORAGE OF THE VENTILATION SYSTEM IS BENEFICIAL IN HOT DRY CLIMATES, however this should be considered in the context of a comprehensive ventilation system closely related to a complementary functions zoning. If a service 'manwar' as specified in the Egyptian building codes is to be included for lighting and ventilating the service areas, the designer should provide an air pressure to prevent odour and moisture problems.

7 APPLYING THE BIOCLIMATIC APPROACH AS DEVISED IN CHAPTER 7 IS ESSENTIAL FOR A COHERENT SOLUTION TO THE ENVIRONMENTAL AND ECONOMICAL PROBLEMS. THE DESIGNER

SHOULD CONSIDER THE BIOCLIMATIC PARAMETERS OF THE ENVIRONMENT BEFORE THE EARLIEST DESIGN DECISION IS MADE. This approach would allow the benefit of environmental control to reach low-income housing.

It is hoped that using the findings of this research and applying them to building design will provide the professional, practising in zones dominated by overheated periods, with a clear approach to achieve a coherent bioclimatic design.

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