==

USE OF THE TRADITIONAL HOUSE AS A MODERN DESIGN GENERATOR IN THE M'ZAB REGION OF ALGERIA

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by

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I want to dedicate this thesis to my parents, for their encouragement, their prayerful support and the sacrifices they accepted for my education, to my brothers and sister.

I would like also to dedicate this work to my daughter Imane Assia.

Last but by no means least, I would like to express my deepest gratitude to my wife, for her patience, encouragement, dedication, extensive support throughout this work and the lovely daughter she gave me.

ABSTRACT

The large programmes of Western style prefabricated buildings undertaken to alleviate the housing crisis in Algeria, are found to be incompatible with comfort and cultural aspects of Algerian society, especially in areas where social tradition still has great relevance to housing morphology.

The objective of this study is to investigate the applicability of traditional building forms and environmental control strategies, as solutions to cultural and climatic requirements in a modern context, with reference to the M'zab region of Algeria.

Thermal and architectural analysis of typical traditional and modern houses, shows the influence of key climatic and design parameters.

A site experiment was carried out during the summer of 1987. Temperatures in five different locations were simultaneously recorded firstly in a traditional house then in a modern house under different ventilation and shading strategies. Spot readings of humidity, air movement and surface radiation were also recorded. The results showed that the traditional house, with judicious internal organisation and appropriate passive methods of environmental control, is well adapted to the local climate. Significant vertical temperature stratification occurs within the dwelling. They also showed that the modern type bears no relation to either the social or environmental factors characterising local architecture, with a consistently high temperature profile throughout the dwelling.

The conclusion was that a design concept of vertical development based on the hierarchical organisation of spaces, in conjunction with the use of evaporatively cooled air, could succeed in creating a comfortable indoor environment. Such a planning arrangement can be sufficiently flexible to accommodate both variable family units, and modern standards of safety and utility.

A new passive evaporative cooling device based on the *mushrabyyah* is presented. In addition to its reliance on locally available materials, ease of use and revival of a traditional architectural element, it also has the advantage of being readily applicable to the already existing houses in order to improve their performance.

CONTENTS

GENERAL INTRODUCTION

Shortly after independence, Algeria undertook to realise an ambitious programme of industrial development. New economic projects started to mushroom all over the country and naturally, these constituted irresistible poles of attraction for both the unemployed and the low-paid from different walks-of-life. Inevitably, the resulting internal migration added to the already very high birth-rate led to an exponential rise in the housing demand which the small number of mostly decayed houses inherited from the colonial period could not satisfy. This was paralleled by building needs in other sectors, such as schools and hospitals. By the mid-1970s, the problem was such that it became a priority in development plans, especially since half the population were at an age of establishing their own homes, and statistics showed that in order to alleviate the pressure, a total of 100 000 housing units would have to be built each year. This was beyond the capacities of the country. Consequently, many building contractors, from different countries, were contracted through international open tendering. They brought with them their mass production equipment, their designs and their standards. Everywhere in the country, prefabrication was the key-word and every single town had its share of reinforced concrete panels and high-rise flats. This form of housing may be found acceptable in some parts of Algeria, especially in the North, because of the climatic similarity with the countries where they originated, the familiarisation of the northern population with European housing style, and last but by no means least, because the general public was thinking of it as a vehicle of modernity. However, there still remain many regions where this international type housing is quite inappropriate for both cultural and climatic reasons. The M'zab in the south of Algeria is one such example.

Questions may arise as to whether historic areas should be protected against any modernism in order to maintain their traditional *cachet* and avoid contrasts. On the other hand, one may ask if it would not be better for people to liberate themselves from a past that is just impeding their aspirations, and concentrate rather on the present with a look ahead to the future. This certainly leads to the most crucial and urgent issue facing the development of modern architecture and many other cultural fields in Ghardaia in particular and Algeria in general - how to facilitate modernisation without losing cultural identity.

Due to a misunderstanding of the definition of modernity, everyone has been expectantly waiting for Western architecture to breath a spirit of that modernity. In terms of architectural development, the attitude of Algerian people to the West is ambivalent, composed of both appreciation and hostility. On the one hand, advantages of Western modern architecture, such as structural and constructional technology, and environmental control systems, have offered better technical solutions to the problems of the built environment than traditional architecture could. People not only enjoy working and living in a well-lit, air-conditioned environment, but also treat the affordability of these as a symbol of social status. In other words, people appreciate the functional and some of the symbolic aspects of modern architecture. On the other hand, people are hostile to modern Western architecture because of its destruction of traditional concepts of spatial organisation and symbolic expression which used to play such important roles in traditional architecture. In other words, people have an animosity towards the cultural aspects of modern Western architecture.

This unreconciled conflict which persists between modern Western architecture and traditional architecture then raises the question as to whether integration between the two would breed a new architecture better than either of its parents, or whether the new will simply destroy the old.

In fact, there have been several occasions throughout history where contacts between different cultures have proved to be landmarks in human progress and architectural development, as different cultures were absorbed, and developed by different people as their own: Greece learnt from Egypt, Rome from Greece, the Arabs from the Roman Empire, and Europe from the Arabs. Moreover, integration does not mean an overwhelming dominance of one over the other, but rather it is mutual influence.

However, during the integration process, there always exist two opposite dangers which are likely to force modern architecture in M'zab in particular and Algeria in general to a single-track development:

The first is that architects, in the course of resistance to foreign influences, fall victim to an intensive anti-modern conservatism;

The second is that local architecture may become completely westernised, retaining nothing of what has hitherto distinguished it.

One might suggest that there is nothing wrong with International Style architecture since we all live in an international community and use international modern inventions and products such as watches, television sets and cars. But architecture is quite different from such transient material goods. One can buy a watch or a car and change it easily. Yet once a building is completed, it will become a long-term part of the built environment and have a great impact upon the formation of the sense of a place spiritually and physically. Consequently, the sense of a place which is so important to the identity of a people will be threatened and lost if most architecture with local or national characteristics is replaced by International Style architecture.

In order to avoid these two extremes, architects must know how far their own cultural heritage in architecture has been diminished by modern standards; and how much of their heritage could be preserved and revived to maintain a distinctive cultural identity.

After having understood the cultural aspect of the problem, through all the implications that a new design would have in a traditional context, the designer would have to concentrate on its climatic side.

Architects are trained to design buildings to fulfil certain functions, giving full consideration to all design aspects, including site and environmental conditions. Building in any climate brings a particular problem of adequate heating and/or cooling, normally solved in the affluent, developed world by mechanical means. But, instead of using non-renewable energy to give a good indoor climate, the architect could give serious consideration to the well tried traditional methods exploiting renewable ambient sources, which have enabled occupants in the past to be comfortable with maximum economy. These traditional solutions should be studied but not copied, as they have been developed under conditions that have changed considerably through time. Unless the design is fundamentally correct in all aspects, no specialist can make it function satisfactorily.

After awakening to this level of consciousness, they should endeavour to re-valuate those applicable aspects of their heritage and readjust them to suit the ideology of the modern society so that modern ideas and technology can be integrated to new architecture in M'zab.

In this sense, the present study tries to investigate ways of improving thermal comfort conditions through a culturally and climatically better suited design. A site experiment concerning the thermal behaviour of the traditional and the modern house was carried out during the summer of 1987, the results of which were related to the forms and other architectural characteristics of the two models. Their comparative analysis revealed that although the modern design has its own environmental and economic advantages, the traditional type was better suited for both thermal and cultural considerations.

This, then, supports a modern vernacular synthesis, which is presented in prototype "idea" form. The intention is not to suggest a definitive solution, but to demonstrate that modern comfort and construction standards are achievable without heavy reliance on expensive mechanical systems, and are reconcilable with traditional cultural values.

The first chapter is meant as an introduction situating the subject of this work historically, geographically and physically.

The second chapter is concerned with the climatic analysis of the region. Environmental factors such as the temperature, humidity and movement of the air are discussed according to their influence on thermal comfort.

The third chapter examines ways in which heat is produced, acquired and lost. It also discusses the influence of clothing and activity. Using the bioclimatic chart and the climatic data, the degree of discomfort is delimited and the appropriate solutions defined.

Chapter four treats the architectural and thermal analysis of two models representing the traditional and the modern houses. The site experiment is presented and its results discussed.

Finally, using the conclusions reached by the experiment as guidelines, a new design is proposed in chapter five.

CHAPTER 1 : CONTEXT

1-1 : Geographic context :

600km south of the capital Algiers, and at a latitude of 32^{o} 30' and 3^{o} 45' in longitude, is a region called M'zab with Ghardaia as the regional capital, (Fig.1-1).
The four other towns of the "pentapole" are: El-Ateuf, Bou-Noura, Beni-Isguen and Melika, which is the nearest to Ghardaia, (Fig.1-2).

The towns lie on knolls or ridges on the floor of the valley of the river M'zab, and at an altitude of about 450m above sea level.

The M'zab valley is one of many dug by fluvial erosion into the Hamada plateau. Being ravined in all directions the region has been given the name: Chebka, literally meaning "net" or "lace".

Two other towns of the same origins, Berriane and Guerrara, are found at 43km and 90km respectively to the north and north-east of Ghardaia.

1-2 : Historic context :

In the year 761, Abderrahmane Ibn Rostom, one of the five missionaries who brought the Ibadie doctrine to Africa, founded the state-city of Tahert, 9km from the present Tiaret. It soon became very prosperous under the leadership of his successors, the Rostomides.

Plundered and burnt by Abdallah Achii, Tahert was abondoned in 947 by its inhabitants and the few Berber tribes who were living on the outskirts with Imam Yacoub. The fugitives choose Ouargla, an old province which recognised Imams and was secure from the ruthless attacks of the tribes who took Tahert.

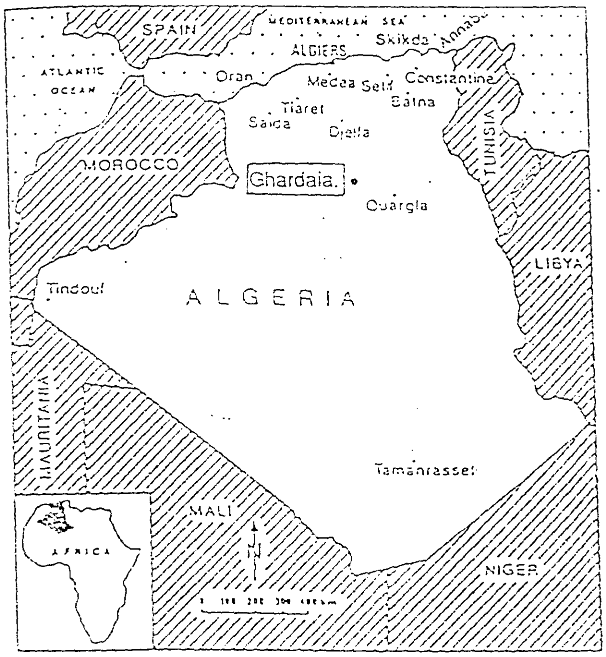


Fig.1-1 : Geo-political location of Ageria.
Source : Boukhemis A. , "Recent urban growth pattern and migration: a case study of Constantine, Algeria." Ph.D, 1983 Glasgow University.

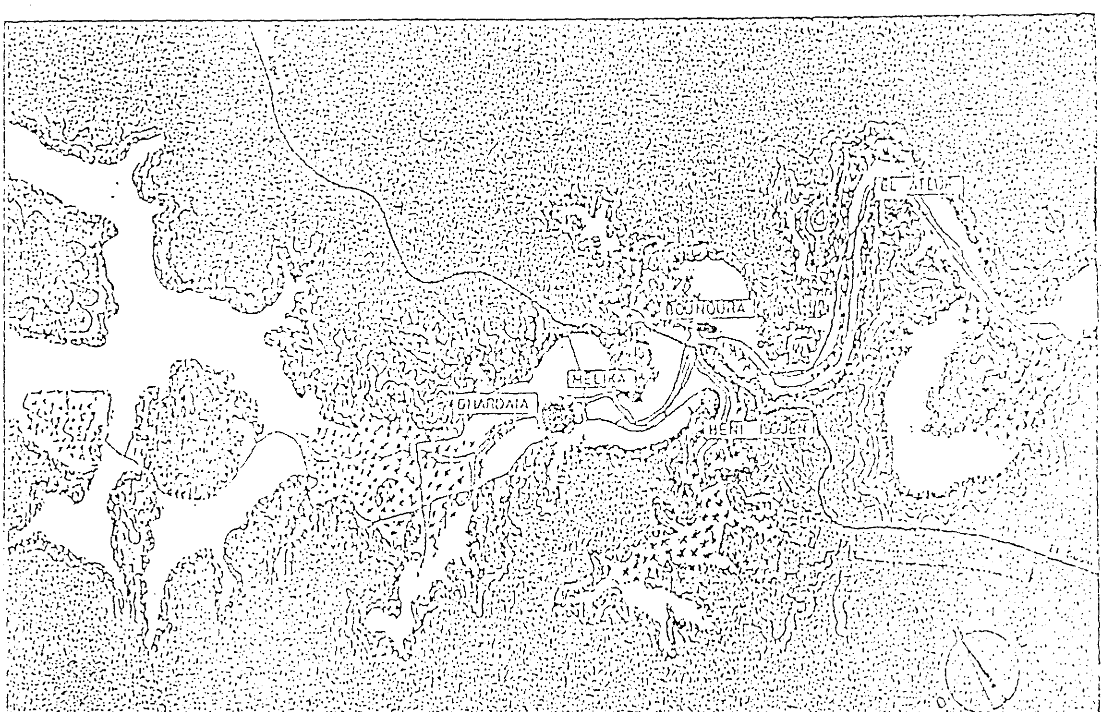


Fig.1-2 : The Mzab valley, Algeria.
Source : "P.U.D. Ghardaia" -C.E.R.A.U.- Nov. 83.

Retired in a region where Ibadism was still freely practised, but protected from the covetousness of the princes by the heat of the Sahara and the aridity of the desert, the exiled of Tahert undertook to erect a city in the image of the one they had just abondoned and which, one day perhaps, would recover the radiance of their fallen capital, and would keep alive their religion.

Not very far from Ouargla, Sedrata was built. It rapidly became an important economic centre. Inevitably, the inner divisions re-opened as before, but worsened this time by the ceaseless attacks from the wandering tribes opposed to the sect. The permanent rivalry between the settled and the nomad made this refuge extremely vulnerable.

The Ibadites then started to look for another site, more defensible, more remote from the movements of caravans and which was not on the route or the camping ground of wandering tribes. They needed to find a territory which would not be the subject of any covetousness of the tribes and would have strategic advantages.

The M'zab, desert inside the desert, with its landscape of crests and hillocks furrowed by ravines, the widest of which is the bed of a river dry for months or even years and called the M'zab ouadi, seemed to meet those criteria. The aridity of the soil, and the sterility of the land, enabled these people to prove their faith through their works, because living and perpetuating the sect required them to strive harder than ever.

Under the guidance of sheikh Khaled Ben Aghar, and well before Sedrata was destroyed around 1070, some pioneers started to raise the walls of what was going to be the first town of M'zab: El-Atteuf was erected in 1014. But the first settlement is believed to have been that of Ar'ram Tal Azdit, the castel of the handful of wool, founded around 904 near the palm-plantation of El-Atteuf. The other towns appeared later: Bou-Noura in 1046, Ghardaia in 1053, Melika in 1124 and Beni-Izguen in 1347. North of the valley, Guerrara was founded in 1630 and finally Berriane in 1679.

1-3 : Physical context :

At the begining, the constitution of a town was not a fact of fate. Its creation as well as its enlargement have been deliberate. The foundation process is still known: a group of adventurers and enterprising people gathered with a sheik, well-known for his piety and his courage, as their chief. They selected a site principally according to its military defence possibilities. The towns are therefore situated on knolls or on ridges, which at the same time clears the cultivable ground and ensures that the dwellings and the urban spaces are out of reach of flood water, (Plate1-1&1-2). The founding group started by building a mosque on the top, which was at the same time a shop, an ammunition depot and a fortress; then the enclosure was carefully laid out. This operation took on a religious and military character. The same thing happened afterwards for the extensions, decided according to the community needs. The towns were, and still are entirely or partly, surrounded by ramparts or rampart-houses, as well as by watch towers, and their urban structure is extremely compact, (Plate1-3).

Nowadays the towns look a bit different, for parts of the ramparts have been destroyed, and new districts have been built, (Fig.1-3&1-4). Also doors and windows opening onto the outside have been pierced into some rampart-houses giving them a European appearance. But in a general manner, they are tiered along the slopes. Having the colour of earth and rocks, they give the impression of being vast clay bee-hives baking under the sun, (Plate1-4).

1-3-1 : Ghardaia :

Ghardaia is the most important town of the "Pentapole". It occupies a hill on the top of which stands the mosque with its high minaret, (Plate1-4). The town has a concentric development, the centre of which is extremely compact. There are 2400 dwellings over a surface area of 26ha. which represents a density of about 93 dwellings / ha. or 108 m^2 per dwelling, including public and community spaces such as mosques, streets and market, (Fig.1-5).

Plate1-1: View of Beni-isguen, Melika and Ghardaia.

Plate1-2 : General view of Ghardaia and its palm-plantation.

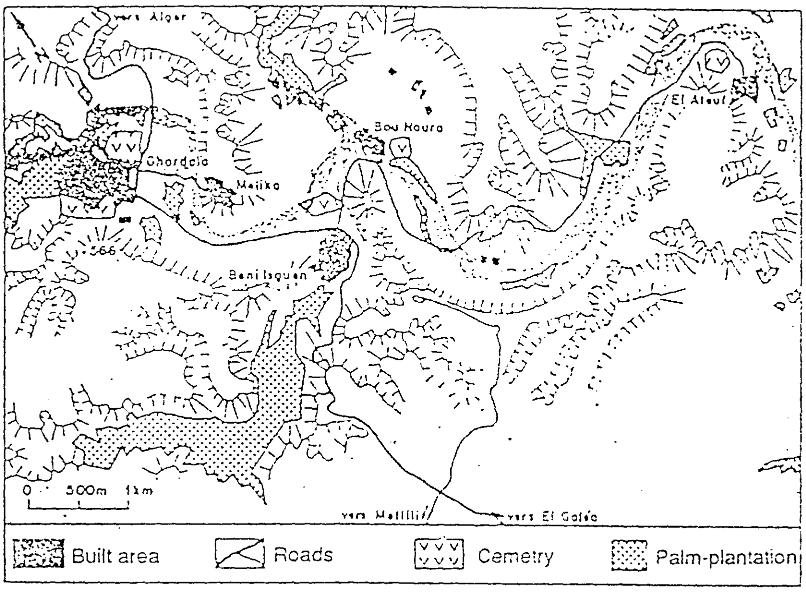


Fig. 1-3 : The towns of the Mzab valley in 1952.
Source : "Les cahiers de l'amenagement de l'espace", n° 8 Oct.-Dec. 1979.

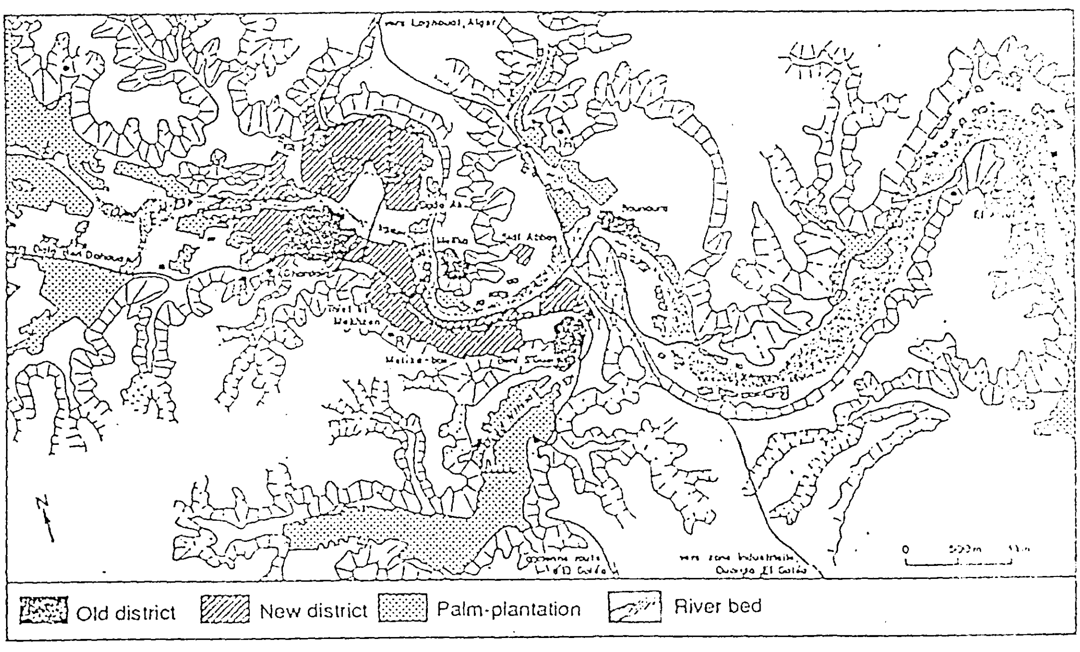


Fig. 1-4 : Towns and new districts in the Mzab valley in 1979.
Source : "Les cahiers de l'amenagement de l'espace", n° 8 Oct.-Dec. 1979.

◄ Plate1-3 : Rampart houses built on the rocky edge of Bou-Noura.The chimney-like construction in the centre is a watch-tower and a stair-case for collecting the wood brought by the river during the flooding.

▼ Plate1-4 : View of the compact, Ksar type housing, with the mosque and its high minaret at the top of the hill surrounded by the terraced houses.

Fig. 1-5 : Urban structure of Ghardaia.
Source: Atelier d'Etudes et de Restauration du Mzab.

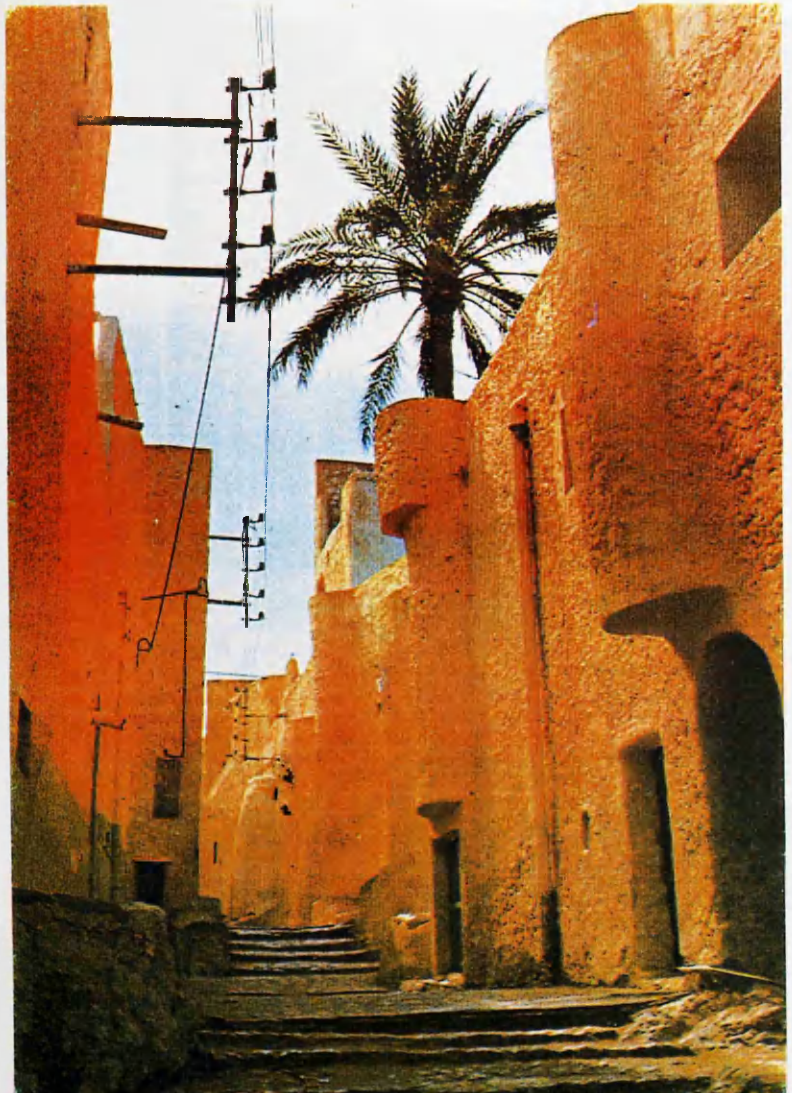
As for thoroughfares, Ghardaia has 124 streets or narrow lanes covering a distance of 12 kms and linking 116 *ilots*. They are between 1 to 3m wide, (Plate1-5), the widest part being around the market place and the gates, and gradually narrowing towards the top. The straight lanes are short and the long ones are somewhat tortuous so that long open views are avoided and maximum shading is created. This layout has resulted in a labyrinth-like pattern meant to cause potential aggressors to lose their bearings, (Plates1-6 & 1-7). In some places, the lane is covered by the houses in order to shade it especially in the case of a north-south oriented alley, where the method of high, close and tortuous facades would not be as effective as in the case of east-west oriented lanes, (Plate1-8).

The nearer the mosque, the lower the headroom under the covered lane which, according to an old local, was purposely designed in order to oblige the attacker to dismount or make him bend thus making him more vulnerable, (Plate1-9).

Architecturally, the lane is animated by the form and colour of the walls, themselves enhanced by the rythm of light and shadow. The only openings in the facades are the entrance door and usually a small window above it. Niches, where oil lamps were put as public lighting before the installation of electricity, can still be seen, (Plate1-7).

Ghardaia, as all the other towns, has wells inside the ramparts supplying the population with water. The drawing and distribution were the responsibility of professional water-carriers, (Plate1-10). Until the early 1970s, this was the only water supply for the town. Nowadays, pumps, pipes and other modern means are used, especially since large quantities of water have been found lying under the region and at a depth traditional wells could not reach. But at the same time this abundance of water has had a negative effect on people's behaviour in that they are becoming less aware of its importance, sometimes carelessly wasting it. This situation could result in the level of the phreatic water being brought up nearer to the surface due to the increase of waste-water. A high concentration of salts and water would be created around the foundations causing them great damage by attacking the reinforcing steel and the chemical properties of the cement.

Plate1-5 : Narrow tortuous streets shaded by high walls.



▶Plate1-6 : Narrow circular street surrounding the mosque-
The arches are used for structural purposes.

◀Plate1-7 : Typical street at mid-day, animated by the rythm of volumes.

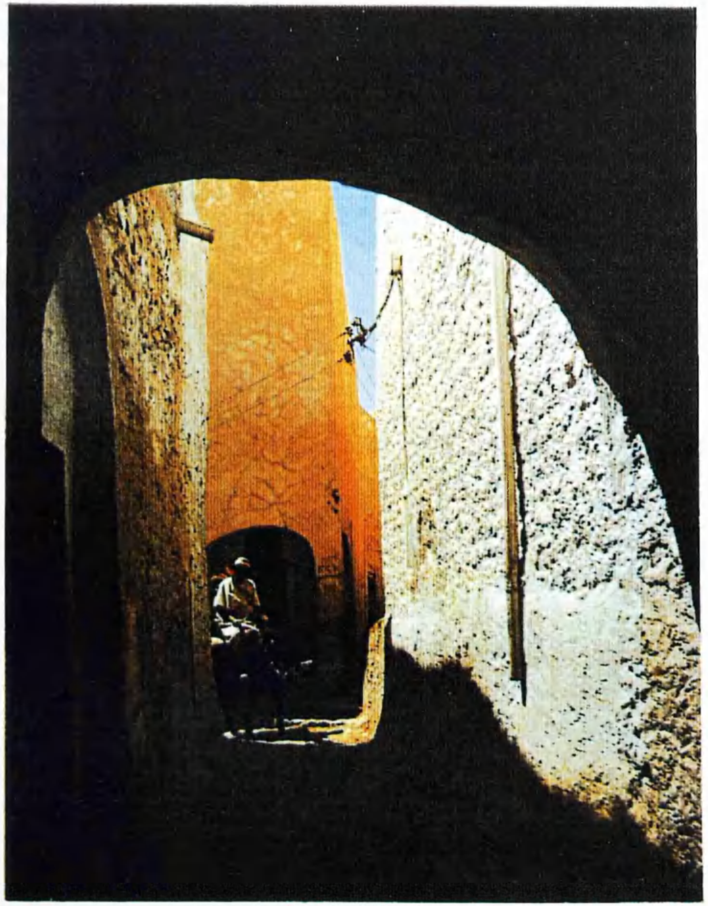


Plate1-8 : Street shaded by high walls and the construction bridging over it.

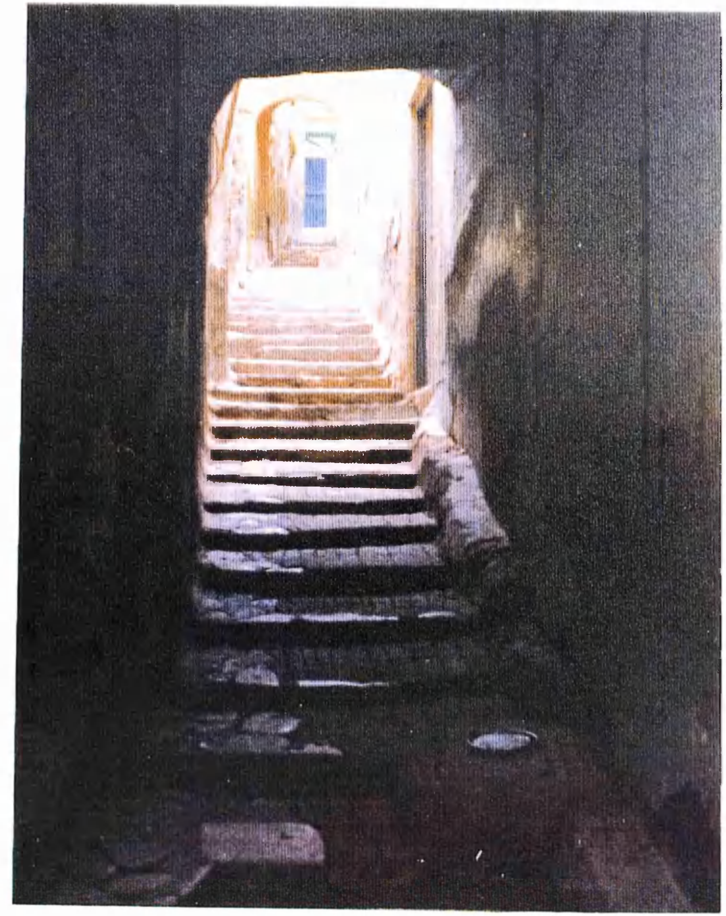


Plate1-9 : Street climbing towards the mosque.

The market place of Ghardaia, which is the most important of the valley, lies to the south-west end of the town, (Fig.1-5). The location at the outskirts was dictated by security considerations. This characteristic is confirmed by the absence of any public spaces deep inside the town which would attract strangers. Until the beginning of this century, caravans used to sell or exchange their goods there. During their stay, the nomads were locked up on the market place to prevent anyone getting in or out at night.

This rectangular place of about 75m by 44m is entirely surrounded by an arcade or gallery, under which are the shops,(Plate1-11). The place is the centre of many minor markets such as the meat market and the vegetables market as well as tens of different activities ranging from the barber, the tooth extractor to the shoe-repairer, which makes it very colourful and lively, (Plate1-12). It also is a joining point of many streets which have an economic function at their end nearest to the market place. Every street has its specific mercantile activity as for example: The embroiderer's street, blaziery street or the tailor's street,(Plate1-13). This spacial division is slowly disappearing today as a result of the decrease in the number of artisans, on the one hand, and the increase in the number of manufactured products in general stores, on the other.

1-3-1-1 : The *ksar* type housing :

This type of housing has its origins during the settlement of the Ibadites and was for a long time the only built-space in the valley. It is a typical urban form of housing, (Plate1-4). The houses are imbricated one into another, have two levels topped by a terrace, have no garden and some have a basement. They are large, and as a result, offer satisfactory conditions of comfort by means of internal migration in accordance with daily and seasonal cycles, compared to the other types of housing found in the valley at the present time.

The urban tissue created by this type of housing is extremely dense. Except for the narrow streets, the space is entirely built to a height of two and a half levels. There are no squares or public places apart from the market place, which is rejected to the outskirts, therefore making the urban layout more continuous and homogeneous.

Plate1-10 : An old well in the street, traditionally used by water-carriers for distributing water to the houses.

Plate1-11 : An corner of the market place of Ghadaia.

Plate1-12 : Shops and other minor activities - here a shoe repairer- under the gallery surrounding the market place.

◀ Plate1-13 : An example of commercial streets around the market place- here the vegetables street-

The state of the houses is variable. They suffer some deterioration from lack of upkeep or due to overcrowding. Some are modified by successive divisions or transformations or transformed and improved or even taken down and rebuilt again.

This type of housing which is the most common in the valley, has for many years represented an environment perfectly adapted to the way of life of the population. But during the last decade, this equilibrium has been broken. A significant rise in the population resulted in a higher density inside the old towns. This housing has an historical value as the first settlement in the valley. It has the value of a testimony to the culture of a community and its adaptation to a particularly hostile site. Although it raises some problems of adaptation to contemporary needs, it certainly remains an example of concentrated housing which responded well to the cultural and climatic requirements of the region.

1-3-1-1-1 : Inside the house :

In M'zab, as in all coutries where the daily life is impregnated by Islam, the threshold of the house marks the separation between the public life of men and the secret, protected life of women. As in almost all Mediterranean architecture, the entrance to the house is marked by a doorstep. The entrance door, which is the largest of the house, is generally open and yet the privacy of the house is preserved from the outside gaze by an entrance in the form of a chicane, the second opening of which may be covered by a curtain, (Plate1-14). Women and children can freely go inside. Children are sent from house to house as emissaries, transmitting messages, asking for something or just go there to play. Men however, whether they belong to the family or not, mark their arrival by calls, coughings or knocks on the door, because they must give time to the women to cover themselves with the veil. Used to this exercise, women are very quick at doing it.

If you are invited, you would have to wait outside until the master of the house has warned the women, who are always designated under the term "family", and then you are asked to go inside. In most of the houses, the man has his own room where he can receive his guests

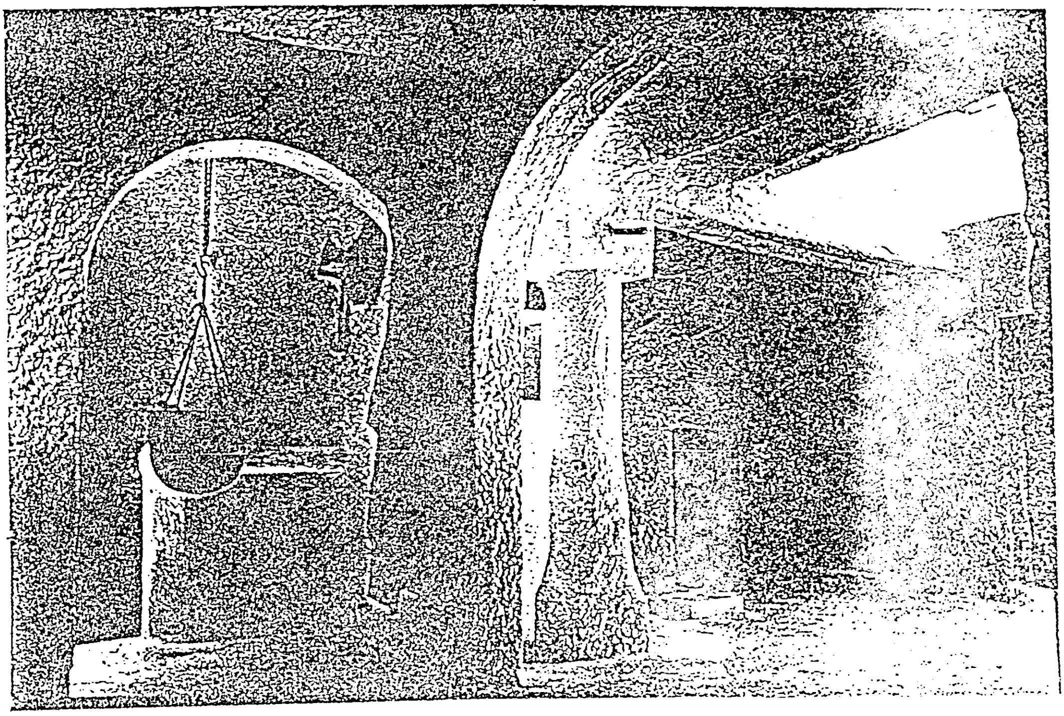


Plate1-14: View of the chicane, with a dellou placed in the path of the air movement, and the central space.

Plate1-15: View from another angle of the entrance and the central space, with the shaft in the ceiling.

without disturbing the family life. It is furnished with matresses, carpets and pillows so that guests may be received comfortably. The walls are often decorated with pictures and souvenirs. It is there that the meal or tea would be served by children or young men and this is probably all that would be seen of the house.

If you are a woman however, the female inhabitants may wish to see you or you could ask to do so and would be permitted to visit the rest of the house, (Fig.1-6). An old grain-mill composed of two millstones may be found in the chicane for the use of the neighbours who do not have one. As soon as the chicane is passed, a fairly large space characterised by a row of niches and a few metal rings attached to the wall, is discovered. In summer, it is a much appreciated place for the weaving loom because of its air movement, (Fig.1-7). This space leads to the central volume and is practically part of it.

The central volume, which many authors refer to as a courtyard, is the largest room of the house. It has no window opening onto the outside, (Plate1-15). A square opening is left in the ceiling, which allows enough light for the daily activities. In summer, and during the day, it is covered to prevent the heat and the sun's rays from reaching the inside, but it is opened during the night to allow the hot air out and the fresh air in. In winter, this hole is closed during the cold night and opened during the day, thus it is not normally necessary to introduce auxiliary heating. It is in this central space that almost all the domestic activities take place. It is not furnished except for the weaving loom, shelves and niches pierced in the walls. Short lengths of wood are inserted along the walls to be used as hangers, (Plate1-16). A *dellou,* a sort of bucket made of goat skin, can be found suspended from a beam in order to cool the water by taking advantage of the air movement and causing it to be fresher as well. In this central room but to one side, is the traditional kitchen containing a hearth, small niches for storing matches and small objects. Opening on the central space and taking advantage of the vertical light, is the "Tisifri" or women's lounge. It is found in all the old houses and it is there that the female guests are received away from the sight of men.

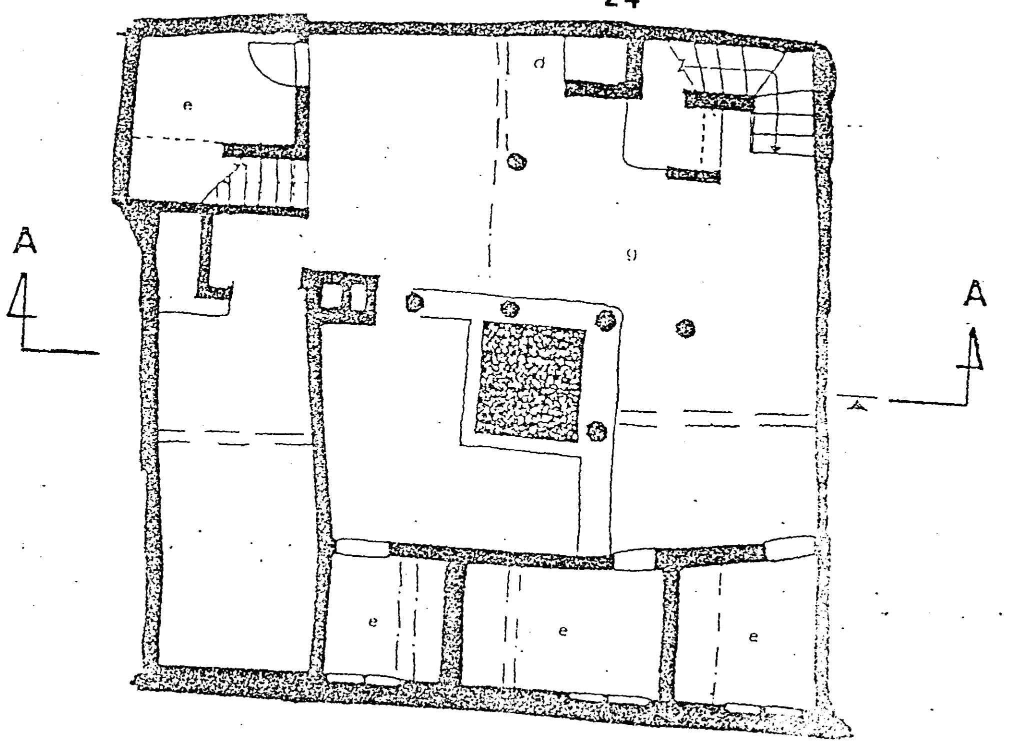


Fig.1-6-b: First-floor plan of traditional house.

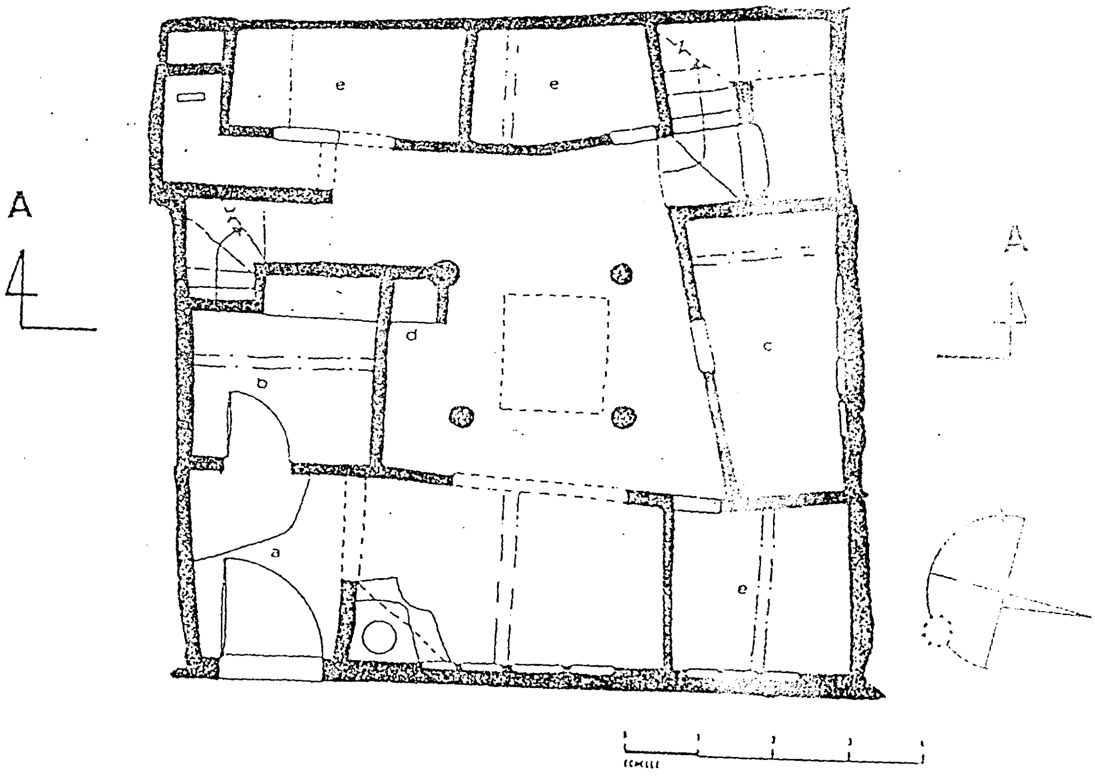


Fig.1-6-a: Ground-floor plan of traditional house.
a) entrance. b) men's room. c) women's room. d) kitchen. e) room. f) toilets. g) galery.

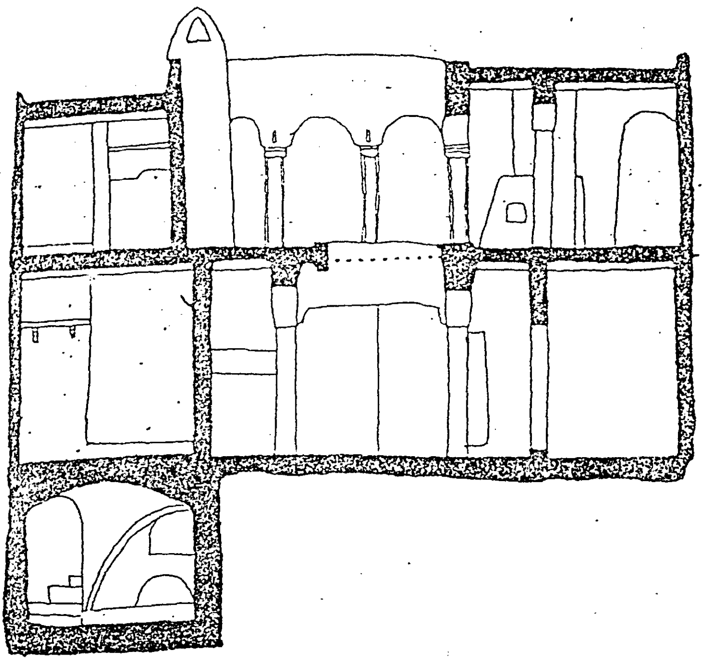


Fig.1-6-c: Section A-A.

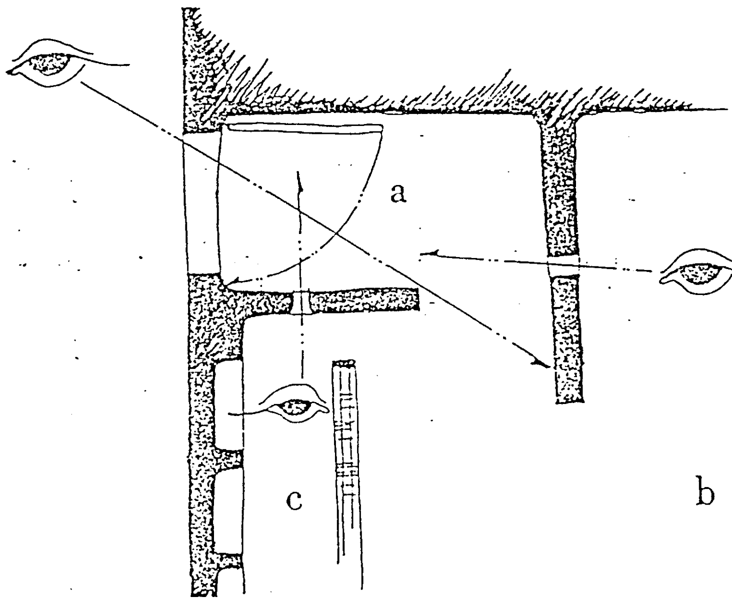


Fig.1-7: Example of a chicane :

a - The entrance.
b - The central space.
c - The weaving loom.

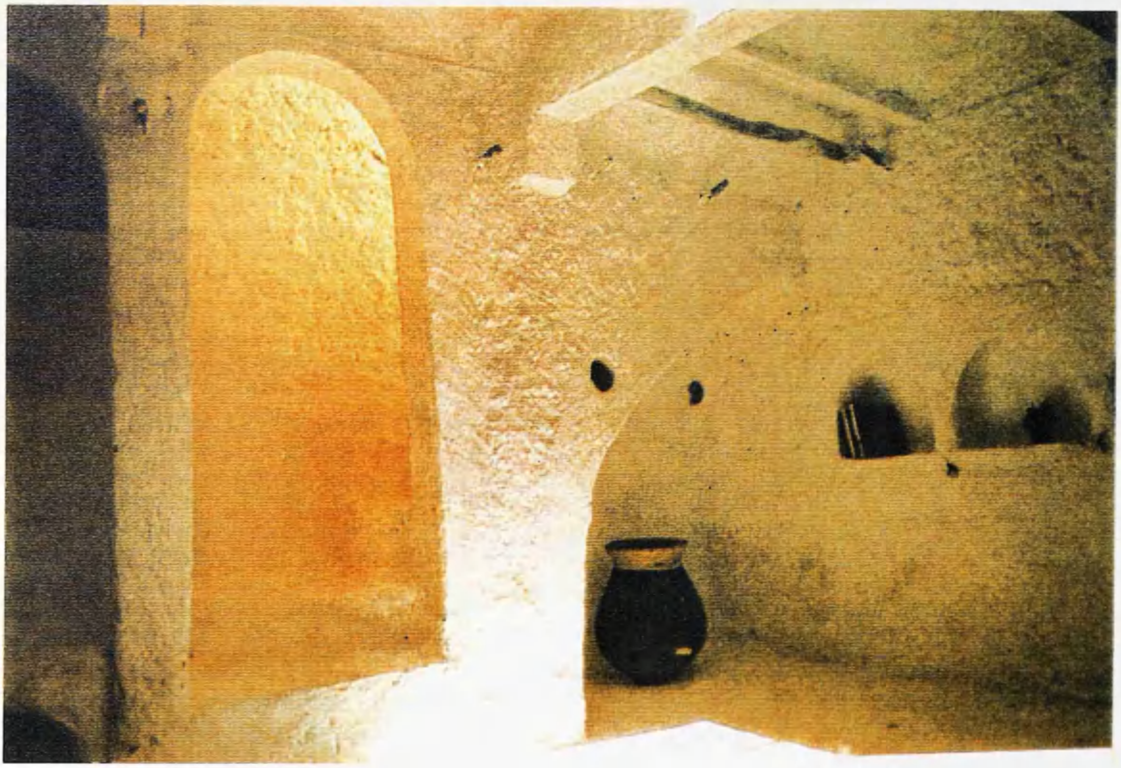


Plate 1-16 : Inside the central space, the built in shelves and the stairs leading to the first-floor.

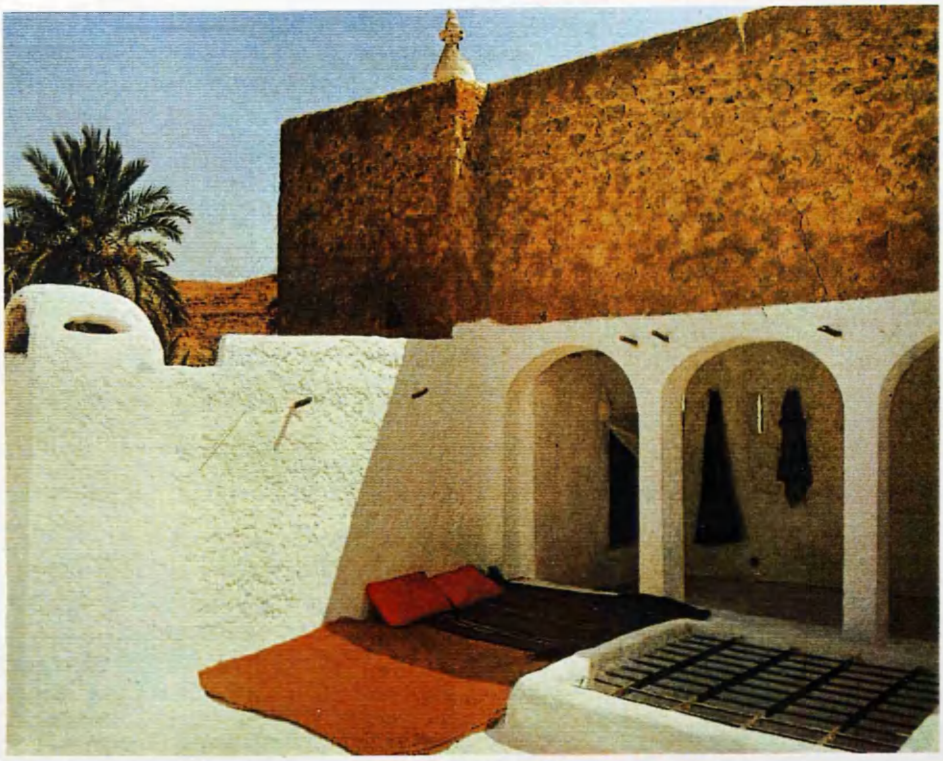


Plate1-17 : Terrace on the first floor, with the gallery, the shaft of the central space and the kitchen chimney.

The other rooms opening on the central space do not have a specific function as they can be used as bedrooms, wardrobe or storage according to need. They all have their walls covered by carpets to a height of about 1meter in winter and most of the furniture is built in. Old people, for whom the stairs can be very tiring, have their room on the ground floor.

The toilets are situated away from the central space. The house often has a shower-room. The stairs leading to the first floor are irregular in height and form. The stair case opens under a gallery where, apart from summer when it is too hot, women cook, do the washing or have tea with their guests, (Plate1-17). In order to avoid overheating the house during the hot season, a second hearth is found on the first floor. This gallery is always facing south in order to shade the rooms behind it from the high sun in summer, and allow the low sun in winter to heat the walls. More rooms are found on this floor which are used during the winter for their warmth.

Everywhere in the walls, sticks of wood are attached for hanging clothes and utensils. Small holes enable women to look out to the street without being seen. The flat roofs on the second floor are accessible to women only. However, if a man has to go there, for repairs for example, he must alert his female neighbours by shouting three times so that they can hide. These upper flat roofs are used for sleeping during the summer and may be partitioned in as many open air rooms as needed by the family. They are also used during the whole year for drying different sorts of foods such as fruits, vegetables, meat and home-made pasta.

1-3-1-2 : The palm-plantation housing :

The palm-plantation housing is the second type of traditional origin. Once a shelter for the worker, it became a summer residence for when the family leaves the main house in the "ksar" to the much cooler palm-plantation.

This type of housing is often detached and scattered among gardens, each unit having a fortified appearance, (Plate1-18). The houses have two levels: the ground floor and the first floor. As far as the internal organisation is concerned, they are similar to those in the *ksar*. The

Plate1-18 : Example of the fortress-like palm-plantation housing.

Plate1-19 : Detail of construction of a roof covering a street.

density is very low: 4 houses / ha. The houses are seldom accessible by car. An efficient network of paths enables people, whether on foot or riding an animal, to circulate everywhere while constantly shaded by trees.

1-3-1-3 : Importance of the palm-plantation :

The impact of the palm-plantation on the M'zab valley lies in three sectors namely: the economy, the micro-climate and the scenery.

1- The economy: The production of the palm-plantations has been the main resource of the valley for centuries. Nowadays, the exploitation of these plantations according to modern agricultural techniques is not possible due to their decay. Consequently, the production is not competitive and has become marginal. Nevertheless, consisting of tall trees, they constitute a moderating screen for the sun's rays and allow three levels of farming: palm trees, fruit trees and vegetables.

2- The micro-climate: The importance of the green cover is such that it creates an environment particularly propicious to life in these desert zones. And so the rainfall, although low, is perceptibly higher in the valley than in the surrounding plateaux. Moreover, the moderating effect of the plantation, lessens the superheating of the valley due to its topography. Finally, the role of the palm-trees in breaking down the wind velocity and in the protection of the soils against erosion is not a negligable one.

3- The scenery: Being the only green site in these barren regions, the plantations are a fundamental characteristic of the landscape of M'zab. By contrasting with the monotonous surroundings, it brings life to the hostile desert.

1-3-2 : Building techniques :

The characteristic of the architecture of M'zab cannot be explained only by the materials used, as none of them implies a unique building technique. On the contrary, many techniques are used for each material. The only constraints facing the builders are of a mechanical nature. Construction is by specialised workers but any one from the community can help or substitute for them. When the owner does not build by himself, he participates nevertheless in the general conception of the house, and from the first stage of its realisation to the last, he discusses the plan with the specialist. He may ask for a wall to be demolished if he feels like modifying the internal organisation of his house due to new family needs. Every project and every realisation are the subject of family discussions. The point of view of women is very important, and very often they seem to be behind the alterations in the house. The man acts as a medium between them and the builder. Buildings were subjected to some genuine rules of urban design. In particular it should not be possible to overlook one's neighbours. Neither should it be possible to completely shade him, the sun being, in a manner of speaking, inalienable. Another rule observed during the building process consists in using a lintel instead of an arch in the extreme opening of the gallery situated on the first floor, to ensure that the forces be transmitted vertically through the column to the foundations and not diagonally towards the neighbouring house, as would happen in the case of an arch. But it should also follow more general rules, of religious derivation. Nothing in the external appearance of the house should reflect the differences in fortunes. The rich must not outshine the poor. This absence of ostentation, very respected until recently, resulted in no house contrasting with the others by its size or its style. The rich and the poor having similar houses where any decoration was banned.

1-3-3 : Building materials :

Formerly, only local materials were used in construction. Nowadays, the opening of new roads has brought to the builders: cement, steel, soft wood, etc. As for the traditional materials, they are:

- Stones: Blocks of variable dimensions extracted from the limestone strata are used without cutting, a rough squaring is done on site just before the laying. Flat stones are kept for horizontal adjustments as tiles.
- Sunbaked bricks: Of the size of a concrete block, they are made from the most argillaceous soils. Wet earth is kneaded and moulded then dried in the sun. Sometimes, straw is added to give more cohesion.

- Sand: If argillaceous, it is directly used as mortar. If not, it is mixed with a setting agent.
- Timchent: It is a sort of traditional plaster, of grey colour, obtained from a hydrated gypsum. Extracted from the limestone plateau where it lies in horizontal layers at a depth of 1m approximately, this gypsum is calcinated in kilns. these are filled with combustible brushwoods and tufts of dry plants, the pieces of gypsum placed in a vault of 1.5 m in thickness over the fire. After combustion, which takes one day or more, timchent is separated from the residue of its fabrication, after collapsing as a result of becoming friable.
- Plaster: It has a quick setting and is locally produced at about 10 kms from Ghardaia. Nowadays, the use of plaster supplants that of timchent.
- Quicklime: It is very abundant in the region. Prepared in kilns of about 2m height, its calcination is similar to that of timchent but requires five to six times more wood. This makes it uneconomic, the more so as wood is not locally available.
- The palm tree: Every part of it is made use of but only after its death. The trunk is cut longitudinally in four parts which are used as beams, on the top of which the palms are laid, (Plate1-19).

1-3-4 : The modern housing :

The new settlement, the concern of this study, "cite du 5 Juillet", is situated about 3Km from the traditional centre of Ghardaia, in an area called: Sidi-Abbaz.

The scheme started in the mid-1980s with 400 dwellings. These have three, four or five bedrooms including the living-room and are organised around a central semi-public space in clusters of eight, distributed on two superimposed levels of four housing units each.

The urban layout of these clusters is represented in figure(1-8). They give the impression of being dispersed on the ground, leaving large bare spaces, ranging from 13m to 35m in width,

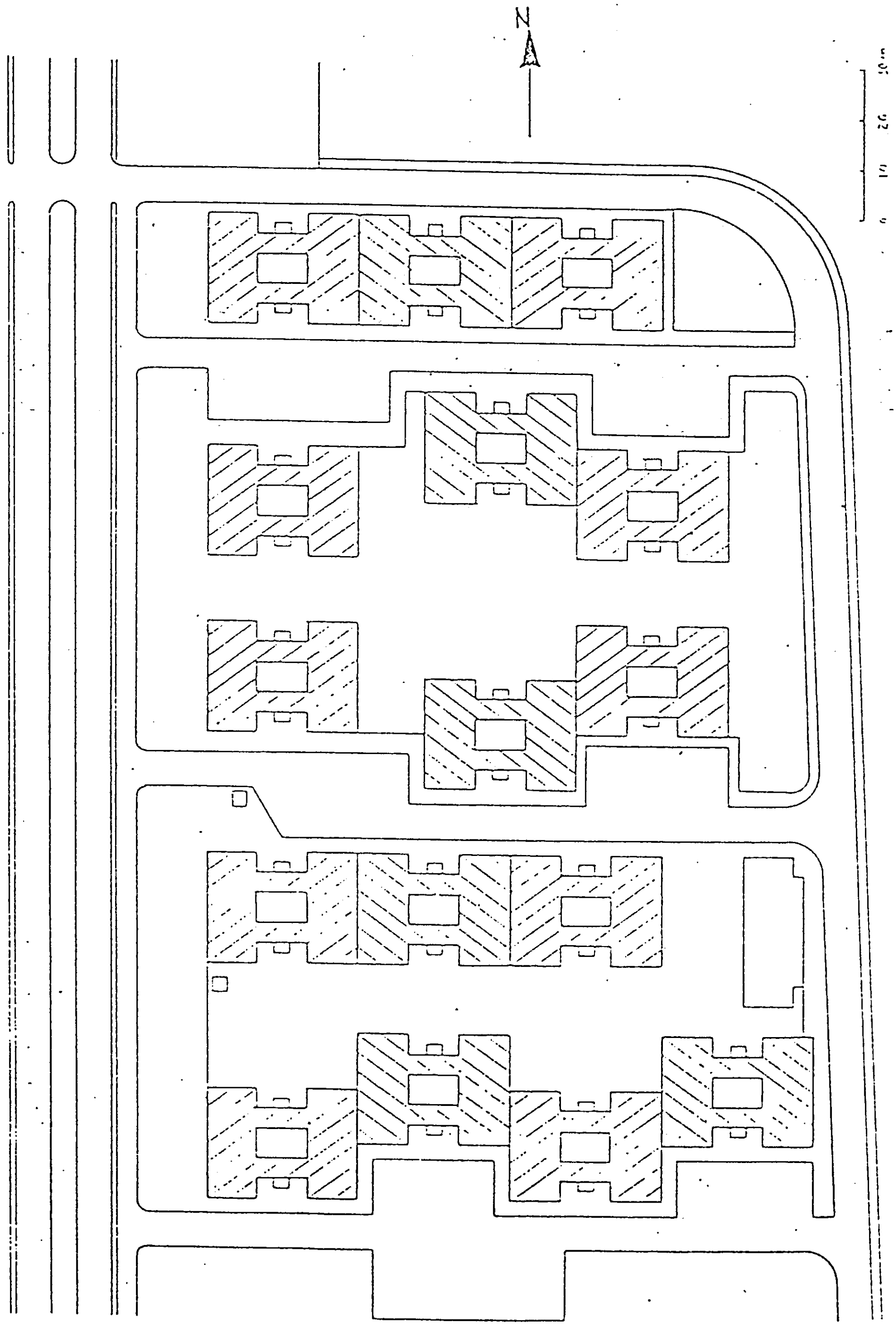


Fig.1-8: Urban layout of modern clusters.

between them. As a consequence, this layout is found to aggravate the effects of the slightest air movement in terms of drifting sand, flying dust and whirlwinds. It also creates long pedestrian paths, reduces the shaded spaces and increases the area of walls exposed to the sun, (Plate1-20 & 1-21).

The analysed model is a three bedroom house situated on the first-floor. Its plan and section are represented in figure(1-9). The first impression that is felt inside is the mixing between day and night living spaces. The kitchen is on the bedroom side, and the bathroom on that of the living-room. Moreover, in a climate where the main source of discomfort is heat, the kitchen is found to have no door isolating it from the rest of the house. This would certainly have the most pernicious effect on indoor environment, especially when considering the lenghty cooking process. There are other conceptual or constructional incongruaties between house-design and climate. For example, use of a single bitumen layer for watertightness on the outer surface of the roof, results in 90% of the solar radiation being absorbed. A second example is that of the bad positioning of openings in the rooms, which results in a reduction of the effectiveness of night ventilation for cooling the structure.

In a general manner, it can be said that this is a typical example of houses being designed from outside for a different culture, at a different latitude. Despite all the attempts to adapt them, they have never been adopted by the locals, either for their cultural incompatibility or their unsuitability to the climate. If the cultural or social aspect of the problem exceeds the limits of this study, that of the climate however, forms the essence of it.

Therefore, for a better understanding of the role of climate in the design process, the following chapter will be concentrating on the detailed analysis of each of the climatic elements characterising the region.

Plate1-20 : Modern flat type housing. No shutters and no accessible terraces.

Plate1-21 : Large distances between clusters, deserted parking area and sand-covered streets.

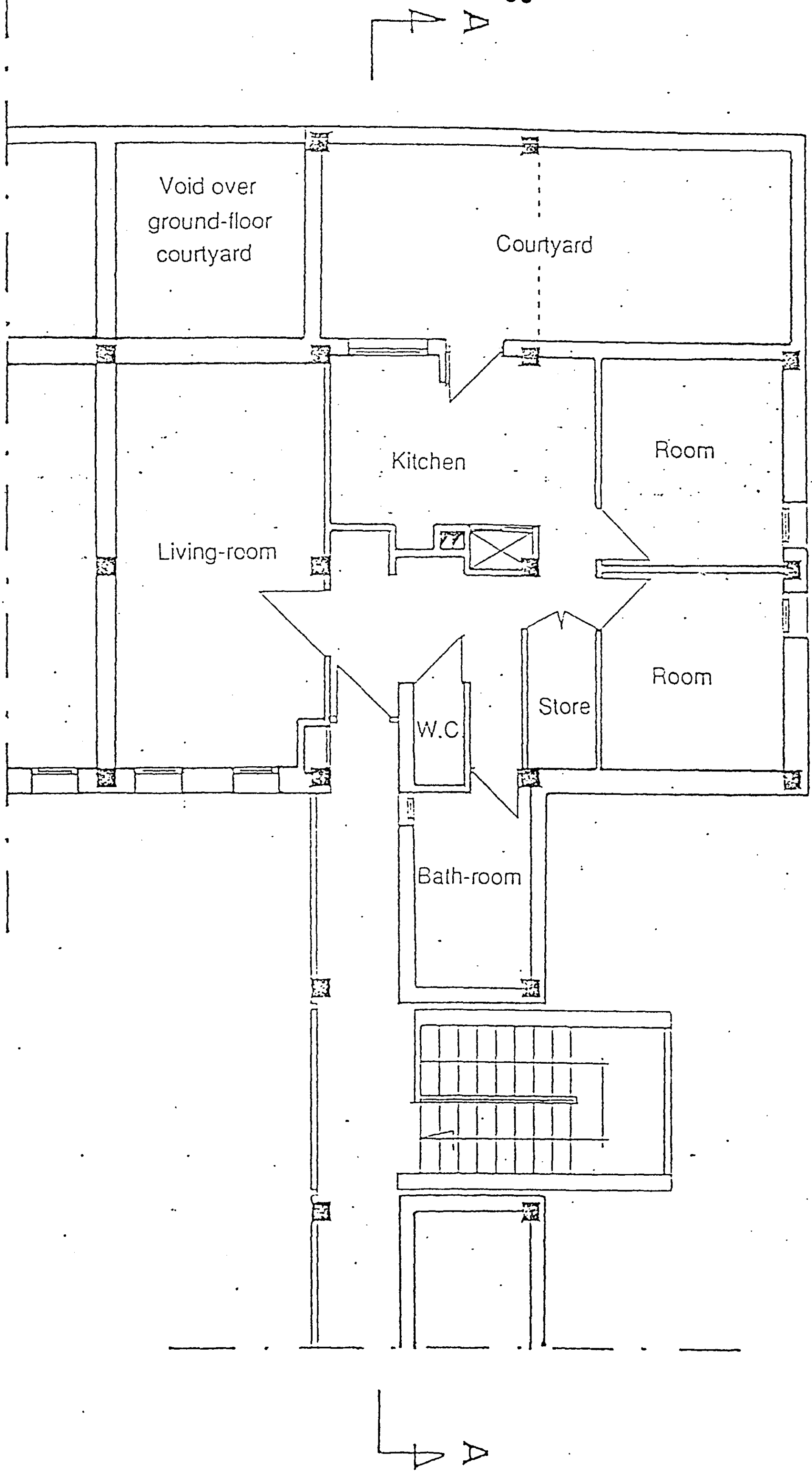


Fig.1-9-a: Plan of modern house, first floor type. Analysed model.

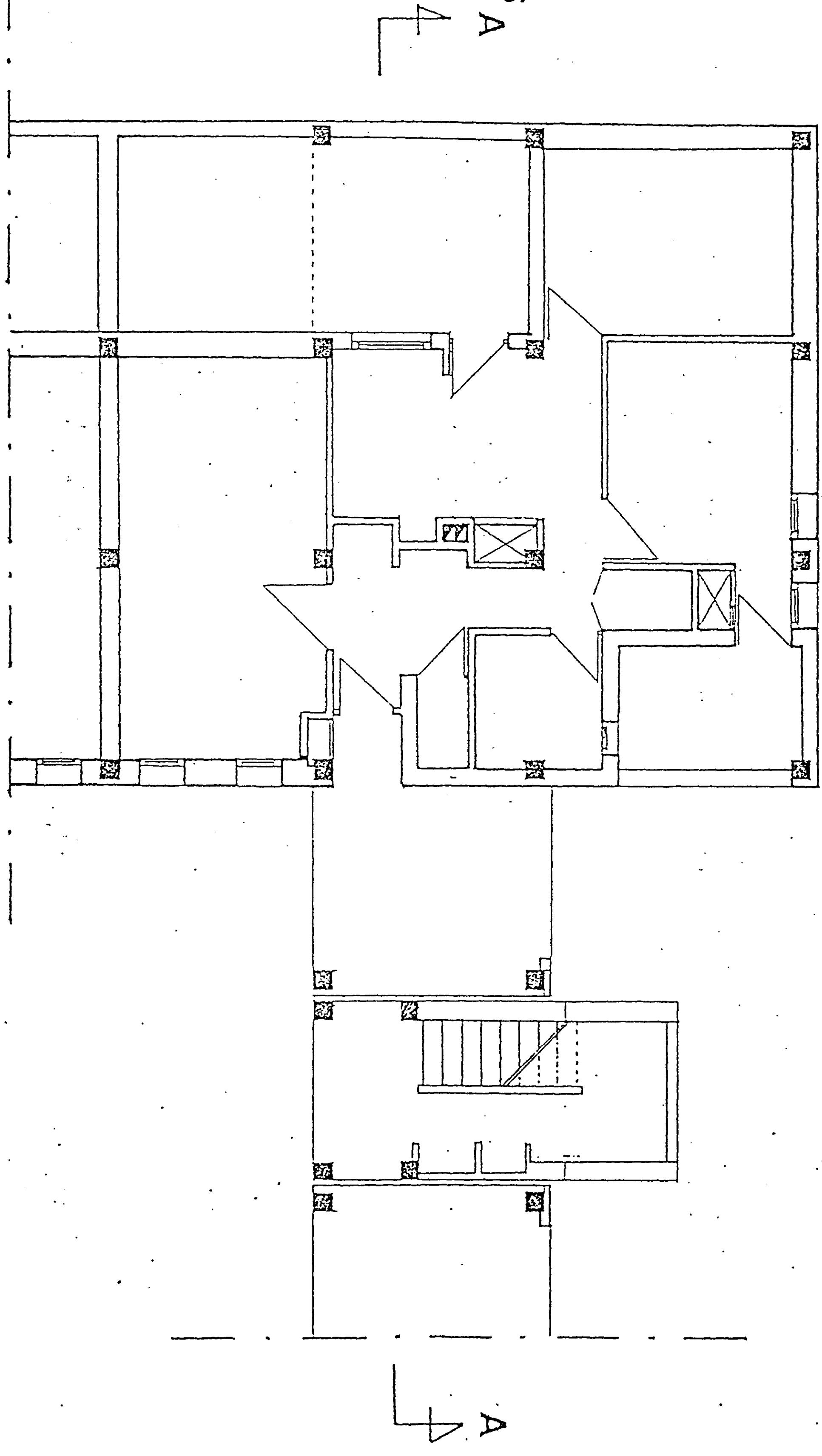


Fig.1-9-b: Plan of modern house, ground floor type.

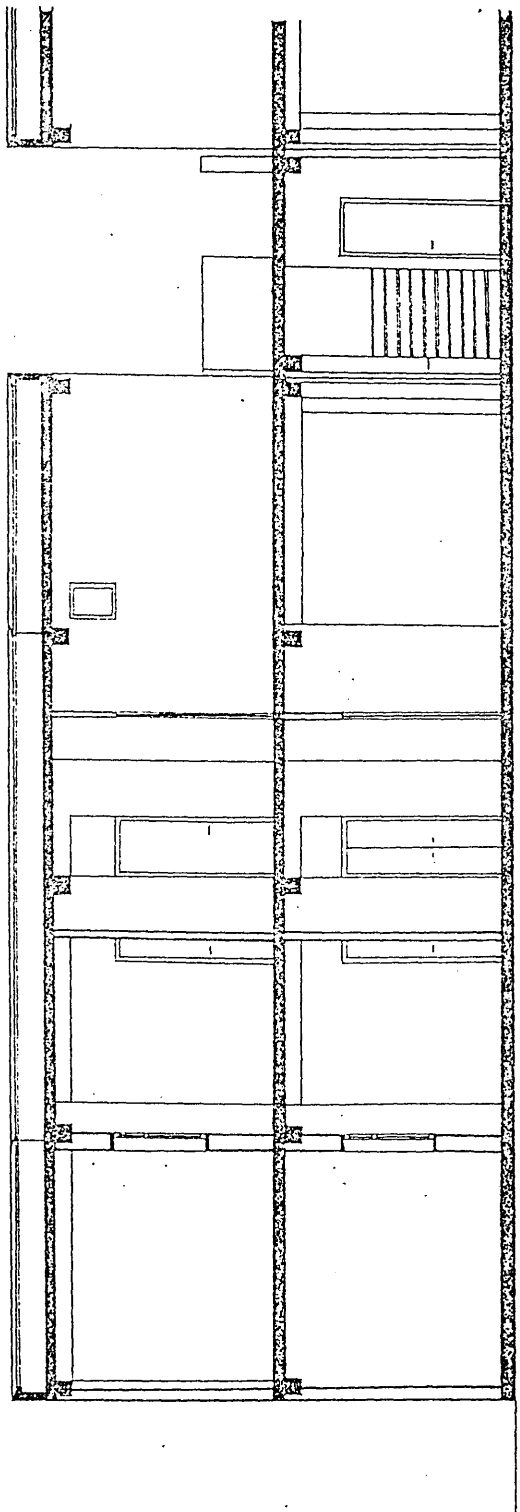


Fig.1-9-c: Section : A-A.

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CHAPTER 2 : THE CLIMATE

2-1 : Introduction :

Algeria has four major climatic zones: firstly, the *littoral* or coast-line including the north versant of the coastal mountains; secondly, the valleys between the coastal mountains and the *Telli Atlas*; thirdly, the high plateaux lying between the *Telli Atlas* and the *Saharan Atlas*; and finally the *Sahara Desert*.

The four corresponding types of climates are respectively: the *Mediterranean marine*, the *Mediterranean mountainous*, the *Mediterranean continental* and lastly the *hot dry* climate.

This chapter deals with the climate of the fourth zone only, i.e., the hot dry, the first three ones having no influence on the subject of this study.
Apart from their meteorological importance, each of the climatic elements will be discussed as regards its influence on human comfort.

2-2 : The hot dry climate :

2-2-1 : History of the climatic observations in the Sahara :

The first regular daily observations started in May 1845 in Biskra, then in Laghouat in August 1864. The weather station of Ghardaia was created in 1883, followed by Ouargla in 1884, Touggourt in 1891 and El Golea in 1892.

The meteorological information collected in the Sahara has been the subject of many general studies on the climate of the region. The first one was that of A. Angot "Etude sur le climat de l'Algerie" in 1881. In 1896, A. Thevenet studied, in his "Essai de climatologie algerienne", the data collected in the northern Sahara until 1894. Later, in 1929, A. Lasserre gave and commented on the means obtained until 1928 in his "Apercu meteorologique des Territoires du sud de l'Algerie". Then came, in October 1943, "Les moyennes meteorologiques du Sahara algerien pour la periode 1925-1939", published by J. Lauriel and J. Dubief. In 1946, P. Seltzer published the calculated means for the period 1913 to 1938 concerning the northern Algerian Sahara in his "Climat de l'Algerie". Finally, in 1959, J. Dubief[1] published "Le climat du Sahara."

2-2-2 : Climatic elements analysis :

In this section, the climatic elements of importance to human comfort and building design in the M'zab valley, will be analysed in detail. Taking Ghardaia (32° 23' N, 03° 49' E, +450m) as an example.

2-2-2-1 : Air temperature :

Winter temperatures can be comfortable during the day but are chilly at night. During summer days, temperatures are consistently high, whereas night temperatures may fall low enough to be just tolerable, (Fig.2-1-a & 2-1-b).

The monthly mean in January is 10.58°C, the daily range being 9.83°C, (Table2-1). The extreme monthly maximum lies between 23.5°C and 25.5°C, and the extreme monthly minimum can reach the class -0.5°C to -2.5°C. The monthly mean in July, is 33.11°C, with a higher daily range of 12.84°C. The extreme monthly maximum and minimum lie between 45.5°C and 47.5°C for the former, and 17.5°C and 19.5°C for the latter. The yearly range of the mean temperature fluctuation is 22.53°C.

During the day the clear, cloudless sky combined with the meagre vegetation cover, results in high day temperatures by allowing an abundance of solar energy to reach the barren surface which becomes intensely heated. But likewise, the absence of clouds allows a rapid loss of heat by radiation to the sky at night, thus rapidly reducing its temperature according to a physical law which says that the higher the temperature of a body, the more rapid is its loss of energy by

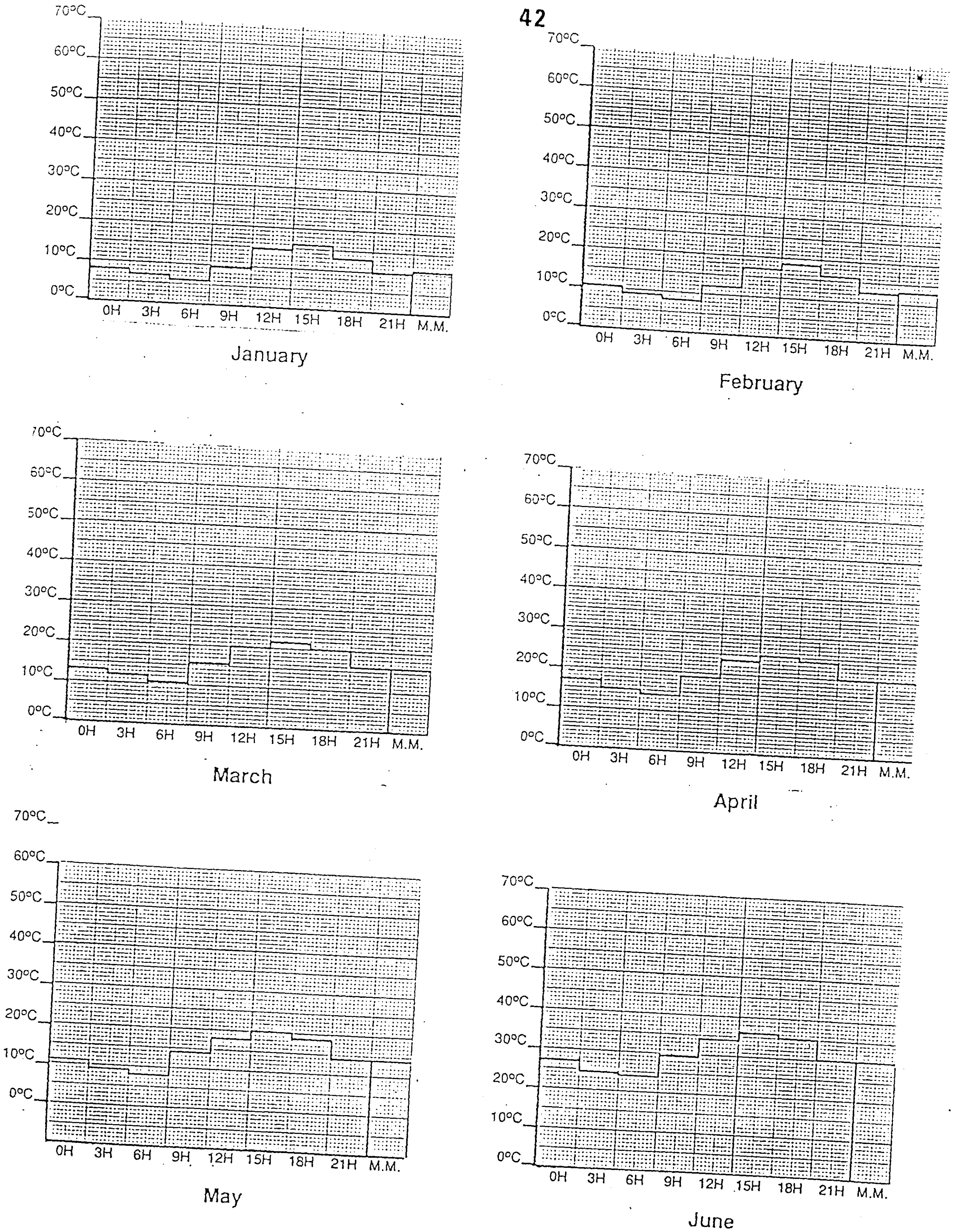
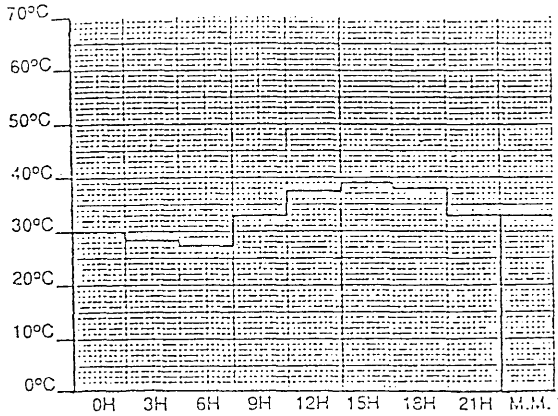
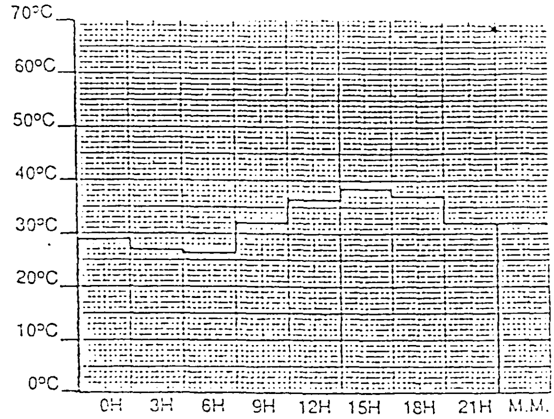


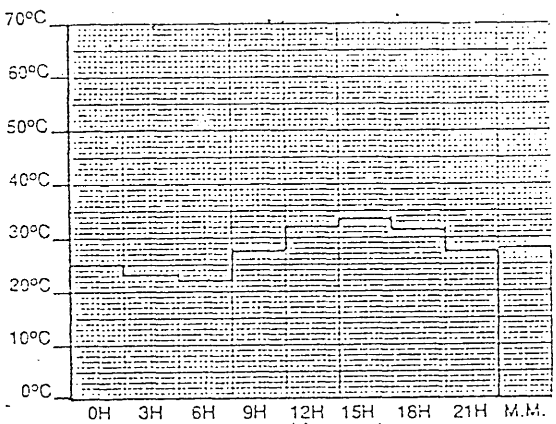
Fig.2-1-a: Mean three hourly & Mean monthly air temperature



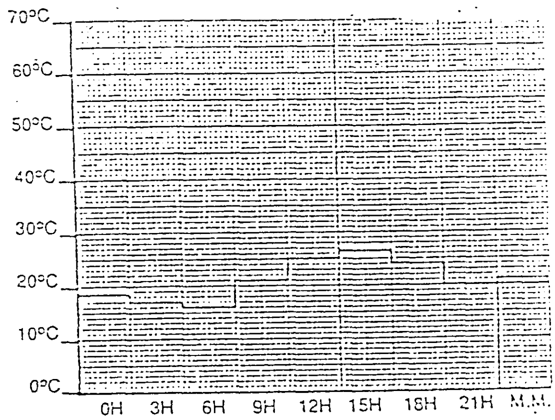
July



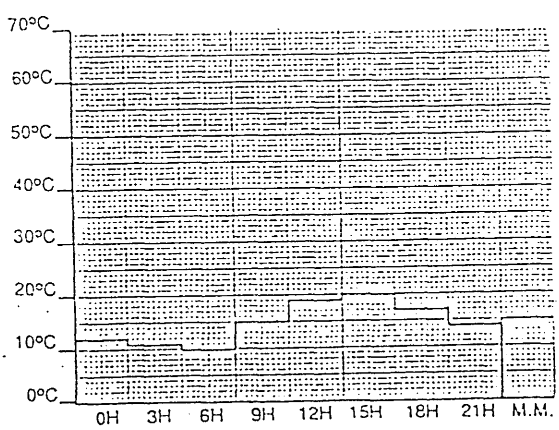
August



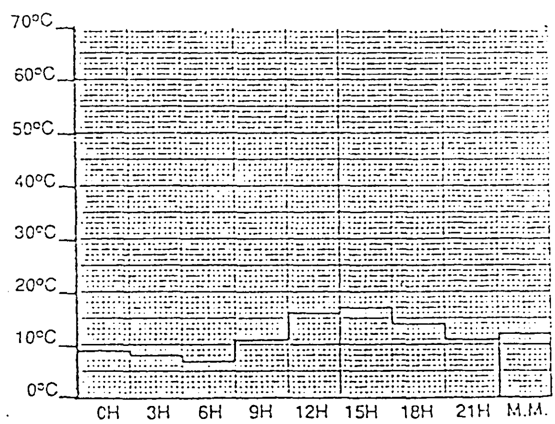
September



October



November



December

Fig.2-1-b: Mean three hourly & Mean monthly air temperature

Table 2-1 : Monthly mean temperatures.

Month	Time of day								Mean
	0H	3H	6H	9H	12H	15H	18H	21H	
January	08.15	07.01	06.22	09.69	14.67	16.05	12.98	09.85	10.58
February	10.51	09.91	08.27	12.15	16.85	18.47	16.16	12.59	13.02
March	13.27	11.58	10.34	15.52	19.74	21.44	19.71	15.71	15.91
April	17.01	15.00	13.80	19.28	23.36	25.28	24.04	19.72	19.69
May	21.19	18.99	18.20	23.68	27.77	29.65	28.50	24.15	24.02
June	26.87	24.50	23.78	29.50	33.99	35.99	35.04	30.08	29.97
July	29.95	27.54	26.41	33.03	37.47	39.25	38.15	33.07	33.11
August	29.23	27.00	25.63	32.09	36.55	38.41	37.02	32.17	32.26
September	25.21	23.29	21.97	27.53	31.87	33.47	31.55	27.43	27.79
October	18.46	16.86	15.75	21.17	25.14	26.48	23.76	20.22	20.98
November	12.26	11.02	10.28	14.83	19.05	20.13	16.86	13.85	14.79
December	09.13	08.09	07.34	11.21	16.08	17.26	13.59	10.68	11.67
Yearly	18.44	16.67	15.67	20.81	25.21	26.82	24.78	20.79	21.15

radiation. This explains why heat is not only acquired quickly, but lost very fast as well. Thus, resulting in large daily ranges.

As far as human comfort is concerned, high daily ranges may lead to additional discomfort since not only are day temperatures too hot, but also night temperatures, although they do not drop very low, may seem cool. As a consequence of which, changes in dress and rapid adaptation to the change in temperature are necessary to maintain comfort. However this is not always possible, especially in the case of the latter. Indeed the daily temperature fluctuation in summer corresponds in magnitude to seasonal differentials. For example, the mean daily range in July of 12.84°C is approximately equal to the variation in the monthly mean temperature between July and April or July and October, (Table2-1).

2-2-2-2 : Precipitation :

Precipitation consists mainly of rain, though very rare and irregular. But snow is by no means unknown to the region even though its rate of occurance is once in every ten years.

The yearly mean calculated over the period 1975-84 is 69.1mm, the driest year being 1983 with 10.7mm and the wettest, with 147mm, was 1980. But since years may pass with absolute drought, means have little meaning in describing the climatic conditions, (Table2-2). The average number of rainy days in a year is 12. It may happen that one day in winter receives the equivalent amount of rain of a whole month, as occasional violent flash storms may suddenly break and last only for a few moments. Examples of such a situation where the daily amount of rain represents that of a month are September, 1975 or May, 1984, (Table2-3).

The consequences of such rains are well known: torrential rains flowing on ravined grounds, which do not have enough time to absorb all the water despite a good permeability, thus causing ground erosion. But over the ten years period of observation, the daily quantity of rain has never exceeded 50mm, (Table2-3).

Table 2-2 : Monthly precipitation over a period of 10 years.

Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Yearly
1975	02.00	11.70	05.00	57.90	06.60	00.00	00.00	00.00	04.00	00.00	01.10	06.90	95.20
1976	24.30	21.80	13.30	00.00	06.20	02.10	00.00	00.00	18.50	02.80	25.30	00.00	114.30
1977	09.40	00.00	09.00	01.80	11.90	00.00	00.00	01.70	00.00	07.80	24.20	00.00	65.80
1978	08.50	11.30	00.00	00.00	03.80	00.00	00.00	04.10	00.00	00.00	01.90	01.00	30.60
1979	07.00	23.90	00.20	00.00	00.80	00.00	00.00	00.00	14.10	07.40	03.30	00.00	56.70
1980	06.20	08.40	00.10	10.90	00.00	00.40	00.00	00.00	00.00	00.80	101.40	18.80	147.00
1981	00.00	02.70	00.70	00.00	13.00	11.60	00.30	02.70	0860	00.00	00.00	00.00	39.60
1982	00.40	04.50	06.50	24.80	01.10	00.00	00.00	00.00	01.20	05.60	14.20	04.20	62.50
1983	00.00	01.20	00.40	00.20	01.70	00.30	00.00	00.10	01.60	00.00	05.20	00.00	10.70
1984	00.00	00.00	04.00	00.00	00.50	00.80	00.30	03.30	02.90	46.60	10.10	00.40	68.90
Mean	05.78	08.55	03.92	09.56	04.56	01.52	00.06	01.19	05.09	07.10	18.67	03.13	69.13

Table 2-3 : Maximum daily precipitation.

Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1975	01.20	06.70	03.00	24.70	04.10	00.00	00.00	00.00	04.00	00.00	01.10	03.30
1976	13.20	11.80	06.70	00.00	05.80	02.10	00.00	00.00	17.20	02.60	12.60	00.00
1977	04.10	00.00	08.30	01.80	06.60	00.00	00.00	01.20	00.00	07.70	17.90	00.00
1978	06.30	11.30	00.00	00.00	02.10	00.00	00.00	02.90	00.00	00.00	01.90	01.00
1979	03.10	18.60	00.20	00.00	00.50	00.00	00.00	00.00	12.00	03.60	02.30	00.00
1980	06.20	05.10	00.10	05.20	00.00	00.40	00.00	00.00	00.00	00.80	46.50	07.20
1981	00.00	02.30	00.40	00.00	13.00	08.90	00.30	02.70	04.00	00.00	00.00	00.00
1982	00.40	02.90	06.50	09.40	00.90	00.00	00.00	00.00	00.70	05.10	08.40	03.90
1983	00.00	01.10	00.40	00.10	01.20	00.30	00.00	00.10	01.40	00.00	02.90	00.00
1984	00.00	00.00	03.90	00.00	00.50	00.70	00.30	03.30	02.30	20.20	08.90	00.20
Max.	13.20	18.60	08.30	24.70	13.00	08.90	00.30	03.30	17.20	20.20	46.50	07.20
Mean	03.45	05.98	02.95	04.12	03.47	01.24	00.06	01.02	04.16	04.00	10.25	01.56

During the summer months, rain may evaporate before reaching the ground, which gives an idea of the dryness of the air, (Fig.2-2).

2-2-2-3 : Humidity :

Although the humidity of the air does not directly affect the load operating on the body, it still plays a very important role in hot climates since it determines the evaporative capacity of the air and hence the cooling efficiency of sweating.

There are many ways of expressing the humidity level of the air: relative humidity, absolute humidity, specific humidity and vapour pressure. A definition of each one of these expressions is given here, as confusion resulting from the use of similar terms may lead to a misunderstanding of their respective roles.

Relative humidity is the ratio of the actual vapour pressure of the air at any temperature, to its saturated vapour pressure at that temperature expressed as a percentage. Absolute humidity is defined as the weight of water vapour per unit volume of the air (g/m^3), whereas the specific humidity or mixing ratio is defined as the weight of the water vapour per unit mass of dry air (g/kg). Finally, the vapour pressure of the air is the part of the whole atmospheric pressure that is due to the water vapour (mb).

Vapour pressure is most convenient when expressing the evaporative capacity of the air, for the latter is determined by the difference between the vapour pressures at the skin and the ambient air.

In the case of Ghardaia, the humidity level is very low, with a yearly mean of 41.32% relative humidity. The lowest relative humidity occurs in July, with a monthly mean of 24.24%. And the most humid month is January, where the monthly mean attains 55.81%, (Fig.2-3-a & 2-3-b). From these histograms it can be seen that the daily fluctuation follows the same pattern for the

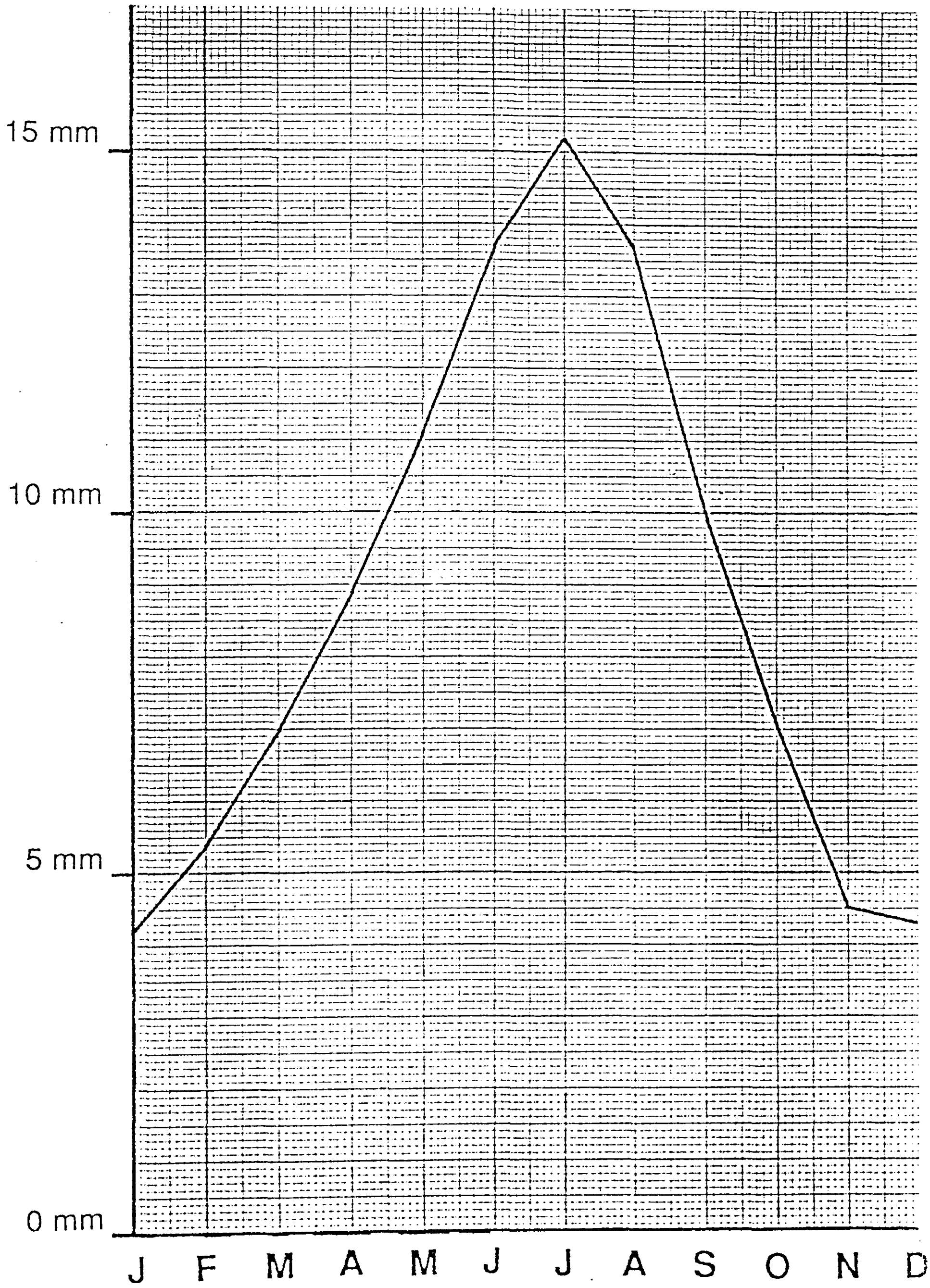


Fig.2-2: Mean monthly evaporation.

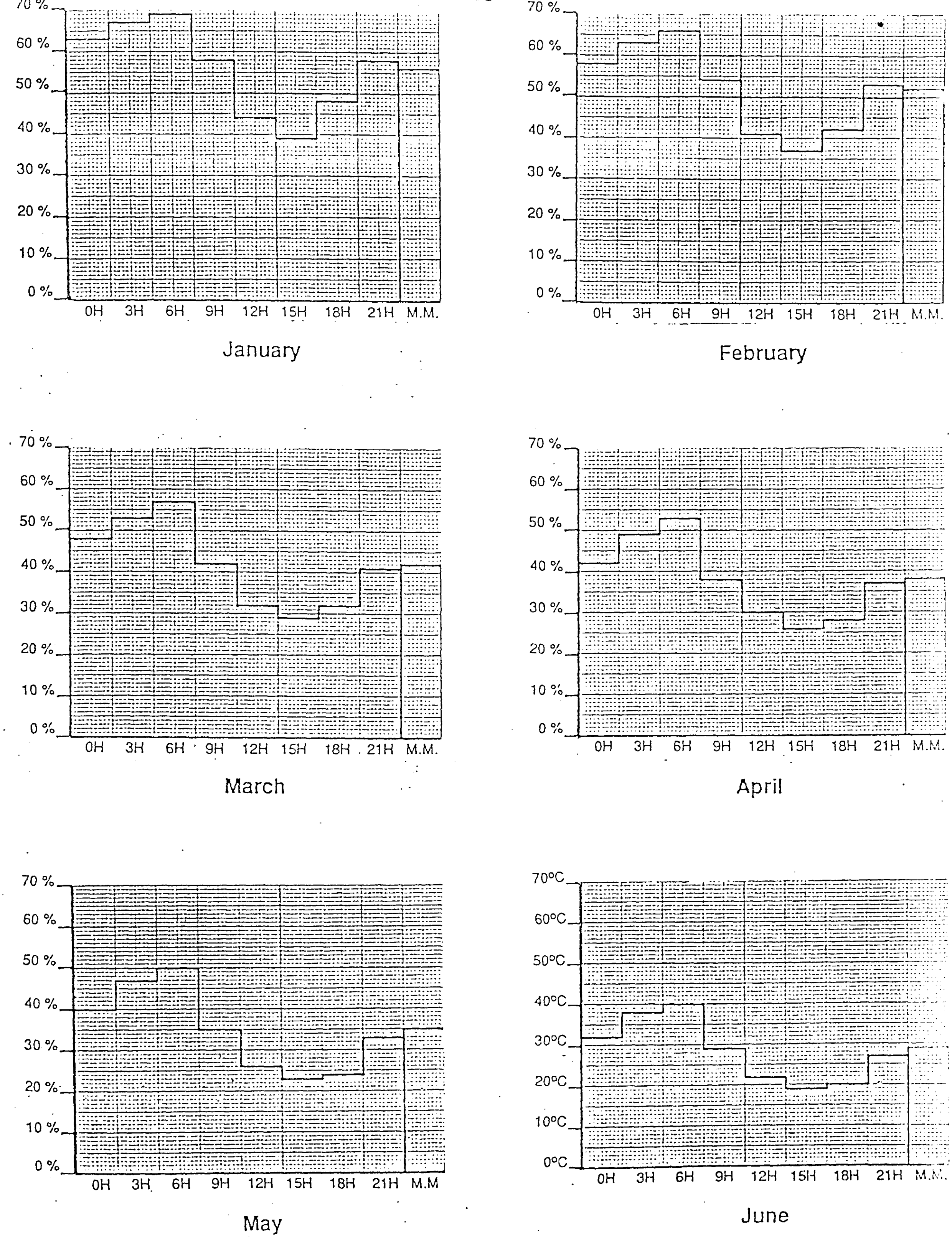


Fig.2-3-a: Mean three hourly & Mean monthly relative humidity

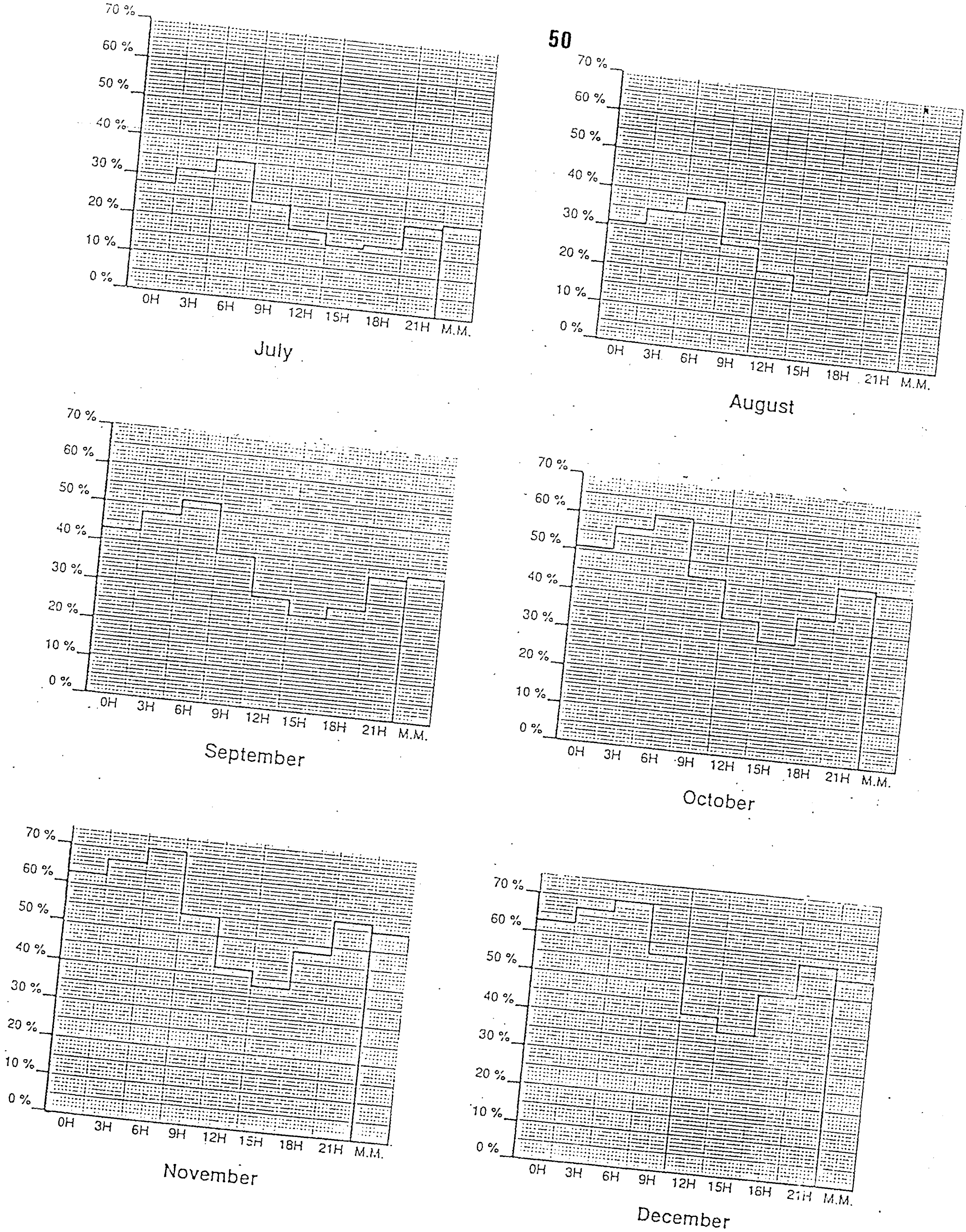


Fig.2-3-b: Mean three hourly & Mean monthly relative humidity twelve months. The maximum humidities occuring at 06.00 hours and the minimums at 15.00 hours.

On the one hand, these low humidities have the advantage of increasing the efficiency of evaporative cooling by allowing the evaporation of great quantities of water and sweat and hence the cooling of the environment and the body. But on the other hand, they may be the cause of excessive dryness of the lips and the mucous membranes of the upper respiratory tract. In addition to that, a hard, horny layer may form with cracks and fissures in the skin, causing irritation and various skin disturbances.

2-2-2-4 : Wind :

Winds result from differential warming of the layers of air and constitute a very unstable parameter in most parts of the world. Their distribution and characteristics, such as direction, speed, gustiness and frequency of calms are all important and are determined by global and local factors. The principal determinants are the seasonal differences in atmospheric pressure between places, the rotation of the earth, the daily variations in heating and cooling of land and sea, and the topography of the given region and its surroundings.

The combination of these factors causes winds to fluctuate markedly with passing weather systems. Their variability is revealed in both their direction, and their speed.

On a micro-climatic scale, the influence of topography may be seen from the movements of air in the immediate vicinity of the ground, as they can be quite different from those high up, (Fig.2-4). The more uneven the ground, the thicker the layer of air that retains contact with the ground and in which changes of velocity and direction are produced. Thus irregular topography, vegetation and buildings become hindrances and diversions. Conversely, a flat, open landscape does not affect air currents very much, and the wind will always blow in various directions across it, frequently accompanied by whirlwinds of sand and dust. The importance of the effect of windborn sand, which depends on the location and the wind speed, may lead people to

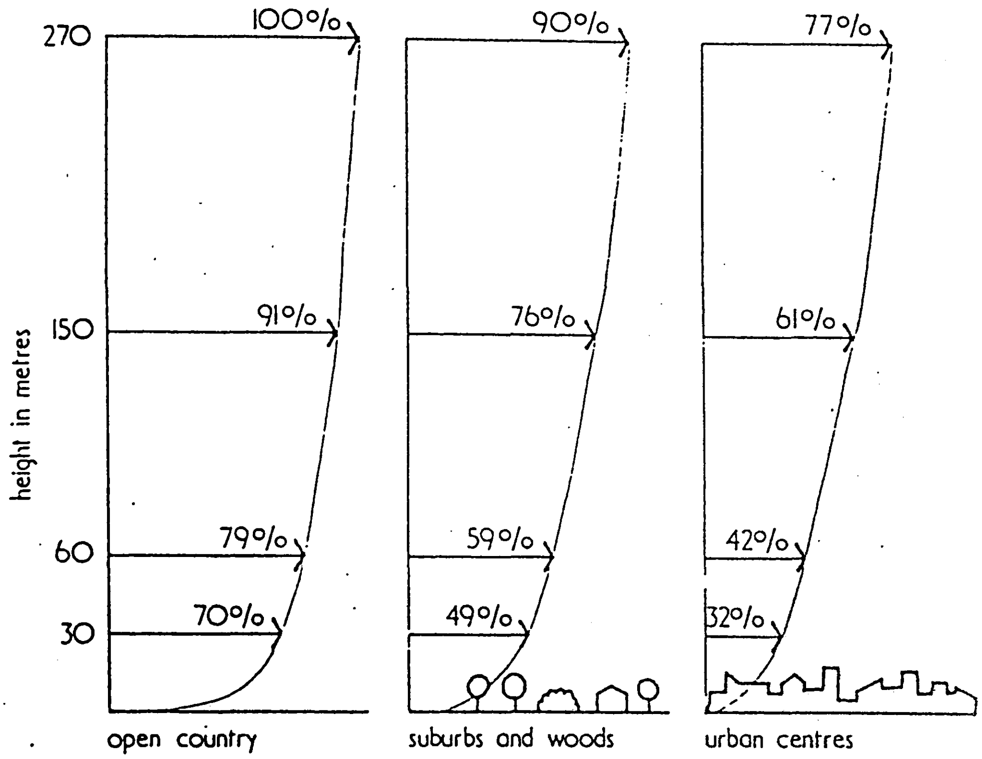


Fig.2-4: When high winds blow, the roughness of the urban area reduces wind speeds at low level.
Source: M. Evans, "Building, Climate and Comfort."

sacrifice the beneficial cooling effect of winds for protection against sand and dust. However, Evans[2] points out that since wind data at most meteorological stations is measured at a point 10m high and in an exposed flat site, a correction factor should be used to reduce this wind speed to the level likely to be found at lower levels and in more sheltered locations.

According to Evans[2], the appropriate correction factor for ground level in flat open country is 0.7; this is reduced to 0.3 in suburban developments and to 0.15 for the centre of built up areas. Hence, once these factors have been applied it will be clear that swept and drifting sand is unlikely to be experienced in suburban areas. This is born out by experience in the centre of towns such as Ghardaia.

As far as wind direction in Ghardaia is concerned, the predominant winds in winter come from north-west, and are cold and humid. Summer winds are strong and warm and blow mainly from north-east, although a very hot wind known as the *sirocco* and blowing from south, is experienced during the hot season, (Fig.2-5 & 2-6).

Regarding the daily distribution of wind speeds on an average day for each of the twelve months, (Fig.2-7-a & 2-7-b) show the same daily variation pattern. Starting from the minimum in the early hours of the morning, the wind speed gradually increases, reaching its maximum around midday. In general, the warm season winds are higher in speed than those in the cold season.

Wind influences the comfort of people through the effect of air movement. Natural ventilation and air movement perform three separate functions which are:

a) The supply of fresh air for health.

b) The cooling of the interior by convection.

c) The cooling of the inhabitants, depending on its temperature, velocity and humidity.

Outdoor wind speeds of up to 2.0m/s can assist in achieving comfort under hot conditions, especially when the humidity is high. But 5.0m/s is the maximum speed that is comfortable. For indoor conditions, Lippsmeier[3] gives the following indicative velocities of air:

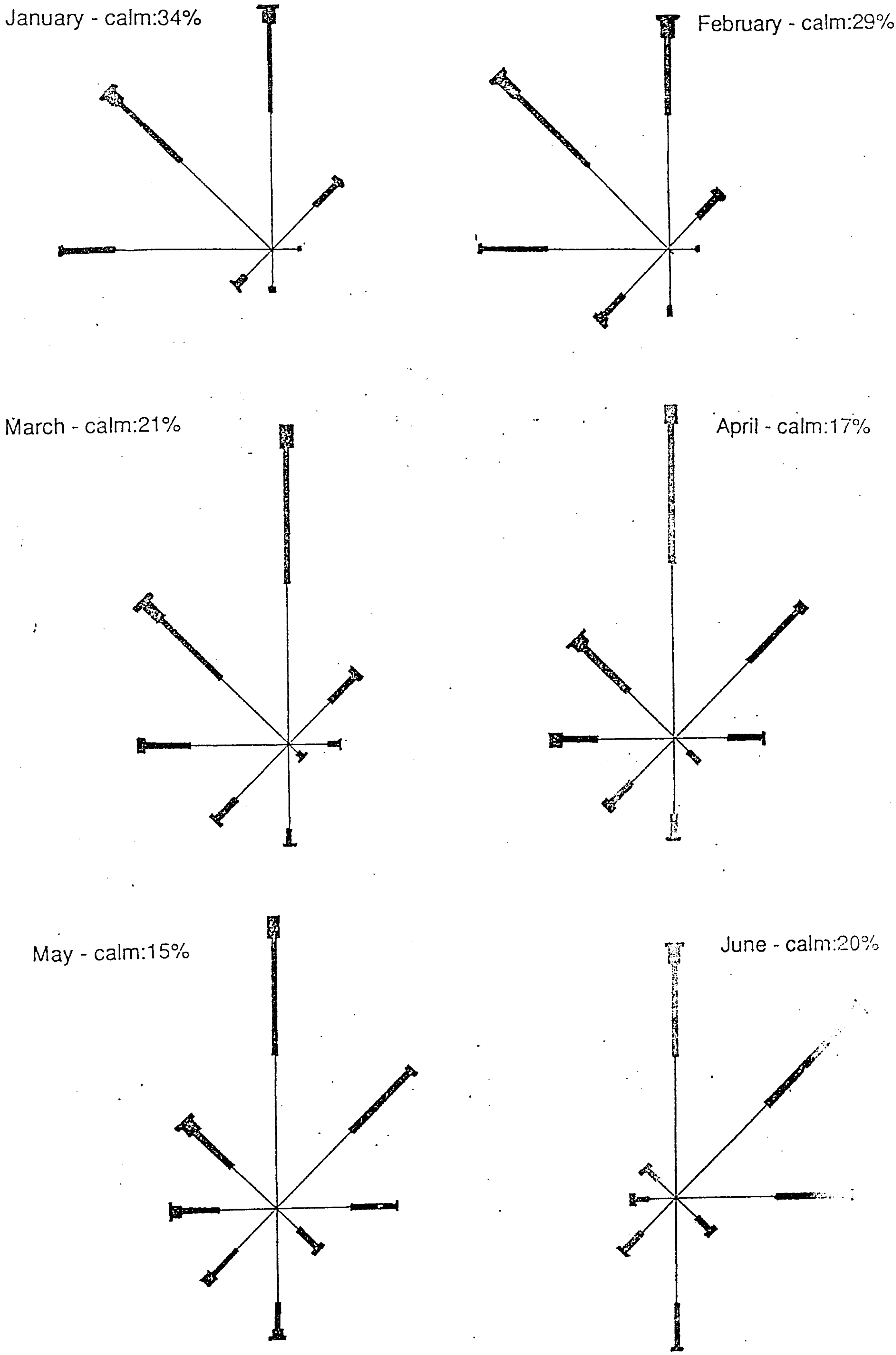
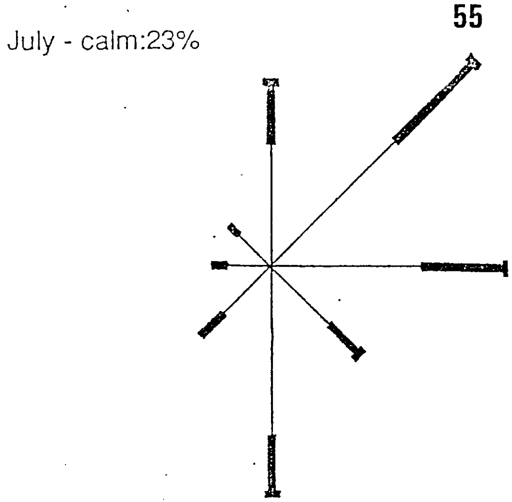
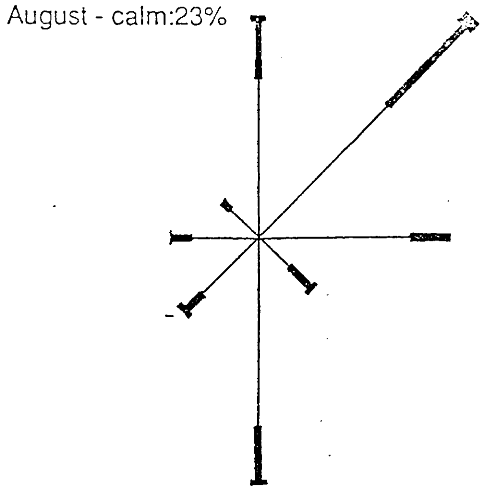
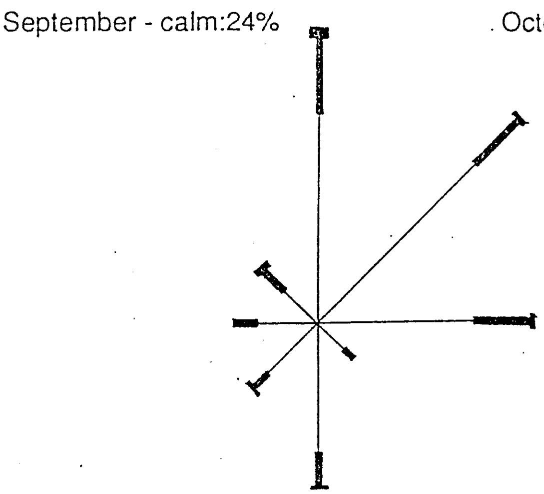
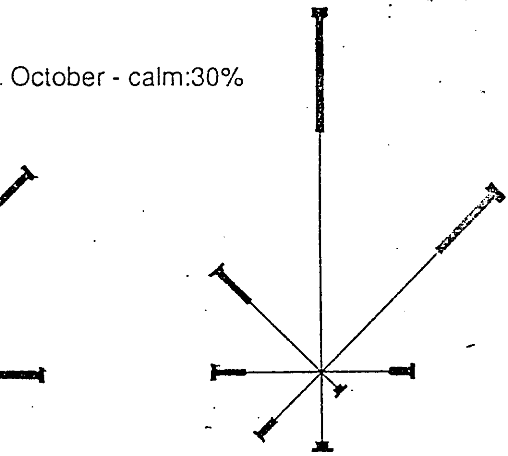


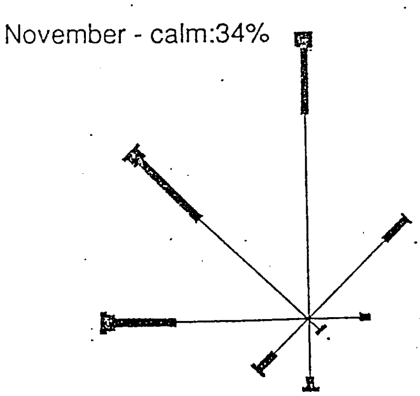
Fig.2-5: Monthly wind direction.

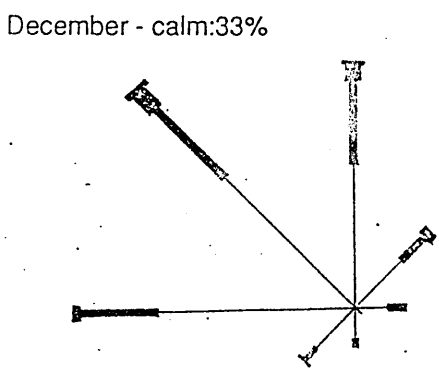












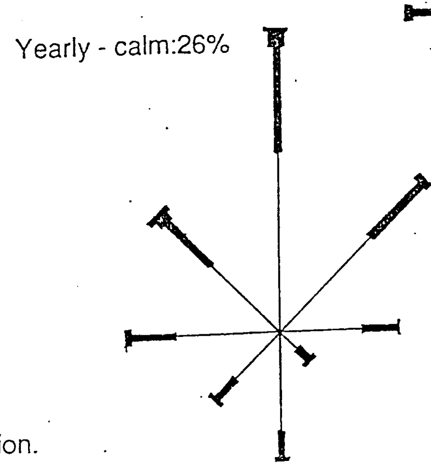
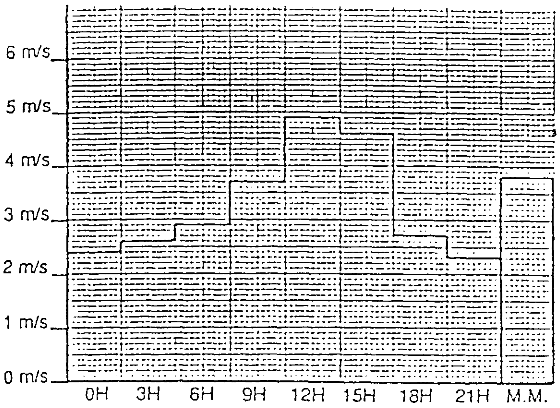
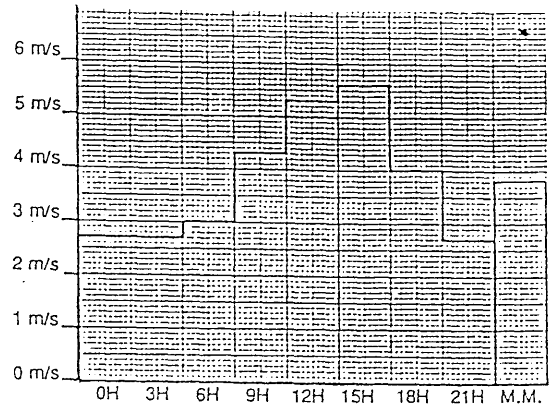


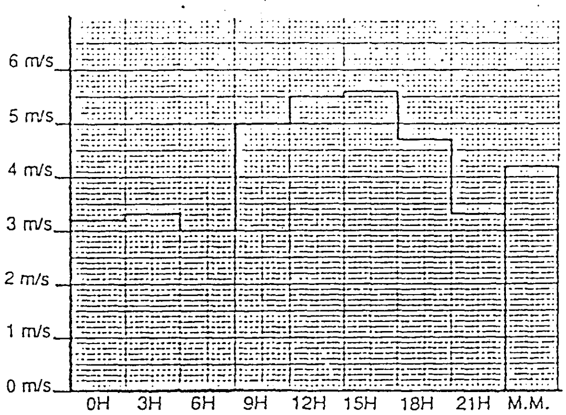
Fig.2-6: Monthly wind direction.



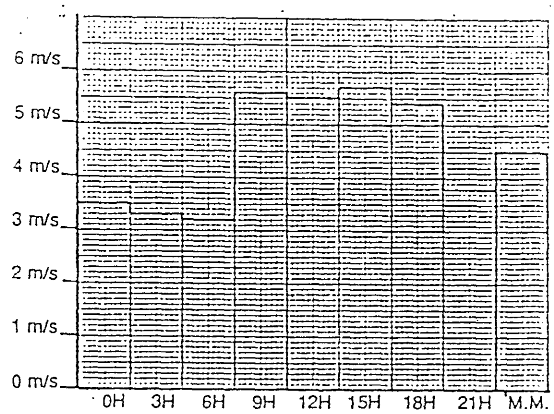
January



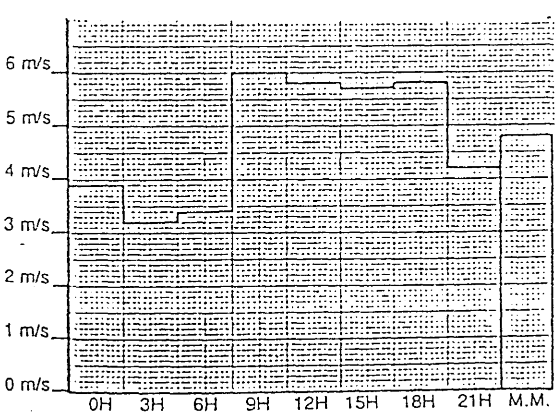
February



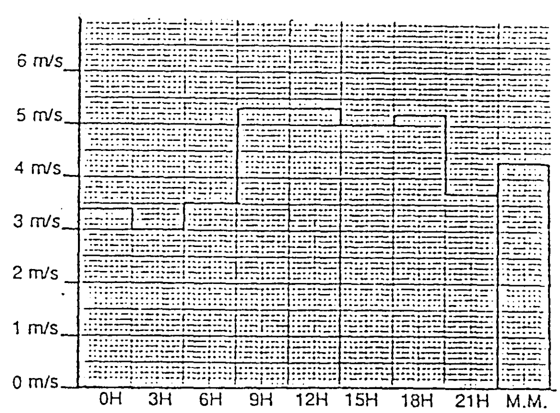
March



April

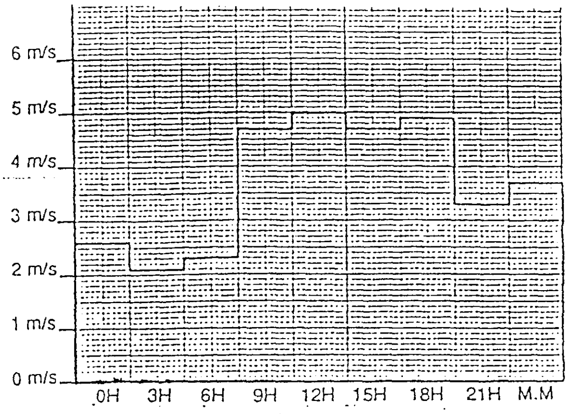


May

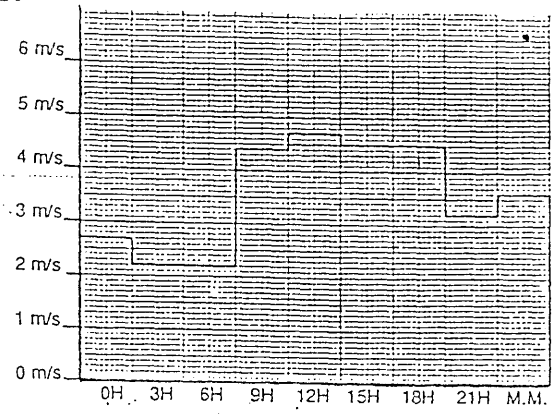


June

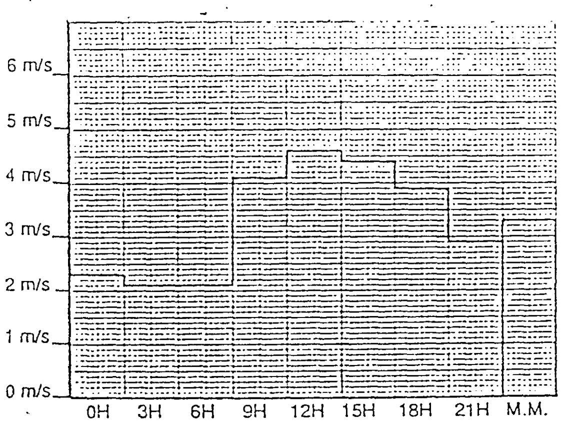
Fig.2-7-a: Mean three hourly & Mean monthly wind speed



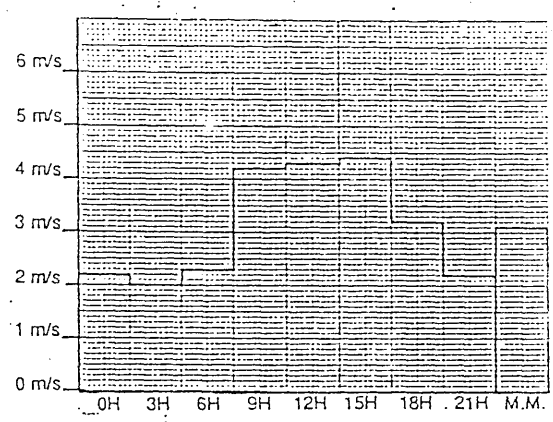
July



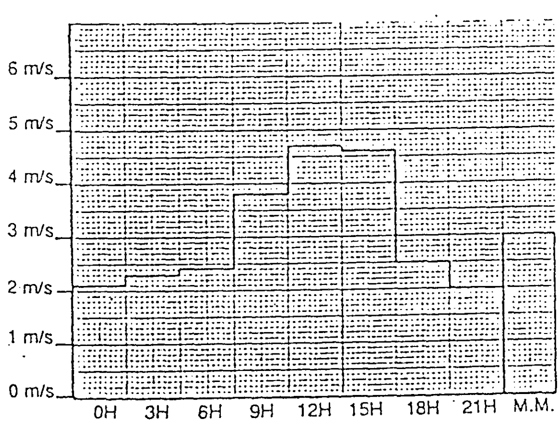
August



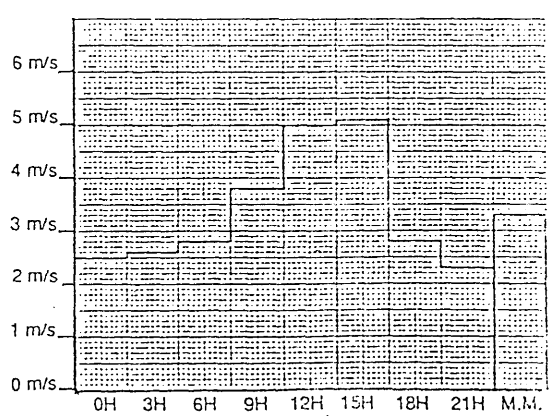
September



October



November



December

Fig.2-7-b: Mean three hourly & Mean monthly wind speed

-- up to 0.25m/s unnoticed.

-- 0.25 to 0.50m/s comfortable, without registration of the air movement.

-- 0.50 to 1.0m/s comfortable, with noticeable movement of air.

-- 1.0 to 1.5m/s light to uncomfortable draught.

-- over 1.5m/s uncomfortable.

Indoor air flow is affected by various factors such as orientation, vegetation and cross ventilation.

2-2-2-5 : Sky condition:

Being the source of almost all the earth's energy, solar radiation is the dominating influence on all climatic phenomena, (Fig.2-8).

The elliptical movement of the earth around the sun and its simultaneous rotation about its polar axis, which is inclined at approximately 23.5°, are responsible for the seasonal changes and the diurnal variations in the incident radiation respectively.

The inclination of the earth's polar axis results in a daily variation in solar declination, the angle between sun to earth and the equator line, (Fig.2-9). This variable changes every day. It is 0° at the vernal and at the autumnal equinoxes, and has a value of approximately +23.5° at the summer solstice and about -23.5° at the winter solstice, (Appendix 2-a).

Another important variable which has to be taken into account for the calculation of solar radiation data is the equation of time. It represents the deviation in clock time with respect to the same position of the sun and to a stationary observer on earth. A detailed explanation with application to the case of Ghardaia is given in (Appendix 2-a).

As far as building design is concerned, the four main channels of radiant heat transfer are, in order of importance[4] :

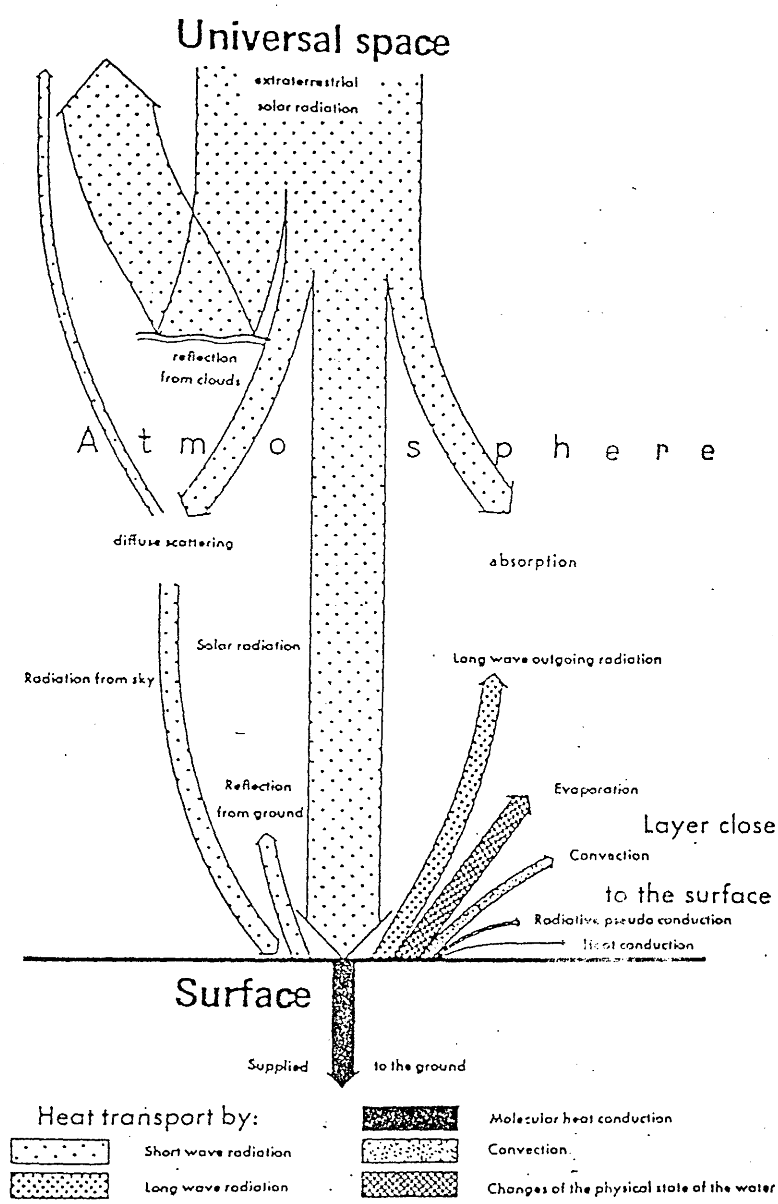


Fig.2-8: Heat exchange at noon for summer day. The width of arrows corresponds to the transferred heat amount.
Source: V. Olgyay, "Design with climate."

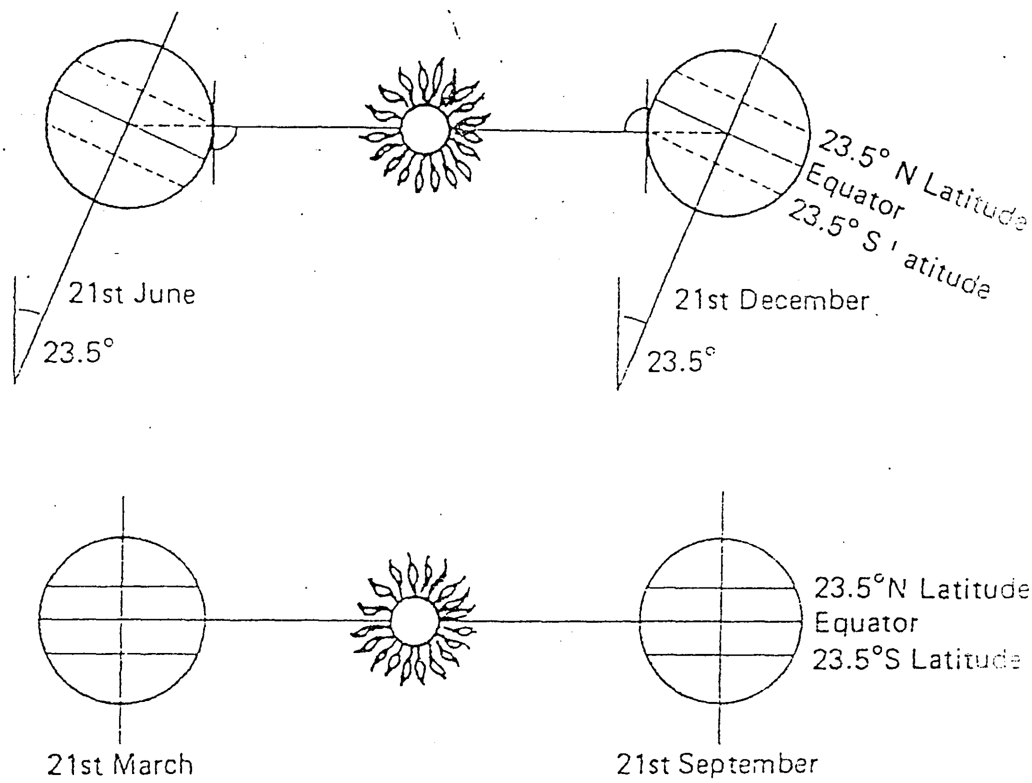


Fig.2-9: A section through the sun, the ecleptic plane and the earth in two directions.
Source: T.A. Markus and E.N. Morris, "Building climate and energy."

-- Direct short-wave radiation from the sun.

-- Diffused short-wave radiation from the sky vault.

-- Reflected short-wave radiation from the surrounding terrain.

-- Long-wave radiation from the heated ground and surrounding objects.

These affect buildings in two ways:

1- By entering through windows and being absorbed by internal surfaces, thus causing a heating effect.

2- Through being absorbed by the outside surfaces of the building creating a heat input.

The effects of solar radiation on a specific location can be essentially determined by: the duration, the intensity and the angle of incidence, the angle between sun to surface and a line normal to the surface, i.e., incident angle = 0° when sun is normal to surface and can be no greater than 90°.

Duration: The daily duration of sunshine is dependent on the season, the latitude of the site and the extent of cloudiness. For the case of Ghardaia, (Fig.2-10) gives the ratio of the average duration of sunshine, measured over a period of 10 years, to the possible/theoretical duration. It can be seen that the longest duration of sunshine occurs in July, with 11.7 hours representing 84.2% of the possible 13.9 hours of sunshine. Also there is no great difference between winter and summer months. The lowest ratio is 72.9% and represents the situation in March where the theoretical and the measured durations of sunshine are respectively 11.8 hours and 8.6 hours.

Intensity: The intensity of solar radiation is determined by the absolute insolation, energy loss in the atmosphere, the angle of incidence on the radiated surface and cloud cover. It should always be remembered that because of atmospheric variations, conditions are never the same, even when they share the same latitude and altitude. Detailed calculated values of solar radiation intensitiesbased on the work of Capderou[5], are given in (Appendix 2-b).

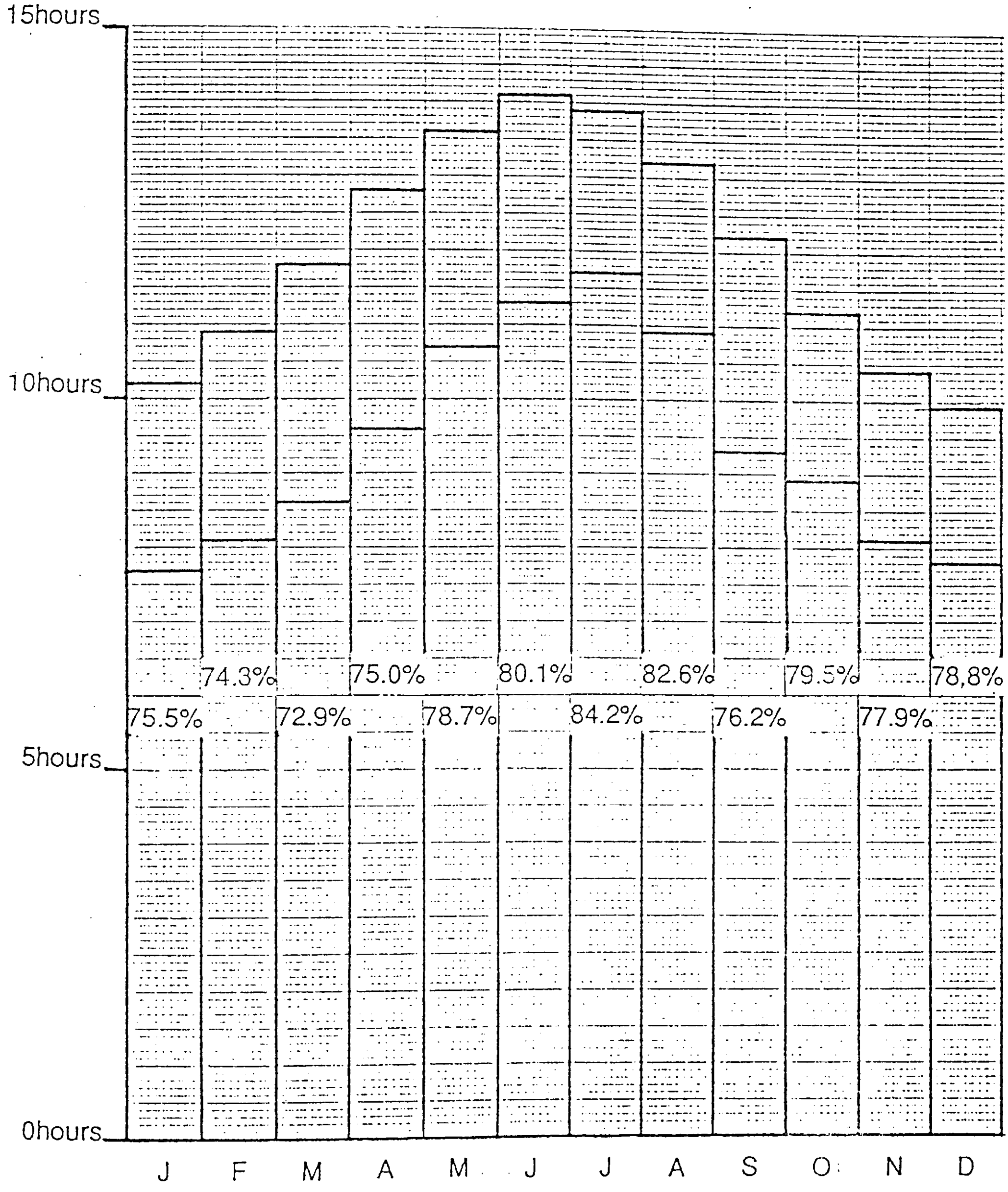


Fig.2-10: Possible (theoretical) & Average (measured over a period of 10years).

Angle of incidence: The angle of incidence is determined by the position of the sun and the observation point on earth relative to each other, and is dependent on: the latitude of the observation point; the season and solar time, itself determined knowing the longitude of the observation point. This leads to the introduction of the solar diagram which gives the exact position of the sun in the sky vault at different times of the day and year, (Fig.2-11). It can be seen from this chart that the sun is virtually vertical in summer, and its lowest altitude is 35°.

It appears from the data represented in this chapter that the climate of the M'zab region of Algeria is dominated by high temperatures and daily ranges, low humidities and high amounts of solar radiation. It can also be noticed from (Fig2-7-a & 2-7-b), that the wind reaches its highest daily speed at mid-day, and its lowest at night, which reduces the effectiveness of night ventilation for cooling the structure. On the other hand, the low humidities infer that evaporative cooling is the most appropriate method of creating comfortable conditions. This is possible by combining the two coinciding factors, viz, humidity and air movement, so that air is admitted into the building after it has been cooled evaporatively. A detailed analysis is presented in the following chapter, which looks at the degree of discomfort caused by the local climate, and ways of correcting it.

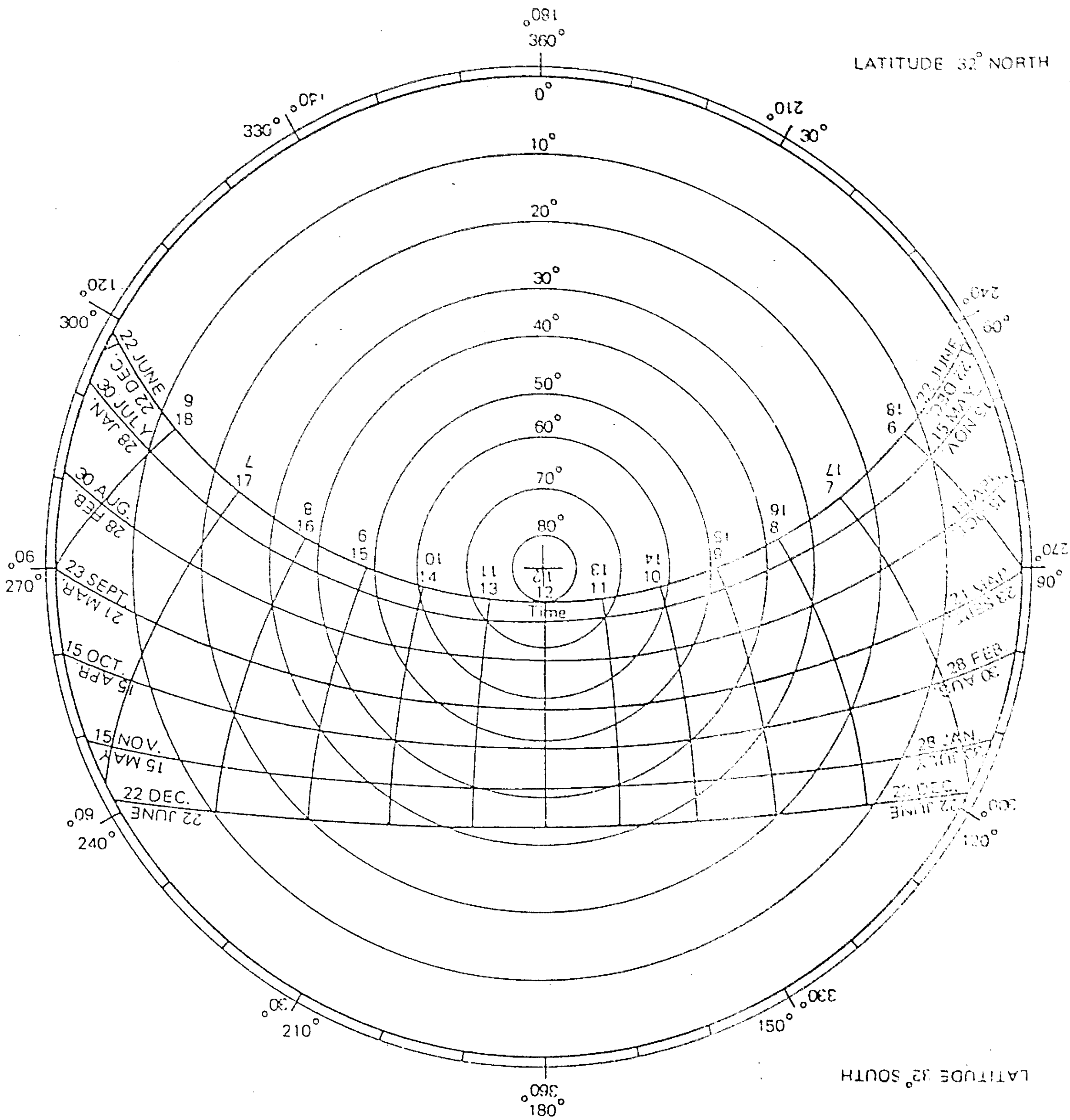


Fig.2-11: Sun path diagram for 32° latitude.

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CHAPTER 3 : COMFORT

3-1 : Introduction :

When designing in relation to climate, the first stage in the process is the preparation of the basic climatic data, as in the previous chapter. This data has then to be analysed by comparing the existing situation with the conditions that are required. In this chapter, therefore, the way in which thermal comfort may be achieved is described. Through the definition of the degree of discomfort caused by the environment, it will be possible to find out how uncomfortable conditions may be improved and which particular method of achieving comfort will be most effective.

3-2 : The biophysical theory of thermal comfort :

With a history of at least 50 years, the biophysical theory of thermal comfort is well represented in the work of Fanger[1] and McIntyre[2].

At its most basic, the theory relates the biophysical heat production of the human body under various physical activities and clothing insulation, to the physical heat exchanges with the environment. It postulates that comfort is attained at the heat balance point, i.e., when heat production is matched exactly by heat loss.

There has also been considerable interest in whether the preferred optimal temperature can be affected by manipulation of non-thermal factors. The most frequently investigated topic has been the idea that the colour of walls and furnishings could influence feelings of warmth, or what is better known as the *hue-heat* hypothesis[3]. But there is almost total agreement that no such effect exists.

Echoing the biophysical theory, it has been agreed that the most important parameters which determine the state of thermal comfort are:

-- Air temperature.

-- Mean radiant temperature.

-- Air humidity.

-- Air velocity.

-- Metabolic rate.

-- Clothing.

These variables may conveniently be divided into two groups termed the *physical* and the *physiological.* The former comprises the environmental factors, namely the air temperature, mean radiant temperature, air humidity and air velocity, while the latter includes the personal characteristics, in this case the metabolic rate and the clothing.

It is not possible to consider the effect of only one of these variables on the desired thermal comfort conditions; the effect of each of them depends also on the other factors through the mechanism of heat exchange between the body and the surroundings.

3-2-1 : Heat exchange processes :

The purpose of the thermoregulatory system of the body is essentially to maintain a constant internal body temperature. Excess heat, either generated in the metabolic process or gained from the environment, has to be dissipated at an adequate rate. Failure to do so will cause the body temperature to rise, giving a sensation of discomfort. Conversely, a person feels the sensation of discomfort from cold when heat is being dissipated at a faster rate than being produced. In the ideal situation, a balance is achieved between the heat gained and that lost according to the equation: $M \pm S = E \pm R \pm C_v \pm C$. (1).

Where:

M : Energy produced by the metabolism, only about 20% is utilised and the surplus 80% must be dissipated as heat.

S : Energy stored in the body.

E : Evaporative heat loss; as latent heat of water is 2400 kJ/kg, water evaporation at a rate of 1.0 kg/h results in a heat loss of $24 \cdot 10^5/3600$ =666 W.

R : Radiative heat exchange, negative in case of loses and positive for gains.

C_v: Convective heat exchange, negative when air is cooler than skin and positive if it is warmer.

C : Conductive heat exchange, negative when the body is in contact with cold surfaces and positive if in contact with warmer bodies.

The satisfaction of this equation means that the body temperature neither tends to increase nor to decrease.

The exchange between the body and its surroundings takes place in four physically different ways, namely: conduction, convection, radiation and evaporation. These physical processes depend on the climate and are influenced in particular by the four climatic factors mentioned above.

The contribution that conduction makes to the heat exchange process depends first and foremost on the nature of the contact between the skin and other materials. According to Hardy[4], the importance of the contact lies in two factors that may affect the resulting sensation, namely the texture of the surfaces and the thermal properties of their materials. The influence of the former can be noted by anyone who touches a cold smooth surface and compares the sensation with that resulting from a contact with a rough surface of the same material at the same temperature. The sensation resulting from the contact with the smooth surface is that it is colder than the rough surface. This is due to the greater area in contact with skin in the former case hence, a greater rate of heat loss. A good example of the role of the latter on the thermal sensation is that of a concrete and a wooden bench, with the same texture and at the same temperature. The sensation felt by a person sitting on concrete is colder than on timber despite the fact that they both have the same temperature. This sensation is due to the difference in the thermal conductivities of the two materials.

The heat exchange between the body and the surrounding air is termed the convective heat transfer, and is dependent mainly upon two factors: firstly, the temperature difference between the body and the air, and secondly, air movement. When air temperature is above that of the skin, heat is received by convection, and vice versa. It is known that upon exposure to strong air currents or winds which occur either naturally or when riding in open conveyances, forced convection is created assuring good evaporation, but also transferring more heat from the hot body. The reason is that the cool air shell which surrounds the body is blown away causing a greater gradient between air and skin temperatures. Shelter from high velocity winds is therefore advisable even though they may feel comfortable at times, due to the higher rate of evaporation induced. Consequently, one pays with body water for being cooled temporarily more than needed.

Radiative heat transfer takes place between the body and surrounding surfaces, the rate of exchange depending on the difference in absolute temperatures raised to the fourth power, i.e., there is a rapid increase in exchange with increasing differentials. Thus exchange by radiation depends on the mean radiant temperature of the environment and the temperature, humidity and movement of the air have no influence on the amount of heat transmitted.

In open areas, the body will be subjected to the heat load from both direct and reflected radiation. When the body is exposed to direct sunlight in summer for example, the skin is generally the coolest object in the environment and sun, sky and surroundings all transfer heat to the body. According to Adolph[5], direct solar radiation may add 170 W to a clothed person.

The body may lose or gain heat by the three processes mentioned above, depending on whether the environment is cooler or warmer than the skin. But generally, at air temperatures above 25°C, the clothed human body cannot get rid of enough heat and the only compensatory solution is the loss of perspiration. Water consumes heat in order to evaporate, and as humans normally lose about one litre of water a day in perspiration, about 2.5 MJ energy, the latent heat of vaporization, is consumed. The cooling efficiency of sweat evaporation depends on the rate and place of the evaporation process. When the latter takes place in the lungs or in the pores of the skin, all the heat is taken from the body. Inversely, the evaporative cooling efficiency is reduced under conditions where part of the heat of vaporization is taken from the ambient air. The extent to which heat is lost by evaporation depends on the clothing, the level of ambient vapour pressure and air movement. The lower the vapour pressure and the more the air movement, the greater the evaporative potential. This is, however, lessened by the clothing which reduces the air movement and increases the humidity over the skin.

The effects of each of the environmental factors on thermal comfort having already been treated in *Chapter 2*, only the personal ones, i.e., metabolic rate and clothing, will be discussed in the following paragraghs.

3-2-2 : The metabolic rate :

The metabolic process produces the necessary energy for growth, work and cell regeneration, through the oxidisation of food. The quantity of food and drink ingested can therefore play a part in affecting the severity of exposure to heat, and it has been suggested that people should refrain from taking food high in proteins and salt during hot weather as a mean of controlling metabolic heat production and reducing water requirements. Muscular activity, blood circulation and respiration take about 20% of the energy produced, the remaining energy is turned into heat.

Although the metabolic rate can be controlled by thermal regulation of respiration, it is mainly dependent on the activity level of the person and size of the body; when the body is submitted to a heavy activity, its metabolic rate rises, producing more energy which is dissipated in the form of heat. As for the size of the body, it influences the amount of heat dissipated through the body area. An estimate of the body surface is given by the Dubois equation:

$$A_{du} = W_b^{0.425} \cdot B_h^{0.725} \cdot 0.2024 \qquad (2)$$

Where: A_{du} : Body *Dubois area* , (m^2).

W_b : Body weight, (kg).

B_h : Body height, (m).

Typical values for adult males and females range from 1.65 to 2.00 m^2 with 1.8 m^2 as an average figure for a single adult.

Some typical examples expressing the metabolic rate per unit surface area of the body under different stages of activity are given in (Table 3-1).

3-2-3 : The clothing :

Second after the regulating system and first, as far as human control is concerned, clothing constitutes a very important mean of achieving thermal comfort. By acting as a barrier just like a building envelope would do at a larger scale, it reduces heat transfer between the body and its environment and allows it to adjust to small fluctuations in the surrounding conditions.

The role of clothing is furthermore increased, since as opposed to occidental society where a semi-nude state is perfectly acceptable, a similar situation cannot be considered in an Islamic society. For better understanding of the impact of clothing on thermal comfort, the way in which it affects the heat and vapour transfer between the body and the environment should be carrefully examined.

The radiative heat transfer between the clothed body and the environment can be expressed as:

$$H_r = A_{eff} * \varepsilon * \sigma ((\theta_{cl} + 273)^4 - (\theta_{mrt} + 273)^4) \qquad (3)$$

Where: H_r : Heat exchange by radiation, (W).

A_{eff} : Effective radiation area of clothed body, (m2).

Values of A_{eff} can be found in (Appendix 3-2-A).

ε : Emissivity, (dimensionless).

σ : Stephan Boltzman constant, $\sigma = 5.78 * 10^{-8}$ W/m^2K^4.

θ_{cl} : Temperature of the outer surface of the clothed body, (°C).

θ_{mrt} : Mean radiant temperature, (°C).

To some extent the heat gain by radiation is influenced by the colour of clothing as well as the texture of its surfaces and the design. White clothes worn in hot environments keep their bearer

Activity	Metabolic Rate H_M/A_N (W/m^2)	Relative Velocity in Still Air (m/s)	Mechanical Efficiency $\eta = W/H_M$
Resting			
Sleeping	30	0	0
Reclining	34	0	0
Seated, quiet	42	0	0
Standing, relaxed	51	0	0
Walking			
On the level km/hr			
3.0	85	0.9	0
4.0	102	1.1	0
4.8	111	1.3	0
5.6	137	1.6	0
6.4	163	1.8	0
8.0	248	2.2	0
Miscellaneous occupations			
Bakery (e.g. cleaning tins, packing boxes)	60-85	0-0.2	0-0.1
Brewery (e.g. filling bottles, loading beer boxes on to belt)	51-102	0-0.2	0-0.2
Carpentry			
Machine sawing	77	0-0.1	0
Sawing by hand	171-205	0.1-0.2	0.1-0.2
Planing by hand	240-274	0.1-0.2	0.1-0.2
Foundary Work			
Fettling (pneumatic hammer)	137	0.1-0.2	0-0.1
Tipping the moulds	171	0.1-0.2	0-0.1
Roughing (i.e. carrying 60 kg)	231	0.1-0.2	0-0.2
Tending the furnaces	291	0.1-0.2	0-0.1
Slag removal	325	0.1-0.2	0-0.1
Garage Work (e.g. replacing tyres, raising cars by jack)	94-128	0.2	0-0.1
Laboratory Work			
Examining slides	60	0	0
General laboratory work	68	0-0.2	0
Setting up apparatus	94	0-0.2	0
Locksmith	94	0.1-0.2	0-0.1
Machine Work			
Light (e.g. electrical industry)	85-103	0-0.2	0-0.1
Machine fitter	120	0-0.9	0-0.1
Heavy (e.g. Paint industry)	171	0-0.2	0-0.1
Manufacture of tins (e.g. filling, labelling and despatch)	85-171	0-0.2	0-0.1
Seated heavy limb movements (e.g. metal worker)	94	0.1-0.4	0-0.2
Shoemaker	85	0-0.1	0-0.1
Shop assistant	85	0.2-0.5	0-0.1
Teacher	68	0	0
Watch repairer	47	0	0

Table3-1: Metabolic rate at different typical activities.
Source: Sodha *et al*, "Passive solar building."

Activity	Metabolic Rate H_M/A_N (W/m^2)	Relative Velocity in Still Air (m/s)	Mechanical Efficiency $\eta = W/H_M$
Vehicle driving			
Car (light traffic)	43	0	0
Car (heavy traffic)	85	0	0
Heavy vehicle (e.g. power truck)	137	0.05	0-0.1
Night flying	51	0	0
Instrument landing	77	0	0
Combat flying	103	0	0
Heavy Work			
Pushing Wheelbarrow (57 kg at 4.5 km/hr)	107	1.4	0.2
Handling 50 kg bags	171	0.5	0.2
Pick and shovel work	171-206	0.5	0.1-0.2
Digging trenches	257	0.5	0.2
Domestic Work			
House cleaning	86-146	0.1-0.3	0-0.1
Cooking	68- 85		0
Washing dishes, standing	68	0-0.2	0
Washing by hand and ironing	85-154	0-0.2	0-0.1
Shaving, washing and dressing	73	0-0.2	0
Domestic Work (cont'd)			
Shopping	68	0.2-1	0
Office Work wpm			
Typing (electrical) 30	38	0.05	0
40	43	0.05	0
Typing (mechanical) 30	47	0.05	0
40	51	0.05	0
Adding machine	51	0	0
Miscellaneous office work (e.g. filling, checking ledgers)	43-51	0-0.1	0
Draughtsman	51	0-0.1	0
Leisure activities			
Gymnastics	128-171	0.5-2	0-0.1
Dancing	103-188	0.2-2	0
Tennis	197	0.5-2	0-0.1
Fencing	292	0.5-2	0
Squash	308	0.5-2	0-0.1
Basketball	325	1-3	0-0.1
Wrestling	372	0.2-0.3	0-0.1

Table3-1: Continued.

cooler than the same clothes in black would do. But a study by Brenckenbridge and Pratt[6], cited by Givoni[7], shows that the difference is very small with other colours such as khaki or green. The texture of clothing affects its reaction to wind velocity, thus affecting the convective heat transfer which can be expressed as:

$$H_c = A_{du} * F_{cl} * h_c (\theta_{cl} - \theta_a) \qquad (4)$$

Where: H_c : Heat dissipated by convection, (W).

A_{du} : Body Dubois area, (m2).

F_{cl} : Ratio of surface area of clothed to nude body.

h_c : Convective heat transfer coefficient, (W/m^2 K).

(Appendix 3-2-B).

θ_{cl} : Temperature of the outer surface of the clothed body, (°C).

θ_a : Ambient air dry-bulb temperature, (°C).

As for the conductive heat transfer from the skin to the outer surface of the clothed body, it can be calculated by the following formula:

$$H_k = A_{du} * (\theta_s - \theta_{cl}) / R_{cl} \qquad (5)$$

Where: H_k : Heat conducted from the body to the ambient, (W).

A_{du} : Body Dubois area, (m^2).

R_{cl} : Heat transfer resistance from skin to outer surface of clothed body, (m^2 K / W).

θ_s : Skin temperature, (°C).

θ_{cl} : Temperature of outer surface of clothed body, (°C).

In addition to the reduction of heat gains, clothing may have the negative effect of impeding heat losses as well, by interfering with the process of sweat evaporation and hence its cooling effect. This does not mean that total evaporation is reduced; in most cases it is in fact increased, but since most of the sweat is absorbed by the clothing, part of the evaporation takes place from the clothing and not from the skin, thus causing a reduction in the cooling effeciency of sweat evaporation.

The thermal resistance provided by clothing depends not only on the resistance of the fabric, but also on the stiffness and fit of the garments. Its unit is the *clo*, which is the thermal insulation required to keep a sedentary person comfortable at 21°C; it is defined quantitatively as an average thermal resistance of $0.155 m^2 K / W$.

Another unit, the tog, equal to a resistance of $0.1 m^2 K / W$, was introduced by Pierce and Rees[8] to measure the thermal insulating value of a fabric or layers of fabric, but has not received such general acceptance as the *clo*. A detailed table of different clothing ensembles insulations can be found in (Appendix 3-2-C).

Bearing in mind that clothing reduces the evaporative cooling potential, one would expect the desert people to be wearing shorts only on account of the very hot environment. But looking at them one would be surprised by the quantity of clothes they wear. In his work about the relation between heat and clothing, Forbes[9] answered this paradox by asking: "Do the desert Arabs with their voluminous and very loose white clothing succeed in reflecting the radiation to a large extent while impeding evaporation only to a small extent? If they do, it means a great saving in sweating and therefore in their water requirements".

Effective ventilation in hot climate clothing is a distinct advantage in keeping people cool. Consequently, the type of clothing usually worn in the M'zab region, and which is common to all the south of Algeria and the Arab world, comes in the form of a long, loose fitting gown. It has open collar and cuffs, with slits on both sides. It is found to aid ventilation appreciably and is usually made of cotton material, which has a very low resistance to the transmission of water vapour, compared to synthetic equivalents, in order to absorb sweat from the skin.

3-3-: Acclimatisation :

Another factor influencing the sensation of thermal comfort and which is being given more and more attention is acclimatisation. A person from a temperate climate who experiences tropical heat for the first time may find it distressing, yet, after several days he finds he can easily cope with the heat. Although part of this improvement may be accounted for by changes in behaviour and learning to live in an appropriate manner, there has also been an important physiological change termed acclimatisation. This is confirmed by the reverse situation where people from the tropics are found to experience some discomfort in temperate climates until few weeks have passed. In general, heating to a temperature of 30°C in winter is uncomfortable to most people, although in summer such a temperature may be comfortable provided the relative humidity is not high or the air movement is pronounced.

The explanation to this is that to a certain extent the human body adapts itself to extreme atmospheric conditions. This adaptation is achieved by changes in internal combustion rates.

Of a similar nature, but requiring more rapid internal adjustment, are local changes of environmental conditions such as met when an individual goes from the hot outside in summer to a conditioned interior. If the inside temperature is in a normal comfort range, yet appreciably colder than outside, an entering occupant may feel cold until readjustments of internal body heat controls are made.

Due to its subjective nature, thermal comfort is not easily quantifiable. However, many attempts have been made in order to define desirable thermal conditions. Consequently, various thermal indices such as, the predicted four hours sweat rate, the resultant temperature and the effective temperature have been proposed as means of assessing thermal comfort. Each of these indices has a major drawback, the effective temperature index for example, takes no accountof the heat exchange by radiation. Nonetheless, it can be cited as a good example in showing the effect of air movement.

More used is the bioclimatic chart proposed by Olgyay[10], for it not only takes into account the role of radiation and other climatic elements, but can give a clear picture of the prevailing situation and the necessary adjustments for improving it.

By plotting the mean monthly temperatures of each month, associated to the mean monthly humidities, on the schematic bioclimatic chart, it is possible to discover what months were comfortable and which were either too cold or too hot, (Fig.3-1). In the case of the latter it is possible to see that an appropriate measure for restoring comfortable conditions is evaporative cooling.

The repetition of the operation on the detailed chart reveals that an amount of moisture in the air between 6 to 8 g/kg of dry air is needed for the evaporative cooling to be effective, (Fig.3-2). As for the winter months, the same chart shows a heating load of 90W for the comfort requirements to be met. But this is not as big a problem as that of the summer. Van Straaten[11] suggests that in order to ensure physiological comfort, buildings must be adapted to summer conditions, as in general winter requirements will be implicitly satisfied by a building in which comfort in ensured for summer.

In chapter five, principles and methods of evaporative cooling will be discussed. A proposed evaporative cooler will be presented, and integrated to a house design.

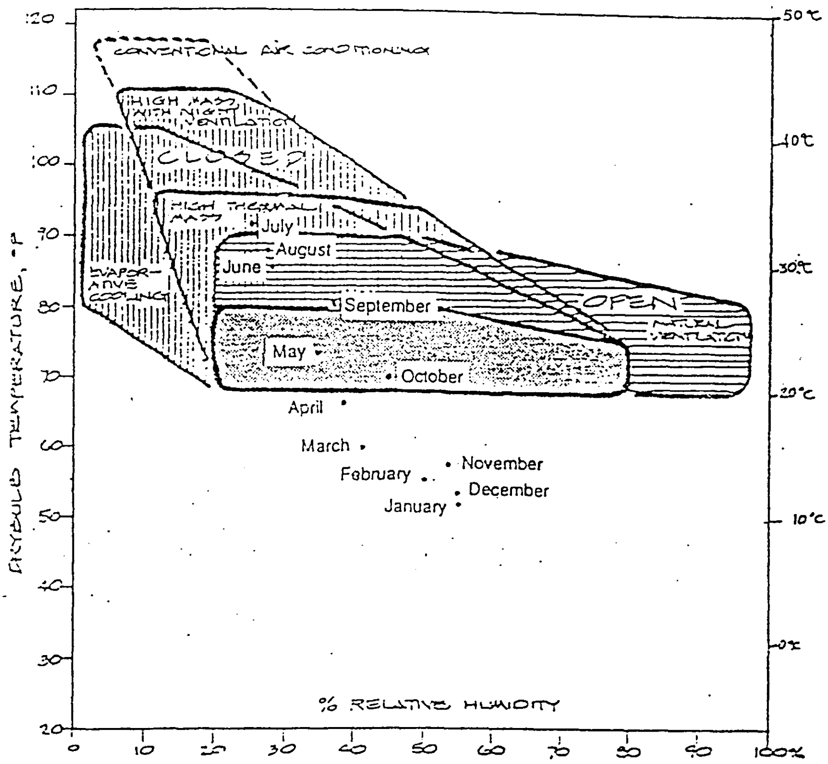

Fig.3-1: Results of the schematic chart.

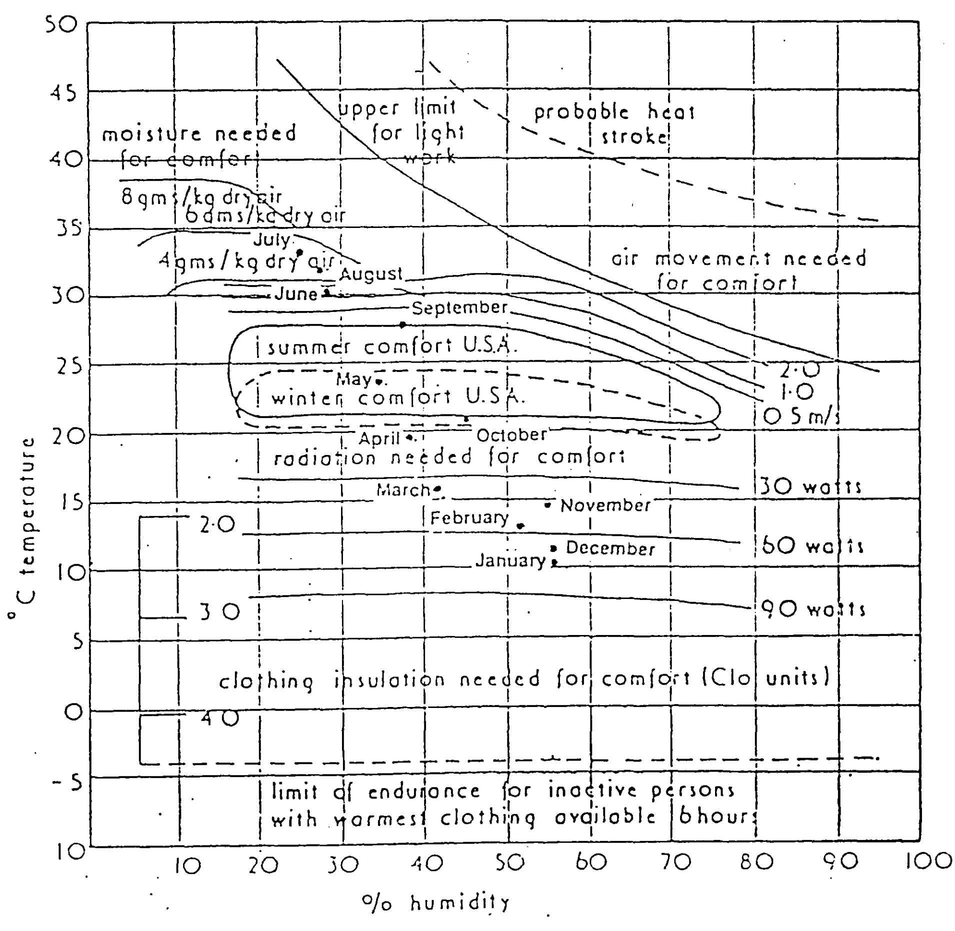

Fig.3-2: Results of the detailed bioclimatic chart.

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CHAPTER 4 : ARCHITECTURAL AND THERMAL ANALYSIS

4-1 : Introduction :

A site experiment was carried out during the summer of 1987, in order to determine which of the traditional and modern houses is better suited to the local climate. It consisted of a series of measurements of environmental parameters, under different combinations of shading and ventilation.

This experiment was conducted in two stages. The first stage consisted of air temperature measurements in three different spaces, of both the traditional and the modern houses. At the second stage of measurements, it was only possible to visit the traditional house. However, more environmental data were obtained. These included air and surface temperatures, air humidity and velocity, and thermal radiation.

A five channels programmable temperature recorder was used to measure the temperatures at fixed intervals and at five different locations, using thermocouple probes. Spot readings of thermal radiations were obtained by use of an *Infratrace*, which also measures surface temperatures. A combined hygrometer/thermometer served for measuring the relative humidity, and, occasionally, the air temperature in order to verify the readings obtained from the 5-channel recorder. The air movement velocities were measured using a hot-wire anemometer.

4-2 : First stage of the experiment :

4-2-1 : Thermal performance of the traditional house :

This part of the experiment is concerned with the thermal performance analysis of the traditional house at Ghardaia, (Fig.4-1).

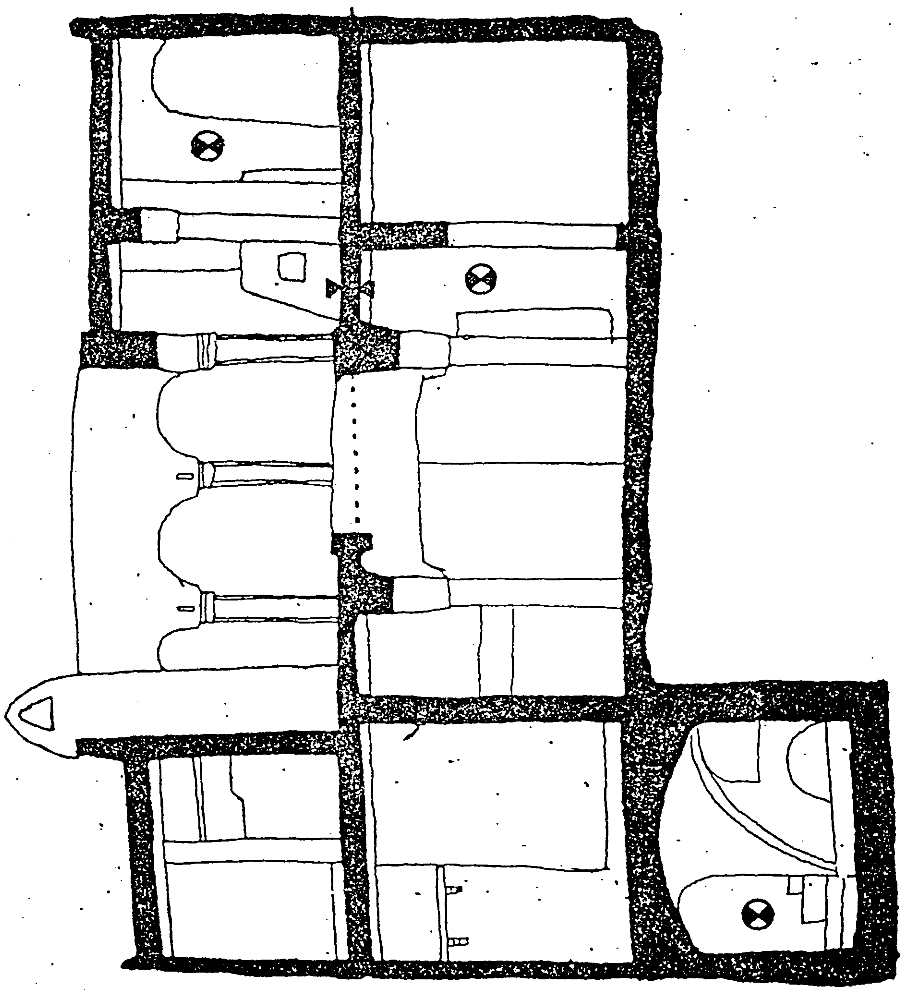

Fig.4-1: Section in the traditional house model, showing position of probes.

From the data recorded during the first stage of temperature measurement, covering the period between July 17th and July 20th 1987 and represented in (Fig.4-2), it can be seen that the basement air temperature followed an almost flat pattern compared to the ground-floor air temperature and outside air temperature.

Whereas the basement air temperature has a daily range of 1K or even less, both ground-floor and outside air temperatures have higher daily ranges of about 4 K for the former and 8 K for the latter. The second observation which can be made is that the basement air temperature is more than 3 K lower than the ground-floor and outside minimums.

The first day situation, where the basement air temperature at 6.00 hours equalled that of the outside air, may have been caused by the use of fans to induce air movement in the basement, used by the owner of the house as a study-room during the hot season. This explanation is based on the fact that the basement air temperature has sharply dropped after the fans were switched off at the beginning of the experiment, since the purpose was to test the passive thermal performance of the traditional house. The temperature then dropped consistently, before becoming stable at about 30°C on the third and fourth days.

Regarding the other air temperatures, it can be noticed primarily that unlike the uniformity of the outside air temperature profile, the ground-floor air temperature fluctuates considerably. These fluctuations are due to the amount of direct radiation received through the light-well and most importantly, to air movement. The pernicious effect of ventilation on the ground-floor temperature can be seen through examination of the temperature profiles between 12.00 and 16.00 hours.

Various combinations have been tested in order to ascertain the effect of ventilation and direct solar radiation on the inside air temperature.

a : Day one of measurements: July 17th : On the first day, both the door and the light-well were closed from 12.00 to 16.00 hours, as a result of which the ground-floor air temperature has dropped from 39.1°C at 12.00 hours to 38.3°C at 16.00 hours before rising

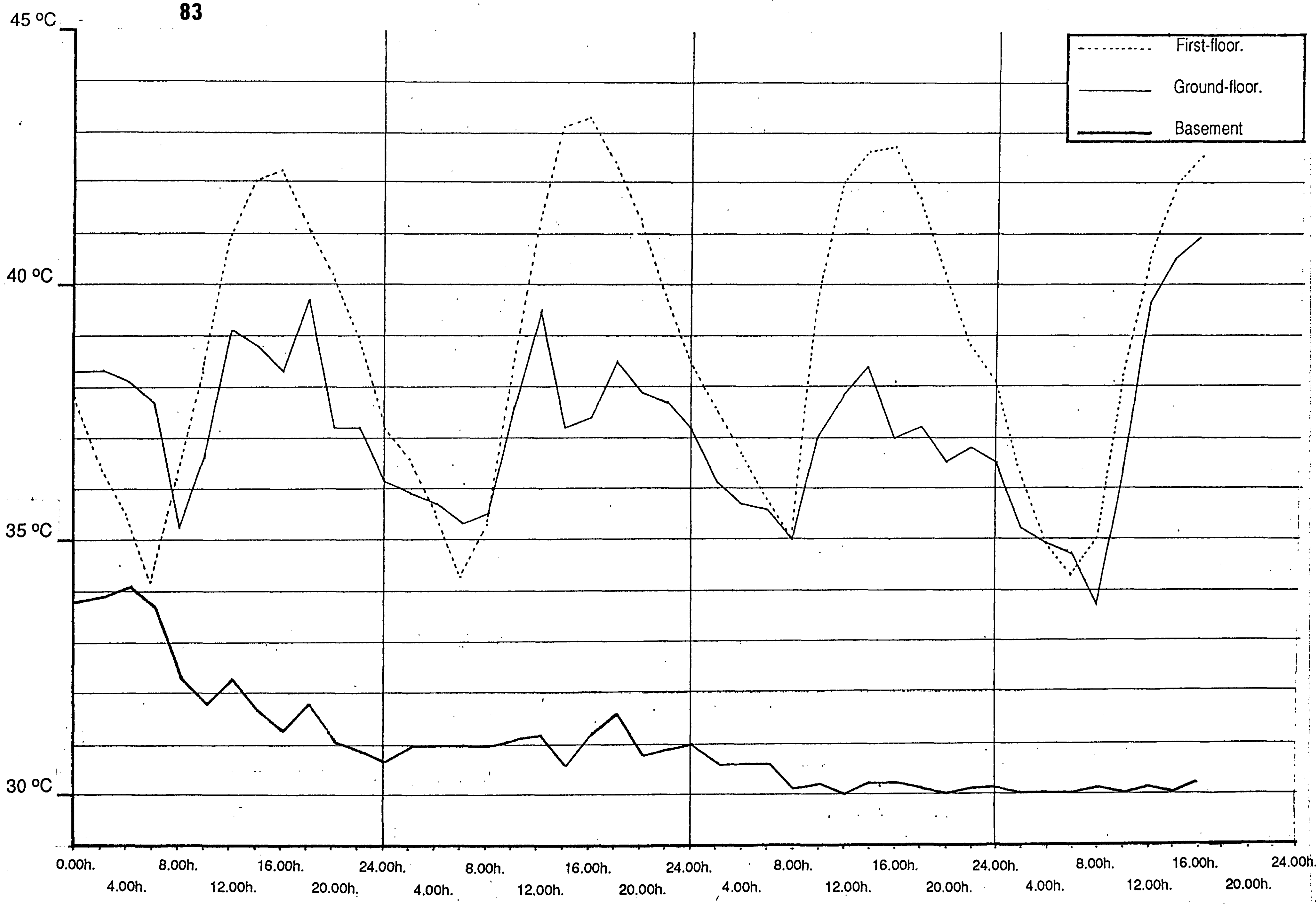

Fig.4-2: Thermal performance of the traditional house - first stage of experiment.

again to reach its maximum of 39.7°C at 18.00 hours. The minimum was equal to 35.2°C and was reached at 08.00 hours. Concerning the outside air temperature, the graph shows a very steady fluctuation having a minimum of 34.2°C and 42.2°C as a maximum at 16.00 hours.
This first test demonstrates that the air temperature of the inside falls when both the door and the light-well or shaft are closed, attesting to direct solar radiation and ventilation as the main sources of heat.

b : Day two of measurements: July 18th : On the second day, in order to determine which of the direct radiation and ventilation had the most significant effect on the rise in inside air temperature, the door was closed from 12.00 to 16.00 hours while the shaft was kept open all the time. This caused a sudden fall in the inside air temperature to 37.2°C at 14.00 hours before it started to rise again, but never reaching the maximum of 39.5°C attained at 12.00 hours. The drop in inside air temperature was equal to 2.3 K over a period of two hours.
This second test showed that the factor which affected the inside air temperature most was ventilation. In other words convection is the most dominant outside to inside heat transfer mode.

c : Day three of measurments: July 19th : On the third day, a similar situation was tested except that the door was closed two hours later and longer than on the previous day, i.e., from 14.00 hours to 20.00 hours. On this occasion the inside air temperature, although it started rising again once the door had been opened, did not rise enough to constitute a second peak. This may be due to the fact that by the time the door was open and cross ventilation of the ground-floor started, the outside air temperature was already too low to have a significant effect on the rise of the inside air temperature.

This can be very useful when trying to determine the time at which cross-ventilation would have lost its heating effect so that it can be used for cooling the structure. In this case therefore, the curve representing the inside air temperature suggests that the time at which doors and windows can be opened to induce cross-ventilation without risk of raising the inside air temperature would be around 20.00 hours.

d : Day four of measurements: July 20th : On the fourth day, both the door and the shaft were kept open from the early morning until 16.00 hours. This was meant to see how bad an effect daytime cross-ventilation would have on the inside air temperature. Figure(4-2) shows the inside air temperature curve tightly following the outside air temperature, rising even after 12.00 hours, when it usually starts dropping, to reach its maximum of 40.9ºC at the same time as the outside air temperature, i.e., 16.00 hours, and being only 1.6 K lower.

4-2-2 : Thermal performance analysis of the modern flat :

The second part of the experiment concerned the thermal performance of the flat type model at Ghardaia, a plan of which is represented in (Fig.4-3), and covered the period between July 22nd and July 24th 1987. However short the period of data recording might have been, some interesting conclusions may be drawn from the results obtained and which are reproduced in (Fig.4-4).

The first noticeable characteristic is that all three curves representing temperature fluctuations in the three different spaces, courtyard, bedroom and living-room, follow the same pattern. This is unlike those in (Fig.4-2) where the basement air temperature was reacting in a different way compared to the ground-floor and outside air temperatures.

As was the case in the traditional house, different combinations of ventilation were tried giving as many different results. In the following paragraph, these combinations and their consequences are examined.

a : Day one of measurements: July 22nd : On the first day, no measures of ventilation regulation were taken. The flat was tested under the usual conditions of its use. The doors and windows were therefore closed at lunchtime after the housework had been done. Consequently, the inside air temperature in both the bedroom and the living-room was found to be tightly following that of the outside air, as can be seen on the first day of (Fig.4-4). And the fact that the air temperature of the bedroom is always higher than that of the living-room may be due to

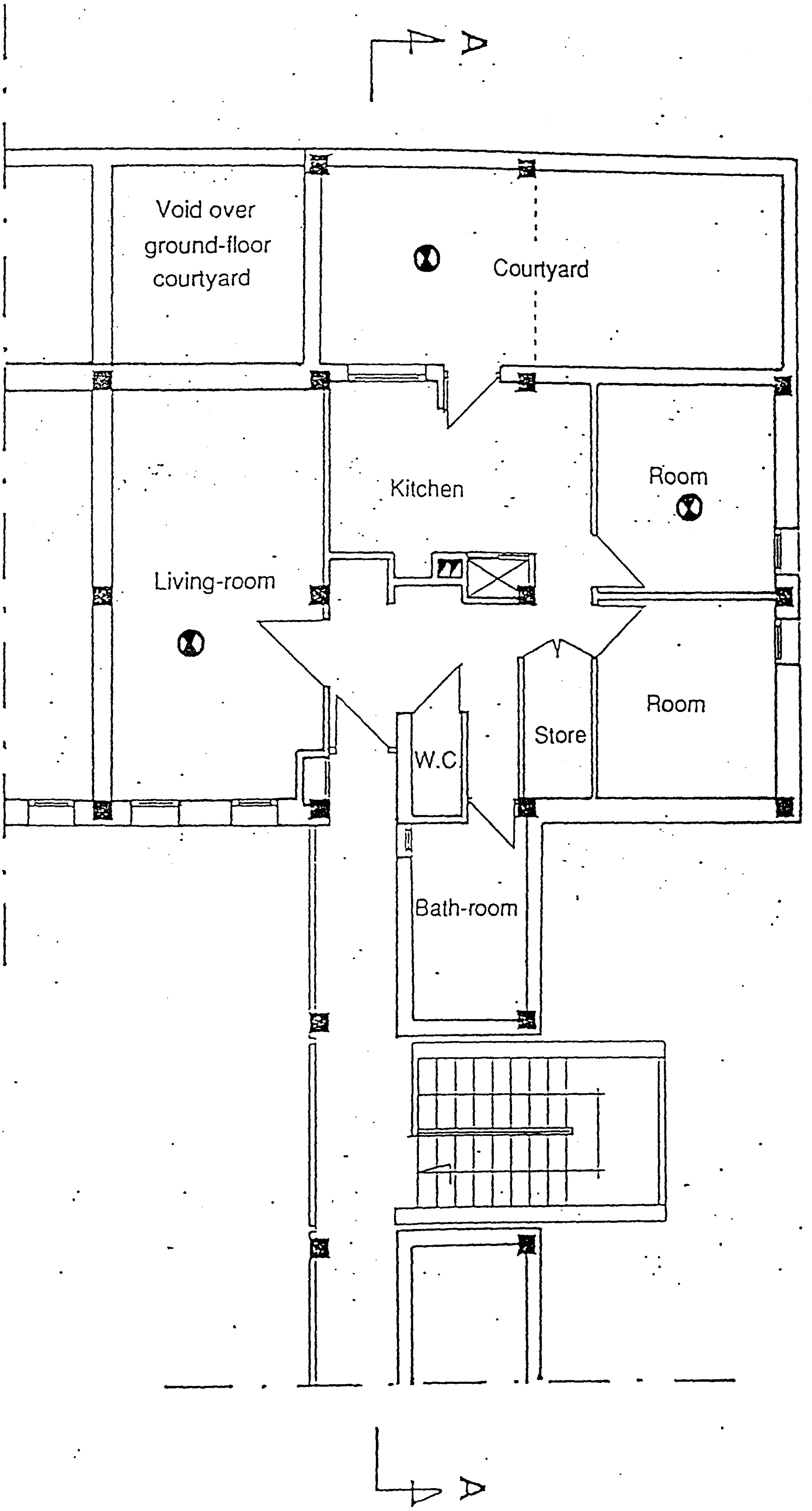

Fig.4-3: Plan of modern house model, showing position of probes. 1/100

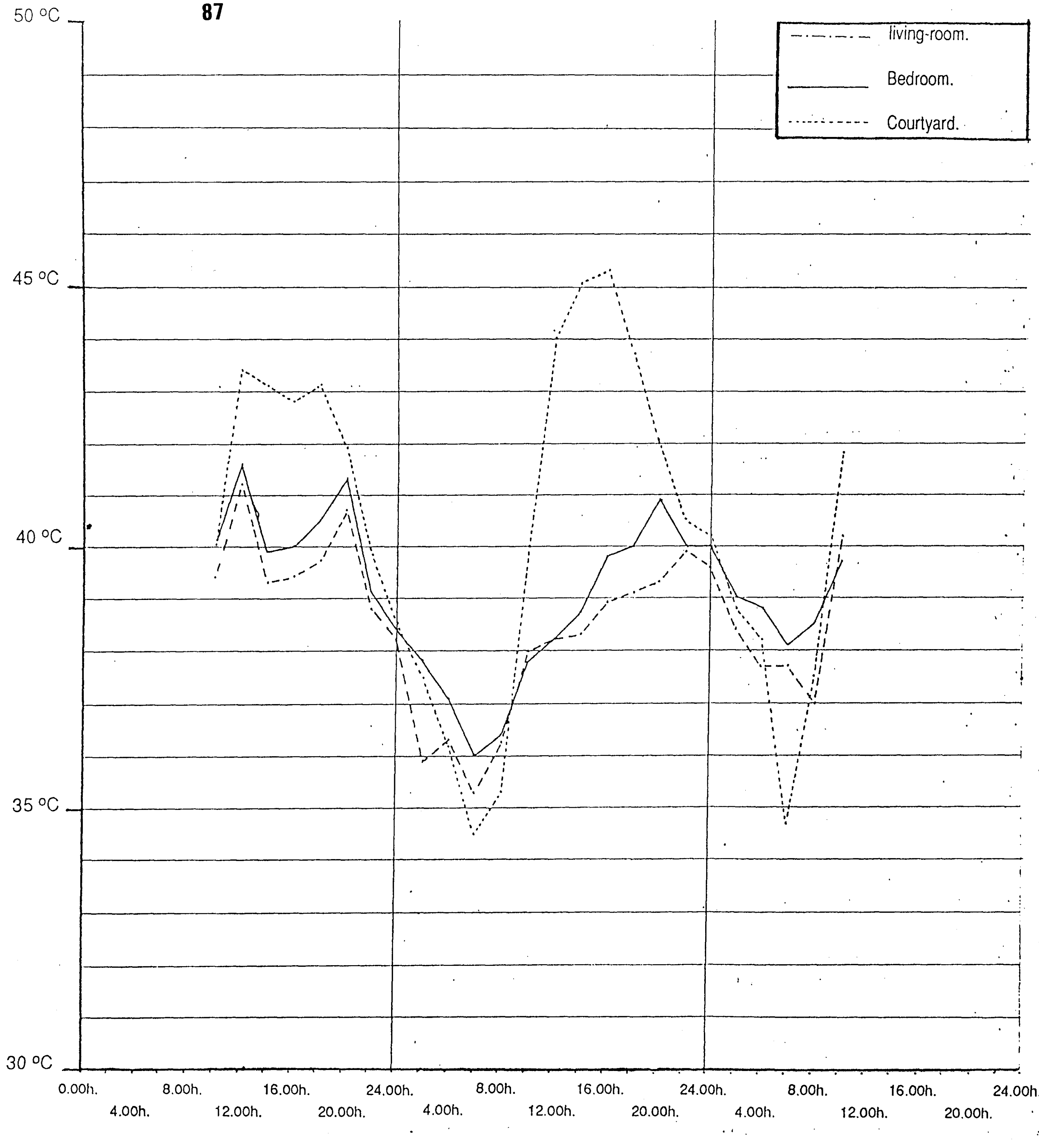

Fig.4-4: Thermal performance of the modern house.

its high surface to volume ratio. These ratios are found to be equual to 0.76 and 0.32 for the bedroom and the living-room respectively. In other words, the bedroom has a ratio more than double that of the living-room but with a floor area less than half that of the living-room. Moreover, on a visit to the building site, where more flats of this type were being constructed, the wall separating the bedroom from the courtyard was discovered to be built of only one layer of hollow concrete blocks unlike the other walls which are constituted from outside to inside of one layer of hollow concrete blocks and one layer of plaster blocks with a cavity between them. The reason for this, according to the foreman, was that they believed that that particular wall did not need to be as thick as the others because it was separating two spaces belonging to the same family, i.e., the courtyard and the room. This infers that more consideration is given to sound comfort than to thermal comfort, with the wall thought of as a partition rather than an external wall protecting the inside atmosphere from the outside environment.

b : Day two of measurements: July 23rd : On the second day, the doors and windows of both the room and the living-room were closed at 08.00 hours after they had been left open overnight. They were opened again from 18.00 to 08.00 hours. Consequently, the graph shows a slow rise in both room and living-room air temperatures towards a maximum of 40.9°C at 20.00 hours for the former and 39.9°C at 22.00 hours for the latter. Being respectively 4.4 K lower with 4 hours delay and 5.4 K lower with 6 hours time lag than the outside air maximum of 45.3°C at 16.00 hours.

Whereas on the first day, the difference between the inside and the outside maximums was equal to 1.8 K with practically no time lag, it was much higher on the second day as explained above. This greater difference was not only due to a rise in the outside temperature, which was in fact 2 K higher than on the first day, but to a lower inside temperature compared to that of the first day as can be seen on (Fig.4-4). The situations tested on the first and second days, illustrate very well the strong influence of the daily window opening schedule.

c : Day three of measurements: July 24th : On the third day, a similar situation to day two was tested except that this time, only the windows were kept open overnight. The doors were closed at about 23.00 hours, this resulted in neither the room nor the living-room air temperatures falling low enough at night. Their minimums were found to be about 2 K higher than recorded on the previous day although the outside air minimums in both cases were the same.

The results of this third test show that openings on two sides of the room give better results than on one side only, for they induce cross-ventilation which proved to be a better way of lowering the temperature of the inside, thus more effective as far as the cooling of the structure is concerned.

4-3 : Second stage of the experiment :

The second series of tests were carried out from September 1st to september 6th, 1987, and concerned the traditional house only.

The measured air temperatures of the basement, ground-floor and the outside, are represented in (Fig.4-5), which shows the same pattern of fluctuation as on the first stage, (Fig.4-2). The inside temperatures have a 4K to 6K daily range, and that of the outside air fluctuates between 32.5°C and 41°C, except for the first day, September 1st, where a minimum and a maximum of 35°C and 44°C respectively were recorded. Yet both minimum and maximum of the ground-floor and outside air temperatures are noticeably lower, by respectively 1K and 2K, than their corresponding temperatures for the month of July, (Fig.4-2).

Most interesting is the air temperature of the basement, which shows an important rise during the month of September, compared to that of July. Whereas (Fig.4-2) shows the basement air temperature nearly stable at about 30°C, (Fig.4-5) shows it fluctuating between 32°C and 33°C, despite the drop in the outside air temperature. Since the basement is completely sunk under the ground, and that no fans or other means of inducing air movement into it were used, this situation can only be explained as an effect of the high heat capacity of the ground. In other words this rise in temperature, during a cooler season, is the response to the outside air

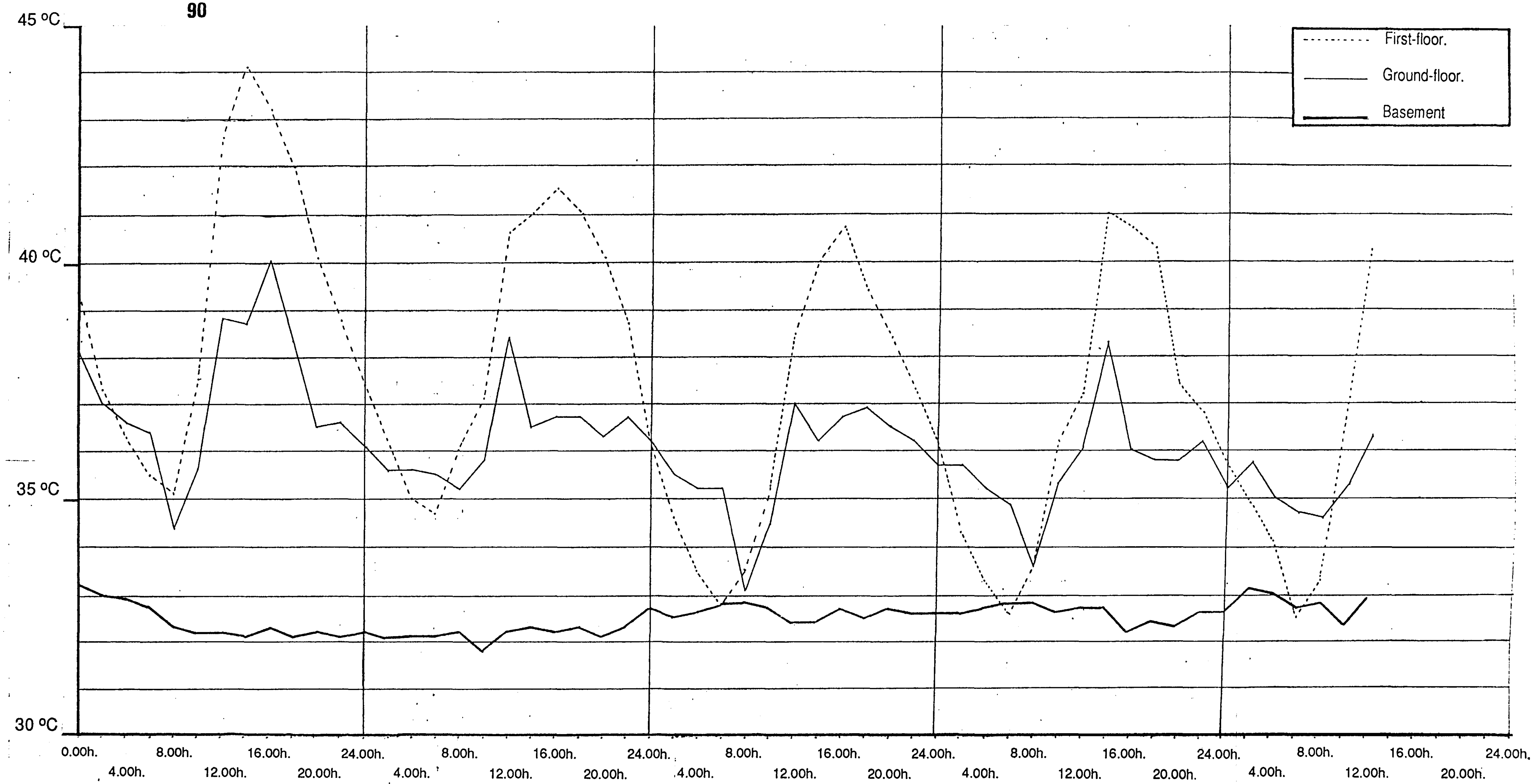

Fig.4-5: Thermal performance of the traditional house - second stage of experiment.

temperature which preceded it by a month or more. The direct implication of this is that the traditional layout would be more adapted to the seasonal changes. The heat accumulated during the hot months is delayed until the winter and vice-versa. This phase-lag, helps the traditional house to be within the comfort range in both seasons.

The temperatures of the inner and outer surfaces of the part of the central space roof situated under the first-floor gallery, were also recorded, (Fig.4-6). And spot readings of the surface temperatures of its sun-lit part, and of the ceiling of the basement were taken at 4 hours interval, (Table 4-1). Figure(4-6) shows an almost flat profile for the inside surface temperature of the shaded roof, under the gallery, compared to its outside surface temperature, attesting to the good damping capacity of the traditional roof construction. The former fluctuates in a 1K range, between 31°C and 32°C, reaching its maximum at 02hours and its minimum at 10hours. The 08hours time-lag from maximum to minimum, and that of 16hours from minimum to maximum imply that the inside surface of the roof cools down quicker than it heats up. The fluctuation of the latter is more pronounced, with a range of 4K to 5K. The maximum and minimum occur at 16hours and 08hours respectively. Consequently, the outside surface is found to heat up quicker than it cools down. The comparison between the two curves gives a time-lag of 10hours between outside and inside maximum surface temperatures.

The spot measurements taken on the unshaded part of the roof in the central space, also show little resemblance between outside and inside temperature fluctuations. The former reached its maximum of 59°C at 12.00hours and a minimum of 32°C at 04.00hours, i.e., a daily range of 27K. The maximum and minimum of the latter occured at 20.00hours and 6.00hours, and were 39°C and 36°C respectively, i.e., a daily fluctuation of 3K. The true minimum and maximum, might have occured at a different time, with greater values, thus, greater daily range. This case also demonstrates the good damping capacity of the roof construction, where the daily variation is stabilised from 27K to 3K.

The spot readings of the surface temperature in the basement, which are given in (Table 4-1), show a constant temperature of 32°C at any time. This means that the outside daily variations

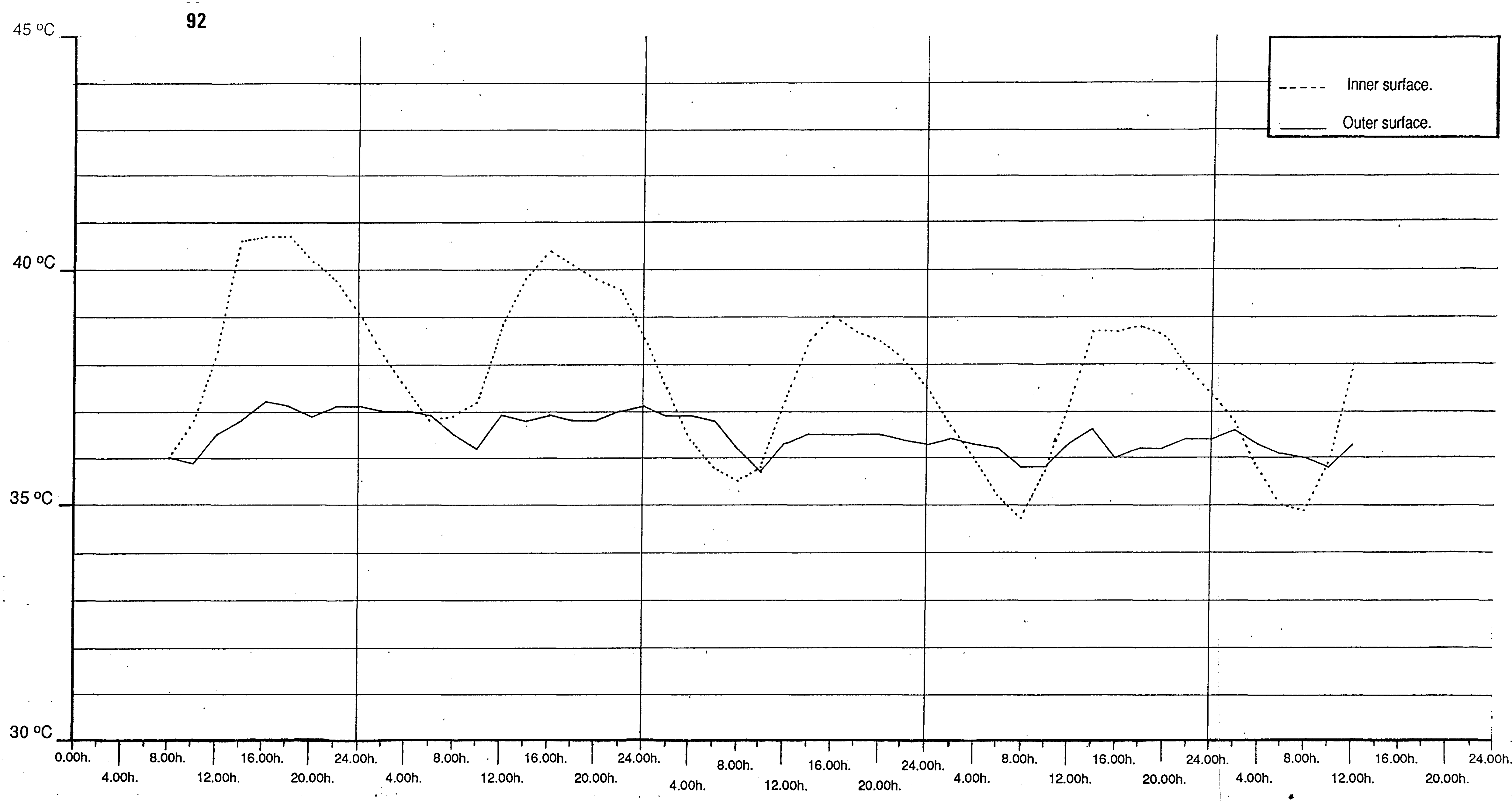

Fig.4-6: Temperature fluctuation of inside and outside roof surfaces in the traditional house model,

have little or no effect on the basement. This is confirmed by the radiation recorded on the ceiling, which showed a very small fluctuation, between a maximum of 487W/m^2 and a minimum of 480W/m^2.

The measurments of thermal radiation on the inside and outside surfaces of both the shaded and the unshaded roofs, showed great similarity with the temperature variation. In the former case, the 45 W/m^2 difference between maximum and minimum of the outside surface resulted in a variation of 5W/m^2 on the inside surface. The latter case also showed a small variation of the inside surface radiation, 15W/m^2, compared to that of the outside surface, fluctuating between a maximum of 694W/m^2 and a minimum of 485W/m^2, (Table 4-1).

The relative humidity of the air followed the same pattern of variation as the two other parameters discussed above. It was very steady in the basement, reaching its maximum of 38% in the early hours of the day and a minimum of 32% in the afternoon. On the first-floor, the relative humidity was noticeably lower, due to a high temperature and movement of the air, and fluctuated between 19% and 33%. Similarly, that of the courtyard on the first-floor was the lowest having a minimum of 14% and a maximum of 27%.

The air movement in the basement hardly exceeds 0.06 m/s, thus imperceptible, (Table 4-1). Most interesting is the air movement on the ground-floor, which is at times higher than that of the first-floor courtyard. This attests to the advantage of the traditional design in creating an air circulation between the door and the shaft. The air movement in the courtyard attains its peak at mid-day, which may be due to the fact that wind speeds are highest as seen in Chapter 2.

4-4 : Conclusions from comparative analysis:

Some very interesting conclusions can be drawn from the two sets of results obtained in the traditional and modern houses. These lead to the definition of factors causing differences in the behaviour of the two models, and hence the necessary solutions.

Table 4-1 : Spot measured data during experiment.

Date	Time	Air movement (m/s)	Humidity (%)	Radiation (W/m2) Shaded part of roof	Unshaded roof	tc	Space
September, 2nd, 1987	12.00	0.00	35	480	===	==	B
		0.08	20	520	545	==	G
		1.80	14	558	770	==	F
	16.00	0.01	32	476	===	==	B
		0.12	19	517	536	==	G
		0.06	17	550	610	==	F
	20.00	0.01	33	480	===	==	B
		0.02	33	520	540	==	G
		0.05	18	553	572	==	F
September, 3rd, 1987	08.00	0.01	36	479	===	==	B
		0.04	23	515	523	==	G
		0.05	22	520	537	==	F
	12.00	0.02	32	480	===	==	B
		0.14	23	519	527	==	G
		0.06	20	540	700	==	F
	16.00	0.03	33	480	===	==	B
		0.08	28	515	530	==	G
		0.2	20	555	620	==	F
	20.00	0.04	34	480	===	==	B
		0.1	31	518	538	39	G
		0.03	18	550	560	42	F
September, 4th, 1987	08.00	0.01	38	485	===	32	B
		0.3	29	510	520	37	G
		0.06	18	505	528	33	F
	12.00	0.04	33	480	===	31	B
		0.3	25	514	524	37	G
		0.14	24	532	694	59	F
	16.00	0.01	32	485	===	32	B
		0.28	22	515	532	33	G
		0.08	23	535	560	42	F
	20.00	0.02	34	480	===	32	B
		0.04	29	515	533	39	G
		0.1	24	535	545	40	F
September, 5th, 1987	00.00	0.01	34	485	===	32	B
		0.02	27	512	528	38	G
		0.05	23	524	510	36	F
	04.00	0.06	36	486	===	32	B
		0.02	27	510	520	37	G
		0.06	26	503	485	32	F
	08.00	0.05	35	487	===	32	B
		0.4	29	510	518	36	G
		0.03	27	505	525	38	F
	12.00	0.03	32	485	===	32	B
		0.12	25	514	520	37	G
		0.14	23	530	697	58	F
	16.00	0.02	34	484	===	32	B
		0.1	30	519	525	38	G
		0.18	19	550	595	47	F
	20.00	0.02	34	483	===	32	B
		0.04	29	512	530	38	G
		0.08	23	532	542	40	F

tc : ceiling temperature. B : basement. G : ground-floor. F : first-floor.

In general terms, and based on temperature profiles in (Fig.4-2 & 4-4), it can be concluded that the traditional type performs better than the modern one.

Figure:4-4 shows a clear resemblance between the outside and inside air temperatures profiles attesting to the influence of the former on the latter. In the case of the traditional house however, the inside air temperature curve is more flattened than that of the modern and thus less subject to outside influences. This is certainly made possible by the use of appropriate design, inducing fresh ventilation by stack effect, and suitable materials with high mass. Furthermore, the traditional type represents the additional advantage of having a vertical development, thus following the temperature stratification of air layers. Being totally sunk under the ground level, where the temperature is well stabilised and almost isothermal, the basement constitutes a reservoir of relatively cool air. Indeed, day three of (Fig.4-2) shows an 8 K difference between the inside air temperatures of the ground floor and the basement, the latter being at the same time 13 K cooler than the outside air. On the fourth day, the difference is even greater due to the ground-floor air temperature, which went high following that of the outside air, whereas the temperature in the basement remained almost flat.

Another very decisive element that helps create comfortable conditions indoors, and which is of a personal nature, is the migration inside the house. It is known under two forms: the seasonal migration, which represents the use of different spaces for the same function but in different seasons; and the daily migration, referring to the use of different spaces for the same purpose and in the same season. A common example illustrating the former is that of the kitchen. During the hot months, cooking takes place in the open-air heart situated on the first-floor courtyard, thus eliminating an important source of heat production from the ground floor. Conversely, the inner kitchen is used during the cold period so that the heat generated would serve for warming the central space and the rooms. On the other hand, the daily migration is probably best seen in the use of the basement for the siesta and the flat roofs at night. The reverse situation is adopted during the cold season, where it is much preferred to have the siesta on the warm flat roof in the shade of a wall or the gallery.

In addition to these migrations, other strategies can be adopted for improving the internal environment. It can be seen for example that *dellous* and *guerbas* filled with water are attached to the ceiling in the path of air currents. These have the double advantage of cooling the air and the contained water which is used for drinking.

During the cold season, *dellous* and *guerbas* are emptied, dried and stored for the next summer. While the walls of the rooms are covered by a woven mat to the level of a person sitting on a matress. The intention is to prevent the radiative heat transfer from the body to the cold wall. By fixing an insulating material, the mean radiant temperature is increased and made the same on the four sides, thus eliminating the radiation draught effect - i.e. the rapid heat loss by radiation from the body to a cold surface. Similarly, in order to avoid the asymmetric radiation effect, which results from the heat being radiated to the body on one side only, it was found during the experiment that traditional houses use mostly fluorescent lighting. This is supported by the fact that illuminance and irradiance are directly related and that the illuminances which produce a difference in the radiant temperature of 10K are: 850 Lux for tungsten filament lamps, 4000Lux for deluxe warm white fluorescent lighting and 8000Lux for white fluorescent lamps. As well as demonstrating people's awareness of the physical nature of the conditions around them, all these strategies attest of their ingenuity in tackling them for the creation of a better environment.

By contrast, the modern flat with its planar development, offers no alternatives for creating a comfortable indoor environment. All the rooms have approximately the same temperature due to their position on the same level, which does not favour the temperature stratification of the enclosed air. The air stratification which does occur is not noticeable due to the small temperature difference between floor and ceiling levels, the low ceilings bringing the hot air mass to a person's level. In such situations, and in order to avoid this air stagnation, the only alternative would be to create an air movement. Therefore, cross ventilation seems to be the solution, (but only when the outside temperature is **lower** than that inside). However, this is not always possible in the case of the modern flat at Ghardaia, for the positioning of the doors and windows is unfavourable to good cross-ventilation of the rooms, (Fig.4-3). The worst case is that of the living-room. The door and windows being practically on the same side, no air movement is induced into this deep volume. In fact, it was experienced that the best place to be as far as air movement is concerned, is the corridor. It proved to be even better than the courtyard where the high, closely spaced walls stopped the air currents from reaching the floor level. The corridor however is like a channel or tunnel for the air circulating between the windows of the two rooms, or the courtyard door, and those of the living-room.

The highest heat built-up is in the bathroom. With its thinner, single layer walls and its position over a walk-way, it has five of its six sides exposed to the outside. Even the small window near the ceiling does not have any significant effect on the inside conditions since it is positioned too near to the door. Another design weakness exists in the kitchen, which is the first internal source of heat, having no door to isolate it from the rest of the house. Finally, the situation is made worse here as in the whole flat by the huge amount of heat entering through the black roof, where a temperature of 69°C was recorded on the outer surface.

It appears from the above comparison that the reasons for the traditional house is still being more acceptable than the modern one, lie in two main factors - climatic suitability and cultural identity. The modern house was found to satisfy neither of these two requirements. However, it would be a mistake to think that it is the entire concept of modern house which is to blame. Despite its climatic inadequacy, the modern house still has some advantages related to other forms of comfort, such as the level of lighting and ventilation inside the rooms. In addition, its use of modern building techniques and materials, which results in a quicker building process and better resistance to environmental factors, makes it more appropriate to the present housing situation in Algeria.

CHAPTER 5 : PROPOSITION

5-1 : Introduction :

The state of the art for passive cooling of buildings lags behind that for heating. Providing cooling for a space inside an unconditioned building by passive means in the regions of hot dry climates poses considerable problems to the designers. Traditional methods to reduce heat gain through the building such as increasing the roof thickness, providing a false ceiling, roof shading and the use of reflective paints, help to reduce the cooling load to some extent. But these are ineffective in removing the heat which is present inside the building space due to various sources like metabolism, lighting and electrical appliances. In contrast, passive evaporative cooling has emerged as a technically viable and economically attractive method to maintain comfortable room temperature in hot dry zones.

5-2 Historical background :

Evaporative cooling represents the oldest application of air-conditioning principles. In its primitive use it flourished mainly in hot desert regions. It was known to the ancient Egyptians dating back about 2500 B.C. Slaves were used to ventilate air through porous earthen pots filled with water, by moving large fans of plaited straw. In India, evaporative cooling was even used to make ice. Another practice, which is still used, consists in hanging in front of the window a form of open weave matting or branches of certain types of trees, and at intervals through the day water is thrown on to it, so that before air enters the room through the window, it is humidified, cooled and filtered from dust. With the advent of piped water, a pipe was sometimes arranged above the branches dripping water onto them through a series of small holes drilled in the pipe. In Iran, the buildings contain pools of running water, *salsabil*, the surface of which receives the outside air through a wind-catcher opening above it. The outside air is diverted across the water surface and into the subterranean rooms. In Baghdad, Cairo and other Middle Eastern cities, the dense urban form with traditional courtyard-dwellings precluded the use of evaporative cooling in windows, where a water filled porous pot was placed in the *mushrabyya*. In addition, high average daytime wind speeds common in desert areas allowed the use of wind scoops or catchers, which project above the roof level and deflect the wind down a vertical duct. Earthen pots full of water were placed, at the top of this shaft in Cairo and at the bottom in Baghdad. As the water evaporates, air was cooled and humidified. A more detailed summary of wind tower design, including modern techniques to improve efficiency, can be found in the work of Benamara[1].

In the northern parts of Algeria as in other north African countries and Islamic architecture in Spain, fountains were used in the courtyards of houses. As for the M'zab region of Algeria, three different types of evaporative coolers were and still are used.

The most commonly used is the *dellou*, which is a sort of semi-spherical bucket made of goat skin. It is found hung in the chicane between the entrance and the central room, thus taking advantage of air currents between the main door and the light-well in the ceiling of the central space. The air in contact is cooled evaporatively not only from the water surface but also from the wet skin by water that passes through the pores.

The second type of traditional evaporative coolers is called *guerba*. It uses the whole skin which is sewn together as in the stuffing process in taxidermy. The joints and sewing points are made watertight using tar. It is hung to the ceiling by joining the four legs, the neck being used for filling or emptying it.

The last type, which is not in use nowadays, came in the form of a large plate placed on the floor. It was made of plaited straw or palm-leaves partly covered on the inner surface with tar for watertightness.

With the advent of refrigerators, these methods have been neglected and are slowly disappearing; people thinking of them just as water coolers and ignoring the beneficial contribution to indoor comfort. The first type, the *dellou*, can still be found in some houses but is mostly used for decorative purposes. The *guerba* can usually be seen in the street, put out by dwellers or shop keepers and intended for the general use by the public as drinking-water supply.

5-3 Basic principles and classification :

Evaporation is a process which occurs when liquid, in the present case water, changes its state to vapour, and is of vital importance for the functional design of buildings. An understanding of the nature of the evaporation process is necessary because it forms the basis of psychrometry, the general principles underlying the relationship between heat and water vapour in the air.

The process is best illustrated by considering a dish of water in a room. If left long enough, the water will gradually disappear by evaporation.
The reason is that since the molecules of the liquid are in a continuous state of vibration, and since they do not all have the same kinetic energy, or product of mass and velocity, some of these molecules acquire enough energy to free them from the other molecules and escape into the air, thus causing evaporation. If the water is heated, the kinetic energy is increased and so is the rate of evaporation. Evaporation is also a surface effect, its rate increasing in proportion to surface area. Another way of increasing its rate is to expose the surface of the liquid to a draught of air, so that the saturated air is replaced by drier air. The air is said to be saturated when it cannot hold any more vapour and consequently, evaporation stops. The factor determining the evaporative capacity is the difference in vapour pressure between air and water. The greater the difference, the higher the evaporative capacity. At the same time as loading the air with moisture, thus increasing its humidity, evaporation lowers its temperature by transfering some of the *sensible heat* present in the air to the water where it is converted into *latent heat* of vaporisation.

5-3-1 : Sensible heat : As implied by the name, this form of heat is detected by the senses. In other words, it is the form of heat which is associated with a change in the temperature of the substance involved. Addition or removal of sensible heat is, therefore always accompanied by changes in temperature.

5-3-2 : **Latent heat** : Latent heat is the term used to express the thermal energy involved in a change of state without changing temperature, as when changing ice to water or water to steam. The latent heat of vaporisation of water at normal temperature is 2400kJ/litre.

Modern evaporative cooling is mainly achieved by use of mechanical systems. Depending on the choice of the operating system, the humidity of the room air may or may not increase. Accordingly, the process may be classified in the following two categories:

a - **Direct evaporative cooling**: The process is called direct evaporative cooling when the air is in direct contact with the water surface, which results in an increased humidity.

b - **Indirect evaporative cooling:** In this process, evaporation occurs separately and air is cooled without humidity gain. The resultant cool air is then used to cool the room.

In general, indirect evaporative cooling methods fall in two categories - passive systems and active systems. Some designs of the latter class can be manufactured in factories as ready-made units, while the former method has to be employed upon the building itself.

5-3-3 : Passive systems: Indirect evaporative cooling by passive methods is commonly associated with the roof surface, and adopts either of the following prccesses:

a : By keeping the exterior surface of the roof wet. The latent heat of vaporisation of the water is taken from the converted sensible heat of the roof surface. This results in a temperature gradient between the inside and outside surfaces of the roof, thus causing the cooling of the interior environment. This concept is usually referred to as: *water film over the roof.* The critical factor determining its performance is the continuous wetness of the roof surface, and hence it needs special attention. Sometimes sprayers are used, in which case the technique is called: *roof spray method.*

b : By having a water pond over the roof surface. Consequently, the roof has to be made structurally sound. The effectiveness of the method increases when the roof is covered during daytime by an insulating material and is left exposed during the night. This helps both in reducing heat gains during the day and increasing losses to the night sky. It should be noted here that this can be used for winter heating by covering the pond with a transparent material only during the day, and with the movable insulation at night. This results in the water pond transmitting the heat it had gained from solar radiation during the day to the roof, at night.

c : By maintaining a moving water-film over the roof surface. This concept utilises the same principle for its operation; the evaporation process being aided by an increase in the relative speed between air and water. This method is most effective under conditions where evaporation is difficult as in humid climates.

From the practical point of view, these methods suffer many drawbacks: Evaporative cooling is most effective in arid conditions, but such regions usually have restricted and costly water supplies; water ponds may provide a breeding ground for mosquitoes; additional problems of maintaining such systems as mould growth, leaking roofs, wind-driven spray or rotting of materials.

5-3-4 : Active systems : Active systems come essentially in the form of kits of hardware, like an air conditioning unit for example, which are applied to a building. They may involve the use of solar collectors, storage tanks, and energy transfer and distribution mechanism with heat pumps and fans. These systems require an external source of energy such as electricity to power the fans and pumps. The high initial cost, the long period of repayment, and its complexity, requiring it to be installed by experts, are the main disadvantages of these systems, particularly in areas where economic constraints and limited technical background exist.

5-3-5 : Hybrid systems : Hybrid systems are the result of a combination between active and passive ones. One such example which appears to be worth mentioning, for it may have an application in the renovation of traditional houses in Ghardaia, is the wind convector undergoing development[2] at University College of Galway in Ireland. The challenge would be to passively use part of active apparatus, in this case the air convector grid itself, as a functional and aesthetic architectural element, such as a window grille.

5-4 : The proposed evaporative cooling device :

In the same vein, but eliminating active elements entirely, the passive system proposed here is based on direct evaporative cooling theoretically, on the *mushrabyyah* architecturally and on the use of local building materials technically.

5-4-1 : Theoretical aspect :

The device comes in the form of a large grid which is fixed on the outside of the window, built into the masonry, (Fig.5-1). The intersected bars of the grid are hollow tubes made of a porous earthen material. These hollow tubes are filled with water, which tends to pass through the porous material to wet the outer surface of the tubes, where it evaporates. The evaporation occurs at the wet surface and into the hot, dry air entering from outside to inside through the window grid. Consequently, the humidity of the air is increased and its temperature lowered. This cool air is then directed into the room where it cools the atmosphere and becomes warmer in the process, thus rising up towards the outlet above the door. The departing air is replaced by cool air from the window, and the repeated cycle results in an air movement by cross-ventilation in the room.

In order to increase the efficiency of the system, only the lower part of the window is opened, whereas the grid is covering the whole surface of the window on the outside. This difference in the surface areas of the two inlets, combined with the space left between them in the depth of the window, and which functions as a humidifying chamber, results in the air being trapped between the glass panel and the grid, thus having more time to absorb more moisture before dropping downwards in this humidifying chamber towards the room inlet.

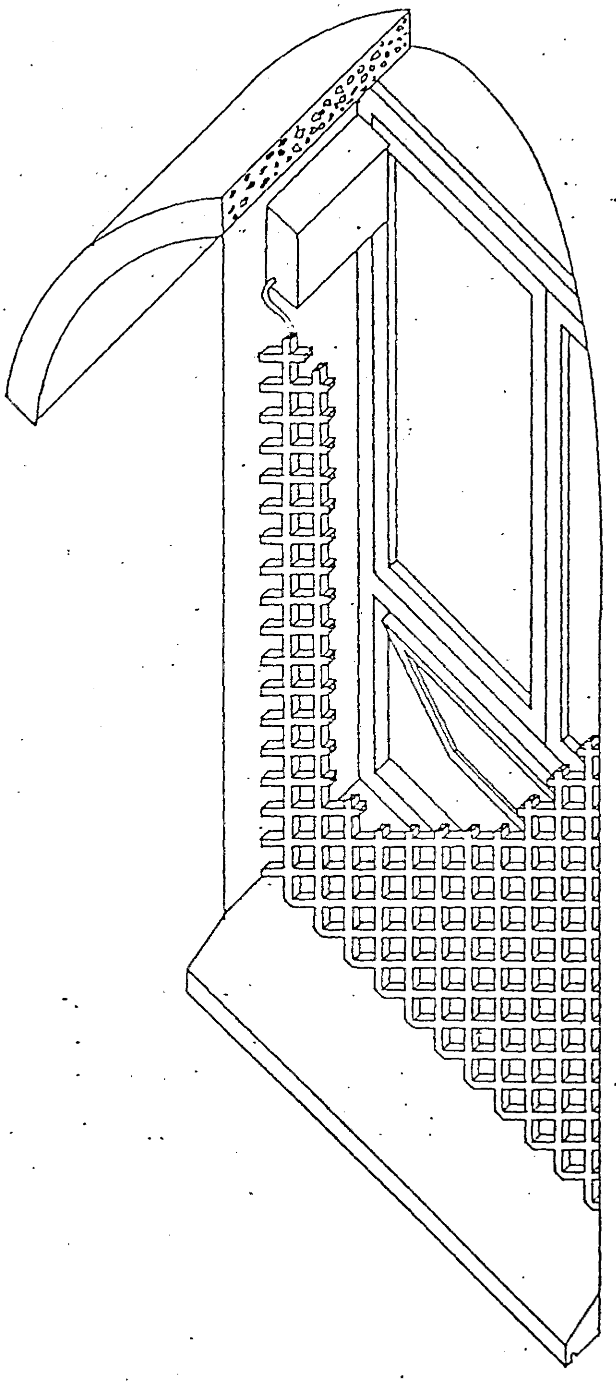

Fig.5-1: Axonometric of the evaporative cooling grid mounted on a window.

The cooling capacity of the new system can be foreseen using a psychrometric chart as represented in (Fig.5-2). The tested example is that of July where the worst situation prevails, with an outside mean air temperature of 40°C and a mean relative humidity of 14%.

From the data plotted on the chart, it can be seen that an increase in the relative humidity of the outside air along a constant enthalpy line, would result in a 19 K drop at saturation level. In other words, air at 40°C dry bulb temperature and 14% relative humidity, would have a new temperature of 21°C and a relative humidity of 100%. However, this is firstly impossible to attain with the proposed system and secondly undesirable due not only to the induced feeling of dampness and stuffiness, but also to the increased moisture level of the skin. In addition, the large differential between inside and outside in terms of temperature and humidity would lead to creating an uncomfortable sensation with respect to both ingress and egress, i.e., for a person going from inside to outside the sensation is too hot, and when from outside to inside it is too cold. As a *broad brush* value, 70% can be reasonably assumed as a maximum suitable relative humidity for air entering the room. This results in bringing the air temperature from 40°C, down to 25.5°C.

Another very important factor which has to be given full consideration is the resulting vapour pressure of the air. Since it is the difference in vapour pressure between skin and air which determines the evaporative capacity of air, the air vapour pressure should never be equal or higher than that of the skin in order to allow sweat evaporation. Skin vapour pressure varies noticeably with skin temperature fluctuations, making it difficult to determine a stable figure for calculation. However, Givoni[3] suggests that a limit of 56 mb can be used for calculation. This means that air entering the room should have a vapour pressure equal or less than 56mb. From the comparison of the results that could be obtained with the new device to the I.H.V.E. guide of psychrometrics[4], it appears that air at 25.5°C and 70% relative humidity has a vapour pressure of 23mb and that in order to attain the limit value of 56mb at the same relative humidity of 70%, the air temperature would have to be 41°C, which is not the case here. Similarly, if the air is assumed to be saturated, which is the extreme case, the temperature at which the vapour pressure would be 56mb is 35°C, which again is not the case here.

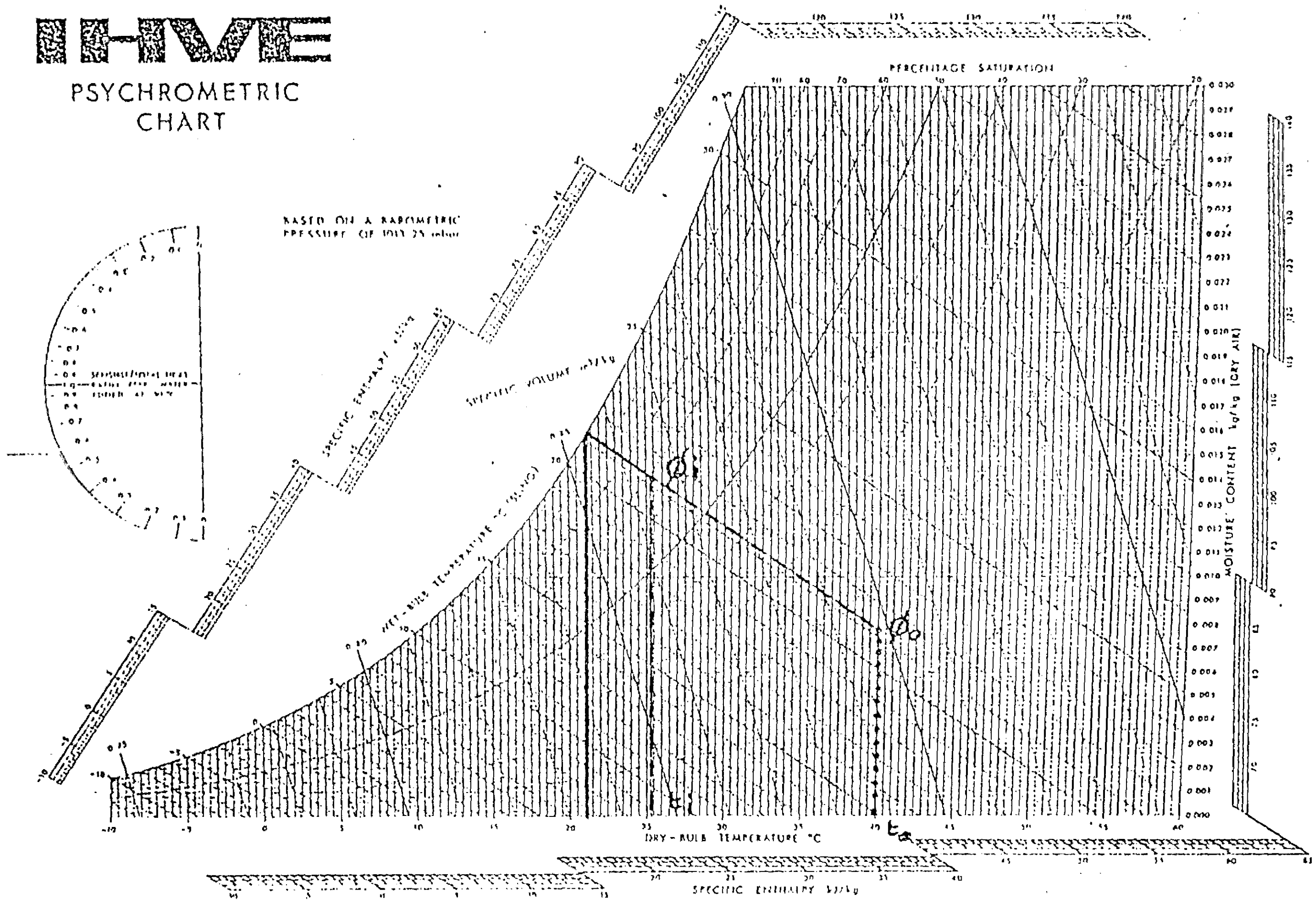

Fig.5-2: Results of the psychrometric chart for the worst case, July.

to = 40.0oC and Øo = 14%	to and Øo : temperature and relative humidity of the ouside air.
ti = 25.5oC and Øi = 70%	ti and Øi : resulting temperature and relative humidity.

From these results it can be safely assumed that the air entering the room through the proposed evaporative cooling system would not interfere with sweat evaporation from the skin since its vapour pressure is always below that of the skin.

5-4-1 : Technical aspect :

In order to overcome the two drawbacks of the *mushrabyyah*, viz, by its reliance on wood and the lengthy skilfull production process, at a time where everyone is engaged in a race against the clock for housing programs, a new method is proposed here which uses local materials and modern techniques of mass production. The proposed material is widely available in the area and consists of a porous earthen mixture used traditionally for making jars and pottery utensils.

The new system is more competitive in terms of production because instead of producing small pieces and then mounting them bit by bit like a jigsaw puzzle, the whole screen is produced in one piece in the form of a large sheet, 2.00.2.80 m for example. The production process is as follows:

A lead grid to the desired size and pattern, is clamped in a sandwich, between two sheets of the earthen porous material. The latter is pressed and moulded around the woven lead bars of the grid, and at the same time the voids are cut. The next stage in the process is the preliminary drying and the firing of the grid. At the same time as the earthen material dries hard, the inner grid melts down and lead is collected to be reused.

The dry element can then be sawn into any shapes and sizes of windows where it is fixed using conventional mortar. A water container in the form of a plastic bottle, which can also serve as a level indicator, is attached to the upper corner of the humidifying chamber and linked to the hollow grid by means of a flexible plastic tube.

5-4-3 : Architectural aspect :

The proposed evaporative cooling device is inspired by the *mushrabyyah* in the spirit of the revival of traditional architecture. The *mushrabyyah* is a very well known characteristic of traditional Arab architecture. Unfortunately, its use is very limited today for the reasons mentioned in the previous paragraph. Not least is the importation of prefabricated buildings from western industrialised countries in order to satisfy the needs in the housing sector. The cumulative effect of these factors is to relegate the *mushrabyyah* to an historic role.

Traditionally, the *mushrabyyah* had three functions:

1: Cooling the air and water evaporatively by the use of jars, (Fig.5-3).

2: Allowing a good air circulation while obstructing the sun's rays and reducing glare.

3: Eliminating the disadvantages of an opening on the outside in terms of privacy.

The proposed solution not only satisfies these requirements but offers other advantages as well. With the traditional *mushrabyyah* the cooling efficiency depends on the size and number of jars placed in the window, representing the wet surface area in contact with air, which was very small compared to that of the air inlet or wooden screen. In addition, not all the incoming air is cooled since air passing above the jars enters the room without being humidified, thus negatively affecting the cooling efficiency. In the new design however, the latter is firstly improved by the use of the *mushrabyyah* screen itself for evaporating water, thus automatically humidifying all the air coming through it; and secondly the contact surface area is increased by using square section tubes which offer higher overall wet surface area. By these two improvements, it is found that the contact surface area can be three times that covered by the *mushrabyyah* screen.

5-5 : House design :

From an urban scale point of view, the aim is to find a design which would make it possible to generate a compact urban tissue. For the latter has proved to be better suited to the local climate as seen in the case of traditional housing. On the other hand, modern requirements relating to safety and utility such as vehicular access, have to be considered. Sociologically, family size and structure were the principal factors when deciding the size of houses. The proposed design offers, therefore, three ranges of dwellings - the three bedroom, four bedroom and five bedroom models, (Fig.5-4, 5-5, 5-6). The first type constitutes the basic form from

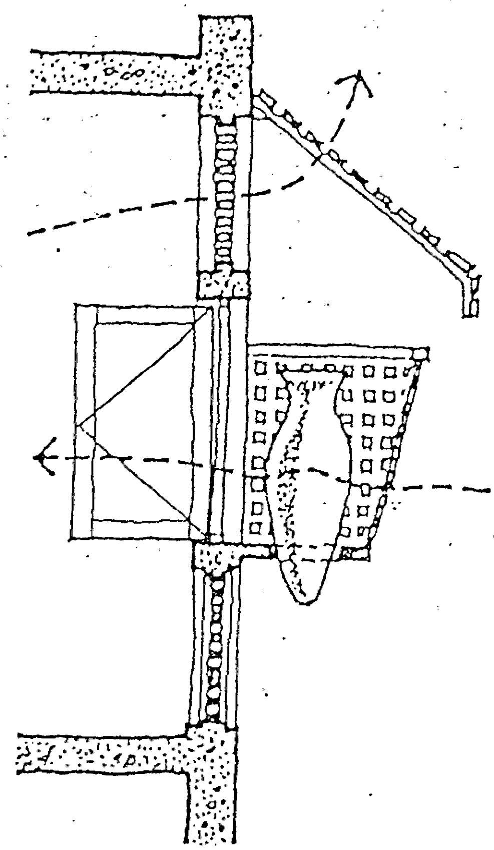

Fig.5-3: Jar in a traditional mushrabyyah. Water is cooled as it passes over surface of water-filled porous pot.
Source: A. Konya, "Design primer for hot climates."

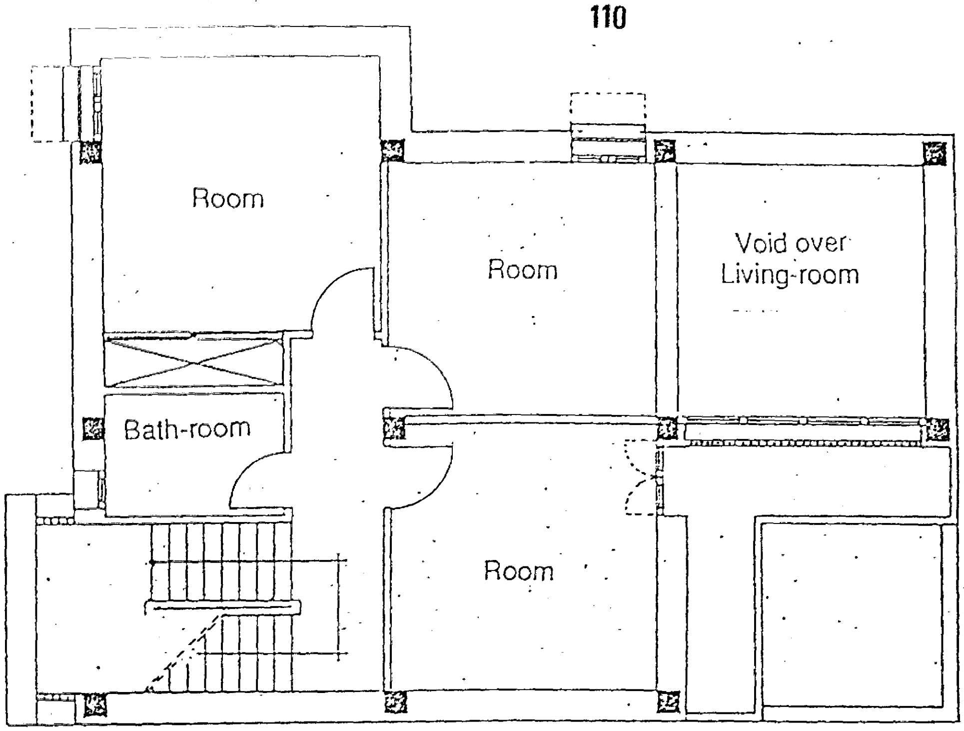

Fig.5-4-b: 5 Bedrooms type, first-floor.

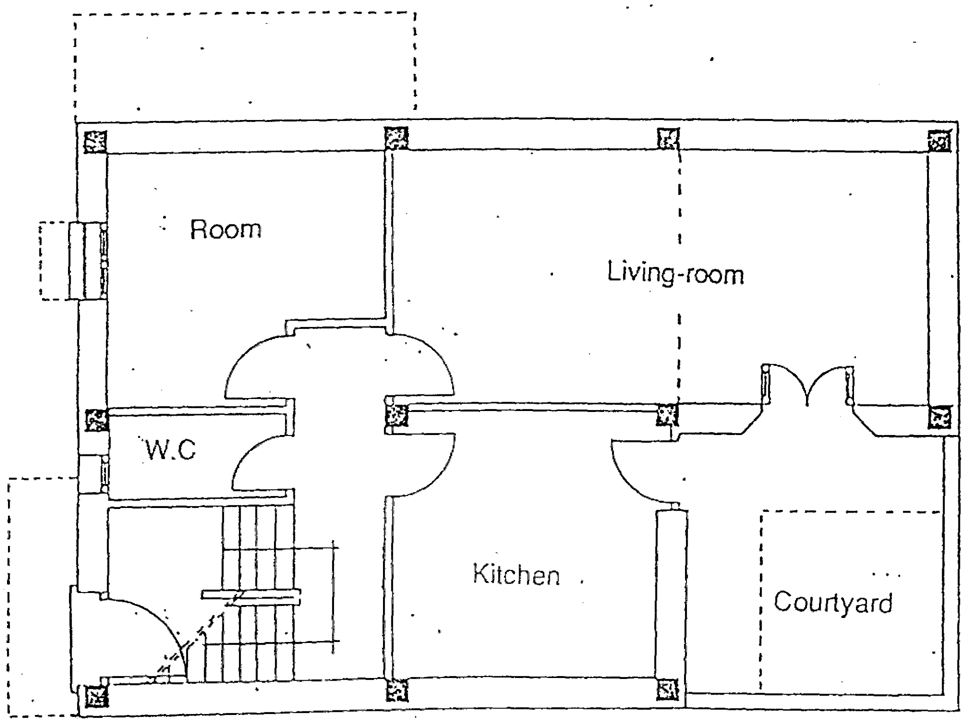

Fig.5-4-a: 5 Bedrooms type, groung-floor.

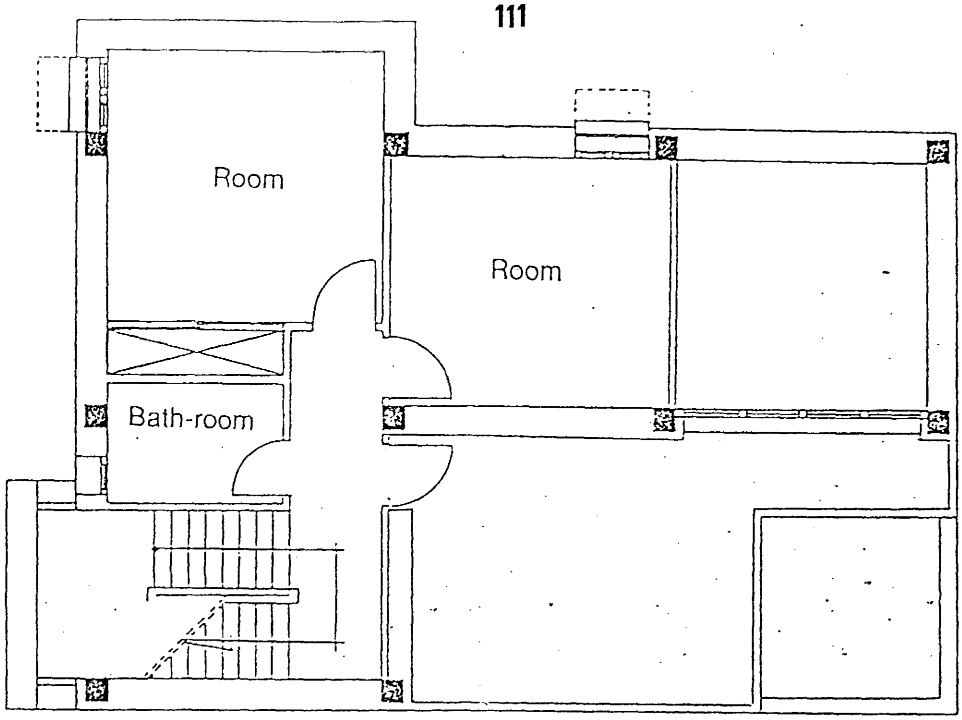

Fig.5-5: 4 Bedrooms type, first-floor. Same ground-floor as (Fig.5-4-a).

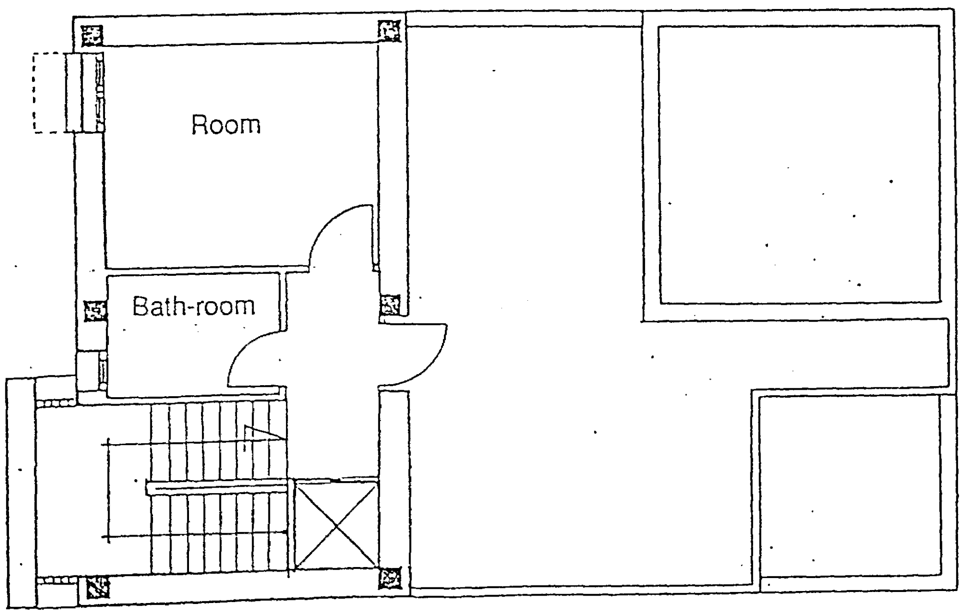

Fig.5-6: 3 Bedrooms type, first-floor. Same ground-floor as (Fig.5-4-a).

which the two others are generated. The houses are grouped around a courtyard to form clusters of four. The courtyard itself is divided into four smaller ones individually used by each dwelling. These clusters can then be arranged side by side to form long East to West running rows, (Fig.5-7), or in *quincunx* rows resulting in an intersected streets pattern. The first option may be used along important vehicular axes on the periphery of large groups of houses, where the second option would be used. This would have the result of recreating a hierarchical organisation of spaces from public to semi-public then private. This was very important in the traditional context for it gave people the sense of the place but is non-existent in modern settlements. With it has disappeared the feeling of space appropriation and neighbourhood, and naturally, people limited their responsibility to their houses. In addition to the sociological benefit of an irregular street pattern of narrow lanes and cul-de-sacs has, there also is an environmental one. This results firstly, in increased shaded areas, secondly, minimising the effects of winds in terms of drifting sand and dust, and thirdly, in preventing hot winds from sweeping away cool air masses that would have sunk into the narrow lanes during the night. North-South orientated alleys are partly shades by first-floor rooms bridging them.

Internally, the dwellings are developed vertically in order to take advantage of the temperature stratification, (Fig.5-8-a & 5-8-b). Consequently, with the open courtyard being the focus of all activities, the daily living spaces are situated on the ground-floor and open onto it. For reasons of intimacy, the ground-floor is inwardly orientated, except for the men's room where the problem does not occur. The first-floor however, which regroups night-time living spaces, is opened onto the outside in order to avoid having openings on the courtyard, which at this level would overlook the neighbours. With its vegetation, use of water and air circulation, the courtyard provides a naturally controlled micro-climate shaded by high walls and creeper plants.

All rooms are provided with cross-ventilation. Air enters the room through the window where it is evaporatively cooled and leaves it through an opening above the door. Warm vitiated air from the room is evacuated to the corridor and rises up in the stair-case, which acts like a big chimney, to eventually escape from openings at the top by stack effect. Openings on the glazed sides of the stair-case allow air in and direct it upwards in order to create a suction effect which

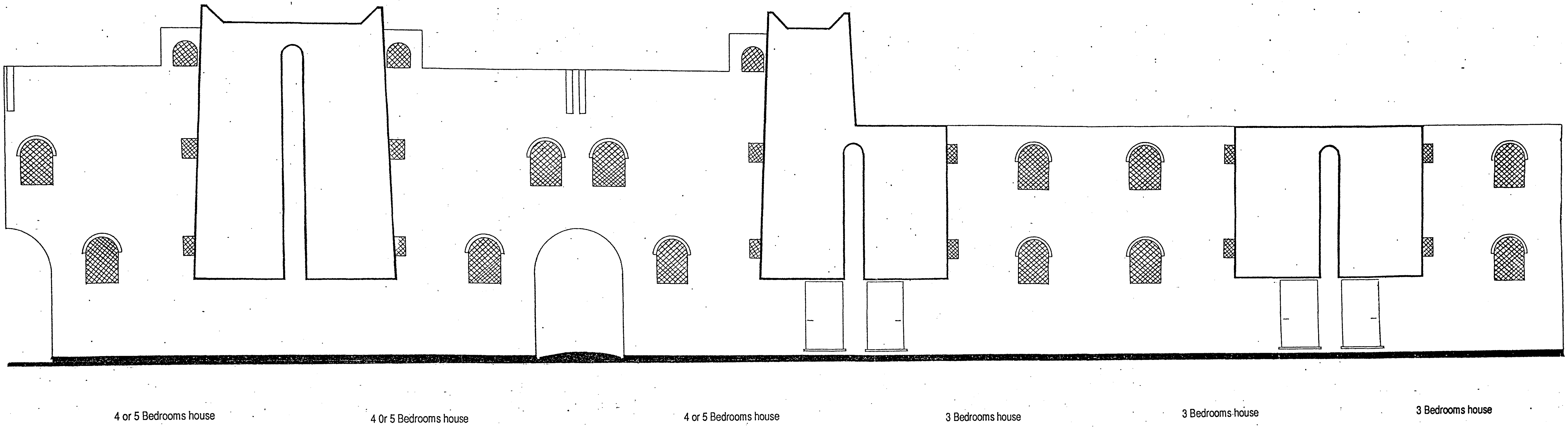

Fig.5-7: Elevation of group of houses.

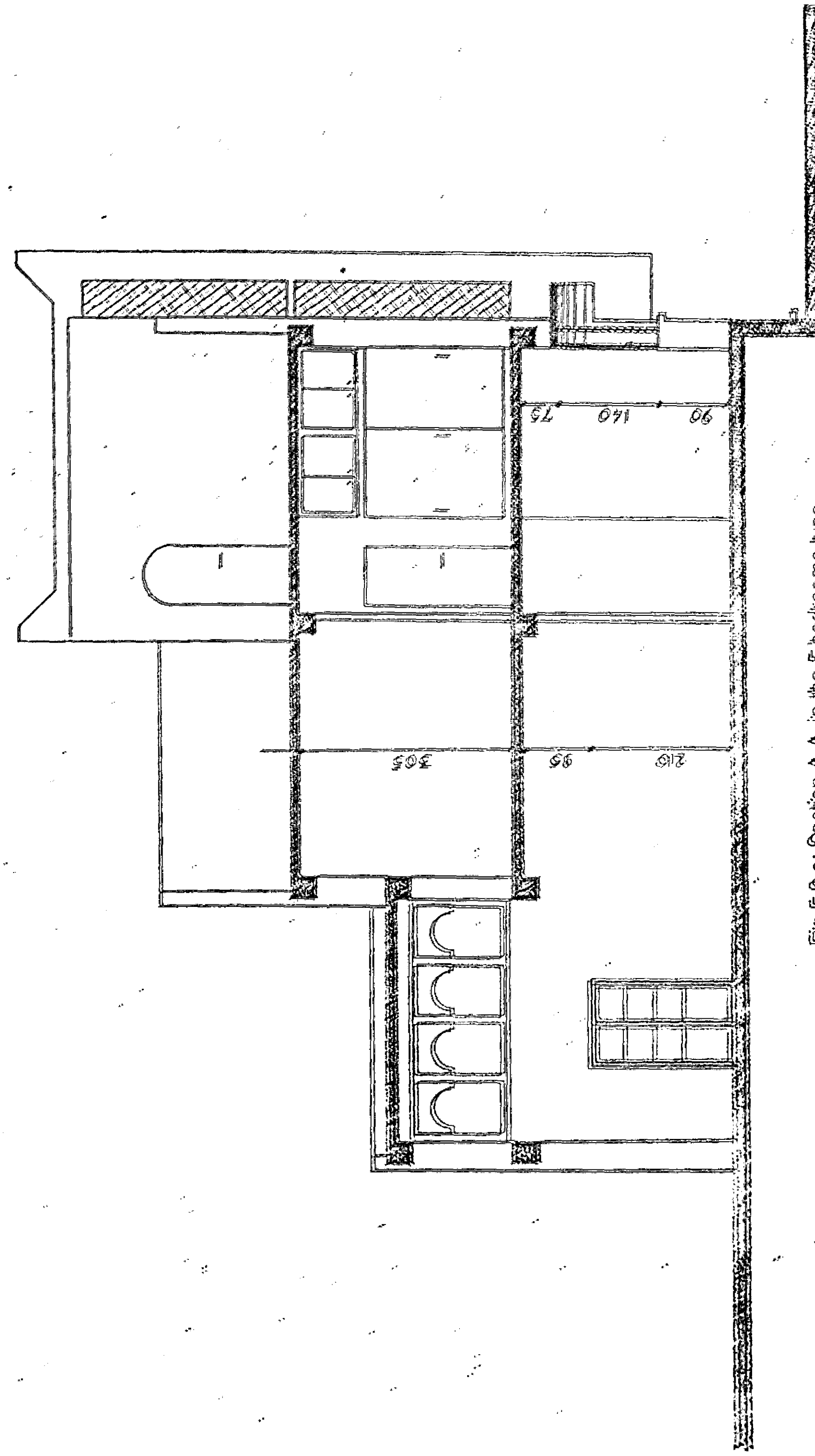

Fig.5-8-a: Section A-A, in the 5 bedrooms type.

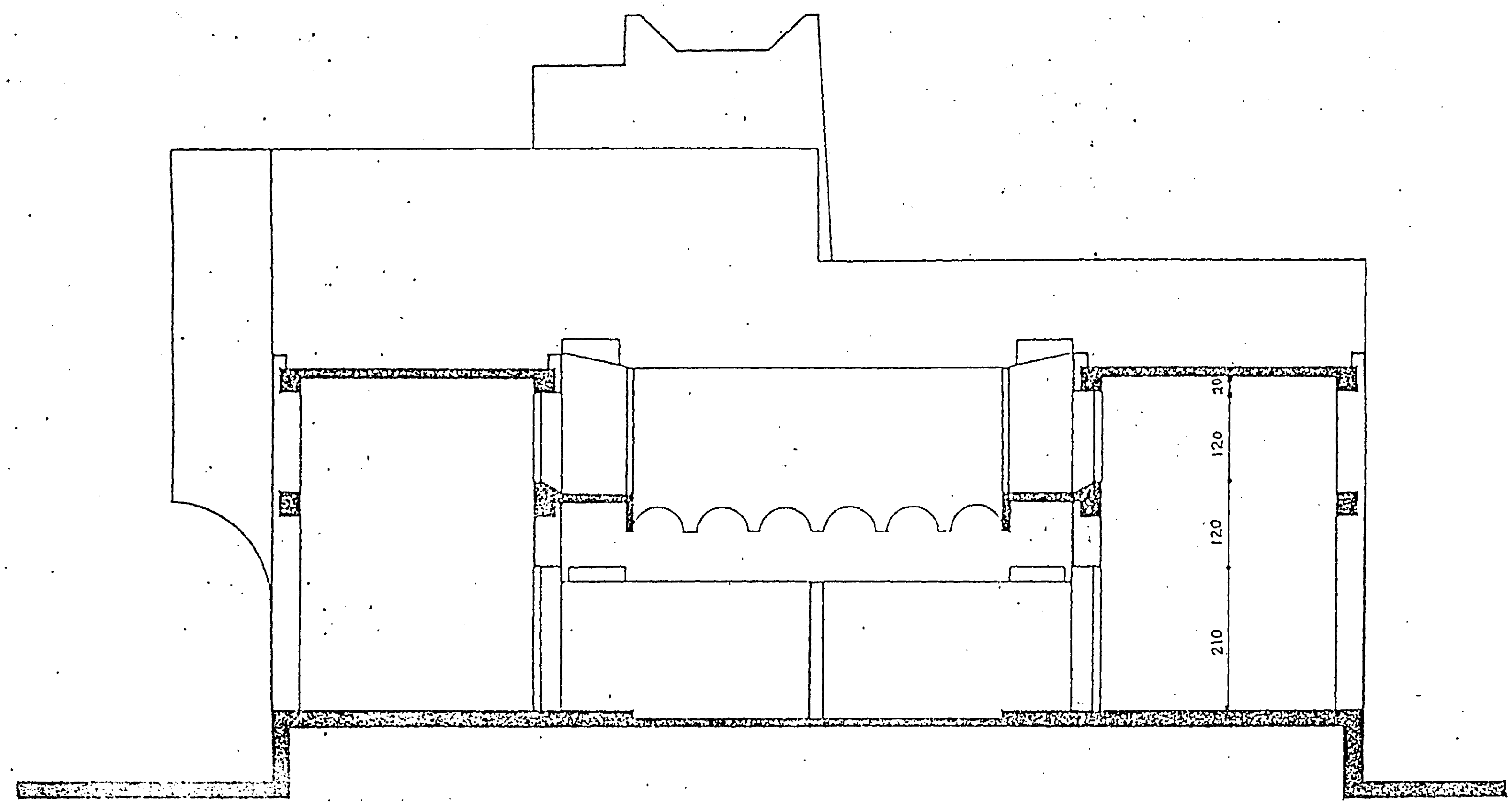

Fig.5-8-b: Section B-B, through the 3 bedrooms (right) and the 4 bedrooms (left) types. 1/100 would increase the negative pressure inside the rooms and thus increase the rate of air movement. The kitchen however, is ventilated to the courtyard by means of long, narrow openings at ceiling level.

According to Danby[5], another method of improving indoor conditions in terms of temperature lies in the use of heavy, traditional building materials for the partitions. With its high porosity and heat capacity this core would act as a storage. In summer months, night ventilation enables the walls to absorb coolth and humidity which are then released during the day resulting in a more stabilised temperature fluctuation curve. On the other hand, daytime ventilation in winter months permits the storage of heat for night use, with the humidity varying correspondingly. Concerning the external walls however, studies carried out by Benamara[6], Bouchahm[7] and Yahiaoui[8], on different compositions of roof and floor construction, showed that a combination of light concrete blocks and insulating material, such as cork or polystyrene, would be better suited since it can have the same time lag or damping factor, and offer a better response to structural and environmental constraints.

Sociologically, the internal migration towards new poles of industry in search for employment and the rigidity of contemporary housing types, which do not permit extensions in accordance with family development, heralded the appearance of the nuclear family. However, this situation is not always willingly accepted - especially in the M'zab region, where the extended family spirit is still very much alive and both parents and children prefer to live together whenever possible. In this respect, flexibility was one of the main determinents of the new house design. The basic type of the proposed houses, the three bedroomed, is destined to house a young family, but can perfectly be adapted to accommodate the same family after it has grown larger. This can be accomplished by adding one or two rooms following the two other models and according to family need. Another option is to open a door between two adjacent dwellings, in the case where they are inhabited by two brothers for example, or the courtyard party wall may be eliminated for the family to be reunited.

Architecturally, the new design draws its inspiration from the traditional one, bearing in mind modern standards of safety, health and comfort, such as vehicular access, lighting and ventilation. The forms are meant to recall those of the local architecture, (Fig.5-7), not only for integration purposes but cultural ones as well. The new design wants to be concerned with identity and tradition but without being nostalgic, because tradition does not only belong to the past, but is cyclical and renewing. And since the act of building is fundamentally cultural, one can only reject internationalist solutions for their inability to carry cultural meanings.

In respect of the local habits, roofs for example, are made accessible so that they can be used for sleeping at night during hot days, as well as drying wool or foods for winter supplies. Similarly, the *mushrabyyah* in conjunction with the *loop-holes* in the wall of the terrace would help women to get out of their isolation by enabling them to have a look outside on the street without being seen.

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CONCLUSION

The problem faced by architecture in the M'zab region in particular and Algeria in general, however multifarious and complicated it may seem, is in reality one of cultural conflict caused by a rapid change in the built environment, which at the same time was proved to be climatically inadequate. This leads to the double interrogation as to whether it would be possible to conceive a modern house which would be compatible with the cultural values of the traditional house, without being at odds with the climatic requirements.

From the results of the thermal experiment carried out on both the traditional and the modern houses, it was demonstrated how the former was better suited to the local environment, by its design and environmental control strategies. The climatic and comfort analyses in chapters two and three respectively, confirmed that the well tried evaporative cooling is the most effective method of achieving thermal comfort in that region. Similarly, the thermal analysis in chapter four showed that the vertical development of the traditional house, along with other urban and building design features, is more appropriate to both climatic and social considerations.

However, to construct housing in imitation of a traditional form infers an illusory traditional society, where rapid changes in family patterns and individual values are held not to have occured. It is equally negative to reproduce western prototypes only upon consideration of their thermal performance. This is supported by the fact that different architectural styles have existed in different parts of the world where the same climate prevailed. Therefore the study concentrates on drawing general conclusions which may serve as design guidelines. These are summarised as follows:

1- Buildings should be planned in compact groups. Large unshaded spaces and long walking distances between the houses and the community facilities should be avoided.

2- The network of paths, the pedestrian movement system of the community, should be formed by the buildings or walls enclosing building plots. Narrow streets will provide maximum amount of shade. Where walls are not present to cast shadows, trees should be provided.

3- The dwellings should have a vertical development. This would help create comfortable conditions inside by allowing temperature stratification of enclosed air masses, with the stair well constituting a ventilation "stack" or "chimney" to the outside. Another advantage is avoidance of co-ownership of the ground plot. This principle can then be used in the self-construction policy currently encouraged in Algeria and which would alleviate the burden on the state-controlled enterprises.

4- A small private outdoor space, surrounded by the indoor living spaces, similar to the traditional courtyard, should be provided. Trees, creeper plants and water in this enclosed space will help to cool the air by evaporation, keep the dust down, provide shade and give visual/psychological relief.

5- Window openings and terraces should avoid overlooking the neighbours, in order to protect the family intimacy. These should be well shaded and relatively small in size. Passive evaporative cooling devices in the form of window screens will assist air movement and natural stratification due to stack effect induced by measures (3) and (4).

6- The terraces should be made accessible, conforming to the local habits of daily and seasonal migrations.

Based on the above, the house design proposed in chapter five showed that it is perfectly possible to reach conciliation between traditional and modern morphologies, and counteract the climatic constraints. These two functions are well represented in the proposed evaporative cooling device, item (5), which fulfils its physical role by making use of a modernised traditional architectural element, the *mushrabyyah*.

Appendix : 2-A : True Solar Time calculation :

$TST = ST + ET + \delta.$

Where : TST : True Solar Time.

ST : Standard Time, for Algeria it is GMT + 1, i.e., reference meridien is 15°E.

ET : Equation of Time, varies according to date, (Table 2-A).

δ : Difference in time between the location and the reference meridien.

In the case of Ghardaia, δ is calculated as follows :

Longitude of Ghardaia is 3° 49' E = 3.82° E.

Difference in longitude between Ghardaia and the reference meridien =3.82 - 15 = -11.18, negative value since Ghardaia is ahead of reference meridien.

Time difference between Ghardaia and the reference meridien is : -11.18 * 4 = -44.72 minutes.

Therefore, TST = ST + ET - 44.7.

Table 2-A

JANUARY			FEBRUARY			MARCH			APRIL			MAY			JUNE		
Day	Dec. −	Equation of Time	Day	Dec. −	Equation of Time	Day	Dec.	Equation of Time	Day	Dec. +	Equation of Time	Day	Dec. +	Equation of Time	Day	Dec. +	Equation of Time
	° ′	m s		° ′	m s		° ′	m s		° ′	m s		° ′	m s		° ′	m s
1	23 04	− 3 09	1	17 19	−13 29	1	−7 52	−12 34	1	4 15	− 4 11	1	14 51	+ 2 47	1	21 57	+ 2 21
2	22 59	− 3 38	2	17 02	−13 38	2	−7 30	−12 22	2	4 38	− 3 53	2	15 09	+ 2 55	2	22 05	+ 2 12
3	22 54	− 4 06	3	16 45	−13 45	3	−7 07	−12 10	3	5 01	− 3 36	3	15 27	+ 3 01	3	22 13	+ 2 02
4	22 48	− 4 34	4	16 27	−13 52	4	−6 44	−11 58	4	5 24	− 3 18	4	15 45	+ 3 08	4	22 21	+ 1 53
5	22 42	− 5 01	5	16 09	−13 58	5	−6 21	−11 45	5	5 47	− 3 01	5	16 02	+ 3 14	5	22 28	+ 1 43
6	22 35	− 5 28	6	15 51	−14 03	6	−5 57	−11 32	6	6 10	− 2 43	6	16 20	+ 3 19	6	22 35	+ 1 32
7	22 28	− 5 54	7	15 32	−14 07	7	−5 34	−11 18	7	6 33	− 2 26	7	16 36	+ 3 24	7	22 41	+ 1 21
8	22 21	− 6 20	8	15 14	−14 10	8	−5 11	−11 04	8	6 55	− 2 09	8	16 53	+ 3 28	8	22 47	+ 1 10
9	22 13	− 6 46	9	14 55	−14 13	9	−4 47	−10 49	9	7 18	− 1 52	9	17 09	+ 3 31	9	22 52	+ 0 59
10	22 04	− 7 11	10	14 36	−14 15	10	−4 24	−10 34	10	7 40	− 1 36	10	17 25	+ 3 34	10	22 57	+ 0 48
11	21 55	− 7 35	11	14 16	−14 16	11	−4 01	−10 18	11	8 02	− 1 19	11	17 41	+ 3 37	11	23 02	+ 0 36
12	21 46	− 7 59	12	13 56	−14 16	12	−3 37	−10 03	12	8 24	− 1 03	12	17 57	+ 3 39	12	23 06	+ 0 24
13	21 36	− 8 22	13	13 37	−14 15	13	−3 13	− 9 47	13	8 46	− 0 48	13	18 12	+ 3 40	13	23 10	+ 0 12
14	21 26	− 8 45	14	13 16	−14 14	14	−2 50	− 9 30	14	9 08	− 0 32	14	18 27	+ 3 41	14	23 14	− 0 01
15	21 16	− 9 07	15	12 56	−14 12	15	−2 26	− 9 14	15	9 30	− 0 17	15	18 41	+ 3 41	15	23 17	− 0 13
16	21 05	− 9 28	16	12 36	−14 09	16	−2 02	− 8 57	16	9 51	− 0 02	16	18 56	+ 3 41	16	23 19	− 0 26
17	20 53	− 9 49	17	12 15	−14 06	17	−1 39	− 8 40	17	10 13	+ 0 12	17	19 10	+ 3 40	17	23 22	− 0 39
18	20 42	−10 09	18	11 54	−14 01	18	−1 15	− 8 22	18	10 34	+ 0 26	18	19 23	+ 3 38	18	23 23	− 0 52
19	20 30	−10 28	19	11 33	−13 57	19	−0 51	− 8 05	19	10 55	+ 0 40	19	19 36	+ 3 36	19	23 25	− 1 05
20	20 17	−10 46	20	11 11	−13 51	20	−0 28	− 7 47	20	11 16	+ 0 53	20	19 49	+ 3 34	20	23 26	− 1 18
21	20 04	−11 04	21	10 50	−13 45	21	−0 04	− 7 30	21	11 36	+ 1 06	21	20 02	+ 3 31	21	23 26	− 1 31
22	19 51	−11 21	22	10 28	−13 38	22	+0 20	− 7 12	22	11 57	+ 1 18	22	20 14	+ 3 27	22	22 27	− 1 44
23	19 37	−11 37	23	10 06	−13 31	23	+0 44	− 6 54	23	12 17	+ 1 30	23	20 25	+ 3 22	23	23 26	− 1 57
24	19 23	−11 53	24	9 44	−13 22	24	+1 07	− 6 36	24	12 37	+ 1 41	24	20 36	+ 3 18	24	23 26	− 2 10
25	19 09	−12 08	25	9 22	−13 14	25	+1 31	− 6 18	25	12 57	+ 1 52	25	20 49	+ 3 12	25	23 25	− 2 23
26	18 54	−12 22	26	9 00	−13 05	26	+1 54	− 6 00	26	13 16	+ 2 03	26	21 00	+ 3 06	26	23 24	− 2 36
27	18 39	−12 35	27	8 38	−12 55	27	+2 18	− 5 41	27	13 36	+ 2 13	27	21 10	+ 3 00	27	23 21	− 2 49
28	18 24	−12 47	28	8 15	−12 44	28	+2 42	− 5 23	28	13 55	+ 2 22	28	21 20	+ 2 53	28	23 19	− 3 01
29	18 08	−12 58				29	+3 05	− 5 05	29	14 14	+ 2 31	29	21 30	+ 2 46	29	23 16	− 3 14
30	17 52	−13 10				30	+3 29	− 4 47	30	14 33	+ 2 39	30	21 40	+ 2 38	30	23 13	− 3 26
31	17 36	−13 20				31	+3 52	− 4 29				31	21 49	+ 2 30			

JULY			AUGUST			SEPTEMBER			OCTOBER			NOVEMBER			DECEMBER		
Day	Dec. +	Equation of Time	Day	Dec. +	Equation of Time	Day	Dec.	Equation of Time	Day	Dec. −	Equation of Time	Day	Dec. −	Equation of Time	Day	Dec. −	Equation of Time
	° ′	m s		° ′	m s		° ′	m s		° ′	m s		° ′	m s		° ′	m s
1	23 10	−3 38	1	18 13	− 6 21	1	+8 33	− 0 18	1	2 54	+10 01	1	14 11	+16 22	1	21 41	+11 19
2	23 06	−3 50	2	17 57	− 6 18	2	+8 12	+ 0 01	2	3 17	+10 21	2	14 30	+16 24	2	21 51	+10 57
3	23 01	−4 01	3	17 42	− 6 14	3	+7 50	+ 0 21	3	3 40	+10 40	3	14 50	+16 25	3	22 00	+10 34
4	22 57	−4 12	4	17 27	− 6 09	4	+7 28	+ 0 40	4	4 03	+10 59	4	15 08	+16 25	4	22 08	+10 11
5	22 51	−4 23	5	17 11	− 6 04	5	+7 06	+ 1 00	5	4 26	+11 18	5	15 27	+16 25	5	22 16	+ 9 47
6	22 46	−4 33	6	16 55	− 5 58	6	+6 43	+ 1 20	6	4 50	+11 36	6	15 45	+16 24	6	22 24	+ 9 22
7	22 40	−4 44	7	16 38	− 5 51	7	+6 21	+ 1 40	7	5 13	+11 54	7	16 03	+16 22	7	22 31	+ 8 57
8	22 34	−4 53	8	16 21	− 5 44	8	+5 59	+ 2 01	8	5 36	+12 11	8	16 21	+16 19	8	22 38	+ 8 31
9	22 27	−5 03	9	16 04	− 5 37	9	+5 36	+ 2 21	9	5 58	+12 28	9	16 38	+16 15	9	22 45	+ 8 05
10	22 20	−5 11	10	15 47	− 5 28	10	+5 14	+ 2 42	10	6 21	+12 45	10	16 56	+16 10	10	22 51	+ 7 39
11	22 12	−5 20	11	15 30	− 5 19	11	+4 51	+ 3 03	11	6 44	+13 01	11	17 13	+16 05	11	22 56	+ 7 12
12	22 05	−5 28	12	15 12	− 5 10	12	+4 28	+ 3 24	12	7 07	+13 17	12	17 29	+15 58	12	23 01	+ 6 44
13	21 56	−5 36	13	14 54	− 5 00	13	+4 05	+ 3 45	13	7 29	+13 32	13	17 46	+15 51	13	23 06	+ 6 16
14	21 48	−5 43	14	14 36	− 4 49	14	+3 42	+ 4 07	14	7 52	+13 46	14	18 02	+15 43	14	23 10	+ 5 48
15	21 39	−5 49	15	14 17	− 4 38	15	+3 19	+ 4 28	15	8 14	+14 00	15	18 17	+15 34	15	23 14	+ 5 20
16	21 29	−5 56	16	13 59	− 4 27	16	+2 56	+ 4 49	16	8 36	+14 14	16	18 33	+15 24	16	23 17	+ 4 51
17	21 20	−6 01	17	13 40	− 4 14	17	+2 33	+ 5 11	17	8 58	+14 27	17	18 48	+15 13	17	23 20	+ 4 22
18	21 10	−6 07	18	13 21	− 4 02	18	+2 10	+ 5 32	18	9 20	+14 39	18	19 03	+15 02	18	23 22	+ 3 52
19	20 59	−6 11	19	13 01	− 3 48	19	+1 47	+ 5 53	19	9 42	+14 51	19	19 17	+14 49	19	23 24	+ 3 23
20	20 48	−6 16	20	12 42	− 3 35	20	+1 23	+ 6 15	20	10 04	+15 02	20	19 31	+14 36	20	23 25	+ 2 53
21	20 37	−6 19	21	12 22	− 3 21	21	+1 00	+ 6 36	21	10 25	+15 13	21	19 45	+14 22	21	23 26	+ 2 23
22	20 26	−6 22	22	12 02	− 3 06	22	+0 37	+ 6 57	22	10 47	+15 22	22	19 58	+14 07	22	23 27	+ 1 53
23	20 14	−6 25	23	11 42	− 2 51	23	+0 13	+ 7 18	23	11 08	+15 32	23	20 11	+13 51	23	23 27	+ 1 23
24	20 02	−6 27	24	11 22	− 2 36	24	−0 10	+ 7 39	24	11 29	+15 40	24	20 24	+13 35	24	23 26	+ 0 53
25	19 49	−6 28	25	11 01	− 2 20	25	−0 33	+ 8 00	25	11 50	+15 48	25	20 36	+13 18	25	23 25	+ 0 23
26	19 36	−6 29	26	10 41	− 2 04	26	−0 57	+ 8 21	26	12 11	+15 55	26	20 48	+13 00	26	23 24	− 0 07
27	19 23	−6 29	27	10 20	− 1 47	27	−1 20	+ 8 41	27	12 31	+16 01	27	20 59	+12 41	27	23 22	− 0 36
28	19 10	−6 29	28	9 59	− 1 30	28	−1 43	+ 9 02	28	12 52	+16 07	28	21 10	+12 21	28	23 19	− 1 06
29	18 56	−6 28	29	9 38	− 1 12	29	−2 07	+ 9 22	29	13 12	+16 12	29	21 21	+12 01	29	23 16	− 1 35
30	18 42	−6 26	30	9 16	− 0 54	30	−2 30	+ 9 42	30	13 32	+16 16	30	21 31	+11 40	30	23 13	− 2 05
31	18 27	−6 24	31	8 55	− 0 36				31	13 52	+16 20				31	23 09	− 2 33

Appendix : 2-B :

Ville étudiée et N° ASA

Valeurs pour le 1, le 11 et le 21 de chaque mois. Pour les autres jours, on procède par interpolation.

Durée d'ensoleillement = (j).$\overline{\sigma}$
durée du jour x fraction d'insolation

Temps Solaire Vrai

Heure Légale = heure donnée par les horloges (Algérie TU+1)

```
*************************
* 04 ALGER              *                 DIVERSES DONNEES COMPLEMENTAIRES                    ASA/n.c [illegible]
*************************                                                                     ---------------
                                                                                              ---------------
=========================POUR LES 1, 11 ET 21 DU MOIS         ! ======= POUR LE JOUR MOYEN DU MOIS

                DUREE   --HEURE T.S.V.--   --HEURE LEGALE--   !       JOUR CLAIR (j.c)        J.ENSOLEIL
                du jour Lever &  Coucher   Lever &  Coucher   !       Trouble atmosph.        MOYEN (jem)
                ------- -------  -------   -------  -------   !       ----------------        ----------
JANV   1        9h32mn  7h14mn  16h46mn    7h55mn  17h27mn    ! JANV  T1=0.99   T3=1.60       Sigma=[illegible]
 -    11        9h40mn  7h10mn  16h50mn    7h51mn  17h32mn    !  -    T2=0.56   Tm=2.02       K1=[illegible]
      21        9h54mn  7h03mn  16h57mn    7h45mn  17h39mn    !  -    T'=1.50   TM=2.60       K0=[illegible]
DECE   1        9h42mn  7h09mn  [illegible]  [illegible]  [illegible]  ! FEVR  T1=[illegible]  T3=1.61   Sigma=[illegible]
 -    11        9h33mn  7h14mn  16h46mn    7h55mn  17h28mn    !
 -    21        9h29mn  7h15mn  16h45mn    7h57mn  17h26mn    !  -    T'=[illegible].63  TM=2.76   K0=[illegible]
C04::asa        ------- -------  -------   -------  -------           ----------------        ----------
```

Coefficients de Trouble atmosphérique

$T'=T_1+T_2$ et $T=T'+T_0$ avec $T_0=T_3-T_{3b}.(1-\sin h)$

T_0 varie entre la valeur minimum

T_m (pour h=0, au lever ou au coucher)

et la valeur maximum

T_M (pour $h=h_o$, à midi).

Fraction d'insolation $\overline{\sigma}$.

K_0 : rapport des énergies quotidiennes incidentes sur le plan horizontal (Global jem)/(Global hors atmosphère).

K_1 : rapport des énergies quotidiennes incidentes sur le plan horizontal (Direct jem)/(Direct j.c)

Ville étudiée et N° ASA

Valeur statistique de l'énergie
pour un jour d'ensoleillement moyen
(jem)

Plan (α , γ) considéré

Plan ($-\alpha$, γ)

α γ

```
xxxxxxxxxxxxxxxxxxxxxx    Energie (en Wh/m2)        ===================
x 36 - [illegible]    x    incidente sur le PLAN    VERTICAL  SUD-OUEST    (jem)    ASA/[illegible].c.[illegible]
xxxxxxxxxxxxxxxxxxxxxx    par tranche horaire       ===================             p:(+[illegible]5,+[illegible]0)
```

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	[illegible]	0	43	193	353	499	615	695	683	545	65	3681
-	Glo G	2	[illegible]	90	178	378	576	744	861	906	960	669	81	5386
-	G /vitr	2	32	71	114	241	432	606	726	775	740	578	71	4338
-	Glo G *	3	43	[illegible]	176	396	616	806	945	1013	982	783	97	5946
FEVR	Dir S	0	0	[illegible]	6	118	282	434	557	636	653	566	189	3441
-	[illegible]	9	59	[illegible]	156	314	521	698	823	878	849	704	237	5357
-	G /vitr	3	[illegible]	[illegible]	[illegible]	194	368	552	684	746	728	606	205	4340
-	Glo G *	4	47	91	159	363	[illegible]	[illegible]	[illegible]	981	971	826	284	5984
DECE	Dir S	0	0	0	56	208	350	487	574	[illegible]	[illegible]	[illegible]	306	3062
-	Glo G	1	35	[illegible]	[illegible]	377	564	722	829	[illegible]	813	608	69	[illegible]
-	G /vitr	1	27	65	[illegible]	245	428	591	701	[illegible]	700	526	66	4199
-	Glo G *	1	[illegible]	81	[illegible]	407	621	804	936	[illegible]	954	731	85	5844
A36+1:.asa		17-18	16-17	15-16	14-15	13-14	12-13	VERTICAL	SUD-EST		((<--- TR.HOR.			JOURNEE wh/m2

S : rayonnement direct
G : rayonnement global
D : ray. diffus D=G-S
G/v : ray. global derrière vitrage
G * : ray. global (j.c)

Energies
reçues par tranches horaires sur les plans mentionnés.

Hourly Solar Irradiation on horizontal surface.
Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 210.

```
***************************        LATITUDE  : 32.23 'N        Station
*                         *        LONGITUDE :  3.49 'E        Meteorologique  :
* 21 - GHARDAIA           *                                    GHARDAIA
*                         *         Altitude:   450  m         Numero OMM : 60566
***************************         Albedo  :  0.30 **         Numero ASA :    21
```

Energie (en Wh/m2) incidente sur le PLAN HORIZONTAL par tranche horaire ASA/m.c.*epau
))))))) Rayonnement par jour clair (S_* & G_*) et hors atmosphere (G_e)

TRANCHES HOR.		4- 5	5- 6	6- 7	7- 8	8- 9	9-10	10-11	11-12	TOTAL JOURNEE	Angles COUCHER	(j) & (m) **********
JANV	Dir S_*	0	0	1	65	232	394	515	578	3570	H= 76	j= 10h08mn
-	Glo G_*	0	0	1	84	275	450	579	646	4070	a= 65	m: 12h55mn
-	Glo G_e	0	0	3	155	406	611	756	831	5524		
FEVR	Dir S_*	0	0	11	139	335	509	636	703	4556	H= 81	j= 10h55mn
-	Glo G_*	0	0	15	171	386	573	708	779	5254	a= 75	m. 12h59mn
-	Glo G_e	0	0	35	277	537	750	900	978	6954		
MARS	Dir S_*	0	0	51	236	445	624	753	821	5860	H= 88	j= 11h50mn
-	Glo G_*	0	0	68	292	508	699	837	909	6606	a= 87	m: 12h54mn
-	Glo G_e	0	0	131	419	682	896	1048	1127	8606		
AVRI	Dir S_*	0	7	122	327	532	707	832	897	6848	H= 96	j= 12h49mn
-	Glo G_*	0	11	157	386	609	796	931	1001	7782	a= 101	m: 12h45mn
-	Glo G_e	0	28	268	552	807	1015	1162	1238	10140		
MAI	Dir S_*	0	29	178	378	573	736	854	915	7326	H= 102	j= 13h39mn
-	Glo G_*	0	44	227	450	661	838	966	1034	8440	a= 112	m: 12h41mn
-	Glo G_e	0	99	369	638	878	1075	1214	1286	11118		
JUIN	Dir S_*	0	44	199	391	577	733	845	903	7384	H= 105	j= 14h05mn
-	Glo G_*	0	68	255	470	672	843	966	1031	8610	a= 117	m: 12h44mn
-	Glo G_e	2	144	412	670	902	1091	1225	1294	11490		
JUIL	Dir S_*	0	34	179	369	554	710	822	880	7096	H= 104	j= 13h55mn
-	Glo G_*	0	55	236	450	653	824	948	1014	8356	a= 115	m: 12h51mn
-	Glo G_e	0	124	393	654	888	1079	1215	1285	11276		
AOUT	Dir S_*	0	12	128	318	510	673	790	851	6564	H= 99	j= 13h13mn
-	Glo G_*	0	21	177	394	605	783	913	981	7748	a= 106	m: 12h43mn
-	Glo G_e	0	54	314	589	835	1036	1178	1251	10514		
SEPT	Dir S_*	0	1	64	241	436	605	727	791	5730	H= 92	j= 12h17mn
-	Glo G_*	0	2	94	305	521	705	839	909	6750	a= 93	m: 12h39mn
-	Glo G_e	0	7	190	476	733	943	1092	1168	9218		
OCTO	Dir S_*	0	0	17	151	338	506	629	693	4668	H= 84	j= 11h17mn
-	Glo G_*	0	0	27	197	407	590	723	792	5472	a= 80	m: 12h36mn
-	Glo G_e	0	0	63	332	591	803	953	1030	7544		
NOVE	Dir S_*	0	0	2	77	243	403	522	585	3664	H= 78	j= 10h24mn
-	Glo G_*	0	0	3	104	296	471	599	666	4278	a= 68	m: 12h30mn
-	Glo G_e	0	0	10	195	448	654	800	876	5966		
DECE	Dir S_*	0	0	0	47	197	352	468	529	3186	H= 74	j= 9h56mn
-	Glo G_*	0	0	0	64	240	410	534	600	3696	a= 62	m: 12h39mn
-	Glo G_e	0	0	0	126	372	574	716	790	5156		
B21-2::asa		19-20	18-19	17-18	16-17	15-16	14-15	13-14	12-13	JOURNEE Wh/m2	ang.hor azimut	********** (j) & (m)

ATLAS SOLAIRE DE L'ALGERIE // Michel CAPDEROU // ASA 1985 -- EPAU - BP 2 - El Harrach ALGER

DUREE du jour MAXIMUM (solstice d'ETE):14h08mn. DUREE du jour MINIMUM (solstice d'HIVER): 9h52mn
Les donnees suivantes sont independantes de la DATE et du PLAN : Fonctions du LIEU uniquement.
Correction d'Altitude : 0.95 Trouble Tl : 0.90 ALGERIE : HEURE LEGALE /toute l'annee/ TU+1
SIGNIFICATION de (j) & (m) :))))) (j) --) DUREE du jour *** (m) --) HEURE LEGALE a midi TSV

Solar Irradiation on Horizontal surface.
Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 211.

******************** * 21 - GHARDAIA * ********************	Energie (en Wh/m2) incidente sur le PLAN HORIZONTAL -- (jem) par tranche horaire	ASA/m.c.*epau p:(+000,+090)

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	46	164	279	364	408	408	364	279	164	46	0	2522
-	Glo G	1	72	234	385	496	554	554	496	385	234	72	1	3484
-	G /vitr	0	33	151	290	398	454	454	398	290	151	33	0	2652
-	Glo G *	1	84	275	450	579	646	646	579	450	275	84	1	4070
FEVR	Dir S	8	109	261	397	496	548	548	496	397	261	109	8	3638
-	Glo G	14	153	348	520	645	711	711	645	520	348	153	14	4782
-	G /vitr	5	84	252	417	538	600	600	538	417	252	84	5	3792
-	Glo G *	15	171	386	573	708	779	779	708	573	386	171	15	5264
MARS	Dir S	39	179	338	474	572	623	623	572	474	338	179	39	4450
-	Glo G	60	250	453	627	754	820	820	754	627	453	250	60	5928
-	G /vitr	27	165	356	523	643	703	703	643	523	356	165	27	4834
-	Glo G *	68	282	508	699	837	909	909	837	699	508	282	68	6606
AVRI	Dir S	88	237	386	512	603	650	650	603	512	386	237	88	4962
-	Glo G	134	332	527	692	813	876	876	813	692	527	332	134	6766
-	G /vitr	76	246	432	588	699	755	755	699	588	432	246	76	5600
-	Glo G *	157	386	609	796	931	1001	1001	931	796	609	386	157	7782
MAI	Dir S	133	282	427	549	636	681	681	636	549	427	282	133	5460
-	Glo G	196	391	578	737	854	914	914	854	737	578	391	196	7416
-	G /vitr	126	304	483	631	735	789	789	735	631	483	304	126	6170
-	Glo G *	227	450	661	838	966	1034	1034	966	838	661	450	227	8440
JUIN	Dir S	154	303	447	568	655	700	700	655	568	447	303	154	5722
-	Glo G	222	414	597	753	867	926	926	867	753	597	414	222	7674
-	G /vitr	149	327	502	646	748	800	800	748	646	502	327	149	6400
-	Glo G *	255	470	672	843	966	1031	1031	966	843	672	470	255	8610
JUIL	Dir S	153	316	474	607	703	753	753	703	607	474	316	153	6070
-	Glo G	214	416	611	777	899	962	962	899	777	611	416	214	7854
-	G /vitr	141	327	513	667	776	832	832	776	667	513	327	141	6556
-	Glo G *	236	450	653	824	948	1014	1014	948	824	653	450	236	8360
AOUT	Dir S	113	280	448	591	694	748	748	694	591	448	280	113	5750
-	Glo G	161	368	573	749	878	945	945	878	749	573	368	161	7386
-	G /vitr	97	280	476	641	757	817	817	757	641	476	280	97	6152
-	Glo G *	177	394	605	783	913	981	981	[illegible]	783	605	394	177	7748
SEPT	Dir S	42	158	286	397	477	519	519	477	397	286	158	42	3760
-	Glo G	77	246	422	574	684	741	741	684	574	422	246	77	5492
-	G /vitr	41	175	340	482	584	636	636	584	482	340	175	41	4518
-	Glo G *	94	305	521	705	839	909	909	839	705	521	305	94	6750
OCTO	Dir S	13	111	249	373	463	511	511	463	373	249	111	13	3440
-	Glo G	23	168	351	511	629	690	690	629	511	351	168	23	4744
-	G /vitr	10	103	264	418	530	587	587	530	418	264	103	10	3824
-	Glo G *	27	197	407	590	723	792	792	723	590	407	197	27	5472
NOVE	Dir S	1	46	145	241	312	350	350	312	241	145	46	1	2190
-	Glo G	3	82	231	367	467	519	519	467	367	231	82	3	3338
-	G /vitr	1	43	158	284	380	429	429	380	284	158	43	1	2590
-	Glo G *	3	104	296	471	599	666	666	599	471	296	104	3	4278
DECE	Dir S	0	34	142	253	336	380	380	336	253	142	34	0	2290
-	Glo G	0	54	205	351	460	516	516	460	351	205	54	0	3172
-	G /vitr	0	24	127	259	364	419	419	364	259	127	24	0	2386
-	Glo G *	0	64	240	410	534	600	600	534	410	240	64	0	3676
A21-1..asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE	/	12 heures	(midi TSV)			JOURNEE Wh/m2

Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 212.

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* 21 - GHARDAIA *
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Energie (en Wh/m2) incidente sur le PLAN VERTICAL SUD (JEM) par tranche horaire

ASA/n.c.32230

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	12	182	341	448	517	552	552	517	448	341	182	12	4104
-	Glo G	18	246	462	617	724	779	779	724	617	462	246	18	5692
-	G /vitr	14	194	380	519	614	662	662	614	519	380	194	14	4766
-	Glo G *	26	325	589	773	896	958	958	896	773	589	325	26	7134
FEVR	Dir S	41	204	339	442	513	549	549	513	442	339	204	41	4176
-	Glo G	58	281	476	632	742	800	800	742	632	476	281	58	5978
-	G /vitr	36	203	375	517	618	671	671	618	517	375	203	36	4840
-	Glo G *	73	335	552	721	839	901	901	839	721	552	335	73	6842
MARS	Dir S	37	137	242	330	393	426	426	393	330	242	137	37	3130
-	Glo G	63	226	391	532	636	691	691	636	532	391	226	63	5079
-	G /vitr	29	138	278	409	506	557	557	506	409	278	138	29	3834
-	Glo G *	77	266	450	605	718	777	777	718	605	450	266	77	5786
AVRI	Dir S	0	37	117	190	243	272	272	243	190	117	37	0	1718
-	Glo G	40	131	267	389	481	530	530	481	389	267	131	40	3682
-	G /vitr	31	79	163	262	345	390	390	345	262	163	79	31	2544
-	Glo G *	44	145	303	444	547	603	603	547	444	303	145	44	4178
MAI	Dir S	0	0	26	89	137	163	163	137	89	26	0	0	830
-	Glo G	56	100	169	277	360	404	404	360	277	169	100	56	2755
-	G /vitr	44	79	115	170	229	265	265	229	170	115	79	44	1822
-	Glo G *	61	103	179	302	396	447	447	396	302	179	103	61	3004
JUIN	Dir S	0	0	2	41	87	112	112	87	41	2	0	0	484
-	Glo G	61	103	143	220	299	341	341	299	220	143	103	61	2370
-	G /vitr	48	81	111	144	186	213	213	186	144	111	81	48	1594
-	Glo G *	68	108	147	233	322	370	370	322	233	147	108	68	2539
JUIL	Dir S	0	0	9	65	117	144	144	117	65	9	0	0	670
-	Glo G	57	100	148	246	331	377	377	331	246	148	100	57	2546
-	G /vitr	45	79	110	153	204	237	237	204	153	110	79	45	1578
-	Glo G *	65	106	153	257	347	396	396	347	257	153	106	65	2684
AOUT	Dir S	0	10	80	158	216	247	247	216	158	80	10	0	1422
-	Glo G	44	101	222	346	440	490	490	440	346	222	101	44	3298
-	G /vitr	35	72	131	217	295	340	340	295	217	131	72	35	2198
-	Glo G *	51	108	235	363	460	512	512	460	363	235	108	51	3472
SEPT	Dir S	10	71	146	213	263	289	289	263	213	146	71	10	1984
-	Glo G	38	156	288	404	491	536	536	491	404	288	156	38	3829
-	G /vitr	22	91	192	296	376	418	418	376	296	192	91	22	2792
-	Glo G *	48	199	363	507	613	669	669	613	507	363	199	48	4800
OCTO	Dir S	30	147	257	346	409	441	441	409	346	257	147	30	3260
-	Glo G	47	224	392	531	632	685	685	632	531	392	224	47	5022
-	G /vitr	26	153	299	426	519	567	567	519	426	299	153	26	3980
-	Glo G *	61	282	478	638	753	812	812	753	638	478	282	61	6049
NOVE	Dir S	10	138	257	342	399	427	427	399	342	257	138	10	3146
-	Glo G	17	203	379	513	606	654	654	606	513	379	203	17	4744
-	G /vitr	12	156	308	427	510	553	553	510	427	308	156	12	3932
-	Glo G *	26	304	546	724	844	906	906	844	724	546	304	26	6700
DECE	Dir S	0	153	334	446	518	554	554	518	446	334	153	0	4010
-	Glo G	0	208	447	607	716	771	771	716	607	447	208	0	5498
-	G /vitr	0	166	371	513	608	656	656	608	513	371	166	0	4628
-	Glo G *	0	273	570	759	884	947	947	884	759	570	273	0	6866
A21+0::asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE / 12 heures (Midi TSV)						JOURNEE Wh/m2

Solar Irradiation on South-West and South-East vertical surface.
Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 213.

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********************      Energie (en Wh/m2)       ====================        ASA/m.c.*epau
* 21 - GHARDAIA     *     incidente sur le PLAN  VERTICAL  SUD-OUEST   (jem)  -------------
********************      par tranche horaire      ====================        p:(+045,+000)
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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	0	0	60	195	331	449	536	573	534	346	27	3051
-	Glo G	0	22	65	170	351	521	660	746	763	686	451	39	4474
-	G /vitr	0	17	51	102	236	405	547	634	654	591	390	34	3661
-	Glo G *	0	25	68	191	414	628	806	925	962	884	600	57	5560
FEVR	Dir S	0	0	0	22	160	318	459	566	622	607	476	123	3353
-	Glo G	4	43	89	151	335	532	695	803	838	782	599	167	5038
-	G /vitr	3	34	70	104	211	396	566	677	716	672	517	145	4111
-	Glo G *	5	47	89	152	362	588	778	911	966	920	722	209	5749
MARS	Dir S	0	0	0	0	76	231	371	481	545	551	474	238	2967
-	Glo G	18	68	112	148	263	460	626	739	783	747	616	314	4894
-	G /vitr	14	53	89	117	168	319	490	610	661	637	527	269	3954
-	Glo G *	20	70	111	144	275	505	700	840	907	884	747	392	5595
AVRI	Dir S	0	0	0	0	13	128	257	359	423	439	395	270	2337
-	Glo G	40	88	130	164	204	355	512	620	666	645	549	365	4419
-	G /vitr	31	69	102	129	151	229	372	490	548	538	461	304	3490
-	Glo G *	44	90	130	163	207	390	581	718	768	780	682	468	5151
MAI	Dir S	0	0	0	0	0	56	177	275	339	360	330	243	1869
-	Glo G	56	100	139	171	195	274	421	527	575	562	485	343	3991
-	G /vitr	44	79	110	135	154	182	282	391	452	453	393	273	3055
-	Glo G *	61	103	141	173	198	292	467	597	665	664	587	428	4551
JUIN	Dir S	0	0	0	0	0	27	140	237	300	322	297	222	1645
-	Glo G	61	103	140	171	194	239	374	478	528	518	449	322	3743
-	G /vitr	48	81	111	135	153	169	242	340	402	407	353	247	2807
-	Glo G *	68	108	145	176	199	251	409	533	598	599	530	391	4218
JUIL	Dir S	0	0	0	0	0	42	168	274	343	364	332	242	1857
-	Glo G	57	100	138	170	194	255	405	517	570	559	482	340	3934
-	G /vitr	45	79	109	134	153	174	263	374	440	444	384	264	2972
-	Glo G *	65	106	142	174	197	264	426	550	613	611	537	390	4254
AOUT	Dir S	0	0	0	0	4	104	246	353	427	443	395	267	2304
-	Glo G	44	90	130	163	193	322	489	605	657	638	541	359	4323
-	G /vitr	35	71	102	129	149	204	340	465	531	526	448	294	3367
-	Glo G *	51	96	134	166	196	333	511	638	700	690	597	410	4623
SEPT	Dir S	0	0	0	0	33	149	259	345	394	396	337	186	2111
-	Glo G	25	72	113	146	209	364	500	591	623	588	478	267	3999
-	G /vitr	20	56	89	115	144	245	380	480	520	497	406	223	3198
-	Glo G *	29	78	118	151	230	437	620	749	808	782	655	384	5073
OCTO	Dir S	0	0	0	7	111	250	374	467	515	500	389	108	2721
-	Glo G	7	49	92	134	281	459	606	701	729	675	513	151	4397
-	G /vitr	6	39	73	101	176	333	486	587	620	578	442	130	3571
-	Glo G *	8	55	96	139	315	532	714	839	888	840	657	200	5283
NOVE	Dir S	0	0	0	36	143	253	351	421	451	420	278	24	2377
-	Glo G	1	27	69	146	298	444	562	633	643	574	385	38	3820
-	G /vitr	1	21	55	93	199	342	463	536	550	494	332	33	3119
-	Glo G *	1	31	74	171	385	595	769	885	920	843	584	60	5318
DECE	Dir S	0	0	2	71	202	334	449	530	559	507	277	0	2931
-	Glo G	0	17	60	174	350	516	649	730	739	650	363	0	4248
-	G /vitr	0	13	46	102	239	404	540	621	634	560	314	0	3473
-	Glo G *	0	19	65	200	416	622	792	902	929	835	480	0	5260
A21+1 :asa		17-18	16-17	15-16	14-15	13-14	12-13	VERTICAL	SUD-EST		(((--- TR.HOR.			JOURNEE Wh/m2

Solar Irradiation on West and East vertical surfaces.
Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 214.

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********************     Energie (en Wh/m2)       ====================               ASA/m.c.*epau
* 21 - GHARDAIA    *     incidente sur le PLAN    VERTICAL  OUEST          (jem)     -------------
********************     par tranche horaire      ====================               p:(+090,+000)
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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	0	0	0	0	0	84	241	363	414	308	26	1436
-	Glo G	0	22	65	100	124	136	234	404	520	546	404	38	2593
-	G /vitr	0	17	51	79	98	108	147	289	421	463	348	33	2054
-	Glo G *	0	25	68	100	123	134	260	484	646	700	537	54	3131
FEVR	Dir S	0	0	0	0	0	0	99	287	438	520	469	133	1946
-	Glo G	4	43	89	125	150	163	278	481	626	683	592	181	3415
-	G /vitr	3	34	70	99	119	129	176	350	511	580	510	157	2738
-	Glo G *	5	47	89	121	145	158	292	533	715	800	713	226	3844
MARS	Dir S	0	0	0	0	0	0	99	287	441	537	533	300	2197
-	Glo G	18	68	112	148	174	187	304	511	662	732	684	391	3991
-	G /vitr	14	53	89	117	137	147	197	375	542	622	589	339	3221
-	Glo G *	20	70	111	144	169	182	321	569	761	865	832	490	4534
AVRI	Dir S	0	0	0	0	0	0	91	264	409	504	523	408	2288
-	Glo G	40	88	130	164	188	201	311	506	649	721	698	532	4362
-	G /vitr	31	69	102	129	149	158	204	371	530	611	599	460	3529
-	Glo G *	44	90	130	163	188	202	337	578	767	876	873	686	5117
MAI	Dir S	0	0	0	0	0	0	87	252	391	485	512	437	2353
-	Glo G	56	100	139	171	195	207	312	499	637	709	697	574	4573
-	G /vitr	44	79	110	135	154	163	206	363	516	598	597	494	3698
-	Glo G *	61	103	141	173	198	211	337	564	740	845	853	723	5312
JUIN	Dir S	0	0	0	0	0	0	86	248	384	476	504	441	2383
-	Glo G	61	103	140	171	194	206	309	492	627	699	690	580	4628
-	G /vitr	48	81	111	135	153	162	203	355	505	588	590	499	3736
-	Glo G *	68	108	145	176	199	212	333	548	716	815	825	712	5314
JUIL	Dir S	0	0	0	0	0	0	94	271	419	518	543	462	2517
-	Glo G	57	100	138	170	194	206	317	513	659	736	724	596	4709
-	G /vitr	45	79	109	134	153	162	206	371	532	620	619	513	3801
-	Glo G *	65	106	142	174	197	210	331	546	712	808	811	685	5149
AOUT	Dir S	0	0	0	0	0	0	100	290	447	546	560	437	2490
-	Glo G	44	90	130	163	188	201	318	526	680	756	730	559	4545
-	G /vitr	35	71	102	129	148	158	206	384	553	640	627	482	3673
-	Glo G *	51	96	134	166	190	204	329	553	724	819	808	638	4965
SEPT	Dir S	0	0	0	0	0	0	78	225	344	415	466	253	1738
-	Glo G	25	72	113	146	169	181	277	444	562	610	561	358	3549
-	G /vitr	20	56	89	115	134	143	183	328	460	517	402	310	2864
-	Glo G *	29	78	118	151	176	189	318	549	724	813	774	515	4481
OCTO	Dir S	0	0	0	0	0	0	88	252	382	450	403	123	1698
-	Glo G	7	49	92	127	151	163	267	448	574	617	531	171	3197
-	G /vitr	6	39	73	100	119	129	172	328	469	525	437	148	2565
-	Glo G *	8	55	96	129	153	165	294	523	692	766	600	227	3788
NOVE	Dir S	0	0	0	0	0	0	69	197	296	336	256	24	1178
-	Glo G	1	27	69	103	126	138	221	364	457	474	357	39	2375
-	G /vitr	1	21	55	81	100	109	143	253	371	401	307	33	1885
-	Glo G *	1	31	74	106	129	141	264	483	640	690	541	59	3159
DECE	Dir S	0	0	0	0	0	0	81	232	345	383	230	0	1279
-	Glo G	0	17	58	92	116	128	222	384	491	506	316	0	2330
-	G /vitr	0	13	46	73	92	101	138	274	397	428	272	0	1834
-	Glo G *	0	19	62	94	116	128	248	460	610	647	417	0	2801
\21+2::asa		17-18	16-17	15-16	14-15	13-14	12-13	VERTICAL	EST		<<<---	TR.HOR.		JOURNEE Wh/m2

Solar Irradiation on North-West and North-East vertical surface.
Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 215.

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********************     Energie (en Wh/m2)          ===================      ASA/m.c.kepau
* 21 - GHARDAIA     *    incidente sur le PLAN   VERTICAL  NORD-OUEST  (jem)   ------------
********************     par tranche horaire         ===================      p:(+135,+000)
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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	0	0	0	0	0	0	0	0	51	89	9	149
-	Glo G	0	22	65	100	124	136	136	124	101	125	133	14	1080
-	G /vitr	0	17	51	79	98	108	108	98	79	70	79	9	796
-	Glo G *	0	25	68	100	123	134	134	123	101	147	175	20	1150
FEVR	Dir S	0	0	0	0	0	0	0	0	19	128	188	65	400
-	Glo G	4	43	89	125	150	163	163	150	147	235	263	90	1622
-	G /vitr	3	34	70	99	119	129	129	119	103	139	185	70	1199
-	Glo G *	5	47	89	121	145	158	158	145	148	264	314	113	1707
MARS	Dir S	0	0	0	0	0	0	0	1	79	209	280	186	755
-	Glo G	18	63	112	149	174	187	187	175	240	353	392	250	2304
-	G /vitr	14	53	89	117	137	147	147	137	150	241	305	207	1744
-	Glo G *	20	70	111	144	169	182	182	170	255	404	470	312	2489
AVRI	Dir S	0	0	0	0	0	0	0	27	155	274	344	307	1151
-	Glo G	40	88	130	164	188	201	201	221	348	451	489	411	3044
-	G /vitr	31	69	102	129	149	158	158	156	226	339	401	349	2363
-	Glo G *	44	90	130	163	188	202	202	229	392	535	605	529	3461
MAI	Dir S	0	0	0	0	0	0	2	52	214	326	393	376	1571
-	Glo G	56	100	139	171	195	207	209	293	426	522	559	551	3641
-	G /vitr	44	79	110	135	154	163	163	167	298	411	467	428	2857
-	Glo G *	61	103	141	173	198	211	214	316	484	614	680	630	4170
JUIN	Dir S	0	0	0	0	0	0	9	114	243	351	416	402	1779
-	Glo G	61	103	140	171	194	206	216	330	459	552	598	534	3911
-	G /vitr	48	81	111	135	153	162	164	211	331	441	493	457	3094
-	Glo G *	68	108	145	176	199	212	225	356	517	639	709	655	4465
JUIL	Dir S	0	0	0	0	0	0	6	109	250	368	436	411	1794
-	Glo G	57	100	138	170	194	206	213	323	462	563	600	537	3855
-	G /vitr	45	79	109	134	153	162	163	204	323	447	503	459	3038
-	Glo G *	65	106	142	174	197	210	218	338	495	615	671	617	4213
AOUT	Dir S	0	0	0	0	0	0	0	57	204	329	397	353	1433
-	Glo G	44	90	130	163	185	201	201	254	399	507	544	457	3219
-	G /vitr	35	71	102	129	148	158	158	167	267	391	451	370	2589
-	Glo G *	51	95	134	166	190	204	204	252	421	547	601	522	3509
SEPT	Dir S	0	0	0	0	0	0	0	6	92	190	237	172	710
-	Glo G	25	72	113	146	169	181	181	176	257	340	358	253	2294
-	G /vitr	20	56	89	115	134	143	143	135	164	246	287	212	1764
-	Glo G *	29	78	118	151	176	189	189	165	305	436	485	352	2733
OCTO	Dir S	0	0	0	0	0	0	0	0	33	136	181	65	416
-	Glo G	7	49	92	127	151	163	163	151	165	251	266	95	1680
-	G /vitr	6	39	73	100	119	129	129	119	110	159	197	76	1255
-	Glo G *	8	55	96	129	153	165	165	153	177	300	337	126	1864
NOVE	Dir S	0	0	0	0	0	0	0	0	3	55	84	10	152
-	Glo G	1	27	69	103	126	138	138	126	105	136	135	16	1121
-	G /vitr	1	21	55	81	100	109	109	100	82	79	87	11	835
-	Glo G *	1	31	74	106	129	141	141	129	112	176	199	24	1263
DECE	Dir S	0	0	0	0	0	0	0	0	0	37	60	0	97
-	Glo G	0	17	58	92	116	128	128	116	92	102	93	0	942
-	G /vitr	0	13	46	73	92	101	101	92	73	57	51	0	699
-	Glo G *	0	19	62	94	116	128	128	116	94	119	121	0	997
A21+3::asa		17-18	16-17	15-16	14-15	13-14	12-13	VERTICAL	NORD-EST		<<<--- TR.HOR.			JOURNEE Wh/m2

Solar Irradiation on North vertical surface.
Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 216.

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*********************        Energie (en Wh/m2)          ====================          ASA/m.c.*epau
* 21 - GHARDAIA      *       incidente sur le PLAN  VERTICAL NORD         (jem)        -------------
*********************        par tranche horaire         ====================          p:(+180,+000)
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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	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	0	22	65	100	124	136	136	124	100	65	22	0	894
-	G /vitr	0	17	51	79	98	108	108	98	79	51	17	0	706
-	Glo G *	0	25	68	100	123	134	134	123	100	68	25	0	900
FEVR	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	4	43	89	125	150	163	163	150	125	89	43	4	1148
-	G /vitr	3	34	70	99	119	129	129	119	99	70	34	3	938
-	Glo G *	5	47	89	121	145	158	158	145	121	89	47	5	1130
MARS	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	18	68	112	148	174	187	187	174	148	112	68	18	1414
-	G /vitr	14	53	89	117	137	147	147	137	117	89	53	14	1114
-	Glo G *	20	70	111	144	169	182	182	169	144	111	70	20	1392
AVRI	Dir S	27	0	0	0	0	0	0	0	0	0	0	27	84
-	Glo G	73	88	130	164	188	201	201	188	164	130	88	73	1735
-	G /vitr	39	69	102	129	149	158	158	149	129	102	69	39	1314
-	Glo G *	88	91	130	163	188	202	202	188	163	130	91	88	1790
MAI	Dir S	94	45	2	0	0	0	0	0	0	2	45	94	493
-	Glo G	167	152	141	171	195	207	207	195	171	141	152	167	2260
-	G /vitr	97	92	110	135	154	163	163	154	135	110	92	97	1629
-	Glo G *	204	169	144	173	198	211	211	198	173	144	169	204	2452
JUIN	Dir S	127	84	22	0	0	0	0	0	0	22	84	127	670
-	Glo G	211	201	167	171	194	206	206	194	171	167	201	211	2606
-	G /vitr	134	117	115	135	153	162	162	153	135	115	117	134	1652
-	Glo G *	255	228	176	176	199	212	212	199	176	176	228	255	2868
JUIL	Dir S	119	73	11	0	0	0	0	0	0	11	73	119	564
-	Glo G	197	184	151	170	194	206	206	194	170	151	184	197	2438
-	G /vitr	120	105	111	134	153	162	162	153	134	111	105	120	1732
-	Glo G *	226	200	157	174	197	210	210	197	174	157	200	226	2612
AOUT	Dir S	59	12	0	0	0	0	0	0	0	0	12	59	194
-	Glo G	114	103	130	163	188	201	201	188	163	130	103	114	1660
-	G /vitr	59	72	102	129	148	158	158	148	129	102	72	59	1332
-	Glo G *	131	111	134	166	190	204	204	190	166	134	111	131	1970
SEPT	Dir S	1	0	0	0	0	0	0	0	0	0	0	1	4
-	Glo G	26	72	113	146	169	181	181	169	146	113	72	26	1419
-	G /vitr	20	56	89	115	134	143	143	134	115	89	56	20	1116
-	Glo G *	32	78	118	151	176	189	189	176	151	118	78	32	1494
OCTO	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	7	49	92	127	151	163	163	151	127	92	49	7	1178
-	G /vitr	6	39	73	100	119	129	129	119	100	73	39	6	932
-	Glo G *	8	55	96	129	153	165	165	153	129	96	55	8	1212
NOVE	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	1	27	69	103	126	138	138	126	103	69	27	1	928
-	G /vitr	1	21	55	81	100	109	109	100	81	55	21	1	734
-	Glo G *	1	31	74	106	129	141	141	129	106	74	31	1	764
DECE	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	0	17	58	92	116	128	128	116	92	58	17	0	822
-	G /vitr	0	13	46	73	92	101	101	92	73	46	13	0	650
-	Glo G *	0	19	62	94	116	128	128	116	94	62	19	0	638
AZI+4::asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE	/	12 Heures	(Midi	TSV)		JOURNEE Wh/m2

Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 217.

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*********************          Energie (en Wh/m2)       ====================          ASA/M.E.Kepau
* 21 - GHARDAIA      *         incidente sur le PLAN    SUD / INCLIN.=LATIT.   (jen)  ============
*********************          par tranche horaire      ====================          p:(+000,+958)
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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	7	136	321	475	584	640	640	584	475	321	136	7	4326
-	Glo G	10	185	423	622	764	838	838	764	622	423	185	10	5684
-	G /vitr	6	131	343	527	655	720	720	655	527	343	131	6	4764
-	Glo G *	15	239	527	763	929	1015	1015	929	763	527	239	15	6976
FEVR	Dir S	29	201	402	572	694	757	757	694	572	402	201	29	5310
-	Glo G	41	266	520	736	892	974	974	892	736	520	266	41	6858
-	G /vitr	21	190	426	626	766	838	838	766	626	426	190	21	5734
-	Glo G *	50	311	595	831	1000	1088	1088	1000	831	595	311	50	7750
MARS	Dir S	52	225	414	577	693	754	754	693	577	414	225	52	5430
-	Glo G	79	310	554	765	919	1000	1000	919	765	554	310	79	7254
-	G /vitr	40	224	455	651	789	860	860	789	651	455	224	40	6038
-	Glo G *	93	359	634	868	1036	1124	1124	1036	868	634	359	93	8228
AVRI	Dir S	60	219	389	534	639	694	694	639	534	389	219	60	5070
-	Glo G	104	321	544	738	882	957	957	882	738	544	321	104	7098
-	G /vitr	56	231	445	627	755	821	821	755	627	445	231	56	5874
-	Glo G *	120	375	634	856	1018	1103	1103	1018	856	634	375	120	8216
MAI	Dir S	62	214	373	511	616	663	663	616	511	373	214	62	4888
-	Glo G	117	322	531	713	849	920	920	849	713	531	322	117	6926
-	G /vitr	64	229	431	603	726	789	789	726	603	431	229	64	5702
-	Glo G *	139	367	607	813	955	1045	1045	955	813	607	367	139	7874
JUIN	Dir S	62	211	367	501	599	651	651	599	501	367	211	62	4782
-	Glo G	119	317	519	696	828	897	897	828	696	519	317	119	6724
-	G /vitr	66	223	419	587	707	768	768	707	587	419	223	66	5565
-	Glo G *	132	356	583	780	925	1002	1002	925	780	583	356	132	7588
JUIL	Dir S	65	227	399	548	656	713	713	656	548	399	227	65	5216
-	Glo G	118	326	542	731	872	947	947	872	731	542	326	118	7093
-	G /vitr	64	230	438	618	747	812	812	747	618	438	230	64	5818
-	Glo G *	128	352	580	778	924	1001	1001	924	778	580	352	128	7554
AOUT	Dir S	64	235	421	583	702	764	764	702	583	421	235	64	5538
-	Glo G	108	328	559	763	914	994	994	914	763	559	328	108	7342
-	G /vitr	57	234	457	648	785	855	855	785	648	457	234	57	6089
-	Glo G *	117	353	594	803	957	1038	1038	957	803	594	353	117	7740
SEPT	Dir S	41	172	320	450	544	593	593	544	450	320	172	41	4240
-	Glo G	76	267	472	651	783	852	852	783	651	472	267	76	6204
-	G /vitr	41	195	387	552	670	730	730	670	552	387	195	41	5152
-	Glo G *	96	340	597	818	980	1065	1065	980	818	597	340	96	7794
OCTO	Dir S	27	173	348	500	610	668	668	610	500	348	173	27	4652
-	Glo G	42	246	475	673	819	895	895	819	673	475	246	42	6300
-	G /vitr	22	177	389	573	702	769	769	702	573	389	177	22	5264
-	Glo G *	53	301	570	799	984	1051	1051	984	799	570	301	53	7476
NOVE	Dir S	6	113	261	387	477	524	524	477	387	261	113	6	3536
-	Glo G	11	169	374	549	675	741	741	675	549	374	169	11	5038
-	G /vitr	6	121	305	465	578	635	635	578	465	305	121	6	4220
-	Glo G *	16	241	520	752	917	1002	1002	917	752	520	241	16	6896
DECE	Dir S	0	110	298	452	561	618	618	561	452	298	110	0	4078
-	Glo G	0	152	393	591	732	805	805	732	591	393	152	0	5346
-	G /vitr	0	108	318	500	627	692	692	627	500	318	108	0	4490
-	Glo G *	0	195	490	723	887	972	972	887	723	490	195	0	6534
A21+S::asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE	//	12 heures	(Midi TSV)			JOURNEE Wh/m2

Daily Solar Irradiance on South surface with variable inclination.
Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 218.

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* 21 - GHARDAIA    *          )) ETUDE POUR CAPTEURS PLANS ((          ASA/M.C.*epau
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                                                                       p:(+000,0/90)
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Energie (en Wh/m2) QUOTIDIENNE sur un Plan SUD d'inclinaison variable ============= | Angle ==

PLAN		VERTC									HORIZ.	O.A.C.	O.M.R.	
inclinaison:		90	80	70	60	50	40	30	20	10	0	33	---->Incl	
Gamma	:	0	10	20	30	40	50	60	70	80	90	57	Gamma	
*														
JANVIER	G :	5724	6118	6344	6406	6296	6020	5580	5002	4290	3476	5714	29	61
Htm = 37	G/v:	4786	5160	5374	5426	5326	5066	4658	4106	3430	2652	4784	28	62
-	Gcp:	4412	4802	5024	5080	4982	4724	4320	3776	3096	2332	4446	29	61
FEVRIER	G :	6018	6602	7016	7248	7288	7140	6804	6296	5628	4818	6912	37	53
Htm = 45	G/v:	4870	5452	5854	6076	6120	5982	5674	5202	4578	3812	5772	37	53
-	Gcp:	4394	5006	5430	5656	5702	5576	5276	4812	4188	3426	5372	38	52
MARS	G :	5125	5886	6508	6968	7258	7366	7288	7026	6592	5992	7326	51	39
Htm = 56	G/v:	3874	4662	5290	5742	6028	6134	6068	5834	5436	4890	6102	51	39
-	Gcp:	3398	4186	4802	5304	5590	5702	5646	5418	5026	4478	5676	52	38
AVRIL	G :	3692	4572	5360	6032	6566	6940	7154	7212	7092	6806	7110	68	22
Htm = 67	G/v:	2558	3396	4182	4844	5364	5730	5934	5984	5878	5624	5894	68	22
-	Gcp:	2214	2976	3744	4414	4942	5306	5516	5560	5460	5208	5474	68	22
MAI	G :	2792	3662	4498	5326	6046	6632	7076	7383	7528	7496	6964	83	7
Htm = 76	G/v:	1854	2558	3376	4164	4858	5422	5840	6114	6242	6226	5740	84	6
-	Gcp:	1636	2220	2968	3730	4426	4990	5410	5678	5804	5786	5310	84	6
JUIN	G :	2364	3164	4036	4874	5674	6348	6896	7328	7590	7666	6750	90	0
Htm = 81	G/v:	1594	2140	2932	3750	4504	5158	5674	6056	6300	6396	5546	90	0
-	Gcp:	1426	1862	2556	3328	4078	4732	5246	5620	5858	5948	5120	90	0
JUILLET	G :	2590	3460	4366	5248	6058	6730	7262	7668	7890	7914	7126	90	0
Htm = 79	G/v:	1704	2360	3210	4060	4838	5468	5992	6348	6554	6608	5870	90	0
-	Gcp:	1516	2042	2800	3620	4390	5048	5548	5902	6098	6146	5425	90	0
AOUT	G :	3322	4234	5130	5922	6584	7088	7430	7614	7612	7422	7348	75	15
Htm = 72	G/v:	2204	3062	3928	4706	5350	5840	6168	6328	6328	6174	6094	75	15
-	Gcp:	1910	2656	3480	4258	4908	5404	5728	5890	5890	5730	5656	75	15
SEPTEMBRE	G :	3632	4524	5116	5594	5938	6142	6198	6106	5866	5485	6194	59	31
Htm = 61	G/v:	2794	3498	4100	4568	4902	5100	5156	5076	4856	4516	5152	59	31
-	Gcp:	2430	3110	3716	4198	4538	4734	4796	4718	4506	4162	4792	59	31
OCTOBRE	G :	5064	5646	6092	6388	6520	6482	6284	5926	5422	4786	6354	43	47
Htm = 49	G/v:	4010	4604	5046	5328	5452	5424	5244	4914	4448	3850	5308	43	47
-	Gcp:	3580	4196	4654	4948	5074	5054	4878	4560	4092	3490	4942	44	46
NOVEMBRE	G :	4786	5156	5398	5504	5464	5284	4972	4536	3982	3336	5070	32	58
Htm = 40	G/v:	3962	4322	4548	4644	4604	4438	4144	3728	3210	2592	4238	32	58
-	Gcp:	3626	4008	4240	4334	4300	4136	3848	3436	2912	2302	3938	32	58
DECEMBRE	G :	5462	5818	6022	6064	5940	5668	5244	4684	4002	3220	5374	28	62
Htm = 35	G/v:	4604	4942	5134	5172	5064	4808	4408	3868	3202	2430	4528	28	62
-	Gcp:	4272	4624	4816	4856	4750	4494	4092	3548	2876	2122	4218	28	62
*														
ANNEE	G e:	5370	6659	7794	8725	9410	9808	9924	9782	9344	8624	9912	59	30
Htmm= 58	G *:	4994	5777	6451	6984	7352	7531	7524	7341	6972	6425	7540	55	35
Lat.= 32	G :	4222	4896	5484	5959	6300	6485	6516	6401	6128	5707	6520	57	33
-	G/v:	3227	3839	4408	4868	5197	5381	5413	5298	5042	4653	5418	57	33
-	Gcp:	2894	3467	4015	4472	4803	4990	5025	4911	4654	4266	5030	57	33
En. captee / an														
kWh/m2	Gcp:	1056	1265	1465	1632	1753	1821	1834	1793	1699	1557	1836	^^	^^
MJ /m2	Gcp:	3803	4556	5276	5876	6311	6557	6603	6453	6115	5666	6609	OAC Ga	In

D121::asa

):) Gamma : Angle de la normale au plan avec le plan horizontal. Gamma+Inclinaison = 90 degres
) O.A.C. : angle Optimum sur l'Annee pour le Capteur
) O.M.R. : angle Optimum pour le Mois considere pour le Rayonnement considere
) Htm : Hauteur du Soleil a Midi / Htmm : Moyenne annuelle, Htmm = 90-Lat., Lat voir p. 210

Complementary data.
Source: "Atlas solaire de l'Algerie." M. Capderou. Volume 2, p. 219.

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* 21 - GHARDAIA    *
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DIVERSES DONNEES COMPLEMENTAIRES

ASA/M.C.*epau

======================== POUR LES 1, 11 ET 21 DU MOIS | ======= POUR LE JOUR MOYEN DU MOIS

		DUREE du jour	--HEURE T.S.V.-- Lever &	Coucher	--HEURE LEGALE-- Lever &	Coucher		JOUR CLAIR (j.c) Trouble atmosph.		J.ENSOLEIL MOYEN(jem)
JANV	1	9h55mn	7h03mn	16h57mn	7h42mn	17h36mn	JANV	T1=0.90	T3=1.58	Sigma=0.75
-	11	10h02mn	6h59mn	17h01mn	7h38mn	17h40mn	-	T2=0.41	Tm=1.81	K1=0.71
-	21	10h13mn	6h54mn	17h06mn	7h33mn	17h46mn	-	T'=1.31	TM=2.46	K0=0.62
FEVR	1	10h29mn	6h45mn	17h15mn	7h25mn	17h54mn	FEVR	T1=0.90	T3=1.59	Sigma=0.83
-	11	10h46mn	6h37mn	17h23mn	7h16mn	18h02mn	-	T2=0.42	Tm=1.82	K1=0.78
-	21	11h05mn	6h28mn	17h32mn	7h07mn	18h11mn	-	T'=1.32	TM=2.59	K0=0.68
MARS	1	11h20mn	6h20mn	17h40mn	6h59mn	18h19mn	MARS	T1=0.90	T3=1.65	Sigma=0.81
-	11	11h40mn	6h10mn	17h50mn	6h49mn	18h29mn	-	T2=0.50	Tm=1.93	K1=0.76
-	21	12h00mn	6h00mn	18h00mn	6h39mn	18h39mn	-	T'=1.40	TM=2.85	K0=0.68
AVRI	1	12h22mn	5h49mn	18h11mn	6h28mn	18h50mn	AVRI	T1=0.90	T3=1.76	Sigma=0.77
-	11	12h42mn	5h39mn	18h21mn	6h18mn	19h00mn	-	T2=0.64	Tm=2.12	K1=0.72
-	21	13h00mn	5h30mn	18h30mn	6h09mn	19h09mn	-	T'=1.54	TM=3.21	K0=0.65
MAI	1	13h18mn	5h21mn	18h39mn	6h00mn	19h18mn	MAI	T1=0.90	T3=1.89	Sigma=0.78
-	11	13h34mn	5h13mn	18h47mn	5h52mn	19h26mn	-	T2=0.81	Tm=2.35	K1=0.74
-	21	13h47mn	5h06mn	18h54mn	5h45mn	19h33mn	-	T'=1.71	TM=3.57	K0=0.66
JUIN	1	13h59mn	5h01mn	18h59mn	5h40mn	19h38mn	JUIN	T1=0.90	T3=1.99	Sigma=0.80
-	11	14h05mn	4h57mn	19h03mn	5h36mn	19h42mn	-	T2=0.94	Tm=2.53	K1=0.77
-	21	14h08mn	4h56mn	19h04mn	5h35mn	19h43mn	-	T'=1.84	TM=3.82	K0=0.66
JUIL	1	14h06mn	4h57mn	19h03mn	5h36mn	19h42mn	JUIL	T1=0.90	T3=2.07	Sigma=0.87
-	11	14h00mn	5h00mn	19h00mn	5h39mn	19h39mn	-	T2=1.05	Tm=2.67	K1=0.86
-	21	13h50mn	5h05mn	18h55mn	5h44mn	19h34mn	-	T'=1.95	TM=4.00	K0=0.69
AOUT	1	13h36mn	5h12mn	18h48mn	5h51mn	19h27mn	AOUT	T1=0.90	T3=2.07	Sigma=0.89
-	11	13h21mn	5h20mn	18h40mn	5h59mn	19h20mn	-	T2=1.04	Tm=2.66	K1=0.88
-	21	13h04mn	5h28mn	18h32mn	6h07mn	19h11mn	-	T'=1.94	TM=3.95	K0=0.69
SEPT	1	12h44mn	5h38mn	18h22mn	6h17mn	19h01mn	SEPT	T1=0.90	T3=2.01	Sigma=0.88
-	11	12h24mn	5h48mn	18h12mn	6h27mn	18h51mn	-	T2=0.96	Tm=2.55	K1=0.65
-	21	12h05mn	5h58mn	18h02mn	6h37mn	18h41mn	-	T'=1.86	TM=3.70	K0=0.58
OCTO	1	11h45mn	6h08mn	17h52mn	6h47mn	18h32mn	OCTO	T1=0.90	T3=1.89	Sigma=0.76
-	11	11h25mn	6h17mn	17h43mn	6h56mn	18h22mn	-	T2=0.81	Tm=2.35	K1=0.74
-	21	11h06mn	6h27mn	17h33mn	7h06mn	18h12mn	-	T'=1.72	TM=3.30	K0=0.62
NOVE	1	10h46mn	6h37mn	17h23mn	7h16mn	18h02mn	NOVE	T1=0.90	T3=1.76	Sigma=0.63
-	11	10h29mn	6h46mn	17h14mn	7h25mn	17h54mn	-	T2=0.65	Tm=2.13	K1=0.60
-	21	10h14mn	6h53mn	17h07mn	7h32mn	17h46mn	-	T'=1.55	TM=2.88	K0=0.55
DECE	1	10h03mn	6h59mn	17h01mn	7h38mn	17h40mn	DECE	T1=0.90	T3=1.66	Sigma=0.75
-	11	9h55mn	7h02mn	16h58mn	7h41mn	17h37mn	-	T2=0.52	Tm=1.96	K1=0.72
-	21	9h52mn	7h04mn	16h56mn	7h43mn	17h35mn	-	T'=1.42	TM=2.60	K0=0.60

C21::asa

Pour les coeff. T1, T2, ... du Trouble atmospherique , voir ATLAS SOLAIRE DE L'ALGERIE / Tome 1
)))) Sigma : Fraction d'Insolation (moyenne mensuelle) MESUREE par la Station meteorologique de GHARDAIA)))) Pour coeff. K0 = (G_ /G_e) et K1 = (S_ /S_*), voir ici pages 210 et 211

Appendix : 3-2-A :

According to Fanger, the term A_{eff} from equation :

$$H_r = A_{eff} \cdot \varepsilon \cdot \sigma\, ((\theta_{cl} + 273)^4 - (\theta_{mrt} + 273)^4)$$

can be written as:

$$A_{eff} = F_{eff} * F_{cl} * A_{du}$$

The value of F_{eff} found by Fanger is: 0.696 for a sedentary body posture and 0.725 for a standing posture and were seemingly independent of sex, weight, height and Dudois area. The difference between the two F_{eff} values for two postures being very small, a mean value of 0.71 can be used as a reasonable approximation in the expression for radiation heat exchange.

For the factor F_{cl}, some typical values are given in (Appendix : 3-2-C)

Appendix : 3-2-B :

$$H_c = A_{du} \cdot F_{cl} \cdot h_c\, (\theta_{cl} - \theta_a)$$

Where the heat transfer coefficient, hc, depends on the nature of the convection process. At low air velocities, V< 0.1m/s, free convection takes place for which Nielsen and Pedersen have suggested the following formula: $h_c = 2.38(\theta_{cl} - \theta_a)^{0.25}$.

For higher velocities, V>0.1m/s, forced convection takes place in which cases, $h_c = 12.1(V)^{0.5}$.

This is a reasonably good approximation for seated or standing persons, when the air flow is across the body. For moving persons, the velocity used is the relative velocity. Using loose clothing in a warm environment will permit as much penetration by ambient air as possible. Consequently, the skin loses heat by convection to the air and by radiation to the inner clothing surface. Some of the heat will be lost by convection and the reminder will pass through the clothing to its surface by conduction and then to the environment by convection and radiation.

Appendix :3-2-C :

Clothing ensemble	I_{cl} clo	F_{cl}
Nude	0	1.0
Shorts	0.1	1.0
Typical Tropical Clothing Ensemble: Shorts, open-neck shirt with short sleeves, light socks and sandals.	0.3-0.4	1.05
Light Summer Clothing: Long lightweight trousers, open-neck shirt with short sleeves.	0.5	1.1
Light Working Ensemble: Athletic shorts, woollen socks, cotton work shirt (open-neck), and work trousers, shirt tail out.	0.6	1.1
Typical Business Suit	1.0	1.15
Typical Business Suit + Cotton Coat	1.5	1.15
Light Outdoor Sportswear: Cotton shirt, trousers, T-shirt, shorts, socks, shoes and single ply poplin (cotton and dacron) jacket.	0.9	1.15
Heavy Traditional European Business Suit: Cotton underwear with long legs and sleeves, shirt, woolen socks, shoes, suit including trousers, jacket and vest.	1.5	1.15-1.2