
APPLICATION OF TRADITIONAL CLIMATE SENSITIVE BUILDING DESIGN TECHNIQUES TO MODERN HOUSING PROGRAMMES IN THE CONSTANTINE REGION OF ALGERIA

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by

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to my mother, my father
and all my family

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ABSTRACT

In common with most developing countries and as a result of an increasing housing shortage, Algeria is undertaking a rapid building development which neglects the climatic aspects and comfort of its inhabitants.

The objective of this work is to investigate and compare the thermal performance of both traditional and modern housing types to define the underlying design features that can usefully be integrated with future housing programmes.

Initially an appraisal of current need and policy within an historical framework established that trends towards medium and high rise prefabricated housing provide a failure in environmental conditions and a steady increase in domestic energy usage.

Climate analysis has verified that the main problem for building in Constantine lies in summer months where strong irradiation prevails, especially on the roof. Solar irradiation values have also been correlated to other climatic features, and representative hourly data have been compiled for use in dynamic thermal simulation. It was also established that solar irradiation would have an effective contribution in winter, where heating is still of importance when calculated as a proportion of disposable income.

The thermal analysis, part steady-state and part dynamic, has shown that a traditional courtyard house compared to a typical modern flat, uses approximately 50% less energy for both heating and cooling; and that the courtyard form is still an efficient architectural concept in both the house and urban context. Thermo-physical characteristics of the building envelope and their role in controlling indoor environment are appraised.

Further optimisaiton of multi-layer thermal diffusivity is explored in relation to modern materials, with relevance to either housing model, but particularly roof construction in the case of the courtyard type.

The conclusion of this work is that the courtyard house form provides many passive solar heating/cooling features that can be evolved in a modern context, to achieve economically compatible thermal strategies for future housing.

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NOMENCLATURE

Q_H - rate of heat output from the heating system [W]

Q_H - monthly heting or cooling load [kWh]

Q_I - rate of internal gains in the building [W]

Q_S - rate of solar gains in the building [W]

AU - sum of thermal transmittance x corresponding area [W/K]

U - thermal transmittance $[W/m^2K]$

0.33nV - Ventilation loss [W/°C]

n - air change per hour [AC/h]

V - Volume $[m^3]$

H - transmittance and ventilation loss [W/°C]

G - sum of internal and solar gains [W]

Q_{st} - solar gain through transparent surface [W]

Q_{so} - solar gain through opaque surface [W]

t_b - base temperature [°C]

t_{bcool} - base temperature for cooling [°C]

t_o - mean outside temperature for cooling [°C]

t_i - mean desired internal temperature [°C]

DD[t_b] - degree days to bease temperature t_b [°Cdays]

H/floor area - heat loss parameter $[W/m^2K]$

R - resistance of each constructional element $[m^2K/W]$

λ - thermal conductivity of each constructional element [W/mK]

L - thickness of the element [m]

heat loss through the floor

b - lesser dimension of the floor [m]

w – width of surrounding walls [m]

L_f – length or greater dimension of the floor [m]

α – absorption coefficent [dimension less]

I_s – global incident solar irrad

I_{sa} – sol-air temperature [°C]

R_{so} – outside surface resistance of the envelope [m^2K/W]

ρ – dry density of air or building material [kg/m^3]

c – specific heat of building material [J/kgK]

$c\rho$ – volumetric thermal capacitance [J/m^3K]

D – Thermal diffusivity [m^2/s]

0 – time lag of building element [hours]

μ – decrement factor of building element [J/m^3K]

u – rate of heat transfer through the material [W/m^2K]

t_e – equivalent exterior temperature [°C]

t_o^* – outside temperature, time lag hours before the time in question [°C]

M – metabolic rate of heat production [W]

R – radiative heat transmission [W]

p – conductive heat transmission [W]

c – convective heat transmission [W]

E – Evaporative heat transmission [W]

INTRODUCTION

In view of the current world energy situation, architecture should aim at fulfilling basic human comfort requirements by providing an indoor environment which mitigates the climatic extremes. To this end climatic features which may cause human stress and discomfort and affect the thermal behaviour of buildings and their indoor climate should be well understood and taken into account in the design.

Housing constitutes by far the most common building type throughout the world. According to Evans(1) half of all the investment is made in construction and over one third of this investment is devoted to housing in both developing and developed countries. In Algeria the goal to build 100,000 housing units each year should clearly support this statement. Therefore, the objective of this massive investment should be to provide not only shelter but security and comfortable living conditions for the occupants. In other words the design of the housing units should be such that basic environmental comfort standards are met without an onerous economic burden to either occupants or nation.

The housing problem in Algeria, as in many third world countries is part of the general development problems. Thus the seriousness of urban housing conditions largely results from a policy that encourages mass rural migration to a few urban centres. Similarly the dependance on expensive imported technology to meet mass programmes often results in the construction of houses which are expensive to heat and cool.

In the past, demand for building was satisfied locally by the use of traditional structures and locally available materials which were adapted to the prevailing climate. History and recent experiences show that the courtyard house is an efficient urban form originally created to respond to local climatic conditions among other requirements. Unfortunately comfronting the rising housing shortage and the accummulated deficit of two million units with a politically and economically motivated image of modernism, Algeria has succumbed to the pressure of imported mass production technology based on European standards and environment. Difficulties and failures have resulted as many of the architectural designs and materials were either inappropriate or have not taken advantage of the local environment and climatic conditions.

Indeed the scale of transfer of such technology in the form of industrialized and prefabricated housing units to Algeria now warrants assessment of its effectiveness in responding to the need of the region - in terms of physical, economic and social performance.

Today the momentum for conventional energy conservation without sacrificing comfort conditions in building, has given architects an ever growing awareness of the importance of thermal design. Consequently there is a responsibility on architects and planners to shape their buildings to exploit ambient energy sources in order to minimise auxilary heating and cooling loads. Algeria in particular has a critical need to elucidate key thermal features of traditional forms which could economically address current demand.

Climate sensitive or passive solar design uses the building itself as a collection, storage and distribution medium for heating and cooling. This means optimising geometry and construction mix, shape, layout, orientation, design of window shading devices and thermophysical properties, in order to moderate external environmental fluctuations within narrower limits set by internal environmental needs.

Passive solar techniques are often thought to be new, but the physical principles involved can be found in the majority of vernacular or traditional architecture. However as a result of the industrial revolution and cheap readily available energy in recent decades, its principles have been forgotten. Passive solar architecture simply stated is in harmony between people and their natural environment. In this context it is anticipated that a study of the traditional courtyard house form, compared to a typical modern flat, type will reveal thermal strategies which can be exploited in future housing programmes.

The work is related to the specific climate characteristics of the Constantine region in the "haute plaines" and comprises five chapters:-

The first contains a review of the housing to demonstrate the need. A study of housing typology is also carried out as an architectural justification for the identification of model types for analysis.

The second chapter briefly presents an appraisal of Constantine climate as well as some physical principles of the weather.

Chapter three gives a bioclimatic study to illustrate the effect of environmental parameters on thermal comfort, linking them with building design.

A comparative thermal analysis of traditional and modern models - part steady-state, part dynamic - to establish seasonal energy loads and daily cyclic performance, is discussed in chapter four.

Finally chapter five attempts to apply the particular lessons of these models to a more general architectural design strategy.

Chapter 1

HOUSING

1.1 Housing and energy

1.1.1 Trend in domestic energy consumption in Algeria

Today, over 98% of our energy comes from fossil fuels. Residential buildings, are the major consumers of this energy. According to Bouchenk Khelladi(2), the annual growth of energy from 1965 - 1980 amounted to 12.9% of a rate of 13.8% in 1965 - 1970; 10.9% in 1970 - 1975 and 14% in 1975 - 1980. However, the fuel distribution shows a rapid decrease in solid combustible, but an increase in natural gas from 11.3% in 1965 to 16% in 1980. Finally, it appears that the share of L.P.G. has almost doubled during the last period due to the nationalisation of distribution of electricity in the whole country by the end of 1987. Figure 1 shows that the total domestic consumption has increased sixteen fold between 1962 (81.5 K t.o.e.) to 1980 (1,332.5 K t.o.e.) and was expected to double in 1985. Thus, an average rate of 17% over 19 years with the dominance of Butane and natural gas.

Domestic energy needs are identified for cooking, heating/cooling, lighting and the use of domestic appliances according to the social needs. Apart from lighting, refrigeration and air conditioning, electricity is rarely used for cooking or water heating, although it may be used by some people to heat water in "cumulus". In practice, in Algeria, the competition is between Butane and natural gas.

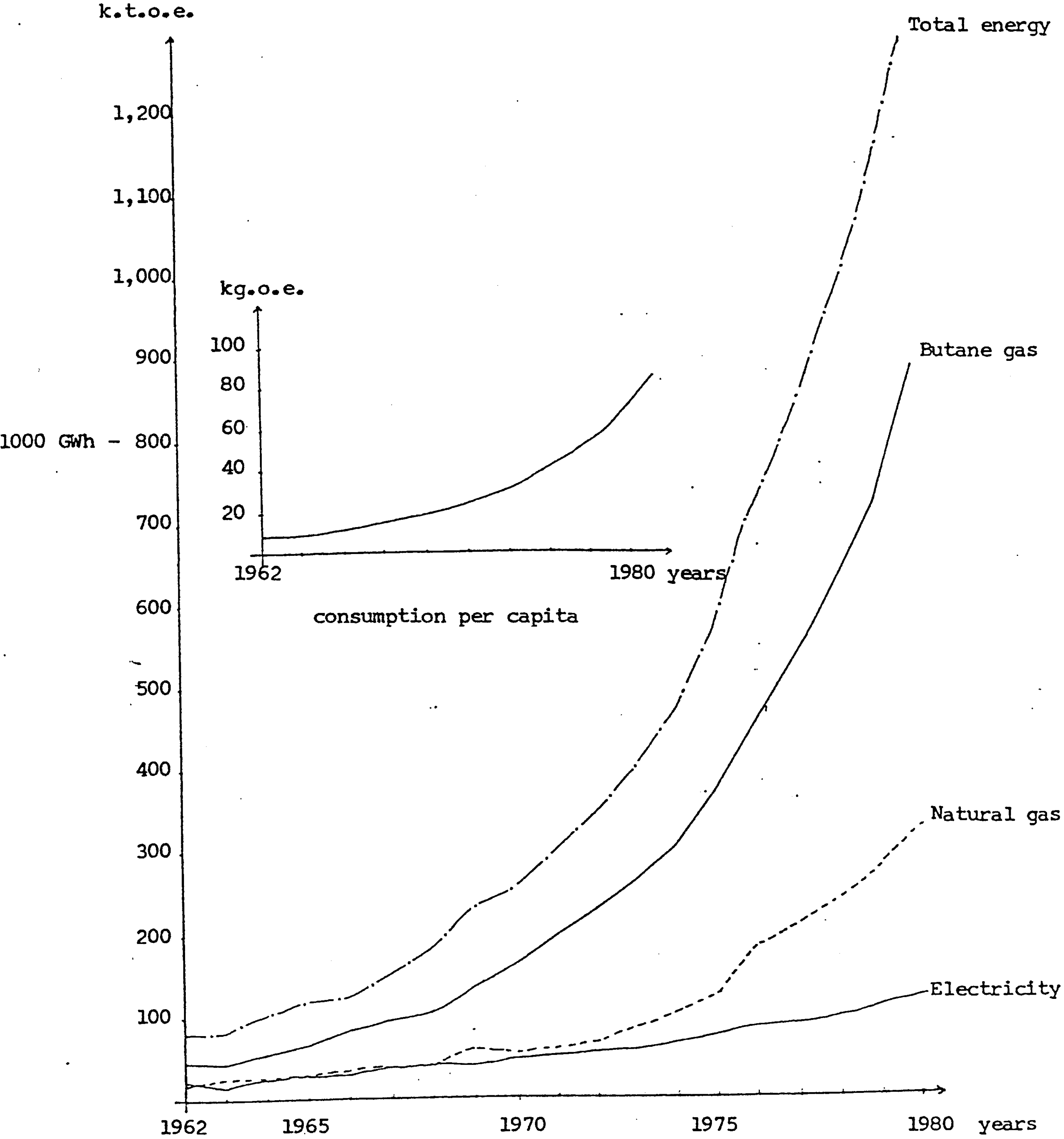


Fig 1 - Domestic energy consumption in Algeria.

Source: "Annuaire statistic de l'Algerie", Algiers 1979 (in French).

k.t.o.e. - thousands of tonnes of oil equivalent.

kg.o.e. - kilogram of oil equivalent.

The main factors for energy expenditure may be summarised as:

- population growth (3.2%)
- increase in housing stocks
- intensive urbanisation
- improvement of living standards and income
- life style change
- inefficiency of the thermal performance of the housing stock

1.1.2 Need for change

Until the 1970's, there was no broad awareness for Algerian planners of the energy problem in the domestic sector. The previous figures show that the situation will get worse if no action is taken. Algeria possesses a huge reserve of natural gas (the fourth largest in the world) and lies 11th and 13th in the league, respectively by the world and O.P.E.C.[2]. The reserves available have always given the feeling of security, but these resources are exhaustible. Many studies show that there are only about three decades left for gas and much less for oil[3]. Moreover, these hydrocarbons constitute the major source of revenues and potential export earning from security for overseas loans (90 - 95% of all exports).

Due to the exponential rising energy demand in housing sector and its importance in the economic investment, besides the prospect of energy shortage resulting from the present trend, Algeria has a crucial need to shift to alternative technologies. In this context, passive solar energy design is most appropriate as the climate favours greater exploitation either for thermal use or the production of electricity by photovoltaic cells. Programmes are ongoing at the "commisariat aux energies nouvelles" and the solar station of Bouzereah (Algiers) nowadays constitutes the most important research infrastructure, having a solar oven of 50 KW with which a temperature of 3,500 °C can be reached. Other universities and national companies, such as SONELGAZ, SONELEC, S.N.S have also started to integrate this option in their research especially for housing.

Even SONATRACK (the state oil company) has significantly reduced its development schemes cancelling many projects, e.g., Arzew, GAS I, ISSERS gas liquefaction plants. These are some measures of conservation besides some studies and programmes of nuclear power plants which are still at the preliminary feasible stage(3).

1.2 Identifying housing needs in Algeria

1.2.1 Background

Algeria is marked by the intensity and rapidity of urban development resulting from massive rural exodus and high population growth rate. The urban problems of this situation, notably the housing shortage, are far from being resolved. The use of foreign imported technologies with no consideration of Algerian social and environmental conditions has not only failed in reaching its objective but has also contributed to the high energy expenditure and/or discomfort due to low thermal performance and high running costs, not to mention social degradation.

Housing is thus the most difficult of socio-economic problems facing the nation. Apart from the maintenance and repair of many existing buildings, the government has assumed the responsibility of coping with the high growth rate by initiating new programmes.

The problem of housing dates from before the Algerian war. In fact in 1954 over 30% of the population of Algiers lived in "shanty towns" and a third of Annaba and Oran also lived in this type of housing. The process was aggravated during the Algerian war when two and half million were regrouped in housing schemes, "cite's de recasement", as they were offered jobs in industry during the plan of Constantine 1959-1963.

After independance in 1962, the development of the country was oriented towards the agricultural sector to increase foreign exchange and exports as a means of sustaining the economy. This had a traumatic impact on the country's urban population in terms of housing. Land ownership was nationalised and solving the housing problems became a function of state planners and administrators.

In 1965 the government policy changed towards the rapid development of capital intensive industry and the initiation of "pole strategy" to consolidate the big cities. However the transfer of population attracted by new jobs caused severe economic and social problems, as no measures were prepared to provide these migrants with housing at the "pole". This resulted in the creation of "shanty towns" and "slums".

Until 1967, no sound assessment was made as far as housing was concerned, despite the excessive growth of towns. The point made by Algerian planners was that the infrastructure inherited from the colonial period could support at least the early stage of industrialisation. These assumptions have proved false. In fact when the Europeans fled from the country in 1962, the bulk of 300,000 housing units were taken by Algerians within a few months. Towns were transformed in size and ethnic composition as they experienced a veritable transfusion of population. It was not until the housing shortage became too apparent that the government initiated a programme of "public housing" and various attempts have since been made to reduce the dimension of the problem. To understand clearly the government commitment, it is worth analysing the economic development plans in the context of housing.

1.2.2 Housing investment during the different national plans

In the period 1967-1977 three development plans were launched, but the number of housing projects expected has never been completed in the time allocated to them.

The first national plan was the three year plan launched as a preliminary concept of "industrializing industries" based on Algeria's own national resources and clearly established within the two four year plans 1970-1973 and 1974-1977.

In the subsequent five year plan 1980-1984, the physical planning of cities was recognised to be essential and resulted in the promotion of the so-called "plan d'urbanism directeur" for urban expansion. Very little investment was devoted to housing during the first two plans as table (1) shows. The pressure on housing increased steadily from 1967-1973, the number of households rising by 230,000 while that of habitable accommodation only by 50,000. Moreover the 1966 census reveals a deficit of 600,000 housing units identifying the need to build about 1.8 million units to satisfy the acceptable rate of occupancy. In 1966 the rate of occupancy was 6.1 per unit or 2.6 per room.

plans	dates	investments	% of total	rate of realisation
3 year plan	1967-69	0.4	3.5	84%
1st four year plan	1970-73	0.9	5.0	132%
2nd four year plan	1974-77	8.3	7.5	110%

Table 1: housing investment in the different economic plans units (billions Algerian Dinards).

Source: M.H. TAMMAR, "Strategy de development independent", 1983.

In 1971 the government undertook a far reaching programme of land reform and initiated the Agrarian revolution and the construction of 1,000 socialist villages to prevent rural exodus and resolve the housing shortage.

A great effort was made in the second four year plan, (table 1), the effort was multiplied by a factor of 8. This plan contains also a regional "decentralisation policy" expressed in population terms so as to stabilize the interior and mountain regions.

In 1975, the census of "Bidonville" clearance scheme was formulated to house those living in inadequate housing. However in 1976 it was revealed that 80.2% of all urban families lived in accommodation varying from 1 to 3 rooms, 16.6% in 4 to 5 rooms and 3% in more than 6 rooms. It can be said that increased investment in housing is becoming more and more important but tables 2 and 3 show a very slow rate of building realisation:

plans	number of projected units	number of completed units			total	number of units under completion
		1967-69	1970-73	1974-77		
1967-69	20,548	9,770	7,140	3,633	20,548	0
1970-73	45,115	-	2,127	18,138	20,445	20,670
1974-77	156,680	-	-	4,208	4,208	152,473
total	222,343	9,770	9,267	25,979	45,201	173,143

Table 2: number of urban housing units programmed (1967-77)

Source: "N.A. Benmatti, "l'Habitat du tiers monde, cas de l'Algerie" 1982.

Table 3 shows that:

- in one decade (1966-77) the population increased by 43.7% whereas the housing stock increased only by 11.5%.
- the rate of population growth is around 3.2% (and 40% of it is concentrated in the big cities)
- half the buildings are more than 30 years old.

In 1977, the deficit in housing was evaluated as 700,000 units on the basis that a household is composed of six persons (table 3). In reality the average size of an Algerian family is 6-10 and by far the greatest of dwellings are 1-3 rooms, testifying the acute housing shortage (tables 4,5).

	1966	1977	1982
population	12,096,347	17,386,484	19,564,000
population growth		5,290,137	2,178,000
Housing stock	1,980,000	2,208,712	2,666,346
occupancy rate/dwelling	6.1	7.1	8.1
age of stock before 1945	45.8%		
growth rate of housing since 1966		228,824	437,522
public		121,000	
private		107,824	

Table 3: Summary of situation 1966-82.

Source: N.A. Benmatti, 1982, pp. 160, 161, 164.
and "Annuair Statistic de l'Algerie", 1985.

size of dwellings	total (%)	urban (%)	rural (%)
1 - 3 rooms	83	81	84.1
4 - 5 rooms	14	15.9	12.9
6 rooms +	3	3	3

Table 4: Repartition of dwellings according to their size.

Source: Dj Benamrane "Recenssement general de la population et de l'habitat" 1977.

size of household	total (%)	urban (%)	rural (%)
1 - 6 persons	49.1	48.6	49.5
7 - 10 persons	35.4	35.5	35.3
11 persons +	15.5	15.5	15.5

Table 5: Repartition of dwellings per size of households in 1977.

Source: Dj Benamrane "Recenssement general de la population et de l'habitat" 1977.

1.2.3 Recent change in housing policy

As a result of the ever growing shortage, in the late 1970's physical planning problems became a major concern. Hence housing and infrastructural development received the highest allocation in the two five year plans, 1980-84 and 1985-89 budgets. Moreover the Ministry of Construction planned by agreement with foreign firms to build 100,000 housing units each year over the present decade to limit the deficit estimated at 1,200,000 units in 1980. Besides this, the government decided to undertake a programme to promote the building of "new towns" in eight "wilayates" of the haute plaines. These are aimed to house about 20% of the population in 1990 in order to slow down the growth speed of big towns.

In the first five year plan, the investment for housing was 15% of the total economic investment (table 6).

sectors	total programme (%)	Authorized expenditure (million A.D.)	
		1980-84	after 84
Industry (1)	211.7	154.5	57.2
housing (2)	92.5 (15%)	60	32.5
total	560.5	400.6	156.9

Table 6: Housing investment in the first five year plan.
Source: M.E. BENISSAD, "Economy de developement en Algerie".

In terms of dwellings the plan programmed 365,000 units for urban, 156,000 for rural and 250,000 for special purposes. However, the rebuilding of El Asnam destroyed by the earthquake in 1980 diverted many of these funds and materials (table 7). Behind the facade of state ownership one finds an increasing emphasis on mobilizing the desire of individuals to contribute to their own houses. This is clearly stated in the "national charter" 1976. In fact the implementation of the decision taken in 1980 to distribute 80,000 plots of land for individual houses would have contributed partly to the housing need. It is worth noting that from 1978 the public contribution to housing greatly increased, the trend to prefabriction system began and all building potentialities were oriented towards imports. Benamrane(4) stated that in 1979, 85% of the housing was from the public sector.

	planned	delivered 1980 - 1982		
		1980	1981	1982
urban	452.679	23.96	28.876	42.68
rural	312.402	10.956	17.270	29.828

Table 7: Housing unit delivery 1980-82.

Source: "Annuair statistic de l'Algerie, 1985".

In the second five year plan 1985-89, the investment spending was set at A.D. 550,000 million, i.e. a 37.5% increase from A.D. 400,000 million allocated to the previous plan. Of the total spending, housing received 15.7%, this testifies to its importance in the economy.

However in 1980-1984 only 407,000 units were built of the planned 700,000, but taking into account projects started before 1985, 542,000 housing units should be completed by 1989.

1.2.4 Present situation

According to Meeds(5), housing shortage reached two million units in 1984 compared with 600,000 in 1966.

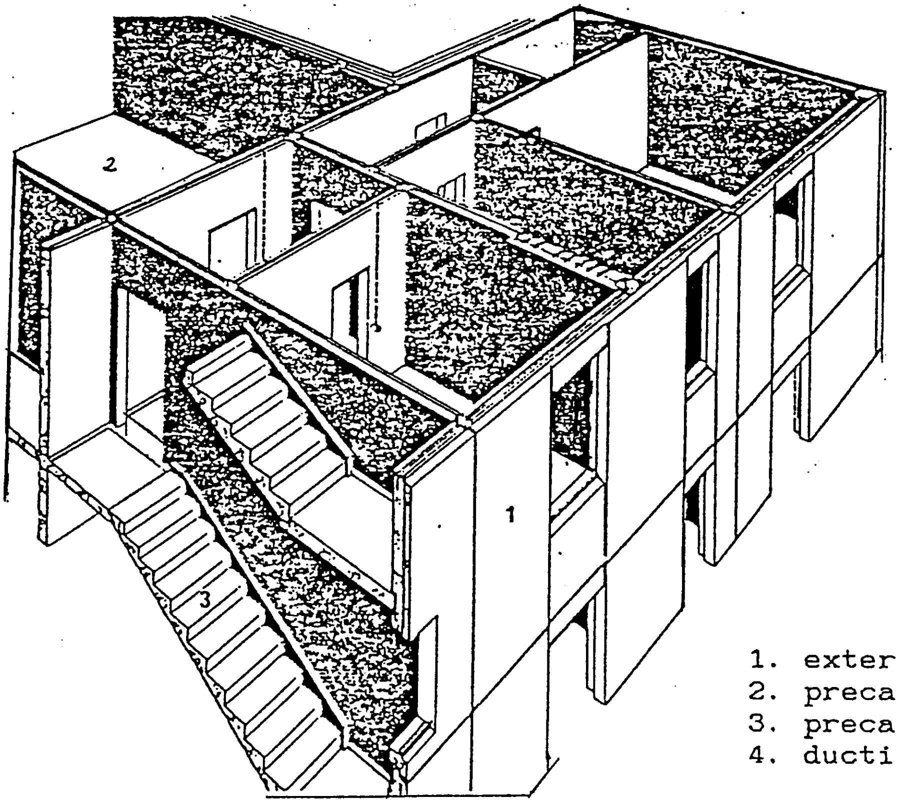
The growth of housing averaged only 1% a year between 1966-78 and the deficit is more pronounced in Eastern regions. The actual demand must consider also the high occupancy estimated at 8.1 in by 1984 El Moudjahed.(6)

The deficit in housing has now reached a point where the minimum fulfilment of the citizens' need to achieve a rate of occupancy of 6 persons would require construction of 250,000 units per annum. According to the report of the economic commission of A.P.N., this would necessitate building two million, supplementary lodgings in a period of ten years. It is noteworthy that in 1977, the rate of occupancy was qualified by O.N.U. as "overpopulation intolerable", with 3.4 persons/room or 7.1 persons/dwelling. According to Rahmani(7) in 1977 about 38.4% of the Algerians have only 4 m^2 of habitable area per person, although the pathological threshold of habitable area is defined by the "O.M.S. (organisation mondiale des surfaces)" to be at least 8-10 square metres per person.

1.2.5 Building industrialisation

Algeria started in 1969 to adopt some industrialized systems. Two national companies were involved: SONATIBA adopted the French system "PASCAL" and ECOTEC enabling a system for prefabrication on site with the collaboration of Polonesian engineers. But in 1975 Ecotec abandoned this system and bought a new one from Switzerland "VERIEL" which became later "VARECO".

In the context of many development programmes, prefabrication was particularly prioritised for housing. 47.3% of units were prefabricated within 1975-1977 against 40% in 1970-1974. Thus at the end of 1977, thirty prefabrication production units were operating in Algeria. Hence prefabricated mass housing, reinforced concrete panels and box systems are being suggested as solutions with the implicit assumption that housing is predominantly a technical problem and that high technology can produce the necessary units in volume in order to put the operation on an economic basis.



1. external wall panel
2. precast floor panel
3. precast staircase
4. ducting unit

scale 1:100

Fig 2: Different components and details of the pascal system.

Source: Techniques de construction - orientation relative aux choix des procedes: Minstere des Travaux publics et de la construction

1.2.6 Conclusion

The acute shortage of housing over the past years has created a serious situation in built environment. It created a pressure to build substandard buildings to shelter people, ignoring the need to produce proper building regulations.

From the above analysis, we can see that the underlying trend reflects a general decay in the living standard, resulting in an increasing number of households of increasing size, but a decrease in space per person. In addition, the high energy costs together with poor insulation and precast concrete construction have resulted in progressively more widespread environmental deprivation for the poorer section of the population.

However to face the ever growing housing crisis, Algeria proceeded with the import of technology without defining a precise policy. Consequently the mixture of diverse techniques, which neither understood nor applied to the environmental conditions, gave the country an aspect of a huge experimental laboratory. The principle criteria that determined the choice of these systems, speed and economy, have been revealed as false.

According to Hardoy(8)

> << Public housing programmes based on such units have run into an expensive and extensive maintenance problems... The results of that is a major balance of payment, since these systems

> involve heavy imports, costs for machinery and the right to use techniques developed elsewhere. >>

These systems have occupied a progressively greater role throughout the territory, but in reality have never been the right answer to the housing shortage. The problem should not be treated on the basis of mass production of readily made standardized dwellings as they have resulted in many deficiencies. But Algeria like all other countries is in a stage of experimentation.

1.3 Housing typology in Constantine

1.3.1 Location -

Constantine is the third largest city in Algeria situated in an inland area in the north part of Algeria, about 450 km south of Algiers. Its site is an irregular plateau bounded by a chasm or ravine. It is in fact a peninsula of rock only united to the main land mass by bridging the abyss on the west side. The city spread over the summit of an immense chalk cliff left by vertigenous gorge of the "Rhumel" river (plate 1)

Around this original rocky site - "the medina" - the French town planning evolved, followed by those of the Algerian authorities in the form of quarters - Z.H.U.N.

The old town was uniquely fitting because of the chasm. However, the last not withstanding, some high rise buildings still dominate the town from the south east shortly after the Rhumel divides into two branches (plates 2a, 2b).

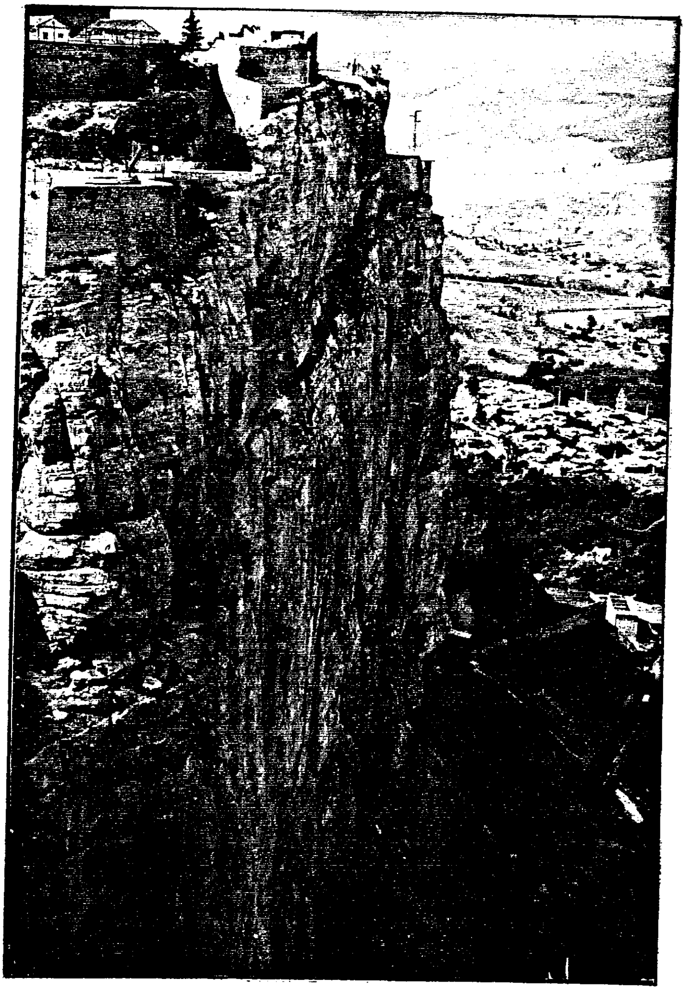


Plate 1 - View of the immense chalk cliff site of the old town of Constantine.

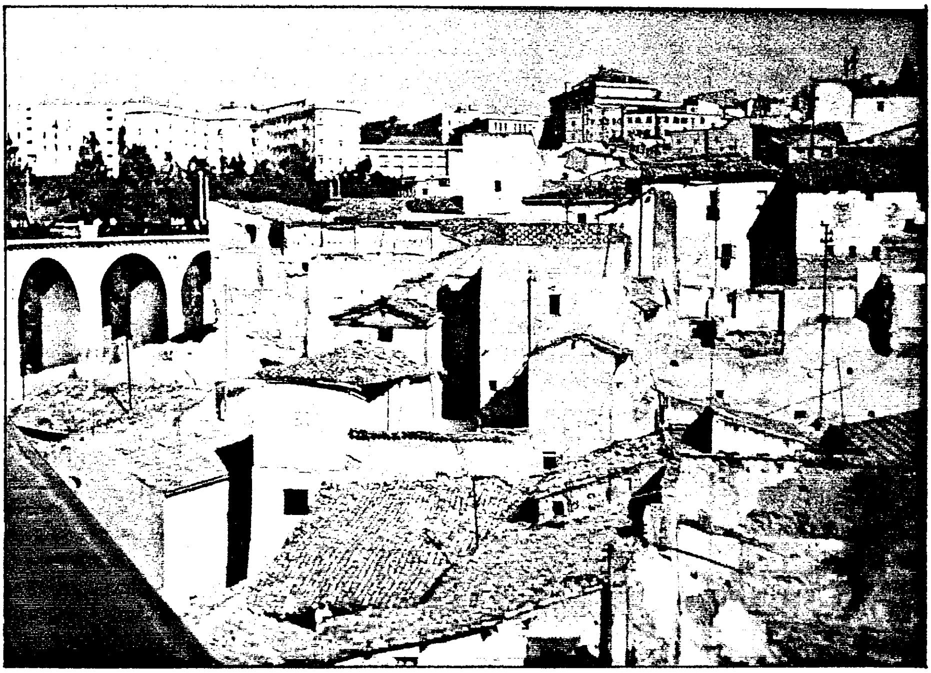


Plate 2a - Housing typology, on the foreground, the traditional compact type characterised by its "cubism".

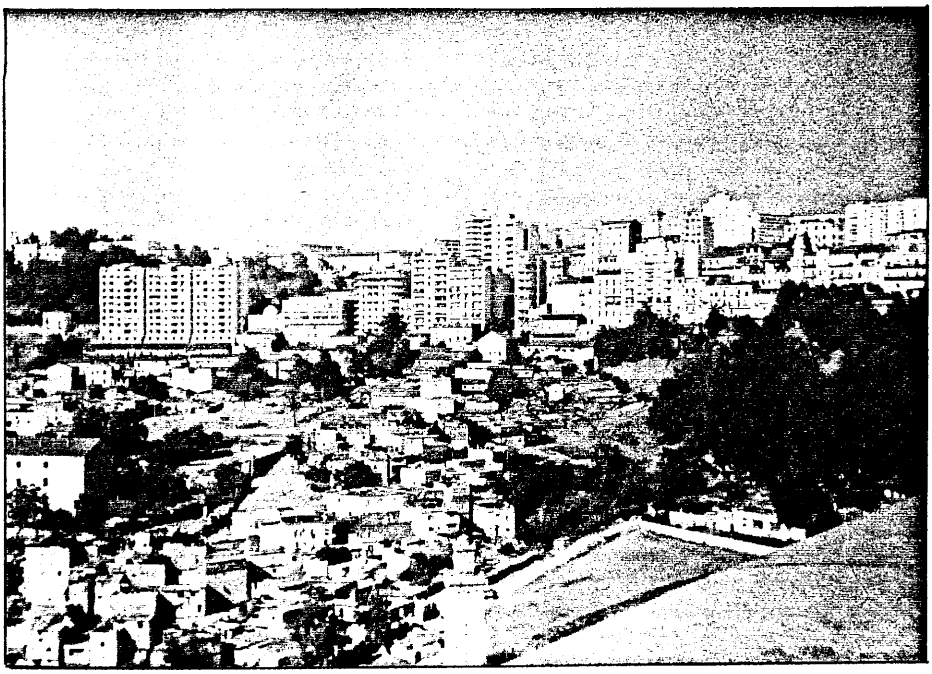


Plate 2b - In the background, the colonial type of housing, high rise buildings dominating the south part.

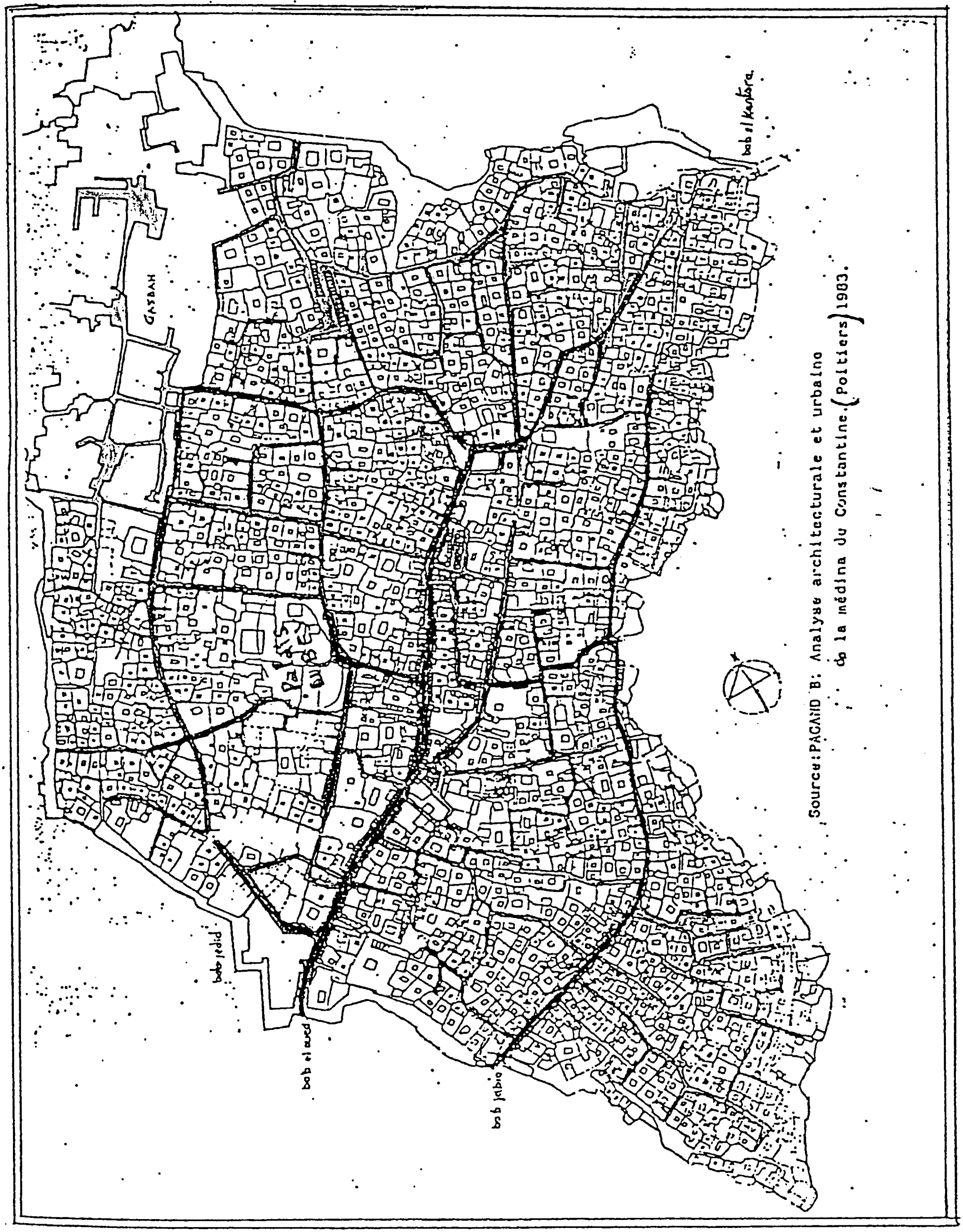
Building in Constantine has passed through different stages of historical development with architectural design experiencing a fast pace of change. To better illustrate this, three architectural types are examined according to their historical, environmental and architectural characteristics.

1.3.2 Traditional type: 'Medina'

1.3.2.1 Urban context

This is the historical arabo-islamic type and today is confined to the old city centre. The various habitations reflects the history of Islam. This type surrounds the old arab forts and palaces of former arab rulers. Built before 1800 it is the only type found before French colonialisation.

Introversion centred on the heart of the house unit and, common to most arabo-islamic cities, is marked in Constantine. The urban community, created originally for defensive purpose, was designed for pedestrians and animal traffic, with irregular patterns of winding, narrow streets and densely packed houses. It is possible to identify a clear hierarchic organisation of circulation from the most public to the semi-private alleyways and cul-de-sacs serving two to three houses. Originally dictated by defensive purposes as well as climatic. This organic spatial network still seems to work in terms of privacy. Both narrowness and ramifications of the streets are determined by the



Source: PAGAND B: Analyse architecturale et urbaine de la médina du Constantine (Poitiers) 1983.

Plate 3a - Constantine town in 1830 showing the urban layout of the old town with its street's ramifications.

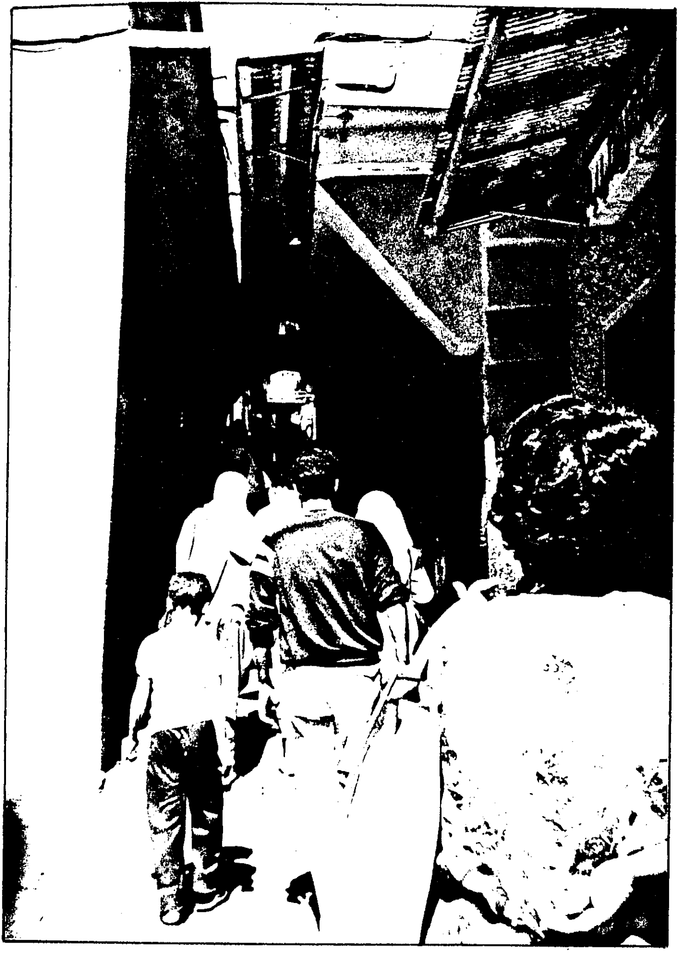
irregular unit shapes and blind perimeter of houses, strongly linked together and close on the alleyways. This spatial configuration generates its own particular visual and climatic ambiance and promotes defensive space. Thus, there is a strong sense of ease, freedom and territory (plate 3a).

The public streets and cul-de-sacs, straight or twisted, covered or open, are usually deep and narrow. Their width ranges from 1.5 to 4 metres, enough to provide a more moderate shaded microclimate, and adequate circulation to support local activities (plate 3b).

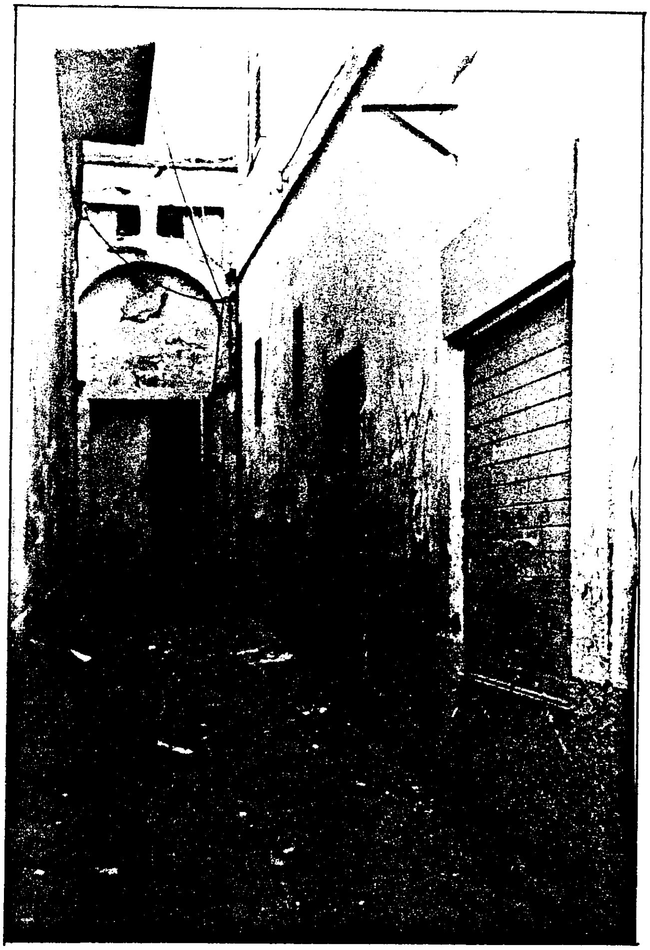
The exclusion of the exterior leads to a system of streets and cul-de-sacs at the urban level, and to the concept of an inner courtyard at the house level. This was the core of every building, private as well as public, and the only regularly shaped space in the town's organism.

It can be concluded that traditional planning insisted on compactness for environmental, social and economic reasons.

> << Investigations have concluded that, in most of these organisations, the climatic, social conditions that influence the form were taken into account. The expansion of the city resulted in a single massive unit. >>(5)



1 - Public semi covered street, the width is sufficient to ensure local activities.



3 - Cul-de-sac regrouping 4 houses (semi private) leading to the skiffa.

2 - Semi public uncovered winding street ensuring shading for pedestrians.

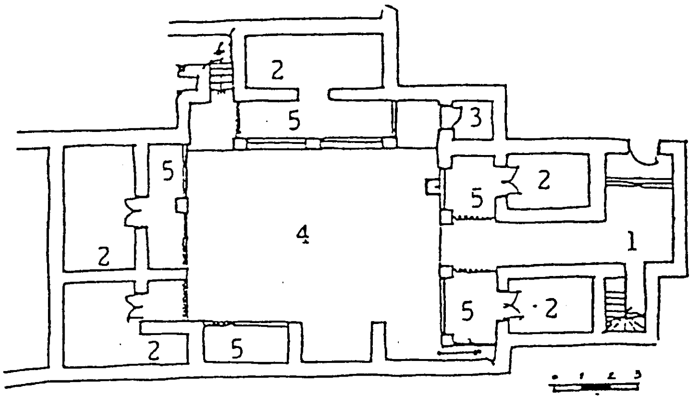
Plate 3b - Street function and characteristics.

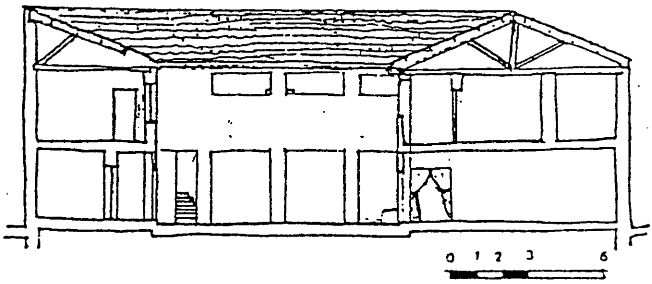
1.3.2.2 House form and design

Privacy in a social sense and protection against the harsh extremes of climatic conditions are fundamental factors influencing the house type found from Morocco to Egypt and far beyond.

When considering the built environment, it may be postulated that nothing affects peoples' health and well being more directly than the home. In this context the courtyard form would appear to be a good example, emphasizing a positive inter-relationship between the different components.

In Constantine all old houses, about 11.7% of the total stock are of the courtyard form, in different shapes and sizes (plate 4). They are generally two to four storeys high. In its simplest form the house is rectangular or square with an open court in the centre, surrounded by the main rooms which are often long and narrow. Rooms rarely exceed 3 metres wide and have a central doorway which allows light penetration. These rooms are generally multifunctional. The size of the courtyard depends on the size of the house, which in turn is proportional to the owner's social wealth. The entrance door does not give directly to the courtyard, but through a 'chicane', off which the reception room is generally located. Secondary spaces such as staircase and toilet, are located on a corner of the courtyard. All storeys give on to the courtyard by means of galleries reduced to collonades on the ground floor (plate 4a).





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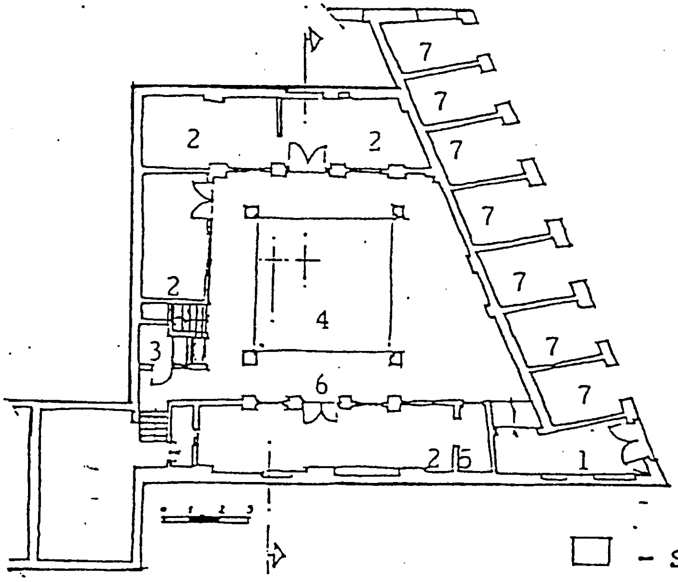

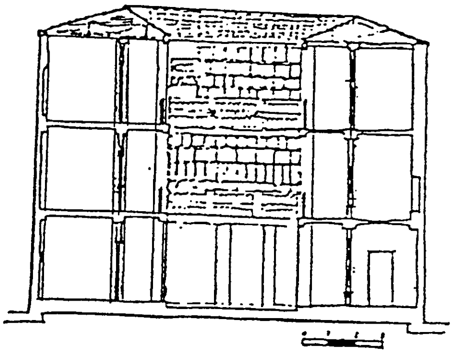

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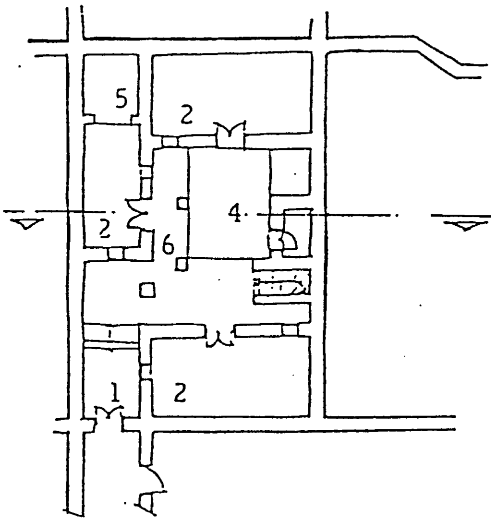

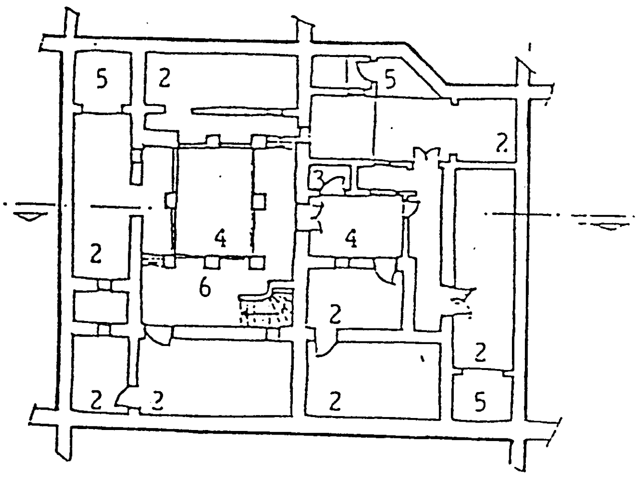

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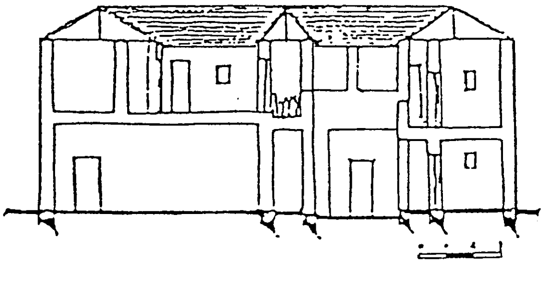
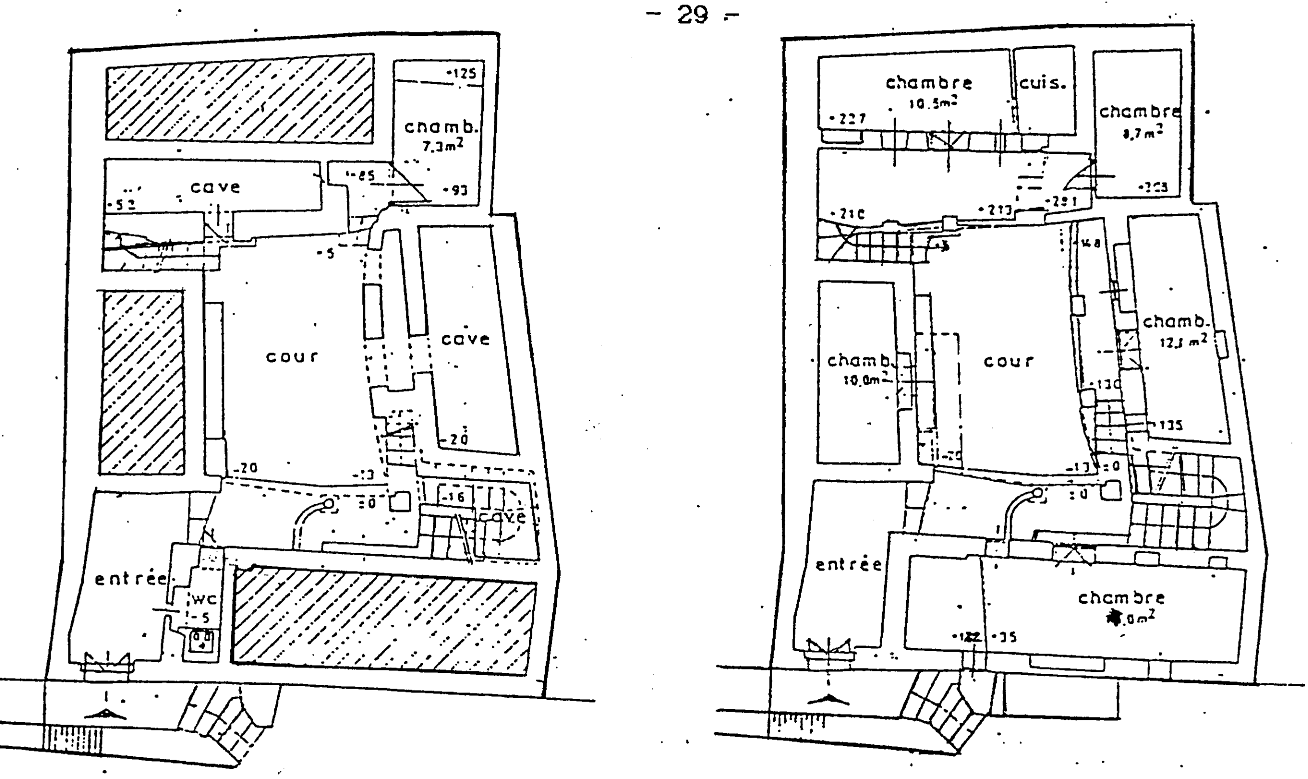


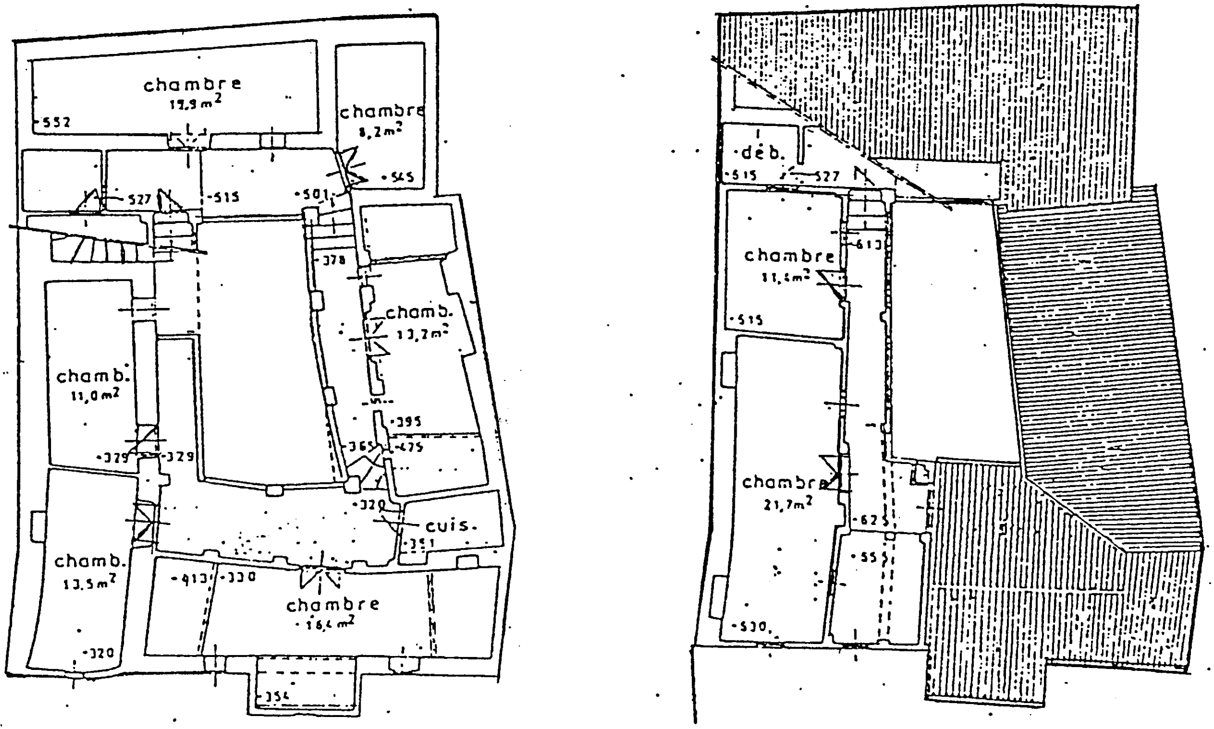
1 - Skiffa (Entrance)
2 - Rooms
3 - W.C.
4 - Courtyard
5 - Doukkana (store)
6 - Gallery
7 - Shops.

Plate 4 - Types of courtyard houses of different shape and size.



Ground floor

First floor

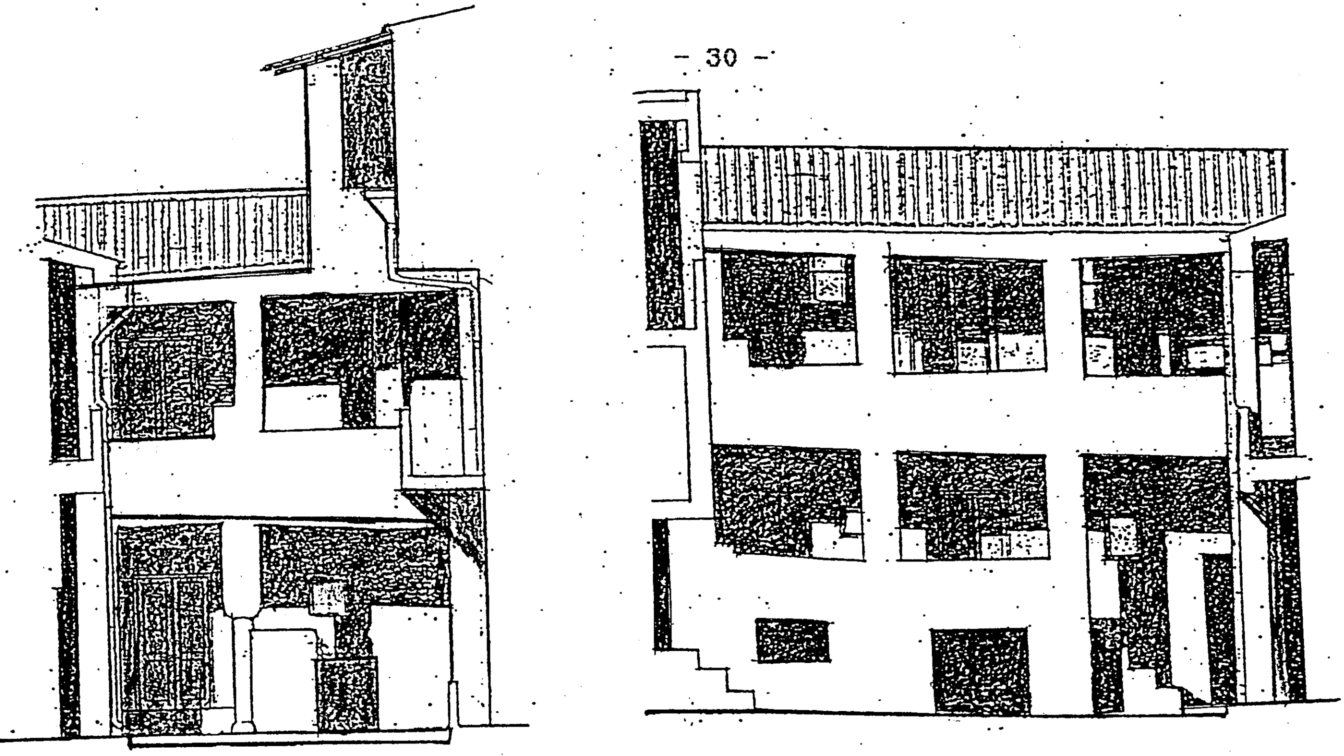


Second floor

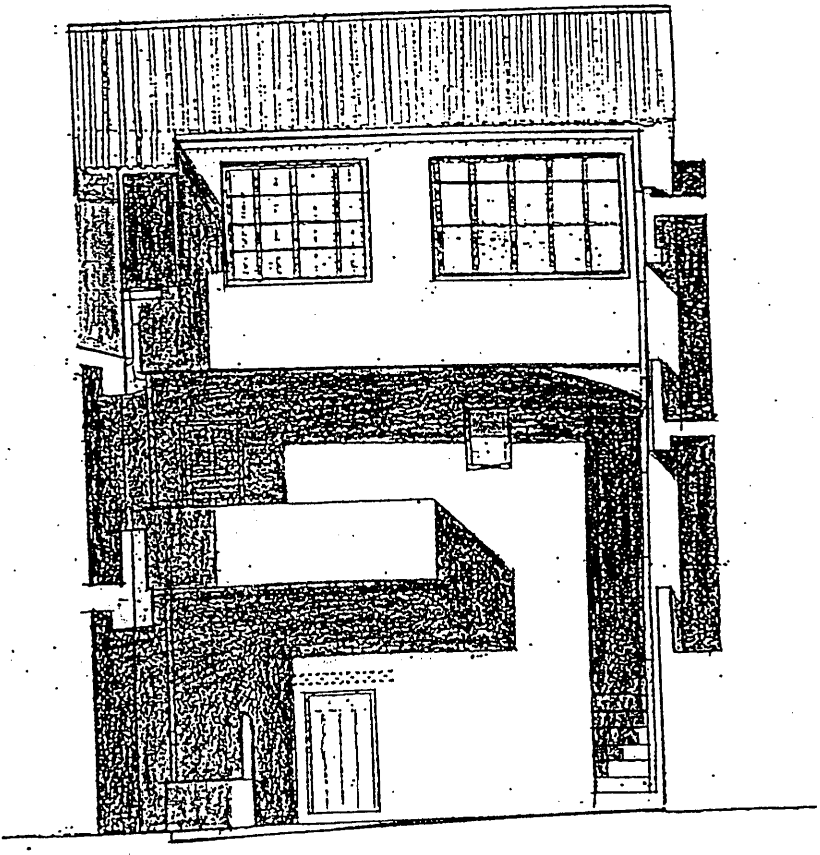
Third floor

Plate 4a - Courtyard house example.

Source: CADAT: study of a project renewable.



Facades giving onto the courtyard



External facade

The courtyard is the heart of the house spacially, socially and environmentally. Upper floors are generally similar to the ground floor. However the roof terrace, if it exists, is surrounded by high walls except the side giving on to the courtyard. This defines the difference between the 'Medina' in Constantine and the 'Casbah' of Algiers which are similar in organisation, but differ in respect that in the former all roofs are pitched while in the latter they are flat.

The house is inward looking therefore, with windowless external walls except the facade giving onto the street. Here the windows are smaller in size and fewer in number, situated at high level and protected to ensure security, privacy and ventilation.

The dwelling are built one against the other giving a tightly knit mass. The widespread existance of this type over the arab world testifies to the presence of a common requirement. People built their houses themselves to satisfy their needs. Privacy, family structure and climate were the most important factors and are clearly enhanced in the design. Enclosure, or more exactly introversion, dominates this type. From outside nothing of the internal ambiance of the family activity is discernable even if the door is open.

Local materials and traditional techniques were used in the building of these houses. The walls are of stone or mud brick 30-120 cm thick, covered with gypsum and mud mortar. Roofs are generally built with wood trunk and branches with

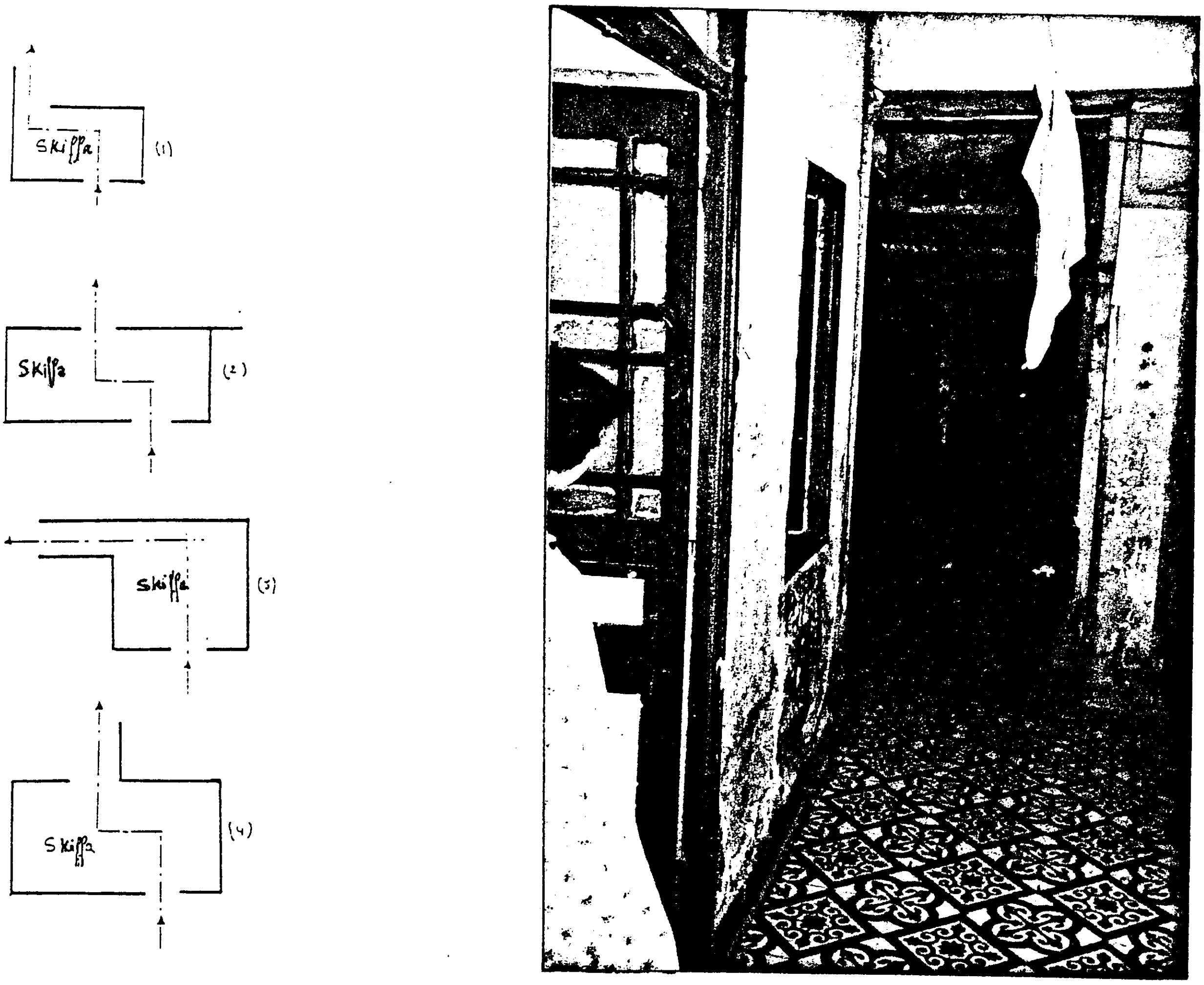


Plate 4b: Skiffa with its various configurations on the right, typical example of the bend entrance enhancing seclusion.

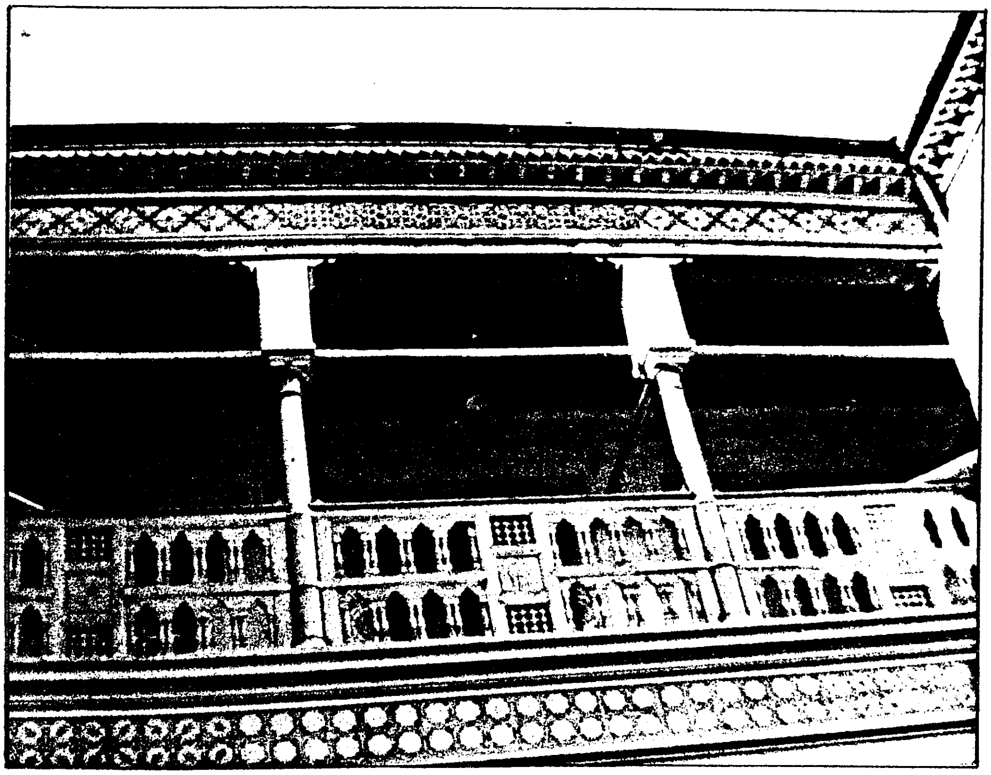


Plate 4c: View on the gallery giving onto the courtyard enhancing shading and circulation.

a layer of mud mortar, reed and tiles. All these materials are locally collected

1 - 3.2.3 Element of the house

Entrance: "Skiffa", rectangular in shape, links the street to the courtyard. Independently of its distributive role, it has a symbolic importance as a transitional space. This 'bend' entrance taking 90° turn is the main feature of the oriental arab house, the complex spatial relationship developed to enhance privacy and security to the courtyard preventing any outdoor gazing or direct view to the inside. (Plate 4b)

El Azzawi(10) also states that this bend or chicane entrance originally had a defensive purpose.

Gallery: "Eshin", located on the upper floors and surrounding the courtyard, serves the rooms and plays the role of overhang for the floors below. Depending on the house size, it can occupy one to four sides of the courtyard. In addition to its role of distribution, it constitutes an extension to the rooms and protects the inhabitants from direct exposure to the sun and rain. (Plate 4c)

Courtyard: "Wast ed dar", closed to the rest of the city, retrenched behind its blind walls, the enclosed space creates the house unit. Open to the sky, it constitutes the heart of the house and enhances the spatial seclusion needed for privacy preservation. The courtyard is generally rectangular or square with a width around 3.5-5 m and an area of 25-30 square metre for an average house. As a focal point in the house, it is a centre of distribution. It also contains the sole source of water (fountain, well) and vegetation which play an important role in moderating the inside climate.

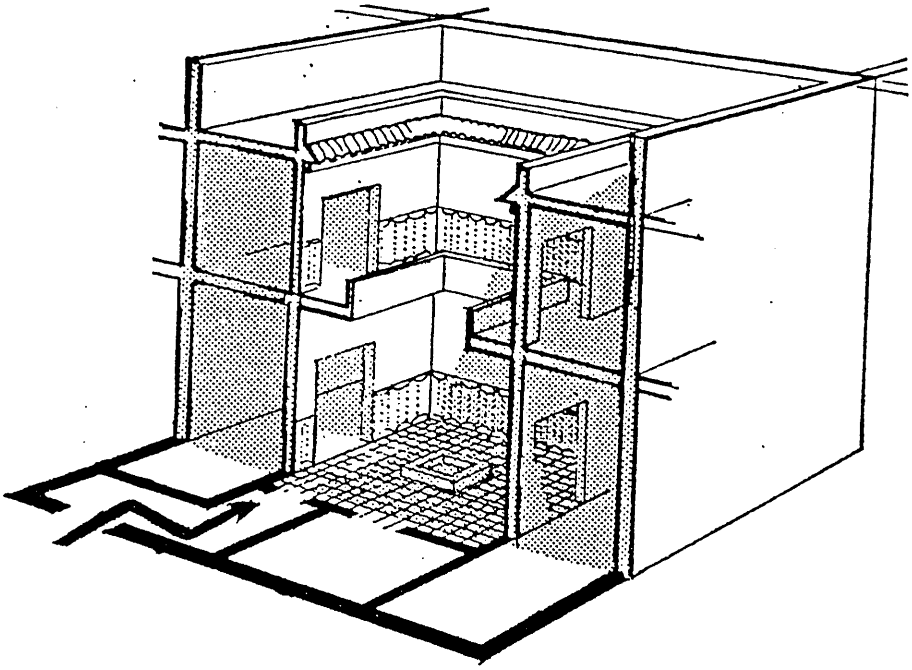


Plate 4d: Typical organisation of the courtyard house elements.

The elementary organisation of the house is uniform. Detailed variations of this configuration may appear within the structure, but always turn around the same architectural theme common to most arab-countries, the residential unit around a courtyard.

The courtyard house is not simply the consequence of socio-cultural factors, the form is also codified by climatic conditions, technology of construction, and availability of materials. It acts as a climatic modifier, sheltering its inhabitants from external climatic extremes.

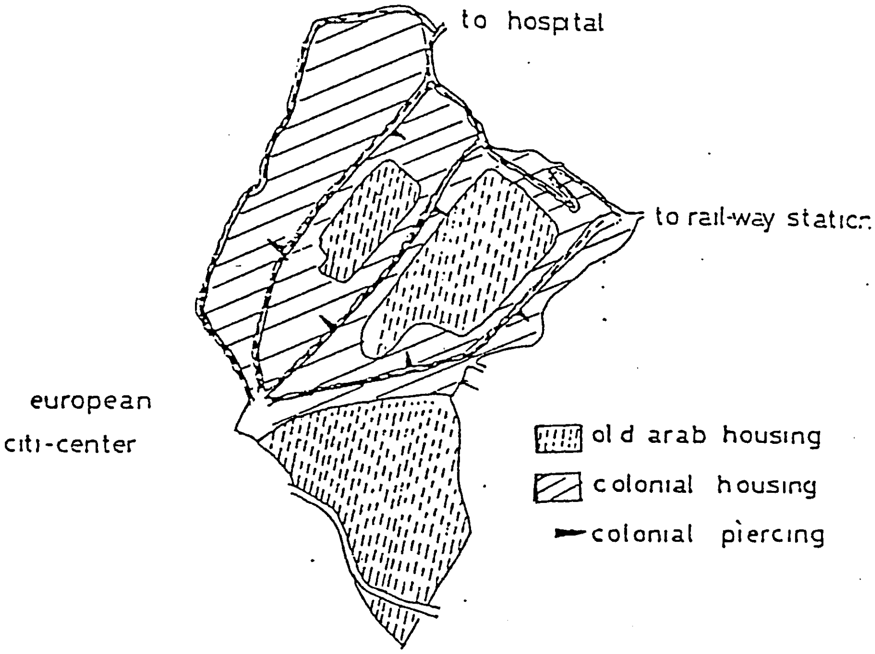
> << Shelter is of supreme importance to man, it is the prime factor in his struggle for survival, in his effort to shelter himself against extremes of weather and climate, he has over the ages evolved many types of dwellings one of which is the courtyard house. >> (11)

1.3.3 Modern colonial type

1.3.3.1 Urban and historical context

Under French control which eventually had a direct influence on all domains of the country, colonial design was introduced and lasted till the mid twentieth century.

The first intervention was the "Hausmannian cut-through" the old town (plate 5a). Later surrounding quarters have been created beyond the limits of the "rock", and are mostly multistorey buildings up to thirteen storeys. These introduced the 'modern flat' concept. They were either designed by Europeans or built in European style and, according to Larouki(12) constitute 18.4% of the total stock, with a further 7.6% in the form of villas. The main characteristics of this type are on the one hand the clear functional definition of each space and their distribution around a central corridor, very open facades and large balconies; and on the other hand the use of modern materials as well as infrastructural facilities and services.



-PLAN_5a THE MEDINA OF CONSTANTINE-

Plate 5a: "Hausmannian cut-through" in the "Medina".

The buildings are spread out in a linear urban organisation with very wide straight streets to accommodate wheeled vehicles. During this period Constantine went through large changes and transformation in the physical texture as well as social structure (plate 5b).

Early colonial town planning "hausmannian cut-through" in the city centre - linear planning.

Late colonial planning in the surrounding quarter (the coudiat).

Plate 5b - French linear town planning.

This type is concentrated on the north part of the town as well as Kondiat, beb el Kantara, Amir Abdelkader and Sidi Mabrouk. The history of French town planning goes back to the early colonialisation in 1830. It was started as a 'military urbanism'. As agressive and impressive as this intervention might be, the new town planning distroyed the homogenous structure of the "Medina" urban fabric. The beginning of the century marked the French presence. Since the 1920's military urbanism became officially 'bureacratic'. Accordingly Constantine started to give shape to its suburbs and new urban centres responding to overseas urban standards and legislation. This period also coincides with the appearance of new materials and revolutionary ideas of architecture set against the revised neo-classicism. First was the creation of social housing or cluster house type, and then with the influence of le Corbusier's ideas, multistorey house forms began to appear. The villa has also been strongly influenced by new trends.

The third period, after 1945 expressed a decisive phase. The influence of modern architecture was expressed by two urban types, linear planning H.L.M.(housing at moderate rent) and housing estates in suburbs, as well as satellite villages such as El Khroub. In fact Constantine sites are steep and rocky. Until 1945 many of such sites remained undeveloped. With the influence of the modern movement in particular the Construction of blocks on stilts or 'pilotis' made their development possible.

1.3.3.2 House design

The architectural principle was quite simple. A cross section of a typical building would show two main parts - a shopping area on the ground floor and residential flats on the upper floors, the social status decreasing upwards. The typical building plan consists of an arrangement of the main spaces around a corridor (plate 5c), with principle rooms facing the street. This internal hierarchy in the building was followed by a similar language on the facades, each storey comprising two to three flats served by a staircase. The pattern is repeated in terraced form exposing two facades. The main facade is characterized by large windows, rich decoration, large balconies and high floor to ceiling dimensions. The rear facade, less decorated, faces a back court which is shared by other blocks.

Thus the result of French period was marked essentially by the regular grid layout for both circulation and military purposes. These conditions produced the dominant urban component of colonial Constantine "ilot block".

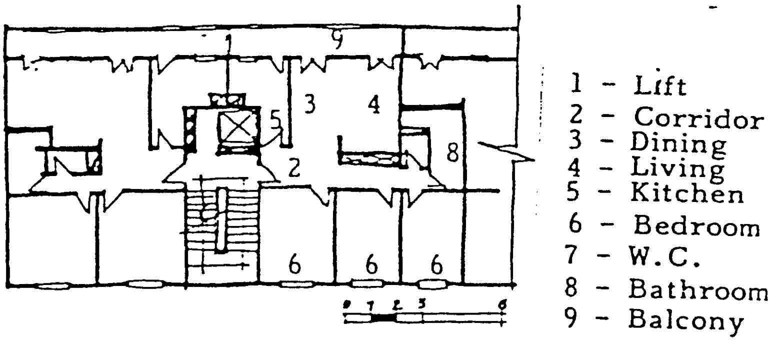


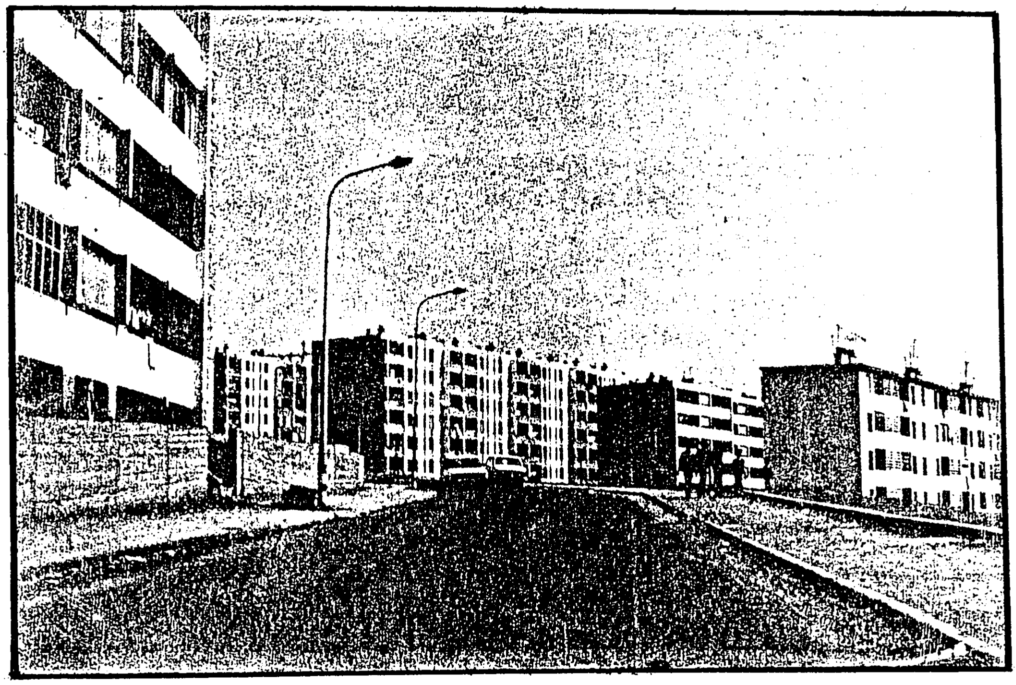
Plate 5c: A typical colonial flat plan.

1.3.4 Modern estate housing

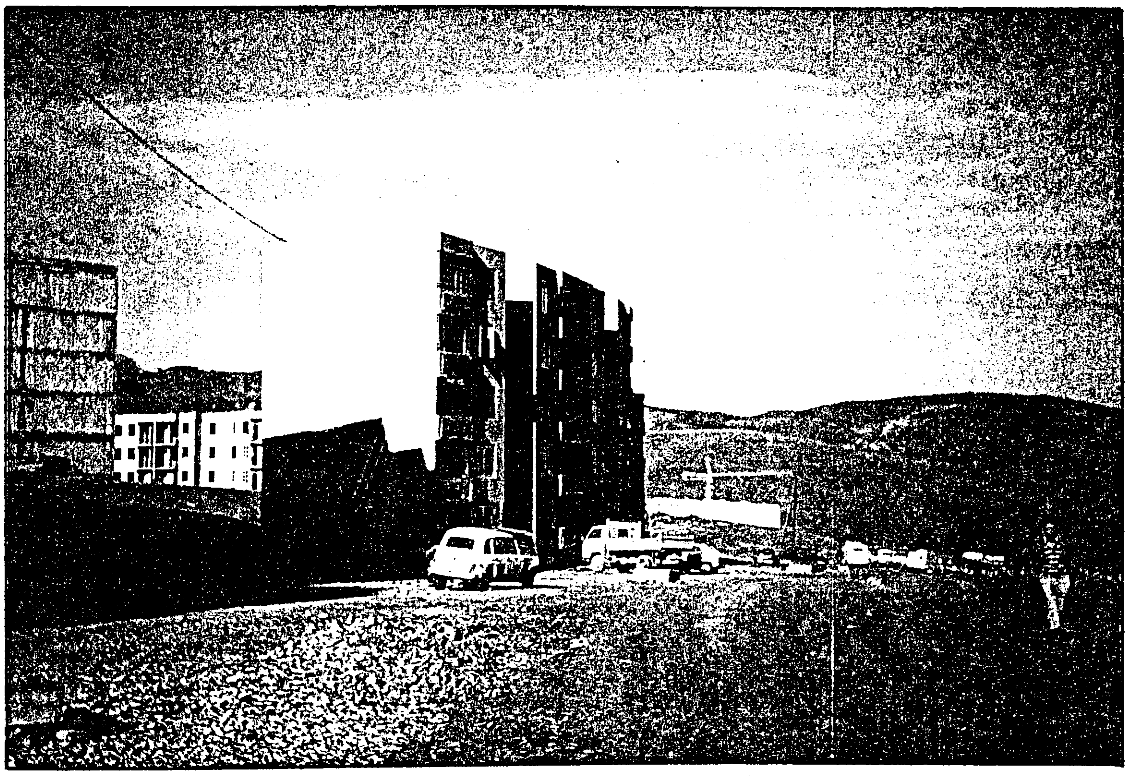
1.3.4.1 Urban context

As we have seen in section 1, the housing shortage became an issue of statistics where human feelings were forgotten in a relentless surge of prefabrication technology, bringing with it new problems to add to those already introduced by the colonial type. Since the whole new era promoted the same urban conception of colonial rules, the housing typology has continued in the same manner. This highly centralised and standardised effort resulted in the production of large urban areas of monotonous and uniform buildings. Five to ten floor buildings are set in rows and placed at equal distances on open areas for parking and recreation. The latter becoming part of the landscape determined by regulation and requirements (plate 6).

In general this type by its outward planning and new space segregation has led to a disintegration in the family structure and consequently social life. Within the blocks, the apartments are all identical, an anonymous prototype imported and applied everywhere. Thus the apprehended effect of mass housing badly experienced in Europe, is now evolving in Algeria.



Prefabricated medium rise building with very arbitrary layout, wide streets, isolated blocks.



The individual block

Plate 6 - Example of modern recent housing.

1.3.4.2 House design

Two new types of housing emerged, one is the medium 4 to 6 storeys while the other is the tower block of more than 8 storeys. Flats vary from 2 to 4 bedrooms, applying space standardisation which is controlled by the industrial system of prefabrication. The average household was assumed to be six and the rate of occupance fixed to two person per room. It is worth noting that all housing programmes allow the highest proportion, about 80%, for the three bedroomed units.

The plans allow the kitchen to be naturally ventilated, but the bathroom to be ventilated through ducts. The main characteristics of this type are large glazing areas with minimum shading and large exposed wall surfaces. Re-entrant and projecting forms are used for aesthetic effects increasing the external surface area and consequently the heat load of buildings (plate 6a).

With respect to aspects such as privacy and climate, both colonial and modern prefabricated flats are the subject of disatisfaction. They suggest to their occupants a certain life style and new practices. Faced with difficulties of communicating, the householder attempts to modify his environment to suit his own aspiration. This is expressed in physical alterations which are regarded as deteriorations. In fact this is the only struggle of the occupants against the imposed new style. Screened balconies or constantly closed bays, testify that privacy is still a requirement of well being in domestic life.

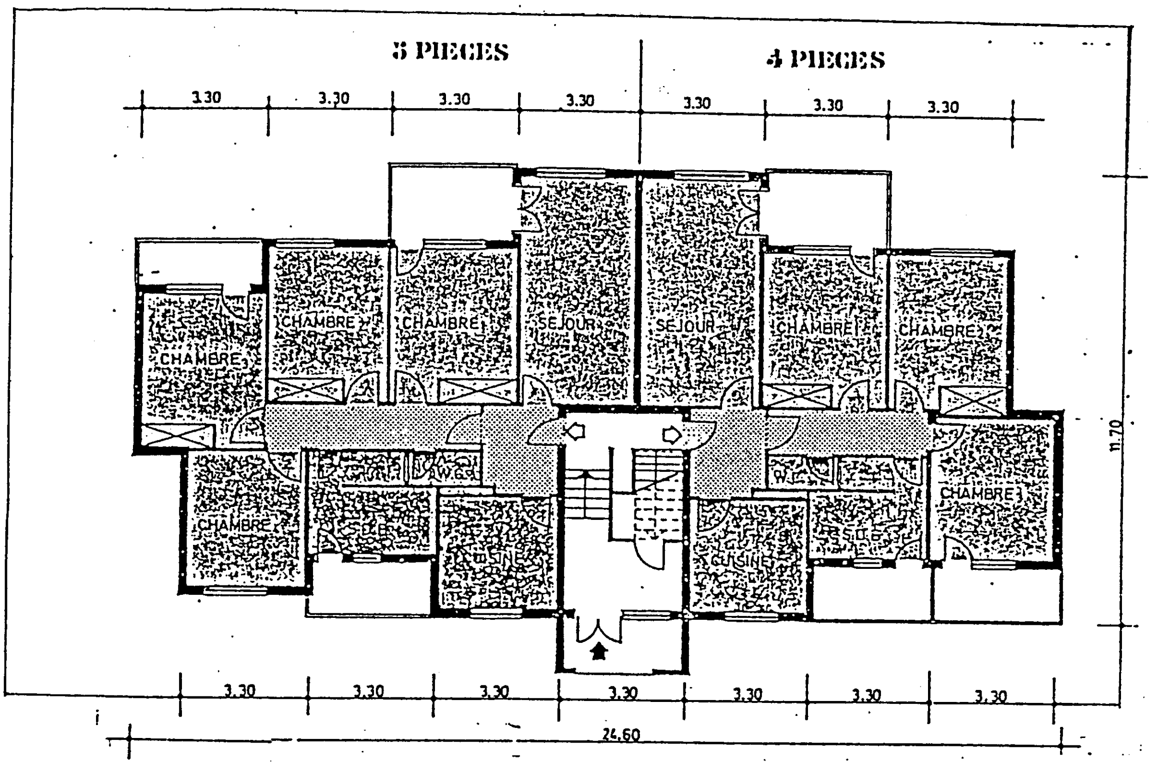


Plate 6a: Example of recent flat types.

1.3.5 Conclusion

From the foregoing study, it can be concluded that although the housing stock has been increased in the last decade, this increase has neither been sufficient nor efficient. Such modern architecture which can be found everywhere irrespective of different climatic and socio-economic factors, has not only failed in resolving the housing problem, but has created a more important one. This is the energy expenditure required to control the thermal environment. The crucial relationship between form and construction of these buildings is inadequately considered in relation to climatic parameters. Hence, the majority of modern housing may be considered thermally inadequate, imposing unknown future running costs to provide the necessary indoor comfort. They are often only made bearable using technical means at a life-cycle cost that can sometimes overstep that of the building.

Danby(13) states: << Ironically it is the production

> methods of prefabrication that have been found to produce unacceptable solutions both in environmental and human terms in many western countries that are now being sold to third world countries. >>

It is this flatted house model which is compared in thermal performance to the traditional courtyard house in chapter four. The aim is neither to idealise the traditional type, nor to condemn the modern type, but rather to demonstrate any inadequacy in the Algerian Context. The objective is not simply to prove that the courtyard type responds to the climate more favourably than the flat, but also to provide useful indications or guidelines in terms of appropriate modern planning and construction related to economic needs in the Algeria/Constantine Context.

As the two types compared are from different historical origins, it is necessary to state the main social and technological changes in order to draw up a range of recommendations.

The main social change is that of the family structure. While in the courtyard type, the extended family of three generations was the norm, in the modern type, the general world-wide change has led to the acceptance of the nuclear family as the housing unit. This will influence the house size. Technological changes have followed the world pattern of car ownership. In Algeria the regulations allow a one family/one car ratio for future housing development. This constitutes another limitation for the courtyard form, as the urban layout was not designed to allow this facility. The other change relates to the development of new building materials and technology, in addition to improved infrastructural services and contemporary amenities. It is the intention of this work to demonstrate that both new technology and standards with respect to access, safety and health can be beneficially and economically integrated with traditional courtyard housing morphology.

It is not the objective of this study to give detailled information about the social, cultural and economic factors in housing. The work is more related to the thermal performance coupled with climate sensitive design. Thus only relevant features were given in the previous chapter.

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Chapter 2

THE CLIMATE

Present throughout the history of building and architecture is the response the designer makes to climate. Buildings are considered as climatic modifiers. Daily and seasonal variability of climate experienced at any location will be a major determinent of the building's internal environment. We can notice that even in the so called primitive architecture, climatic design found subtle and sophisticated expressions. Climatic analysis is thus crucial in understanding the thermal performance of the building. Hence, human thermal needs and design characteristics to satisfy them must be related directly to the climatic type.

The interaction of solar radiation with the atmosphere, and distribution of land and sea masses together with the gravitational force and earth's rotation produce a wide range of climates.

2.1 Climatic elements

Weather is an ensemble of all meteorological variables. The elements appear in combination and it is difficult to determine their relative importance. Since the general approach of the study is based on human comfort sensation and building design, the principal climatic elements are: solar radiation, temperature, humidity, wind and precipitation. It is not intended to give detailed description of these elements. However to understand their interaction with building design, a brief summary is given as follows.

2.1.1 Air temperature

Air temperature provides the first important indication of the climate. The rate of heating and cooling of the surface of the earth is the main determinant of the temperature of the air above it. Daily and yearly variations of atmospheric temperature are dominated by the incoming solar radiation. The generally accepted dates, December 21st and June 21st, correspond to the solar solstices, and correlate to both conditions of cold and warmth, each delayed by approximately one month due to the capacitance of land/sea mass.

The daily variation of temperature depends on the state of the sky which controls both solar and terrestrial radiation during the night. During clear conditions, a large amount of incoming radiation during the day, and free path for outgoing radiation during the night produces a wide daily temperature range. During the day the terrestrial or longwave radiation from a surface is inconsequential compared to incoming shortwave radiation or insolation.

During the night terrestrial radiation to the sky takes place due to the absence of insolation, the rate dependent on cloud cover, and thus progressively reduces the temperature near the surface. On a seasonal basis the same holds true.

The important feature is that radiation exchange is proportional to the fourth power of absolute temperature, governed by Stefan Bolzman's Constant - $\sigma = 5.67 \times 10^{-8}$. Thus radiant exchange between ground/surface and sky may be written as

$$\Phi_r \text{ (grd/sky)} = 5.67 \times 10^{-8} \times \epsilon (T^4_{grd} - T^4_{sky}) \quad [W/m^2]$$

where ϵ = emissivity of ground/surface.

This outgoing radiation is strongest towards the zenith and practically ceases towards the horizon. It can constitute an important channel for heat disposal in housing especially in hot seasons. Altitude can also affect the temperature of the air.

2.1.2 Solar radiation

The main cause of climatic differentiation is the amount of insolation received, dependent on duration and intensity, both of which are controlled by solar geometry in conjunction with the weather system.

2.1.2.1 Solar geometry

The path of the earth around the sun is slightly elliptical (Fig 3). The apparent movement of the sun through the sky is the result of the earth's rotation on its own axis every 24 hours. The shift in the daily path is the result of the earth rotation about the sun every 365 days. For many design purposes the position of the sun at a given date and time has to be known to predict the faces of building which are sunlit, and calculate the shadows cast around the building.

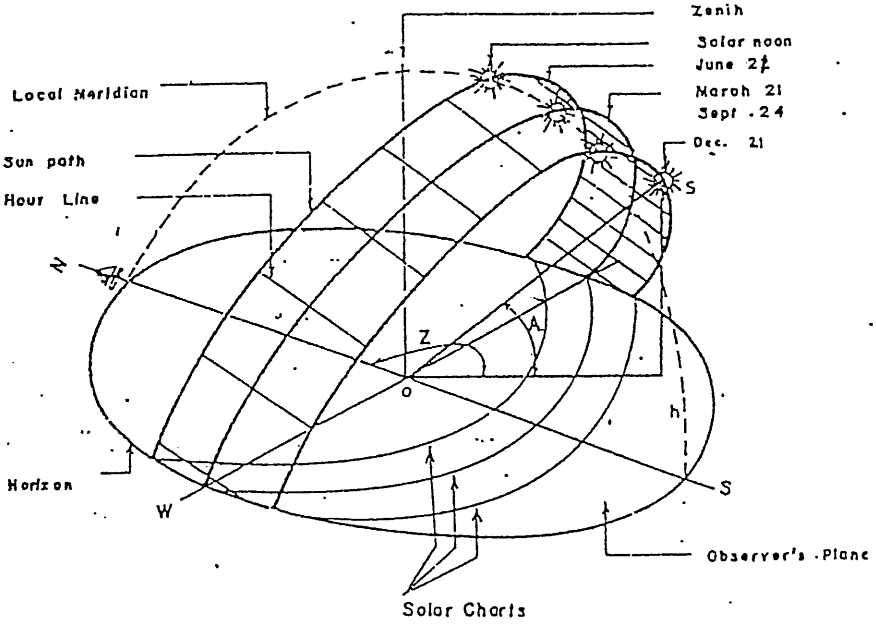


Fig 3: Geometry of the sun's apparent motion.

The axis of the earth is tilted with respect to the plane which passes through the sun and the equator at 23.5°. This tilt accounts for the changes of seasons and length of day. In fact if the axis were at right angles to this plane, there would be uniform conditions throghout the year. (Fig 4) shows the earth-sun relationship, the elliptic plane and the earth in two directions. One represents the equinoxes March 21st and September 21st and the other, the summer and winter solstices.

The tilt is constant as we orbit the sun, so that in summer months, the north hemisphere receives more hours of sunshine and incoming radiation is closer to the perpendicular to the earth surface. On 21st June areas along latitude 23.5° North are normal to the sun rays. During winter the situation is reversed, summer prevails in the southern hemisphere.

On March 21st and September 21st areas along the equator are normal to the sun's rays and experience a zenith path of the sun. For all other latitudes these are equinox days, where day and night are of equal length 12 hours. The angle between the earth - sun line and the equatorial plane is known as the angle of declination.

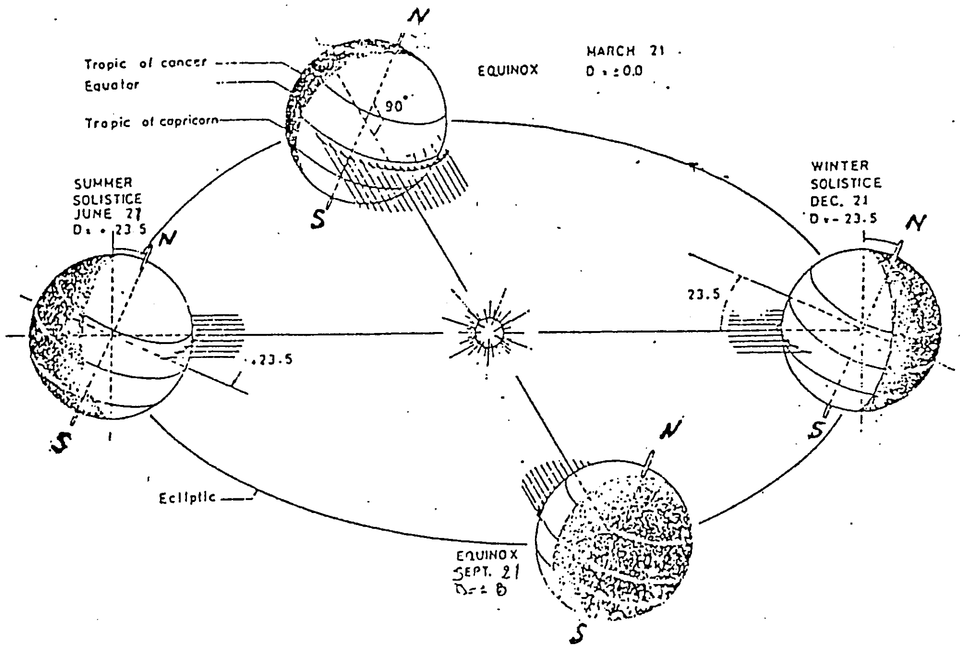


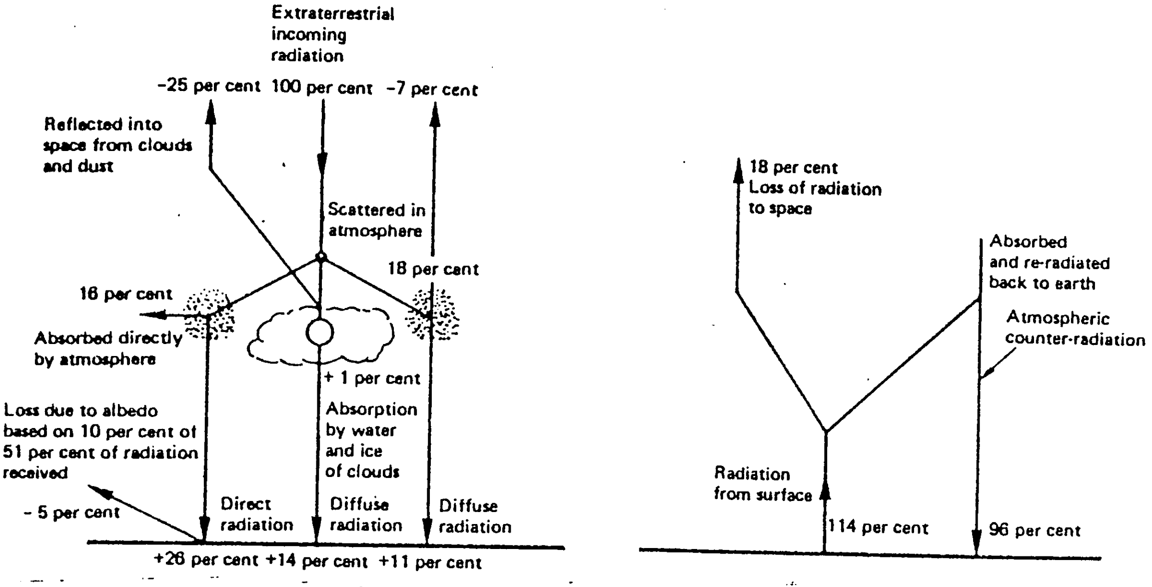
Fig 4: The earth sun relationship and the different seasons.

2.1.2.2 Intensity

The intensity of solar radiation measured at the upper surface of the atmosphere is taken as a "solar constant" usually given a value of 1.353 kW/m^2.(1) However it may actually vary ± 2% due to the variation in the output of the sun itself and ± 3% due to the change in the earth - sun distance. This energy constitutes almost all the earth's energy. Consequently it is the dominant factor in all climatic phenomena.

However, before it reaches the ground, solar radiation is reduced in intensity. Part of it is reflected back into space from cloud, atmospheric dust...etc, part of the remaining portion while passing through the earth's atmosphere is scattered and comes to the earth as diffuse radiation from all parts of the sky dome. Scattered radiation primarily in the blue portion of the visible spectrum is responsible for the blue colour of the clear sky. Another part is absorbed by the ozone, water, carbon dioxide. Ozone removes all high frequency, and the potentially dangerous ultra-violet radiation reaching the earth's surface. Peak flow irradiance does not normally exceed 1,000 W/m^2(2) at any point on the earth surface (figure 5).

The total heat absorbed by the earth is balanced by the corresponding heat loss. Without this cooling, the thermal balance of the earth could not be maintained as well as life. The earth releases heat by three processes - longwave radiation, convection and evaporation.



(a) shortwave radiation (b) longwave radiation

Fig 5: Heat exchange of the planet earth (refered to 100 units of incoming solar radiation)

Source: M.A. Markus, "Building, Climate and Energy".

The intensity of radiation received on the earth's surface will vary according to the atmospheric layer traversed by sun rays, increasing with the increase in altitude. It depends also on the angle of incidence, resulting in greater intensities when the rays are perpendicular to the surface, while a fall occurs after 30° and becomes increasingly rapid after 60° (figure 6). Thus solar geometry has a strong influence, the largest proportion of total radiation arriving at times when the ratio of clear sky diffuse to direct radiation is smallest. The annual global irradiation on a horizontal surface is

2,300 - 2,400 kWh/m² at the tropics of Cancer and Capricorn, whereas it is only 1,000 - 1,600 kWh/m² at the equator, reflecting a climatic cloud cover rather than geometric influence. Clearly for building design, it is important to know the relative proportions of direct, diffuse and ground reflected irradiation for a particular location.

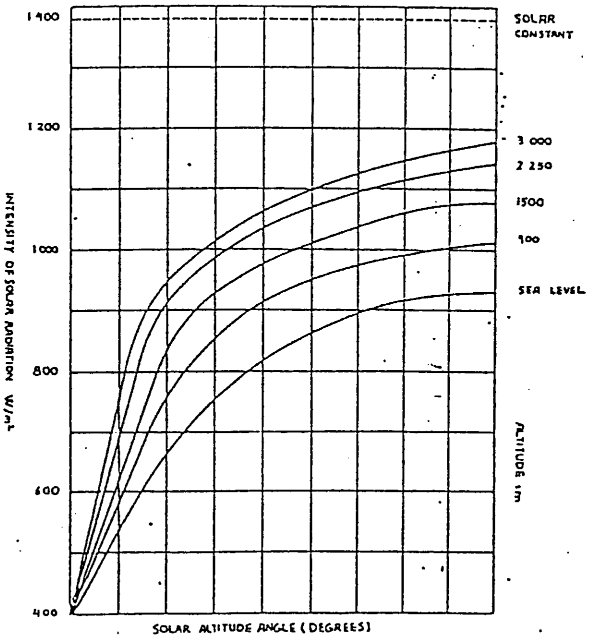


Fig 6: Variation of direct solar intensity with height and angle of incidence

Source: S.V. Szokolay, "Solar energy and building".

2.1.3 Wind

A number of global and local factors determine the distribution and characteristics of the wind over a given region. The main factors are daily and seasonal differences in atmospheric pressure between places, the earth's rotation and the thermal balance of the land and sea, besides the regional topography.

The differential radiation balance on the earth's surface varying with latitude is one of the major causes of the general circulation of air. Due to intensive day-time radiation in low latitudes compared to relatively uniform night radiative losses, warm air moves upwards leaving a belt of low pressure and flows off at high level towards colder regions. Figure 7 shows the global wind patterns. Tropical zones are characterised by north-east and south-east trade winds, while above and below the tropics, winds may be much more variable, but still with dominant trends. According to Markus(3) trade winds are the result of coriolis forces causing wind to blow in the opposite direction of the earth's rotation. Up to 60° latitude, westerlies predominate primarily under the influence of angular momentum.

The effects of free atmosphere are modified and slowed down at lower and ground levels. The effect of wind on housing has to be considered both on the outside and within the dwelling itself. Air movement has to be evaluated in terms of both ventilation energy losses and environmental comfort. For example, increased ventilation can diminish a cooling load, provided velocities are compatible with activity/clothing, or conversely, reduced ventilation can diminish a heating load, provided rates of air change are compatible with indoor pollution.

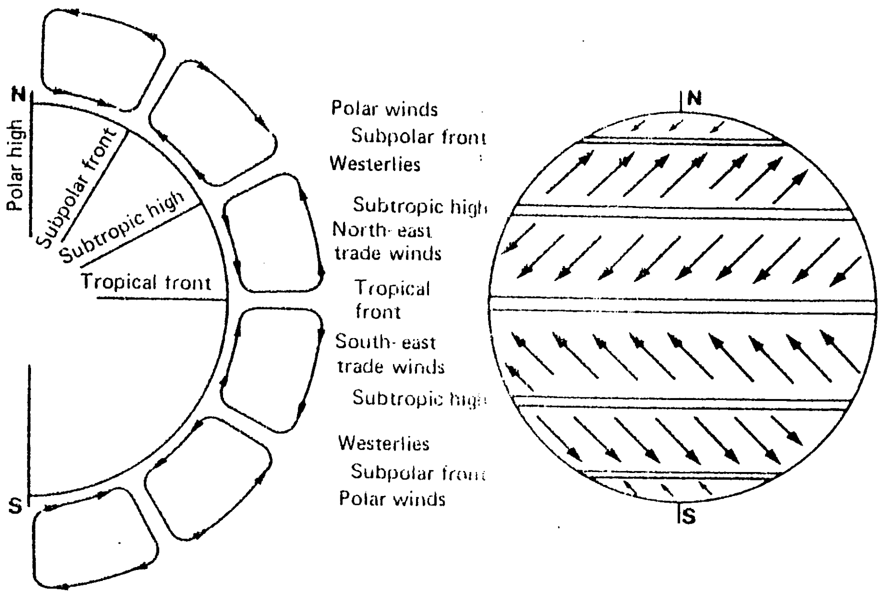


Fig 7: Global wind patterns

Source: Markus and Morris, "Building, Climate and Energy".

2.1.4 Humidity

Humidity is the term used to define the quantity of water vapour that the air contains. The latter comes through the process of evaporation from exposed water surfaces and moist ground and vegetation. The capacity of the air for water vapour increases progressively as its temperature rises up to saturation level. To express the moisture content we generally use relative humidity, i.e., the proportion of water vapour relative to temperature, given by the ratio of vapour pressure of the air to saturated vapour pressure expressed as a percentage. Absolute humidity expressed as a mixing ratio (usually grammes of moist air to kg of dry air) or vapour pressure, can be expressed as a function of temperature in a simple psychometric chart, (figure 8), the saturation curve representing 100% relative humidity or R.H.

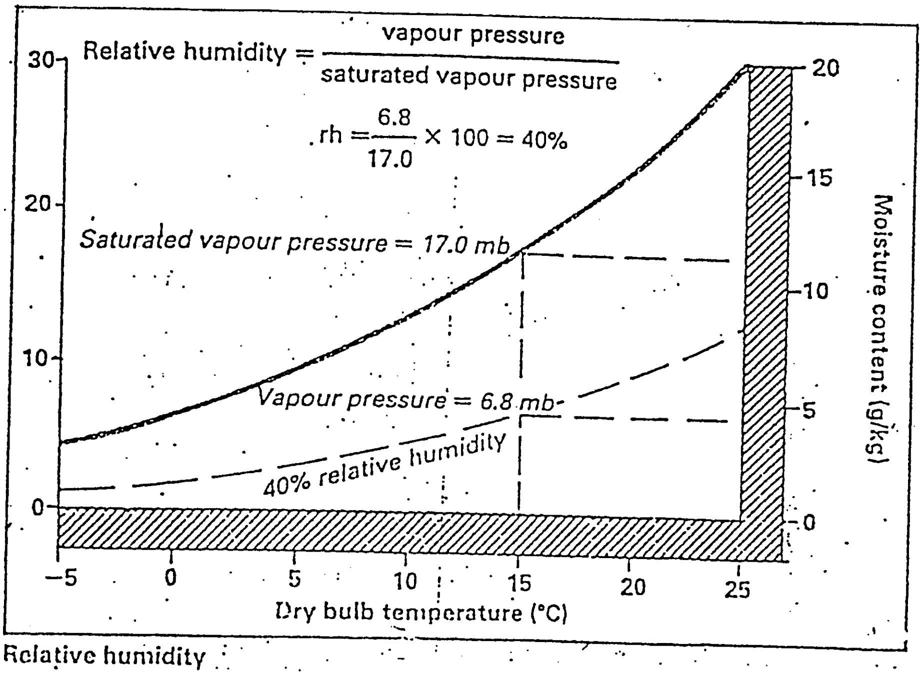


Fig 8: Relative Humidity Chart on the relationship between dry bulb temperature and moisture.

Source: "Energy in Building".

2.1.5 Precipitation

The total amount of precipitation received at the earth's surface is generally computed on an annual basis. It is agreed that the largest amount is to be found near latitude 5°N, corresponding to the relatively low solar irradiation (see 2.1.2.2).

When air with a certain amount of water vapour is cooled, its moisture holding capacity is reduced, and its relative humidity increases up to dew point, the air being saturated at that moment. Air may be cooled in three ways:-

coming into contact with cooler surfaces; by expansion associated with rising air currents; mixing with cooler air. The "adiabatic" cooling results in the formation of clouds, which are composed of innumerable tiny water droplets, which, with the air rising, become larger until they fall by gravity as precipitation.

For building design, the knowledge of the total value of rainfall for each month is important as well as the maximum value, since they enable us to ensure protection from condensation, adequate drainage, paved surfaces, etc. In some areas, the combined effect of wind and rain are of significance to building design.

2.2 Analysis of Constantine climate

2.2.1 Introduction

Algeria, the second largest country in Africa, is situated between 18° - 38°N latitude and 9°W - 12°E longitude (figure 9). It covers in area of 2,381,000 sq km. of which 90% is arid or semi-arid, but it possesses a splendid Mediteranean "littoral" of 1,200 km. The climate and physical conditions have influenced the density of population. Concentration tends to be in those areas in which the average annual rainfall exceeds 100 mm. It is in the north strip where the climate is most hospitable. The north covers 10% of the total area and has 90% of the population.

The country divides naturally into a series of zones aligned approximately east-west. Some 800 - 900 km deep strips succeed each other from the coast - mountain chains followed by depressions or hautes plains, the Saharahan Atlas and finally the Sahara.

The climate embraces extremes in cold and heat, drought, winds and seasonal inequality between the region. However, it is the lands of mountains, desert and interior plateaux that are subject to the greatest climatic handicaps, and it is important to identify the relative Mediteranean and continental land masses influences, prevailing in the successive narrow strips.

Nearly all French and Algerian writers identify five distinct zones, each with a particular climatic characteristics

- The littoral: with Mediteranean maritime climate due to the effect of the sea.
- Tellier Atlas: presents the intermediate position between the tellien climate of mountains - cold, rainy with small temperature range; and that of tellier plains - more dry, relatively hot with large temperature range.
- Hautes plains: with Mediteranean continental climate.
- Saharan Atlas: with Mediteranean mountainous climate, the greatest significance of this belt is the protection it gives to Algeria from the drying Saharan winds (sirocco).

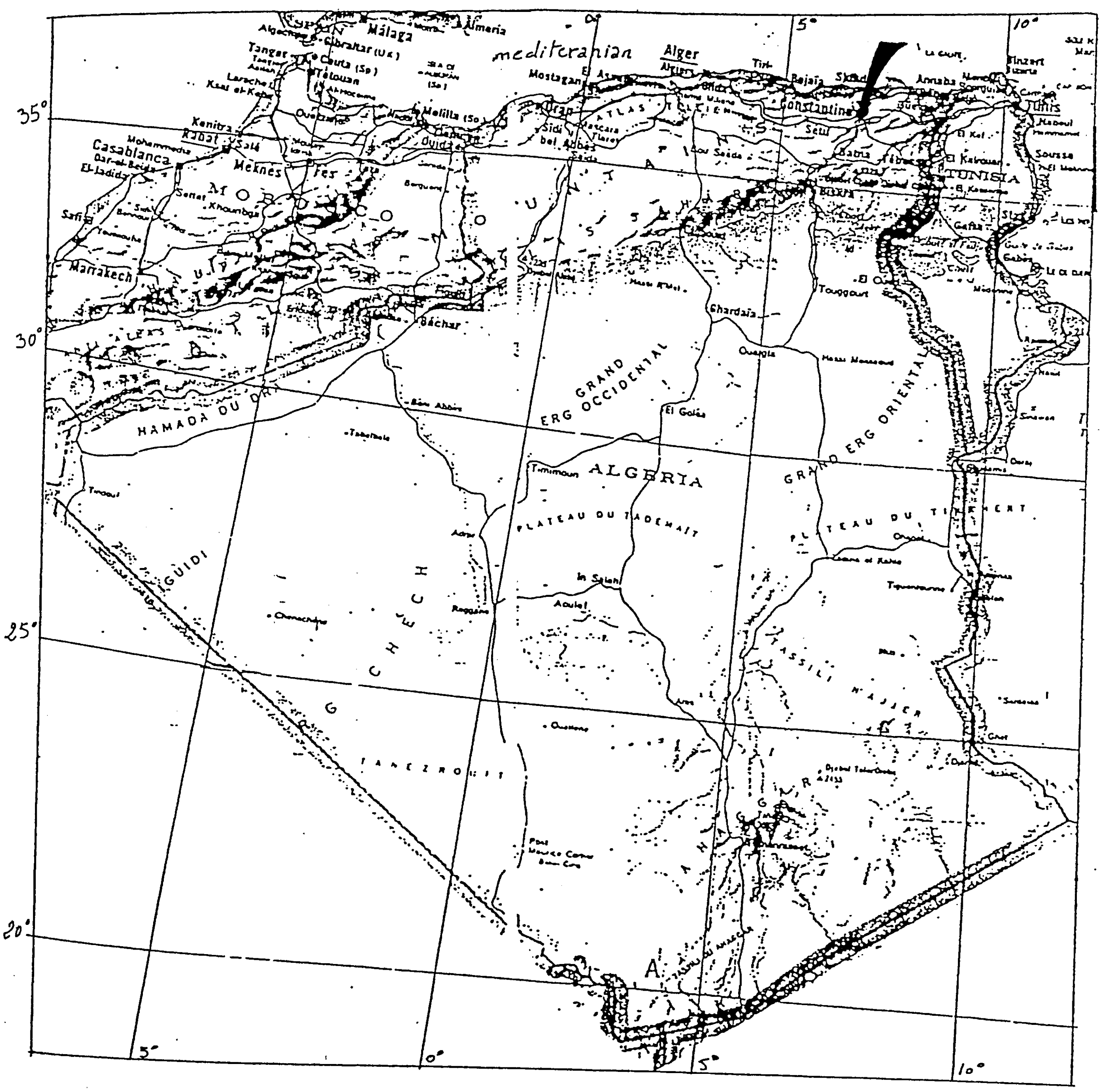


Fig 9: Map of Algeria with the location of Constantine (indicated by the arrow).

- The Sahara: with its arid climate and vast desert area, its characteristics are similar to those in other parts of the Sahara which covers an area astride the tropic of Cancer, extending from the Atlantic to the Red sea.

In general, in terms of precipitation, the decrease may be noticed in two directions: north-south and east-west. The decrease from east-west is explained by the fact that Algeria is located immediately in the rain shadow of the middle Atlas reference mountains, on which west and northwest winds deposit their bulk of moisture. However, the eastern region is higher, and to the south, (figure 5).

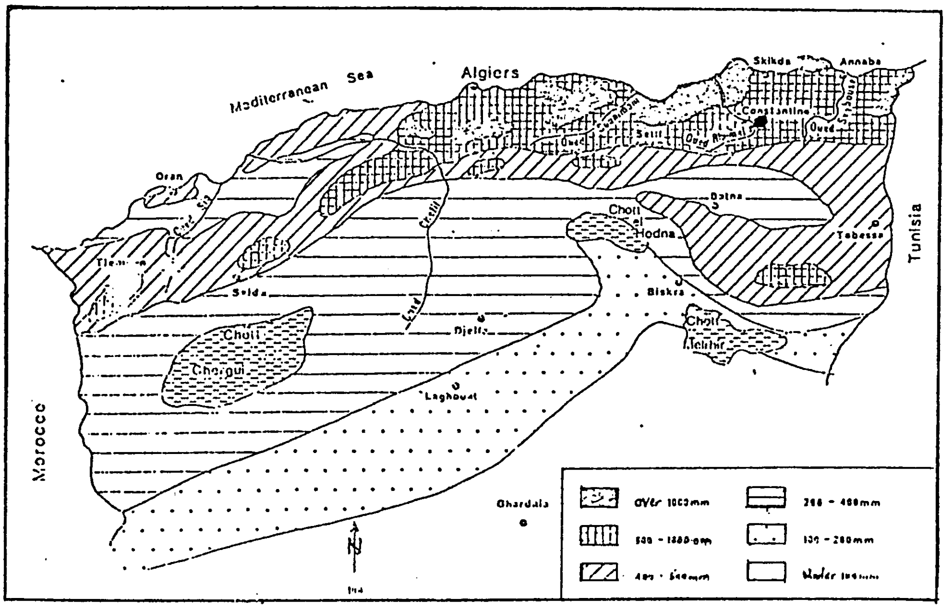


Fig 10: Rainfall distribution in Algeria

Source: Seltzer "le climat de l'Algerie" 1946.

In terms of temperature the contrast is more pronounced, due to the continental position of Algeria. Temperatures often vary greatly within short distances, the dry summer beginning usually in late May and lasting till September, (table 8).

Physical Units		Stations	Temperatures (degrees Centigrade)		Mean Annual Rainfall (Millimetres)
			Coldest month	Hottest month	
Littoral		Oran	12	26	428
		Algiers	13	26	647
		Annaba	11	25	787
Tell Atlas	Mountain	Medea	7	25	800
		Tizi-Ouzou	9	28	893
	Basin	Sidi Bel-Abbes	8	25	395
		Guelma	9	27	677
Hautes-Plaines	Northern limit	Tiaret	6	27	622
		Setif	5	25	469
		Constantine	7	26	594
	Southern limit	Saida	7	27	430
		Batna	5	25	346
Saharan Atlas		Djelfa	4	25	308
		Biskra	11	34	156
Sahara		Bechar	8	33	79
		Ghardaia	10	34	68
		El-Oued	11	34	73

Table 8: Climate Characteristics of Selected Areas in Different Zones

Source: Seltzer "le climat de l'Algerie" 1946.

2.2.2 Constantine climate

Constantine is located in the haute plaine region to the east, at 36.17°N latitude, 6.37°E longitude and 687 m altitude. One of the outstanding features of this region is the contrast between the seasons - rainy, cool to cold winter, and hot, dry summer with more moderate spring and autumn. The Mediteranean continental climate results from its intermediate position between the Mediteranean to the north and the Sahara to the south, besides the influence of the Atlantic ocean to the west. Also, its position in the haute plaines region gives it a character of internal Algerian cities influenced by changes from west to east. In winter, it experiences the depressions of temperate latitudes and receives most of its rainfall. Moreover, the area of low pressure generated by relatively warm sea water create a cyclonic pattern of air movement which picks up the north trade winds over the Atlantic and results in cold weather. In summer, it is under the influence of dry winds of the subtropical belt of high pressure enhancing the Saharan influence and bringing about dry, hot conditions.

The analysis of the climate of this region is made on the basis of meteorological data collected from Ain El Bey station at the nearest airport for a period of 15 years, 1970 - 1985, and the study done for 25 years 1960 - 85.

2.2.2.1 Temperature

The annual temperature variation depends on the proximity to the sea and the Sahara, altitude and exposure. The study of (figure 11) and (table 9) averaged over 15 years show that the winter is relatively cold with a mean temperature in January - the coldest month - of 6.9°C, a mean maximum of 11.47°C and a mean minimum of 2.34°C. The temperature increases gradually to reach a mean of 27°C in July with a mean maximum of 35.3°C and mean minimum of 18.76°C. Thus January and July constitute the extremes. It is approximately one month behind the solar solstice with a fairly symetrical curve about mid July. The main

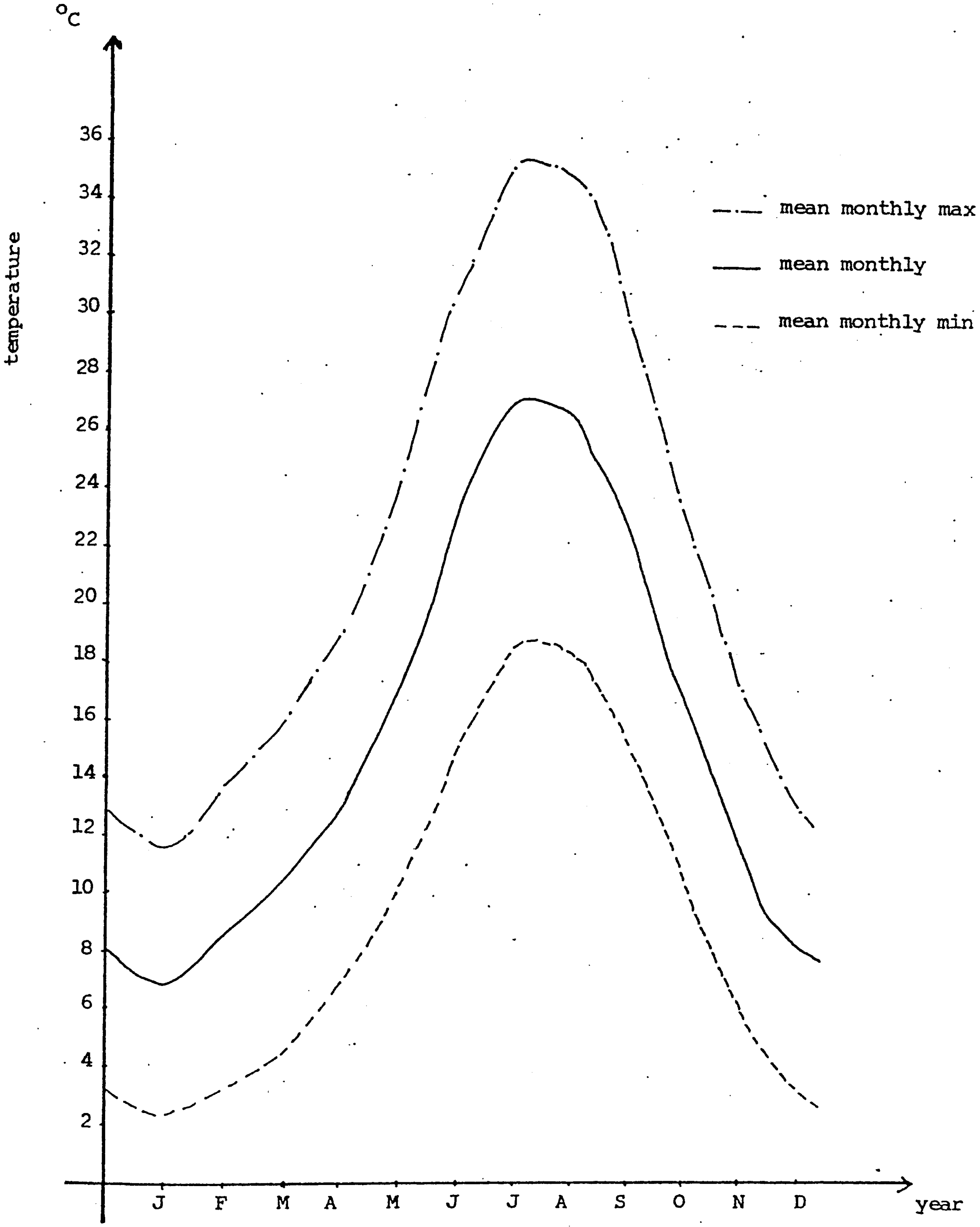


Fig 11: Mean monthly temperature in Constantine.

Source: Meteorological Station at Ain El Bey, averaged over 15 years.

Mean monthly data	J	F	M	A	M	J	J	A	S	O	N	D
Temperature (°C)	6,9	8,68	10,0	12,92	17,29	22,9	27,03	26,67	22,6	16,93	11,53	8,1
Relative humidity (%)	76,8	75,1	73,12	72,68	68,37	60,68	48,87	51,25	61,5	69,5	72,43	76,0
Wind speed (m/s)	2,77	3,0	2,75	2,48	2,31	2,24	2,29	2,08	1,82	2,26	2,26	2,41
Insolation (hours)	142,75	150,33	188,66	202,83	272,08	316,66	353,25	318,25	237,0	202,0	178,83	149,7
Daily insolation (hours)	4,6	5,18	6,08	6,76	8,77	10,58	11,39	10,26	7,9	6,5	5,96	4,8
Rainfall (mm)	62,8	53,8	56,2	59,6	42,3	19,3	8,0	11,2	37,5	38,6	44,6	73,2
Evaporation (mm)	59,0	68,0	80,0	94,0	121,0	165,0	244,0	219,0	145,0	103,0	70,0	56,0

Table 9: Mean monthly climatic data of Constantine average over 15 years. (1970 - 85)

Source: Meteorological station at Ain El Bey.

characteristic in summer is the large daily temperature range reaching 17°C in July. In winter as in other internal cities, temperature may fall to 0°C. The mean annual recorded temperature is 16.95°C, although this region is protected from the Mediteranean by the series of mountains that have in turn their effect on the continentality of the climate. The temperature is also governed by cold trade winds from Europe and frequent strong hot winds from the Sahara (sirocco). Therefore both winter and summer conditions have their influence on building design with the longer hot season generally dominant.

2.2.2.2 Solar radiation

If we examine the world energy map (figure 12), we will find that Algeria on the whole benefits from one of the highest amounts, about 2,250 kWh/m^2 a year.

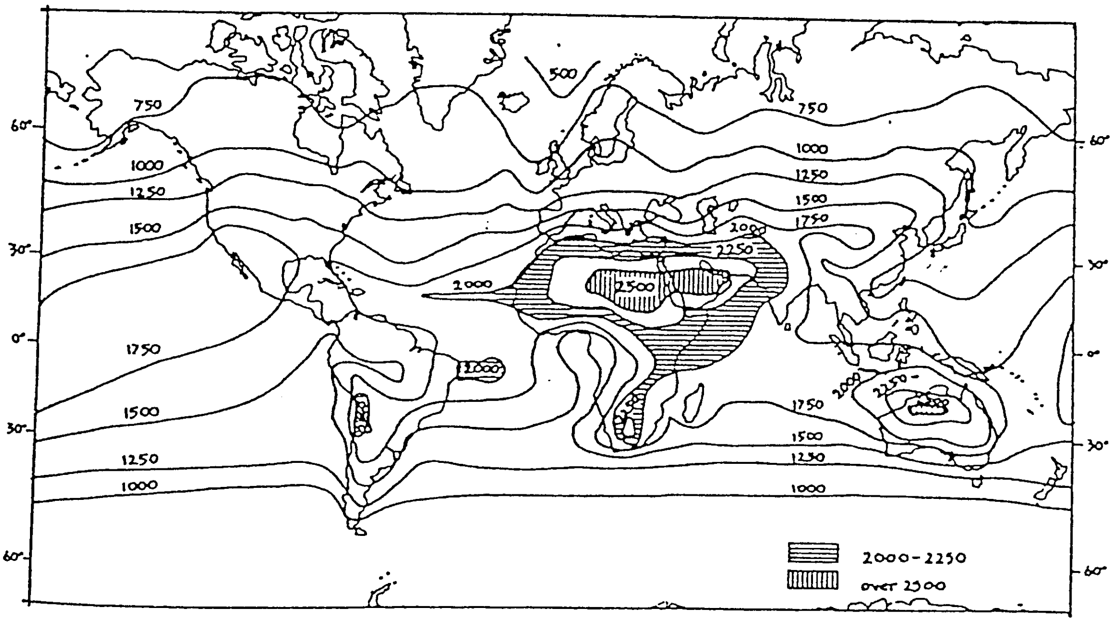


Fig 12: World solar energy map.

Source: Szockolay "building and energy".

During, the last few years several attempts have been made to develop climatological maps of global radiation, particularly with the new option of solar energy use in buildings. Recently the "Solar Atlas of Algeria"(4) was prepared giving sinusoidally generated predicted values of irradiation on different orientations and tilts for the whole country.

Relatively high global irradiation prevails throughout the year. A daily annual average of 6.78 hours of bright sunshine illustrated in (figure 13) and (table 3) reflects the solar geometry winter/summer daylight differential of 5 hours, with a maximum of 11.39 hours in July and 4.6 hours in January.

Since a record of sunshine hours does not in itself provide a measure of solar radiation, a monthly mean global irradiation on horizontal and vertical surfaces are represented on (figure 14), and appendix A. It shows that the highest intensity falls on a horizontal surface, but even the north vertical receives a considerable amount in summer due to a strong diffuse component. The south vertical receives far less irradiation in summer compared to winter due to the high solar altitude angle, (figures 15a, 15b, 15c, 15d).

High mean daily totals of global irradiation prevail throughout the summer season reaching a value up to 7.48 kWh/m^2 as against 2.33 kWh/m^2 in January on a horizontal surface. In winter, the amount of cloud cover and solar declination decreases the mean daily totals of global

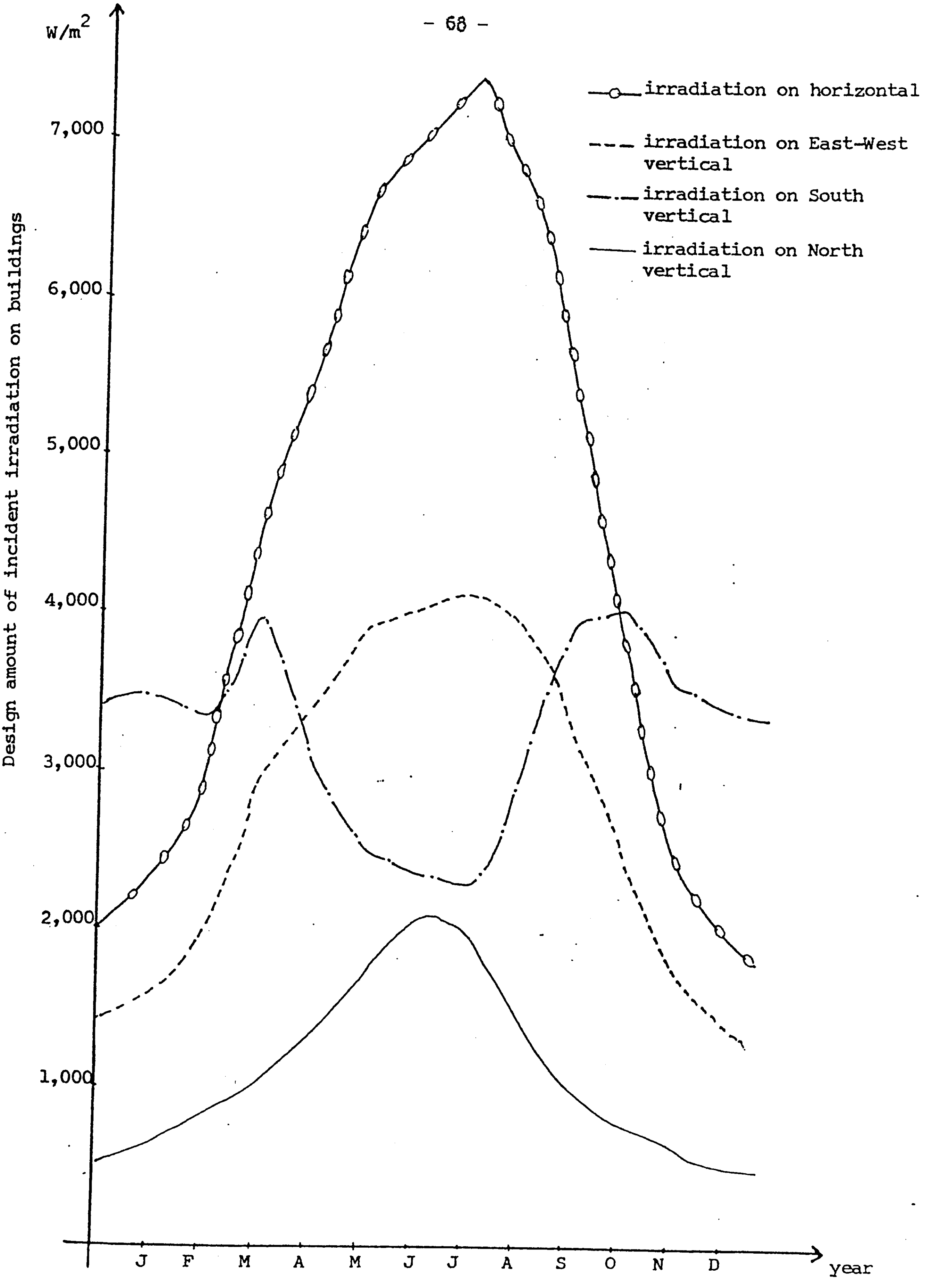


Fig 14: Mean day monthly distribution of solar irradiation on different surfaces.

Source: "Atlas Solaire de l'Algerie" Capderou Algiers 1985.

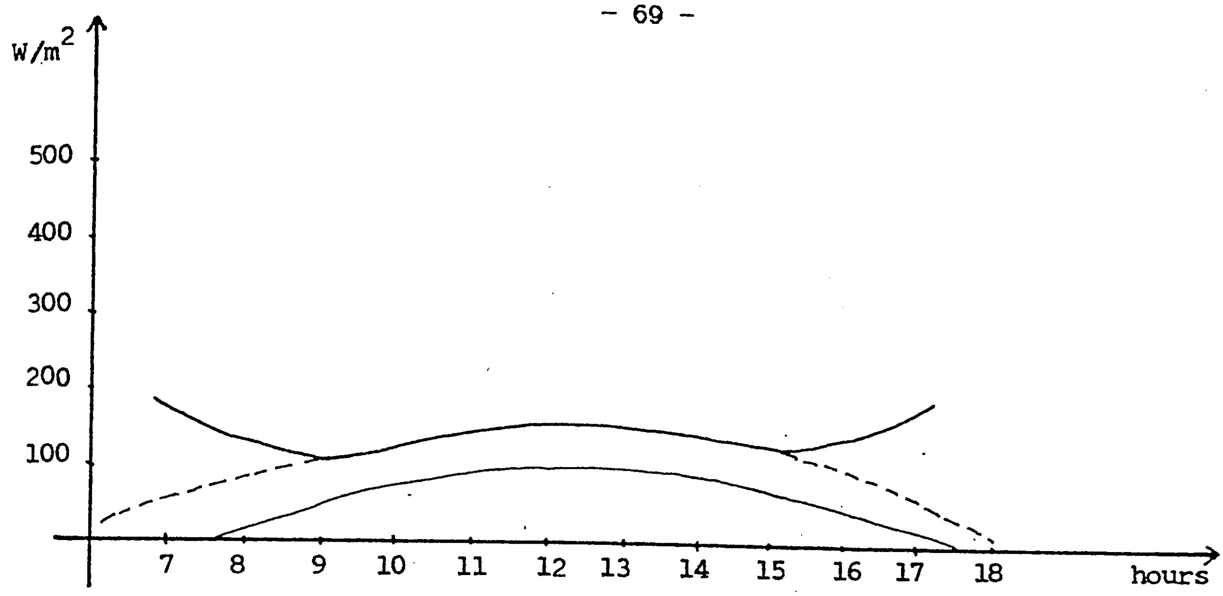


Fig 15b: Mean day hourly global irradiation on North vertical.

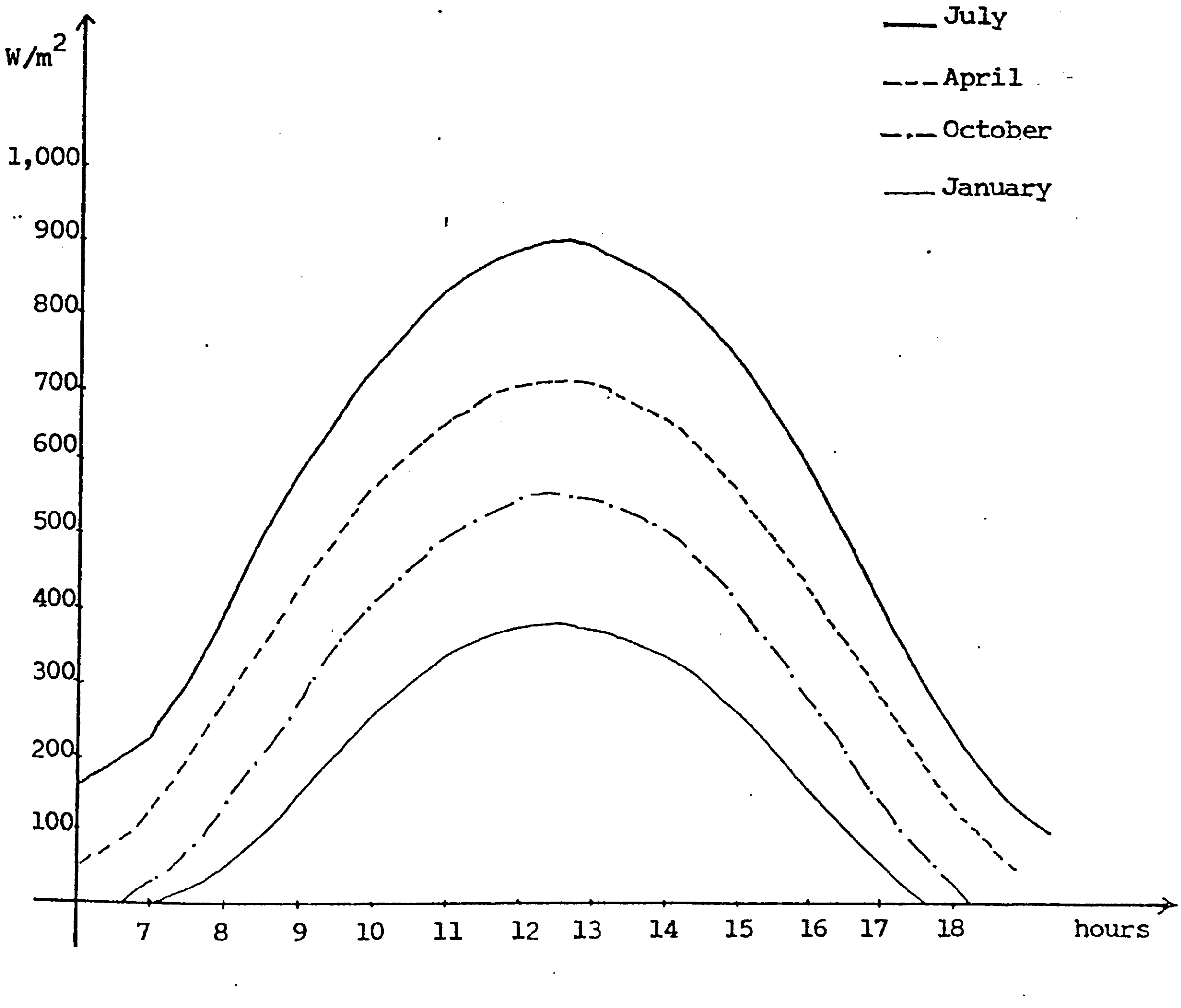


Fig 15a: Mean day hourly global irradiation on horizontal. plane

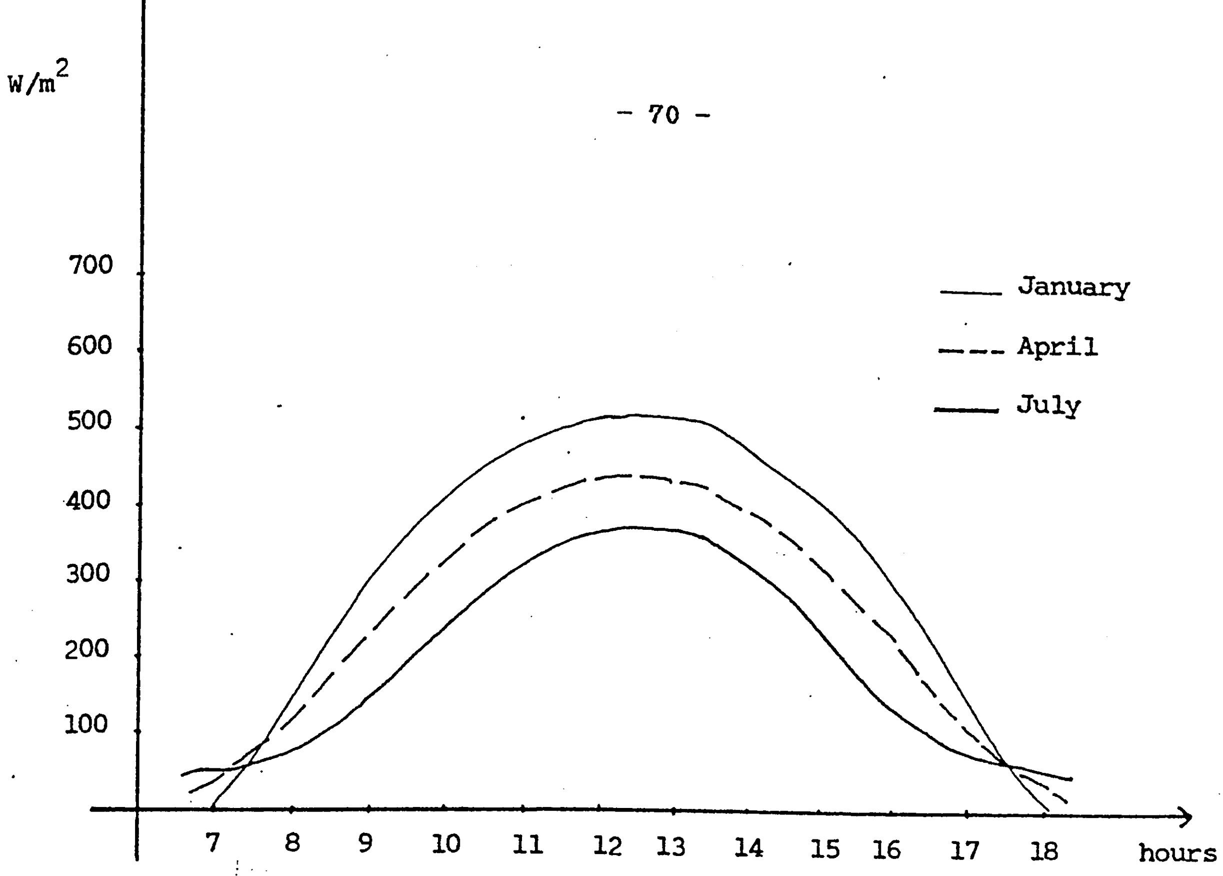


Fig 15c: Mean day hourly global irradiation on South vertical.

Fig 15d: Mean day hourly global irradiation on East and West vertical

irradiation and hence the mean daily temperature values. In fact, the ratio of diffuse to direct is 0.82 in January and only 0.32 in July.

Figures of the seasonal distribtion of solar energy components show that on a horizontal plane, the diffuse irradiation is insignificant compared to the direct (figure 16a), especially between March and October. However, the case is reversed for the north vertical (figure 16b). For the south vertical, the mean annual direct and diffuse are nearly equal (figure 16c). Finally, for the east and west verticals, diffuse irradiation is slightly lower in summer (figure 16d).

Thus the roof constitutes a critical element of the house in summer and north/south orientations would be more efficient related to both summer cooling and winter heating for this climate.

2.2.2.3 Humidity

Records of the mean monthly relative humidity taken for a period of 15 years and averaged in (figure 13) and (table 9) show that Constantine in general is characterised by relatively low summer values. The annual means of the daily range throughout the year commonly fall within acceptable comfort bands, the minimum and maximum mean being 48.9% and 76.8% respectively.

The rise in humidity in winter and decrease in summer are governed respectively by the moist northern and western

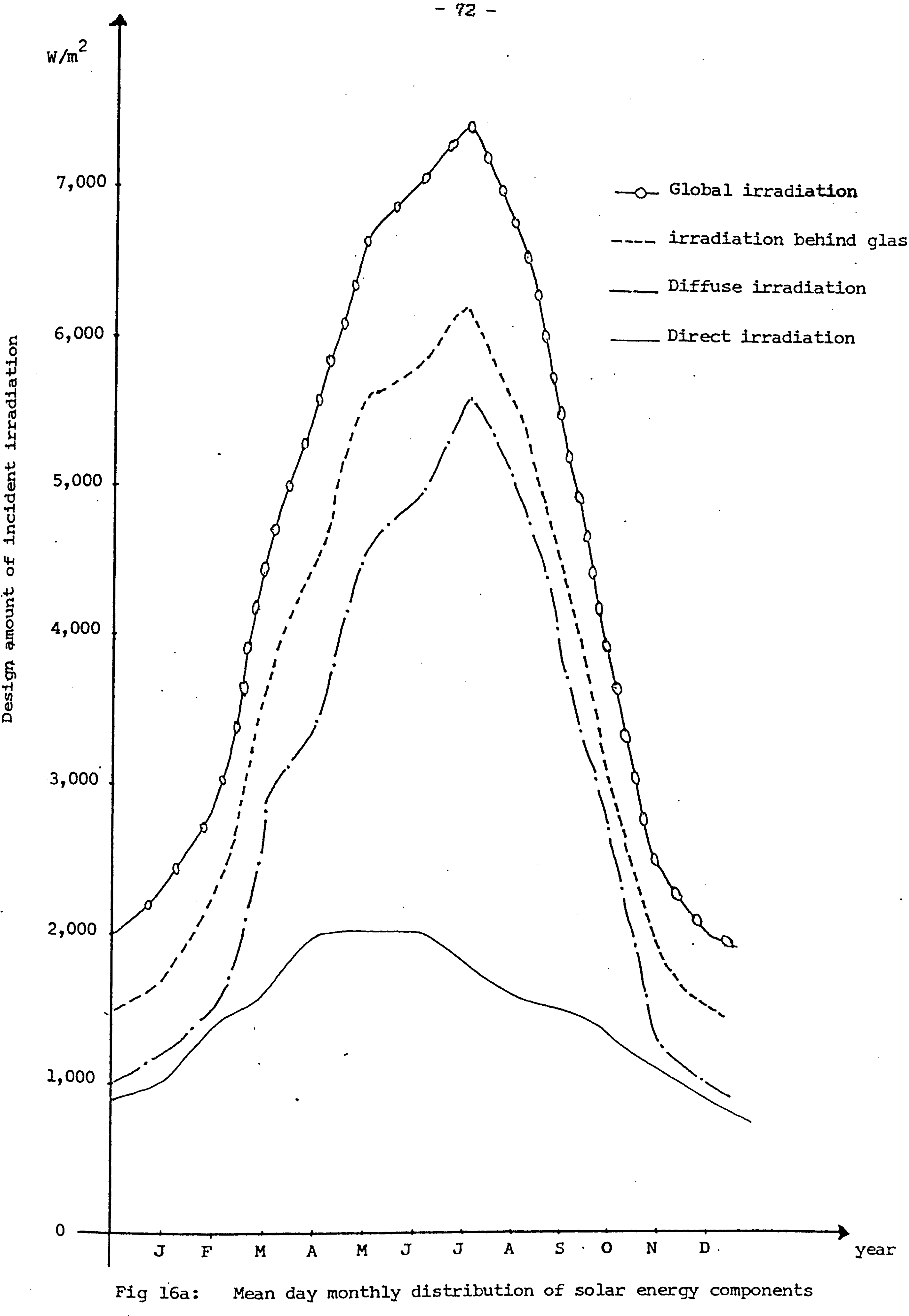


Fig 16a: Mean day monthly distribution of solar energy components on horizontal plane.

Source: "Atlas Solaire de l'Algerie" Capderou Algiers 1985.

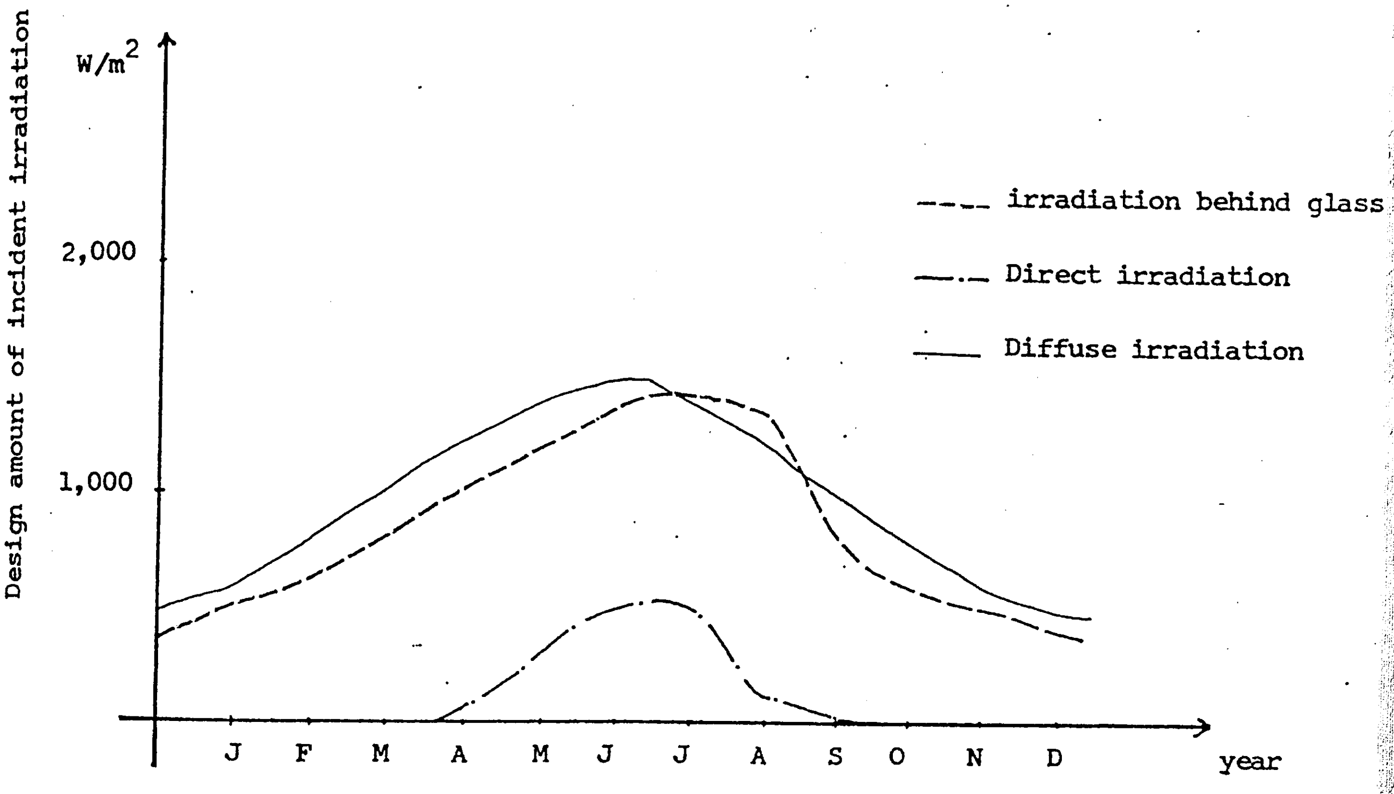


Fig 16b: Mean day monthly distribution of solar energy components on North vertical.

Source: "Atlas Solaire de l'Algerie", Capderou, 1985.

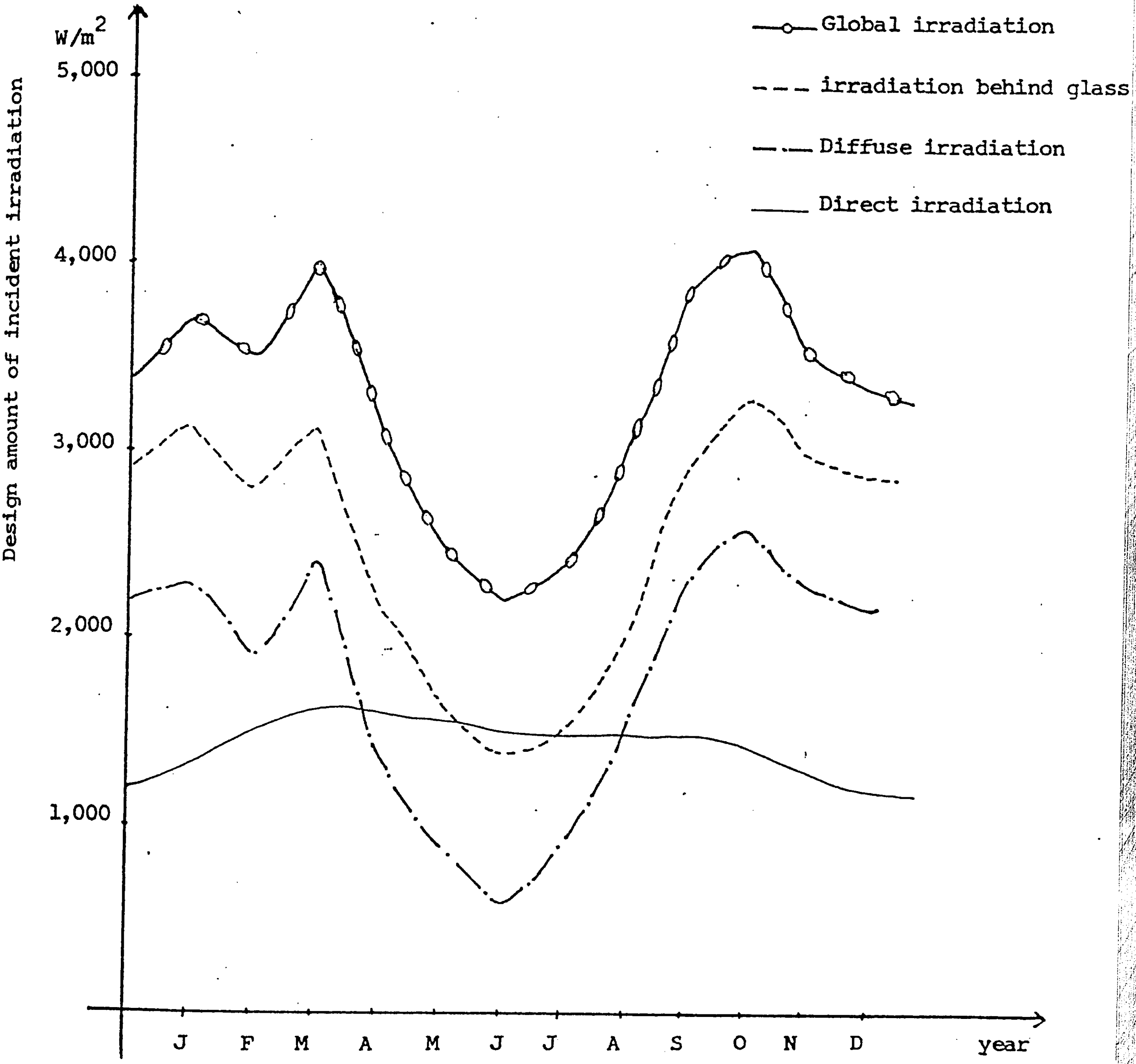


Fig 16c: Mean day monthly distribution of solar energy components on South vertical.

Source: "Atlas Solaire de l'Algerie", Capderou, 1985.

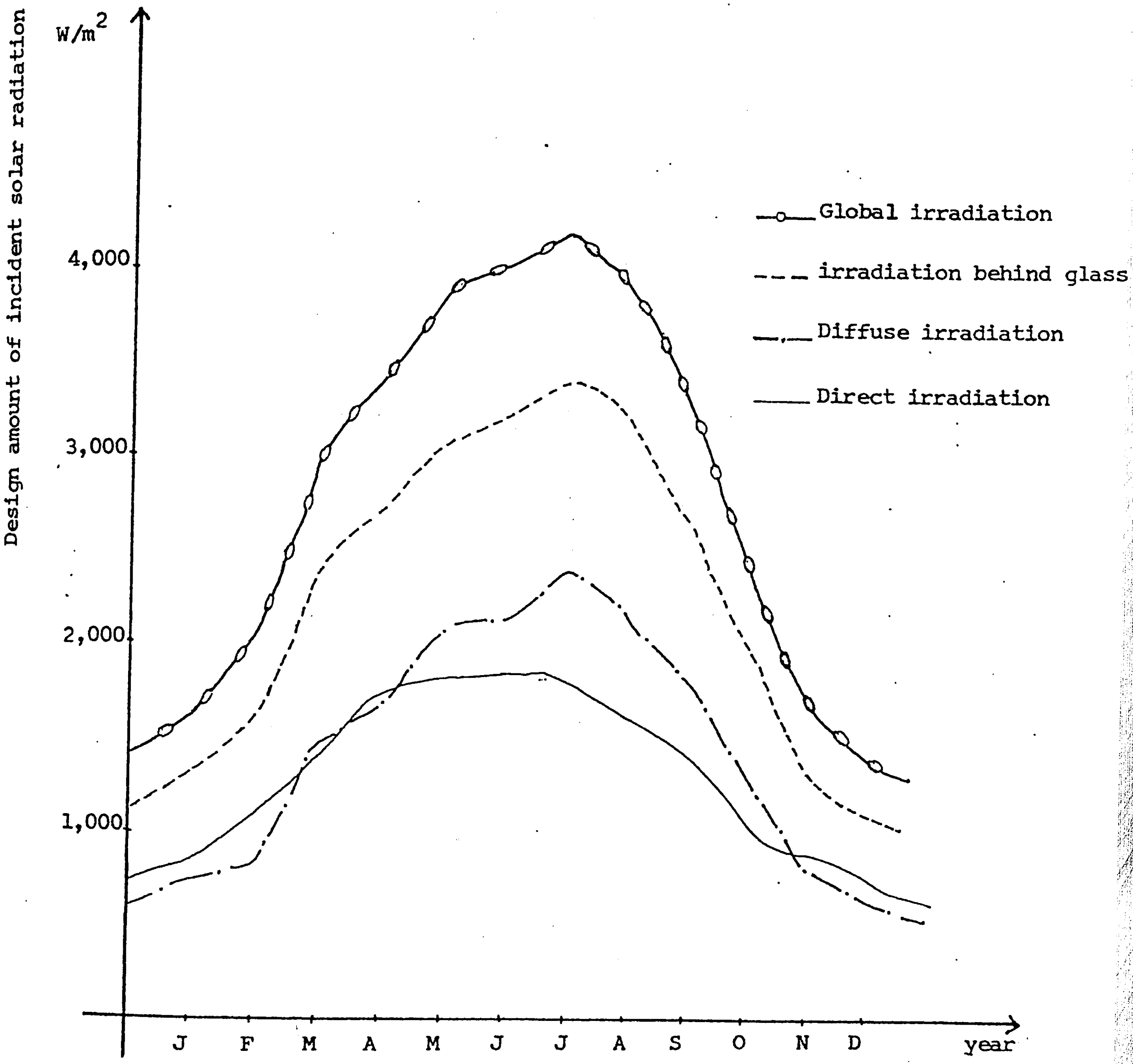


Fig 16d: Mean day monthly distribution of solar energy components on East and West verticals.
Source: 'Atlas Solaire de l'Algerie', 1985.

winds, and southern sirocco winds resulting in dryness and temperature increase. As far as buildings are concerned, a side effect is the alteration of moisture content and hence the conductivity of porous materials, but without prolonged saturation, variations are unlikely to be of significant magnitude.

2.2.2.4 Precipitation

The feature of rainfall in Constantine follows the general climate of the Mediteranean. According to the meteorological station, the mean monthly records illustrated in (figure 13) and (table 9) show that rainfall occurs throughout the year, reaching a maximum in December 73.2 mm and a minimum of 8.77 mm in July. The annual mean amount ranges from a modest 504 - 614 mm, with the Atlas mountains acting as a barrier to maritime influences. It is also noticed that the monthly mean average amount correlates with the number of days with rainfall, indicating a steady rather than erratic regime.

2.2.2.5 Pressure and wind

Different pressure systems affect the region of Constantine at different times of the year giving the area its seasonal variation.

The prevailing winds which depend upon the distribution of pressure also change with the season. According to the meteorological data, the principal direction is west to south-west in winter, reaching respectively 14% and 12% of the total winds in December. Most of these winds having crossed the Atlantic are laden with moisture. In summer, by contrast, the winds blow not towards the sea, but to the lower pressure system over the Sahara. Thus north-north-west and west winds prevail with respectively 10% and 11% in July (see monthly wind roses on figure 17). So the conditions in summer are those of the Sahara with lower pressure and dry descending winds.

Apart from western winds, the outstanding ones are the sirocco which are hot, dusty, dry winds from the Sahara. These winds are more persistant during autumn due to widespread low pressure with peak gradient over the west Mediteranean.

(Table 9) shows that the mean monthly wind speed ranges from 3 m/s to 1.82 m/s with the maximum in February and an annual mean of about 2.2 m/s.

Wind speed and direction affect the thermal regime of buildings in two ways. It determines the external surface resistance, and hence insulation of the shell. It also affects the infiltration rate through openings, and thus the total heat balance. In this case due to relatively low velocities, the surface resistances, will be correspondingly high and natural infiltration fairly low.

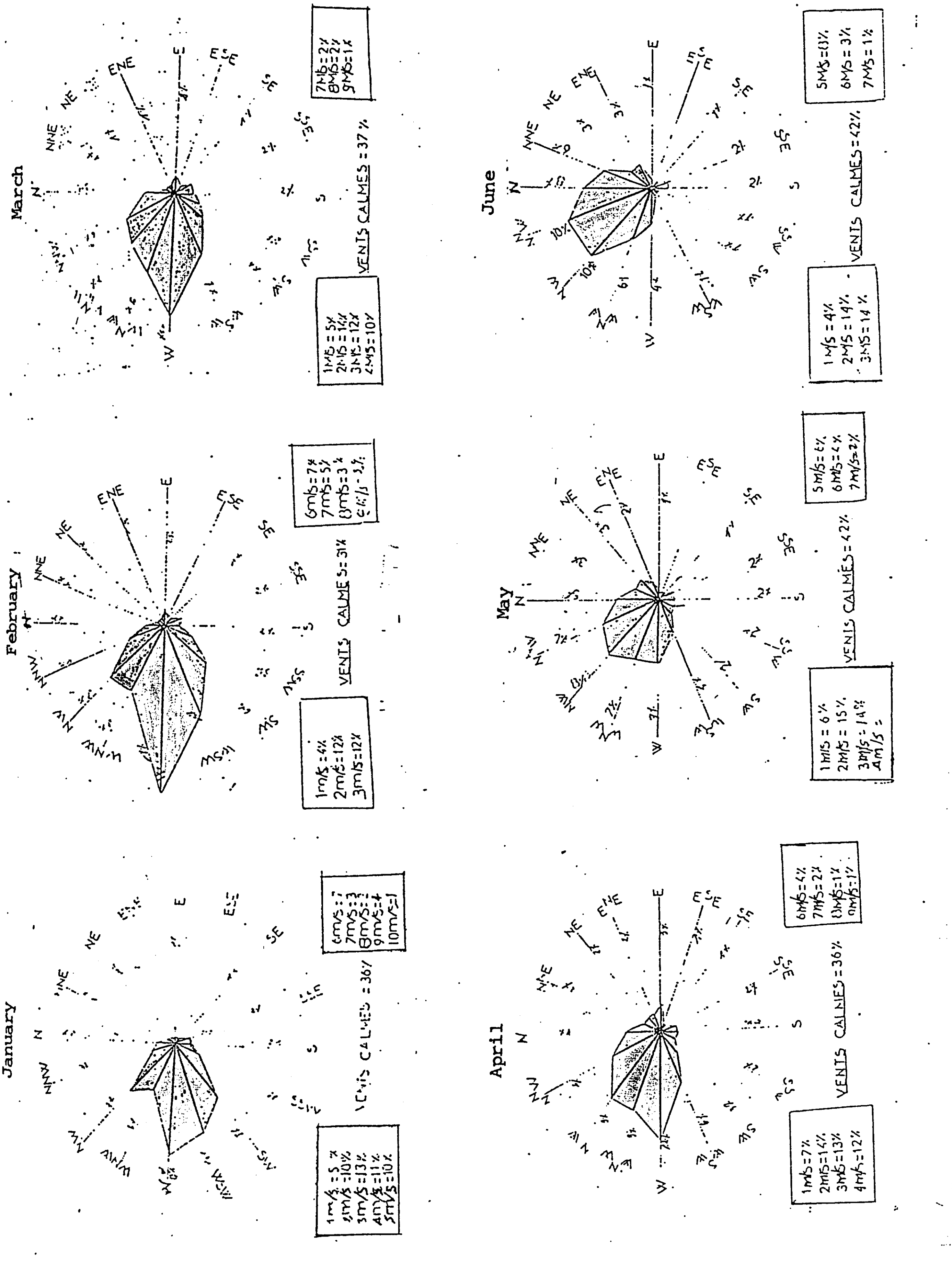
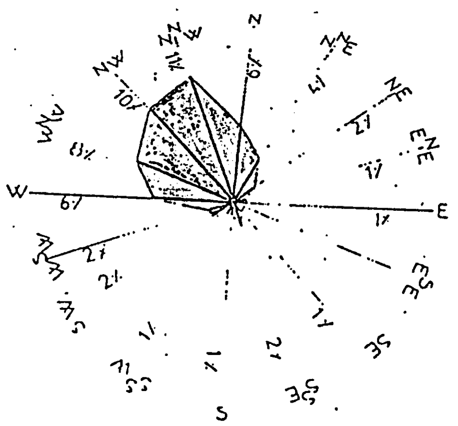


Fig 17: Monthly wind roses - Direction and speed.

July

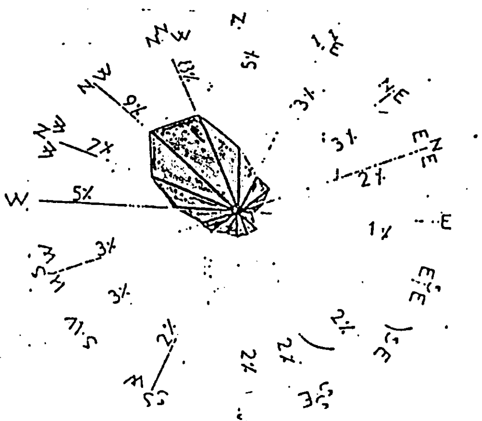


1 M/S = 4%
2 M/S = 13%
3 M/S 12%
4 M/S 12%

VENTS CALMES = 41%

5 M/S = 10%
6 M/S = 5%
7 M/S = [illegible]
8 M/S = [illegible]

August

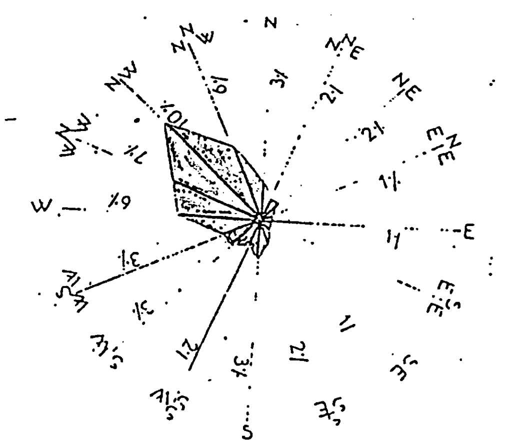


1 M/S = 7%
2 M/S = 13%
3 M/S = 13%
4 M/S = 12%

VENTS CALMES = 42%

5 M/S = 8%
6 M/S = 4%
7 M/S = 1%

September

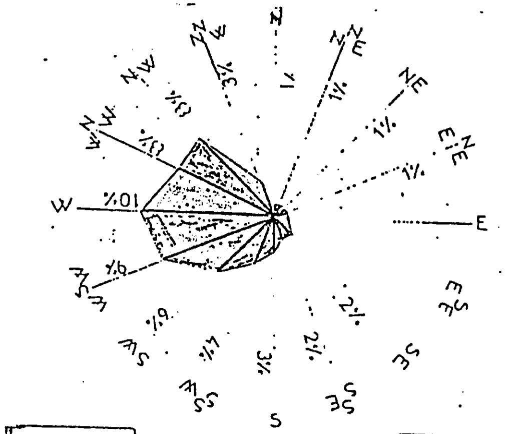


1 M/S = 7%
2 M/S = 15%
3 M/S = 12%
4 M/S = 9%

VENTS CALMES = 47%

5 M/S = 6%
6 M/S = 2%
7 M/S = 1%

October

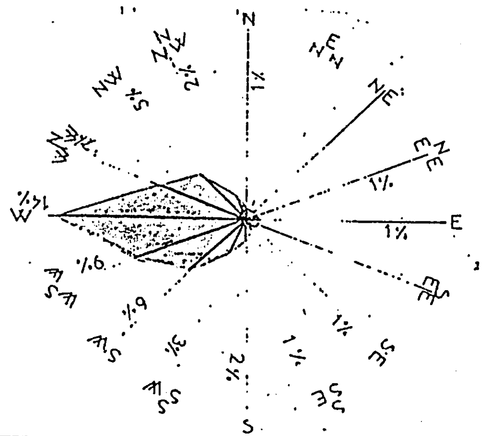


1 M/S = 4%
2 M/S = 14%
3 M/S = 12%
4 M/S = 11%

VENTS CALMES = 41%

5 M/S = 8%
6 M/S = 5%
7 M/S = 2%
8 M/S = 1%

November

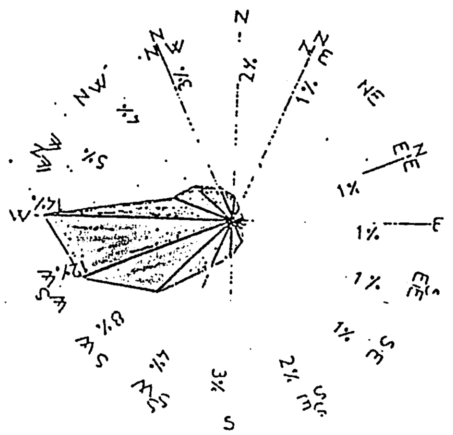


1 M/S = 6%
2 M/S = 12%
[illegible] = 12%

VENTS CALMES = 47%

5 M/S = 7%
6 M/S = 4%
7 M/S - 2%

December



1 M/S = 6%
2 M/S = 11%
3 M/S = 12%

VENTS CALMES = 30%

6 M/S = 5%
7 M/S = 3%
8 M/S = 1%

2.2.2.6 Solar radiation related to other relevant climatic features

From the foregoing analysis, it can be seen that temperatures are closely related to insolation, day length and terrestrial capacitance. Reference to values shown graphically in (figure 13) confirms that solar radiation correlates with sunshine hours with a peak occuring in July and that autumn air temperatures are considerably higher than corresponding months in spring. This favours solar contribution in winter and perhaps spring, but constitutes a disadvantage in summer and autumn.

Comparision of irradiation and rainfall confirms a closely opposing relationship, rainfall peaks coinciding with radiation troughs. The same applies for relative humidity. There is no such relationship concerning wind speed. but the latter generally follows the same trend with higher values in winter.

In general for buildings, the main problem encountered is the longer period of summer heat. Having identified the relationship between climatic factors, if these can in turn be related to specific building characteristics, useful early design decisions should emerge.

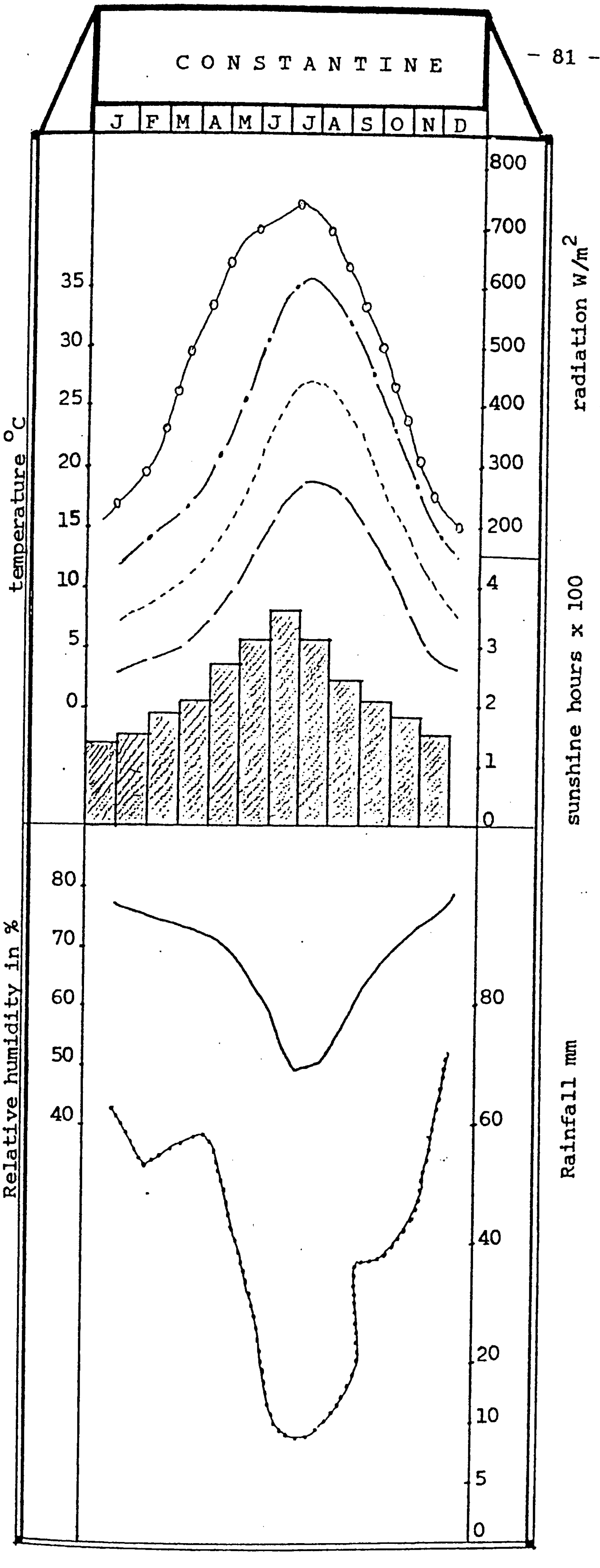


Fig 13: Relationship between relevant climatic features of Constantine

Source: Meteorological station at Ain-El-Bey.

- "Atlas Solaire de l'Algerie", Capderou, 1985.

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CHAPTER 3

BIOCLIMATIC ANALYSIS

In order to design an energy efficient building, and satisfy the human feeling for comfort, it is essential to understand the heat exchange between the human body and its environment. The maintenance of thermal equilibrium between the body and its surroundings is the primary requirement for comfort and health.

3.1 Thermal comfort

Thermal comfort was defined by ASHRAE(1) as that condition of mind which expresses satisfaction with the thermal environment. However, thermal comfort is a subjective assessment of environmental conditions and its measure is not accurate. Despite this subjective nature and variability in individual response, the definition of desirable thermal comfort conditions is an essential input in the design process. On the other hand, thermal comfort should not be confused with thermal balance. The latter, while essential for comfort, can also be achieved under conditions of discomfort through activation of thermoregulatory mechanisms.

3.1.1 Human body heat transfer

A human body can be visualized as a machine using food as fuel. This metabolic process within the body produces heat. According to C.R.A.U.(2), the body uses only 20% of this energy for muscles' activity, blood circulation and breathing, the rest being tranformed into heat. This internal heat production should be balanced by heat loss in order to maintain a stable temperature. The body produces heat at various rates depending on physical and mental activities (Fig 18), but whatever the rate of heat production, the body attempts to maintain a constant core temperature around 37°C.

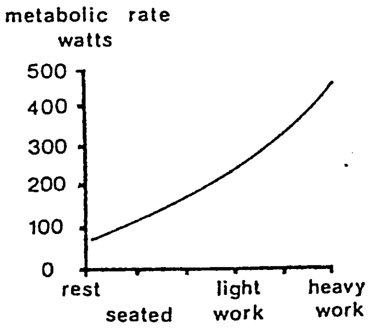

Fig 18: Variation of metabolic rate with activity.

Source: Brundrett, "Criteria for thermal comfort".

Brundrett(3), gives a daily value per person of 0.4 kWh for simple home activities such as dressing, washing.

Pound(4) indicates that "Comfort is believed to require the maintenance of skin temperature at about 34°C, which most persons achieve in sedentary state in surrounding at about 22°C, with normal indoor clothes".

The mode of heat exchange is governed by physical laws, but the physiological mechanism enables the body to regulate heat exchange and maintain an equilibrium. It basically involves four processes: radiation, conduction, convection, and evaporation, summarised in the following equation

$$M \pm R \pm p \pm C - E = 0$$

Heat gain

Metabolic (M) from - basal process
- activity
- digestion and muscular tension

Radiation (+R) from - the sun directly or reflected
- infrared thermal radiation
- ground and other hot objects
- internal surfaces

Conduction (+p) from - air above skin temperature
- by contact with hotter objects

Convection (+c) - occurs when temperature of advected air exceeds skin temperature

Heat loss

Radiation (-R) - by outward radiation to the skin
- to colder surroundings

Conduction (-p) - to air below skin temperature
- by contact with colder surfaces

Convection (-C) - when air temperature is below skin temperature

Evaporation (E) - from the respiratory tract
- from skin (sweat)

3.1.2 Factors affecting comfort

It is generally accepted that there are four main factors affecting comfort and these are: air temperature, radiation, humidity and air movement (Fig. 19).

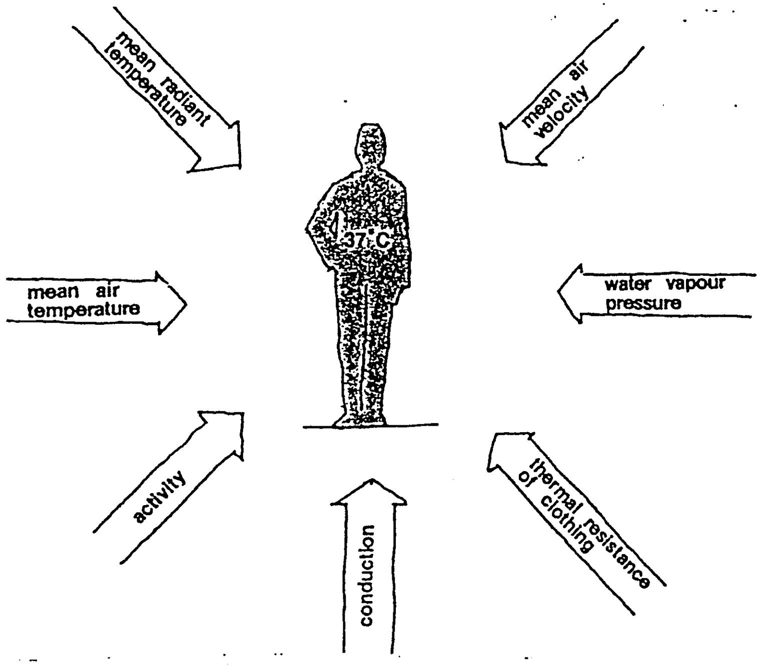

Fig 19: Environmental comfort parameters

3.1.2.1 Air temperature

Although the deep body temperature remains at 37°C or 37.2°C, the skin temperature varies, the range for normal temperature lying between 31°C and 34°C (Sodha(5) et al). Air temperature above that of the skin's results in heat input to the body. Consequently skin temperature are elevated and so radiant and convective heat dissipation is increased. According to Brunderett, sweating usually starts at skin temperature of 34.5°C, and the rate depends on humidity level and air velocity. However, the primary physiological response to the drop in air temperature is the reduction of blood flow to the skin, which results in a drop in skin temperature. Shivering may then occur causing in turns an increase in the metabolic heat production. Evans(6) indicates that the range of dry bulb temperatures within which comfort is established is approximately between 16 and 28°C. Below 16°C, extra clothing or higher activity rates are required. Above 30°C excessive air movement and sweating are required to maintain comfort even at low activity rate.

Mean skin temperature for comfort may be expressed:

$T_s = 35.7 - 0.0274 \times M \quad [°C]$

where M - metabolic rate [W/m^2] "Brundrett"

3.1.2.2 Humidity

As mentioned above, at higher temperatures evaporation becomes increasingly important and the humidity of the atmosphere will determine the ease of evaporation.

Humidity of the air does not directly affect the heat load operating on the body, but determines the evaporative capacity of air, hence sweating. However, extremely low or high humidities may cause discomfort and should be avoided. Practical considerations limit the relative humidity range between 30 - 65%. Evans states that a humidity below 20% is likely to cause dryness which can be expressed by lip cracks, eye irritation, or a sore throat. On the other hand, a relative humidity above 90% leads to sensation of dampness and clamminess.

At a high humidity and air temperature, air velocity plays a significant role in increasing the rate of evaporation. Optimum humidity depends on the overall requirement for evaporative cooling, air velocity and clothing. At medium range temperatures between 20 - 25°C, humidity does not significantly affect the body, and variations of 30% to 85% are almost imperceptible; but at temperatures above 25°C, the effect of humidity gradually increases.

3.1.2.3 Air movement

The effect of air movement on a body can be summarised in two ways. Firstly it determines the convective heat exchange, and secondly the evaporative capacity of the air and thus the cooling efficiency of sweating.

When air temperature is below skin temperature, the two effects of air movement operate in the same direction. So an increase in air velocity produces a cooling effect which increases as the air temperature is lowered. At air temperatures above 34°C, any increase in air velocity will conversely increase the convection heat gain from the environment. Waston(7) adds that because the rate of heat exchange caused by increasing air movement is coupled to vapour pressure as well as to dry bulb temperature, the lines of equal comfort are skewed, favouring high temperature at low vapour pressure and lower temperature at high vapour pressure. Evans indicates that wind speed below 0.1 m/s may lead to a feeling of stuffiness, while wind speeds up to 1 m/s are comfortable indoors when air movement is required. Above this level, discomfort generally increases although 2 m/s may be comfortable in hot, humid conditions.

Givoni(8) states that:

> "In most cases, the recommended air velocity at high temperatures is 50% more than inferred from physiological considerations".

3.1.2.4 Radiation

The thermal effect of solar radiation indoors or outdoors, depends on the area of the body exposed to the sun, the surface albedo, air velocity, clothing, activity and posture. The area of the body exposed to solar radiation depends on solar latitude, e.g., in summer months at latitude 35°N between 9.00 am and 3.00 pm, it has been estimated that the amount of direct radiation falling on a semi-nude man, wearing a hat in a standing position, is about 70% of that of a man sitting with his back to the sun.(9) It is also estimated that the amount of radiation reflected from the surroundings is about 50% lower for sitting than for the upright position. Mean radiant indoor temperatures also affect the body. The actual energy absorbed by a person from a heating source depends upon the energy spectrum of the source and the spectral reflection characteristics of the skin and outer clothes. According to Brundrett "skin will reflect a large part of sunshine (30 - 40%) but completely absorbs the radiation from heated ceilings". Consequently longwave radiant exchange can have a profound influence on comfort, particularly indoors.

3.1.2.5 Activity

The level of physical activity also affects the metabolic heat rate and hence comfort conditions. When work is performed, the metabolic rate increases to provide the energy needed for the work, depending on age and sex. The range of activity within a dwelling varies from a minimum at sleeping to a maximum when accomplishing heavy work. The indoor activity rate for two common domestic activities, the first when sleeping, the second for light sedentary work, range from 0.8 "met" (asleep) to (1.4 - 1.8) "met" in the kitchen. The "met" indicates a value of one metabolic unit. This is defined by ASHRAE, Sodha et al as 58 W/m^2, which for an average size man corresponds to an energy output of 100 W. Table(10) shows the range of heat productivity which depends on activity. However, the growing dependance on mechanisation would gradually decrease domestic physical activity and thus higher environmental temperatures may be required for comfort.

RECOMMENDED VALUES OF ACTIVITY RATES FOR DIFFERENT ACTIVITIES

Activity	Metabolic rate [met]
RESTING	
Sleeping	0.8
Sitting	1.0
Standing relaxed	1.4
WALKING	
Slow walking 3.2 km/h	2
Normal walking 4.8 km/h	2.2
Fast walking 6.1 km/h	3.2
DOMESTIC WORK	
House cleaning	2-3
Cooking	1.4-2
Washing by hand and ironing	2-3
Shaving, washing and dressing	1.5
OFFICE WORK	
Typing	1.2
Drafting	1.2
Teaching	1.4

Table 10: Values of activity rates for different activities.

Source: P.O. Fanger, thermal comfort analysis and applications in environmental engineering.

3.1.2.6 Clothing

Outside the body, clothing is the first solution to control heat transfer, by either reducing heat gain or preventing heat loss. Moreover, it reduces the air velocity over the skin and interferes with the process of sweat evaporation. In addition, it reduces the sensitivity of the body to the variations in radiant heat exchange.

The properties of clothing can be considered in terms of their total thermal resistance expressed in "clo" which is a convenient scale for the units of thermal insulation of clothing. One "clo" is equivalent to 0.155 m^2 °C/W (1 tog = 0.1 m^2 °C/W).

The maximum clothing which could be comfortably warm in houses for normal household activity is estimated as just over 1 clo, the reasonable range taken between 0.5 and 1 clo. When sleeping much higher values are normal - For example a 12.5 'tog' or 8 clo duvet for temperatures around 15°C. (Table 11) shows the range of combination of clothing with their values. However, clothing is also affected by other factors such as seasonal variation, activity and fashion, as well as culture and tradition. In Algeria the latter factor would limit the freedom of people to chose their clothing, especially in summer when conditions are very hot.

Clothing ensemble	Insulation [clo]
Nude	0
Shorts	0.1
Tropical ensemble (shorts, open-neck short-sleeved, shirt, light socks, sandals or women's equivalent)	0.3-0.4
Men's light summer clothing (long light weight trousers, open-neck short-sleeved shirt)	0.5
Typical men's business suit (+cotton underwear, long-sleeved shirt, tie, woollen socks, shoes)	1.0
Men's heavy three-piece business suit (+cotton underwear, long-sleeved shirt, tie, woollen socks, shoes)	1.5
Women's indoor ensemble (skirt, long-sleeved blouse and jumper, normal underwear, stockings, shoes)	0.7-0.9
Men's heavy suit as above + woollen overcoat	2.0-2.5

Table 11: Values of "clo" for various clothing ensembles.

Source: Markus and Morris, Buildings, Climate and Energy.

3.2 Comfort zone

As we have seen, all factors interact and each one depends on the others. Therefore a number of attempts have been carried out to define boundaries where human bodies can be in comfort, in terms of a single parameter combining all environmental factors and human response. Over the years, a number of such charts have been developed gradually changing to take account of more relevant criteria. Firstly, thermal indices, then psychometric charts and finally bioclimatic charts.

Comfort zone means the combination of environmental elements for which comfort sensation is experienced. However, like thermal comfort, this zone is also somewhat subjective depending on thermal response of people, age, sex, geographical location, and acclimatisation. Olgyay(10) reports that British comfort lies between 16 - 21°C, that of the Tropics between 22 and 27°C, and in the United States the range is 21 - 26.5°C. Finally Bedford(11) defines it in the range of 14 - 23°C.

It is worth distinguishing between "comfortable" and "tolerable" temperature limits. In the case of public housing there is an unfortunate political and economic motivation to advocate temperatures which may be tolerable, but often not comfortable. Hence, there are apparently puzzling discrepancies between comfort ranges in different building types. For example, U.K. offices, where activities are comparable to housing, generally admit to higher comfort temperatures. It could be that the same motivation in Algeria would promote acceptance of summer temperatures within limits of acclimatised tolerance, but far removed from optimum comfort.

Humphreys(12) considered an equation to show the range of environment in which equilibrium can be maintained without perceptible sweating or shivering. He divided the heat transfer into three stages - from body core to skin, from skin to outer surface of clothing, and from clothing surface to the air. He considered the tabulated metabolic rate, activity and clothing. He concluded that people can be in thermal equilibrium over a wide range of temperatures if they choose their clothing and activity, and that the width of comfort zone in terms of metabolic rate is greater at higher temperatures than at lower. But the problem arises when people cannot choose their activity and/or clothing. Some writers, for simplicity consider the ideal temperature as a midway between the two extremes of heat stroke (upper limit >40°C) and freezing point (lower limit 0°C).

3.3.1 Bioclimatic chart

The effect of the climatic elements can be assembled into a single chart. The latter shows the comfort zone in the centre. The climatic elements around it are shown by means of curves which indicate the nature of corrective measures, necessary to restore the feeling of comfort at any point outside the comfort zone. This chart (figure 20) was built up with dry bulb temperature as ordinate and relative humidity as abscissa. Thus these two factors, of any region can be plotted on the chart. If the plotted points are outside the comfort zone corrective measures are needed.

- If the point is higher than the upper limit of comfort zone, increased air movement is required. The numbers on the chart indicate the required velocity.
- If the temperature is high and relative humidity is low, air movement is of little help, without evaporative cooling.

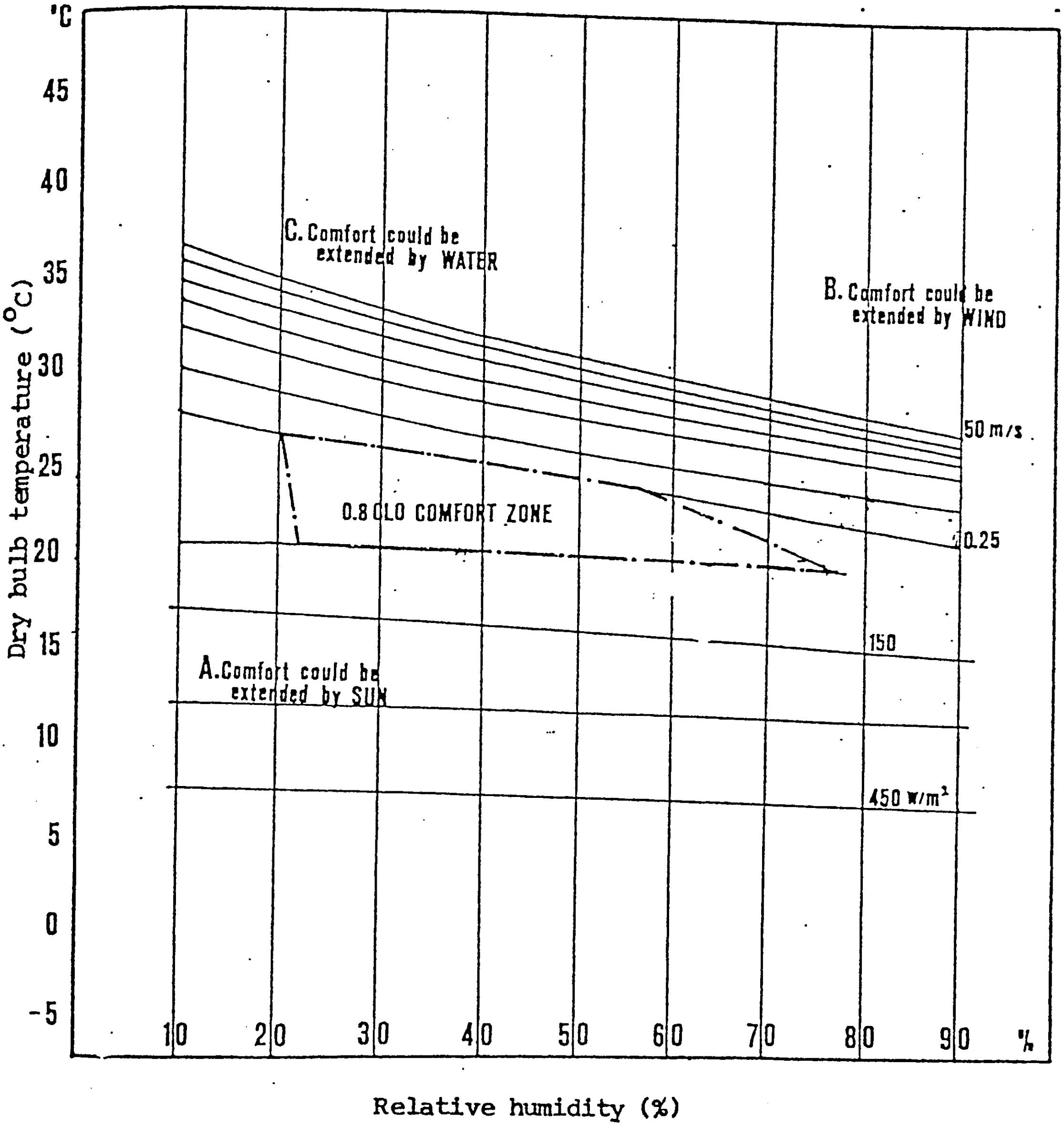

Fig 20: Bioclimatic chart. Indoor climatic conditions related to comfort zone and the different corrective measures.

The lower perimeter of the comfort zone denotes the line above which shading is needed. Conversely increased radiation is necessary below this line, to counteract lower dry bulb temperature. The amount of radiation needed is given for outdoor conditions for which 70 W/m^2 is considered equal to a rise in temperature of 1°C. For indoor conditions a mean radiant temperature (M.R.T.) scale shows that an increase of 0.8°C in M.R.T., compensates for a decrease of 1°C in dry bulb temperature up to a limit of 5°C M.R.T. It has been also suggested that a 20 - 26° range is valid for 49° latitude and that comfort zone temperature should move up by 1°C for every 12° latitude reduction. This infers recognition of acclimatisation, and challenges the logic of the bioclimatic chart. For example, the high humidity at Singapore on the equator would lower acceptable temperatures compared with a dry location on the tropic of Cancer.

While the bioclimatic chart relates comfort directly to dry bulb temperature a large number of temperature scales/charts are also used to express comfort. Two such are effective temperature (ET) and corrected effective temprature (CET). The former scale does not take account of radiant energy and both are only used for sedentary activity. Another comfort scale is dry resultant temperature, recommended by C.I.B.S.(13). This temperature equals

1/2 air temperature + 1/2 mean radiant temperature

where the latter is often taken as mean surface temperature for simplicity. Much seminal work was done by Fanger(14) producing a series of comfort charts which use, mean radiant temperature with clothing, humidity, air movement and activity. The standard effective temperature (SET) used by

ASHRAE is similar to the Fanger chart, but for 4 - 6 clo and sedentary activity.

3.3.2 Use of bioclimatic chart

Bioclimatic evaluation is the starting point for any architecural design aiming at environmental climate balance. Prevailing climatic conditions can be easily plotted on the chart. It is a visual method which will show the architects what corrective measures are needed for comfort. Many of these measures may be achieved by natural means by adapting architectural design to utilise climatic elements. The task is to produce a healthful house in relation to cost saving by reducing dependance on mechanical aids.

> (15) <<It is for this reason that throughout the ages, in response to this obvious necessity of comfort, humankind has been fashioning forms of shelter, initially to ensure survival and ultimately to provide a reasonable degree of thermal comfort during the conduct of diverse activities.>>

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Chapter 4

THERMAL ANALYSIS

The aim of this chapter is to investigate and compare the thermal performance of a typical modern flat to a traditional courtyard house in the Constantine region of Algeria in order to validate the potential for passive design techniques which minimize non renewable energy demand.

For comfort the human body requires to be maintained within a limited range of environmental conditions (see chapter 3). The energy requirement is the energy needed to maintain the building within the comfort band. Therefore besides economic and social factors, the aim of a designer is to work towards a thermally optimized building taking into account all parameters influencing comfort.

4.1. Methodology of thermal evaluation

It is necessary in the thermal performance evaluation of buildings to follow temperature variation from outside to inside through the building envelope, which may be considered as a filter. For this study, the appraisal of the model building is based on the relationship between regional climatic variables, some measured and some predicted, and the energy gain and loss for each building element.

To obtain heating and/or cooling loads for a building with a 24 hour occupancy such as housing, it is normally adequate to use steady state methodology. The dynamic effect will tend to cancel out. The product of specific heat loss and a mean daily inside/outside temperature difference will not vary significantly from a much more complex integral of small time-step energy exchanges, these changes summed over 24 hour periods. However, where buildings subdivide naturally into distinct thermal zones, each with a particular occupancy timetable, it is necessary to move from a purely steady state to some form of periodic analysis which will take account of the thermal damping and time lag effects.

4.1.1 Steady state procedure

When designing buildings to have a satisfactorily comfortable environment, it is necessary to determine the seasonal energy requirement and the maximum demand at any time.

In order to calculate the monthly energy load for the two housing models, the following procedure used in BREDEM(7) was applied:

The basic model considers a house which is uniformly heated throughout. The heat transfer between the house and its surrounding may be written as.

$$Q_H + Q_I + Q_S = (\sum AU + 0.33nV)(t_i - t_o) + \triangleright \quad \text{------------} \quad (1)$$

where

Q_H = heat output from the heating system [Watts]

(in our case this is the unknowing variable which we need to calculate.)

Q_I = other internal heat gains [Watts]

Q_S = solar gains [Watts]

AU = transmission heat loss per degree [W/K]

0.33nV = ventilation heat loss per degree [W/K]

where n = air changes per hour

and V = volume [m^3]

t_i = internal temperature [°C]

(in our case, the mean internal design temperature)

t_o = mean external temperature [°C]

$\triangleright$ = rate of heat storage within the structure [W]

All terms in this equation will normally vary continually with time. This variation may broadly be represented by a daily cycle superimposed on a seasonal trend, with random departures from that scenario caused by the vagaries of the weather.

Therefore for a 24 hour mean value, the heat storage will be neglible on the assumption that thermal capacity effect will cancel when the heat requirement for each day is totalled over a heating or cooling season. Equation (1) may then be written as.

$$Q_H + Q_I + Q_S = (\Sigma AU + 0.33nV)(t_i - t_o) \quad [\text{Watts}] \text{ ---- } (1)$$

From this equation we can identify the specific heat loss as

$$H = (\Sigma AU + 0.33nV) \quad [W/K]$$

and $G = Q_S + Q_I$ the sum of fortuitous solar and incidental heat gain.

Therefore the mean daily heating or cooling load required to maintain an internal temperature t_i may be expressed as

(2a) $Q_H = H(t_i - G/H - t_o)$ [Watts]

or (2b) $Q_H = H(t_b - t_o)$ [Watts]

Where we introduce a conceptual base temperature, t_b reduced below design temperature by the solar and incidental gain, where

$t_b = t_i - G/H$ [°C]

To solve equation (2b) we therefore require to calculate the individual terms in H and G.

With respect to transmission or fabric losses AU, the transmittance coefficient or U-value denotes the rate of heat flow per unit area per unit difference in temperature between inside and outside. The U-value is the inverse of the total resistance to the heat flow of all surfaces, layers and cavities in bounding elements from outside to inside air. The resistance of each layer is the product of thickness and resistivity, the latter being the inverse of the thermal conductivity of the material.

Thus

$$U \text{ value} = \frac{1}{R_{si} + R_1 + R_2 + \ldots\ldots R_n + R_{so}} \quad [\mathrm{W/m^2K}]$$

where R_{si} and R_{so} are respectively the inside and outside surface resistances, dependant on surface emissivity, radiation and convection coefficient.

R_1, R_2 .... R_n = resistance of each layer of wall or roof.

$R = \frac{L}{\lambda}$ [m^2K/W] where λ = thermal conductivity [W/mK]

L = thickness of a layer [m]

U-values for windows are commonly tabulated according to the percentage of the frame and exposure.

U-value calculation for a solid ground floor is more complex, and can be found using the standard CIBS[2] procedure for four exposed edges as follow:

$$U = \frac{2\lambda e\ B}{\frac{1}{2}b\pi} \tanh{-1}\left(\frac{\frac{1}{2}b}{\frac{1}{2}b + \frac{1}{2}w}\right)$$

where

$$B = \text{exponential}\left(\frac{\frac{1}{2}b}{L_f}\right) \text{ where}$$

L_f = length or greater dimension of floor

b = breadth or lesser dimension

w = thickness of surrounding walls

λ = thermal conductivity of earth, dependant on moisture content and can vary from

0.7 to 2.1 (W/mK)

The problem is finding an appropriate temperature difference. While CIBS simply uses "t_o", work by Spooner[3] taking a UK example, finds the mean annual ground temperature at 1.2 m depth outside the house gives a reasonably close fit to measured results and that the CIBS method overestimates the rate of heat loss by a factor of approximately two.

However, in a traditional Algerian courtyard house, there is a neglible exposed perimeter and relatively high mean ground temperatures, so that the heat sink effect is likely to be greatly enhanced. Accordingly it seems probable that the ground floor will be in virtual equilibrium throughout the year, and it has been assumed that the ground is an adjacent zone with an identical temperature to the zone above, as in the case of the intermediate flat model.

With respect to ventilation heat loss, the constant in term 0.33nV is derived from $c\rho/3600$ where ρ and c are respectively, the dry density and the specific heat capacity of air with ρ commonly taken as 1.2 kg/m^3 for air at 21°C and c as 1.0×10^3 J/kgK giving a value of 1/3 or 0.33 for the combined term.

Having found all terms in H we must now determine the terms in G.

Considering first term Q_s, in winter we are concerned with the "useful" contribution and in summer cooling conditions with the "residual" gain after shading/screening tactics.

Solar gain Q_s may be subdivided into transparent and opaque components Q_{st} and Q_{so}. Considering the former, some of the solar radiation incident upon the windows is reflected, some is absorbed by the glass, and the remainder is transmitted into the interior. The physical properties of glass and the angle of incidence of direct irradiation will determine the proportion in which this occurs.

Once inside, shortwave irradiation is absorbed by surfaces including furnishing and re-emitted as low temperature longwave radiation. This is trapped within the space by what is known as "Green house" effect, since glass is relatively opaque to longwave. However, conduction and convection exchanges will occur at all surfaces and the thin dense glass has low resistance to these transmission losses. The cold surface of the glass at night or in winter will also radiate out to the outside, and convection exchanges at the cold internal surface tend to cause uncomfortable down draughts.

The "Atlas solar de l'Algerie"(4) provides sinusoidally generated hourly solar irradiation data incident on and behind glazed surfaces of various tilts and azimuths. The ratio of the latter to the former yields the heat gain factor. The incident global radiation comprises a direct, diffuse, and ground reflected components. In order to estimate useful transmitted solar gain it is found necessary to deduct the shaded percentage from the direct component. This is found using the tables and sun chart presented in appendices A and B. The net unshaded direct component is then added to diffuse and ground reflected component and the heat gain factor applied to give a net transmitted irradiation:

[(direct × unshaded %) + (global - direct)] × heat gain factor

It is then necessary to test for overheating during periods of peak gain for a particular mean monthly day.

Peak gains are found using the standard Pilkington(5) procedure. Short and longwave shading coefficients are applied to incident irradiation, the total coefficient for thin glass being unity which corresponds to a heat gain factor of 0.87.

We now have the net transmitted irradiation and require to know what proportion is useful. Thus we test for a cooling load at a particular peak period:

i.e. if $Q_H = H(t_{b_{cool}} - t_{omax})$ is a negative value where

$$t_{b_{cool}} = t_{imax} - \frac{(\text{net transmitted solar}) + (\text{other gain})}{H}$$

and $t_{b_{cool}}$ is the base temperature related to a maximum comfort temperature, taken as 25°C. If there is no cooling or heating load $Q_H = 0$ and $t_{b_{cool}} = t_{omax}$. Thus substituting t_{omax} for $t_{b_{cool}}$ above, and rearranging the the equation, we have a net useful or residual solar gain

$$Q_{st} = H(t_{imax} - t_{omax}) - (Q_{so} + Q_i) \qquad \text{(W)}$$

If $t_{max} > t_{imax}$, there will be no useful solar gain and after appropriate architectural screening steps are taken, we will be left with a residual transmitted gain Q_{st}. It would thus be necessary to cool by other means - such as increasing ventilation.

If $t_{omax} < t_{imax}$, we may have a useful contribution Q_{st} having deducted incidental Q_i and solar gains through opaque surfaces, Q_{so}. We then have to ascertain what design measures may be required to reduce the useful gain to this value.

The solar heat gain through opaque surfaces can be calculated using the concept of sol air temperature:

$$Q_{so} = AU\ (t_{sa} - t_i) \qquad [\text{Watts}]$$

where

A = area of opaque surfaces [m^2]

U = transmitted coefficient of opaque surface [W/m^2K]

T_{sa} = sol air temperature [°C]

t_i = meam internal temperature [°C]

The sol air temperature is defined as a hypothetical temperature of outdoor air which, in the absence of solar radiation, would give the same rate of heat transfer as would occur with the actual conditions of outdoor air temperature and incident radiation.

$$T_{sa} = t_o + \alpha I_s R_{so} \qquad [°C]$$

where

t_o = average external temperature [°C]

α = absorptivity coefficient

I_s = global incident solar irradiation (for a shaded wall, only diffuse and ground reflected component are used)

R_{so} = outside surface resistance

Having estimated solar gain using the above procedure, incidental or casual gains, Q_I, may be computed, making certain occupancy assumptions. A BRE(1) handbook describing a domestic energy model, BREDEM, provides a table illustrated in appendix C for heat gains in Watts averaged over a 24 hour period, including metabolic, appliances, lighting, cooking and water heating.

We can now evaluate all the terms in equation (2b), We may either assume a single mean t_b value for a particular period related to a t_o profile, where the zone below t_b is a heating load and above it is a cooling load; or an upper and lower t_b value related to t_{imax} and t_{imin} design temperatures defining a comfort range. In either case considering firstly heating, we can use the standard U.K. degree day method:

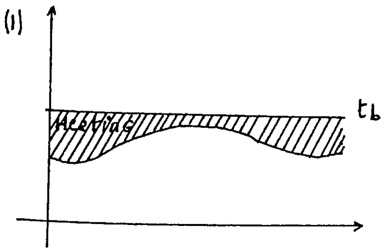
1) if $t_b > t_{omax}$, $DD = t_b - 0.5\,(t_{omax} + t_{omin})$

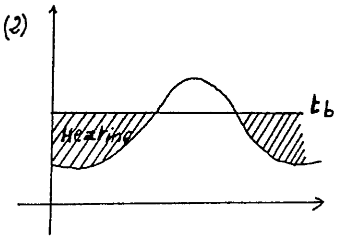
2) if $t_{omax} > t_b$ and $t_{omin} < t_b$ and $(t_{omax} - t_b) < (t_b - t_{omin})$

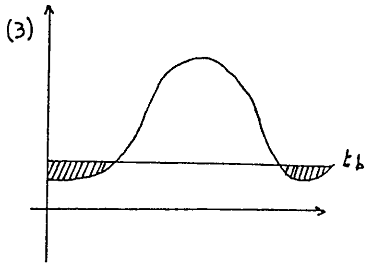
$$DD = 0.5(t_b - t_{omin}) - 0.25(t_{omax} - t_b)$$

3) if $t_{omax} > t_b$ and $t_{omin} < t_b$ and $(t_{omax} - t_b) > (t_b - t_{omin})$

$$DD = 0.25(t_b - t_{omin})$$







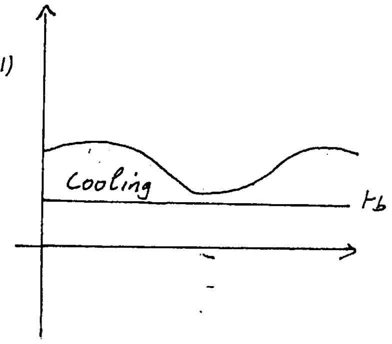
Considering cooling we simply reverse the procedure

1) if $t_b < t_{omax}$, $DD = 0.5\,(t_{omax} + t_{omin}) - t_b$

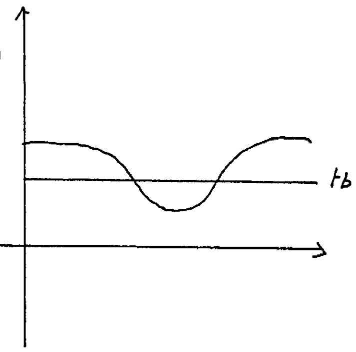
2) if $t_{omax} > t_b$ and $t_{omin} < t_b$ and $(t_{omax} - t_b) > (t_b - t_{omin})$ } $DD = 0.5(t_{omax} - t_b) - 0.25(t_b - t_{omin})$

3) if $t_{omax} > t_b$ and $t_{omin} < t_b$ and $(t_{omax} - t_b) < (t_b - t_{omin})$ } $DD = 0.25(t_{omax} - t_b)$

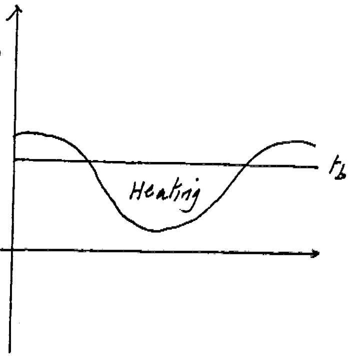
(1)



(2)



(3)



For a more accurate assessment of energy loads, a two zone model was used. The house is divided into two distinct thermal zones, each with a different internal demand temperature. The load is calculated for each zone separately and then summed. The two zones are:

- living room - zone I
- rest of the house - zone II

For a given demand schedule, that is the user's temperature requirement in each zone, the resulting mean internal temperature depends on the thermal characteristics of the house, outer shell and zone divisions, together with the distribution of internal and solar gain. In the case of

BREDEM(5) the two-zone house model provides convenient tables of internal temperatures resulting from different demand temperatures, varying heat loss characteristics, heating systems and regimes (see Appendix C)

However, in our case, rather than compare the performance of the two models with the same demand temperature but different internal air temperatures, the comparison is made assuming identical air temperatures and inferring different demand settings.

4.1.2 Dynamic model

A house with high thermal capacity smooths out temperature fluctuations resulting from various heat inputs, whilst a low thermal capacity house will have a more peaky profile, (Fig 21). It is not possible to examine such capacitance influences using the above steady state approach with a mean $t_b - t_o$ temperature differential. Therefore a dynamic computer programme, " $\mu - t_e$", was used to determine another conceptual temperature, equivalent external temperature "t_e", this is substituted for "t_o" in the same manner as sol-air temperature and takes account of thermal damping and time lag effect. It will be then possible to determine the performance of the individual zone in separate slices of the day, enabling a closer fit to occupancy patterns. Effectively we are translating the original storage term of equation (1) to a much more convenient temperature differential. Capacitance effects are dependant on the ratio of thermal conductivity $[W/m^2K]$ to volumetric thermal capacitance ρc [J/m²K] known as thermal diffusivity D [m²/s]. We require to know time lag θ, the time it takes for a temperature rise on one side to be felt on the other, and decrement factor μ, the ratio of respective internal/external surface heat flux (see fig.21)

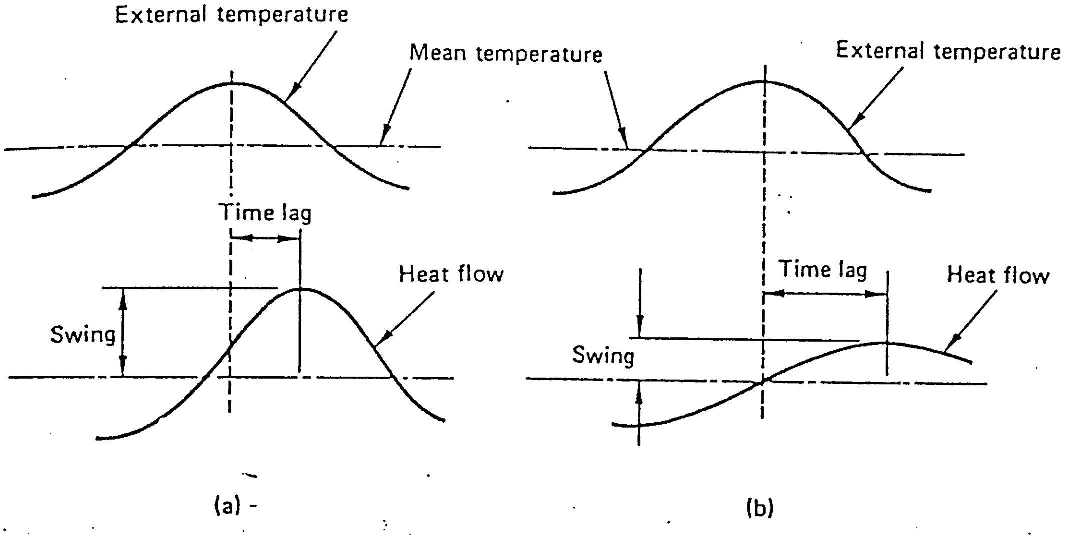


Figure 21: Effect of (a) lightweight and (b) heavgy weight structure on heat flow variation.

Source: T.A. Markus and E.N. Morris, Buildings, Climate and Energy.

For a single homogeneous layer, a simple equation suffices;

$$\theta = L \times 0.023 \sqrt{1/D} \qquad [\text{hours}]$$

$$\mu = \exp[- L \times 0.00218 \sqrt{1/D}]$$

where

D = diffusivity = $\lambda / \rho c$ [m²/s]

L = thickness of layer [m]

However, for multilayer constructions, more complex methods are required. The time lag is calculated using the concept of time constant, since the resistance of one layer will affect the rate of heat flow to the adjacent layer. In addition the thermal capacity of one layer will determine the quantity of heat available to be transmitted to the rest. Thus the time lag cannot be taken as the sum of individual time lags but will depend on the properties and sequences of layers.

The time constant was explained by Evans as the time taken for a layer to increase in temperature by a certain proportion of instantaneous change in external temperature. This is defined by a $\frac{Q}{U}$ ratio:

$$\frac{Q}{U} = \left(\frac{Q_1}{U_1} + \frac{Q_2}{U_2} + \frac{Q_3}{U_3} + \ldots\ldots\ldots\frac{Q_n}{U_n}\right) \Big/ 3600 \quad [\text{hours}]$$

where

Q = volumetric heat capacity of the envelope i.e. ρc

U = rate of heat transfer of the material

First layer $\frac{Q_1}{U_1} = \left(R_{so} + \frac{r_1 L_1}{2}\right)\left(L_1 C_1 \rho_1\right)$

Second layer $\frac{Q_2}{U_2} = \left(R_{so} + r_1 L_1 + \frac{r_2 L_2}{2}\right)\left(L_2 C_2 \rho_2\right)$

Third layer $\frac{Q_3}{U_3} = \left(R_{so} + r_1 L_1 + r_2 L_2 + \frac{r_3 L_3}{2}\right)\left(L_3 C_3 \rho_3\right)$

where

R_{so} = external surface resistance [m^2K/W]

r_1, r_2 = resistivity of first and second layers

L_1, L_2 = thickness of first and second layers

ρ_1, ρ_2 = density of first and second layers

C_1, C_2 = specific heat of first and second layers

Then Givani's(7) formula was applied for time lag θ

$$\theta = 1.18 + \frac{2\pi}{24}\,\frac{Q}{U} \qquad \text{[hours]}$$

The above procedure assumes that the temperature fluctuation is generated externally, the time lag calculated from outside to inside. To find the decrement factor, the standard CIBS(8) admittance procedure was used. This also yields admittance or Y value and surface factor. For convenience, the programme incorporated the time constant procedure (above) together with the following equation to give an equivalent temperature, "t_e" corresponding to the Constantine hourly "t_o" values -

$$t_e = \mu(t_o^* - t_o) + t_o \qquad [^\circ\text{C}]$$

where

t_o^* is the external temperature 'time lag' hours before the time in question.

t_o is the mean external temperature.

The equivalent external temperature (t_e) will have the same effect under steady state conditions as the actual temperature under periodic heat flow. "t_e" is thus used to illustrate the combined effect of air temperature and solar irradiation with the delaying effect of heavy construciton on heat transfer. Thus the wave pattern of "t_o" will be reduced to "t_e" according to the value of μ and θ.

Having obtained the "t_e" profile for each opaque surface the steady state is now effectively converted to a simple periodic dynamic procedure. Naturally "t_o" values will remain for transmission through very thin surfaces such as windows and ventilation losses, but can be considered simply as "t_e" values in a modified form of equation (2b).

$$Q_H = H\,[t_b - t_e]$$

where the appropriate "t_e" value is applied to each component of H.

i.e.,

$$H = A_1U_1(t_b - t_{e1}) + A_2U_2(t_b - t_{e2})\ldots + 0.33nV(t_b - t_{ox})$$

where t_{ox} is the mean outside temperature for a particular period.

The procedure can for example be used to analyse the effect of the construction when external temperatures are cooler than internal permitting ventilation to be used for cooling.

The remaining analytical problem lies with temperature stratification in the courtyard of the traditional model and with obtaining accurate data with respect to the thermal properties of traditional building materials. These aspects will be covered in more detail in the next sections which describe the models and translate the architectural implications of the thermal analysis.

4.2 Description of models analysed

To carry out this analysis, I have considered models which are disassociated from unnecessary components. The two typical housing example analysed are

- a suburban modern concrete block flat
- an urban traditional stone and mud brick courtyard house. Both types have been examined under Constantine weather conditions. The main focus has been on performance evaluation. Knowledge gained through the understanding of the behaviour of existing buildings will be used both to predict the performance of future buildings, and to devise strategies to make them more effective. Thus the thermal models have been used to identify the influences of both building design parameters and weather characteristics on performance.

4.2.1 The courtyard house

The model is a three storey house situated in a sheltered position in the city centre, surrounded by similar houses. The site is densely bounded by buildings inducing certain microclimatic characteristics. This has influenced the outside surface resistance taken as (0.09) and window U value 4.2 W/m^{2}K representing 30% wooden framed in a sheltered position. However, as a result of a lack of site meteorological data, apart from an attempt to quantify the temperature stratification in the courtyard, it was assumed that climate data affecting this house are those recorded at

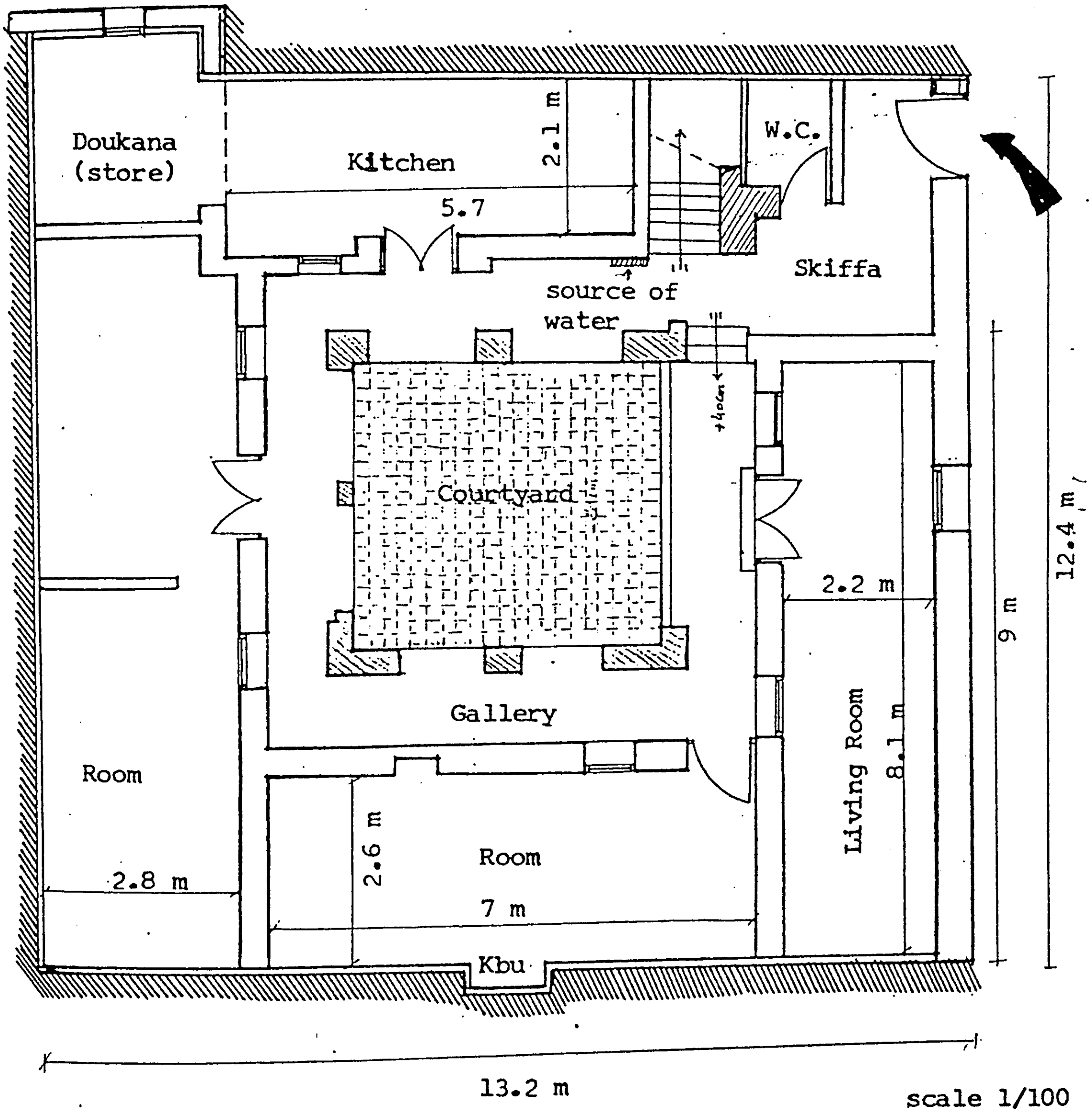


Plate 7a: Courtyard house : Ground floor

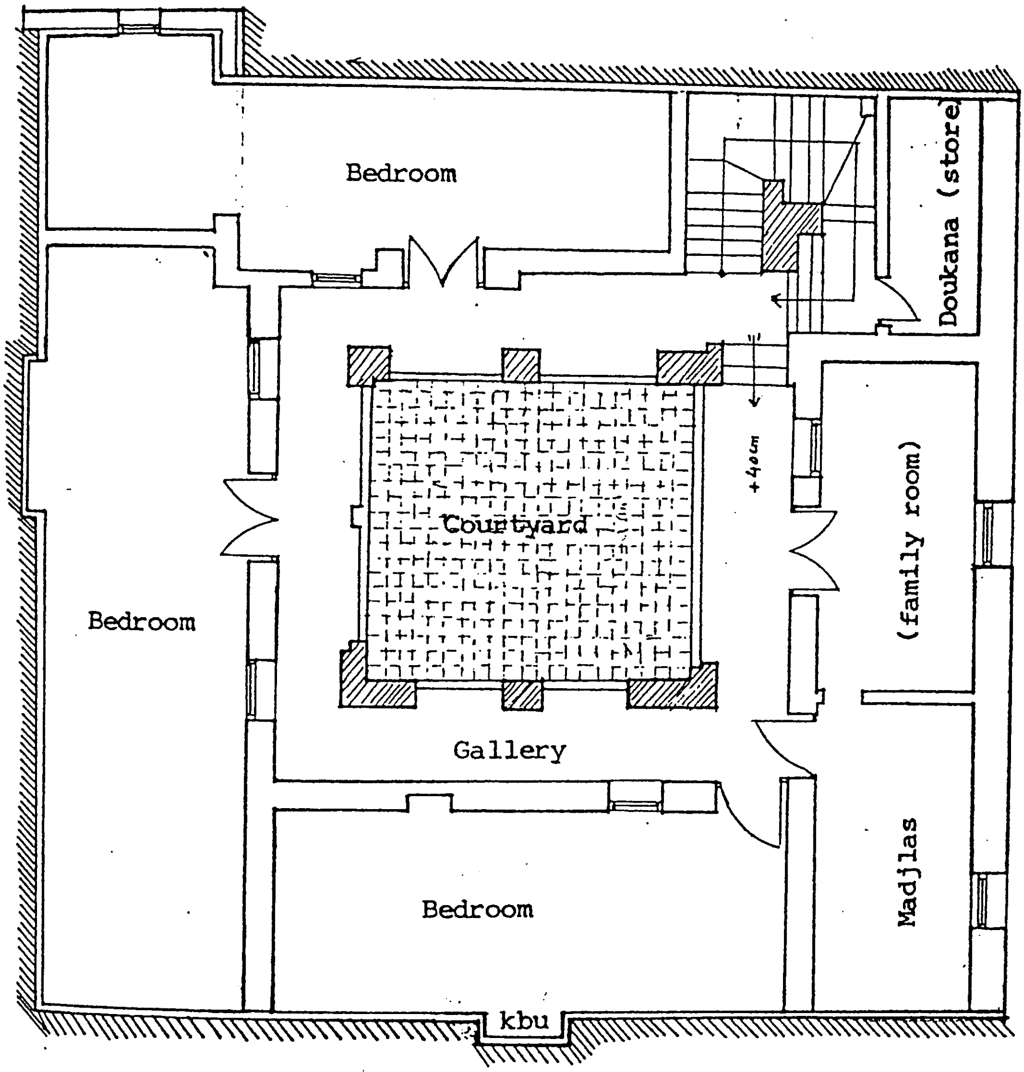
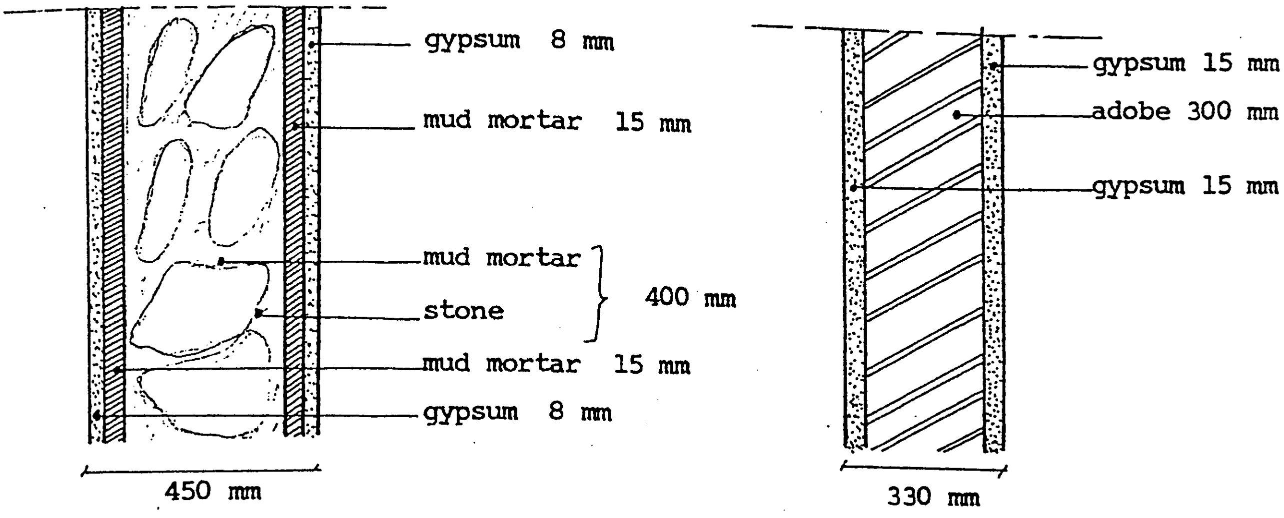


Plate 7b: Courtyard house : Upper floor



wall I

wall II

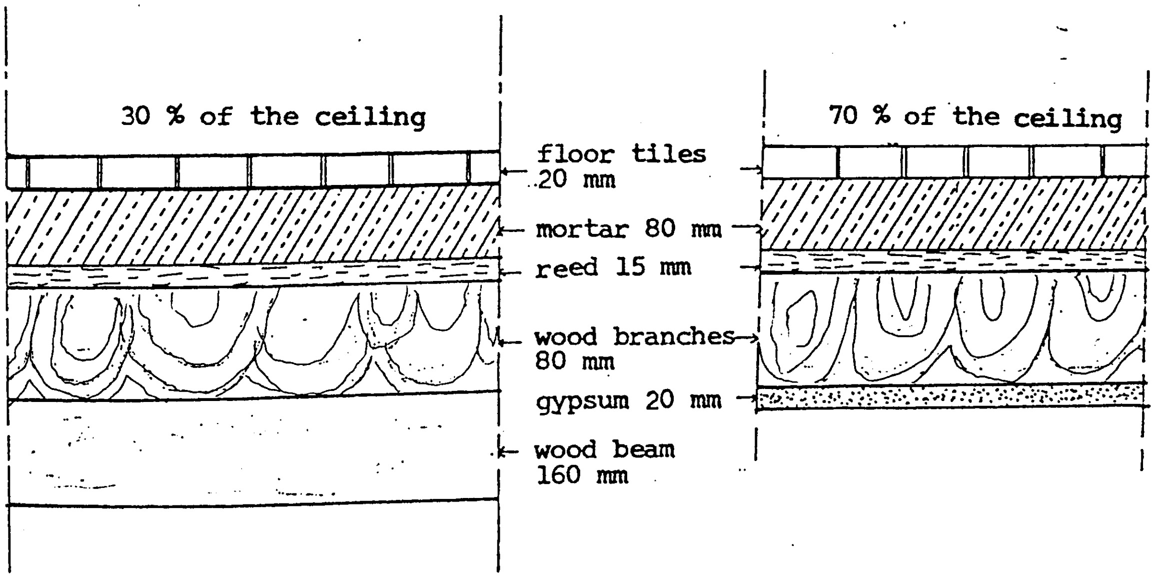


Fig 22: Courtyard house : wall and ceiling physical characteristics.

a - Wall I

	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Gypsum	700	0.280	840	0.008
Mortar	1840	0.430	750	0.015
Stone	1952	1.120	730	0.400
Mortar	1840	0.430	750	0.015
Gypsum	700	0.280	840	0.008

Number of layers = 5
No. Construction = 0

Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.090

Properties
u-value : 1.435
Decrement factor : 0.130
Admittance value : 4.121
Surface Factor : 0.534

Time Lag :- 16.169

b - Wall II

	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Gypsum	700	0.280	840	0.015
Adobe	1690	0.518	730	0.300
Gypsum	700	0.280	840	0.015

Number of layers = 3
No. Construction = 0

Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.090

Properties
u-value : 1.112
Decrement factor : 0.196
Admittance value : 3.516
Surface Factor : 0.620

Time Lag :- 13.394

c - Shutters

	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Window	2066	0.542	1350	0.018
Air Space	1.2	0.280	1180	0.050
Shutter	820	0.140	2400	0.012

Number of layers = 3
No. Construction = 0

Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.090

Properties
u-value : 1.959
Decrement factor : 0.927
Admittance value : 3.188
Surface Factor : 0.710

Time Lag :- 2.764

Table 12 (a,b,c): Thermal Characteristics of wall and shutters of the courtyard house.

the nearest meteorological station.

The house has a useable floor area of 297 m^2, - courtyard not included, and the ground floor area is 99 m^2. The building is nearly a square patio house with a pitched roof. The walls are parallel to the North, South and East - West geographical axes with only one facade exposed to the street. The volume of ground floor is 209.6 m^3 and the glazing area constitutes only 6.78% of the total wall surfaces (see plates 7a, 7b).

The house is built of traditional materials. External walls and foundations are of stone, and wall thickness is 45 cm (but may reach 120 cm in some houses). The walls giving on to the courtyard and partitions are built of mud brick covered with gypsum. These walls are generally covered to 160 cm height by a layer of marble or tiles to act as a cooling device. Ceilings are composed of wood trunk and branches covered with reeds and a layer of mud mortar are shown on (fig 22).

As a result of the lack of accurate data, the thermal properties of some materials were assumed from a number of reference sources. For example, the conductivity of mud brick was taken similar to that found in U.S.A. 0.518 mK/W and that of mud 0.43 m K/W. Consequently the U-value of external and internal walls were respectively 1.43 W/m^2K and 1.1 W/m^2K which may be considered on the high side compared to the thermal insulations of traditional materials. The thermal properties of the materials are illustrated on tables 12 (a,b,c).

The door is assumed to be 4 cm wood block with a U-value of 2 W/m^{2}K and a time lag of 1.7 hours.

4.2.2 Flat type

The model is a four bedroom prefabricated flat, occupied by ten people according to the Algerian regulation where the rate of occupancy per room is fixed to two, including the living room. Situated in a suburban area "Cite Bousouf ou 2500 logements", it is considered to be of normal exposure. The flat is in the medium floor of an isolated five storey block composed of two flats per floor. Plan, section, and elevation are shown on plates (8a, 8b, 8c). The same climatic data were applied for this model. The flat has a useable floor area of 100 m^2 and a volume of 223 m^3. It is a rectangular shape with three exposed external walls. The glazing area constitutes 12.5% of the total external walls.

The flat is built of reinforced prefabricated concrete panels typical for recent housing. The thickness of the walls varies between 10 and 20 cm. Some external walls consist of sandwich panels. The outside surface resistance is taken 0.055 as for normal exposure and the U-values for different walls were calculated depending on their thickness. They vary between 1.49 W/m^{2}K for the insulated wall to 2.73 W/m^{2}K. The U-value for the window was taken as 4.7 W/m^{2}K - for 30% wooden frame and normal exposure.

The physical and thermal properties are shown in figs. 23 and tables (13a, 13b).

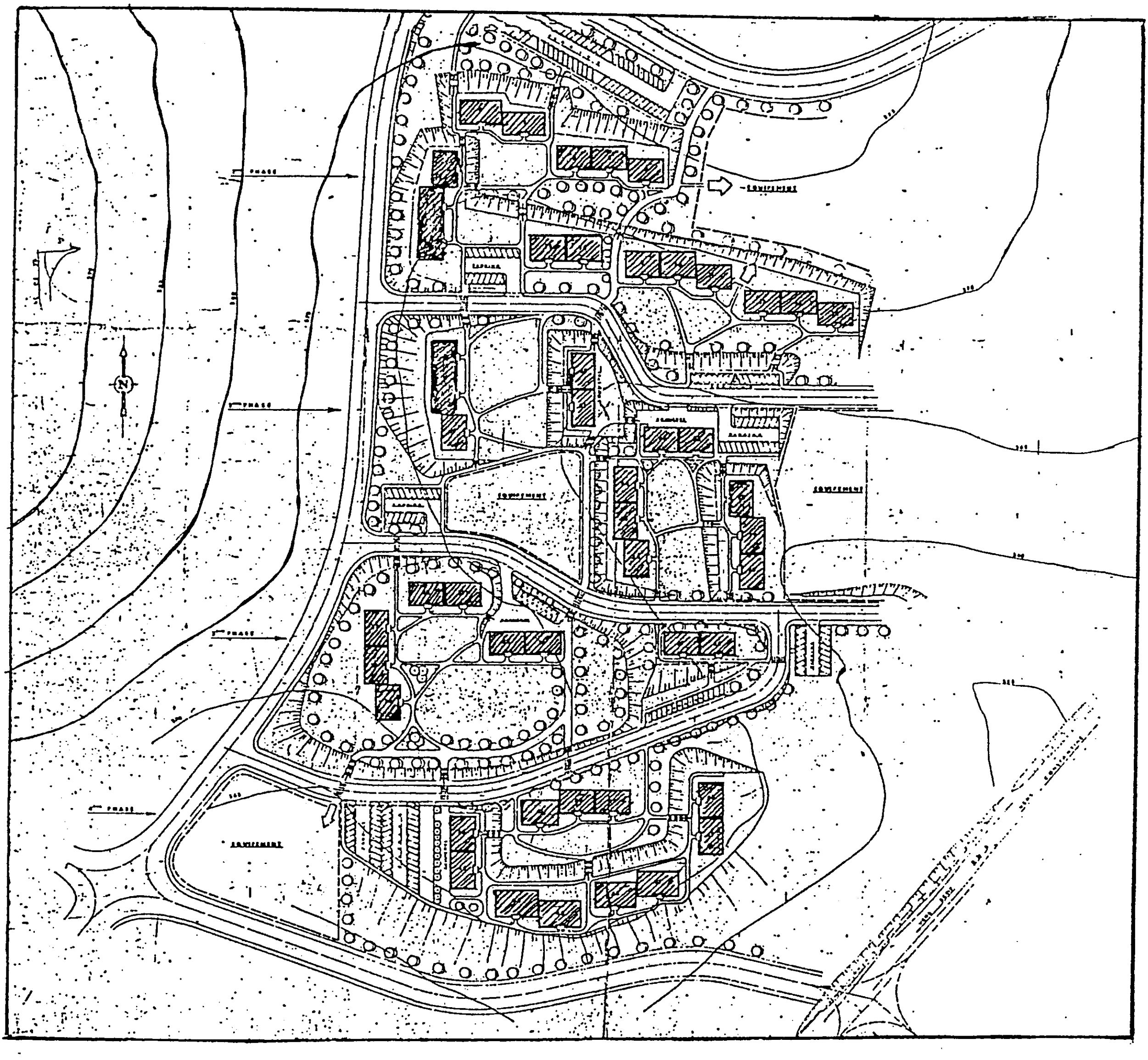


Plate 8a: Flat type in its urban layout.

▨ Blocks of flats

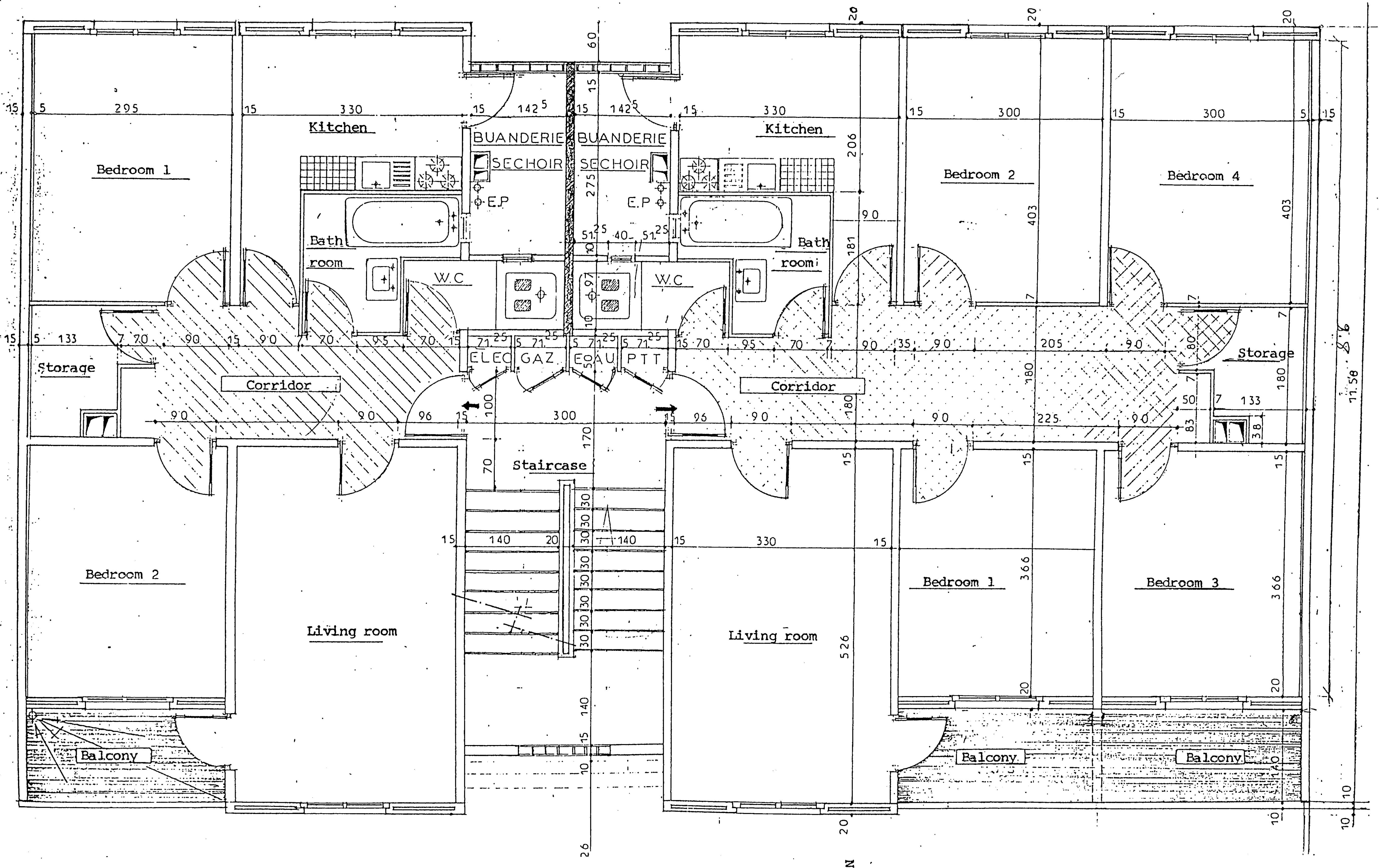


Plate 8b: flat, spatial organisation: medium floor of a prefabricated block
(flat on the right)

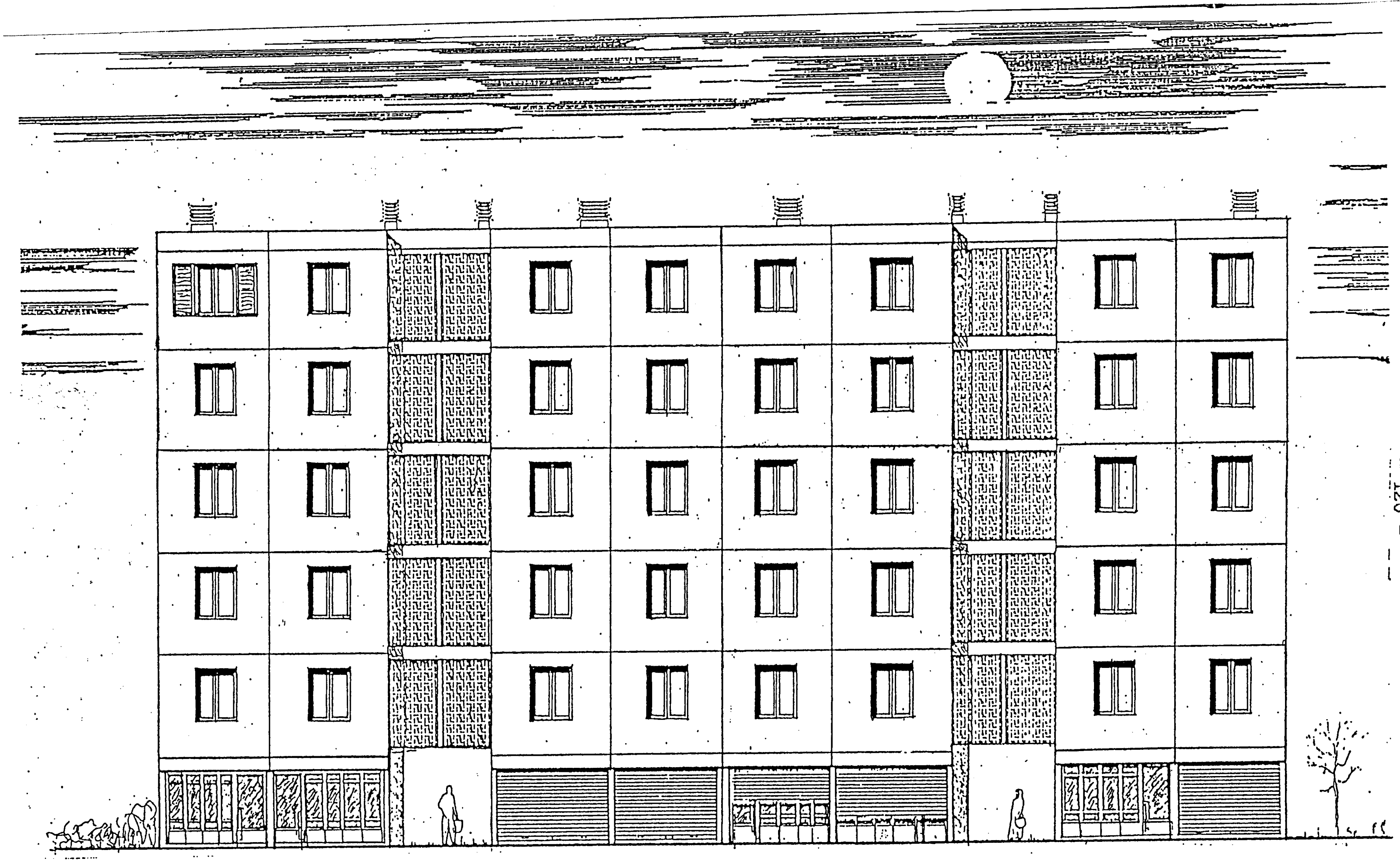


Plate $8c_1$: facade of a prefabricated block of prototype flats showing the flat analysed with its outward looking and the ignorance of shading devices.

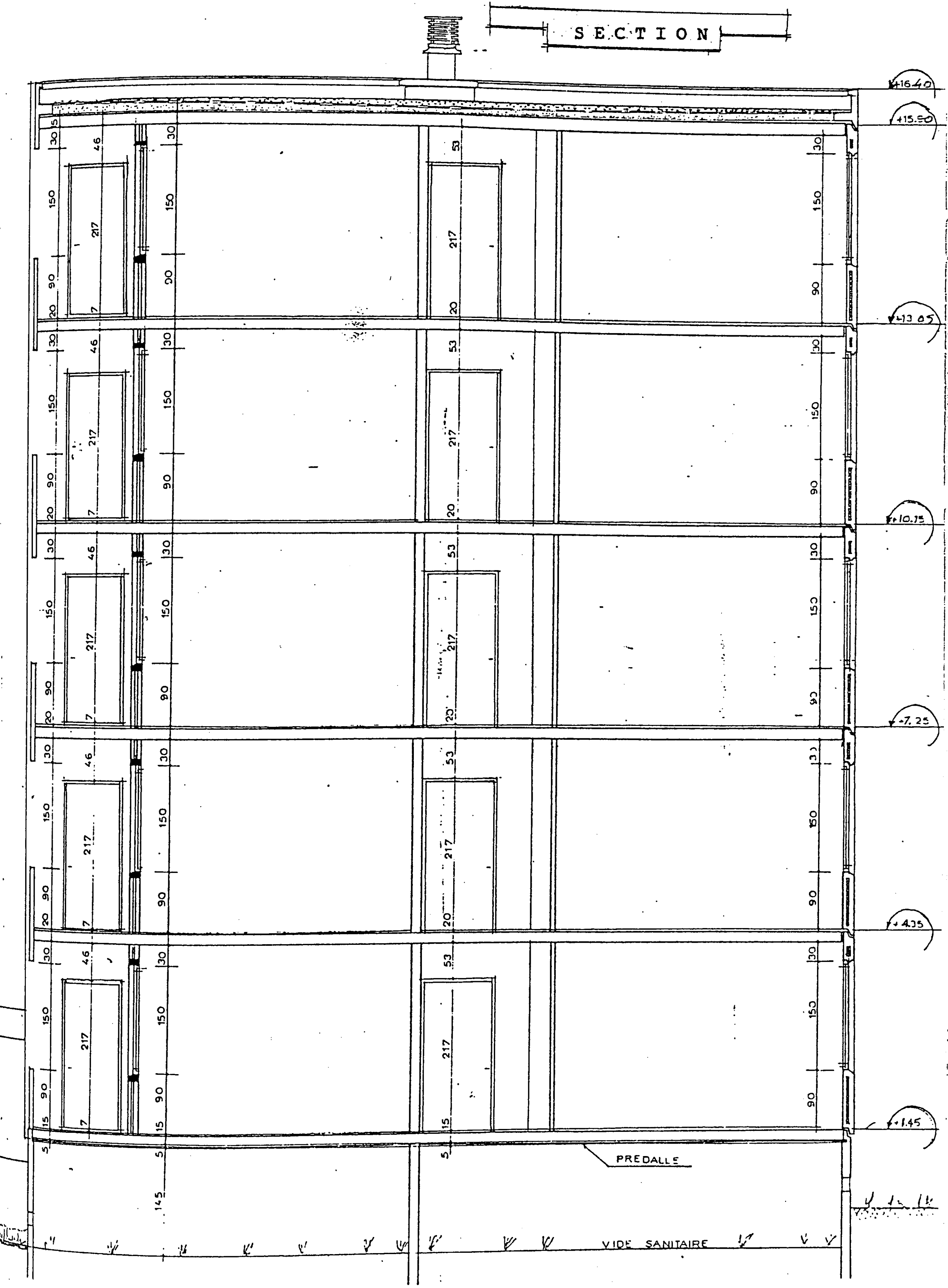
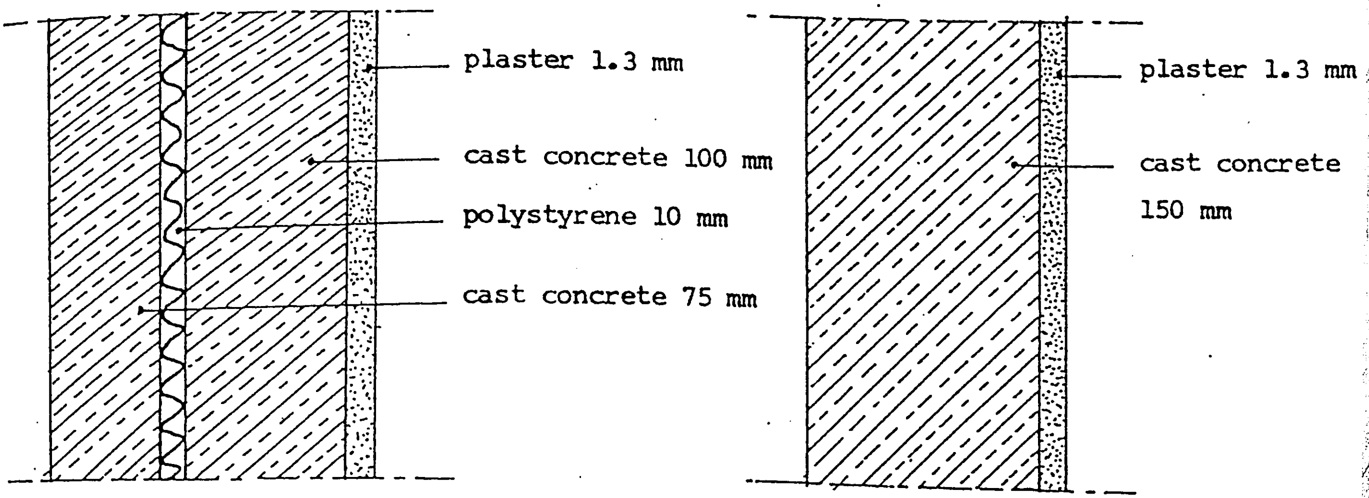
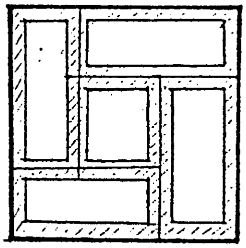


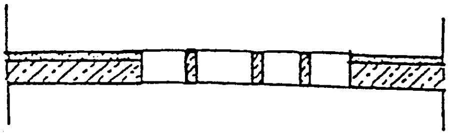
Plate 8c$_2$: section in the prefabricated block of flats showing some constructional details and ceiling height.



wall I

wall II





drying space, external composed wall

Fig 23: Flat: Wall physical characteristics.

Wall I

	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Plaster	600	0.160	1000	0.013
Concrete	2100	1.400	840	0.100
Polystyrene	25	0.035	1400	0.010
Concrete	2100	1.400	840	0.075

Number of layers = 4
No. Construction = 4

Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.055

Properties
u-value : 1.493
Decrement factor : 0.400
Admittance value : 4.017
Surface Factor : 0.554

Time Lag :- 7.777

Wall II

	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Plaster	600	0.160	1000	0.013
Concrete	2100	1.400	840	0.150

Number of layers = 2
No. Construction = 1

Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.055

Properties
u-value : 2.729
Decrement factor : 0.641
Admittance value : 3.786
Surface Factor : 0.559

Time Lag :- 3.384

Wall III

	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Plaster	600	0.160	1000	0.013
Concrete	2100	1.400	840	0.150
Plaster	600	0.160	1000	0.013
Air Space	1.2	0.140	1180	0.025
Plaster	600	0.160	1000	0.013
Concrete	2100	1.400	840	0.055

Number of layers = 6
No. Construction = 1

Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.055

Properties
u-value : 1.339
Decrement factor : 0.279
Admittance value : 4.053
Surface Factor : 0.531

Time Lag :- 11.747

Table 13a: Thermal Characteristic of 5 walls in the flat

Wall IV

	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Plaster	600	0.160	1000	0.013
Concrete	2100	1.400	840	0.150
Plaster	600	0.160	1000	0.013

Number of layers = 3
No. Construction = 1

Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.090

Properties
u-value : 2.072
Decrement factor : 0.433
Admittance value : 3.963
Surface Factor : 0.542

Time Lag :- 5.761

Wall V

	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Plaster	600	0.160	1000	0.013
Concrete	2100	1.400	840	0.100
Plaster	600	0.160	1000	0.013

Number of layers = 3
No. Construction = 1

Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.090

Properties
u-value : 2.237
Decrement factor : 0.596
Admittance value : 3.847
Surface Factor : 0.566

Time Lag :- 4.070

Fig 13b

For calculation, two different mean internal temperatures were taken for each model, an average of 18°C in zone I and 15°C in zone II. For simplicity, air changes are defined by recommended standards. The number of air changes is taken 1.5 AC/hour in zone I and 1.7 AC/hour in zone II which is the average of composite spaces, (bathroom 2 AC/hour, kitchen 3 AC/hour, hall and corridor 1.5 AC/hour, bedroom 0.5 - 1 AC/hour). In the courtyard it was taken 1.6 AC/hour as there was no bathroom. Average 24 hours casual heat gains generated by metabolic process, lighting and applicances are assumed identical in both models:

zone I	- metabolic 62 x N = 62 x 5 =	310	Watts
	- lighting and appliances	55	Watts
	a total of	365	Watts
zone II	- metabolic 62 x N =	310	Watts
	- lighting and appliances	129	Watts
	- cooking (gas)	136	Watts
	- water heating (16 x 5 + 25) =	105	Watts
	a total of	680	Watts

4.3. Thermal performance

4.3.1 Comparative steady state appraisal

The comparison concerned a medium floor flat and the ground floor of the courtyard house, both with approximately the same useable floor area 100 m^2. Since all traditional houses were originally built for extended families they were very large, and hence the decision to use one floor only for comparative purposes.

A number of characteristics such as occupancy, casual gains, rate of ventilation and mean internal temperature were assumed to be the same, so that the comparative performance reflects the plan and construction characteristics.

Analysis of both models adhered to the procedure described in section 4.1. Table 14 and table 15 summarize the specific heat loss calculation for each.

It has been noted that the respective zone I and zone II heat loss parameters infer different demand temperatures in order to achieve the same mean internal temperature values of 18°C and 15°C. If the same demand setting had been chosen, for example 21°C for half house heated on a whole daily cycle with a responsive heating system, we arrive at the following mean temperatures using BREDEM(6)

	zone I	zone II	
Courtyard	19.6	16.4	(°C)
Flat	19.2	14.5	(°C)

zone I, living room	Effective area	U value	Heat loss
Construction description	m^2	$W/m^2\ °C$	$W/°C$
(1) wall - west	25.0	1.43	35.75
(2) wall - east	12.48	1.1	13.72
door - east	2.4	2.0	4.8
window - west	0.48	4.2	2.016
window - east	1.92	4.2	8.06
ceiling	18.04		
Transmission loss	ΣAU	=	68.12
Ventilation loss	0.33 x 1.5 x 46.9	=	23.2
Specific heat loss	H	=	91.32
heat loss parameter	91.32/18.04	=	5.06
zone II, rest of the house	Effective area	U value	Heat loss
Construction description	m^2	$W/m^2\ °C$	$W/°C$
(1) wall - north	11.48	1.1	12.62
(2) wall - west	12.48	1.1	13.72
(3) wall - south	14.56	1.1	16.01
(4) wall - south	7.36	1.43	10.52
(5) wall - north	0.96	4.2	4.03
door - north	2.4	2.0	4.8
window - west	1.92	4.2	8.06
door -	2.4	2.0	4.8
window - south	0.96	4.2	4.03
door -	2.4	2.0	4.8
window - south	0.48	4.2	2.016
ceiling	80.62	0.14	11.28
Transmission loss	ΣAU	=	96.68
Ventilation loss	0.33 x 1.6 x 209.61	=	110.67
Specific heat loss	H_2	=	207.35
heat loss parameter	207.32/80.62	=	2.57
Specific heat loss	$H_1 + H_2$	=	298.67
Whole house heat loss parameter	298.67/91.32	=	3.0

Casual gain	zone I	zone II
metabolic (10 people)	310	310 W over 24 hours
water		105 = (16 x 5 + 25)
cooling (gas)		136
appliances		
lighting	55	129
Total casual gain	365 watts	680 watts

<u>when shutters are used</u>

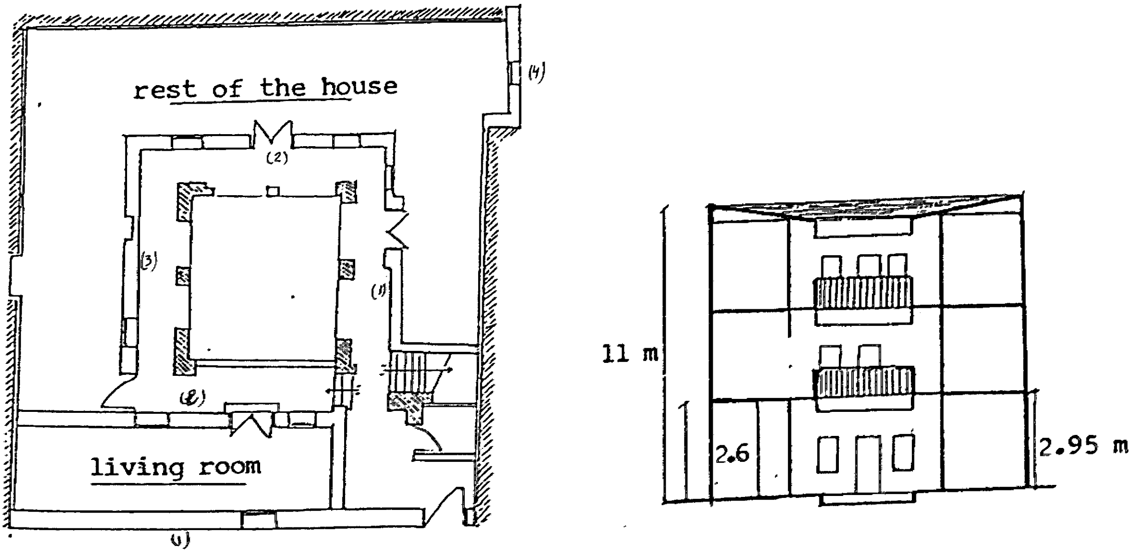
U value window = 1.96 W/m²°C, H = 86.0 W/°C for zone I

AU = 62.37, H = 197.37 W/°C for zone II

<u>when the windows are open</u>

zone I: 0.33nV = 331.74, AU = 81.24 } H = 412.98 W/°C

zone II: 0.33nV = 830.05, AU = 121.45 } H = 951.5 W/°C



section

Courtyard house: schematic representation

Table 14: Summary of heat loss calculation in the courtyard and house.

zone I, living room	Effective area	U value	Heat loss
Construction description	m^2	W/m^2 °C	W/°C
(1) external wall - west	8.64	1.49	12.87
(2) wall - south	2.75	2.73	7.57
(3) wall - north$_{(1)}$	8.64	1.49	12.87
(4) wall - north$_{(2)}$	8.64	1.49	12.87
window - west	1.8	4.7	8.46
door - south	1.89	2.5	4.72
Transmission loss	ΣAU	=	58.9
Ventilation loss	0.33 x 1.5 x 18.87	=	23.2
Specific heat loss	H_1	=	82.1
heat loss parameter	82.1/17.36	=	4.73
zone II, rest of the floor	Effective area	U value	Heat loss
Construction description	m^2	W/m^2 °C	W/°C
(1) wall - west	14.67	1.49	21.86
(2) wall - south	29.58	2.73	80.75
(3) wall - east	23.31	1.49	34.73
(4) wall - north	2.03	2.73	5.54
(5) wall - east	5.51	2.07	11.4
(6) wall - west	3.89	2.24	8.71
(7) wall - north	1.95	1.34	2.61
window - west	3.6	4.7	16.92
window - east	5.6	4.7	26.32
window - north	0.16	4.7	0.75
window - east	0.16	4.7	0.75
door -	1.89	2.5	4.72
Transmission loss	ΣAU	=	219.26
Ventilation loss	0.33 x 1.7 x 223	=	125.1
Specific heat loss	H_2	=	344.36
heat loss parameter	344.36/82.65	=	4.16
Specific heat loss	$H_1 + H_2$	=	426.36
Whole house heat loss parameter		=	4.25
heat loss parameter H/floor area = 4.25	Air temperature t_i		
	zone I	zone II	
	18°C	15°C	

Casual gain	zone I	zone II
metabolic (10 people)	310	310 W over 24 hours
water		105 = (16 x 5 + 25)
cooling (gas)		136
appliances		
lighting	55	129
Total casual gain	365 watts	680 watts

<u>when shutters are used</u>

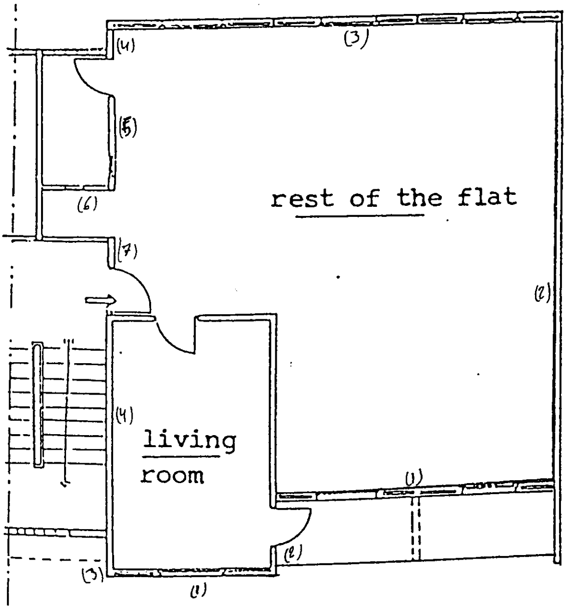
U value = 2.1 $W/m^2{}^\circ C$, H = 77.36 W/°C for zone I

AU = 195.05, H = 320.15 W/°C for zone II

<u>when the windows are open</u>

zone I: (n = 19), 0.33nV = 293.87; AU = 50.38 } H = 344.25 W/°C

zone II: 0.33nV = 1,471.48; AU = 175.48 } H = 1,647.28 W/°C



Flat type = schematic representation

Table 15: Heat loss calculation for the flat

For a whole house heated on a twice daily cycle

	zone I	zone II	
Courtyard	18.4	16.7	(°C)
Flat	17.7	15.6	(°C)

It is interesting that although the flat has a lower heat loss parameter for zone I, the influence of the bounding zone II, with a much lower heat loss parameter in the case of the courtyard house, results in higher temperatures for both zones.

Steady state monthly load calculations summarised in table 16 and figs. 24, 24a, show that for the climatic conditions of Constantine, the main problem for buildings lies with the cooling loads. Figures for both types clearly illustrate this statement. For example, for the coldest month, January, the heating load was 36 kWh/day for the courtyard house and 54.8 kWh/day for the flat. For the hottest month, July, the cooling load was 166.5 kWh/day for former and 246 kWh for the latter. Thus cooling is about four and half times that of heating load. However these figures are based on the optimum internal mean temperature of 18°C and 15°C for heating. If we allow a maximum comfort limit of 25°C, the load would be reduced to 68.16 kWh/day and 90 kWh/day for the two models. Thus the ratio decreases to just over one and half times that of the heating load.

heating/cooling loads / months	Courtyard house		Flat	
	Rate of heat output [W]	load [kWh/month]	Rate of heat output [W]	load [kWh/month]
January	1,499.86	1,115.89	2,283.93	1,700.0
March	775.0	576.6	934.22	695.05
April	243.97	175.65	333.3	239.97
May	-2,721.19	-2,024.56	-4,219.3	-3,139.16
with shutters	-2,527.04	-1,880.1	-3507.75	-2,609.76
at t_i = 25°C	-213.8	-159.06	-192.25	-143.03
June	-5,189.8	-3,736.6	-7,825.66	-5,634.47
with shutters	-4,983.82	-3,588.3	-6,749.94	-4,859.95
at t_i = 25°C	-1,378.97	-992.85	-1,478.8	-1,064.73
July	-6,939.55	-5,163.02	-10,269.69	-7,640.64
with shutters	-6,726.34	-5,004.39	-9,620.47	-7,157.62
at t_i = 25°C	-2,840.0	-2,112.96	-2,703.83	-2,011.65
August	-6,737.18	-5,012.46	-1,031.54	-7,675.5
with shutters	-6,537.23	-4,863.69	-9,606.63	-7,147.33
at t_i = 25°C	-2,615.28	-1,945.76	-3,529.4	-2,625.87
October	-1,727.42	-1,285.2	-3,597.35	-2,676.42
with shutters	-1,634.22	-1,215.85	-3,139.26	-2,335.6
at t_i = 25°C	-78.9	-58.7	-75.93	-56.49
November	516.7	372.02	642.7	462.74
December			1,695.45	1,261.41

Table 16: Comparative steady-state heat output and monthly heating/cooling loads.

Being both related to the same outside temperature, for the two extreme months, the load in the flat is 52% higher than the courtyard house for the heating and 48% for the cooling (negative sign denotes a cooling load) to maintain the same comfort level.

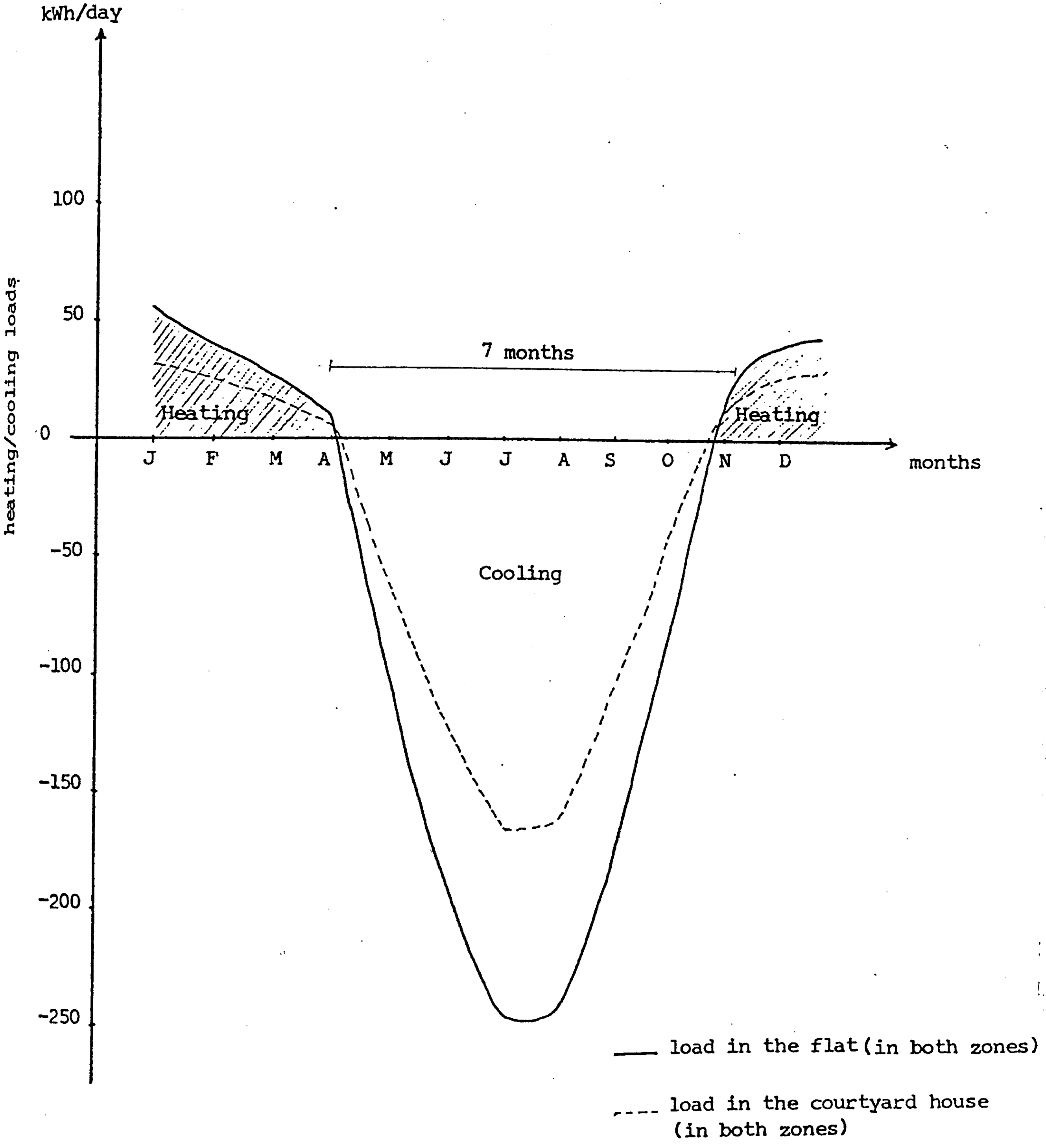


Fig 24: Comparative steady-state monthly heating/cooling loads. The cooling is more important for both types and the period is longer i.e. about seven months.

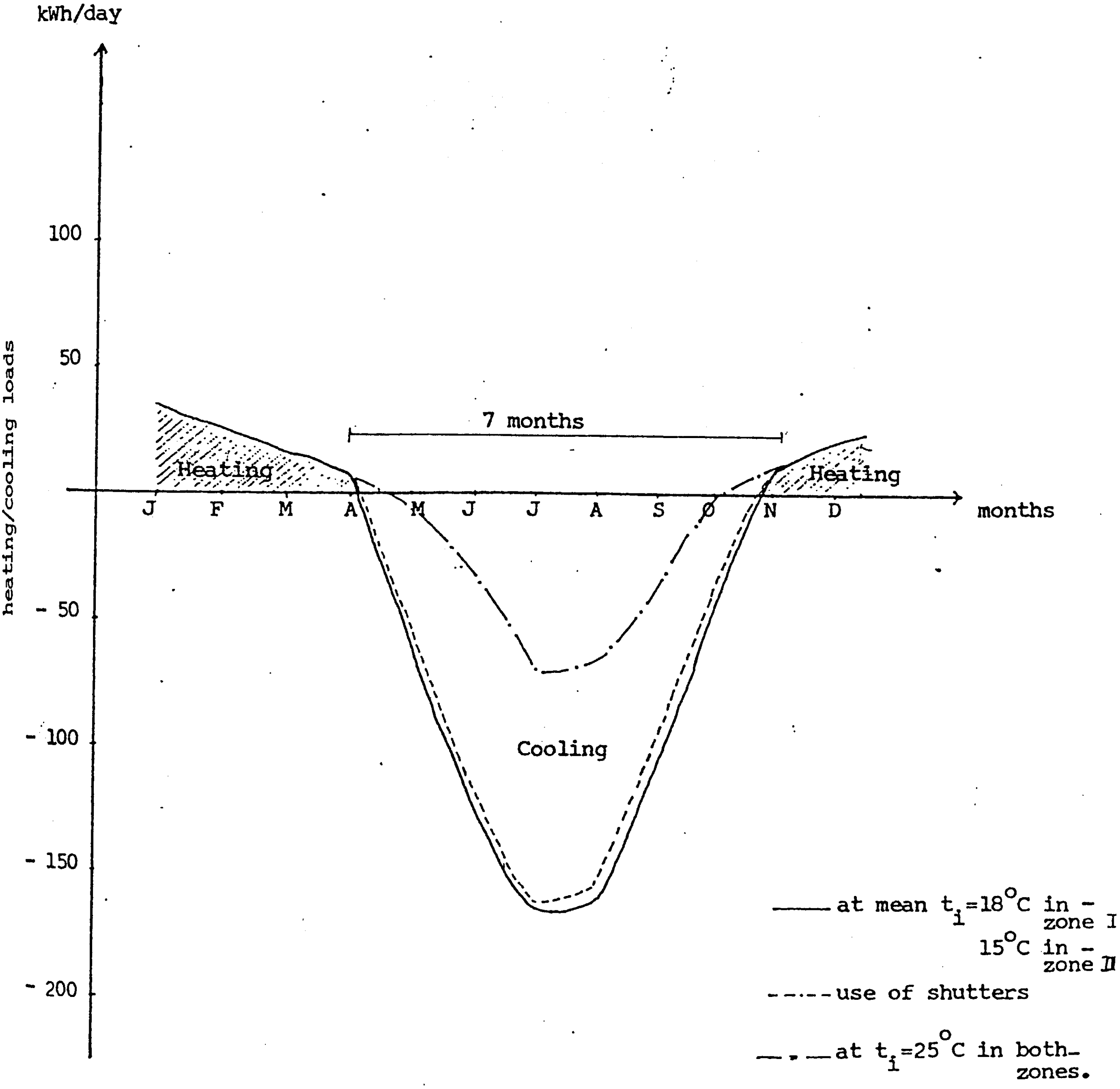


Fig 24a - Mean day monthly loads in the courtyard type, the use of shutters for a 24 h cycle is not significant. For t_i= 25°C, the cooling load approximates that of heating.

It is also found from the analysis that although as a whole floor the courtyard house performs better, tables (17a and 17b) appear to show that the load in the living room of the flat is smaller than in that of the courtyard house. This is perhaps misleading, since the values for zone II include the heat loss from zone I through dividing partitions. We have already shown that starting with identical demand temperatures, zone II influence gives a higher internal temperature in the courtyard house living room. However, the courtyard house living room does suffer from its position in the house together with large wall areas exposed to the street and courtyard. This organisation may be inconvenient for the courtyard house according to modern life and functional specification of spaces, where the living room is assumed to be the most occupied space, requiring higher comfort temperature. In the original courtyard house by contrast, multifunctionality of spaces. together with daily and seasonal migration around the house seeking economic comfort was very frequent.

On the other hand, in the flat its position gives it the advantage of limited exposed area, the smallest dimension being the most insulated wall, and sufficient glazing area to benefit from solar radiation in winter. Therefore the relocation of the living room in the courtyard model, with the application of temperature stratification would give better results for both summer and winter.

Courtyard	Living room: zone I at 18°C [kWh]			Rest of house: zone II at 15°C [kWh]		
January	14.39			21.59		
March	8.82			9.77		
April	2.27			3.58		
		with shutters	t_i=25°C		with shutters	t_i=25°C
May	-17.33	-15.46	-1.83	-47.97	-45.18	-3.3
June	-37.71	-35.77	-11.82	-86.83	-83.84	-21.26
July	-51.94	-49.93	-24.91	-114.60	-111.5	-39.50
August	-50.12	-48.27	-23.26	-111.57	-108.61	-39.50
September				-41.45	-39.22	-1.89
October	0.39					
November	6.18			6.22		

Table 17a: Courtyard monthly heating/cooling loads.

Flat	Living room: zone I at 18°C [kWh]			Rest of house: zone II at 15°C [kWh]		
January	11.41			43.38		
March	5.72			16.69		
April	2.21			5.78		
		with shutters	t_i=25°C		with shutters	t_i=25°C
May	-17.37	-14.07	-1.86	-83.88	-70.16	-2.74
June	-34.75	-31.19	-8.96	-153.05	-130.8	-26.5
July	-47.21	-43.37	-24.76	-199.26	-187.52	-64.89
August	-46.18	-43.57	-21.35	-201.4	-186.98	-63.35
October	-12.22	-10.52	-1.32	-74.11	-64.81	-0.499
November	4.32			11.09		
December	4.9			35.78		

Table 17b: Flat monthly heating/cooling loads.

The analysis also shows that the difference in performance betwen the two models is more pronounced in summer. This effect is mainly caused by shading conditions, as all walls and windows in the courtyard house were shaded most of the day, compared to the limited screening and shading components in the case of the flat. It is noteworthy that when external shutters were applied to the 24 hour steady state appraisal, no significant change in energy load was obtained in either type. In reality, the use of shutters in Algeria is a necessity in all housing units, partly for privacy and security, partly to reduce solar penetration in summer and heat loss in winter. However, their use for the whole day is neither physiologically nor psychologically acceptable, since they reduce daylight penetration, and can make summer internal conditions more uncomfortable at night when the outside temperature drops. This is the main reason for the previous results. Finally, when a maximum comfort temperature (25°C) was allowed, the cooling loads were approximately halved. In practice, it is probable that people would not use air conditioning to reach the optimum comfort temperature of 18°C or 21°C in summer. Reference to chapt 3 shows that the range of comfort temperatures lies between 16°C and 26°C for climates such as Constantine's. Therefore economically there is no incentive to heat up to the upper limit or cool to the lower limit.

As far as the two types are concerned, it is clearly shown in table 16 that the courtyard house performs better;

the load in the flat is 52% higher in winter and 48% in summer; although more favourable boundary conditions are taken for the flat:

- The flat is situated in an intermediate floor and thus only heat flow from external walls was considered in calculation, assuming that the heat flow from floor and ceiling are balanced by the adjacent flats.
- The example chosen has insulated walls which is often not the case in this type of prefabricated building.
- In the courtyard house, the ground floor was selected. It was assumed that only the ground floor was heated and ground floor losses were set at zero, corresponding to the flat. However heat flow through the ceiling was included.
- No account of temperature stratification was taken in the courtyard house as no complete monthly records were available. Thus the courtyard house was related to the meteorological outside temperature, which is the worst possible condition.

This last aspect appears to be one of the key thermal attributes of the courtyard and thus merits further investigation.

4.3.2 Temperature stratification in the courtyard

Extensive theoretical work explores the thermal behaviour of traditional courtyard houses, but very little measured data is available especially in winter.

According to both Durham(9) and Fathi(10), during the hot season the fluctuation of heat exchange between the sun, ground and boundary surfaces is greater in hot climates than elsewhere. The slight cloud cover and the increased transparency of air allows maximum amount of solar irradiation to be absorbed by unshaded surfaces during the day, and be emitted during the night as longwave radiation to the clear sky. In fact, the exposed surfaces undergo much larger changes than the air above them. The highest temperatures during the day are found on unshaded ground, and the same surface becomes the coolest place during the night. The air above it is then cooled in successive layers upwards by convection. The lowest part remains the coolest until the rising sun raises the surface temperature and reverses the process (fig 25).

The courtyard floor and earth beneath act as a combined radiating and storage unit. The surrounding walls shade it and protect it from direct sunlight during most of the day, but leave it open to the coldest part of the sky "zenith" at night.

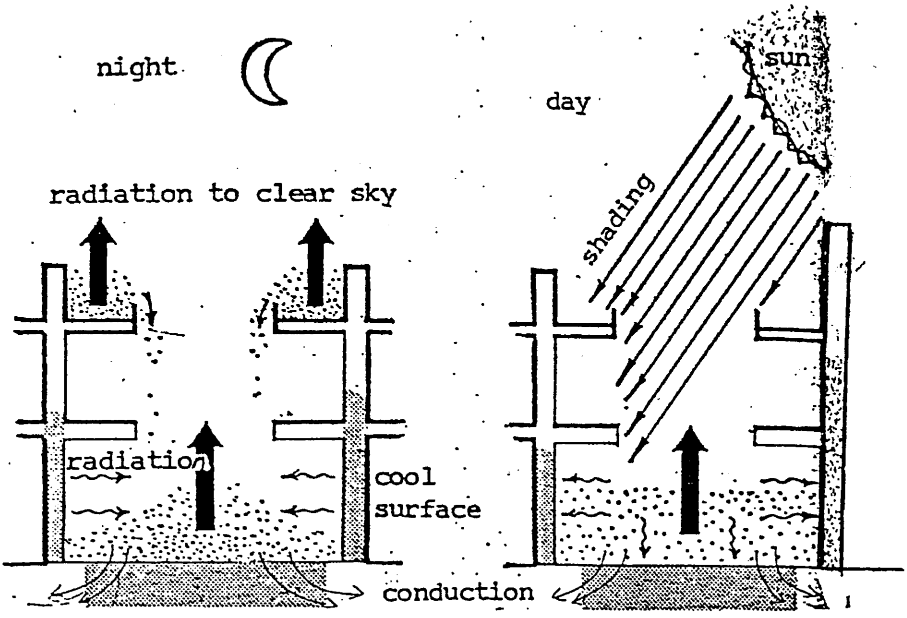


Fig 25: Courtyard as a temperature regulator

4.3.2.1 Measured data for winter

Since no reference was available concerning winter temperatures, some records of temperatures in the courtyard were taken in a three storey traditional house in Constantine for a week in January (see table 18). They show that the average daily temperature at ground floor level is slightly warmer than that on the roof of the second floor. More significantly, the temperature fluctuation is much less pronounced on the ground floor, where the average minimum is 10°C and average maximum 16.7°C.

Days	Ground floor 2 m		Second floor (eaves) 10 m	
	minimum temp. (°C)	max temp. (°C)	minimum temp. (°C)	max temp. (°C)
16th	10	16.5	5	19.5
17th	10	16.5	6	20
18th	10	16.5	5	19.5
19th	10	17.5	6	20
20th	10	17	6	20
21th	10	17	6	20
22th	10	16.5	5	19.5
Average	10	16.7	5.57	19.78
Average range	6.7		14.21	
Mean	13.35		12.67	

Table 18: Readings from 16 - 22nd January 1987 in a courtyard house of "Swika" in Constantine.

Since horizontal surfaces at roof and ground floor levels will have a similar radiant view of sky, it is the configuration of courtyard well which, by limiting convective exchanges and increasing longwave radiant exchanges within a confined space, must account for the marked differential between the two sets of readings.

4.3.2.2 Measured and theoretical data for summer

With respect to summer conditions, Warren(11) indicates that the temperature gradient is more pronounced but acts in the opposite direction, the ground floor becoming much cooler than the upper floors. For example, in Baghdad he states:

"In summer the courtyard acts as a vertical vent through levels with a 20°C differential between the ground floor and the roof". He adds that rooms opening North or East are more preferred to those opening South and West:

"There being a 2°C to 3°C difference even between basements on opposite sides of the courtyard, and the mass construction offers such protection that the temperature in the ground floor may vary as little as 3°C during the whole day". Figure (26) shows the temperature stratification in a Baghdad courtyard house.

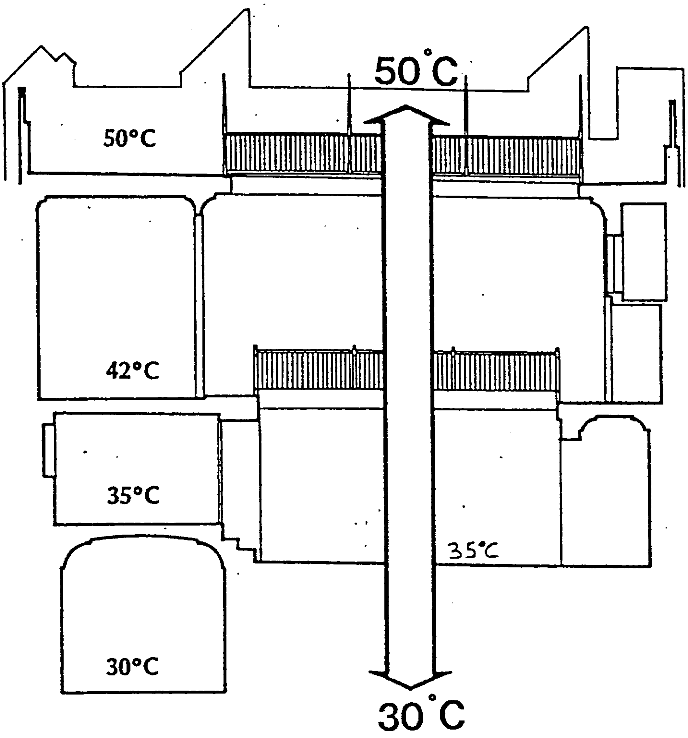


Fig. (26) Temperature stratification in a Baghdadi courtyard house.

Source: J. Warren "Traditional houses in Baghdad".

However, it is probable that these temperatures would be overestimated for Constantine conditions where the mean maximum temperature during the hottest month does not exceed 35.4°C. Moreover, these figures have taken into account the cooling effect of both planting water and the "wind catcher". The latter has a big effect but is not used in a traditional Constantine house. Therefore reference to other works concerning courtyard thermal effect has been used as a guide to the Constantine model.

Work by Nour(12) in Egypt shows that the courtyard air temperature is lower than the air on the roof during a period of 10 to 12 hours per day, and the differential reaches a maximum of 4°C to 7°C. This peak usually lasts about 4 hours from 12.00 to 16.00 in July. It is worth noting that the measured temperatures take no account of any cooling device - water, vegetation, etc. Thus these features seem to be more appropriate for Constantine.

Another work, including measurements carried out by Al-Douri (13) in IRAQ supports that of Nour, in addition he explained clearly the air velocity gradient in the courtyard due to the temperature differential or stack effect. The conclusion is that there is a turbulent air movement at the upper parts of the courtyard by which an increase and decrease in temperature could take place. However, Al-Douri found that the lower part of the courtyard maintained a lower air velocity particularly at the bottom where people carry out their daily activities and have their rest. The phenomenon of air tending to rise is well known. The reason for the warm air rising is due to its lower density than that of cold air, the variation in air density being directly proportional to the absolute temperature of the air. Therefore the variation in air density produces a convective flow of air. Hence, the turbulent air movement is due to temperature difference of air strata at different levels of the courtyard inducing a pressure difference between the courtyard and the highest levels at which the air stream maintains highest velocity. In the evenings, there is generally less turbulence compared to the morning hours. this is due to the absence of radiation and the low pressure difference between top and bottom of the courtyard as the heating effect is limited to the longwave radiation from the surrounding surfaces. Here again trees and water are suggested by Geiger(14) and Koenigsberger(15) to substantiate the low wind velocity to the lower part and turbulent wind in the upper parts of the courtyard, especially for cooling purposes in summer.

4.3.2.3 Effect of winter and summer temperature stratification in load reduction

The application of the measured mean 24 hour temperature gradients in January had a significant effect in the reduction of heating loads as well as the rate of heat loss through the structure. The load decreased to 31.12 kWh/day from 36 kWh/day, i.e. 16% difference for only 0.67°C mean increase in the courtyard temperature.

With respect to summer, steady state analysis had little influence on the results as the mean daily courtyard temperature was close to the mean outside temperature. However, the saving was much more significant when only parts of the day were considered, taking into account the dynamic effect for both summer and winter. Thus, let us now move to examine the capacitance influence on respective zones during different parts of the daily cycle.

4.3.3 Comparative dynamic appraisal

4.3.3.1 Fabric effect

In nature, the variation of climatic conditions produces a non steady state daily fluctuation in temperature and radiant intensity. The architectural and physical properties of the building envelope modify the maximum and minimum internal air temperature, but also the time at which they occur. While thin surfaces, such as glazing have very little dynamic influence - the temperature profile inside a greenhouse will closely follow the outside temperature - heavy opaque boundary surfaces, delaying and damping external fluctuations, will be relevant to particular occupancy patterns during a 24 hour period.

In winter when external surface temperatures are lower than the heated interior, the heat capacity of the envelope only smooths over the fluctuations, without affecting the direction of the thermal gradient. But in summer, the external surface temperature may be above the internal during the day and below during the night, permitting heat flux in each direction.

To understand and compare the respective influence of thermal diffusivity - ratio of conductivity to volumetric heat capacity - characteristics of the opaque elements, periods of occupancy were assumed in each zone in each model. Zone I is occupied from 8.00 to mid night but the number of occupants is different in two sub-periods. From 8.00 - 18.00 and 18.00 - 24.00. Zone II is occupied from

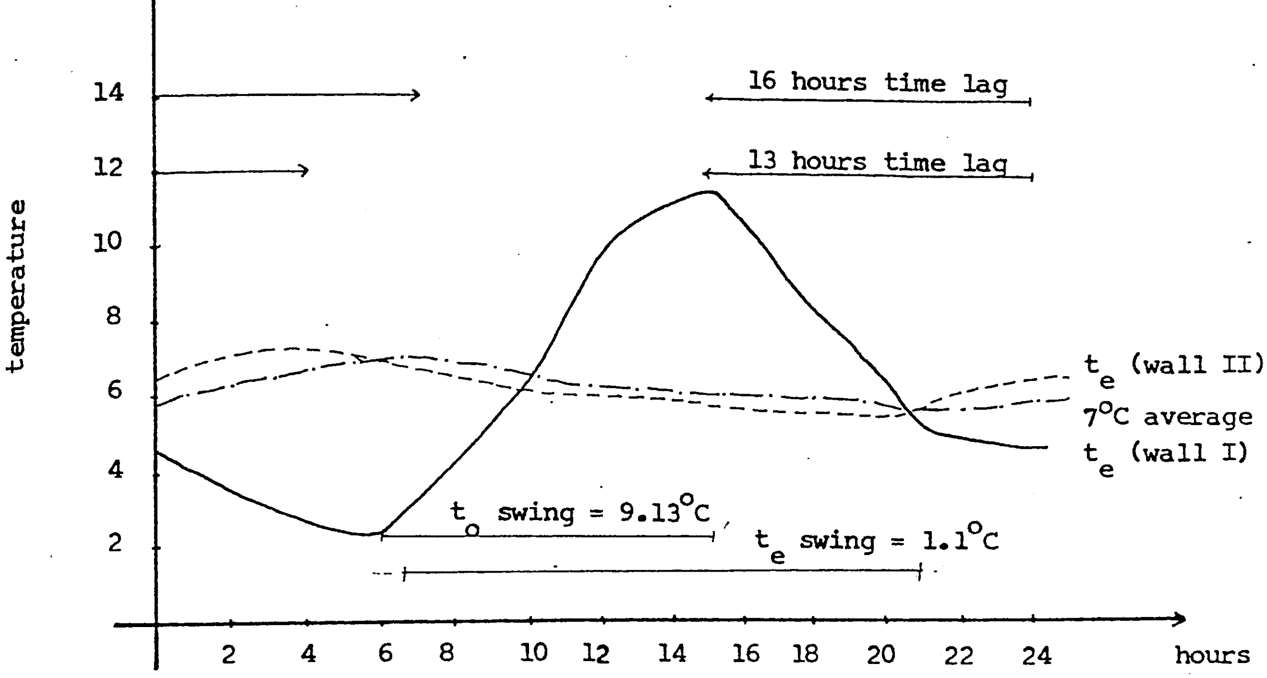
20.00 to 8.00 in the morning, with internal temperatures of 21°C and 15°C respectively in winter and 21°C for both zones in summer.

Hourly values of air temperature and intensity of incident radiation (appendix A), served as input data for the micro-computer programme "$\mu - t_{eq}$". The thermal model gives the hourly heat flow for each multilayer constructional element as well as the time lag, decrement factor and the equivalent external temperature. The analysis was undertaken for the two extreme months, January and July.

(Fig. 27 and 28) and appendix D summarise the cyclical thermal performance of the walls and show that for the courtyard house, the massive walls give an equivalent external temperature close to the daily mean at all times of the day with a time lag varying between 13 and 16 hours. However big savings can be obtained during the period 10.00 and 22.00 where the average equivalent external temperature is 26°C in July compared to 31°C for outside temperature. It can also be seen that the temperature fluctuation is negligible, as it is damped throughout the day by the structure. Moreover for this time lag the maximum outside temperature peak coincides with the trough of the minimum equivalent temperature.

For the flat the average equivalent external temperature is higher at 28°C. More significantly its daily profile follows the outside temperature fluctuation more closely. The time lag varies between 4 hours for the

Damping effect of walls in January with t_e profile



t_e - Equivalent external temperature

Damping effect of walls in July with t_e profile

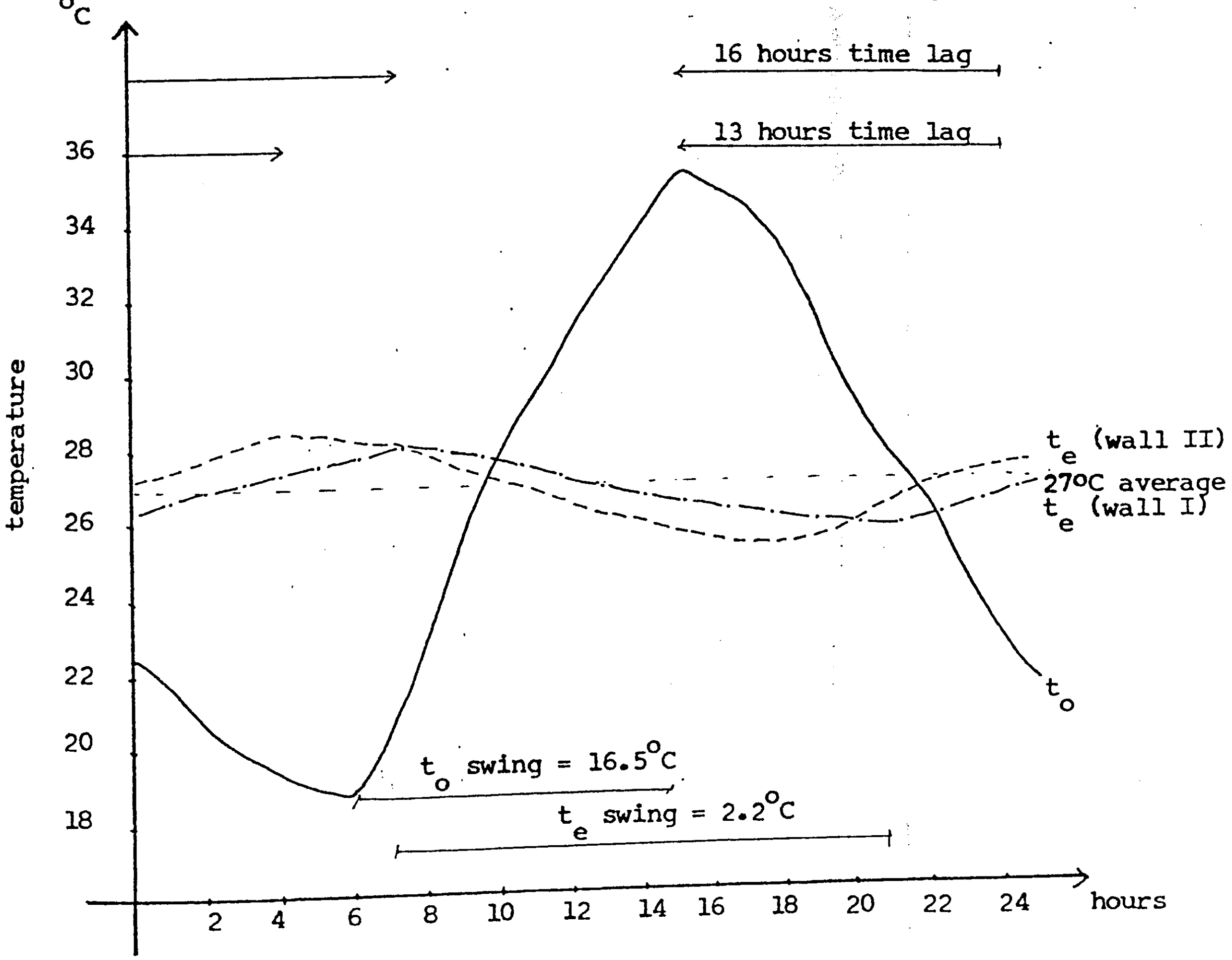


Fig 27: Thermal cyclic performance of walls in the courtyard house in January and July.

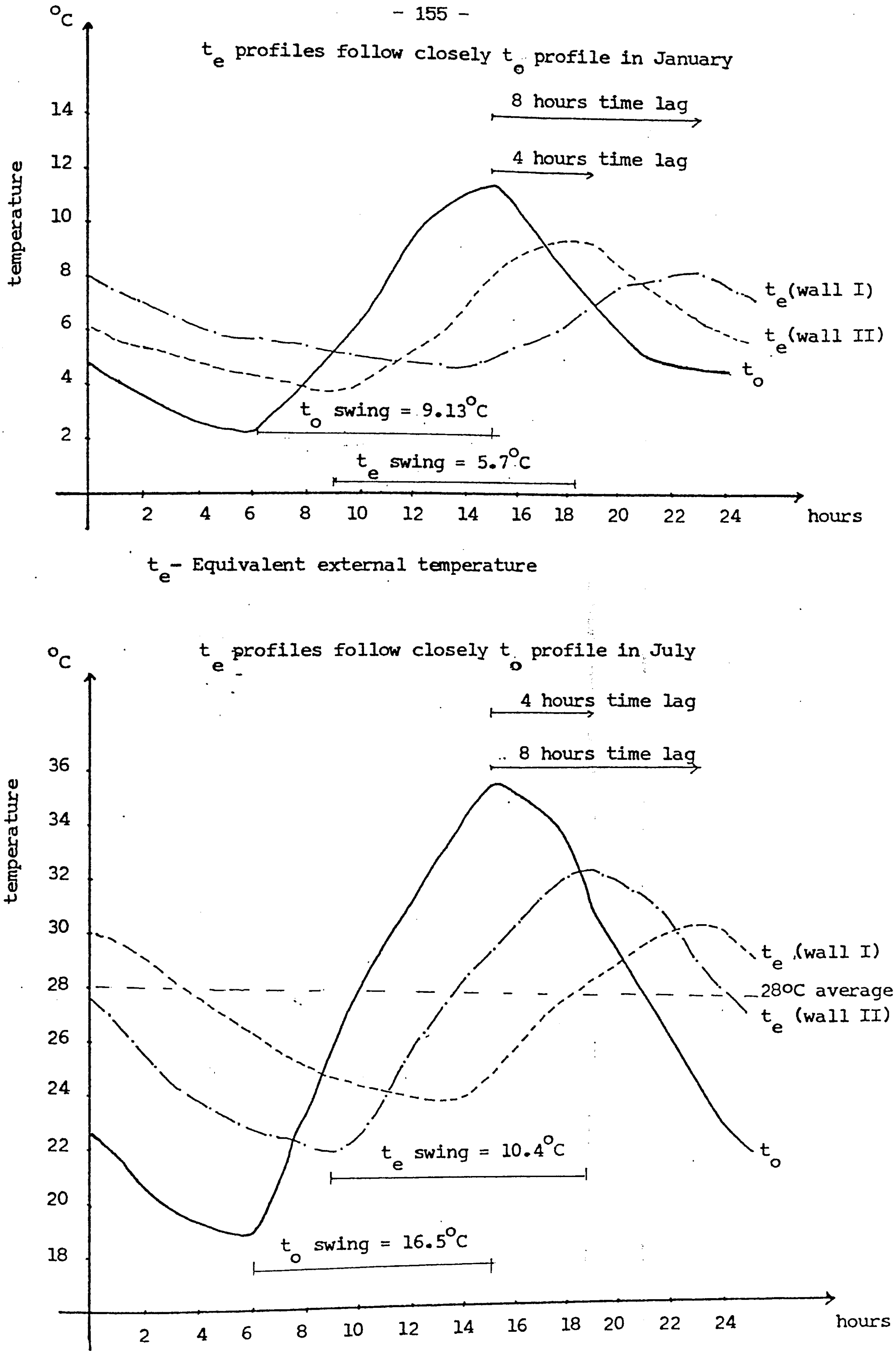


Fig 28: Cyclic thermal performance of walls in the flat in January and July. (results of the computer programme)

uninsulated wall and 8 hours for the insulated one.

It was found from the analysis that for the same outside conditions the daily load in the flat was 38% higher than the courtyard house in January, i.e. 30 kWh against 41.4 kWh (see Appendix D for results). When temperature gradient in the court was considered, the load dropped to 23 kWh or by approximately 30% enlarging its difference to the flat to about 50%. It can be concluded that the effect of heavy mass is very significant in the reduction of heating load.

4.3.3.2 Ventilation effect

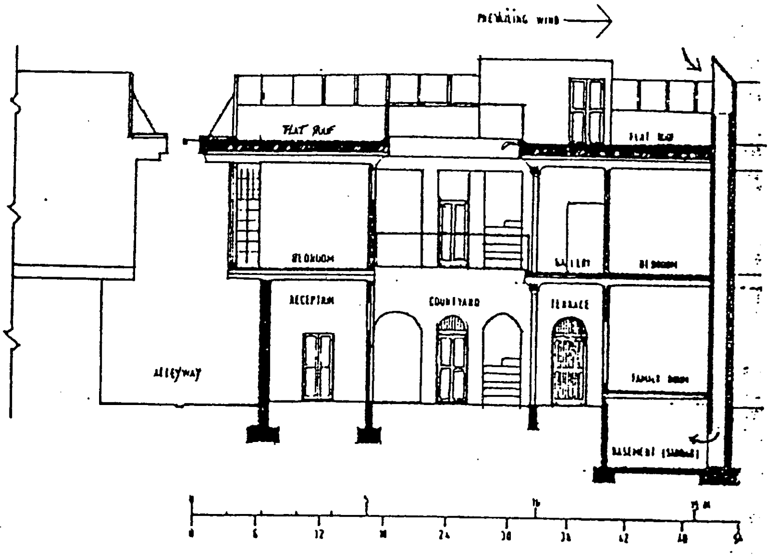
In July when windows were assumed open during the night with an assumed 1 m/s wind velocity, ventilation rates were calculated to provide 23 AC/h in zone I and 12 AC/h in zone II in the courtyard house, and 19 AC/h and 20 AC/h in the flat. It was then found that the daily cooling in the courtyard model was 75 kWh against 99 kWh in the flat to maintain 21°C in both zones. When windows were supposed closed at night, the cooling load in the courtyard house dropped to 51 kWh compared to 58 kWh in the flat.

It is worth noting that an increase in ventilation during the night in July increased the load in both models since the outside air temperature exceeds the internal desired temperature of 21°C. Also the assumed value for wind velocity is probably high in the case of the courtyard where according to Al Douri a value between 0.3 - 0.6 m/s is more probable. However, although the air velocity in the court is low, the night temperature at the bottom of the court is higher than the top due to the radiation from the boundary mass (see fig. 25). The two night time courtyard characteristics, lowering velocity but raising temperature, thus appear to cancel in comparison to the open flat situation. Nevertheless the courtyard may have beneficial ventilation effect in early evening when cooler air from the court can be introduced. If cooling devices were taken into account, say the use of water and vegetation, night temperatures in the court could be lowered below outside temperature at roof level. Otherwise it appears that ventilation would bring no relief for cooling loads. However, if we allow a maximum rather than optimum comfort temperature, even with the previous conditions, ventilation shows a potential for cooling in both models as the outside temperature falls below 25°C during the night. This scenario probably reflects realistic conditions where internal air and surface temperatures have risen well above 21°C say to 30°C during the day due to lack of cooling facility.

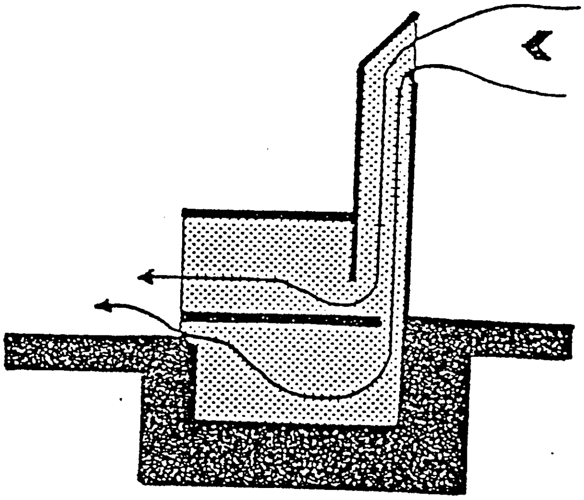
Thus the load to maintain 25°C in the courtyard house dropped to 29 kWh, and when the shutters were also used for the second period in the living room, the load falls to 26 kWh. Results also show that ventilation had a significant effect in zone II where the load dropped from 32 kWh to 2 kWh. But with very low differentials, large rates of air change would be required, and the courtyard clearly offers a greater opportunity to maintain a reasonable differential for longer periods during the daily cycle.

It can be concluded that a high thermal capacity structure has a big advantage for the Constantine climate in both summer and winter. But in the absence of natural cooling devices this may be a problem. During summer nights when outside temperature drops, the interior remains too warm for comfort.

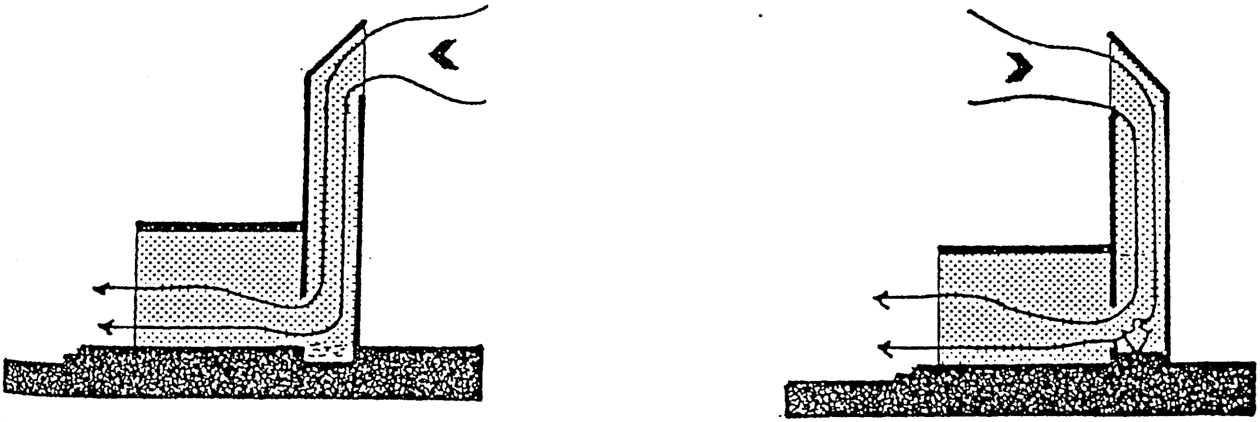
To overcome this problem, people in traditional houses practice a daily migration such as sleeping in the courtyard or galleries. Other alternatives can be used such as building the upper floor for bedrooms of lightweight materials to increase heat losses at night when the temperature drops, so that they can be used for sleeping. This solution was sometimes used in Baghdadi traditional houses and it could well work in Constantine provided care is taken to insulate. It follows that the use of natural cooling aids such as planting and water sources, which are already used in the Constantine courtyard house, still offer economic environmental cooling. Planting reduces air temperatures by latent heat of evaporation as well as shading. Then ventilation may be a very effective system for cooling in this type of design, since without adequate ventilation, heat gain cannot be removed at a rate to prevent excessive heat building up. Another possible method of both further cooling air and increasing rates of ventilation is the utilisation of "wind catchers" which are very appropriate to courtyard house form and are used in



Example of a wind catcher used in a Baghdadi courtyard house.



Where the basement walls of the shaft are damp, the air travelling down through damp walls is cooled evaporatively by vaporizing water on the walls.



The air coming down through the wind-catcher is cooled evaporatively by passing over the pool of water before being discharged into the room.

A porous eartherware pot full of water causes the air coming down through the shaft to be cooled evaporatively.

Fig. 30: Function of "wind catcher" and its various techniques.

Source: Sodgar Behzad "passive solar designs: an approach to energy conservation in hot dry climates with special reference to IRAN.

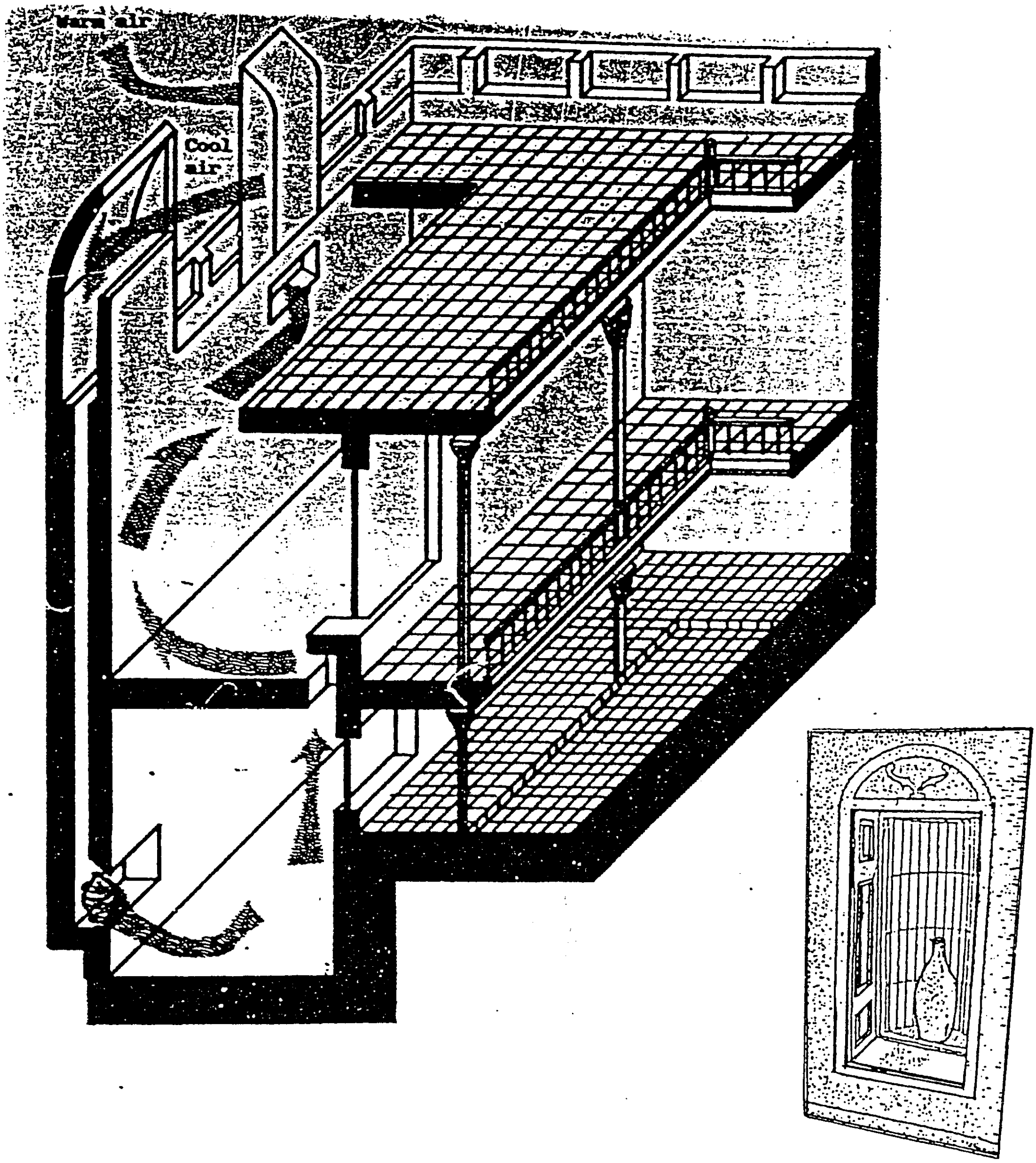


Fig 30a: Beneficial effect of "wind catcher" in a courtyard house.

Source: Al Douri, "Building materials and thermal behaviour in hot dry climates with particular reference to IRAQ", Ph.D theses, Newcastle University, 1985.

The figure shows the cool air circulation between the basement and the top rooms in the courtyard house using a wind catcher and chimney duct principles. On the right, the sophisticated window enhancing the evaporative cooling (using an earth pot in the top part of the wind catcher).

housing in hot regions. Reference to many works in Iraq, Iran, Egypt show their high effectiveness their technique is clearly shown in (Figs. 30, 30a).

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Chapter 5

ARCHITECTURAL IMPLICATIONS

Building design embraces a large number of parameters that affect the thermal behaviour of the building. These parameters include the climatological ones (already discussed in chapter 2) and the design variables. While climatological parameters are environmental variables outside human control, the second category are under the control of architects. These include orientation, the exposed surface area of the outer envelope, window size and shading devices, building shape and finally the thermo-physical properties of the building envelope.

The thermal analysis has shown that the courtyard house performs more favourably both in terms of heating and cooling loads. Having identified certain thermal behaviour characteristics related to particular parameters it is worth attempting to define the general architectural implications.

5.1 Layout in an urban context

As the house cannot be considered in isolation but rather integrated within a whole city or town structure, this aspect should be given special attention as related to energy. Thus, the objective of planning controls may be on the one hand to ensure a certain amount of solar radiation on appropriate surfaces, but on the other to protect from unwanted radiation. Positive energy conscious planning can create comfortable microclimate conditions around the house, but the requirements are different for each climatic condition.

In cold climates the town structure is organised in such a way that buildings are grouped. The spacing is very important. In Britain 20 - 23 m is suggested between two storey terraced houses(7).

In hot climates, by contrast, the aim is to reduce the solar heat gain. Compact planning and narrow streets provide shade and reduce exposed area. In a composite climate such as in Constantine, a compromise must be found to suit both the cold and hot seasons. The traditonal type of layout was compact and resulted in houses with inner courtyards accessed via narrow streets (see plate 3a). This outcome gives a better chance for buildings to protect each other from outside heat and cold. The width of the streets is such that even with high altitude sun angle which occurs at noon in mid summer, little direct sun strikes the facades. Thus even the streets are designed to create a comfortable microclimate and function in the same way as the courtyard, to regulate the temperature. Thus from the energy point of view, this planning is very efficient. However, one disadvantage is the difficulty of providing the necessary access infrastructure needed today for adequate servicing and safety.

Unfortunately the modern layout takes no account of environmental factors. Isolated flat blocks are arbitrarily placed leaving a maximum area exposed to the outside, thus increasing rates of heat loss and gain. Also straight, wide asphalt covered streets surround the buildings, worsening discomfort in summer as a result of ground reflected radiation (see plate 6).

Figure 31 shows the proposed urban setting in a modern context. It can be seen that with small 2-3 storey courtyard units, we can reach a very compact mass, and equally provide the necessary facilities as well as high density. It is worth mentioning here work done by Settouane(2) showing that the courtyard house unit is competitive to flats in terms of density and land use, although one of the reasons for the implementation of the latter was land use efficiency.

5.2 Building shape and orientation

The form of the house can be adjusted to take advantage of the beneficial aspect of the climate and reduce the impact of unfavourable aspects. Assuming orthogonal geometry, a compact building shape as close to a cube as possible is the ideal solution in terms of energy efficiency (Markus(3), 1980, Donalts(4), 1983). From a purely thermal argument, the ideal situation would be an underground cave. Figure 32 indicates the seasonal temperature fluctuation at different depths in an area where the outside temperature swings as much as 22°C annually. The temperature of the soil is virtually constant at a depth of 8 metres in open ground. However, there are obvious difficulties of convenience, economy, lighting and ventilation. Assuming

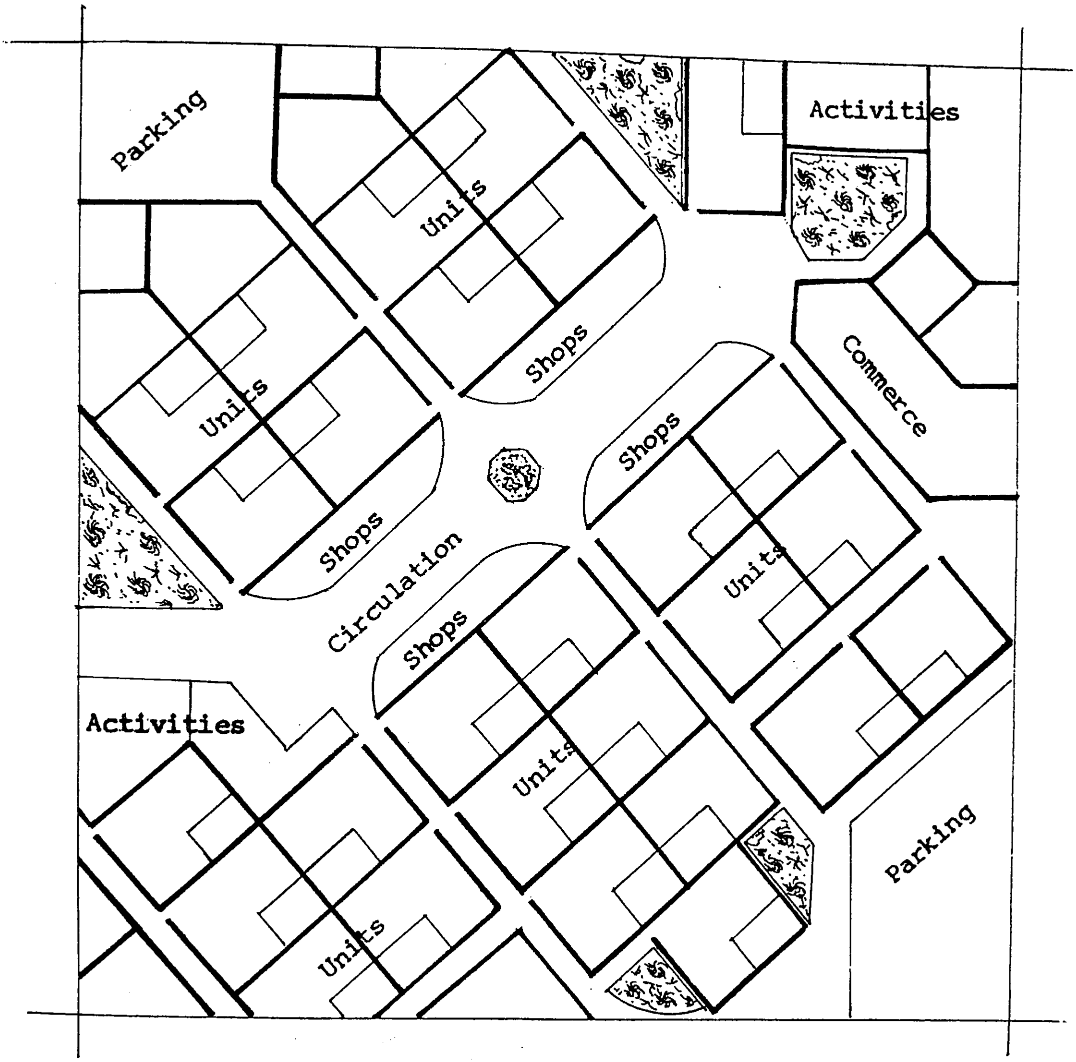


Fig 31: Proposed urban setting: groupment of housing units (schematic representation).

then the case of buildings above ground, but without openings, the best solution is the hemisphere, the cube or at least a square house plan.

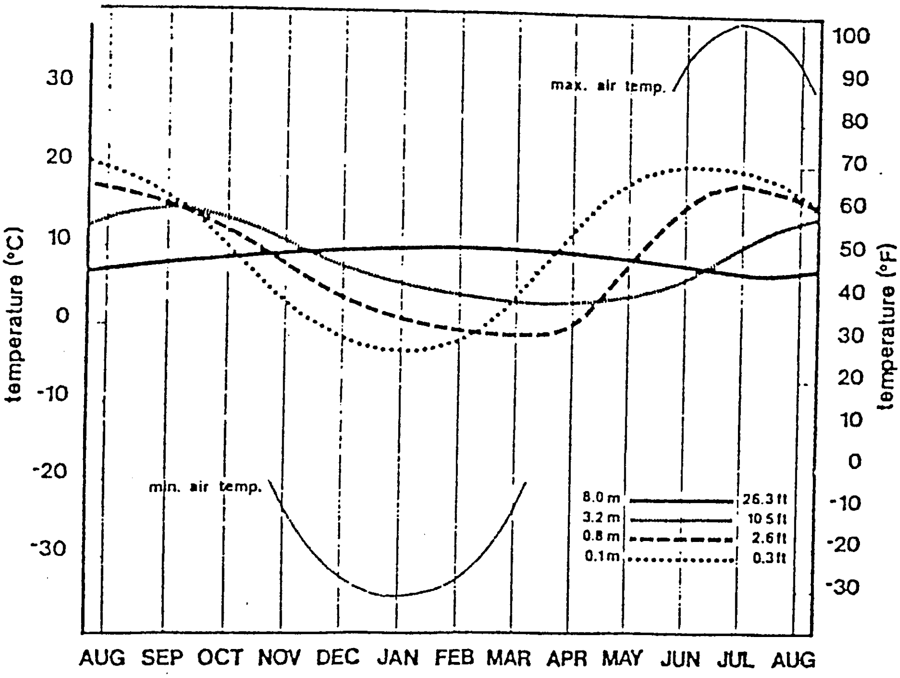


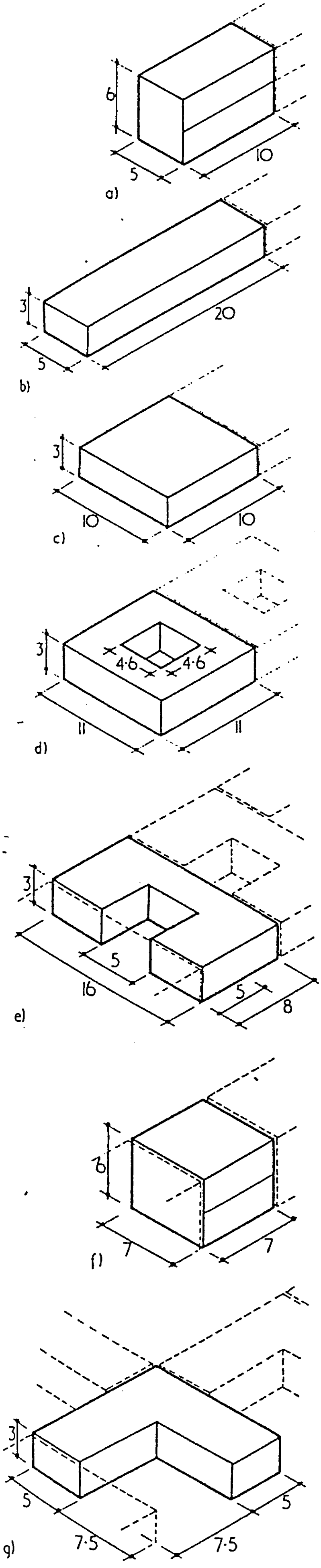
Fig 32: Annual temperature fluctuation of the ground

Source: Ekistics No. 307, July/August 1984.

The volume of a house will influence its thermal capacity, i.e., its ability to store heat, while the exposed surface area will be related to the rate at which the house gains or loses heat. Therefore the ratio of volume to surface area is an important indicator of the speed at which the house will heat up or cool down. Evans(5) indicates that when the temperature range is high, a high volume to surface ratio is preferable. The room height has also an effect. The living conditions fix the minimum height to 2.2 m. This condition is not critical in the presence of adequate ventilation and thermal comfort, and would be economic in building materials.

The objective then is to optimise the building shape so that the fabric heat transfer will compromise according to the climate, thus emphasising the regional character.

As far as the two models are concerned, the courtyard house is seen to answer more effectively the requirements, as it is nearly a cube with reduced exposed surface area. However, the most significant feature of this shape is the courtyard concept and its role as a light well and air shaft with beneficial temperature stratification. The provision of trees and water will also help in evaporative cooling of the air in summer. Its geometry is partly determined according to the latitude to maintain shade to all rooms in summer and receive solar penetration to some rooms in other seasons, the courtyard being higher than its width. This inward-looking plan was also the solution to compact planning. Work by Mohsen(6) in his theoretical study, found that a square courtyard of varying dimensions yields the least change in irradiation caused by change in orientation, and courtyard forms with a lower ratio of perimeter to height are the least affected. Work by Sadha(7) based on Arumi's computer programme showed that the orientation is not important for a courtyard form at latitudes 30° to 40° and that multiple small courtyards are better than few large ones. Evans also shows that the courtyard form generates the lowest room depths (figure 33), an important feature where good internal air flow is required. The flat permits cross ventilation, but not for individual rooms, and the



Proportions of different building forms (all building forms have the same volume and floor area)

Situation	Surface area	West wall	South wall	Building depth
(a) Detached	*230*	*30*	*60*	*5*
Centre terrace	*170*	—	*60*	*5*
(b) Detached	*249*	*15*	*60*	*5*
Centre terrace	*219*	—	*60*	*5*
(c) Detached	*219*	*30*	*30*	*10*
Centre attached	*159*	—	*30*	*10*
(d) Detached	*287*	*46·8*	*46·5*	*3 approx*
Centre terrace	*222*	*13·8*	*46·5*	*7 approx*
Dwellings adjoining on 3 sides	*188*	*13·8*	*13·8*	*10 approx*
(e) Detached	*274*	*48*	*39*	*7 approx*
Centre terrace	*193*	*15*	*39*	*7 approx*
(f) Detached	*216*	*42*	*42*	*7*
Centre terrace	*132*	—	*42*	*7*
(g) Detached	*250*	*37·5*	*37·5*	*5–7*
Centre terrace	*212*	*22·5*	*37·5*	*6 approx*
Dwellings adjoining on 3 sides	*190*	*22·5*	*22·5*	*7 approx*

Fig 33: The courtyard form gives the lowest room depth (d), an important feature where air flow is required.

Source: Evans, M., "Housing, Climate and Comfort", 1980.

rectangular shape exposing three facades gives a high rate of heat transfer promoting discomfort from both heat and cold.

5.2.1 With respect to solar radiation

For modern building forms orientation has a substantial influence on the end use of energy consumption of buildings. This is governed on the one hand by the amount of radiation incident on the building envelope, on the other hand by the local wind pattern as it affects ventilation and infiltration rates.

For comfort the optimum orientation is when solar radiation is at its maximum during cold season and at a minimum during overheated period. Solar radiation plays a dominant role in affecting the indoor micro-climate either by entering directly through windows or conducted through the fabric, the former normally being the dominant influence. Many attempts have been tried to determine the optimum orientation. Olgyay(8), concluded that orientation eastwards from south gives a better performance and a more equal heat distribution. He promoted the use of sol-air temperature, since air temperature is lower in the morning and higher in the afternoon.

Buchberg(9) studied the effect of orientation and solar radiation of a building situated at 36.4°N, taking the basic square plan and changing width to length ratios. He concluded that buildings with the same orientation, but between 1 - 1.5 to 1 - 2.5 width to length ratio is the most favourable to minimize solar collection in summer and maximize it in winter. In all cases the roof absorbs the highest amount. For Constantine, referring back to chapter 2 and according to Mazria[70], for latitude 36°N, it can be concluded that a building elongated on an east-west axis exposes the larger south side to maximize heat gain in winter, while minimizing it in summer (figure 34).

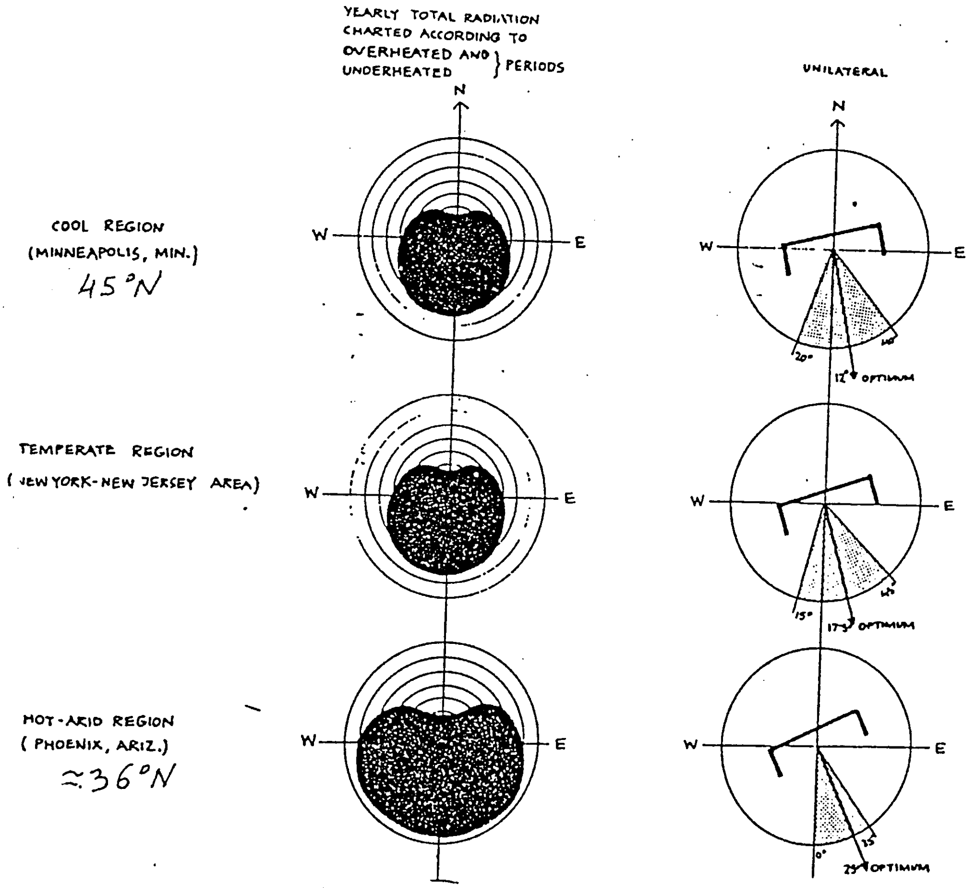


Fig 34: Regional orientation chart

Source: V. Olgyay, "Design with Climate", this shows for about 36°N orientation North-South is better. However the optimum can be reached with slight deviation of 25° S.E.

Moreover, he indicates that for all latitudes 32° to 56°N, the south vertical receives nearly three times as much radiation in winter than East or West. During summer, the situation is reversed. However, the amount of elongation depends on climate. In Constantine, a more compact building form is required. The significance of orientation also depends greatly on the external colour of the envelope, size of windows and shading devices as well as the thermophysical properties of the fabric. In climates such as Constantine, when surfaces are whitewashed and windows are small, orientation is of little significance. But when windows are larger, north-south windows are prefered to east-west ones.

5.2.2 With respect to wind

Wind velocity increases with height above the ground and the difference in pressure between inside and outside will cause air to flow into the building through openings or cracks, generating either heat loss or heat gain (figure 35). Thus wind effect may be used to produce natural ventilation for cooling purposes. For architectural practices, the best orientation of openings to give optimum conditions is normally assumed to be that facing the prevailing wind but Givoni(11) found that in some cases better ventilation can be achieved when the wind is oblique to the inlet opening. When the wind is at 45° to the inlet, air takes up a turbulent circling motion in the room, increasing flow along the side walls, and in the corners.

However, when the two windows are located in adjacent walls, better ventilation is obtained with wind perpendicular to the inlet, than the oblique (table 19). Landsberg(12) indicates that with cross ventilation, the air flow through the house is about 30% of the outside wind velocity. In rooms with only a single window and closed door, air flow will be only 10% of the outside wind velocity.

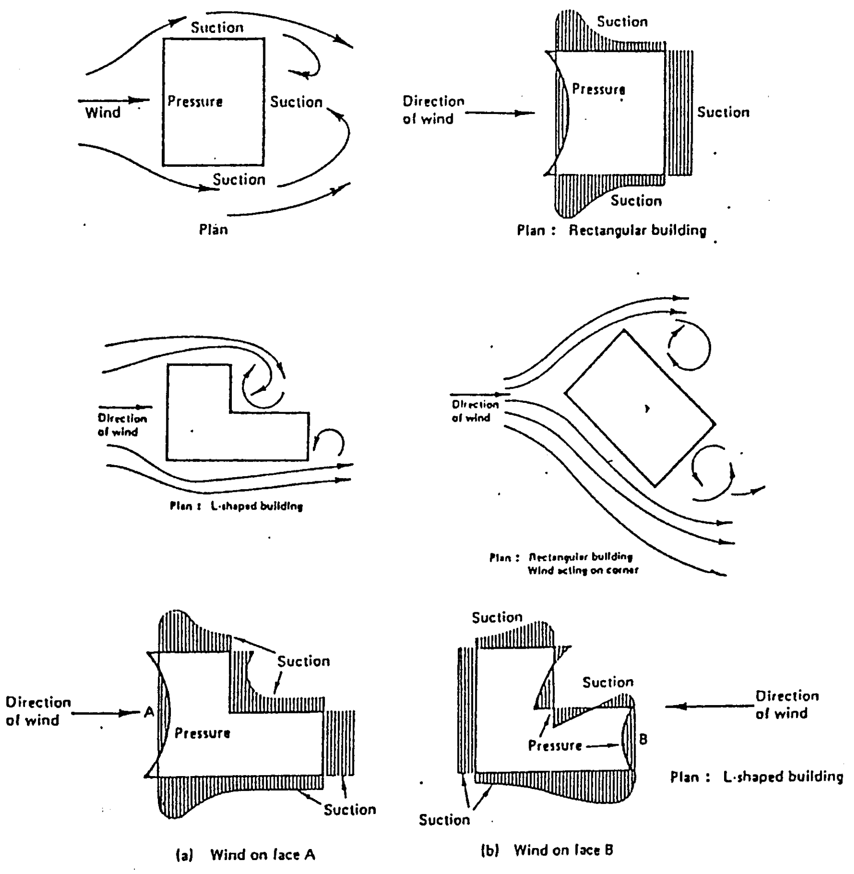


Fig 35: Wind pressure and suction around buildings

Source: T.A. Markus and E.N. Morris, "Building, Climate and Energy".

EFFECT OF WINDOW LOCATION AND WIND DIRECTION ON AVERAGE AIR VELOCITIES (PER CENT OF EXTERNAL VELOCITY)

Inlet width	Outlet width	Windows in opposite walls		Windows in adjacent walls	
		Wind perpend	Wind oblique	Wind perpend	Wind oblique
1/3	1/3	35	42	45	37
1/3	2/3	39	40	39	40
2/3	1/3	34	43	51	36
2/3	2/3	37	51	--	--
1/3	3/3	44	44	51	45
3/3	1/3	32	41	50	37
2/3	3/3	35	59	--	--
3/3	2/3	36	62	--	--
3/3	3/3	47	65	--	--

Table 19 Effect of window location and wind direction on average air velocities.

Source: B. Givoni "Man, Climate and Architecture".

The influence of window size depends to a great extent on whether the room is cross ventilated or not. If the room is cross ventilated, the increase in the size of openings has a significant effect when both inlet and outlet are increased simultaneously. But the air speed is not proportional to the window size. Givoni found from laboratory experiments that the combination of a small inlet and large outlet produces the largest air velocity. In rooms where windows are only on one side, the size will have little effect on internal velocity. But when wind is oblique, there is appreciable effect when window size is increased. This is due to the pressure variation along the width of the wall, where air can enter through one part of the window and leave through the other.

In rooms with one external wall, it is possible to provide two lateral windows at the upwind and downwind sides to improve the ventilation conditions. But the velocity is still moderate. High velocities were found by Givoni to occur in rooms with two windows and a vertical projection between them. By this means, artificial high and low pressure zones are created inducing air movement. The indoor air flow is also influenced by shading devices and vegetation, obstruction (figure 36). Finally, it is noteworthy that air flow is not only due to the dynamic wind effect but can be generated by stack-effect resulting from temperature difference between inside and outside.

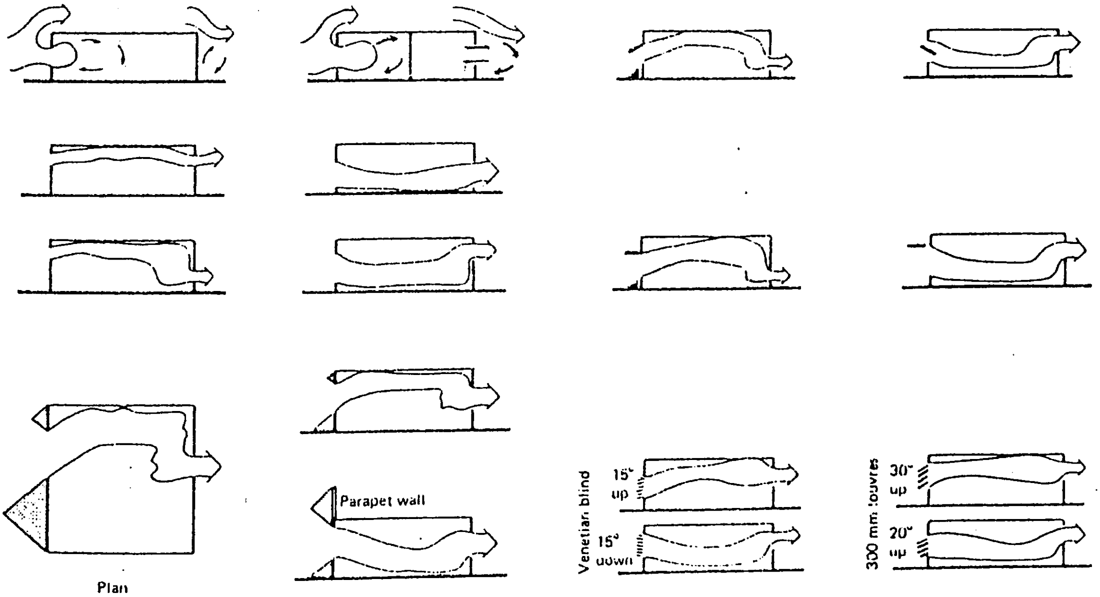


Fig 36: Some effect of air flow through openings.

Source: Koenigsberger et al.
(narrower arrow stream indicates increase in velocity)

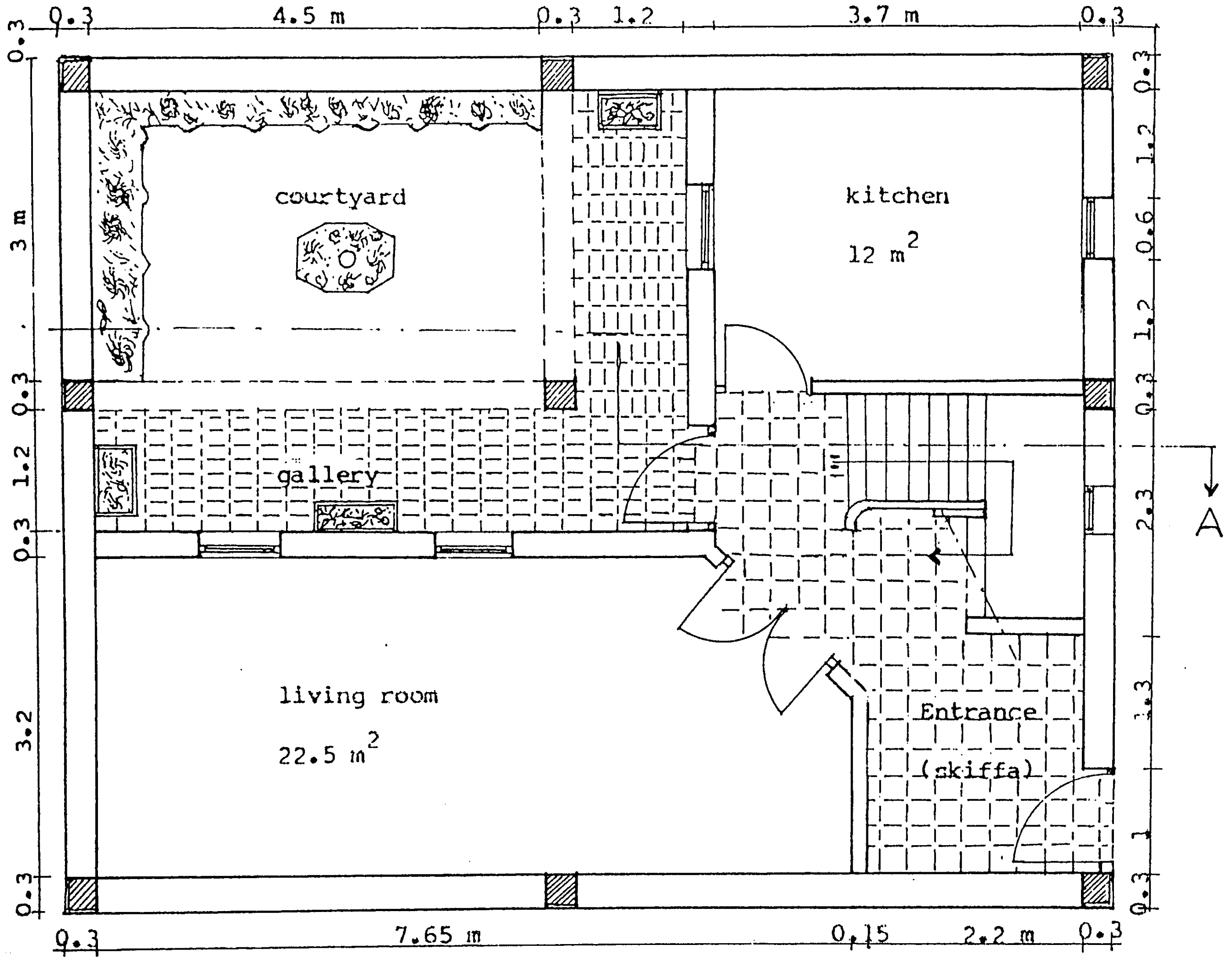
In continental, Mediterranean climates, and during the summer season when night air temperatures drop below internal ones, air movement within the building can substantially reduce the cooling loads and increase thermal comfort conditons, thus emphasising the importance of cross-ventilation. It can be added that in housing where daylighting is not of prime importance, as in some public buildings, windows should be closed during the daytime unless incoming air can be economically cooled such as in the use of "wind catcher", water and vegetation.

Concerning the two models, the main facade was oriented due west. This, as we have seen, constitutes the worst orientation from either wind or solar radiation point of view, as western winds are more dominant in winter and solar radiation is at its maximum intensity in summer. Neverthless, in the courtyard house type other techniques were used, namely shading devices and stack-effect ventilation as well as wind breaks resulting from the surroundings. However, for the isolated flat, larger glazing area together with minimum shading devices have been worsened by this orientation. It can be seen that although the provision of adequate ventilation is not an easy task, many options are open to the designers. On the other hand, other climatic design techniques, such as sun control and orientation, can help to impede air movement. Overall in Constantine the provision of air movement within the building at night is as important as sun control during the day.

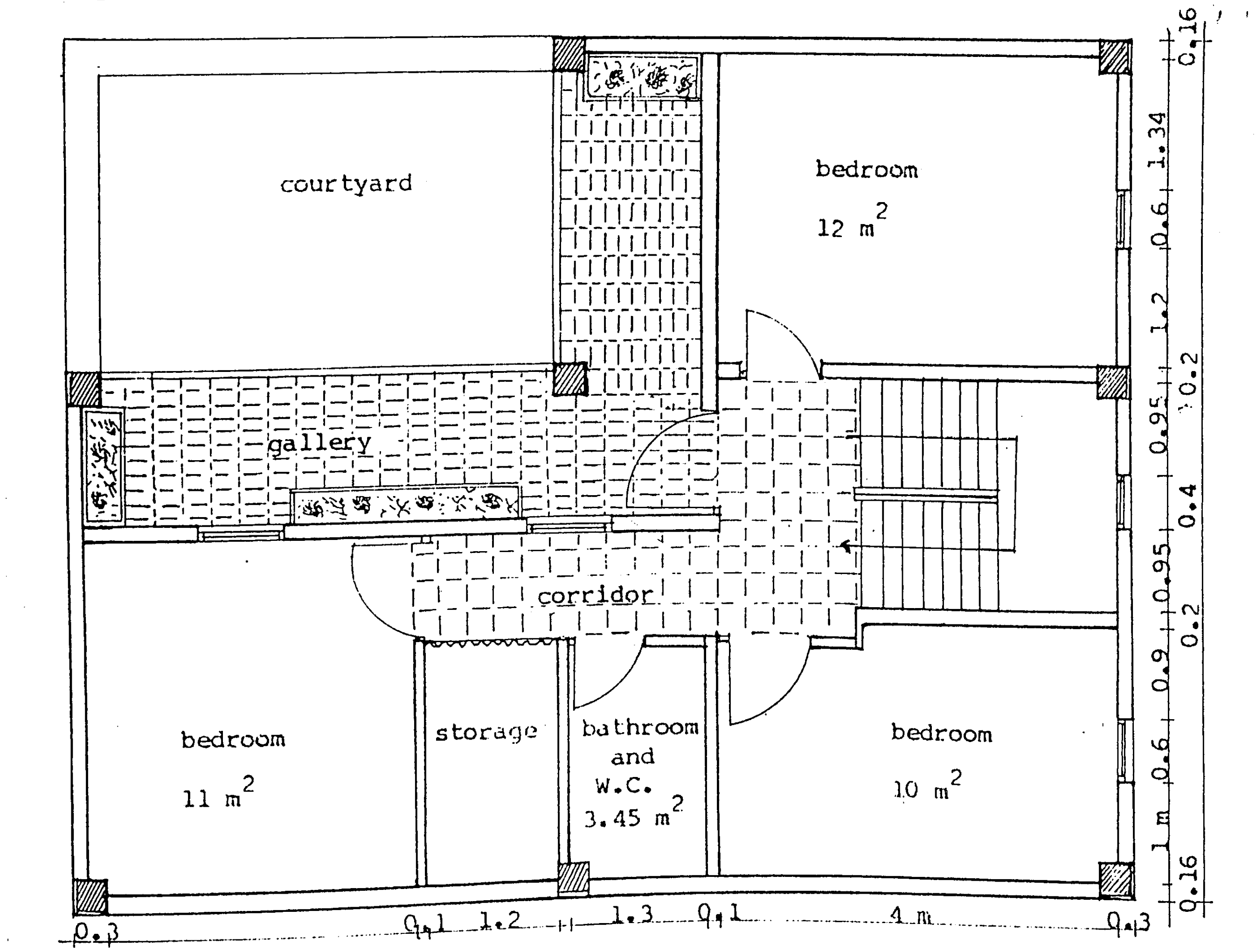
Figure 37 illustrates how traditional principles may be integrated in modern housing programmes to provide more energy efficient units by optimizing the shape and the design of the envelope. This type of units also provides the possibility of using wind catchers for a group of houses to facilitate cross ventilation and provide evaporative cooling. Dimensioning of units is based on the Algerian standard for different habitable spaces, considered as minimum allowable and used for the design of flats (see table in appendix E).

5.3 The envelope approach

The building envelope separates the indoor space from the external environment, modifying the direct impact of climatic elements. The envelope can usefully be classified into two headings: opaque (fabric) and transparent (glass). The quantitative effect of the envelope as a climatic modifier depends on the thermophysical properties of individual materials and the relationship between adjacent layers (section 4.3). According to Evans(13), an external envelope of high thermal capacity damps the temperature variation at internal surfaces to only about 15 to 20% of the external sol-air temperature. This decrease in temperature is associated with the time lag advantage. He suggested that the time lag should be between 8 - 16 hours. If it is very large, say, 20 - 30 hours, the equivalent external profile will become very flat, approximating the mean outside temperature. The advantage of "t_e" troughs

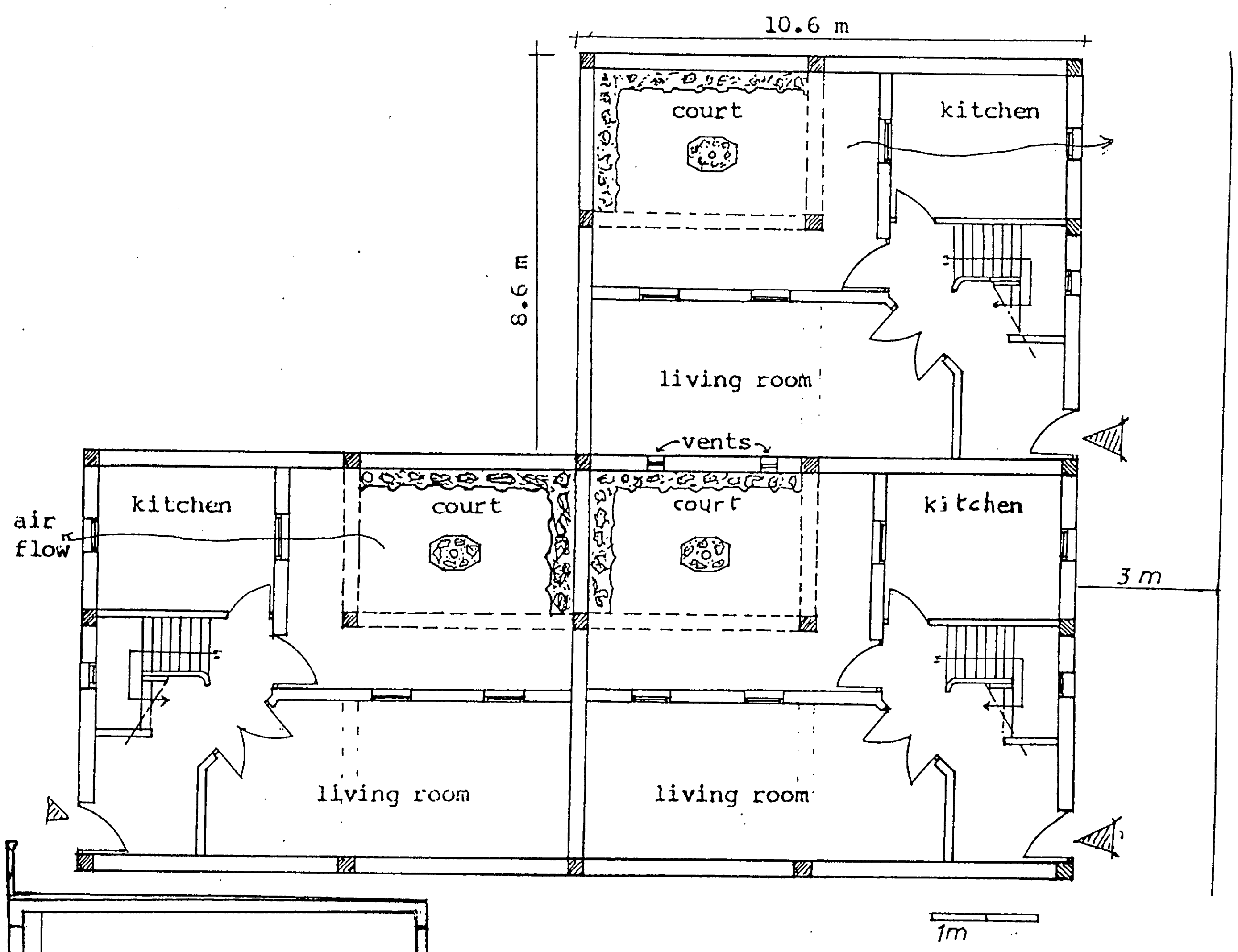


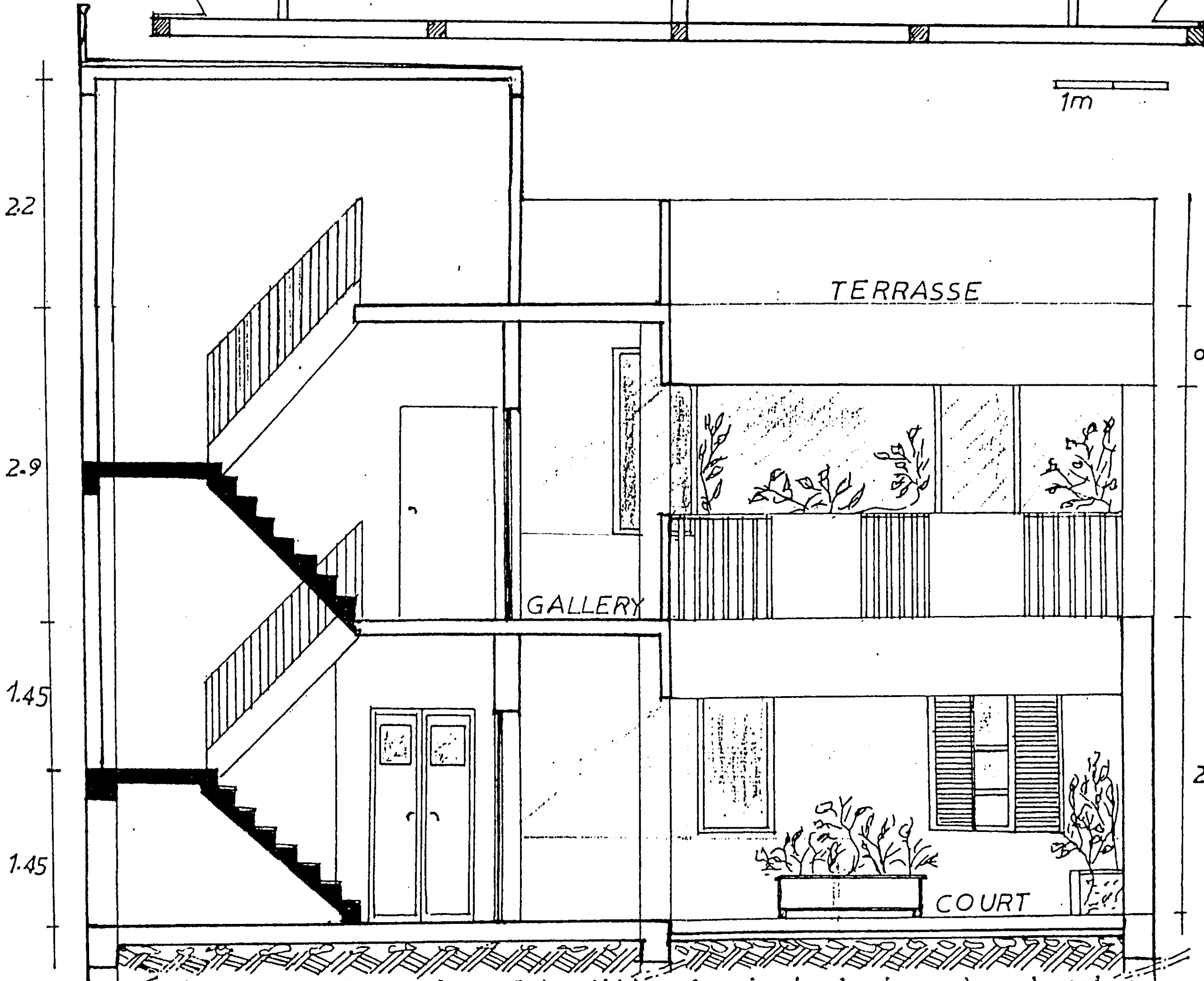
Ground floor scale:1/75



First floor scale:1/75

group of units





section A-A
scale: 1/75

Fig 37: Integration of traditional principals in modern housing.

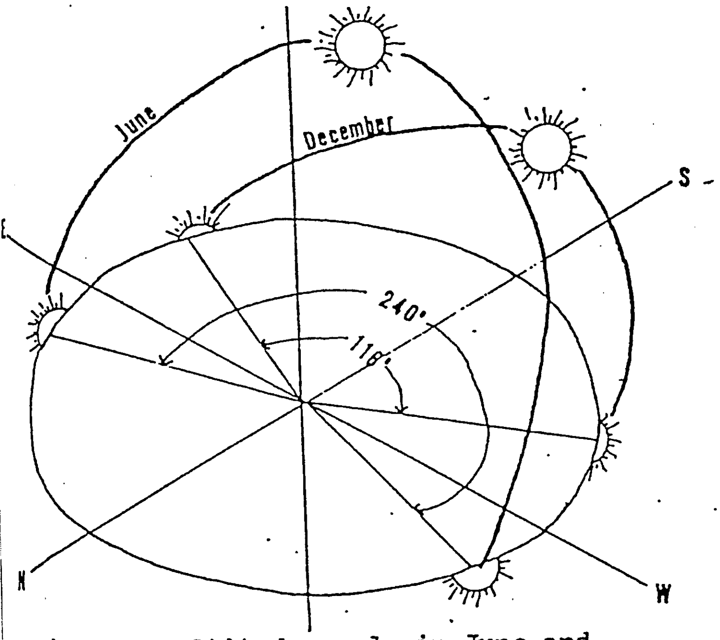
occuring at particular times relating to occupancy may therefore be missed. Reference to temperature (t_o - t_w) profiles of the courtyard house (section 4.3) shows the importance of a large time lag in damping the temperature fluctuations. This enhances the underground cave principle where the earth temperature is nearly constant (see figure 32). On the other hand, if temperatures are cool at night, the heat stored in the heavy structure may be reduced by ventilation. Evans also stated that a U value of 2.0 W/m^{2}K can generally be considered a good value of insulation except for cold climates. However, results of the analysis show that even a U value of 1.43 W/m^{2}K gives a very large load in the case of Constantine.

From the thermal performance point of view, glazed windows are the weakest links in the chain of enclosing elements. However, it is a unique building element which performs three distinct functions: it admits daylight, provides visual links and permits ventilation in a controllable way. The amount of direct solar radiation passing through the glass is affected by the angle of incidence and optical properties of glass. The latter depends upon its thickness and composition. In fact, when the angle exceeds 30^o, the transmission begins to decrease, the fall off becoming very rapid after 60^o. The thermal effect of windows depends mainly on their size and shading conditions which are generally used to reduce the solar load on glass surfaces.

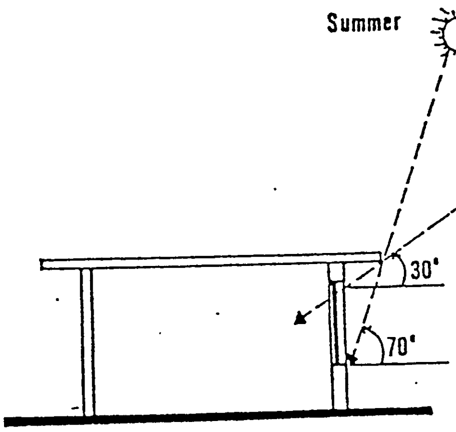
Internal blinds and curtains intercept the solar energy inside the building. Some of this absorbed portion is convected and irradiated into the space, but half of the reflected portion is trapped by the "greenhouse" effect. Consequently, the space between the glass and shading device is overheated and may cause discomfort. Hence, internal devices are not very effective, but are used in Constantine for privacy.

External shading devices are more efficient as they can obstruct the passage of direct solar rays through the glass. The extent of shading is determined by solar geometry. Horizontal devices block out light from above, and thus are more efficient when the sun is at a high angle. If we use the sun-path diagram for latitude 36°N, (see appendix B), the sun in midday summer is respectively at altitudes 77° normal to south, 42° east and west. Thus horizontal devices are effective for the south facades and vertical devices are generally most effective for east and west. Also vertical screening can provide a better distribution of air movement inside the room with openings on one wall only.

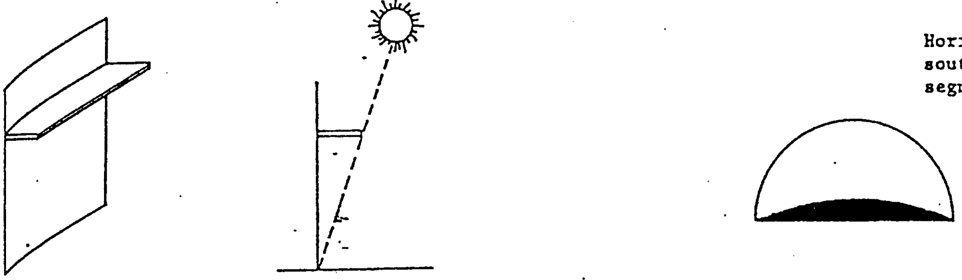
The combination of both devices is an efficient solution for many orientations depending upon detail dimensions, as they exclude more radiation (figure 38). However, their use is more effective in regions where hot conditions prevail all the year. In Constantine where solar radiation is needed in winter, they will not be so effective, besides other disadvantages such as limiting view and trapping hot air. Therefore attention has to be paid to



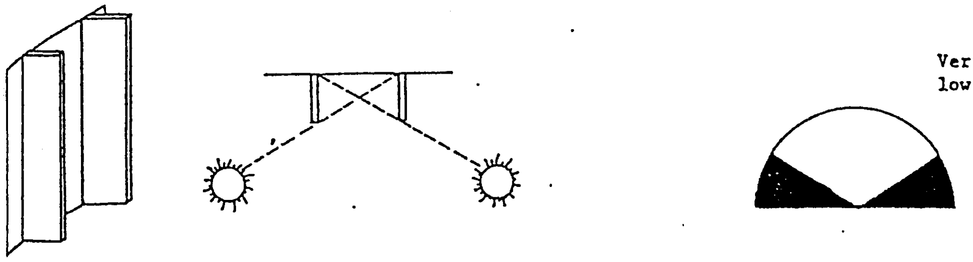
a) Solar altitude angle in June and December for 36°N



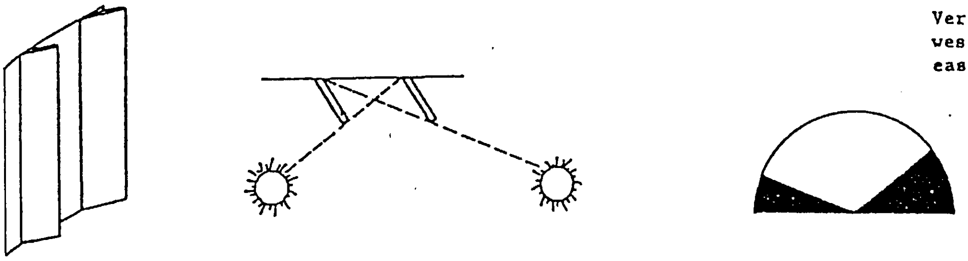
The overhang function of excluding solar rays in summer and allowing them in winter.



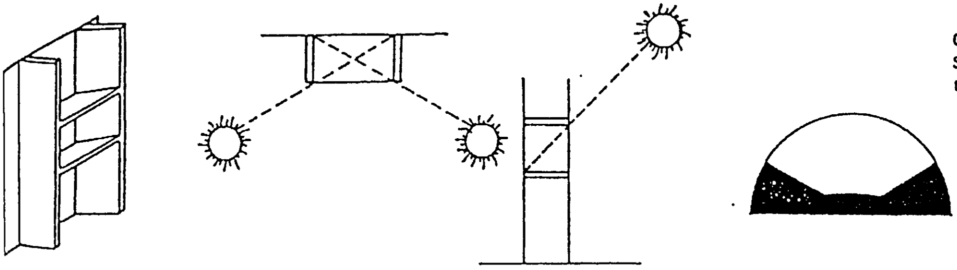
Horizontal overhang efficient towards southern exposure. Shadow mask is segmented.



Vertical fins efficient in intercepting low sun from west.



Vertical fins efficient in intercepting west solar radiation but little from east shadow mask is assymetrical.



Combined horizontal and vertical. Shadow mask is a superimposed of the two masks.

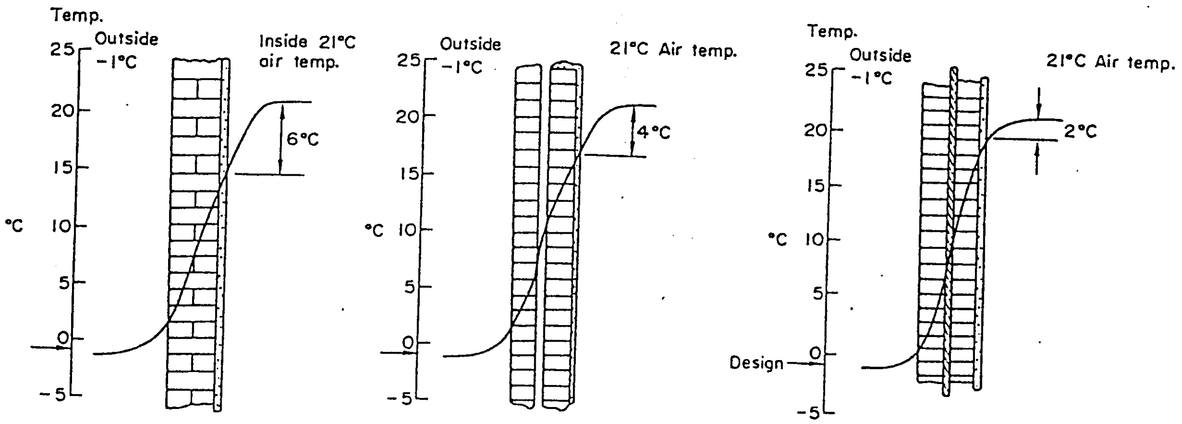
Fig 38: Examples of sun control devices.
Source: Olgyay "Design with climate".

the design of these devices as their inefficient use can have adverse consequences. For example, it can be argued that shading devices should be made of lightweight materials to avoid heat storage and its dissipation at night, and light colours are also preferred for their reflectivity. Outward sloping surfaces are most suitable since neither direct nor much diffuse radiation can reach the facades.

When windows are opened, even though shaded, the increase in their size may elevate the internal temperature caused by higher ventilation and infiltration rate. When closed and shaded, conducted exchanges will still be thermally significant. The solution to this problem clearly lies with moveable devices, i.e., shutters which were considered in the thermal analysis.

In Constantine, the main problem for buildings is the summer heat, with strong solar radiation and high daily temperature range. The objective is to enable as much as 10°C in indoor temperature below that of the outdoor mean maximum in summer, and allow effective cooling ventilation at night. These objectives can be attained by the choice of high thermal capacity and appropriate design features so that the heat operating on it and the rate of heating during the day is minimal, and much higher cooling during the evening is possible. Large openings are not desirable in housing where high levels of daylighting are not specifically required since they provide little thermal resistance to heat flow even if they are well shaded. On the other hand, good ventilation can be achieved even with small windows, provided they are placed in the right position.

In the description of models and thermal analysis, we can say that in the courtyard house type, attention was given to the heat capacity and insulation. The use of massive walls provide a time lag around 16 hours, significantly diffusing the thermal impact to the inside; In winter, the heat transfer is very slow and the thermal effect of the courtyard is very important in keeping reasonable comfort. The effect of insulation on modern materials is also significant in temperature fluctuations (figure 39).



(a) Solid double brick with plaster
$U = 2{\cdot}1\ W/m^2{\cdot}°C$
$Q = 44\ W/m^2$

(b) Cavity brick with plaster
$U = 1{\cdot}5\ W/m^2{\cdot}°C$
$Q = 31{\cdot}5\ W/m^2$

(c) Brick, 13 mm polystyrene light wt. concrete and plaster
$U = 0{\cdot}7\ W/m^2{\cdot}°C$
$Q = 14{\cdot}7\ W/m^2$

Fig 39: Effect of insulation on walls: air temperature differences.

Source: Brundrett, p. 242.

Openings are mostly small in size and few in number except those giving on to the courtyard. These are of reasonable size to ensure light and ventilation, and they are mostly shaded by colonades and galleries besides the use of shutters. In some houses "Musharabya" are used to provide ventilation and shading for the inside as well as for the outside streets. The distribution of glazing ratio with respect to different orientation is also important. Such a disposition is climatically favourable in both winter and summer.

However, the roof is the most critical element in the whole building since it is exposed all day to both heat and cold, and receives about 3 times more incident radiation than vertical facades. In traditional houses, heavy, insulated roofs are also used. It can be advanced that the utilisation of a double roof with ventilated roof space is one effective method of protection from solar radiation, but might be an expensive solution. Another alternative is the use of high reflective light coloured materials, together with insulation and capacitance. Yet another solution would be the use of a "roof pond" (figure 40), as a means of cooling and heating. However, this may be economically unsuitable as it requires structural attention and water usage.

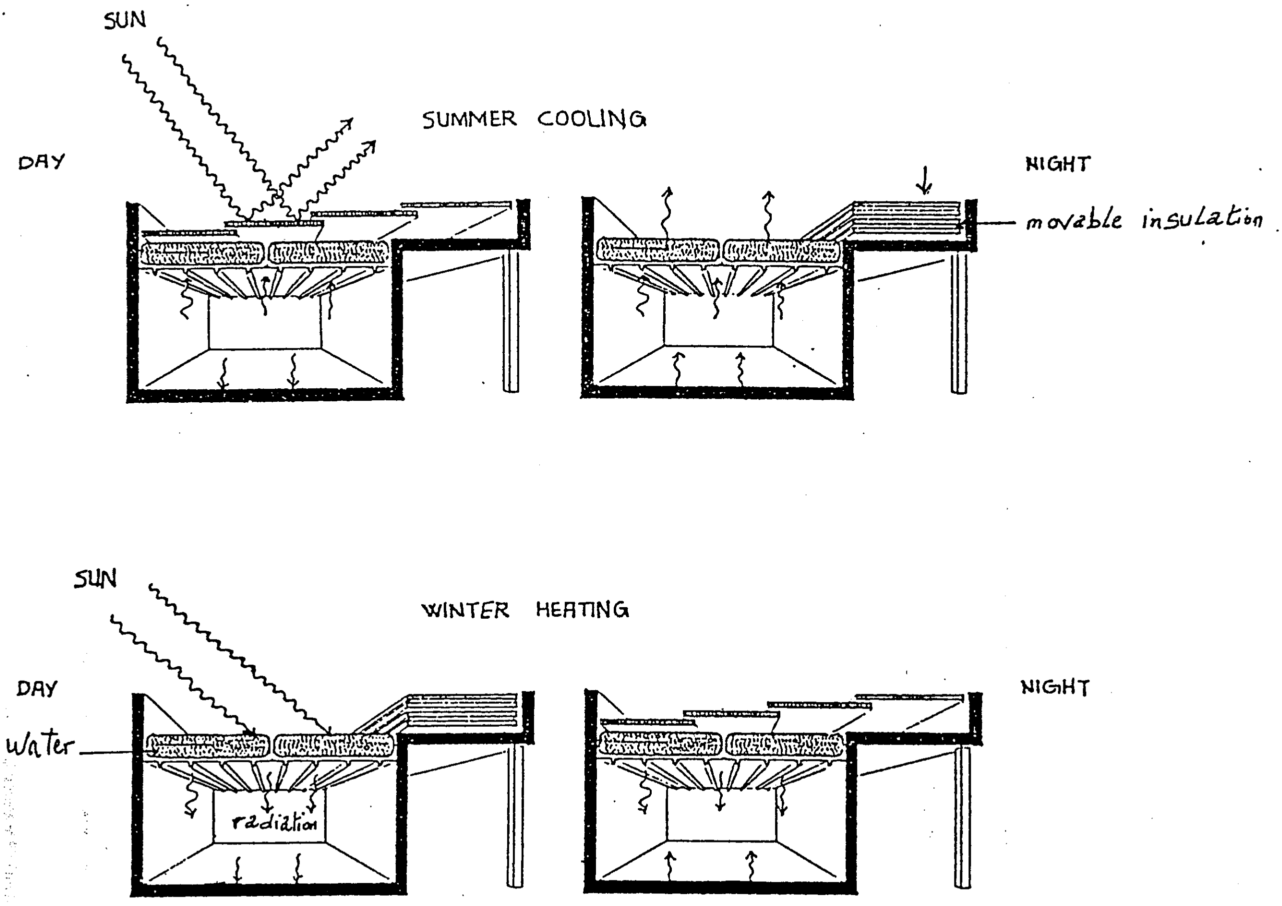


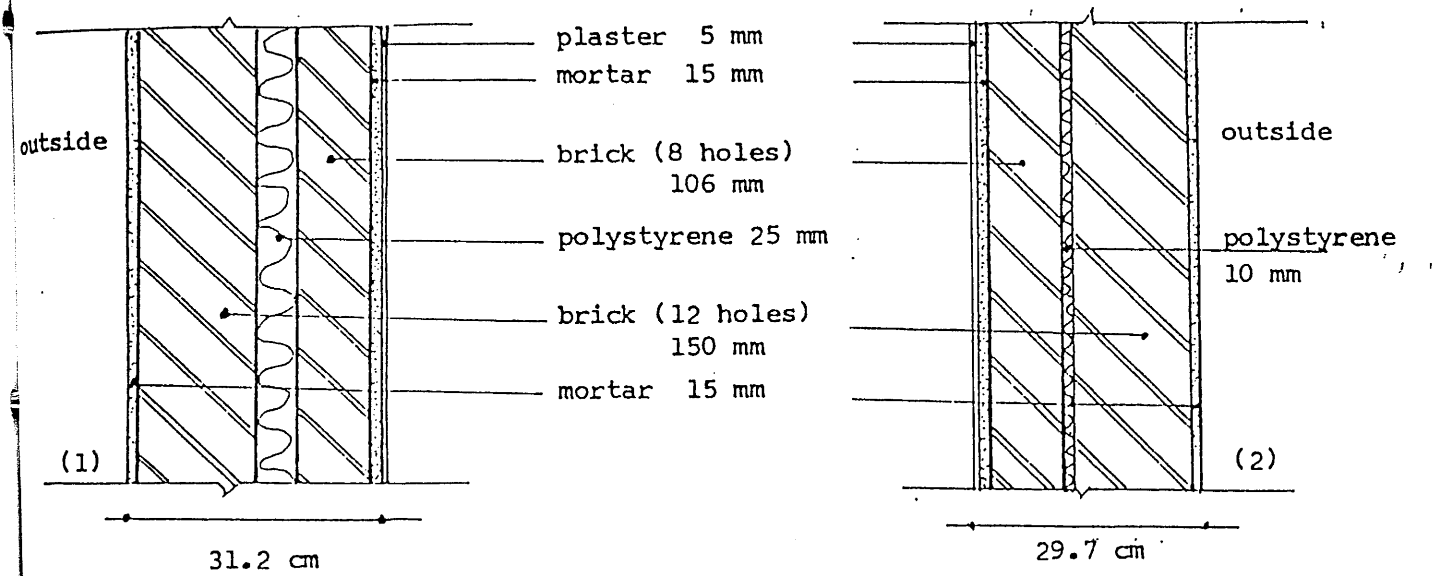
Fig. 40: Roof pond principles for heating and cooling.

Source: Redrawn from "solar home book", Bruce Anderson.

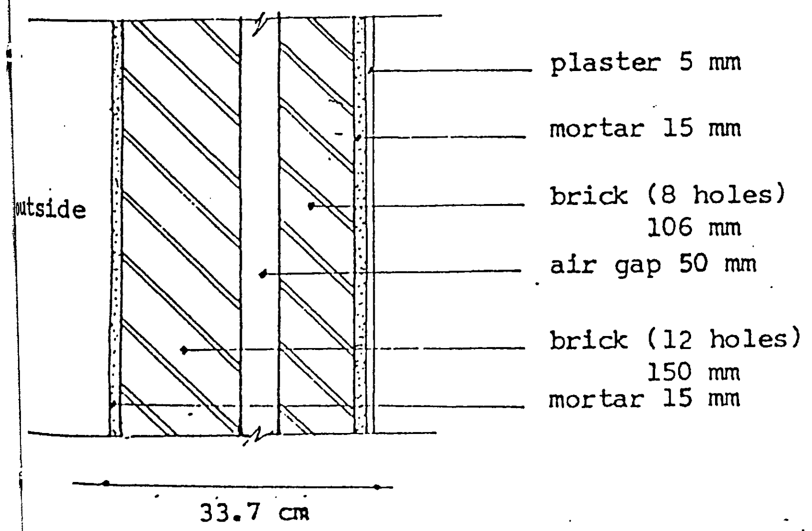
Traditional materials give a high thermal performance, but they are no longer used for reasons of strength, maintenance and aesthetic problems. Fig 41 shows the combination of modern local materials and the integration of insulation in order to reach a high thermal capacitance for the ground floor (most occupied space) and a rather high resistance in the upper floor (generally occupied during the night for sleeping). It can be seen that we can readily improve thermal properties as we reached a lower "U" value and a similar time lag to the traditional example analysed.

Proposed walls construction for future housing

1 - Ground floor walls (high thermal capacity and high thermal resistance)

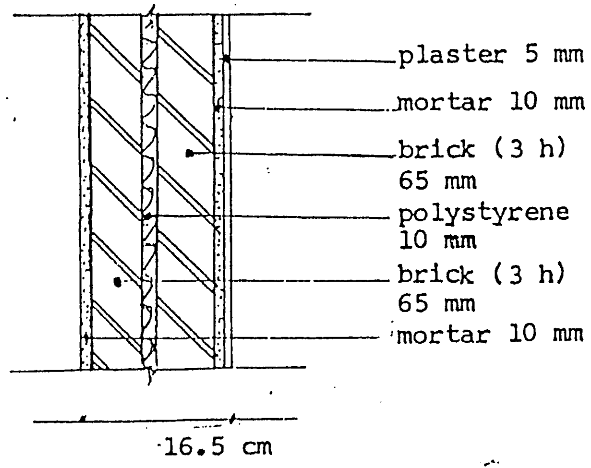


a) insulated brick wall



b) brick cavity wall

2 - Upper floor walls



c) upper floor wall (thermal resistance is more important than thermal capacity)

The combination of modern materials results in a good thermal capacity and resistance. The thermal characteristics of the proposed walls construction provide a U-value of 0.6-1.14 and a time lag of 7-17 hours. Thus if compared to both models analysed, (see tables 12 and 13), the new solution would provide a far better thermal performance. Hence a more reduction in heating and cooling loads. Consequently the modern building materials will enhance the courtyard form and add their beneficial effect to reach a more energy efficient housing units.

Fig 41: Physical and thermal characteristics of proposed walls construction.

See appendix F for thermal characteristics of hollow brick.

Wall a(1)

	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Plaster	600	0.160	1000	0.005
Mortar	2130	1.400	945	0.015
Hollow Brick (8 h)	922.18	0.378	1080.16	0.106
Polystyrene	25	0.033	1380	0.025
Hollow Brick (12 h)	862.82	0.375	1086.59	0.150
Mortar	2130	1.400	945	0.015

* h = holes

Number of layers = 6
No. Construction = 0

Surface Resistances
Internal (.12) : 0.123
External (.06) : 0.090

Properties
u-value : 0.587
Decrement factor : 0.202
Admittance Factor: 4.034
Surface Factor : 0.618

Time Lag Out/In 18.987
Time Lag In/Out 21.821

Wall a(2)

When we use only 10 mm of polystyrene in wall a(1), we get the following thermal characteristics

u-value = 0.801 W/m²K , Time Lag Out/In = 14.361 Hours
Decrement Factor = 0.244 , Time Lag In/Out = 16.142 Hours

Wall b

	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Plaster	600	0.160	1000	0.005
Mortar	2130	1.400	945	0.015
Hollow Brick (8 h)	922.18	0.378	1080.16	0.106
Air Gap	1.2	0.280	1180	0.050
Hollow Brick (12 h)	862.82	0.375	1086.59	0.150
Mortar	2130	1.400	945	0.015

* h = holes

Number of layers = 6
No. Construction = 0

Surface Resistances
Internal (.12) : 0.123
External (.06) : 0.090

Properties
u-value : 0.889
Decrement factor : 0.264
Admittance Factor: 3.894
Surface Factor : 0.625

Time Lag Out/In 13.091
Time Lag In/Out 14.585

Wall c

	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
Plaster	600	0.160	1000	0.005
Mortar	2130	1.400	945	0.010
Hollow Brick (3 h)	1076.88	0.416	1061.03	0.065
Polystyrene	25	0.033	1380	0.010
Hollow Brick (3 h)	1076.88	0.416	1061.03	0.065
Mortar	2130	1.400	945	0.010

* h = holes

Number of layers = 6
No. Construction = 0

Surface Resistances
Internal (.12) : 0.123
External (.06) : 0.090

Properties
u-value : 1.144
Decrement factor : 0.576
Admittance Factor: 3.775
Surface Factor : 0.662

Time Lag Out/In 6.910
Time Lag In/Out 7.663

if we use 25 mm of polystyrene in Wall c, the u-value drops to 0.75 W/m²K.

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CONCLUSION

Passive solar energy in architecture may be considered as displacing rather than replacing the auxiliary energy used for heating and cooling. The fundamental problem which is always highlighted is the adaptation of the building to its environment enabling the creation of a comfortable artificial microclimate.

The study investigates the thermal performance of modern and traditional housing types in the context of the Constantine climate. It has been demonstrated that the latter is not only more energy efficient, but also economically compatible with modern standards and still the socially and culturally preferred model. It is important to remember that our context is one of shortage, within which no waste is affordable; but implementation by means of prefabricated systems appear less affordable costed in terms of environmental and social consequences. The work is an attempt to draw the attention of those concerned with the shaping of our environment, to the necessity of economically exploiting our ambient and physical resources. Thus, this contribution should be seen as a start, a claim for change and improvement, rather than historical conservation or simply a critical approach to particular housing forms.

The conclusions may be summarised under three headings:-

1 - Energy performance, plan and Construction:

The foregoing study shows that the traditional courtyard house outperforms the modern flat, having both lower heating and cooling loads. The relatively poor performance of the new type reflects the small volume to surface ratio, higher U values, the relatively large glazed area and lack of shading provision. The courtyard configuration inately rectifies each of these shortcomings.

Shape: In Constantine, an important objective in the choice of the urban and house form is to reduce the external exposed surfaces to minimise heat transfer through the building envelope. Streets and courtyard proportions are also important, providing shade to perimeter surfaces in summer and promoting a warmer micro-climate in winter. With respect to the former, heat transmission through a shaded wall has been predicted to be less than half that of an unshaded wall. Courtyards are also prominent features, effective in resolving the problem of orientation and inducing air inside as a result of wind and stack-effect, as well as cross ventilation in some individual rooms. Temperature stratification in the courtyard is also beneficial in both summer and winter. Areas of vegetation will be advantageous in absorbing radiation and promoting evaporative cooling and shading.

Orientation: The courtyard configuration renders orientation less critical, whereas North/South orientation is essential for the flatted type. This offers much greater planning flexibility without compromising energy requirements. Since ventilation is largely stack induced, again orientation can vary; but planning streets in a North-South or a North West-South-East axis certainly allows seasonal Northern winds to flow deeply inside the urban area. Ventilation and air movement are a very effective means of satisfying the main requirements of thermal comfort and structural cooling.

Envelope - Opaque/transparent: Glazing area largely controls the internal temperature and thus should be minimized. Windows are not advisable on the west orientation, but if unavoidable, it is important that appropriate shading devices are provided to mitigate the stress. Moreover, the need for sunlight/daylight penetration in the livingrooms should be considered. As far as the fabric is concerned, a combined heavy/lightweight insulated system for the living/sleeping accomodation will result in a more comfortable environment related to the occupancy time-table. For instance, a lightweight insulated structure over the upper floor bedrooms would allow more rapid night cooling, but would not compromise heating loads. Special attention should be given to roof construction which should have adequate thermal resistivity and the upper surface highly reflective. A double roof with ventilated roof space is also possible, but may incur economic problems.

Although traditional building materials offer a suitable thermal balance between resistance and capacitance, they require frequent maintenance and have a limited duration. Thus modern building materials can be advantageous provided care is taken with the required thermal performance characteristics, especially resistance and capacitance. By these means, we can provide even better thermal characteristics than traditional models, which have evolved empirically, but without the benefit of theoretical scientific knowledge.

The obsolescence of many traditional materials is marked by a growing number of new materials which have superior properties. These materials are currently introduced by reason of their durability, strength or flexibility or even modernity, but thermal performance is rarely considered. Their adoption may also have undesirable economical effects, where imported technologies contribute to a balance of payment deficit. A more rational and quantitative use of local modern materials is therefore recommended. The use of red brick, which is locally produced in Constantine together with cheaper insulative materials such as polystyrene could economically bridge the traditional/ modern gap.

2 - Unit morphology and family structure:

Traditional buildings may however be a misleading source of design. Hence, we must take care in interpreting the lessons gained from it, because the conditions in which and for which it was developed have changed. It must be stressed that the large extended family courtyard house type requires modification to align with modern housing programmes. Following the world changes, Algeria also accepted the nuclear family as a norm for new housing.

The proposed courtyard type (section 5), confirms compatability with the smaller family unit averaging 6 persons, and dimensioning is based on the Algerian standard defined as a floor area of 20 m^2 per person. It was not the intention to introduce a standard prototype, but simply to demonstrate economic feasibility. The range of individual detailed solutions to a particular site is virtually limitless within this format, and still compatible with social structure. However, one must accept that migration potential around the house is more restricted and should be compensated by modern improvement.

3 - Grouped morphology:

The beneficial effect of high grouping, is still compatible with modern standards of access, safety and health. This type is also competitive in terms of density and land use compared to the modern flats. Proper attention should be given to landscaping as a social, visual and climate modifier. Besides satisfying the instinctive need for protection, trees also contribute much to the immediate physical environment, for example, reducing air born sound with great efficiency. But an especially beneficial effect is their thermal performance. In winter, evergreen windbreaks can reduce heat loss from poorly insulated buildings. In summer, the surface of grass and leaves absorbs radiation and their evaporative process can cool air temperature. Above all they provide generous shade at the right season.

It can be argued that the flat type can also be environmentally improved by adding insulation, although it is dubious whether results would be economically reasonable. The systems are industrially prepared, so that a change in one part will bring about an alteration in the technical means of the whole system. Moreover, the economic assumption that building systems on a large scale are by definition bound to be cheaper pro rata than smaller scale operations based on traditional craft methods, have been found to be untrue when total costs are taken into consideration. For instance, it was found that prefabricated panels require 30 times* the consumption of cement than conventional systems of brick and mortar for one housing unit. Furthermore, it is very difficult for a designer using such systems, to avoid producing a dull, repetitive and inhuman environment. Many systems have been found to produce high maintenance costs, mainly because of the difficulties of achieving an adequate air and watertight shell. If we add to these disadvantages, the poor thermal performance of these buildings, set against the new option of the Algerian government of encouraging private individual initiative, we will find that a two to three storey courtyard house unit can be built to a relatively high density. Such layouts need suffer no sacrifice of modern amenity or environmental quality. For example, through ventilation may be achieved using techniques such as ventilation "flues" or "wind catchers". These features can be built into the structure, as well as screened windows

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* Hardoy (see reference 8 in chapter 1)

provided on the street side to allow opening on both street and courtyard sides.

The courtyard house therefore needs to be rediscovered, not out of nostalgia, but out of a genuine recognition of all its inherent potentialities. Once this type is re-accepted as a valuable housing unit, further research should follow. Iterative analysis could optimise ratio of volume to surface area, courtyard dimensions, glazing distribution and ratio; and explore the life cycle benefits of more elaborate, natural solar devices such as a "wind catcher", or "roof pond".

Considering its potentialities with respect to housing shortage, the courtyard type could be either part of public or private housing development, or a product of small scale industrialisation to deal with speed, or even part of a small scale project identified within an urban renewal programme. Last, and most important is being energy efficient, both at the individual house and the composite level.

A traditionally based option, drawing on many generations of use, also most closely approximates to the essential requirements of privacy. Consequently, if vernacular organic principles are evolved to accomodate our modern challenge, it will reduce to a large extent the reliance on mechanical means and foreign dependancy. Accordingly, it will mitigate the burden of central government for housing supply.

Appendix A: Mean hourly monthly temperature and radiation data for Constantine.

months hours	J	F	M	A	M	J	J	A	S	O	N	D
1	4,1	5,7	6,8	9,25	12,8	16,85	21,6	21,85	18,1	13,2	7,55	4,75
2	3,6	5,0	6,15	8,6	12,1	16,1	20,7	20,8	17,4	12,55	7,05	4,4
3	3,25	4,4	5,75	7,9	11,4	15,4	19,9	20,0	16,8	12,0	6,7	4,0
4	2,85	4,0	4,75	7,6	11,2	15,3	19,2	19,5	16,35	11,6	6,4	3,8
5	2,6	3,7	4,3	7,2	11,0	15,1	18,7	19,0	15,85	11,05	6,0	3,55
6	2,34	3,5	4,3	6,8	10,89	15,0	18,76	18,45	15,4	10,73	5,83	3,27
7	3,2	4,4	5,9	8,9	12,6	17,8	20,7	21,0	17,75	13,0	8,0	4,6
8	4,1	6,0	7,5	11,2	14,8	21,3	23,3	24,1	20,1	15,4	10,0	6,2
9	5,25	7,1	9,0	13,1	16,8	24,0	25,9	26,6	22,4	17,2	11,7	7,9
10	6,4	8,6	10,4	14,6	18,8	25,6	27,95	28,5	24,1	18,5	13,0	9,1
11	8,0	10,2	12,1	16,0	20,6	27,4	29,5	30,6	26,2	20,4	14,7	10,3
12	10,0	11,4	13,9	17,3	21,9	28,8	31,1	32,1	27,9	21,8	16,2	11,8
13	10,5	12,2	14,4	17,9	28,8	29,4	32,6	33,0	28,6	22,3	16,3	12,2
14	11,1	13,0	15,0	18,5	23,8	30,4	34,2	34,15	29,2	22,8	17,1	12,6
15	11,47	13,87	15,7	19,05	24,3	30,87	35,3	34,9	29,8	23,13	17,24	12,87
16	10,6	12,8	15,1	17,4	24,0	30,4	35,0	34,4	29,0	22,4	16,3	11,9
17	9,4	11,9	14,4	15,8	23,4	30,0	34,4	33,9	28,3	21,3	15,2	10,3
18	8,4	11,0	13,8	14,3	23,0	29,8	33,9	33,2	27,75	20,3	14,0	9,0
19	7,35	9,8	12,6	13,9	21,6	28,15	31,9	31,8	26,4	19,2	13,6	8,0
20	6,15	8,55	11,3	13,5	20,0	26,4	29,8	29,8	24,95	18,0	13,0	6,95
21	5,2	7,2	10,0	13,0	18,45	24,85	27,8	28,0	23,8	16,85	12,5	6,0
22	5,0	7,0	9,2	12,0	16,75	22,4	26,0	26,4	22,2	15,9	11,0	5,4
23	4,7	6,75	8,2	11,0	15,3	21,85	24,0	24,2	20,4	14,5	9,3	5,2
24	4,6	6,4	7,4	9,9	13,65	17,6	22,6	22,4	18,65	13,95	8,0	5,0

Table A1: Predicted mean day hourly monthly temperatures in "Constantine" (L.A.T. - Local Apparent Time).

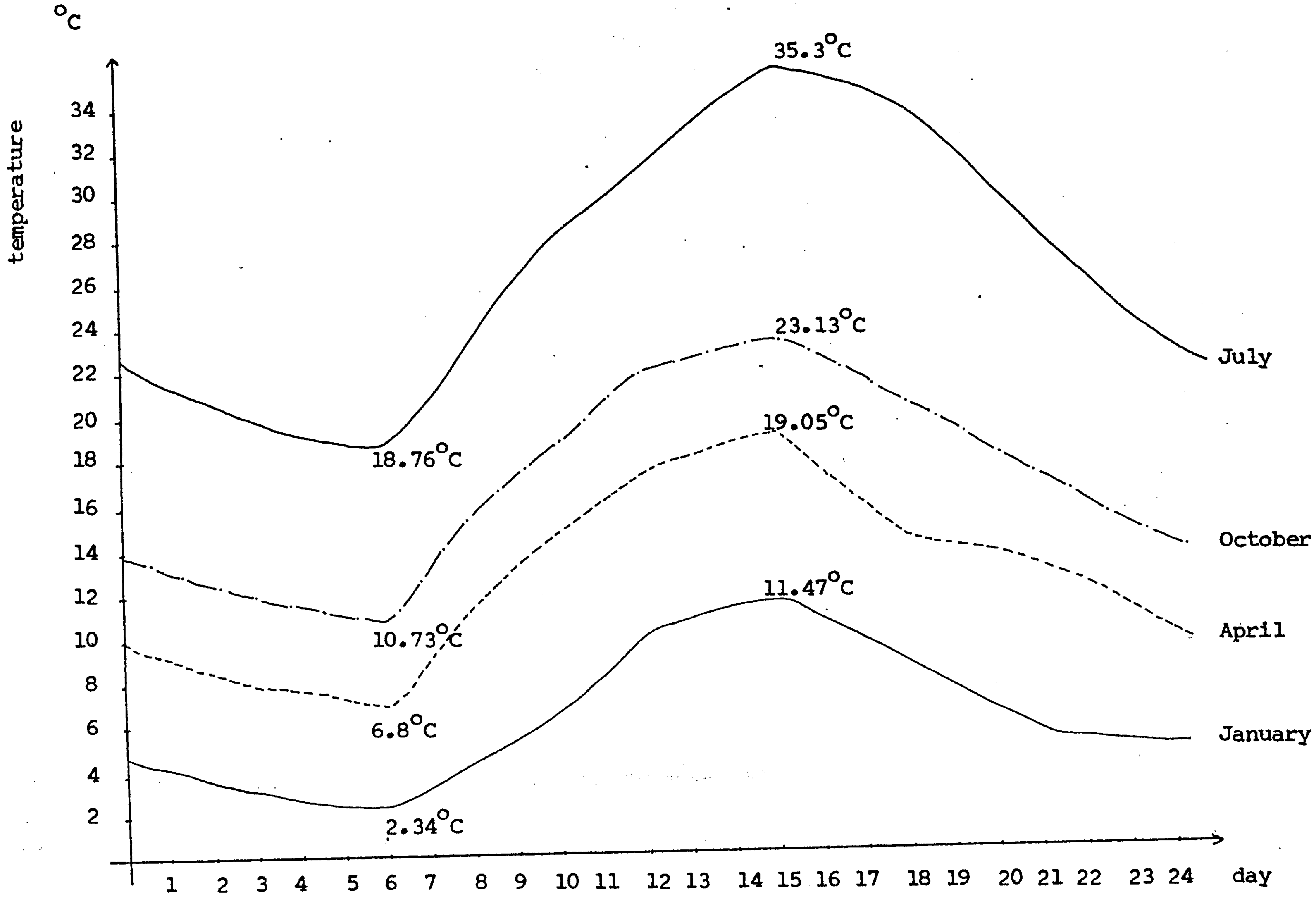

Fig A1: Hourly mean daily monthly temperature (For 4 critical months).

°C months	Mean Max	Mean min	Mean
January	11,47	2,34	6,9
February	13,87	3,5	8,68
March	15,7	4,3	10,0
April	19,05	6,8	12,92
May	24,3	10,29	17,29
June	30,87	15,0	22,9
July	35,3	18,76	27,03
August	34,9	18,45	26,67
September	29,8	15,4	22,6
October	23,13	10,73	16,93
November	17,24	5,83	11,53
December	12,87	3,27	8,1

Table A2: Mean temperatures in Constantine average over 15 years (1970 - 1985).

Source: Meteorological Station in Ain-El-Bey.

Dir S = Direct, G = Global, G/vitr = Global behind glass

G^* = Global in atmosphere.

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********************      Energie (en Wh/m2)      ====================          ASA/m.c.*epau
* 06 - CONSTANTINE  *     incidente sur le PLAN   HORIZONTAL  --          (jem)  -------------
********************      par tranche horaire     ====================          p:(+000,+090)
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TRANCHES HOR.		6- 7	7- 8	8- 9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	TOTAL JOURNEE
JANV	Dir S	0	19	80	142	187	211	211	187	142	80	19	0	1278
-	Glo G	0	42	154	259	336	376	376	336	259	154	42	0	2334
-	G /vitr	0	20	98	190	263	301	301	263	190	98	20	0	1744
-	Glo G *	0	60	236	404	527	591	591	527	404	236	60	0	3636
FEVR	Dir S	2	43	107	165	207	229	229	207	165	107	43	2	1506
-	Glo G	7	96	219	324	400	440	440	400	324	219	96	7	2972
-	G /vitr	3	57	157	255	327	364	364	327	255	157	57	3	2326
-	Glo G *	10	151	357	536	665	732	732	665	536	357	151	10	4902
MARS	Dir S	27	122	227	317	382	416	416	382	317	227	122	27	2982
-	Glo G	50	200	357	491	587	638	638	587	491	357	200	50	4646
-	G /vitr	24	132	277	405	495	542	542	495	405	277	132	24	3750
-	Glo G *	66	274	491	674	806	875	875	806	674	491	274	66	6372
AVRI	Dir S	68	171	272	356	417	449	449	417	356	272	171	68	3476
-	Glo G	123	281	433	561	653	702	702	653	561	433	281	123	5530
-	G /vitr	73	209	353	473	557	601	601	557	473	353	209	73	4542
-	Glo G *	169	393	607	786	915	982	982	915	786	607	393	169	7734
MAI	Dir S	127	250	368	466	536	573	573	536	466	368	250	127	4694
-	Glo G	197	367	528	664	762	814	814	762	664	528	367	197	6762
-	G /vitr	130	287	440	566	655	701	701	655	566	440	287	130	5604
-	Glo G *	251	468	671	840	963	1027	1027	963	840	671	468	251	8562
JUIN	Dir S	149	273	390	488	558	594	594	558	488	390	273	149	4992
-	Glo G	226	393	551	684	781	832	832	781	684	551	393	226	7086
-	G /vitr	155	312	462	585	672	717	717	672	585	462	312	155	5884
-	Glo G *	284	493	688	851	968	1030	1030	968	851	688	493	284	8818
JUIL	Dir S	160	304	443	559	642	685	685	642	559	443	304	160	5666
-	Glo G	225	408	582	729	837	894	894	837	729	582	408	225	7480
-	G /vitr	150	322	488	625	722	772	772	722	625	488	322	150	6220
-	Glo G *	262	470	666	829	948	1010	1010	948	829	666	470	262	8524
AOUT	Dir S	111	252	392	510	595	639	639	595	510	392	252	111	5024
-	Glo G	163	346	523	674	784	842	842	784	674	523	346	163	6712
-	G /vitr	99	263	433	575	675	726	726	675	575	433	263	99	5562
-	Glo G *	193	406	609	779	903	967	967	903	779	609	406	193	7772
SEPT	Dir S	47	166	295	405	484	526	526	484	405	295	166	47	3848
-	Glo G	79	245	415	561	667	723	723	667	561	415	245	79	5384
-	G /vitr	41	171	331	470	568	619	619	568	470	331	171	41	4402
-	Glo G *	97	303	511	687	815	881	881	815	687	511	303	97	6592
OCTO	Dir S	8	78	178	267	332	366	366	332	267	178	78	8	2458
-	Glo G	18	135	282	410	503	552	552	503	410	282	135	18	3800
-	G /vitr	8	81	208	330	418	464	464	418	330	208	81	8	3018
-	Glo G *	23	181	383	558	685	751	751	685	558	383	181	23	5162
NOVE	Dir S	0	25	90	154	201	226	226	201	154	90	25	0	1392
-	Glo G	1	56	171	277	354	395	395	354	277	171	56	1	2508
-	G /vitr	0	29	114	209	282	321	321	282	209	114	29	0	1910
-	Glo G *	1	80	261	429	551	615	615	551	429	261	80	1	3874
DECE	Dir S	0	12	64	120	163	185	185	163	120	64	12	0	1088
-	Glo G	0	29	129	227	299	337	337	299	227	129	29	0	2042
-	G /vitr	0	14	79	163	231	267	267	231	163	79	14	0	1508
-	Glo G *	0	41	200	362	481	543	543	481	362	200	41	0	3254
A06-1::asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE	/	12 heures		(Midi TSV)		JOURNEE Wh/m2

Table A2: Mean monthly hourly solar irradiation on horizontal plane.

Source: "Atlas Solaire de l'Algerie", 1985.

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*********************        Energie (en Wh/m2)          ====================                ASA/m.c.*epau
* 06 - CONSTANTINE  *        incidente sur le PLAN  VERTICAL  NORD             (jem)         -------------
*********************        par tranche horaire         ====================                p:(+180,+000)

TRANCHES HOR.   6- 7  7- 8  8- 9  9-10 10-11 11-12 12-13 13-14 14-15 15-16 16-17 17-18     TOTAL
                ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----   JOURNEE
JANV  Dir S        0     0     0     0     0     0     0     0     0     0     0     0         0
  -   Glo G        0    13    46    72    90    98    98    90    72    46    13     0       638
  -   G /vitr      0    10    36    57    71    78    78    71    57    36    10     0       504
  -   Glo G *      0    15    48    70    85    93    93    85    70    48    15     0       622
FEVR  Dir S        0     0     0     0     0     0     0     0     0     0     0     0         0
  -   Glo G        2    31    66    92   110   119   119   110    92    66    31     2       840
  -   G /vitr      2    25    52    73    87    94    94    87    73    52    25     2       666
  -   Glo G *      2    34    64    86   102   110   110   102    86    64    34     2       796
MARS  Dir S        0     0     0     0     0     0     0     0     0     0     0     0         0
  -   Glo G       14    52    85   111   128   137   137   128   111    85    52    14      1054
  -   G /vitr     11    41    67    87   101   108   108   101    87    67    41    11       830
  -   Glo G *     16    53    81   104   120   129   129   120   104    81    53    16      1006
AVRI  Dir S       18     0     0     0     0     0     0     0     0     0     0    18        64
  -   Glo G       58    71   101   125   141   149   149   141   125   101    71    58      1338
  -   G /vitr     32    56    80    98   111   118   118   111    98    80    56    32      1012
  -   Glo G *     78    70    97   119   136   145   145   136   119    97    70    78      1370
MAI   Dir S       78    25     0     0     0     0     0     0     0     0    25    78       342
  -   Glo G      143   110   108   130   145   153   153   145   130   108   110   143      1786
  -   G /vitr     81    69    85   102   114   121   121   114   102    85    69    81      1288
  -   Glo G *    192   124   106   128   145   154   154   145   128   106   124   192      1998
JUIN  Dir S      108    56     5     0     0     0     0     0     0     5    56   108       570
  -   Glo G      183   151   115   130   145   153   153   145   130   115   151   183      2102
  -   G /vitr    112    86    87   102   114   120   120   114   102    87    86   112      1490
  -   Glo G *    243   180   117   131   147   156   156   147   131   117   180   243      2444
JUIL  Dir S      109    49     2     0     0     0     0     0     0     2    49   109       534
  -   Glo G      177   136   107   126   142   150   150   142   126   107   136   177      1990
  -   G /vitr    103    77    83    99   111   118   118   111    99    83    77   103      1400
  -   Glo.G *    215   153   110   129   145   154   154   145   129   110   153   215      2220
AOUT  Dir S       49     4     0     0     0     0     0     0     0     0     4    49       180
  -   Glo G       97    75    98   120   136   144   144   136   120    98    75    97      1452
  -   G /vitr     49    56    77    94   107   113   113   107    94    77    56    49      1056
  -   Glo G *    121    81   101   123   139   148   148   139   123   101    81   121      1576
SEPT  Dir S        1     0     0     0     0     0     0     0     0     0     0     1         4
  -   Glo G       22    56    86   109   125   134   134   125   109    86    56    22      1068
  -   G /vitr     16    44    67    86    98   105   105    98    86    67    44    16       834
  -   Glo G *     27    61    88   110   127   135   135   127   110    88    61    27      1102
OCTO  Dir S        0     0     0     0     0     0     0     0     0     0     0     0         0
  -   Glo G        5    36    68    93   110   118   118   110    93    68    36     5       860
  -   G /vitr      4    29    54    73    86    93    93    86    73    54    29     4       678
  -   Glo G *      6    41    71    93   109   117   117   109    93    71    41     6       874
NOVE  Dir S        0     0     0     0     0     0     0     0     0     0     0     0         0
  -   Glo G        0    18    50    75    92   100   100    92    75    50    18     0       670
  -   G /vitr      0    14    39    59    73    79    79    73    59    39    14     0       528
  -   Glo G *      0    20    53    75    91    98    98    91    75    53    20     0       674
DECE  Dir S        0     0     0     0     0     0     0     0     0     0     0     0         0
  -   Glo G        0     9    39    65    82    91    91    82    65    39     9     0       572
  -   G /vitr      0     7    31    51    65    72    72    65    51    31     7     0       452
  -   Glo G *      0    10    43    66    81    88    88    81    66    43    10     0       576
                ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----   JOURNEE
A06+4.:asa      17-18 16-17 15-16 14-15 13-14 12-13  SYMETRIE  /  12 heures  (Midi TSV)     Wh/m2
```

Table A3: Mean monthly hourly solar irradiation on north vertical.

Source: "Atlas Solaire de l'Algerie", 1985.

```
********************     Energie (en Wh/m2)          ====================              ASA/m.c.*epau
* 06 - CONSTANTINE  *    incidente sur le PLAN       VERTICAL   SUD          (jem)     -------------
********************     par tranche horaire         ====================              p:(+000,+000)
```

TRANCHES HOR.		6- 7	7- 8	8- 9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	TOTAL JOURNEE
JANV	Dir S	0	94	200	266	309	330	330	309	266	200	94	0	2398
-	Glo G	0	143	303	411	485	524	524	485	411	303	143	0	3732
4	G /vitr	0	114	251	347	412	446	446	412	347	251	114	0	3140
-	Glo G *	0	287	589	779	904	967	967	904	779	589	287	0	7052
FEVR	Dir S	18	95	161	211	246	263	263	246	211	161	95	18	1988
-	Glo G	30	162	279	374	441	476	476	441	374	279	162	30	3524
-	G /vitr	19	119	223	308	369	400	400	369	308	223	119	19	2876
-	Glo G *	69	338	561	732	852	913	913	852	732	561	338	69	6930
MARS	Dir S	29	107	187	254	303	328	328	303	254	187	107	29	2416
-	Glo G	52	183	314	426	508	551	551	508	426	314	183	52	4068
-	G /vitr	24	115	230	335	412	452	452	412	335	230	115	24	3136
-	Glo G *	80	274	461	619	732	791	791	732	619	461	274	80	5914
AVRI	Dir S	1	38	103	160	202	225	225	202	160	103	38	1	1458
-	Glo G	36	118	230	328	402	441	441	402	328	230	118	36	3116
-	G /vitr	27	69	145	231	300	337	337	300	231	145	69	27	2224
-	Glo G *	40	151	314	457	562	618	618	562	457	314	151	40	4292
MAI	Dir S	0	2	46	108	154	179	179	154	108	46	2	0	978
-	Glo G	48	83	163	263	337	377	377	337	263	163	83	48	2569
-	G /vitr	38	64	99	161	222	257	257	222	161	99	64	38	1704
-	Glo G *	52	84	185	314	411	462	462	411	314	185	84	52	3046
JUIN	Dir S	0	0	13	69	113	137	137	113	69	13	0	0	664
-	Glo G	53	83	125	214	285	324	324	285	214	125	83	53	2210
-	G /vitr	42	66	88	128	176	206	206	176	128	88	66	42	1446
-	Glo G *	57	85	132	245	336	384	384	336	245	132	85	57	2526
JUIL	Dir S	0	0	30	99	152	180	180	152	99	30	0	0	922
-	Glo G	49	79	140	243	324	367	367	324	243	140	79	49	2436
-	G /vitr	39	62	89	142	201	237	237	201	142	89	62	39	1564
-	Glo G *	55	83	150	269	360	409	409	360	269	150	83	55	2690
AOUT	Dir S	0	19	98	174	231	260	260	231	174	98	19	0	1564
-	Glo G	38	93	213	326	412	458	458	412	326	213	93	38	3092
-	G /vitr	30	59	122	211	288	332	332	288	211	122	59	30	2094
-	Glo G *	44	103	244	375	473	526	526	473	375	244	103	44	3544
SEPT	Dir S	15	88	177	255	311	341	341	311	255	177	88	15	2374
-	Glo G	38	161	295	413	501	548	548	501	413	295	161	38	3914
-	G /vitr	20	91	200	310	394	439	439	394	310	200	91	20	2908
-	Glo G *	50	205	372	518	625	681	681	625	518	372	205	50	4904
OCTO	Dir S	24	119	210	284	335	362	362	335	284	210	119	24	2668
-	Glo G	38	185	325	440	523	567	567	523	440	325	185	38	4156
-	G /vitr	22	129	252	358	434	474	474	434	358	252	129	22	3338
-	Glo G *	61	286	486	648	763	823	823	763	648	486	286	61	6134
NOVE	Dir S	6	96	189	254	297	319	319	297	254	189	96	6	2322
-	Glo G	10	150	292	398	471	510	510	471	398	292	150	10	3662
-	G /vitr	7	117	239	334	399	433	433	399	334	239	117	7	3058
-	Glo G *	22	293	547	729	852	914	914	852	729	547	293	22	6714
DECE	Dir S	0	76	183	250	292	313	313	292	250	183	76	0	2228
-	Glo G	0	121	279	386	458	495	495	458	386	279	121	0	3478
-	G /vitr	0	97	233	327	390	422	422	390	327	233	97	0	2938
-	Glo G *	0	254	565	762	889	953	953	889	762	565	254	0	6846
A06+0::asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE	/	12 heures		(Midi TSV)		JOURNEE Wh/m2

Table A4: Mean monthly hourly solar irradiation on south vertical.

Source: "Atlas Solaire de l'Algerie", 1985.

******************** Energie (en Wh/m2) ==================== ASA/m.c.*epau
* 06 - CONSTANTINE * incidente sur le PLAN VERTICAL OUEST (jem) ------------
******************** par tranche horaire ==================== p:(+090,+000)

TRANCHES HOR.		6- 7	7- 8	8- 9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	TOTAL JOURNEE
JANV	Dir S	0	0	0	0	0	0	48	138	207	235	153	0	781
-	Glo G	0	13	46	72	90	98	160	266	336	349	227	0	1657
-	G /vitr	0	10	36	57	71	78	102	191	272	295	195	0	1307
-	Glo G *	0	15	48	70	85	93	220	451	623	685	462	0	2752
FEVR	Dir S	0	0	0	0	0	0	45	129	197	235	212	56	874
-	Glo G	2	31	66	92	110	119	180	284	355	378	324	89	2030
-	G /vitr	2	25	52	73	87	94	119	208	289	320	279	77	1625
-	Glo G *	2	34	64	86	102	110	247	496	690	790	714	216	3551
MARS	Dir S	0	0	0	0	0	0	70	201	311	381	383	224	1570
-	Glo G	14	52	85	111	128	137	225	380	495	551	522	310	3010
-	G /vitr	11	41	67	87	101	108	145	279	406	469	450	269	2433
-	Glo G *	16	53	81	104	120	129	270	527	733	855	844	517	4249
AVRI	Dir S	0	0	0	0	0	0	65	189	293	363	383	315	1691
-	Glo G	35	71	101	125	141	149	234	384	496	555	545	436	3402
-	G /vitr	27	56	80	98	111	118	153	281	405	470	468	376	2756
-	Glo G *	38	70	97	119	136	145	282	533	736	864	885	735	4865
MAI	Dir S	0	0	0	0	0	0	75	217	337	420	451	403	2110
-	Glo G	48	80	108	130	145	153	247	415	543	616	620	535	3940
-	G /vitr	38	63	85	102	114	121	158	300	440	521	532	461	3194
-	Glo G *	52	81	106	128	145	154	282	518	708	832	864	768	5077
JUIN	Dir S	0	0	0	0	0	0	74	214	332	415	447	407	2166
-	Glo G	53	83	109	130	145	153	245	410	537	610	617	542	4039
-	G /vitr	42	66	86	102	114	120	156	294	432	514	528	467	3270
-	Glo G *	57	85	110	131	147	156	279	503	684	802	835	755	5122
JUIL	Dir S	0	0	0	0	0	0	87	251	390	485	517	461	2471
-	Glo G	49	79	105	126	142	150	254	442	588	673	680	589	4272
-	G /vitr	39	62	83	99	111	118	159	317	475	568	583	508	3462
-	Glo G *	55	83	108	129	145	154	277	501	680	795	822	729	4989
AOUT	Dir S	0	0	0	0	0	0	88	255	394	486	507	418	2298
-	Glo G	38	70	98	120	136	144	250	441	586	667	662	537	3964
-	G /vitr	30	55	77	94	107	113	157	319	478	566	569	464	3215
-	Glo G *	44	75	101	123	139	148	276	509	694	807	820	684	4709
SEPT	Dir S	0	0	0	0	0	0	82	238	365	443	442	293	1886
-	Glo G	20	56	86	109	125	134	233	412	545	611	582	395	3345
-	G /vitr	16	44	67	86	98	105	147	301	447	520	501	342	2706
-	Glo G *	25	61	88	110	127	135	267	507	695	802	787	554	4213
OCTO	Dir S	0	0	0	0	0	0	67	193	293	346	313	95	1307
-	Glo G	5	36	68	93	110	118	201	347	451	490	428	140	2487
-	G /vitr	4	29	54	73	86	93	128	253	369	417	369	121	1996
-	Glo G *	6	41	71	93	109	117	248	485	666	755	685	230	3506
NOVE	Dir S	0	0	0	0	0	0	49	140	209	237	173	14	822
-	Glo G	0	18	50	75	92	100	163	270	342	355	260	23	1748
-	G /vitr	0	14	39	59	73	79	105	196	277	301	224	20	1387
-	Glo G *	0	20	53	75	91	98	223	449	616	676	519	52	2872
DECE	Dir S	0	0	0	0	0	0	44	126	187	205	117	0	679
-	Glo G	0	9	39	65	82	91	147	244	305	308	181	0	1471
-	G /vitr	0	7	31	51	65	72	94	174	246	261	156	0	1157
-	Glo G *	0	10	43	66	81	88	210	428	586	628	387	0	2527
A06+2::asa		17-18	16-17	15-16	14-15	13-14	12-13	VERTICAL	EST		<<<---	TR.HOR.		JOURNEE Wh/m2

Table A5: Mean monthly hourly solar irradiation on east and west verticals.

Source: "Atlas Solaire de l'Algerie", 1985.

Appendix B: Sun path diagrams for 36°N latitude.
(used for shading calculation)

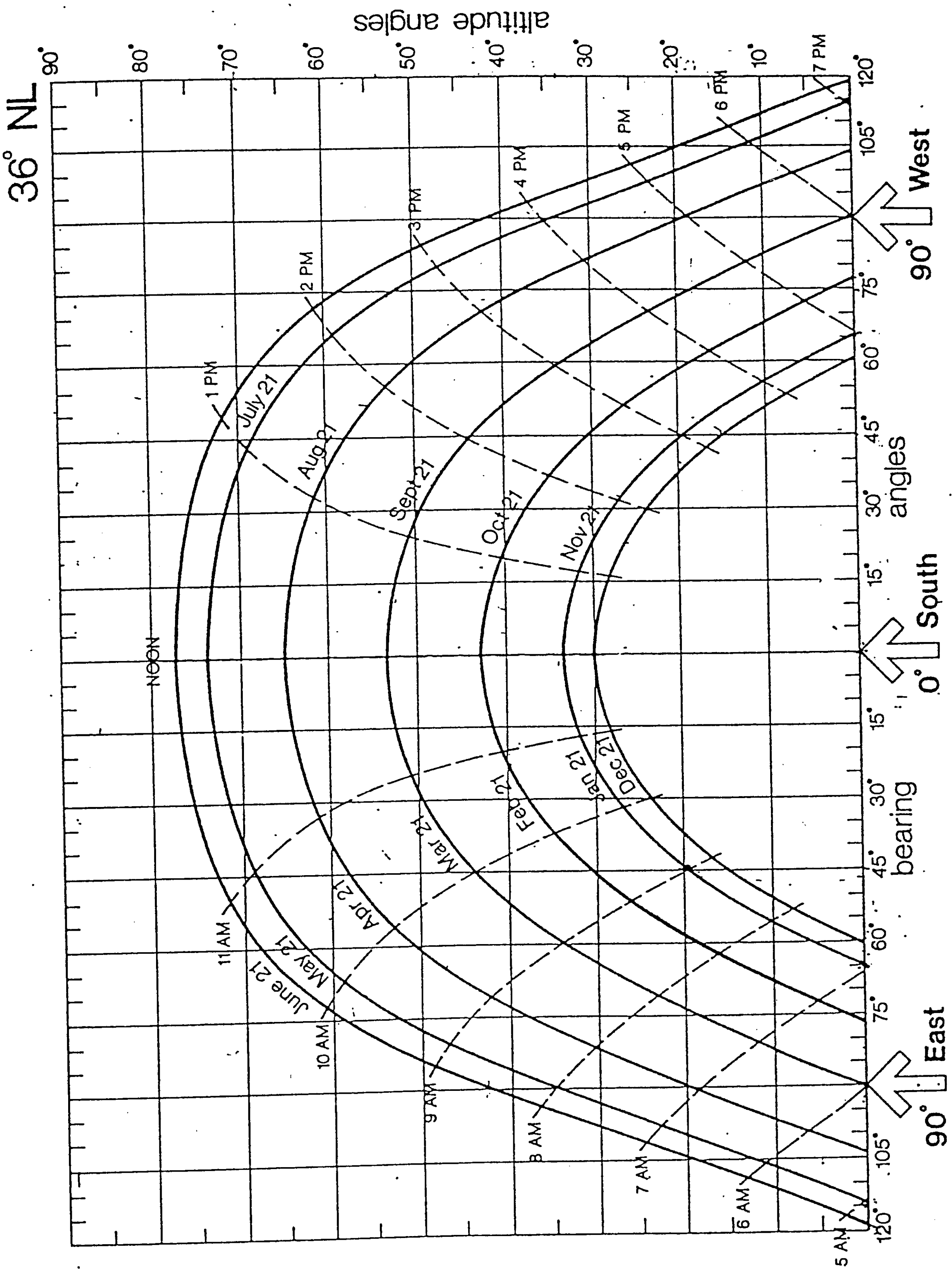


Fig B1: Sun path diagram for 36°N

Source: Mazria, "The Passive Solar Energy Book", 1979.

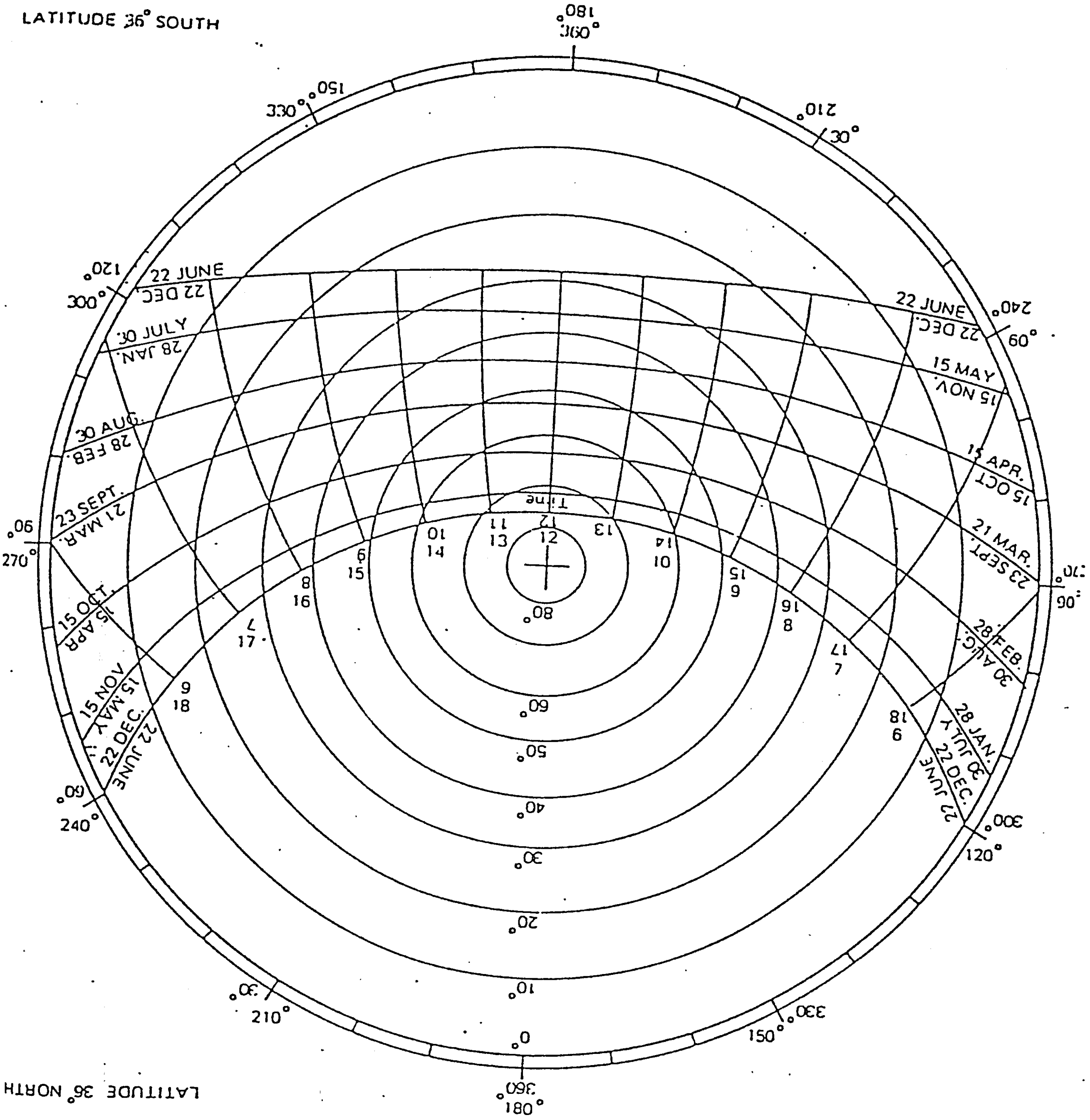
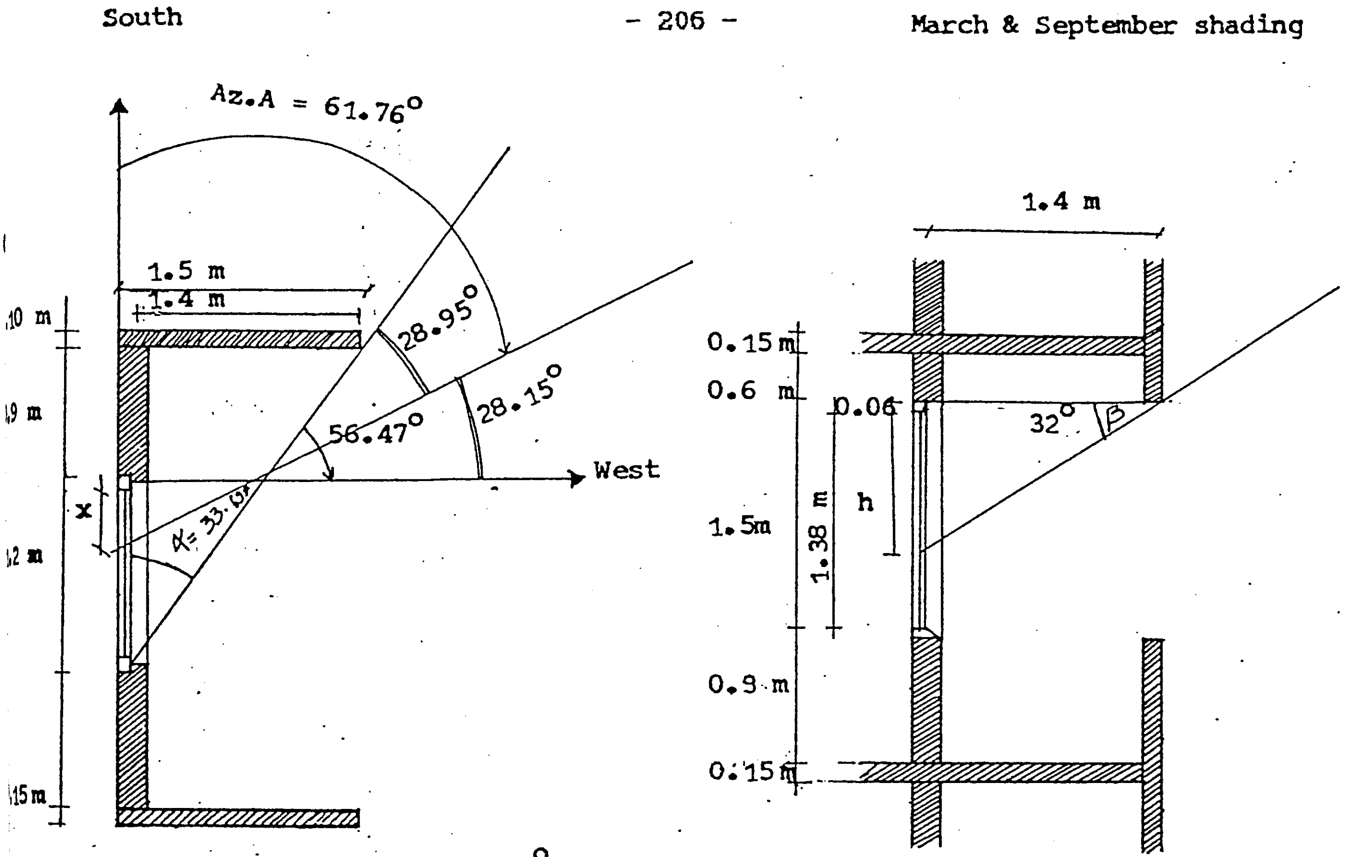


Fig B2: Sun path diagram for 36°**N**

- The vertical graduations from 0° to 90° represent the angle of altitude measured from the horizontal (0°) up to the zenith (90°).
- The horizontal graduation from 0° to 360° represent the azimuth or horizontal bearing from (0°) North, through 90°(East), 180°(South), 270°(West) to 360° North.
- The longer curved arcs represent the path of the sun across the sky on the 15th of each month.
- The shorter curved arcs represent the "mean solar time".

March & September shading



Az.A - Azimuth angle = 61.76°

β - Altitude angle = 32°

Sun set angle (in March, September) = 90°

α - angle for which the window is totally shaded.

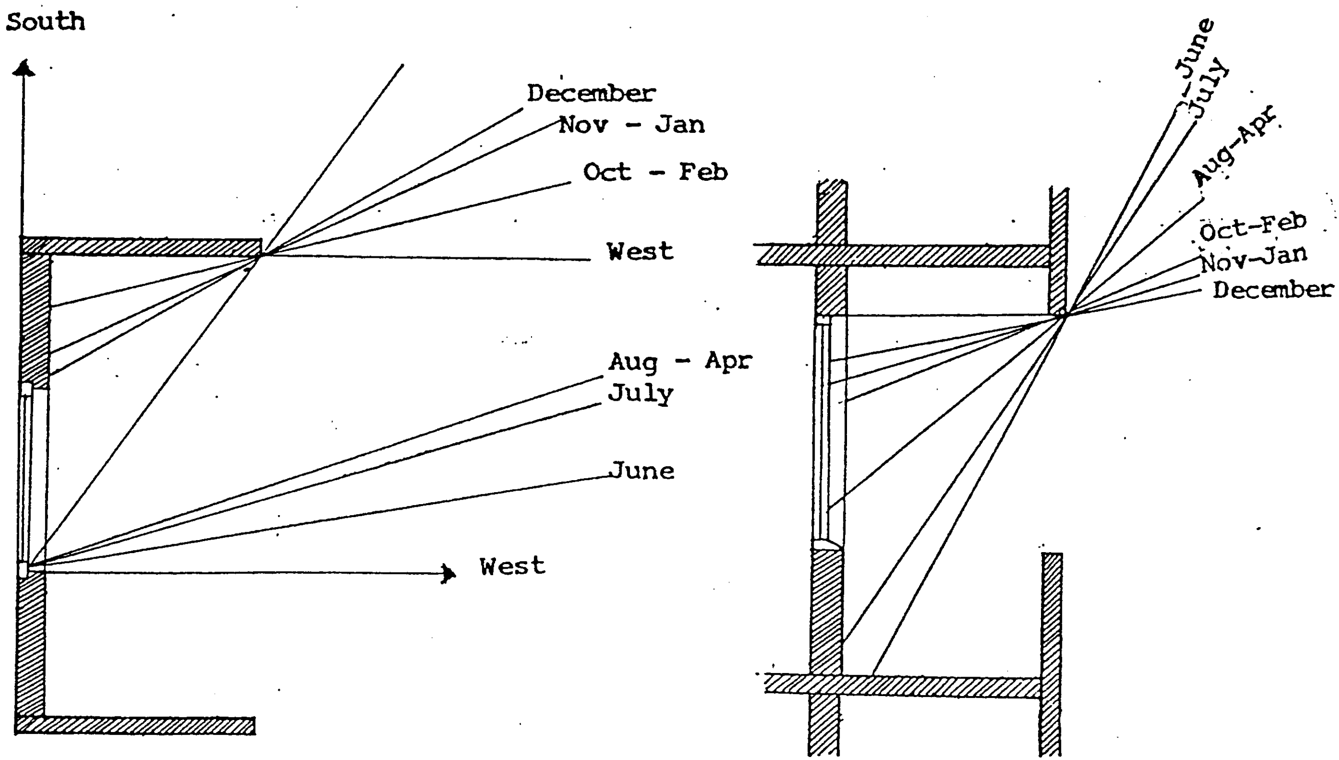


Fig B1: shading calculation for a west window in the flat type using the sun chart diagram for 36°N.

Example of average shading calculation in March and September using the sum path diagram for 36°N latitude.

Vertical Shading

$$\text{Average Az.A} = \frac{(\text{sunset angle} - \alpha)}{2} + \alpha$$

$$\text{Tangent Az.A} = \frac{1.4}{x + 0.9 + 0.06} \qquad x = \frac{1.4}{\text{tg Az.A}} - 0.9 - 0.06$$

$x = -0.2$ so, the verical fins do not do any shading.

Horizontal Shading

$$\text{Tangent} = \frac{h + 0.06}{1.4} \qquad h = \text{tg}\,(32^\circ) \times 1.4 - 0.06$$

$$h = 0.814$$

Thus the percentage of shading is 0.814/1.38 = 0.589

Area of glazing is 1.26 m²

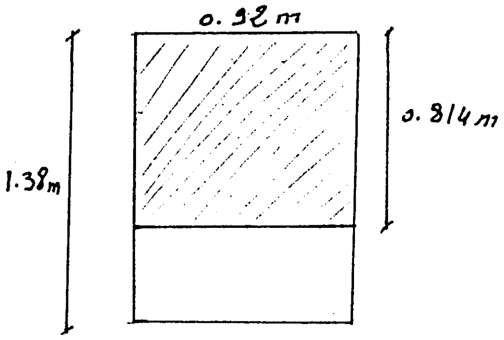
33.69o corresponds to 100% shaded window

33.69o/90o = 0.374 --------> 1

0.589 corresponds to (1 - 0.374) = 0.626

the real shading is (0.1374 x 1) + (0.589 x 0.626)

Thus the shading portion is 0.742 --------> 74.2%



Appendix C: Useful tables used in thermal analysis.

The following information should be used to provide an estimate of the mean rates of gains G_1 and G_2, from the number of persons in the household N. The values are given in watts (averaged over 24 hours) for the calculation of base temperature and, for lighting and electrical appliances, in GJ/annum for the estimation of total energy inputs to dwellings.

Source	W	Estimate GJ/annum	Proportion between zones Zone 1	 Zone 2
			%	%
Metabolic	62 N		50	50
Water heating	16 N+25		0	100
Cooking: Electric	108			
Gas	136		0	100
Lighting and electrical appliances:				
— Refrigerator	30	(0.95)	0	100
— Kettle	20	(0.63)	0	100
— Freezer	77	(2.43)	0	100
— Television	27	(0.85)	100	0
— Washing machine—				
— hot fill	5	(0.16)	0	100
— cold fill	18	(0.57)	0	100
— Dishwasher	31	(0.98)	0	100
— Tumble drier	17	(0.54)	0	100
— Lights—				
— small house, no children	13	(0.41)	50	50
— medium house, no children	25	(0.79)	50	50
— large house, no children	38	(1.20)	50	50
— add if children:	12	(0.38)	50	50
Miscellaneous items	14	(0.44)	30	70
Total for lighting and electrical appliances:	Between 108 and 260, depending on number of appliances etc. In absence of information take middle of range: 184	(5.80)	30	70

Table C1: Internal gains.

Source: "BREDEM", p. 39.

Demand temperature level in the living room - 21°C responsive heating system.

Heating demand	Heat loss parameter (Whole house)		Mean internal temperatures		
			Living room	Rest of house	Average
WHOLE HOUSE HEATED:					
All day	6.0		18.5	16.0	16.7
	4.0		19.2	17.2	17.7
	2.0		19.9	18.4	18.8
Twice per day	6.0		16.6	14.1	14.8
	4.0		17.8	15.8	16.3
	2.0		19.0	17.5	17.9
Evening only	6.0		13.1	10.6	11.2
	4.0		14.2	12.2	12.7
	2.0		16.2	14.7	15.1
HALF HOUSE HEATED:					
	Zone 1	Zone 2			
All day	Any	6.0	18.7	13.2	14.6
		4.0	19.2	14.6	15.8
		2.0	19.7	16.7	17.4
Twice per day	6.0	6.0	16.6	11.9	13.1
		4.0	17.6	13.4	14.5
	4.0	6.0	17.0	12.1	13.3
		4.0	17.8	13.7	14.7
		2.0	18.7	15.9	16.6
	2.0	4.0	18.1	13.9	15.0
		2.0	19.0	16.2	16.9
Evening only	6.0	6.0	13.1	9.7	10.5
		4.0	13.9	10.9	11.6
	4.0	6.0	13.3	9.9	10.7
		4.0	14.2	11.2	11.9
		2.0	15.5	13.3	13.9
	2.0	4.0	14.5	11.5	12.2
		2.0	16.2	14.0	14.5
LIVING ROOM HEATED:					
All day	Any	6.0	18.7	10.0	12.2
		4.0	19.2	11.6	13.5
		2.0	19.7	15.0	16.1
Twice per day	6.0	6.0	16.6	9.6	11.4
		4.0	17.6	11.1	12.7
	4.0	6.0	17.0	9.7	11.5
		4.0	17.8	11.2	12.9
		2.0	18.7	14.5	15.6
	2.0	4.0	18.1	11.3	13.0
		2.0	19.0	14.7	15.8
Evening only	6.0	6.0	13.1	8.9	9.9
		4.0	13.9	10.1	11.1
	4.0	6.0	13.3	8.9	10.0
		4.0	14.2	10.2	11.2
		2.0	15.5	13.1	13.7
	2.0	4.0	14.5	10.3	11.4
		2.0	16.2	13.5	14.1

Table C2: Mean internal temperatures, depending on heat loss parameters, heating system and regime.

Source: "BREDEM", p. 41.

Table Thermal conductivities of various standard constructional elements

Material	*Density (kg/m³)*	*Thermal Conductivity (W/m/°C)*	*Specific Heat Capacity (J/kg/°C)*
Walls (external and internal)			
Asbestos cement sheet	700	0.36	1050
Asbestos cement decking	1500	0.36	1050
Brickwork (outer leaf)	1700	0.84	800
Brickwork (inner leaf)	1700	0.62	800
Cast concrete (dense)	2100	1.40	840
Cast concrete (lightweight)	1200	0.38	1000
Concrete block (heavyweight)	2300	1.63	1000
Concrete block (medium weight)	1400	0.51	1000
Concrete block (lightweight)	600	0.19	1000
Fibreboard	300	0.06	1000
Plasterboard	950	0.16	840
Tile hanging	1900	0.84	800
Surface finishes			
External rendering	1300	0.50	1000
Plaster (dense)	1300	0.50	1000
Plaster (lightweight)	600	0.16	1000
Roofs			
Aerated concrete slab	500	0.16	840
Asphalt	1700	0.50	1000
Felt/bitumen layers	1700	0.50	1000
Screed	1200	0.41	840
Stone chippings	1800	0.96	1000
Tile	1900	0.84	800
Wood-wool slab	500	0.10	1000
Floors			
Cast concrete	2000	1.13	1000
Metal tray	7800	50.00	480
Screed	1200	0.41	840
Timber flooring	650	0.14	1200
Wood blocks	650	0.14	1200
Insulation			
Expanded polystyrene (EPS) slab	25	0.035	1400
Glass fibre quilt	12	0.040	840
Glass fibre slab	25	0.035	1000
Mineral fibre slab	30	0.035	1000
Phenolic foam	30	0.040	1400
Polyurethane board	30	0.025	1400
Urea formaldehyde (UF) foam	10	0.040	1400

Table C3: Thermo-physical properties of some common materials.

Source: Kenneth Fowler, "Design of thermal loads for building structure", Vol. 2, Longman, New York 1985.

Appendix D: Some results of the dynamic thermal analysis

The calculations have been carried out for the two extreme months - January and July. The load was calculated according to the occupancy timetable and number of occupants in each zone related to the Algerian way of life.

Living room - From 8.00 - 18.00 (4 persons)
From 18.00 - 24.00 (8 persons)
to maintain an internal temperature of 21°C
Rest of the floor - From 20.00 - 8.00 (10 persons)
to maintain a minimum temperature of 15°C in January and a maximum of 21°C and 25°C in July.

I January

1) Courtyard house

a) no account taken of the courtyard temperature stratification

8.00 - 18.00 ---- 9.09 kWh zone I
18.00 - 24.00 ---- 4.5 kWh t_i = 21°C

20.00 - 8.00 ---- 16.5 kWh zone II t_i = 15°C

For both zones, the heating load is 30.09 KWh/day.

b) taking into account the courtyard temperature stratification

8.00 - 18.00 ---- 8.97 kWh
18.00 - 24.00 ---- 3.86 kWh
20.00 - 8.00 ---- 10.13 kWh

For both zones, the heating load is 22.96 kWh/day.

Thus (b) yields a 31% reduction in heating load. This emphasizes the thermal importance of the courtyard form.

2) Flat type

8.00 - 18.00 ---- 7.23 kWh zone I
18.00 - 24.00 ---- 3.19 kWh t_i = 21°C

20.00 - 8.00 ---- 30.98 kWh - zone I t_i = 15°C
For both zones, the heating load is 41.4 kWh/day

II July

1) Courtyard house

a) no account taken of the courtyard temperature stratification

8.00 - 18.00 ---- 25.8 kWh zone I
18.00 - 24.00 ---- -17.99 kWh (windows open) t_i = 21°C
---- -8.90 kWh (windows closed)
---- -4.39 kWh for t_i = 25°C
20.00 - 8.00 ---- -32.57 kWh (windows open) zone II
---- -17.87 kWh (windows closed) t_i = 21°C

For both zones the cooling load is 76.36 kWh/day (windows open) and the load drops to 50.96 kWh/day (windows closed)

For t_i = 25°C and windows open during the second and third period

8.00 - 18.00 ---- -19.26 kWh
18.00 - 24.00 ---- -7.47 kWh
20.00 - 8.00 ---- - 2.45 kWh

For both zones, the cooling load is -29.18 kWh/day

If the shutters are used during 18.00 - 24.00, the load drops to -4.67 kWh. Thus the cooling load in both zones will be 26.36 kWh/day.

b) taking into account the courtyard temperature stratification

8.00 - 18.00 ---- -21.13 kWh

18.00 - 24.00 ---- -17.19 kWh (windows open)

---- -8.21 kWh (windows closed)

20.00 - 8.00 ---- -47.33 kWh (windows open)

---- -22.13 kWh (windows closed)

For both zones, the cooling load is 86.12 kWh/day (windows open) and it drops to 51.47 kWh/day (windows closed)

2) Flat type: $t_i = 21^{\circ}C$

8.00 - 18.00 ---- -20.77 kWh

18.00 - 24.00 ---- -19.25 kWh (windows open)

---- -7.95 kWh (windows closed)

20.00 - 8.00 ---- -59. kWh (windows open)

---- -22.58 kWh (windows closed)

For the whole flat the cooling load is 99.02 kWh/day (windows open) and the load drops to 58.3 kWh/day (windows closed)

In January: only the shutters were assumed open during the first period and closed during the second and third period.

In July: for the first period, the shutters were assumed closed. For the second and third periods, in one case windows and shutters were assumed open, in the other case only windows were assumed closed.

Some computer output is given in the following pages. The tables include hourly "t_e" and heat transfer for each constructional element of the envelope.

Flat : zone I

N	Area	U val	T.lag	F	
1	8.6	1.49	7.8	0.40	wall 1
2	2.8	2.73	3.4	0.64	wall 2
3	2.6	2.73	3.4	0.64	wall 3
4	13.6	1.34	11.7	0.28	wall 4
5	1.9	2.50	1.2	1.00	door

F = decrement factor

```
                                   Q-heat R/P/T-Results X-back to Dec Fact
File Name : A.DAT Data for Month : JAN Int. Temp. : 21
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time  | T.o   T.e   No.  1 | T.o   T.e   No.  2 | T.o   T.e   No.  3 |
          T.o   T.e   No.  4 | T.o   T.e   No.  5 |            Heat Loss Tot
|  1.00 | 4.1   7.4   173.9  | 4.1   5.5   118.5  | 4.1   5.5   110.0 |
          4.1   7.5   246.1  | 4.1   4.6    77.8  |                   |   726.3
|  2.00 | 3.6   7.0   179.0  | 3.6   5.3   119.7  | 3.6   5.3   111.2 |
          3.6   7.6   243.4  | 3.6   4.2    80.0  |                   |   733.4
|  3.00 | 3.3   6.6   184.6  | 3.3   5.2   120.6  | 3.3   5.2   112.0 |
          3.3   7.6   243.4  | 3.3   3.7    82.2  |                   |   742.8
|  4.00 | 2.8   6.1   190.5  | 2.8   5.0   122.4  | 2.8   5.0   113.7 |
          2.8   7.4   248.4  | 2.8   3.3    84.0  |                   |   758.9
|  5.00 | 2.6   5.8   194.6  | 2.6   4.7   124.8  | 2.6   4.7   115.9 |
          2.6   7.1   254.2  | 2.6   2.9    85.8  |                   |   775.3
|  6.00 | 2.3   5.7   195.7  | 2.3   4.4   126.7  | 2.3   4.4   117.7 |
          2.3   6.8   259.4  | 2.3   2.6    87.2  |                   |   786.6
|  7.00 | 3.2   5.6   197.0  | 3.2   4.2   128.6  | 3.2   4.2   119.4 |
          3.2   6.5   265.0  | 3.2   2.4    88.4  |                   |   798.4
|  8.00 | 4.1   5.5   198.0  | 4.1   4.0   130.1  | 4.1   4.0   120.8 |
          4.1   6.1   270.7  | 4.1   3.0    85.4  |                   |   805.0
|  9.00 | 5.3   5.3   200.7  | 5.3   3.8   131.4  | 5.3   3.8   122.0 |
          5.3   5.9   274.4  | 5.3   3.9    81.1  |                   |   809.6
| 10.00 | 6.4   5.2   202.9  | 6.4   4.1   129.3  | 6.4   4.1   120.1 |
          6.4   5.9   275.6  | 6.4   5.0    75.9  |                   |   803.8
| 11.00 | 8.0   5.0   204.8  | 8.0   4.6   125.0  | 8.0   4.6   116.1 |
          8.0   5.8   276.8  | 8.0   6.2    70.4  |                   |   793.1
| 12.00 |10.0   4.9   206.7  |10.0   5.3   119.9  |10.0   5.3   111.3 |
         10.0   5.7   278.0  |10.0   7.7    63.3  |                   |   779.1
| 13.00 |10.5   4.8   207.9  |10.5   6.1   114.3  |10.5   6.1   106.1 |
         10.5   5.6   280.7  |10.5   9.6    54.1  |                   |   763.1
| 14.00 |11.1   4.8   208.1  |11.1   7.0   107.3  |11.1   7.0    99.6 |
         11.1   5.5   282.8  |11.1  10.4    50.4  |                   |   748.2
| 15.00 |11.5   5.1   203.7  |11.5   8.1    98.3  |11.5   8.1    91.3 |
         11.5   5.4   284.7  |11.5  11.0    47.6  |                   |   725.5
| 16.00 |10.6   5.5   198.8  |10.6   8.8    92.9  |10.6   8.8    86.3 |
         10.6   5.3   286.5  |10.6  11.4    45.6  |                   |   710.1
| 17.00 | 9.4   5.9   192.9  | 9.4   9.2    90.2  | 9.4   9.2    83.7 |
          9.4   5.2   287.8  | 9.4  10.8    48.6  |                   |   703.2
| 18.00 | 8.4   6.4   186.6  | 8.4   9.5    87.9  | 8.4   9.5    81.6 |
          8.4   5.2   287.4  | 8.4   9.6    54.0  |                   |   697.5
| 19.00 | 7.3   7.1   178.0  | 7.3   9.3    89.8  | 7.3   9.3    83.3 |
          7.3   5.5   282.9  | 7.3   8.6    58.9  |                   |   692.9
| 20.00 | 6.2   7.8   169.2  | 6.2   8.6    95.0  | 6.2   8.6    88.2 |
          6.2   5.7   278.0  | 6.2   7.6    63.8  |                   |   694.2
| 21.00 | 5.2   8.0   166.6  | 5.2   7.9   100.3  | 5.2   7.9    93.1 |
          5.2   6.1   272.1  | 5.2   6.4    69.4  |                   |   701.4
| 22.00 | 5.0   8.2   163.7  | 5.0   7.2   105.3  | 5.0   7.2    97.8 |
          5.0   6.4   265.5  | 5.0   5.4    74.1  |                   |   706.5
| 23.00 | 4.7   8.3   163.1  | 4.7   6.5   110.9  | 4.7   6.5   103.0 |
          4.7   6.9   256.8  | 4.7   5.0    75.8  |                   |   709.5
| 24.00 | 4.6   7.9   167.9  | 4.6   5.8   116.0  | 4.6   5.8   107.7 |
          4.6   7.3   248.8  | 4.6   4.8    77.1  |                   |   717.6

| Total Heat loss          643.75 MegaJoules
```

```
File Name : A.DAT Data for Month : JUL Int. Temp. : 21
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time  | T.o  T.e    No.  1  | T.o  T.e    No.  2 | T.o  T.e    No.  3 |
        | T.o  T.e    No.  4  | T.o  T.e    No.  5 |         Heat Loss Tot
|  1.00 |21.9 29.7   -112.1   | 21.9 26.7   -43.3  | 21.9 26.7   -40.2 |
         21.9 28.5   -137.4   | 21.9 22.8    -8.5  |              |      -341.5
|  2.00 |20.5 29.2   -105.3   | 20.5 25.5   -34.7  | 20.5 25.5   -32.2 |
         20.5 28.9   -144.8   | 20.5 22.0    -4.8  |              |      -321.8
|  3.00 |19.9 28.2    -92.9   | 19.9 24.4   -26.2  | 19.9 24.4   -24.3 |
         19.9 29.1   -148.3   | 19.9 20.8     1.0  |              |      -290.7
|  4.00 |19.2 27.6    -84.4   | 19.2 23.8   -21.4  | 19.2 23.8   -19.8 |
         19.2 29.0   -146.3   | 19.2 20.0     4.7  |              |      -267.2
|  5.00 |19.0 27.0    -76.5   | 19.0 23.1   -16.2  | 19.0 23.1   -15.0 |
         19.0 28.8   -142.6   | 19.0 19.3     7.9  |              |      -242.5
|  6.00 |18.8 26.3    -67.9   | 18.8 22.5   -11.7  | 18.8 22.5   -10.9 |
         18.8 28.4   -13[illegible]   | 18.8 19.0     9.3  |              |      -216.2
|  7.00 |20.7 25.6    -58.6   | 20.7 22.1    -8.5  | 20.7 22.1    -7.9 |
         20.7 27.8   -123.2   | 20.7 18.8    10.4  |              |      -187.7
|  8.00 |23.3 25.0    -51.3   | 23.3 21.9    -6.5  | 23.3 21.9    -6.0 |
         23.3 27.3   -114.8   | 23.3 20.3     3.3  |              |      -175.4
|  9.00 |25.9 24.7    -47.6   | 25.9 21.7    -5.4  | 25.9 21.7    -5.0 |
         25.9 26.9   -106.9   | 25.9 22.8    -8.5  |              |      -173.4
| 10.00 |28.0 24.2    -41.2   | 28.0 22.4   -10.6  | 28.0 22.4    -9.9 |
         28.0 26.4    -98.2   | 28.0 25.4   -20.8  |              |      -180.7
| 11.00 |29.5 24.0    -38.0   | 29.5 23.9   -22.1  | 29.5 23.9   -20.5 |
         29.5 25.9    -89.1   | 29.5 27.5   -31.1  |              |      -200.7
| 12.00 |31.1 23.7    -35.0   | 31.1 25.5   -34.8  | 31.1 25.5   -32.3 |
         31.1 25.5    -82.3   | 31.1 29.2   -38.9  |              |      -223.3
| 13.00 |32.6 23.6    -33.9   | 32.6 27.0   -45.9  | 32.6 27.0   -42.6 |
         32.6 25.3    -78.2   | 32.6 30.8   -46.5  |              |      -247.1
| 14.00 |34.2 23.7    -34.9   | 34.2 28.1   -54.4  | 34.2 28.1   -50.6 |
         34.2 25.0    -72.3   | 34.2 32.3   -53.7  |              |      -265.9
| 15.00 |35.3 24.6    -45.5   | 35.3 29.1   -62.2  | 35.3 29.1   -57.7 |
         35.3 24.8    -69.1   | 35.3 33.9   -61.2  |              |      -295.7
| 16.00 |35.0 25.6    -58.9   | 35.0 30.1   -69.7  | 35.0 30.1   -64.7 |
         35.0 24.6    -66.3   | 35.0 35.1   -66.9  |              |      -326.5
| 17.00 |34.4 26.6    -71.6   | 34.4 31.1   -77.3  | 34.4 31.1   -71.8 |
         34.4 24.6    -65.2   | 34.4 35.1   -66.8  |              |      -352.8
| 18.00 |33.4 27.4    -81.6   | 33.4 31.9   -83.7  | 33.4 31.9   -77.7 |
         33.4 24.7    -67.3   | 33.4 34.5   -64.2  |              |      -374.6
| 19.00 |30.8 28.0    -89.6   | 30.8 32.1   -85.0  | 30.8 32.1   -78.9 |
         30.8 25.3    -78.2   | 30.8 33.6   -59.9  |              |      -391.6
| 20.00 |29.1 28.6    -97.7   | 29.1 31.8   -82.6  | 29.1 31.8   -76.7 |
         29.1 26.0    -91.5   | 29.1 31.3   -49.0  |              |      -397.6
| 21.00 |27.6 29.2   -105.5   | 27.6 31.3   -78.5  | 27.6 31.3   -72.9 |
         27.6 26.7   -103.9   | 27.6 29.4   -40.1  |              |      -400.9
| 22.00 |26.0 29.8   -113.2   | 26.0 30.0   -68.9  | 26.0 30.0   -64.0 |
         26.0 27.2   -113.6   | 26.0 27.9   -32.8  |              |      -392.5
| 23.00 |24.1 30.2   -117.4   | 24.1 28.7   -58.8  | 24.1 28.7   -54.6 |
         24.1 27.7   -121.6   | 24.1 26.3   -25.1  |              |      -377.6
| 24.00 |22.5 30.0   -115.5   | 22.5 27.7   -51.1  | 22.5 27.7   -47.5 |
         22.5 28.1   -129.6   | 22.5 24.5   -16.5  |              |      -360.2

| Total Heat loss      -252.14 MegaJoules
```

Flat : zone II

N	Area	U val	T.lag	F	
1	14.7	1.49	7.8	0.40	wall 1
2	29.6	2.73	3.4	0.64	wall 2
3	23.3	1.49	7.8	0.40	wall 3
4	2.0	2.73	3.4	0.64	wall 4
5	5.5	2.07	5.8	0.43	wall 5

F = decrement factor

```
File Name : A.DAT Data for Month : JAN Int. Temp. : 15
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time  | T.o  T.e    No.  1 | T.o  T.e    No.  2 | T.o  T.e    No.  3 |
        | T.o  T.e    No.  4 | T.o  T.e    No.  5 |          Heat Loss Tot
|  1.00 | 4.1  7.4    165.7  | 4.1  5.5    767.4  | 4.1  7.4   262.7  |
          4.1  5.5     52.6  | 4.1  6.6     95.4  |                   |  1343.9
|  2.00 | 3.6  7.0    174.6  | 3.6  5.3    780.9  | 3.6  7.0   276.7  |
          3.6  5.3     53.6  | 3.6  6.1    101.0  |                   |  1386.8
|  3.00 | 3.3  6.6    184.1  | 3.3  5.2    790.2  | 3.3  6.6   291.7  |
          3.3  5.2     54.2  | 3.3  5.8    104.9  |                   |  1425.1
|  4.00 | 2.8  6.1    194.1  | 2.8  5.0    809.3  | 2.8  6.1   307.7  |
          2.8  5.0     55.5  | 2.8  5.7    106.0  |                   |  1472.7
|  5.00 | 2.6  5.8    201.1  | 2.6  4.7    834.7  | 2.6  5.8   318.8  |
          2.6  4.7     57.2  | 2.6  5.6    107.3  |                   |  1519.2
|  6.00 | 2.3  5.7    203.1  | 2.3  4.4    854.8  | 2.3  5.7   321.9  |
          2.3  4.4     58.6  | 2.3  5.5    108.2  |                   |  1546.6
|  7.00 | 3.2  5.6    205.3  | 3.2  4.2    874.5  | 3.2  5.6   325.5  |
          3.2  4.2     60.0  | 3.2  5.3    110.8  |                   |  1576.1
|  8.00 | 4.1  5.5    207.0  | 4.1  4.0    890.5  | 4.1  5.5   328.1  |
          4.1  4.0     61.1  | 4.1  5.1    112.9  |                   |  1599.6
|  9.00 | 5.3  5.3    211.7  | 5.3  3.8    903.8  | 5.3  5.3   335.5  |
          5.3  3.8     62.0  | 5.3  4.9    114.7  |                   |  1627.6
| 10.00 | 6.4  5.2    215.4  | 6.4  4.1    882.5  | 6.4  5.2   341.5  |
          6.4  4.1     60.5  | 6.4  4.8    116.5  |                   |  1616.3
| 11.00 | 8.0  5.0    218.6  | 8.0  4.6    836.7  | 8.0  5.0   346.4  |
          8.0  4.6     57.4  | 8.0  4.7    117.7  |                   |  1576.9
| 12.00 |10.0  4.9    221.8  |10.0  5.3    782.4  |10.0  4.9   351.6  |
         10.0  5.3     53.7  |10.0  4.6    117.9  |                   |  1527.4
| 13.00 |10.5  4.8    224.0  |10.5  6.1    723.0  |10.5  4.8   355.1  |
         10.5  6.1     49.6  |10.5  5.0    113.6  |                   |  1465.3
| 14.00 |11.1  4.8    224.3  |11.1  7.0    649.5  |11.1  4.8   355.6  |
         11.1  7.0     44.5  |11.1  5.4    109.0  |                   |  1383.0
| 15.00 |11.5  5.1    216.7  |11.5  8.1    554.4  |11.5  5.1   343.5  |
         11.5  8.1     38.0  |11.5  5.9    103.4  |                   |  1256.0
| 16.00 |10.6  5.5    208.4  |10.6  8.8    497.5  |10.6  5.5   330.3  |
         10.6  8.8     34.1  |10.6  6.5     97.3  |                   |  1167.6
| 17.00 | 9.4  5.9    198.3  | 9.4  9.2    468.5  | 9.4  5.9   314.4  |
          9.4  9.2     32.1  | 9.4  7.2     89.1  |                   |  1102.4
| 18.00 | 8.4  6.4    187.5  | 8.4  9.5    444.6  | 8.4  6.4   297.2  |
          8.4  9.5     30.5  | 8.4  7.9     80.7  |                   |  1040.5
| 19.00 | 7.3  7.1    172.8  | 7.3  9.3    464.0  | 7.3  7.1   273.8  |
          7.3  9.3     31.8  | 7.3  8.1     78.2  |                   |  1020.6
| 20.00 | 6.2  7.8    157.9  | 6.2  8.6    519.2  | 6.2  7.8   250.2  |
          6.2  8.6     35.6  | 6.2  8.4     75.5  |                   |  1038.4
| 21.00 | 5.2  8.0    153.3  | 5.2  7.9    575.1  | 5.2  8.0   243.0  |
          5.2  7.9     39.4  | 5.2  8.4     74.9  |                   |  1085.7
| 22.00 | 5.0  8.2    148.5  | 5.0  7.2    628.3  | 5.0  8.2   235.3  |
          5.0  7.2     43.1  | 5.0  8.0     79.5  |                   |  1134.6
| 23.00 | 4.7  8.3    147.4  | 4.7  6.5    687.3  | 4.7  8.3   233.6  |
          4.7  6.5     47.1  | 4.7  7.5     85.1  |                   |  1200.6
| 24.00 | 4.6  7.9    155.6  | 4.6  5.8    741.6  | 4.6  7.9   246.6  |
          4.6  5.8     50.9  | 4.6  7.1     90.1  |                   |  1284.7

| Total Heat loss        1166.31 MegaJoules
```

```
File Name : A.DAT Data for Month : JUL Int. Temp. : 21
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time  | T.o  T.e    No.  1 | T.o  T.e    No.  2 | T.o  T.e    No.  3 |
          T.o  T.e    No.  4 | T.o  T.e    No.  5 |          Heat Loss Tot
|  1.00 |21.9 29.7  -191.5   21.9 26.7  -458.1   21.9 29.7  -303.6 |
         21.9 26.7   -31.4   21.9 28.4   -83.8                   |    -1068.5
|  2.00 |20.5 29.2  -180.0   20.5 25.5  -366.6   20.5 29.2  -285.3 |
         20.5 25.5   -25.1   20.5 27.6   -75.7                   |     -932.7
|  3.00 |19.9 28.2  -158.8   19.9 24.4  -277.1   19.9 28.2  -251.7 |
         19.9 24.4   -19.0   19.9 27.0   -68.2                   |     -774.8
|  4.00 |19.2 27.6  -144.2   19.2 23.8  -225.9   19.2 27.6  -228.6 |
         19.2 23.8   -15.5   19.2 26.3   -59.9                   |     -674.2
|  5.00 |19.0 27.0  -130.8   19.0 23.1  -171.1   19.0 27.0  -207.4 |
         19.0 23.1   -11.7   19.0 25.5   -51.0                   |     -572.1
|  6.00 |18.8 26.3  -116.0   18.8 22.5  -123.5   18.8 26.3  -183.9 |
         18.8 22.5    -8.5   18.8 24.9   -44.0                   |     -476.0
|  7.00 |20.7 25.6  -100.2   20.7 22.1   -89.4   20.7 25.6  -158.8 |
         20.7 22.1    -6.1   20.7 24.6   -40.5                   |     -395.0
|  8.00 |23.3 25.0   -87.6   23.3 21.9   -68.7   23.3 25.0  -138.9 |
         23.3 21.9    -4.7   23.3 24.0   -34.4                   |     -334.4
|  9.00 |25.9 24.7   -81.3   25.9 21.7   -57.1   25.9 24.7  -128.9 |
         25.9 21.7    -3.9   25.9 23.8   -31.4                   |     -302.7
| 10.00 |28.0 24.2   -70.5   28.0 22.4  -112.4   28.0 24.2  -111.7 |
         28.0 22.4    -7.7   28.0 23.5   -28.5                   |     -330.7
| 11.00 |29.5 24.0   -65.0   29.5 23.9  -233.2   29.5 24.0  -103.1 |
         29.5 23.9   -16.0   29.5 23.4   -27.5                   |     -444.7
| 12.00 |31.1 23.7   -59.8   31.1 25.5  -367.6   31.1 23.7   -94.8 |
         31.1 25.5   -25.2   31.1 23.5   -28.4                   |     -575.8
| 13.00 |32.6 23.6   -58.0   32.6 27.0  -485.0   32.6 23.6   -91.9 |
         32.6 27.0   -33.3   32.6 24.4   -38.6                   |     -706.7
| 14.00 |34.2 23.7   -59.7   34.2 28.1  -575.5   34.2 23.7   -94.6 |
         34.2 28.1   -39.5   34.2 25.5   -51.3                   |     -820.6
| 15.00 |35.3 24.6   -77.8   35.3 29.1  -657.3   35.3 24.6  -123.4 |
         35.3 29.1   -45.1   35.3 26.6   -63.5                   |     -967.0
| 16.00 |35.0 25.6  -100.6   35.0 30.1  -736.9   35.0 25.6  -159.5 |
         35.0 30.1   -50.5   35.0 27.4   -73.0                   |    -1120.5
| 17.00 |34.4 26.6  -122.4   34.4 31.1  -817.6   34.4 26.6  -194.0 |
         34.4 31.1   -56.1   34.4 28.1   -80.7                   |    -1270.8
| 18.00 |33.4 27.4  -139.5   33.4 31.9  -884.8   33.4 27.4  -221.1 |
         33.4 31.9   -60.7   33.4 28.8   -88.4                   |    -1394.5
| 19.00 |30.8 28.0  -153.2   30.8 32.1  -898.3   30.8 28.0  -242.8 |
         30.8 32.1   -61.6   30.8 29.4   -95.8                   |    -1451.7
| 20.00 |29.1 28.6  -167.0   29.1 31.8  -873.4   29.1 28.6  -264.7 |
         29.1 31.8   -59.9   29.1 30.1  -103.2                   |    -1468.3
| 21.00 |27.6 29.2  -180.3   27.6 31.3  -830.0   27.6 29.2  -285.8 |
         27.6 31.3   -56.9   27.6 30.4  -107.2                   |    -1460.3
| 22.00 |26.0 29.8  -193.5   26.0 30.0  -728.6   26.0 29.8  -306.7 |
         26.0 30.0   -50.0   26.0 30.3  -105.4                   |    -1384.2
| 23.00 |24.1 30.2  -200.7   24.1 28.7  -622.1   24.1 30.2  -318.1 |
         24.1 28.7   -42.7   24.1 30.0  -102.1                   |    -1285.6
| 24.00 |22.5 30.0  -197.5   22.5 27.7  -540.4   22.5 30.0  -313.1 |
         22.5 27.7   -37.1   22.5 29.4   -95.6                   |    -1183.6

| Total Heat loss      -770.22 MegaJoules
```

Flat : zone II (continue)

N	Area	U val	T.lag	F	
1	3.9	2.24	4.0	0.60	wall 6
2	2.2	1.34	11.7	0.38	wall 7
3	1.9	2.50	1.2	1.00	door
4	3.6	2.10	2.8	0.94	window with shutter

F = decrement factor

```
File Name : A.DAT Data for Month : JAN Int. Temp. : 15
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time  | T.o   T.e    No.  1 | T.o   T.e     No.  2 | T.o   T.e    No.  3 |
        | T.o   T.e    No.  4 |                                     Heat Loss Tot
|  1.00 | 4.1   5.6     81.7  |  4.1   7.9     20.4 | 4.1   4.6     49.3 |
          4.1   5.0     75.5                                           |     226.8
|  2.00 | 3.6   5.5     82.7  |  3.6   8.1     19.8 | 3.6   4.2     51.5 |
          3.6   4.8     77.3                                           |     231.3
|  3.00 | 3.3   5.3     84.3  |  3.3   8.1     19.8 | 3.3   3.7     53.7 |
          3.3   4.6     78.7                                           |     236.5
|  4.00 | 2.8   5.3     84.8  |  2.8   7.8     20.8 | 2.8   3.3     55.5 |
          2.8   4.1     82.5                                           |     243.6
|  5.00 | 2.6   4.9     87.7  |  2.6   7.3     22.1 | 2.6   2.9     57.3 |
          2.6   3.7     85.5                                           |     252.6
|  6.00 | 2.3   4.7     90.0  |  2.3   6.9     23.2 | 2.3   2.6     58.7 |
          2.3   3.3     88.1                                           |     259.9
|  7.00 | 3.2   4.5     91.8  |  3.2   6.5     24.4 | 3.2   2.4     59.9 |
          3.2   3.0     90.7                                           |     266.8
|  8.00 | 4.1   4.2     93.9  |  4.1   6.1     25.6 | 4.1   3.0     56.9 |
          4.1   2.8     92.5                                           |     268.9
|  9.00 | 5.3   4.1     95.2  |  5.3   5.8     26.4 | 5.3   3.9     52.6 |
          5.3   2.8     92.6                                           |     266.8
| 10.00 | 6.4   3.9     96.5  |  6.4   5.7     26.7 | 6.4   5.0     47.4 |
          6.4   3.6     86.4                                           |     257.0
| 11.00 | 8.0   4.4     92.1  |  8.0   5.7     26.9 | 8.0   6.2     41.9 |
          8.0   4.5     79.6                                           |     240.6
| 12.00 |10.0   5.0     87.4  | 10.0   5.6     27.2 |10.0   7.7     34.8 |
         10.0   5.5     71.5                                           |     220.8
| 13.00 |10.5   5.7     81.4  | 10.5   5.4     27.8 |10.5   9.6     25.6 |
         10.5   6.7     62.6                                           |     197.4
| 14.00 |11.1   6.3     75.4  | 11.1   5.2     28.2 |11.1  10.4     21.9 |
         11.1   8.3     50.6                                           |     176.1
| 15.00 |11.5   7.3     67.1  | 11.5   5.1     28.6 |11.5  11.0     19.1 |
         11.5   9.9     38.7                                           |     153.6
| 16.00 |10.6   8.5     56.8  | 10.6   4.9     29.0 |10.6  11.4     17.1 |
         10.6  10.4     35.0                                           |     137.9
| 17.00 | 9.4   8.8     54.2  |  9.4   4.8     29.3 | 9.4  10.8     20.1 |
          9.4  10.9     31.1                                           |     134.6
| 18.00 | 8.4   9.1     51.0  |  8.4   4.9     29.2 | 8.4   9.6     25.5 |
          8.4  11.0     30.4                                           |     136.1
| 19.00 | 7.3   9.4     49.1  |  7.3   5.2     28.2 | 7.3   8.6     30.4 |
          7.3  10.1     37.1                                           |     144.9
| 20.00 | 6.2   8.8     53.6  |  6.2   5.6     27.2 | 6.2   7.6     35.3 |
          6.2   9.0     45.3                                           |     161.5
| 21.00 | 5.2   8.1     59.9  |  5.2   6.0     25.9 | 5.2   6.4     40.9 |
          5.2   8.1     52.5                                           |     179.2
| 22.00 | 5.0   7.5     65.1  |  5.0   6.5     24.5 | 5.0   5.4     45.6 |
          5.0   7.0     60.2                                           |     195.4
| 23.00 | 4.7   6.9     70.5  |  4.7   7.1     22.6 | 4.7   5.0     47.3 |
          4.7   6.0     68.3                                           |     208.8
| 24.00 | 4.6   6.2     76.7  |  4.6   7.7     20.9 | 4.6   4.8     48.6 |
          4.6   5.2     73.9                                           |     220.3

| Total Heat loss          180.62 MegaJoules
```

```
File Name : A.DAT Data for Month : JUL Int. Temp. : 21
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time   | T.o  T.e    No.  1 | T.o  T.e    No.  2 | T.o  T.e    No.  3 |
           T.o  T.e    No.  4                               Heat Loss Tot
|  1.00  |21.9 27.3    -54.6  | 21.9 29.2     -23.5 | 21.9 22.8     -8.5 |
          21.9 25.6    -34.9  |                                           |   -121.5
|  2.00  |20.5 26.3    -46.0  | 20.5 29.7     -25.1 | 20.5 22.0     -4.8 |
          20.5 23.9    -22.1  |                                           |    -98.0
|  3.00  |19.9 25.2    -36.4  | 19.9 30.0     -25.8 | 19.9 20.8      1.0 |
          19.9 22.6    -12.1  |                                           |    -73.3
|  4.00  |19.2 24.2    -27.9  | 19.2 29.8     -25.4 | 19.2 20.0      4.7 |
          19.2 21.9     -6.8  |                                           |    -55.5
|  5.00  |19.0 23.9    -25.0  | 19.0 29.6     -24.6 | 19.0 19.3      7.9 |
          19.0 20.8      1.9  |                                           |    -39.9
|  6.00  |18.8 23.0    -17.7  | 18.8 29.0     -23.0 | 18.8 19.0      9.3 |
          18.8 20.2      6.3  |                                           |    -25.2
|  7.00  |20.7 22.7    -14.6  | 20.7 28.1     -20.5 | 20.7 18.8     10.4 |
          20.7 19.6     10.5  |                                           |    -14.2
|  8.00  |23.3 22.3    -11.0  | 23.3 27.5     -18.7 | 23.3 20.3      3.3 |
          23.3 19.4     12.0  |                                           |    -14.4
|  9.00  |25.9 22.1     -9.9  | 25.9 26.9     -17.0 | 25.9 22.8     -8.5 |
          25.9 19.6     10.3  |                                           |    -25.1
| 10.00  |28.0 22.0     -8.7  | 28.0 26.3     -15.1 | 28.0 25.4    -20.8 |
          28.0 21.6     -4.6  |                                           |    -49.2
| 11.00  |29.5 23.2    -18.8  | 29.5 25.6     -13.2 | 29.5 27.5    -31.1 |
          29.5 24.0    -23.0  |                                           |    -86.0
| 12.00  |31.1 24.7    -32.3  | 31.1 25.1     -11.7 | 31.1 29.2    -38.9 |
          31.1 26.4    -40.6  |                                           |   -123.6
| 13.00  |32.6 26.3    -45.8  | 32.6 24.8     -10.9 | 32.6 30.8    -46.5 |
          32.6 28.2    -54.4  |                                           |   -157.5
| 14.00  |34.2 27.5    -56.4  | 34.2 24.3      -9.6 | 34.2 32.3    -53.7 |
          34.2 29.7    -65.5  |                                           |   -185.2
| 15.00  |35.3 28.4    -64.5  | 35.3 24.1      -8.9 | 35.3 33.9    -61.2 |
          35.3 31.2    -76.7  |                                           |   -211.3
| 16.00  |35.0 29.4    -72.8  | 35.0 23.9      -8.3 | 35.0 35.1    -66.9 |
          35.0 32.6    -87.6  |                                           |   -235.5
| 17.00  |34.4 30.2    -80.6  | 34.4 23.8      -8.1 | 34.4 35.1    -66.8 |
          34.4 34.0    -98.1  |                                           |   -253.6
| 18.00  |33.4 31.2    -88.9  | 33.4 24.0      -8.5 | 33.4 34.5    -64.2 |
          33.4 34.7   -103.8  |                                           |   -265.4
| 19.00  |30.8 31.9    -94.6  | 30.8 24.8     -10.9 | 30.8 33.6    -59.9 |
          30.8 34.4   -101.2  |                                           |   -266.5
| 20.00  |29.1 31.7    -93.0  | 29.1 25.8     -13.7 | 29.1 31.3    -49.0 |
          29.1 33.7    -96.3  |                                           |   -252.0
| 21.00  |27.6 31.3    -89.9  | 27.6 26.7     -16.4 | 27.6 29.4    -40.1 |
          27.6 32.5    -86.7  |                                           |   -233.0
| 22.00  |26.0 30.7    -84.7  | 26.0 27.4     -18.4 | 26.0 27.9    -32.8 |
          26.0 30.2    -69.6  |                                           |   -205.5
| 23.00  |24.1 29.2    -71.2  | 24.1 28.0     -20.1 | 24.1 26.3    -25.1 |
          24.1 28.7    -57.8  |                                           |   -174.3
| 24.00  |22.5 28.2    -62.4  | 22.5 28.6     -21.9 | 22.5 24.5    -16.5 |
          22.5 27.2    -46.9  |                                           |   -147.7

| Total Heat loss      -119.28 MegaJoules
```

Courtyard house : zone I

(no account of temperature stratification in the courtyard)

N	Area	U val	T.lag	F	
1	25.0	1.43	16.2	0.13	wall 1
2	12.5	1.10	13.4	0.20	wall 2
3	1.9	1.96	2.8	0.93	window with shutter
4	2.4	2.00	1.7	0.98	door

F = decrement factor

```
                                           Heat R/F          X-back to Dec Fact
File Name : A.DAT Data for Month : JA                    : 21
Start Time : 1 Stop Time        Time Increment : 1


| Time    |   T.e     No.  1 | T.o   T.e    No.  2 | T.o   T.e     No.  3 |
          T.o   T.e   No.  4 |                                            Heat Loss Tot
|  1.00 | 4.1   6.1    532.9 |  4.1   6.8    194.6 |  4.1   5.0    59.5 |
          4.1   4.7     78.2 |                                       |          865.2
|  2.00 | 3.6   6.2    527.5 |  3.6   7.1    191.6 |  3.6   4.8    60.4 |
          3.6   4.5     79.3 |                                       |          858.9
|  3.00 | 3.3   6.4    520.5 |  3.3   7.2    190.1 |  3.3   4.6    61.0 |
          3.3   4.0     81.8 |                                       |          853.4
|  4.00 | 2.8   6.7    511.6 |  2.8   7.3    188.8 |  2.8   4.1    62.9 |
          2.8   3.6     83.8 |                                       |          847.0
|  5.00 | 2.6   6.8    507.9 |  2.6   7.2    189.8 |  2.6   3.7    64.3 |
          2.6   3.2     85.5 |                                       |          847.5
|  6.00 | 2.3   6.9    505.2 |  2.3   7.0    192.8 |  2.3   3.4    65.6 |
          2.3   2.8     87.1 |                                       |          850.7
|  7.00 | 3.2   6.9    503.3 |  3.2   6.8    195.7 |  3.2   3.0    66.9 |
          3.2   2.6     88.3 |                                       |          854.2
|  8.00 | 4.1   6.8    506.1 |  4.1   6.6    198.6 |  4.1   2.8    67.7 |
          4.1   2.7     88.0 |                                       |          860.5
|  9.00 | 5.3   6.7    511.4 |  5.3   6.3    201.7 |  5.3   2.8    67.9 |
          5.3   3.5     83.9 |                                       |          864.9
| 10.00 | 6.4   6.6    516.2 |  6.4   6.1    204.6 |  6.4   3.6    64.9 |
          6.4  -4.5     79.3 |                                       |          865.0
| 11.00 | 8.0.  6.4    521.1 |  8.0   6.0    206.0 |  8.0   4.5    61.6 |
          8.0   5.6     73.9 |                                       |          862.5
| 12.00 |10.0   6.3    526.5 | 10.0   6.0    206.7 | 10.0   5.5    57.6 |
         10.0   6.9     67.8 |                                       |          858.6
| 13.00 |10.5   6.1    531.2 | 10.5   5.9    207.2 | 10.5   6.7    53.3 |
         10.5   8.6     59.7 |                                       |          851.4
| 14.00 |11.1   6.1    532.8 | 11.1   5.9    208.2 | 11.1   8.2    47.5 |
         11.1  10.1     52.5 |                                       |          840.9
| 15.00 |11.5   6.1    534.1 | 11.5   5.8    209.6 | 11.5   9.8    41.6 |
         11.5  10.6     50.0 |                                       |          835.2
| 16.00 |10.6   6.0    534.7 | 10.6   5.7    210.6 | 10.6  10.3    39.8 |
         10.6  11.1     47.5 |                                       |          832.6
| 17.00 | 9.4   6.0    536.9 |  9.4   5.6    211.7 |  9.4  10.8    37.9 |
          9.4  11.1     47.5 |                                       |          833.9
| 18.00 | 8.4   5.9    539.1 |  8.4   5.5    212.5 |  8.4  10.9    37.5 |
          8.4  10.2     52.0 |                                       |          841.1
| 19.00 | 7.3   5.9    540.8 |  7.3   5.5    213.2 |  7.3  10.1    40.7 |
          7.3   9.0     57.4 |                                       |          852.1
| 20.00 | 6.2   5.8    542.6 |  6.2   5.6    212.1 |  6.2   9.0    44.7 |
          6.2   8.0     62.2 |                                       |          861.6
| 21.00 | 5.2   5.8    543.9 |  5.2   5.8    209.7 |  5.2   8.1    48.2 |
          5.2   7.0     67.3 |                                       |          869.1
| 22.00 | 5.0   5.8    545.1 |  5.0   6.0    206.8 |  5.0   7.1    51.9 |
          5.0   5.9     72.6 |                                       |          876.4
| 23.00 | 4.7   5.8    542.1 |  4.7   6.2    203.6 |  4.7   6.0    55.9 |
          4.7   5.2     76.0 |                                       |          877.7
| 24.00 | 4.6   6.0    538.0 |  4.6   6.5    199.7 |  4.6   5.2    58.7 |
          4.6   4.9     77.1 |                                       |          873.5


| Total Heat loss        739.23 MegaJoules
```

```
File Name : A.DAT Data for Month : JUL Int. Temp. : 21
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time   | T.o  T.e    No.  1  | T.o  T.e     No.  2 | T.o  T.e     No.  3 |
           T.o  T.e    No.  4  |                                Heat Loss Tot
|  1.00  |21.9 26.6   -200.0   | 21.9 27.5    -89.5  | 21.9 25.7   -17.4   |
          21.9 23.7    -12.8   |                                       -319.7
|  2.00  |20.5 26.9   -210.0   | 20.5 27.8    -93.8  | 20.5 24.0   -11.1   |
          20.5 22.4     -6.6   |                                       -321.5
|  3.00  |19.9 27.1   -217.7   | 19.9 28.1    -98.1  | 19.9 22.7    -6.1   |
          19.9 21.6     -2.8   |                                       -324.7
|  4.00  |19.2 27.3   -225.1   | 19.2 28.4   -101.6  | 19.2 22.0    -3.7   |
          19.2 20.4      2.6   |                                       -327.7
|  5.00  |19.0 27.5   -232.1   | 19.0 28.4   -102.4  | 19.0 20.8     0.6   |
          19.0 19.8      5.6   |                                       -328.3
|  6.00  |18.8 27.7   -239.5   | 18.8 28.3   -101.0  | 18.8 20.3     2.8   |
          18.8 19.3      8.2   |                                       -329.5
|  7.00  |20.7 27.9   -245.1   | 20.7 28.2    -98.7  | 20.7 19.7     4.9   |
          20.7 19.1      9.2   |                                       -329.7
|  8.00  |23.3 27.9   -245.0   | 23.3 27.8    -93.3  | 23.3 19.5     5.6   |
          23.3 19.5      7.2   |                                       -325.5
|  9.00  |25.9 27.8   -242.5   | 25.9 27.4    -87.7  | 25.9 19.7     4.9   |
          25.9 21.6     -2.8   |                                       -328.0
| 10.00  |28.0 27.7   -238.2   | 28.0 27.1    -83.3  | 28.0 21.6    -2.3   |
          28.0 24.1    -15.0   |                                       -338.8
| 11.00  |29.5 27.4   -227.6   | 29.5 26.7    -79.0  | 29.5 24.0   -11.3   |
          29.5 26.5    -26.5   |                                       -344.3
| 12.00  |31.1 27.1   -218.9   | 31.1 26.4    -74.1  | 31.1 26.3   -19.9   |
          31.1 28.4    -35.4   |                                       -348.3
| 13.00  |32.6 26.9   -211.7   | 32.6 26.0    -69.3  | 32.6 28.2   -26.6   |
          32.6 29.9    -42.8   |                                       -350.5
| 14.00  |34.2 26.7   -204.2   | 34.2 25.8    -66.6  | 34.2 29.6   -32.1   |
          34.2 31.5    -50.2   |                                       -353.0
| 15.00  |35.3 26.5   -195.8   | 35.3 25.6    -63.7  | 35.3 31.1   -37.5   |
          35.3 33.0    -57.4   |                                       -354.4
| 16.00  |35.0 26.3   -187.9   | 35.0 25.4    -61.2  | 35.0 32.5   -42.8   |
          35.0 34.4    -64.2   |                                       -356.1
| 17.00  |34.4 26.2   -184.3   | 34.4 25.3    -59.3  | 34.4 33.9   -48.0   |
          34.4 35.0    -67.4   |                                       -359.1
| 18.00  |33.4 26.0   -178.6   | 33.4 25.2    -58.2  | 33.4 34.6   -50.8   |
          33.4 34.7    -65.6   |                                       -353.2
| 19.00  |30.8 25.9   -175.1   | 30.8 25.2    -57.6  | 30.8 34.3   -49.6   |
          30.8 34.0    -62.2   |                                       -344.5
| 20.00  |29.1 25.8   -171.9   | 29.1 25.4    -60.6  | 29.1 33.7   -47.2   |
          29.1 32.5    -55.2   |                                       -334.9
| 21.00  |27.6 25.8   -170.5   | 27.6 25.9    -67.0  | 27.6 32.5   -42.6   |
          27.6 30.2    -44.3   |                                       -324.4
| 22.00  |26.0 25.7   -169.4   | 26.0 26.4    -74.1  | 26.0 30.2   -34.5   |
          26.0 28.6    -36.5   |                                       -314.4
| 23.00  |24.1 25.9   -176.4   | 24.1 26.8    -80.4  | 24.1 28.7   -28.5   |
          24.1 27.1    -29.3   |                                       -314.6
| 24.00  |22.5 26.3   -187.9   | 22.5 27.2    -85.2  | 22.5 27.2   -23.2   |
          22.5 25.4    -21.2   |                                       -317.6

| Total Heat loss       -289.54 MegaJoules
```

```
File Name : A.DAT Data for Month : JUL Int. Temp. : 25
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time   | T.o  T.e     No.  1 | T.o  T.e     No.  2 | T.o  T.e     No.  3 |
           T.o  T.e     No.  4                                      Heat Loss Tot
|  1.00  |21.9 26.6    -57.0  | 21.9 27.5    -34.5  | 21.9 25.7     -2.5 |
          21.9 23.7      6.4                                       |       -87.6
|  2.00  |20.5 26.9    -67.0  | 20.5 27.8    -38.8  | 20.5 24.0      3.8 |
          20.5 22.4     12.6                                       |       -89.4
|  3.00  |19.9 27.1    -74.7  | 19.9 28.1    -43.1  | 19.9 22.7      8.7 |
          19.9 21.6     16.4                                       |       -92.6
|  4.00  |19.2 27.3    -82.1  | 19.2 28.4    -46.6  | 19.2 22.0     11.2 |
          19.2 20.4     21.8                                       |       -95.6
|  5.00  |19.0 27.5    -89.1  | 19.0 28.4    -47.4  | 19.0 20.8     15.5 |
          19.0 19.8     24.8                                       |       -96.2
|  6.00  |18.8 27.7    -96.5  | 18.8 28.3    -46.0  | 18.8 20.3     17.7 |
          18.8 19.3     27.4                                       |       -97.4
|  7.00  |20.7 27.9   -102.1  | 20.7 28.2    -43.7  | 20.7 19.7     19.8 |
          20.7 19.1     28.4                                       |       -97.6
|  8.00  |23.3 27.9   -102.0  | 23.3 27.8    -38.3  | 23.3 19.5     20.5 |
          23.3 19.5     26.4                                       |       -93.4
|  9.00  |25.9 27.8    -99.5  | 25.9 27.4    -32.7  | 25.9 19.7     19.8 |
          25.9 21.6     16.4                                       |       -95.9
| 10.00  |28.0 27.7    -95.2  | 28.0 27.1    -28.3  | 28.0 21.6     12.6 |
          28.0 24.1      4.2                                       |      -106.7
| 11.00  |29.5 27.4    -84.6  | 29.5 26.7    -24.0  | 29.5 24.0      3.6 |
          29.5 26.5     -7.3                                       |      -112.2
| 12.00  |31.1 27.1    -75.9  | 31.1 26.4    -19.1  | 31.1 26.3     -5.0 |
          31.1 28.4    -16.2                                       |      -116.2
| 13.00  |32.6 26.9    -68.7  | 32.6 26.0    -14.3  | 32.6 28.2    -11.8 |
          32.6 29.9    -23.6                                       |      -118.4
| 14.00  |34.2 26.7    -61.2  | 34.2 25.8    -11.6  | 34.2 29.6    -17.2 |
          34.2 31.5    -31.0                                       |      -120.9
| 15.00  |35.3 26.5    -52.8  | 35.3 25.6     -8.7  | 35.3 31.1    -22.6 |
          35.3 33.0    -38.2                                       |      -122.3
| 16.00  |35.0 26.3    -44.9  | 35.0 25.4     -6.2  | 35.0 32.5    -27.9 |
          35.0 34.4    -45.0                                       |      -124.0
| 17.00  |34.4 26.2    -41.3  | 34.4 25.3     -4.3  | 34.4 33.9    -33.1 |
          34.4 35.0    -48.2                                       |      -127.0
| 18.00  |33.4 26.0    -35.6  | 33.4 25.2     -3.2  | 33.4 34.6    -35.9 |
          33.4 34.7    -46.4                                       |      -121.1
| 19.00  |30.8 25.9    -32.1  | 30.8 25.2     -2.6  | 30.8 34.3    -34.7 |
          30.8 34.0    -43.0                                       |      -112.4
| 20.00  |29.1 25.8    -28.9  | 29.1 25.4     -5.6  | 29.1 33.7    -32.3 |
          29.1 32.5    -36.0                                       |      -102.8
| 21.00  |27.6 25.8    -27.5  | 27.6 25.9    -12.0  | 27.6 32.5    -27.8 |
          27.6 30.2    -25.1                                       |       -92.3
| 22.00  |26.0 25.7    -26.4  | 26.0 26.4    -19.1  | 26.0 30.2    -19.4 |
          26.0 28.6    -17.3                                       |       -82.3
| 23.00  |24.1 25.9    -33.4  | 24.1 26.8    -25.4  | 24.1 28.7    -13.6 |
          24.1 27.1    -10.1                                       |       -82.5
| 24.00  |22.5 26.3    -44.9  | 22.5 27.2    -30.2  | 22.5 27.2     -8.3 |
          22.5 25.4     -2.0                                       |       -85.5

| Total Heat loss        -89.01 MegaJoules
```

Courtyard house : zone II

N	Area	U val	T.lag	F	
1	11.5	1.10	13.4	0.20	wall 1
2	12.5	1.10	13.4	0.20	wall 2
3	14.6	1.10	13.4	0.20	wall 3
4	7.4	1.43	16.2	0.13	wall 4
5	1.0	1.96	2.8	0.93	window

F = decrement factor

```
File Name : A.DAT Data for Month : JAN Int. Temp. : 15
Start Time : 1 Stop Time : 24 Time Increment : 1

|  Time  |  T.o   T.e   No.  1 |  T.o   T.e   No.  2 |  T.o   T.e   No.  3 |
            T.o   T.e   No.  4 |  T.o   T.e   No.  5 |          Heat Loss Tot
|   1.00 |  4.1   6.8    103.2 |  4.1   6.8    112.1 |  4.1   6.8    131.0 |
            4.1   6.1     94.2 |  4.1   5.0     19.5 |                    |  460.1
|   2.00 |  3.6   7.1    100.4 |  3.6   7.1    109.1 |  3.6   7.1    127.5 |
            3.6   6.2     92.7 |  3.6   4.8     20.0 |                    |  449.6
|   3.00 |  3.3   7.2     99.0 |  3.3   7.2    107.6 |  3.3   7.2    125.7 |
            3.3   6.4     90.6 |  3.3   4.6     20.4 |                    |  443.2
|   4.00 |  2.8   7.3     97.8 |  2.8   7.3    106.3 |  2.8   7.3    124.2 |
            2.8   6.7     87.9 |  2.8   4.1     21.3 |                    |  437.6
|   5.00 |  2.6   7.2     98.8 |  2.6   7.2    107.3 |  2.6   7.2    125.4 |
            2.6   6.8     86.8 |  2.6   3.7     22.1 |                    |  440.4
|   6.00 |  2.3   7.0    101.5 |  2.3   7.0    110.3 |  2.3   7.0    128.8 |
            2.3   6.9     86.0 |  2.3   3.4     22.8 |                    |  449.4
|   7.00 |  3.2   6.8    104.2 |  3.2   6.8    113.2 |  3.2   6.8    132.3 |
            3.2   6.9     85.5 |  3.2   3.0     23.4 |                    |  458.6
|   8.00 |  4.1   6.6    106.8 |  4.1   6.6    116.1 |  4.1   6.6    135.6 |
            4.1   6.8     86.3 |  4.1   2.8     23.9 |                    |  468.7
|   9.00 |  5.3   6.3    109.7 |  5.3   6.3    119.2 |  5.3   6.3    139.2 |
            5.3   6.7     87.9 |  5.3   2.8     24.0 |                    |  480.0
|  10.00 |  6.4   6.1    112.3 |  6.4   6.1    122.1 |  6.4   6.1    142.6 |
            6.4   6.6     89.3 |  6.4   3.6     22.4 |                    |  488.8
|  11.00 |  8.0   6.0    113.6 |  8.0   6.0    123.5 |  8.0   6.0    144.2 |
            8.0   6.4     90.7 |  8.0   4.5     20.6 |                    |  492.7
|  12.00 | 10.0   6.0    114.3 | 10.0   6.0    124.2 | 10.0   6.0    145.1 |
           10.0   6.3     92.4 | 10.0   5.5     18.6 |                    |  494.4
|  13.00 | 10.5   5.9    114.7 | 10.5   5.9    124.7 | 10.5   5.9    145.6 |
           10.5   6.1     93.7 | 10.5   6.7     16.3 |                    |  495.1
|  14.00 | 11.1   5.9    115.7 | 11.1   5.9    125.7 | 11.1   5.9    146.8 |
           11.1   6.1     94.2 | 11.1   8.2     13.2 |                    |  495.6
|  15.00 | 11.5   5.8    116.9 | 11.5   5.8    127.1 | 11.5   5.8    148.4 |
           11.5   6.1     94.6 | 11.5   9.8     10.1 |                    |  497.1
|  16.00 | 10.6   5.7    117.9 | 10.6   5.7    128.1 | 10.6   5.7    149.7 |
           10.6   6.0     94.8 | 10.6  10.3      9.2 |                    |  499.6
|  17.00 |  9.4   5.6    118.8 |  9.4   5.6    129.2 |  9.4   5.6    150.9 |
            9.4   6.0     95.4 |  9.4  10.8      8.2 |                    |  502.5
|  18.00 |  8.4   5.5    119.6 |  8.4   5.5    130.0 |  8.4   5.5    151.9 |
            8.4   5.9     96.1 |  8.4  10.9      8.0 |                    |  505.5
|  19.00 |  7.3   5.5    120.3 |  7.3   5.5    130.7 |  7.3   5.5    152.7 |
            7.3   5.9     96.6 |  7.3  10.1      9.7 |                    |  509.9
|  20.00 |  6.2   5.6    119.2 |  6.2   5.6    129.6 |  6.2   5.6    151.4 |
            6.2   5.8     97.1 |  6.2   9.0     11.8 |                    |  509.1
|  21.00 |  5.2   5.8    117.0 |  5.2   5.8    127.2 |  5.2   5.8    148.5 |
            5.2   5.8     97.5 |  5.2   8.1     13.6 |                    |  503.8
|  22.00 |  5.0   6.0    114.3 |  5.0   6.0    124.3 |  5.0   6.0    145.2 |
            5.0   5.8     97.9 |  5.0   7.1     15.6 |                    |  497.2
|  23.00 |  4.7   6.2    111.4 |  4.7   6.2    121.1 |  4.7   6.2    141.5 |
            4.7   5.8     97.0 |  4.7   6.0     17.7 |                    |  488.7
|  24.00 |  4.6   6.5    107.8 |  4.6   6.5    117.2 |  4.6   6.5    136.9 |
            4.6   6.0     95.8 |  4.6   5.2     19.1 |                    |  476.8

| Total Heat loss        415.60 MegaJoules
```

```
File Name : A.DAT Data for Month : JUL Int. Temp. : 21
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time   | T.o  T.e     No.  1 | T.o  T.e      No.  2 | T.o  T.e     No.  3 |
           T.o  T.e     No.  4 |  T.o  T.e     No.  5 |                   Heat Loss Tot
|  1.00  |21.9 27.5     -82.4  | 21.9 27.5     -89.5  | 21.9 27.5   -104.6  |
          21.9 26.6     -59.2  | 21.9 25.7      -9.1  |                     |  -344.9
|  2.00  |20.5 27.8     -86.3  | 20.5 27.8     -93.8  | 20.5 27.8   -109.5  |
          20.5 26.9     -62.2  | 20.5 24.0      -5.8  |                     |  -357.6
|  3.00  |19.9 28.1     -90.2  | 19.9 28.1     -98.1  | 19.9 28.1   -114.5  |
          19.9 27.1     -64.4  | 19.9 22.7      -3.2  |                     |  -370.5
|  4.00  |19.2 28.4     -93.5  | 19.2 28.4    -101.6  | 19.2 28.4   -118.7  |
          19.2 27.3     -66.6  | 19.2 22.0      -1.9  |                     |  -382.4
|  5.00  |19.0 28.4     -94.2  | 19.0 28.4    -102.4  | 19.0 28.4   -119.6  |
          19.0 27.5     -68.7  | 19.0 20.8       0.3  |                     |  -384.5
|  6.00  |18.8 28.3     -93.0  | 18.8 28.3    -101.0  | 18.8 28.3   -118.0  |
          18.8 27.7     -70.9  | 18.8 20.3       1.5  |                     |  -381.4
|  7.00  |20.7 28.2     -90.8  | 20.7 28.2     -98.7  | 20.7 28.2   -115.3  |
          20.7 27.9     -72.5  | 20.7 19.7       2.6  |                     |  -374.9
|  8.00  |23.3 27.8     -85.9  | 23.3 27.8     -93.3  | 23.3 27.8   -109.0  |
          23.3 27.9     -72.5  | 23.3 19.5       2.9  |                     |  -357.8
|  9.00  |25.9 27.4     -80.7  | 25.9 27.4     -87.7  | 25.9 27.4   -102.4  |
          25.9 27.8     -71.8  | 25.9 19.7       2.6  |                     |  -339.9
| 10.00  |28.0 27.1     -76.7  | 28.0 27.1     -83.3  | 28.0 27.1    -97.3  |
          28.0 27.7     -70.5  | 28.0 21.6      -1.2  |                     |  -329.0
| 11.00  |29.5 26.7     -72.6  | 29.5 26.7     -79.0  | 29.5 26.7    -92.2  |
          29.5 27.4     -67.4  | 29.5 24.0      -5.9  |                     |  -317.1
| 12.00  |31.1 26.4     -68.2  | 31.1 26.4     -74.1  | 31.1 26.4    -86.5  |
          31.1 27.1     -64.8  | 31.1 26.3     -10.5  |                     |  -304.0
| 13.00  |32.6 26.0     -63.8  | 32.6 26.0     -69.3  | 32.6 26.0    -81.0  |
          32.6 26.9     -62.7  | 32.6 28.2     -14.0  |                     |  -290.8
| 14.00  |34.2 25.8     -61.3  | 34.2 25.8     -66.6  | 34.2 25.8    -77.8  |
          34.2 26.7     -60.4  | 34.2 29.6     -16.9  |                     |  -283.0
| 15.00  |35.3 25.6     -58.6  | 35.3 25.6     -63.7  | 35.3 25.6    -74.4  |
          35.3 26.5     -57.9  | 35.3 31.1     -19.7  |                     |  -274.4
| 16.00  |35.0 25.4     -56.3  | 35.0 25.4     -61.2  | 35.0 25.4    -71.4  |
          35.0 26.3     -55.6  | 35.0 32.5     -22.5  |                     |  -267.0
| 17.00  |34.4 25.3     -54.6  | 34.4 25.3     -59.3  | 34.4 25.3    -69.3  |
          34.4 26.2     -54.6  | 34.4 33.9     -25.3  |                     |  -263.1
| 18.00  |33.4 25.2     -53.6  | 33.4 25.2     -58.2  | 33.4 25.2    -68.0  |
          33.4 26.0     -52.9  | 33.4 34.6     -26.7  |                     |  -259.5
| 19.00  |30.8 25.2     -53.0  | 30.8 25.2     -57.6  | 30.8 25.2    -67.3  |
          30.8 25.9     -51.8  | 30.8 34.3     -26.1  |                     |  -255.9
| 20.00  |29.1 25.4     -55.7  | 29.1 25.4     -60.6  | 29.1 25.4    -70.7  |
          29.1 25.8     -50.9  | 29.1 33.7     -24.9  |                     |  -262.8
| 21.00  |27.6 25.9     -61.6  | 27.6 25.9     -67.0  | 27.6 25.9    -78.2  |
          27.6 25.8     -50.5  | 27.6 32.5     -22.4  |                     |  -279.8
| 22.00  |26.0 26.4     -68.2  | 26.0 26.4     -74.1  | 26.0 26.4    -86.6  |
          26.0 25.7     -50.2  | 26.0 30.2     -18.0  |                     |  -297.1
| 23.00  |24.1 26.8     -74.0  | 24.1 26.8     -80.4  | 24.1 26.8    -93.9  |
          24.1 25.9     -52.2  | 24.1 28.7     -15.0  |                     |  -315.5
| 24.00  |22.5 27.2     -78.4  | 22.5 27.2     -85.2  | 22.5 27.2    -99.5  |
          22.5 26.3     -55.6  | 22.5 27.2     -12.2  |                     |  -330.9

| Total Heat loss         -274.46 MegaJoules
```

```
File Name : A.DAT Data for Month   JUL Int. Temp. : 25
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time    | T.o   T.e     No.  1 | T.o   T.e     No.  2 |  T.o   T.e      No.  3 |
            T.o   T.e     No.  4   T.o   T.e     No.  5                     Heat Loss Tot
|  1.00   |21.9  27.5    -31.8   | 21.9  27.5    -34.5  |  21.9  27.5    -40.3   |
           21.9  26.6    -16.9     21.9  25.7     -1.3                                -124.8
|  2.00   |20.5  27.8    -35.7   | 20.5  27.8    -38.8  |  20.5  27.8    -45.3   |
           20.5  26.9    -19.8     20.5  24.0      2.0                                -137.6
|  3.00   |19.9  28.1    -39.6   | 19.9  28.1    -43.1  |  19.9  28.1    -50.3   |
           19.9  27.1    -22.1     19.9  22.7      4.6                                -150.5
|  4.00   |19.2  28.4    -42.9   | 19.2  28.4    -46.6  |  19.2  28.4    -54.5   |
           19.2  27.3    -24.3     19.2  22.0      5.9                                -162.4
|  5.00   |19.0  28.4    -43.6   | 19.0  28.4    -47.4  |  19.0  28.4    -55.3   |
           19.0  27.5    -26.4     19.0  20.8      8.2                                -164.5
|  6.00   |18.8  28.3    -42.4   | 18.8  28.3    -46.0  |  18.8  28.3    -53.8   |
           18.8  27.7    -28.6     18.8  20.3      9.3                                -161.4
|  7.00   |20.7  28.2    -40.2   | 20.7  28.2    -43.7  |  20.7  28.2    -51.1   |
           20.7  27.9    -30.2     20.7  19.7     10.4                                -154.8
|  8.00   |23.3  27.8    -35.3   | 23.3  27.8    -38.3  |  23.3  27.8    -44.8   |
           23.3  27.9    -30.2     23.3  19.5     10.8                                -137.8
|  9.00   |25.9  27.4    -30.1   | 25.9  27.4    -32.7  |  25.9  27.4    -38.2   |
           25.9  27.8    -29.4     25.9  19.7     10.4                                -119.9
| 10.00   |28.0  27.1    -26.1   | 28.0  27.1    -28.3  |  28.0  27.1    -33.1   |
           28.0  27.7    -28.2     28.0  21.6      6.6                                -109.0
| 11.00   |29.5  26.7    -22.0   | 29.5  26.7    -24.0  |  29.5  26.7    -28.0   |
           29.5  27.4    -25.0     29.5  24.0      1.9                                 -97.1
| 12.00   |31.1  26.4    -17.6   | 31.1  26.4    -19.1  |  31.1  26.4    -22.3   |
           31.1  27.1    -22.5     31.1  26.3     -2.6                                 -84.0
| 13.00   |32.6  26.0    -13.2   | 32.6  26.0    -14.3  |  32.6  26.0    -16.7   |
           32.6  26.9    -20.3     32.6  28.2     -6.2                                 -70.8
| 14.00   |34.2  25.8    -10.7   | 34.2  25.8    -11.6  |  34.2  25.8    -13.6   |
           34.2  26.7    -18.1     34.2  29.6     -9.0                                 -63.0
| 15.00   |35.3  25.6     -8.0   | 35.3  25.6     -8.7  |  35.3  25.6    -10.2   |
           35.3  26.5    -15.6     35.3  31.1    -11.9                                 -54.4
| 16.00   |35.0  25.4     -5.7   | 35.0  25.4     -6.2  |  35.0  25.4     -7.2   |
           35.0  26.3    -13.3     35.0  32.5    -14.7                                 -47.0
| 17.00   |34.4  25.3     -4.0   | 34.4  25.3     -4.3  |  34.4  25.3     -5.1   |
           34.4  26.2    -12.2     34.4  33.9    -17.4                                 -43.1
| 18.00   |33.4  25.2     -3.0   | 33.4  25.2     -3.2  |  33.4  25.2     -3.8   |
           33.4  26.0    -10.5     33.4  34.6    -18.9                                 -39.5
| 19.00   |30.8  25.2     -2.4   | 30.8  25.2     -2.6  |  30.8  25.2     -3.1   |
           30.8  25.9     -9.5     30.8  34.3    -18.3                                 -35.9
| 20.00   |29.1  25.4     -5.1   | 29.1  25.4     -5.6  |  29.1  25.4     -6.5   |
           29.1  25.8     -8.6     29.1  33.7    -17.0                                 -42.8
| 21.00   |27.6  25.9    -11.0   | 27.6  25.9    -12.0  |  27.6  25.9    -14.0   |
           27.6  25.8     -8.1     27.6  32.5    -14.6                                 -59.8
| 22.00   |26.0  26.4    -17.6   | 26.0  26.4    -19.1  |  26.0  26.4    -22.4   |
           26.0  25.7     -7.8     26.0  30.2    -10.2                                 -77.1
| 23.00   |24.1  26.8    -23.4   | 24.1  26.8    -25.4  |  24.1  26.8    -29.7   |
           24.1  25.9     -9.9     24.1  28.7     -7.2                                 -95.5
| 24.00   |22.5  27.2    -27.8   | 22.5  27.2    -30.2  |  22.5  27.2    -35.3   |
           22.5  26.3    -13.3     22.5  27.2     -4.4                                -110.9

| Total Heat loss        -84.37 MegaJoules
```

Courtyard house : zone I

(taking into account temperature stratification)

N	Area	U val	T.lag	F	
1	25.0	1.43	16.2	0.13	wall 1
2	12.5	1.10	13.4	0.20	wall 2
3	1.9	1.96	2.8	0.93	window with shutter
4	2.4	2.00	1.7	0.98	door

F = decrement factor

```
                                            Q-heat R/P/T-Results X-back to Dec Fact
File Name : J.DAT Data for Month : JAN Int. Temp. : 21
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time   | T.o   T.e    No.  1 | T.o   T.e      No.  2 |  T.o   T.e     No.  3 |
           T.o   T.e    No.  4                                     Heat Loss To
|  1.00  | 7.1   7.3     489.2   7.1   7.4      186.8 |  7.1   7.3      51.1 |
           7.1   7.2      66.2                                      |        793.3
|  2.00  | 7.0   7.3     488.5   7.0   7.5      186.1 |  7.0   7.2      51.3 |
           7.0   7.2      66.4                                      |        792.3
|  3.00  | 7.0   7.4     487.6   7.0   7.5      185.9 |  7.0   7.2      51.4 |
           7.0   7.1      66.8                                      |        791.7
|  4.00  | 7.0   7.4     485.9   7.0   7.5      185.8 |  7.0   7.1      51.8 |
           7.0   7.0      67.2                                      |        790.6
|  5.00  | 6.9   7.4     485.1   6.9   7.5      185.8 |  6.9   7.0      52.0 |
           6.9   7.0      67.2                                      |        790.1
|  6.00  | 6.8   7.4     484.7   6.8   7.5      185.9 |  6.8   7.0      52.0 |
           6.8   7.0      67.3                                      |        789.9
|  7.00  | 6.9   7.4     484.6   6.9   7.5      186.2 |  6.9   7.0      52.1 |
           6.9   6.9      67.8                                      |        790.7
|  8.00  | 7.0   7.4     484.6   7.0   7.4      186.6 |  7.0   6.9      52.5 |
           7.0   6.8      68.0                                      |        791.6
|  9.00  | 7.0   7.4     484.9   7.0   7.4      187.2 |  7.0   6.9      52.7 |
           7.0   6.9      67.5                                      |        792.3
| 10.00  | 7.2   7.4     485.4   7.2   7.4      187.6 |  7.2   7.0      52.3 |
           7.2   7.0      67.2                                      |        792.5
| 11.00  | 7.4   7.4     486.3   7.4   7.4      187.7 |  7.4   7.0      52.0 |
           7.4   7.1      66.9                                      |        792.9
| 12.00  | 7.8   7.4     487.2   7.8   7.3      187.9 |  7.8   7.1      51.9 |
           7.8   7.3      65.9                                      |        792.9
| 13.00  | 7.9   7.4     487.7   7.9   7.3      188.0 |  7.9   7.2      51.2 |
           7.9   7.5      64.7                                      |        791.6
| 14.00  | 8.0   7.4     487.8   8.0   7.3      188.1 |  8.0   7.5      50.4 |
           8.0   7.8      63.3                                      |        789.6
| 15.00  | 8.0   7.3     488.2   8.0   7.3      188.4 |  8.0   7.8      49.2 |
           8.0   7.9      62.8                                      |        788.6
| 16.00  | 8.0   7.3     488.3   8.0   7.3      188.5 |  8.0   7.9      48.9 |
           8.0   8.0      62.5                                      |        788.1
| 17.00  | 7.9   7.3     488.7   7.9   7.3      188.5 |  7.9   8.0      48.6 |
           7.9   8.0      62.5                                      |        788.2
| 18.00  | 7.8   7.3     489.1   7.8   7.3      188.7 |  7.8   8.0      48.6 |
           7.8   8.0      62.6                                      |        789.0
| 19.00  | 7.6   7.3     489.2   7.6   7.3      189.0 |  7.6   7.9      48.6 |
           7.6   7.9      63.1                                      |        789.9
| 20.00  | 7.4   7.3     489.2   7.4   7.3      188.9 |  7.4   7.8      49.0 |
           7.4   7.7      63.7                                      |        790.8
| 21.00  | 7.3   7.3     489.6   7.3   7.3      188.6 |  7.3   7.7      49.4 |
           7.3   7.5      64.6                                      |        792.3
| 22.00  | 7.3   7.3     490.1   7.3   7.3      188.5 |  7.3   7.5      50.1 |
           7.3   7.4      65.4                                      |        794.1
| 23.00  | 7.2   7.3     489.8   7.2   7.3      188.2 |  7.2   7.4      50.7 |
           7.2   7.3      65.8                                      |        794.4
| 24.00  | 7.2   7.3     489.3   7.2   7.4      187.6 |  7.2   7.3      51.0 |
           7.2   7.3      65.9                                      |        793.8

| Total Heat loss        683.69 MegaJoules
```

```
File Name : J.DAT Data for Month : JUL Int. Temp. : 21
Start Time : 1 Stop Time : 24 Time Increment : 1

| Time  | T.o  T.e    No.  1 | T.o  T.e     No.  2 | T.o  T.e    No.  3 |
          T.o  T.e    No.  4                                Heat Loss Tot
|  1.00 |23.4 25.8  -170.8   | 23.4 26.5   -75.7 | 23.4 25.8   -17.9 |
          23.4 24.8   -18.2                                             -282.6
|  2.00 |22.8 26.0  -178.4     22.8 26.7   -78.7 | 22.8 24.9   -14.6 |
          22.8 24.0   -14.4                                             -286.2
|  3.00 |22.0 26.2  -185.1     22.0 26.8   -80.1 | 22.0 24.2   -11.8 |
          22.0 23.3   -10.9                                             -288.0
|  4.00 |22.0 26.4  -192.4     22.0 26.9   -80.4 | 22.0 23.5    -9.2 |
          22.0 22.6    -7.8                                             -289.8
|  5.00 |21.2 26.5  -196.8     21.2 26.9   -80.4 | 21.2 22.9    -7.0 |
          21.2 22.1    -5.2                                             -289.5
|  6.00 |21.0 26.6  -198.7     21.0 26.9   -80.4 | 21.0 22.3    -4.8 |
          21.0 21.8    -4.1                                             -288.0
|  7.00 |21.8 26.6  -199.0     21.8 26.9   -80.4 | 21.8 22.1    -4.2 |
          21.8 21.2    -1.1                                             -284.8
|  8.00 |22.6 26.6  -199.0     22.6 26.8   -79.9 | 22.6 21.5    -1.9 |
          22.6 21.3    -1.6                                             -282.4
|  9.00 |24.4 26.6  -199.0     24.4 26.7   -78.0 | 24.4 21.5    -1.9 |
          24.4 22.1    -5.4                                             -284.2
| 10.00 |26.0 26.6  -199.0     26.0 26.4   -74.2 | 26.0 22.2    -4.6 |
          26.0 23.2   -10.6                                             -288.4
| 11.00 |27.4 26.5  -197.9     27.4 26.1   -70.5 | 27.4 23.2    -8.1 |
          27.4 24.9   -18.7                                             -295.2
| 12.00 |29.0 26.4  -193.9     29.0 25.9   -67.5 | 29.0 24.8   -14.2 |
          29.0 26.4   -26.0                                             -301.5
| 13.00 |29.8 26.2  -187.0     29.8 25.7   -65.1 | 29.8 26.3   -19.6 |
          29.8 27.8   -32.8                                             -304.5
| 14.00 |30.1 26.1  -181.0     30.1 25.6   -62.9 | 30.1 27.6   -24.6 |
          30.1 29.2   -39.2                                             -307.8
| 15.00 |30.1 25.9  -176.2     30.1 25.4   -61.0 | 30.1 28.9   -29.6 |
          30.1 29.8   -42.3                                             -309.1
| 16.00 |30.1 25.8  -172.3     30.1 25.3   -59.0 | 30.1 29.6   -32.0 |
          30.1 30.0   -43.3                                             -306.6
| 17.00 |30.1 25.7  -168.6     30.1 25.2   -58.2 | 30.1 29.8   -32.8 |
          30.1 30.0   -43.3                                             -302.9
| 18.00 |30.1 25.6  -165.6     30.1 25.1   -56.8 | 30.1 29.8   -32.8 |
          30.1 30.0   -43.3                                             -298.6
| 19.00 |29.8 25.5  -162.1     29.8 25.0   -55.6 | 29.8 29.8   -32.8 |
          29.8 30.0   -43.3                                             -293.8
| 20.00 |28.8 25.5  -161.3     28.8 25.1   -56.7 | 28.8 29.8   -32.8 |
          28.8 29.9   -42.9                                             -293.8
| 21.00 |27.2 25.4  -158.4     27.2 25.3   -58.9 | 27.2 29.8   -32.6 |
          27.2 29.4   -40.5                                             -290.4
| 22.00 |26.0 25.4  -156.9     26.0 25.6   -62.8 | 26.0 29.4   -31.1 |
          26.0 28.3   -34.9                                             -285.7
| 23.00 |25.0 25.5  -159.7     25.0 25.9   -67.4 | 25.0 28.3   -27.2 |
          25.0 26.8   -28.0                                             -282.2
| 24.00 |24.2 25.6  -163.4     24.2 26.2   -71.5 | 24.2 26.9   -22.0 |
          24.2 25.7   -22.6 |                                           -279.4

| Total Heat loss          -252.54 MegaJoules
```

Appendix E: Space standardisation in modern housing programmes.

Housing Standards

The general organisation of an urban agglomeration generally comprises three main zones.

- housing zone
- activities zone
- leisure zone

And according to the proposals the housing zone is itself subdivided into:

- the housing estate
- the housing groupment
- the housing unit

Then the number of inhabitants (future dwellers) is worked out as shown in the following table.

Dwelling size per size of household

Dwelling size	Household size
1 room	2 persons
2 rooms	3 persons
3 rooms	6 persons
4 rooms	8 persons
5 rooms	11 persons

Source: Ministere des travaux publics et de la construction Instruction relatives a la realisation du programme d'habitat urban. 1974-1977 p.8.

Every unit has, or should have, according to the source

- 2 to 5 rooms (including lounge and bedrooms)
- 1 kitchen
- 1 bathroom
- 1 W.C.
- storing space (larder)
- drying space
- loggia

with the according areas:

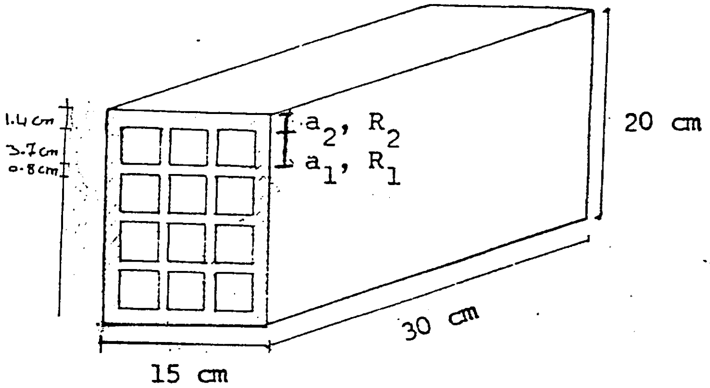
Minimum habitable area

	Unit size			
Area in m^2	2 rooms	3 rooms	4 rooms	5 rooms
Lounge	18.50	18.50	21.50	21.50
Rooms	11.50	11.00	11.00	11.00
Kitchen	9.00	9.00	11.00	11.00
Bathroom	3.50	3.50	3.50	3.50
W.C.	1.00	1.00	1.00	1.00
Storage	0.50	1.00	1.50	2.00
Total	55.50	66.50	82.50	92.00
Clearing	6.50	8.50	10.50	13.50
Habitable area	-	-	-	-

Appendix F: Hollow Brick's Thermal Characteristics

Modern building materials:

In constantine, the building material which is mostly used for small scale and private individual housing units is the hollow red brick. This material is locally produced in the region (in different type and size) by the national company S.N.M.C. either in Didouche Mourad or Mila. The annual production of each factory is 100,000 tonnes.



Finding the resistance of the hollow brick (12 holes): CIBS method:

Resistance of void (R_v) = 0.18 m^2K/W

Resistance of solid part (R_s) = 0.73 m^2K/W

$$R_1 = R_s + R_v + R_s + R_v + R_s + R_v + R_s$$

$$R_1 = 2 \times \frac{0.014}{0.73} + 3 \times 0.18 + 2 \times \frac{0.008}{0.73} \longrightarrow \quad R_1 = 0.6$$

$$R_2 = \frac{0.15}{0.73} = 0.205$$

$$\frac{A}{R} = \frac{A_1}{R_1} + \frac{A_2}{R_2}$$ for a composed material.

A_1 = area of $(\sum a_1) = (0.148 \times 0.3)\ m^2$

A_2 = area of $(\sum a_2) = (0.052 \times 0.3)\ m^2$

$A = (0.2 \times 0.3)\ m^2$

$L = 0.15\ m$

$R = 0.4\ m^2K/W$

$$\lambda = \frac{L}{R} = 0.375\ W/mK$$

Average density and specific heat of the hollow brick

solid part: ρ = 1800 kg/m^3, c = 985 J/kgK

air space: ρ = 1.2 kg/m^3, c = 1180 J/kgK

% of air space in the total area of the brick = 52.1%

% of solid part in the total area of the brick = 47.9%

ρ = 862.82 kg/m^3

c = 1086.59 J/kgK

The same procedure has been applied for the 8 holes and 3 holes bricks.

Other references used in this study.

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