PASSIVE ENERGY DESIGN FOR SCHOOLS IN THE CONSTANTINE REGION OF ALGERIA

by

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"Praise be to GOD the Cherisher and Sustainer of the World"

Abstract

The purpose of this work is to investigate the potential for passive thermal design techniques to preheat and cool school buildings, with emphasis on opaque/ transparent shell design and ventilation characteristics.

The educational policy and the current need for school buildings which accommodate a particualr use during a predetermined period of the day and year, present special problems - winter preheating and summer cooling - in relation to the part Mediterranean part Saharan influenced climate. It provides a favourable subject for the use of passive solar or climate sensitive design with reference to window sizing, shadings and orientation together with transmittance, capacitance, response and ventilation characteristics. In order to quantify the influence of these parameters, it is necessary to analyse both daily and seasonal heating and cooling loads, taking into account cyclical thermal behaviour. The model for analysis is a classroom in a typical modern school with two exposed walls - north-east, relatively unshaded and south-west, protected by an overhang which at the same time roofs an open corridor.

Standard admittance and thermal time constant procedure has been used on a micro computer to predict monthly mean daily equivalent external temperature profiles. The programme contains subroutines to calculate the thermal transmittance (U-value), decrement factor, admittance value

and time lag for multilayer construction. Sinusoidally generated solar resource data, together with estimated incidental or casual gains determine 'heating' and 'cooling' base temperatures at the upper and lower limits of a comfort band. These enable estimates of residual heating/cooling loads required during both unoccupied and occupied periods, based on a simple temperature differential, base temperature minus equivalent external temperature, which takes into account dynamic thermal behaviour.

The study showed that there is no need to heat during the occupied period even during the heating season, whereas heating is required during the unoccupied or the preheating period. With respect to cooling, it also showed the ineffectiveness of summer cross-ventilation due to high external air temperature, even with the application of maximum shading measures.

The conclusion was that mass storage in conjuction with a passive solar thermosiphon loop could avoid winter overheating and fulfil the morning preheat demand, while summer cooling could be met using the same store and delivery system, but separate passive cool air intake and hot exhaust.

CONTENTS

Introduction

Since Algeria's accession to independance, considerable human and material support has been given to the education sector. In spite of this, the rapid increase in the school population, which far exceeds the schools' accommodation due to the growth of migration to the city of Constantine, has laid an important responsibility on the government to build faster. Hence, traditional architectural forms have been abandoned and have continued to take a back seat, while standardisation has been encouraged. This has given the opportunity to architects, engineers and planners from all over the world to express their own ideas and introduce new materials and technologies, which unfortunately take no account of prevailing environmental conditions.

The resultant lack of attention to climate sensitive design or construction techniques, combined with energy-intensive heating, air conditioning and lighting systems, has exacerbated dependance on expensive fossil fuel, which is the prime source of finance of public investment in Algeria. These natural sources are exhaustible, and they should not be burnt freely for simple tasks such as the heating and cooling of buildings. Therefore it is time to re-examine climate-conscious design which was once the norm.

Thus the current need for energy conservation and the improvement of energy performance, has laid an important responsibility on architects and planners to shape their buildings to exploit the local climate to its maximum advantage. Consequently, they should understand the natural environment and its phenomena in order to live in harmony with nature. Climate sensitive design is one approach to this goal. This is therefore the main aim of this study - to provide some guidelines for passive techniques, which will minimise residual auxiliary heating and cooling loads in school buildings.

At the moment, lack of such design techniques is due partly to political and/or economic forces, but partly to professional ignorance with respect to simple thermal analysis methodology. Even steady-state analysis is a barrier to some architects. Hence, taking account of mass influenced, cyclical thermal behaviour in a building, with a specific daytime timetable and known energy input from occupants, is left to intuition rather than quantitative estimates. Specialised consultants, are employed but usually after key architectural decisions are made. The result is that consultants design and size active heating/cooling systems, and of course, generate their fees from so doing. Thus a design system is perpetuated which is against the national interest.

The aim of this work is to use the simplest possible methodology, which will permit a reasonably accurate quantitative appraisal of solar driven cyclical thermal behaviour, recognising the strong potential of mass and ventilation as a means of regulating internal environment. These effects are computed using conceptual temperature differentials which take account of time lag, damping and decrement factor in conjunction with solar and incidental gains - base temperature, surface temperature and equivalent external temperature.

Iterative analysis, always using the same Constantine climate data, can then simply determine the influence of varying design parameters: optimising window area and shading devices, increasing ventilation rate and pre-cooling ventilation air.

The dissertation begins with a review of educational development and systems. It investigates the school age population growth and its effect on the school building needs and type. It also briefly touches on thermal standards, and shortcomings with respect to performance. In Section 2 the semi-arid Continental climate and its characteristics are discussed. Solar radiation, air temperature, humidity, precipitation, sky condition, wind speed and direction, and their correlation have been analysed in order to understand their influences on buildings. The following section outlines the method used to predict heating and cooling loads, taking into account the dynamic thermal behaviour of a typical modern classroom unit. The fourth section examines the result of the analysis of the existing model, hence determining the contribution of climatic characteristics and various building design parameters. The final section proposes a solution whereby the chosen model could be adapted to eliminate both preheating and cooling loads.

Section 1

ANALYSIS OF THE DEVELOPMENT OF EDUCATION AND EDUCATIONAL BUILDINGS

ANALYSIS OF THE DEVELOPMENT OF EDUCATION AND EDUCATIONAL BUILDINGS

1.1 Introduction.

Education inevitably reflects a population's way of life, culture and aspirations.

Algerian education since independence has been indentified by four characteristics: democratic, revolutionary, national and scientific. The policy is to make instruction available to as large a body of people as possible and to give back the Algerian civilisation the place due to it in schools and universities.

The development of school buildings relates to the French colonial period, during which there were two categories of education: Firstly a well developed system catering much more for the French population than Arab (among 20,265 pupils in 1960 just 5392 were Algerian)[1]. Secondly, a religious system was authorised at the level of 'coran' school (Ecole coranique) or Zaouits, from which the 'cooperative des Savants Musulmans' was developed and guided by IBN Badis. Consequently, after independence Algeria was left with a 90% illiterate population. Tables 1.1 and 1.2 appendix 1 illustrate the limited number of schools, which was insufficient to absorb the school age population.

1.2 Algerian Policy Towards Education.

Democratisation has been the basic aim of the Algerian education system since independence. The objectives of this policy were in the first place to make instruction available to all school-age Algerians (6 years old and more) in order to reduce the enormous discrepancy between the different regions; and in the second place to provide scientific and technical cadre in sufficient numbers to enhance the human and material potential of the country and thereby build an up-to-date national economy. Hence heavy investment was allocated to education, and this in turn has contributed to the development of Algerian potential.

1.2.1 Investment.

Considerable initiatives were taken by the new government towards education as a key instrument in furthering the social and economic aims of the country. School building had to play an important role, not only in terms of assisting minor change in society, but also as agencies for an intensive cultural revolution. Although large sums have been allocated to education, Table 1.3 appendix 1, the output of the educational system has remained low in terms of quantity and quality. Both of these factors have severely handicapped government development plans. There are several reasons for this situation:

- The rapid increase in the school population.

- The mismanagement of the educational budget.
- The inability of staff to fully exploit imported equipment and materials.

1.2.2 Development of Educational Systems.

Figure 1.1 illustrates the difference between the two educational systems: the traditional educational system left by the French and current system in Algeria. The latter is known as the fundamental system and is considered to be the cornerstone of totally reformed education. (reformed by the Ministry of Education in 1974)[2]. It is superseding the old primary and middle schools. Its structure and objectives are shown in figures 1.2, 1.3 and 1.4.

1.3 Analysis of Constantine School Buildings - Statistics, Characteristics and Future Strategy.

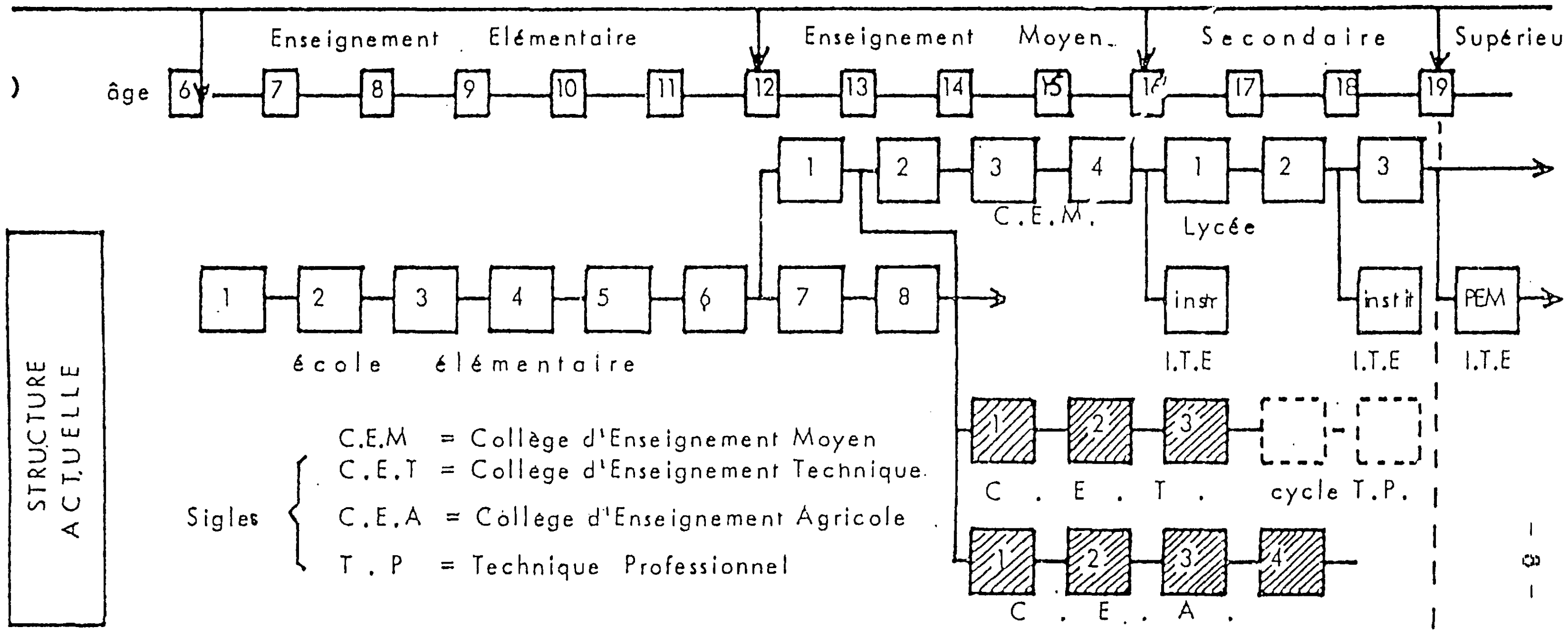
1.3.1 School building need

During the period between the independence in 1963 and the reform of education in 1974, Constantine was facing a position of imbalance between school accommmodation and pupils. Table 1.1 and 1.2 illustrate the increasing number of pupils and the need for schools. Up till 1966 there were 60 schools accommodating 47,163 pupils in 637 classrooms. The rate of occupancy was 74.04%[1] pupils/classroom, whilst in 1976-77 the problem became worse and the occupancy rate reached 92.35%[1] pupils/class. During the recent period (1980-86) which is characterised by the application of the

Figure 1.1

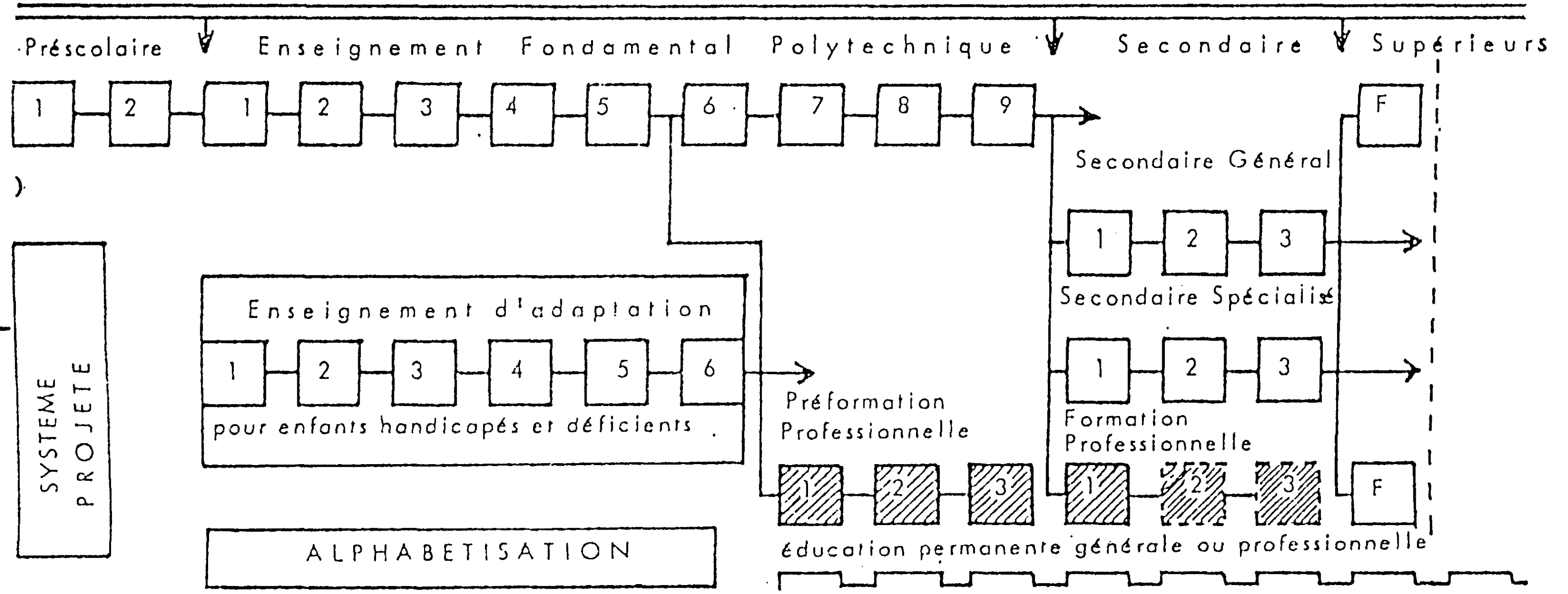
Traditional educational system left by the French

(A)



Projected educational system - Fundamental system -

(B)



Age	Cycle	Duration of Education and Content	Characteristics Psyco-Biologic
6-9 years	Basic Cycle	Duration 3 years. - Reading. - Writing. - Number work (calculations).	- Development of psycho- - Self-control (Moitrise du schema corporel). - Intelligent practice and initiatives. - Social curiosity.
9-12/13 years	Awakening Cycle	Duration 3 years. - Polytechnic education. - Social sciences. - Exact sciences. - Introduction of foreign language. - Sport or physical education.	- Pre-Puberty Period. - Awakening and abstract thought. - Possibility of thought. - Awakening of moral direction (sense). - (Esprit de groupe) To be social.
12/13 - 15/16 years	Orientation Cycle	Duration 3 years. - Polytechnic education. - Scientific education. - Social sciences education.	- Period of puberty. - Ability of reasoning (arguing). - Training of personnal ethic. - Responsibility of Intervention and Participation. - Awakening of professional motivations.

Figure 1.2 Structure of the Fundamental School

Source: Ministere de lenseignement Primaire et secondaire 1974 la reforme scolaire Alger.

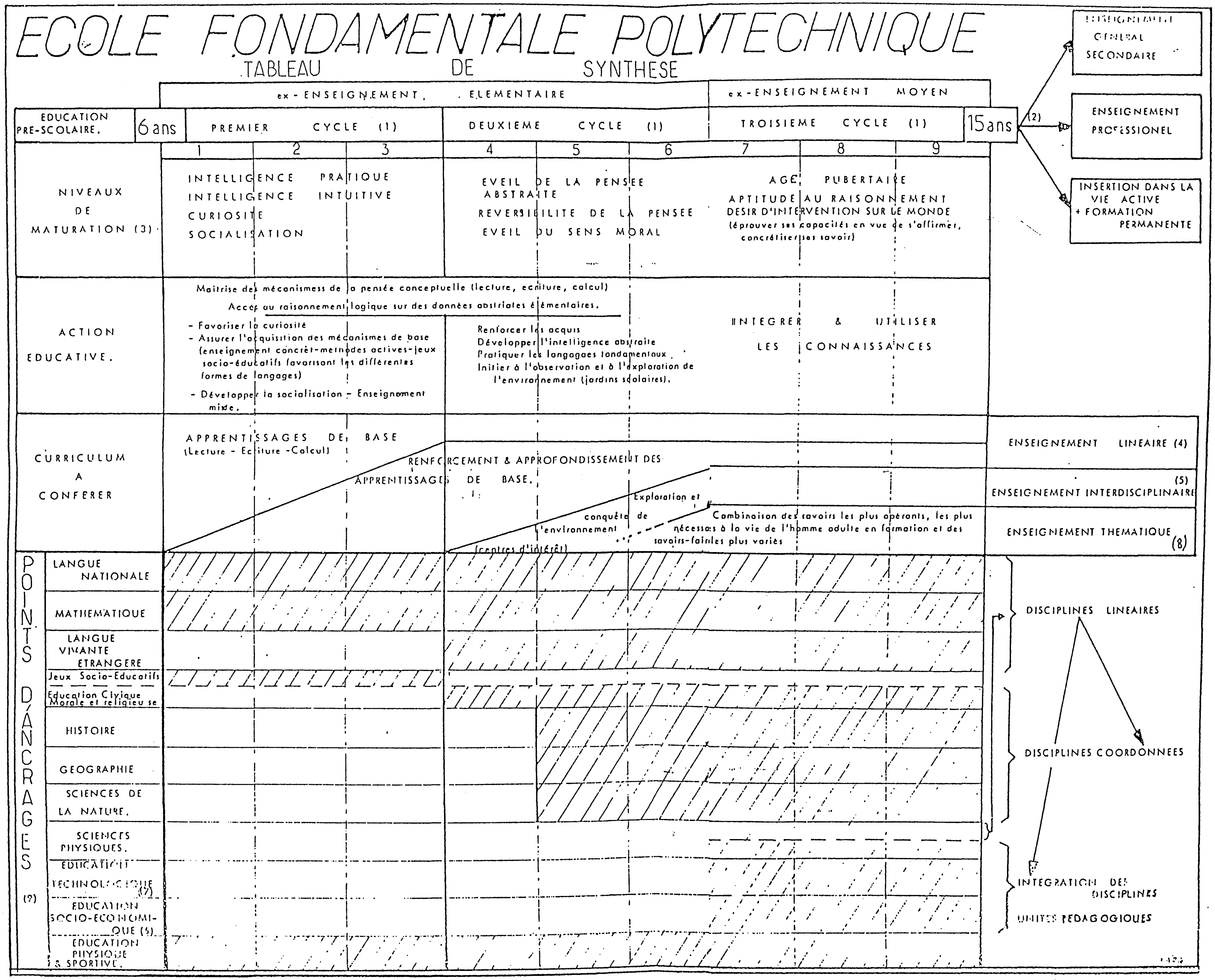


Figure 1.3 Structure of the Fundamental Education.

Source: La Reforme Scolaire - Objectifs de l'Enseignement: Identification des Contenus et des Methods Pedagogiques, Alger 1974.

OBJECTIFS D'ENSEIGNEMENT

	SAVOIR	SAVOIR - FAIRE	SAVOIR - ETRE
LANGUE NATIONALE	- Acquisition des moyens d'expression et des structures de la Langue Arabe - Compréhension de son fonctionnement & de ses caractéristiques - Assimilation de la langue en tant que support de la culture arabo - islamique et moyen d'enracinement.	- COMPETENCE LINGUISTIQUE: MAITRISE - du Discours ORAL & ECRIT (Aptitude à comprendre, à s'exprimer, à communiquer)	- INSERTION SOCIO - CULTURELLE - PARTICIPATION A UNE DYNAMIQUE DE LA LANGUE ARAB - SENS ESTHETIQUE
LANGUE VIVANTE ETRANGERE : I	- ACQUISITION DU VOCABULAIRE & DES STRUCTURES USUELS DE LA LANGUE	- APTITUDE A COMPRENDRE UN MESSAGE ET A S'EXPRIMER CORRECTEMENT DANS CETTE LANGUE .	- OUVERTURE SUR LE MONDE - ACCES A LA CULTURE UNIVERSELLE.
GÉOGRAPHIE	CONNAISSANCE PRECISES SUR LE MILIEU PHYSIQUE, LA GEOGRAPHIE HUMAINE ET POLITIQUE & LA VIE ECONOMIQUE DE L'ALGERIE & D'AUTRES PAYS . A partir du milieu environnant le champ d'étude s'élargira progressivement à la région, au pays, au Maghreb'.........	- LECTURE & REALISATION DE PLANS & CARTES. - COMPREHENSION & INTEPRETATION DE TABLEAUX STATISTIQUES & DIAGRAMMES .	- SE SITUER DANS SON MILIEU GEOGRAPHIQUE, ECONOMIQUE & POLITIQUE . - SITUER UNE REGION DANS UN ENSEMBLE PLUS GRAND
HISTOIRE	CONNAISSANCE DES GRANDS FAITS HISTORIQUES CONCERNANT LES PEUPLES ET DES NATIONS . Par extension concentrique et progressive: Histoire locale, nationale, le Maghreb, le Monde arabe l'Afrique et autres.	- Utilisation des Documents Historiques .	- sens de la perspective de l'Histoire (relier le passé au présent - Développement de l'Amour de la patrie. - Esprit de compréhension envers les autres peuples & les autres civilisations . - Respect du patrimoine Historique . - Goût de l'Esthétique de l'Artisanat Traditionnel .
Etude du milieu			
SCIENCES DE LA NATURE	Etude Elémentaire de types d'Animaux, de Plantes, et des Rochers choisis dans le milieu environnant . — (Classification) - COMPREHENSION DES PHENOMENES SIMPLES DE LA NATURE (Phénomènes Biologiques, Physiques, ...)	- Intervention Rationnelle sur la Nature . - Protection et Amélioration de l'Environnement .	- Respect de la Nature et sens Esthétique .
MATHEMATIQUE	FORMATION INTELLECTUELLE : (Abstraire, généraliser, raisonner inductivement et déductivement synthétiser, clarifier ....)	- Acquisition de l'Outil mathématique indispensable à l'homme du ~~XX~~ ~~ème~~ siècle . - Utilisation concrète de cet Outil dans des situations réelles. (opérations numériques, usage de tables , etc.....) - Prérequis à la construction de l'Edifice Mathématique .	- Savoir Mathématiser une situation (logique, rigueur, ordre, précision) - Développer le Goût de l'Effort et de la Recherche .
SCIENCES PHYSIQUES	FORMATION INTELLECTUELLE : Développement de toutes les facultés de l'Enfant . (Eveil de la curiosité, sens de l'Observation , esprit critique)	- Usage de la Méthode Expérimentale . - Utilisation des lois Physiques à des fins utilitaires . - Intégration des notions mathématiques .	- Attitude Scientifique . - Goût de la Recherche en équipe .
EDUCATION TECHNOLOGIQUE	Savoir réfléchir, observer, rechercher, trier, choisir, ... pour comprendre les mécanismes usuels du Monde Technologique Moderne... Information sur les débouchés et professions etc.....	Esprit pratique, Textérité sensori- motrice pour la Transformation élémentaire de la matière ... Expression graphique et Esthétique (Normalisation, Convention, Lecture du Dessin Technique) etc....	Formation de l'esprit scientifique et Technique . Attitude Expérimentale. Destruction de l'esprit Dogmatique. Goût de la logique de l'analyse, de la synthèse, du travail d'équipe. Amour du Travail Manuel et Intellectuel . Susciter des Vocations Techniques etc.....
EDUCATION PHYSIQ & SPORTIVE	CONNAISSANCE DE SON CORPS . (Possibilités - limites) REGLES DE JEUX ET DE CERTAINS SPORTS .	- Pratique rationnelle de l'Education Physique et de sports. (1 au minimum)	- Respect de la Règle . - Esprit d'Equipe . - Esprit Sportif. - Equilibre Psycho - Moteur .

Figure 1.4 Objectives of the Fundamental Education.

Source: La Reforme Scolaire - Objectifs de l'Enseignement: Identification des Contenus et des Methods Pedagogiques, Alger 1974.

fundamental system, this rate was reduced to 60.6%[3] – see Table 1.4 appendix 1. To reduce the phenomenon of concentration illustrated by figure 1.5, new administrative divisions have been implemented (1983-1984). This is planned to develop new regional and suburban areas and endow them with educational buildings.

1.3.2 School building age and type.

School buildings vary in their age, size, construction and layout. They can be roughly grouped chronologically as pre-war traditional schools, colonial schools, post-war schools and modern schools. The chronology follows a general and architectural trend with the development of the educational system and the way in which schools are used.

Pre-war or traditional schools, initially based on Islamic education were not housed in specific buildings; but when the education became formalised, new buildings attached to the mosque were built (Zaouiat or Madrassa). The architectural conception and the space utilisation are illustrated in figures 1.6, 1.7 and 1.8. The foundation of the first school Madrassa of Constantine in 1774[1] dates to the Turkish period before French colonisation.

The colonial schools were developed during the French period and reached in 1960, 57[1] schools accommodating mainly French pupils. Their form and architecture have in part been determined by responding to French teaching patterns – see figure 1.9.

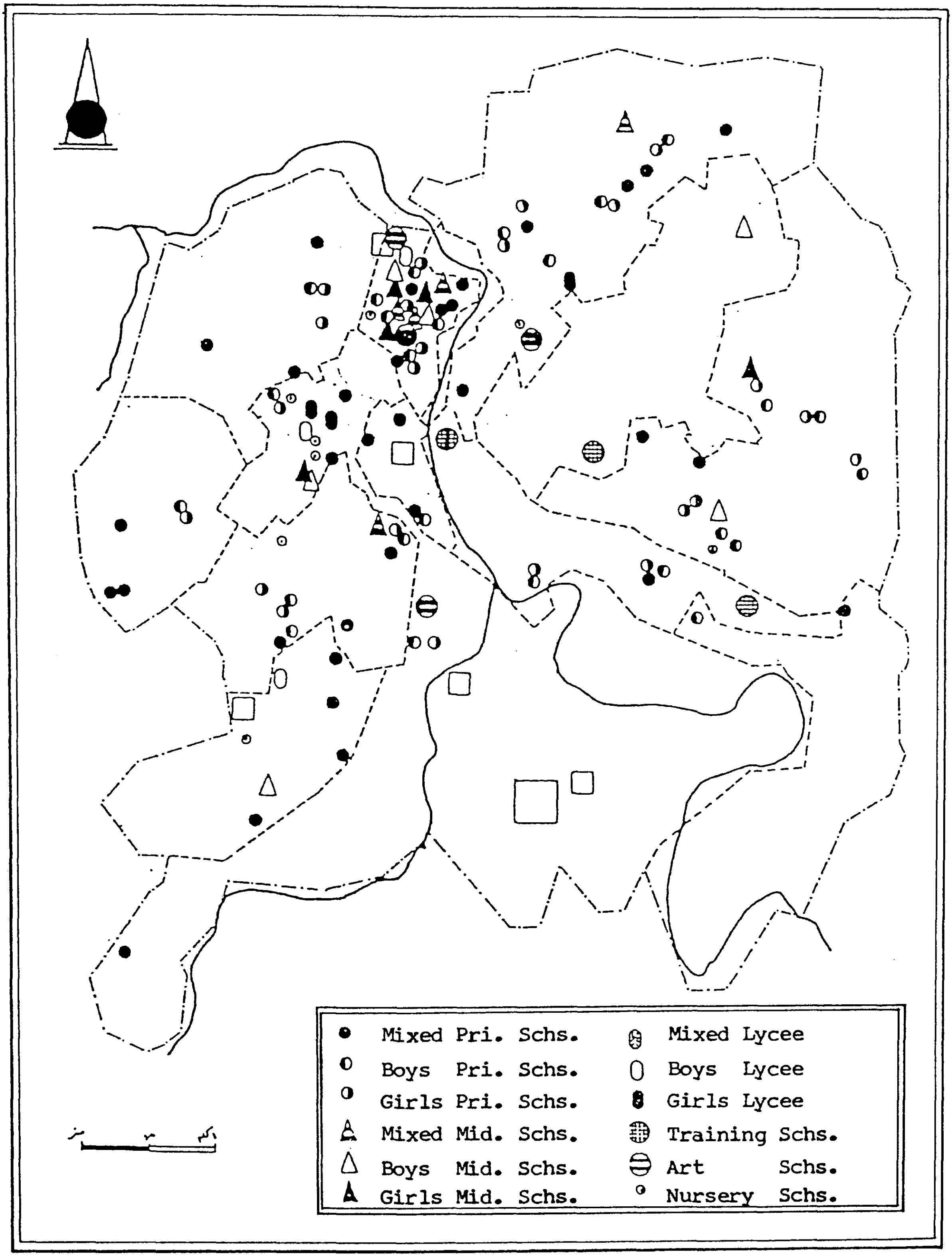
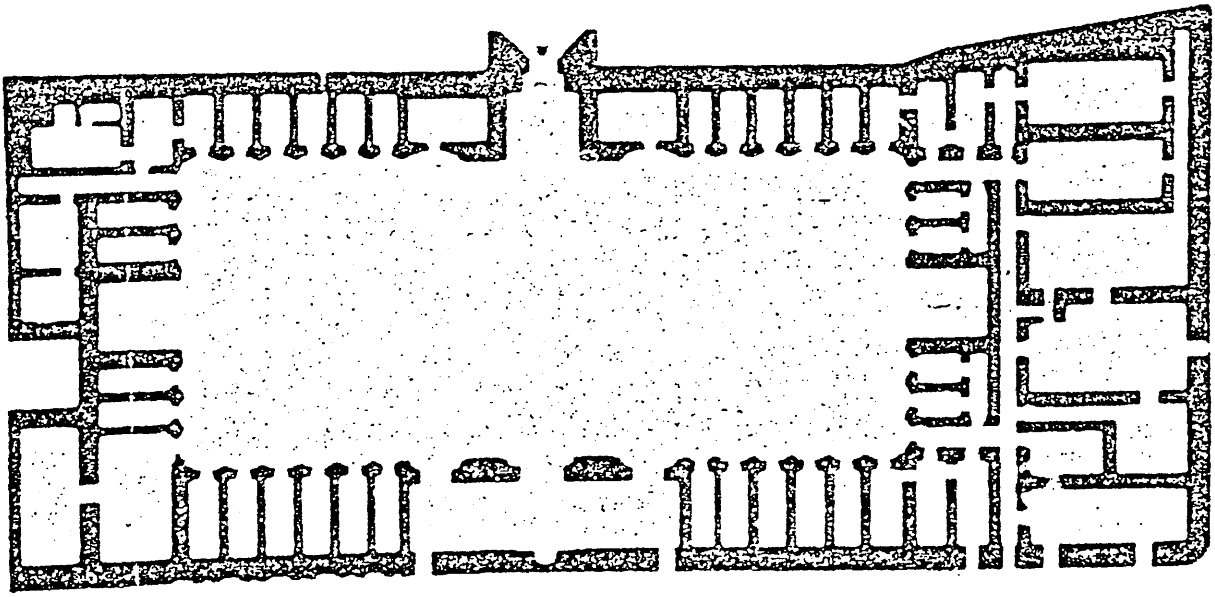
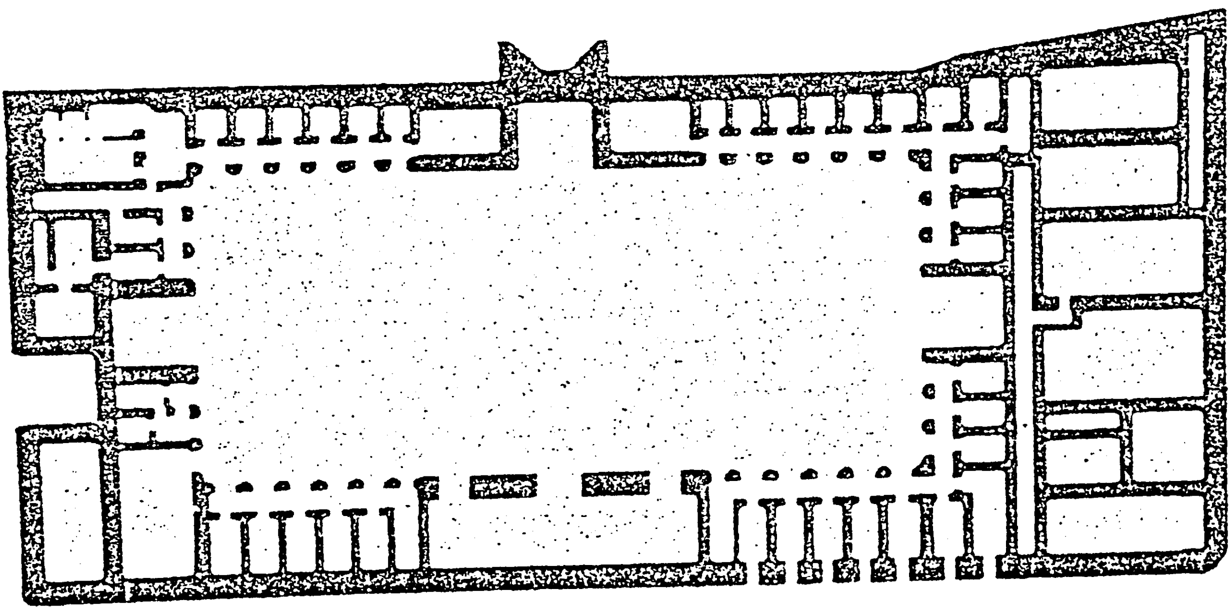


Figure 1.5 School and other educational building distribution in Constantine.

Source: Larouk, M.E. Etude sur la Geographie Urbaine de Constantine ville, O.P.U. ENAL Alger 1984, p. 296.

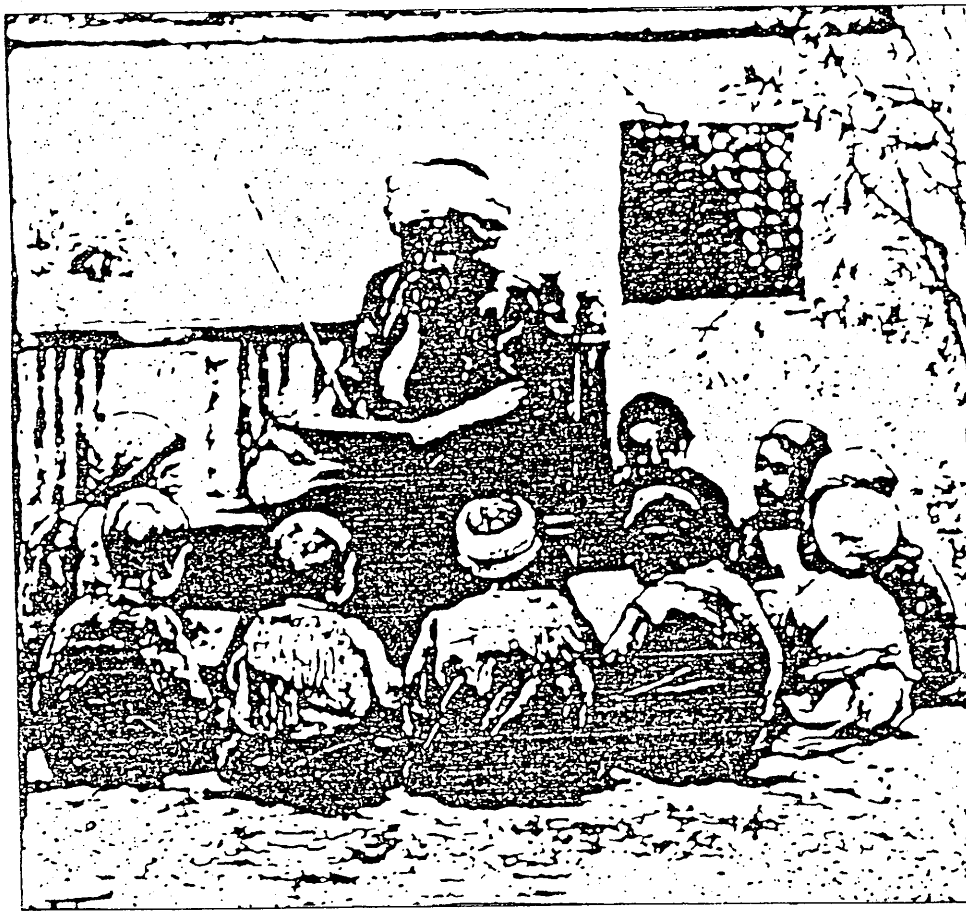


A : Ground floor



B : First floor

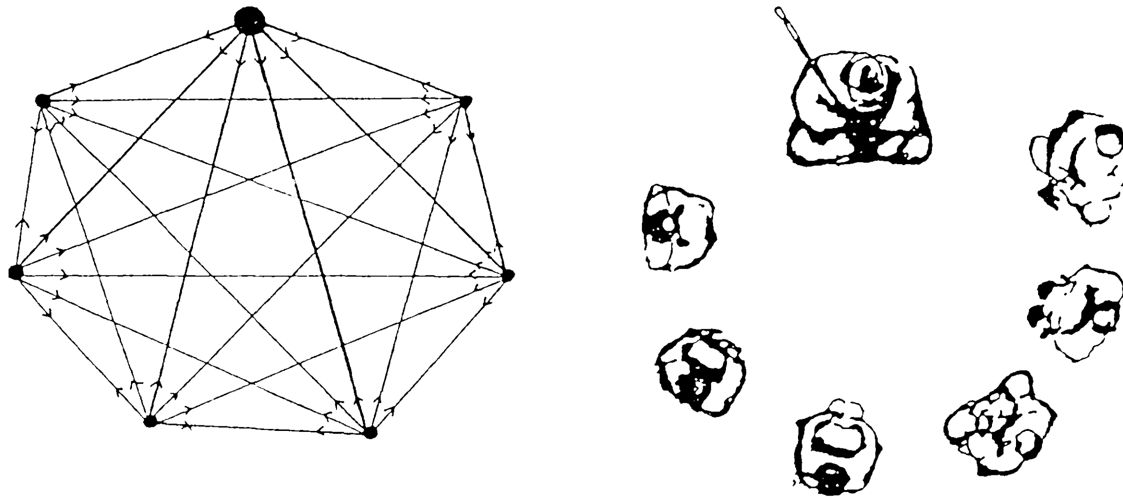
Figure 1.6 El Mustansirya in Baghdad - Example of traditional school.



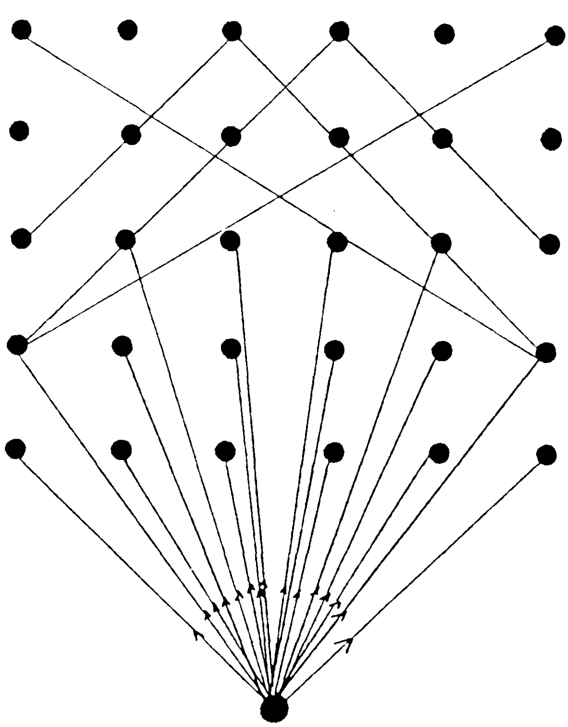
A : Traditional space use

B : Modern use

Figure 1.7 The utilisation of space in traditional and modern schools.



a) Traditional pattern of use of the classroom (Coran School)



b) Modern pattern of use of the classroom

Figure 1.8 Classroom Utilisation.

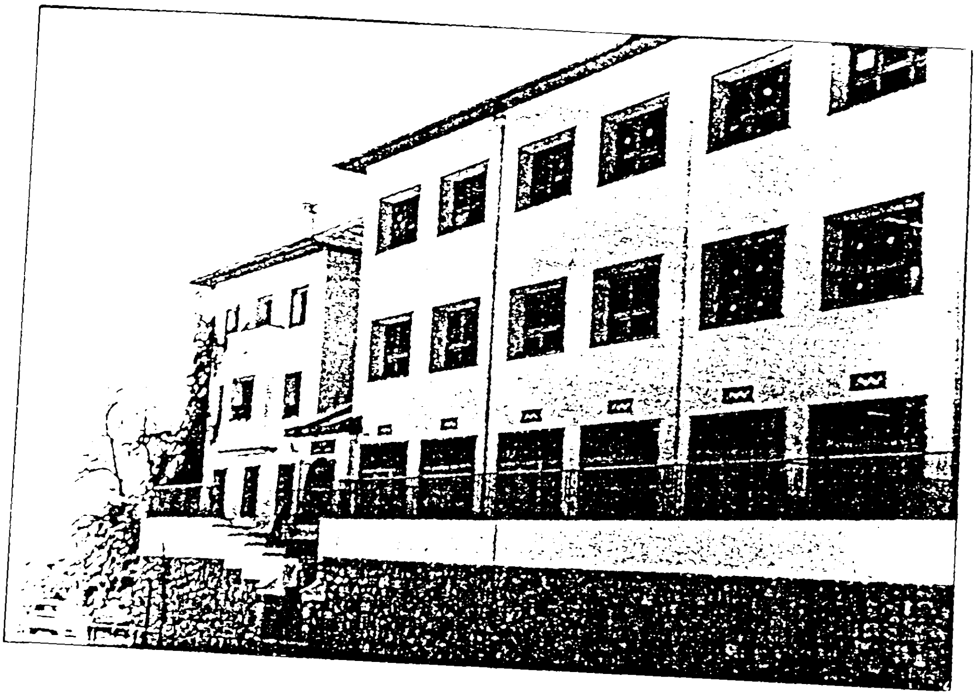


Figure 1.9 Architectural aspect of colonial schools.

In 1963, one year after the independence, Constantine faced the great problem of accommodating 35,834 pupils.[1] Unfortunately to meet this need, modern technology and architecture (heavy-weight and light-weight prefabricated school buildingsin figure 1.10) have been imported blindly from western countries, creating an irrelevant and inefficient environment with respect to Constantine.

With the application of the fundamental educational system, new regulations and guidelines have been established leading to standardised solutions. Figure 1.11 illustrates the type and capacity of schools adapted to different groups of pupils. This type is found particularly in new suburban or rural areas due to large site requirements.

1.3.3 Schools buildings characteristics: Social, economic and thermal.

The responsibility for a newly independent country was in the first place to make instruction available to all school age Algerians. Therefore consideration of either economic or thermal characteristics of school buildings could not be a priority. Hence it may be postulated that present unsatisfactory thermal conditions are linked to social and economic factors in the following respects:

- Rapid growth of school age population led to the use of new materials and techniques to meet the large accommodation demand.

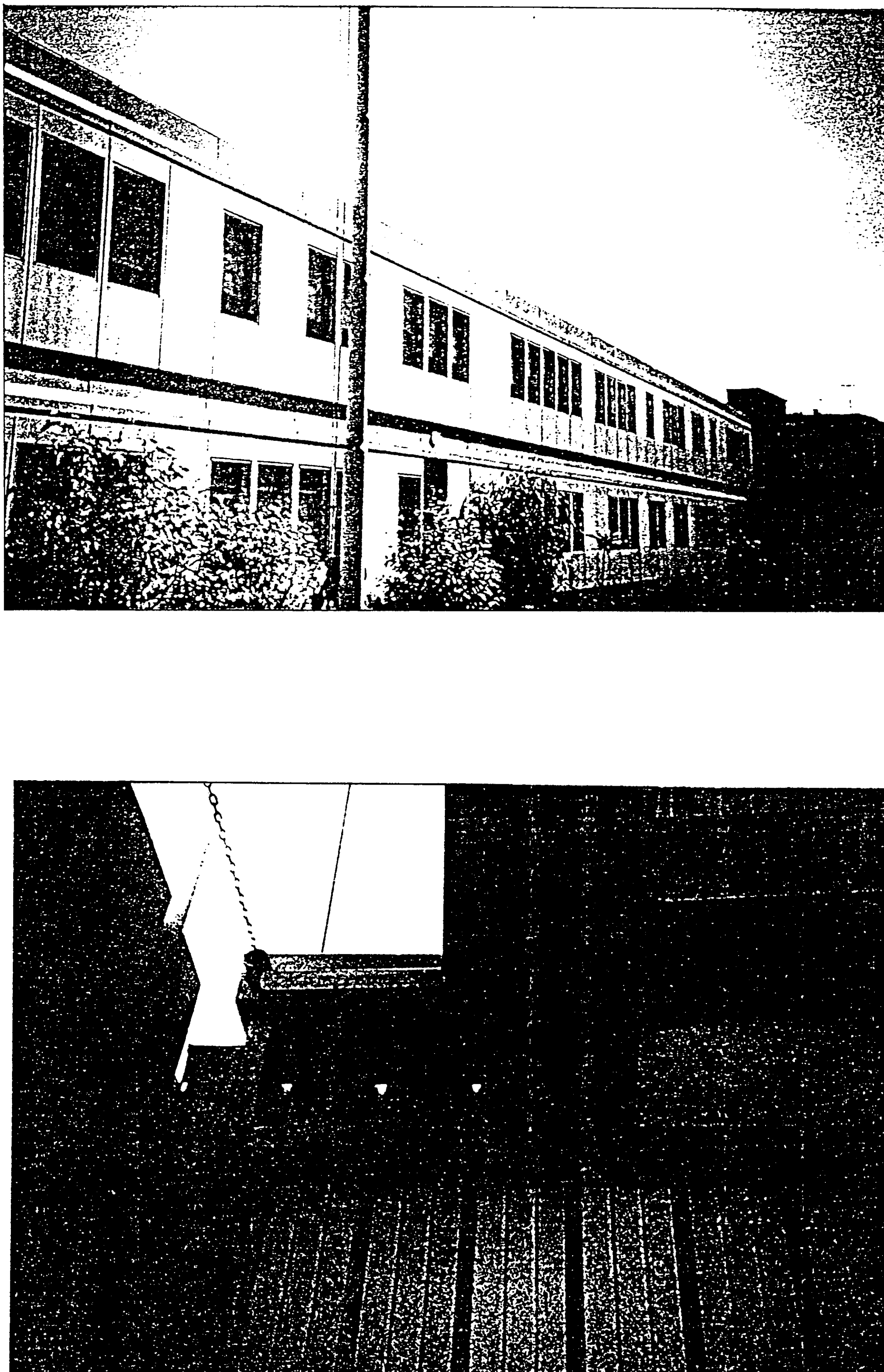


Figure 1.10 Light weight Prefabricated School.

(Portolaso Construction)

TYPE	720	1080	1440(*)
Divisions	18	27	36
Basic cycle	240 (6 x 40)	360 (9 x 40)	480 (12 x 40)
Awakening cycle	240 (6 x 40)	360 (9 x 40)	480 (12 x 40)
Orientation cycle	240 (6 x 40)	360 (9 x 40)	480 (12 x 40)

Figure 1.11 Schools Typology and Divisions

Source: Ministere de l'education Ecole Fondamentale Polytechnique - Aspects structure et Programme de Construction Juin 1980.

* Footnote: The 1440 School type is the limit of proposed scale.

- Many of these materials and techniques have been introduced with little thought to performance in the specific climate of Constantine.
- Their adoption may have undesirable side effects on the economy of the country.
- Initial costs are high, unless with large multiple contracts contributing to their rapid development all over the country.
- Systems can require highly skilled construction personnel who might not be available in the country and have to be expensively imported.
- If one element is damaged (door, window, appliances, walls, etc.) it may be replaced in a traditional way which may affect the standard and thermal performance of the buildings.
- The architectural conception has been realised without taking into consideration the appropriate response to Algerian teaching patterns.
- A social survey was carried out last September in three schools at Constantine in which teachers's comments give the impression that the winter (December to March) is very cold. The problem can be solved by the use of an auxiliary traditional heating, but overheating in summer is not readily ameliorated and school work is thus adversely affected. In addition, the number of pupils in the classroom is very high.

1.3.4 Thermal standards.

By the establishment of school buildings Guideline (Regulations) in 1982 the Ministry of Education and Fundamental Studies has defined the school buildings thermal standards in the following ways:

A. Building orientations have to take into account:

a - The effects of sunshine.

b - The effects of prevailing wind, their speed, frequency, and humidity.

c - Altitude.

d - Characteristics of the construction determine thermal capacity.

e - Provision of natural ventilation.

f - Protection from noise sources.

g - In general educational buildings are oriented North-South to prevent the effects of the sun during the hot season.

B. Classroom dimensions:

a - Number of occupants (40).

b - Area needed: 1.4 m^2 to 1.5 m^2/pupil.

c - Recommended horizontal dimensions

if rectangular shape 8.4 m x 7.2 m or 9 m x 6.6 m.

if square shape 7.8 m x 7.8 m.

d - Ceiling height is 3 m or 3.5 m maximum.

C. Openings.

a - In order to meet the daylighting and the climatic constraints the glazing area is limited between 10 and 15% of the floor area depending on the location.

b - If the windows are located on one side only, the depth of the classroom should not exceed 7.2 m.

c - All windows are double glazed and openable.

D. Ventilation.

a - In order to create comfort conditions, the ventilation required is 4 to 5 m^3/pupil hour.

b - Floor finish

Clay tiles (ceramic material) are required because of their good resistance to chemical attack, to moisture and to the temperature variation.

E. Heating system.

a - To provide 18°C required comfort temperature.

b - The heating system should have thermostats to maintain recommended room temperature.

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Section 2

CONSTANTINE CLIMATE ANALYSIS

2.1 Introduction.

2.2 Climatic elements analysis.

2.2.1 Temperature.

2.2.2 Solar radiation and sunshine hours.

2.2.3 Cloud cover.

2.2.4 Solar radiation related to temperature, sunshine duration and cloud cover.

2.2.5 Relative Humidity.

2.2.6 Rainfall.

2.2.7 Wind speed and direction.

2.2.8 Temperature related to relative humidity evaporation, rainfall, cloud cover and wind.

2.3 Conclusion.

CONSTANTINE CLIMATE ANALYSIS

2.1 Introduction.

The aim of this section is to correlate climate characteristics which are relevant to passive solar heating and cooling design in Constantine. In particular solar radiation and temperature data are required for the thermal analysis in this work; but wind vector, relative humidity and precipitation are also relevant to building design strategy and the maintenance of internal environmental comfort with minimum utilisation of conventional fuels.

Algeria is the middle country of North Africa (The Maghreb) see figure 2.1 which extends over an area of 2,381741[1] square kilometres. Bounded on one side by the Mediterranean for a length of 1,200 km[1], Algeria has common frontiers with Morroco and Moritania on the west, with Mali and Niger on the south and with Libya and Tunisia on the east. It lies in the subtropical high pressure belt between the parallels of 19° and 37° north latitude and between 9° west and 12° east longitude, see figure 2.2.

Algeria's position between the Mediterranean and the Sahara is responsible for the outstanding feature of the climate, which is seasonal constrast. It is characterised by relatively cold winters with considerable rainfall in specific areas due to depressions of temperate latitudes. In summer it is under the influence of the dry and hot wind of a subtropical belt of high pressures, where there is usually abundant sunshine in all months of the year. The

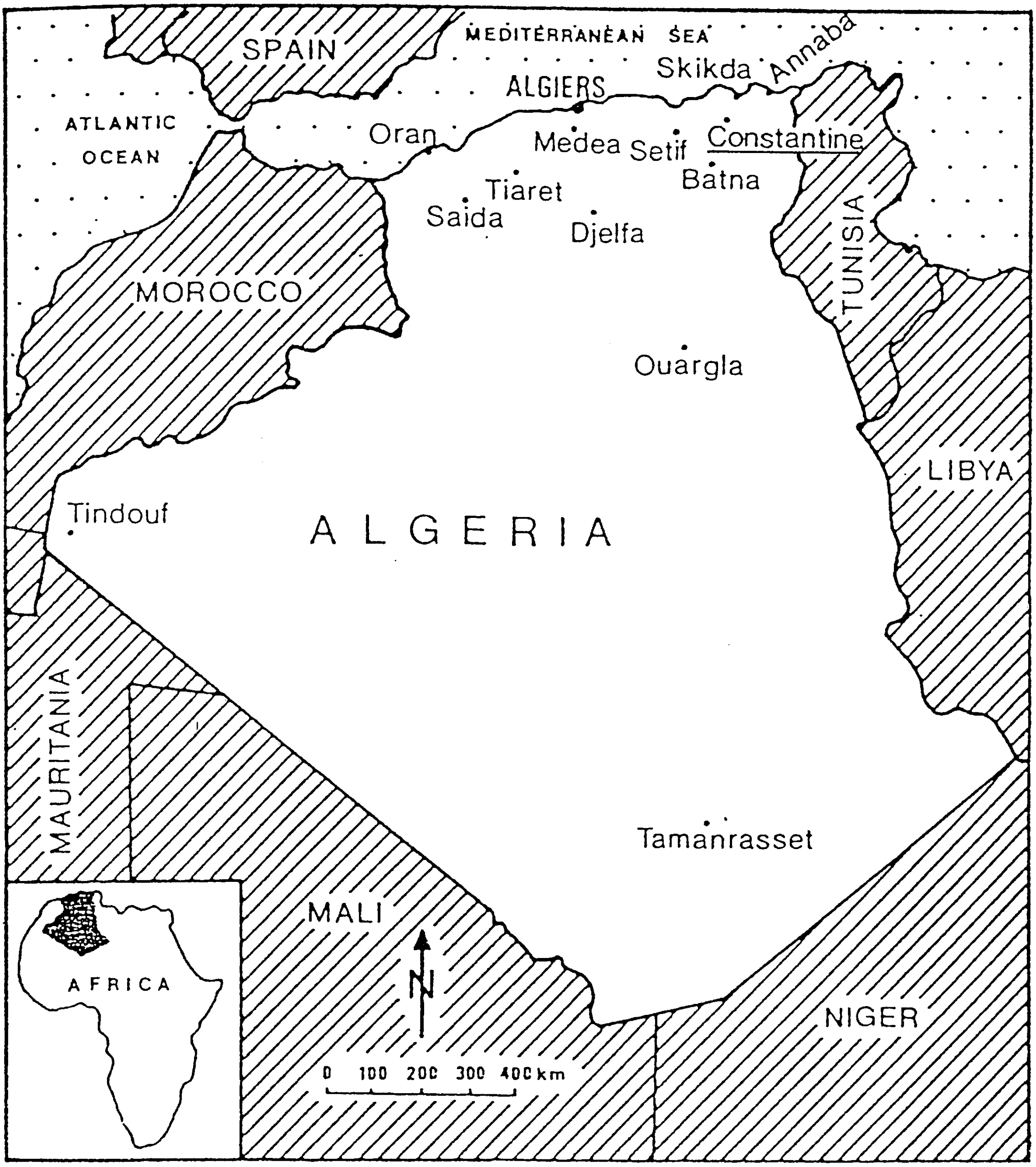


Figure 2.1 Geo-political location of Algeria

Source: Boukhemis, A., 'Recent Urban Growth pattern and migration: a case study of Constantine, Algeria', Ph.D, 1983 Glasgow University.

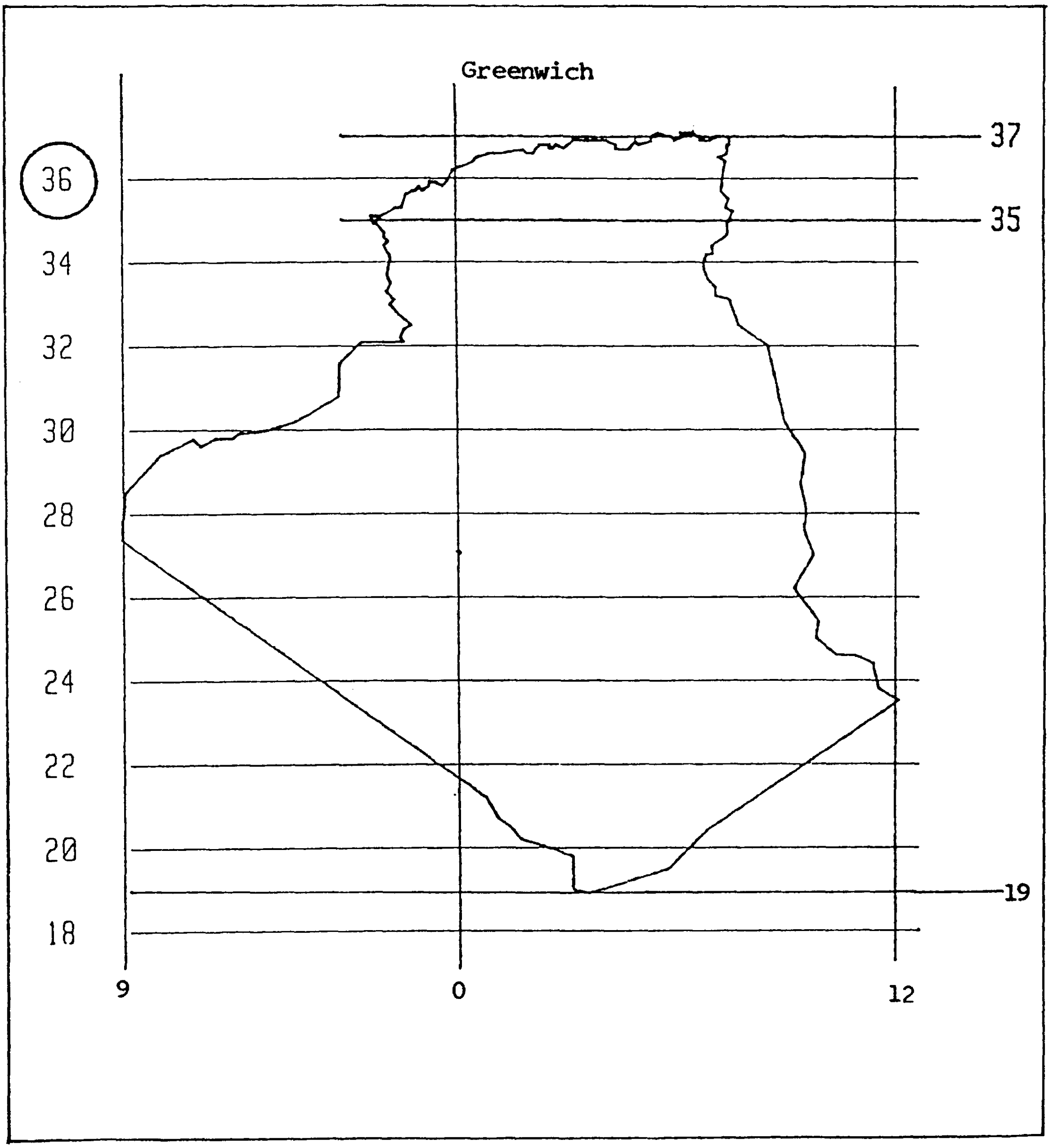


Figure 2.2 Algeria geographical location - (Latitudes and Longitudes)

Source: CAPDEROU, Atlas solar de l'Algerie, p. 56.

essence of seasonal contrast lies in the amount of rainfall which varies considerably from place to place. It is the most potent factor influencing economic development and population distribution. Algeria is divided fairly naturally into four climatic zones, figure 2.3., and the coastal zone with its maritime Mediterranean climate has cool and mild winters and hot rainless summers. The inner 'Tell' has cold winters, often with considerable snowfall. The 'Haute plaines' (Constantine location) and Saharan Atlas have a continental climate with very marked seasonal constrast. The winters are cold, while the summers are hot with often dry air, unclouded skies and large diurnal/nocturnal temperature swings, sometimes exceeding 17°C. The rain falls mainly in the spring though thunderstorms may occur in summer. Finally the Sahara has a typical hot dry desert climate with a mean annual temperature exceeding 40°C. (2)

According to Cote (3) - figure 2.4 and 2.5 - the Constantine climate falls in the semi-arid continental climate zone. Geographically it is situated in the eastern depressions between the mountainous chains, the Tell and the Saharan Atlas the 'Haute plaines'. It is located at 36°17' (4) north latitude 6°37' east Greenwich longitude and at an altitude of 687 m.

Owing to the proximity of the sea and the Sahara, the Constantine location is affected by different pressure systems at different times of the year, resulting in seasonal variation. In winter the Sahara is colder than the

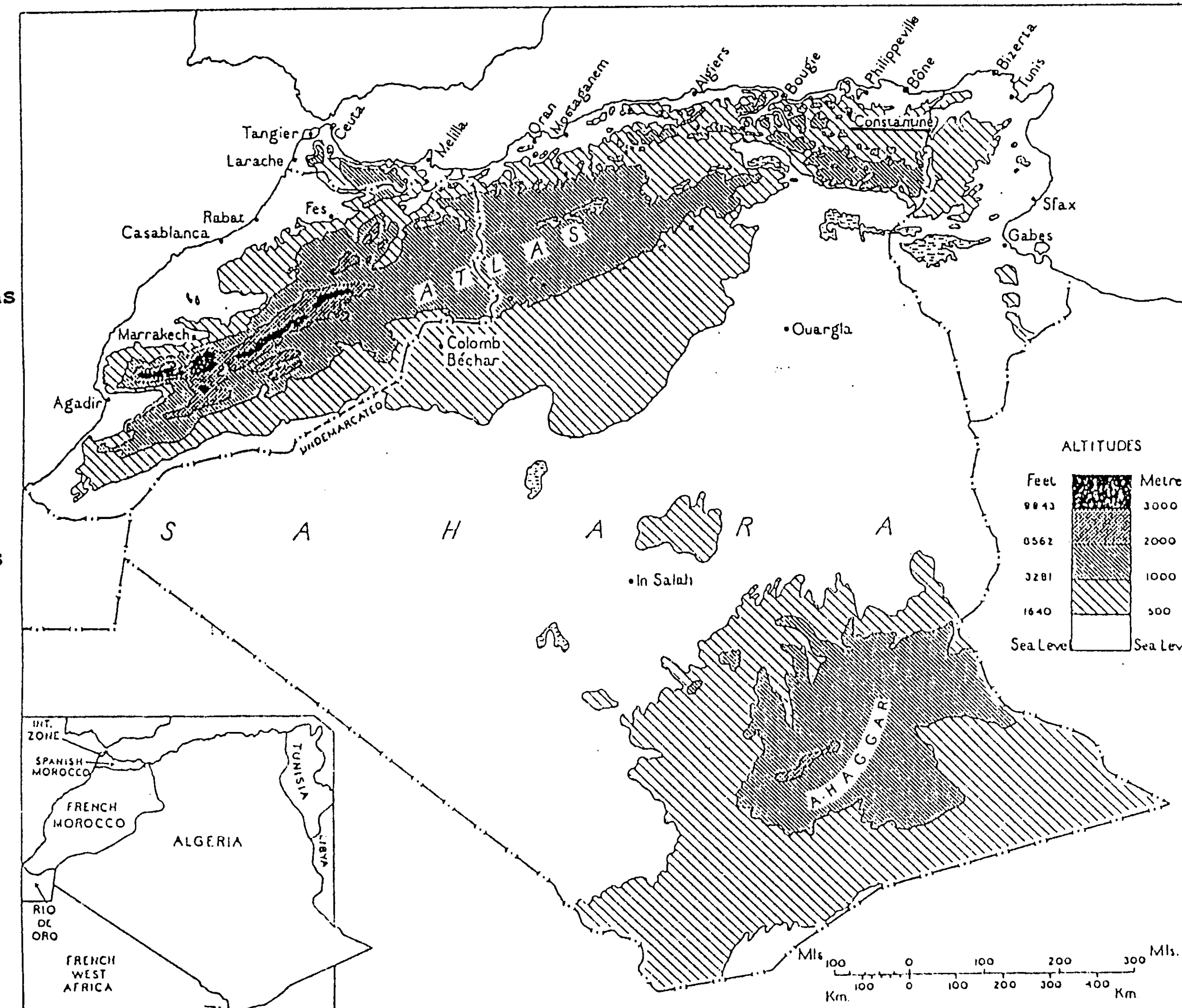
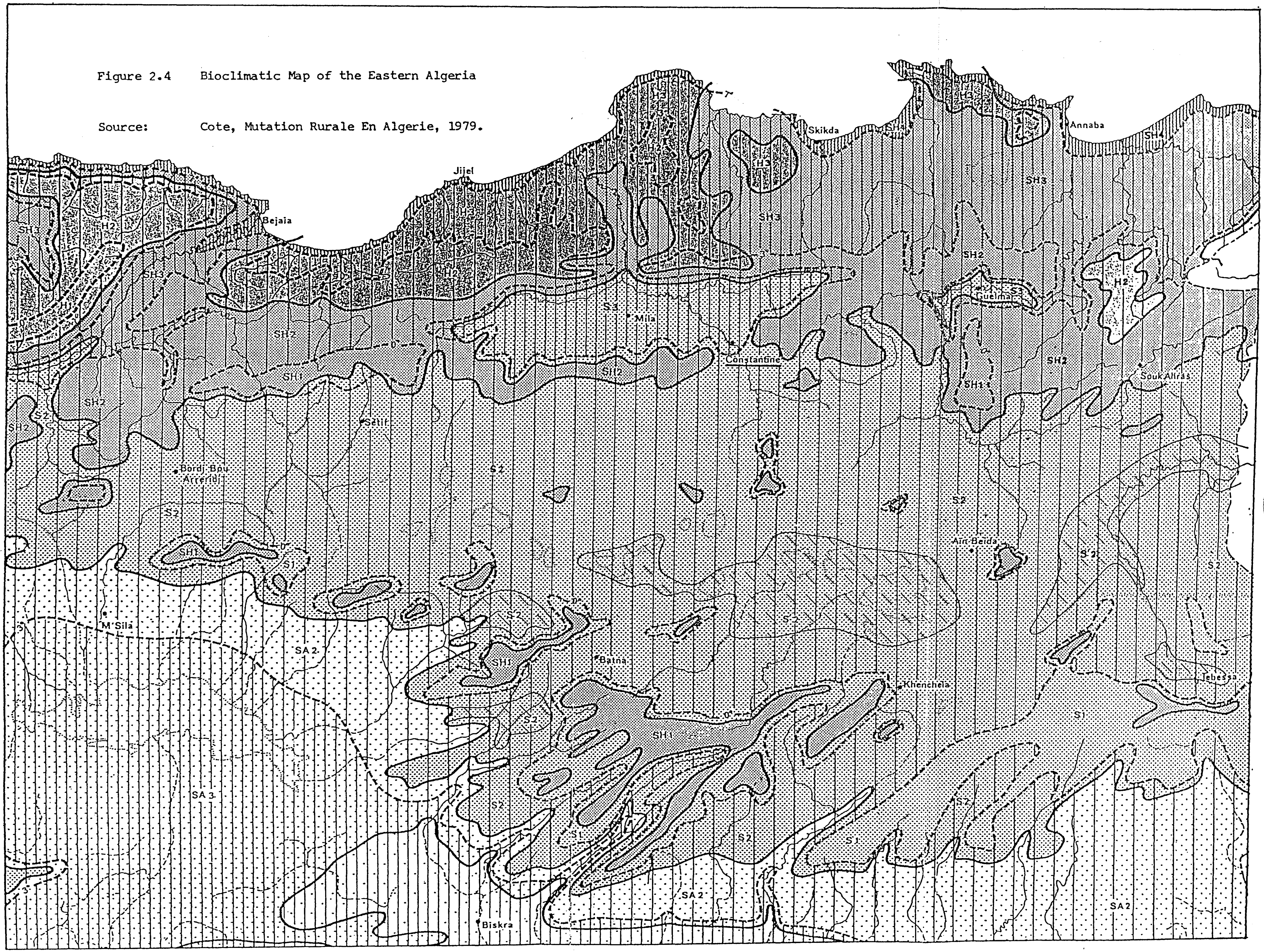


Figure 2.3 The major Geophysical regions of Algeria and The climatic Zones delimitation.

Source: Naval intelligence division Geographical Handbook Series Volume 1, 1943.

Figure 2.4 Bioclimatic Map of the Eastern Algeria

Source: Cote, Mutation Rurale En Algerie, 1979.



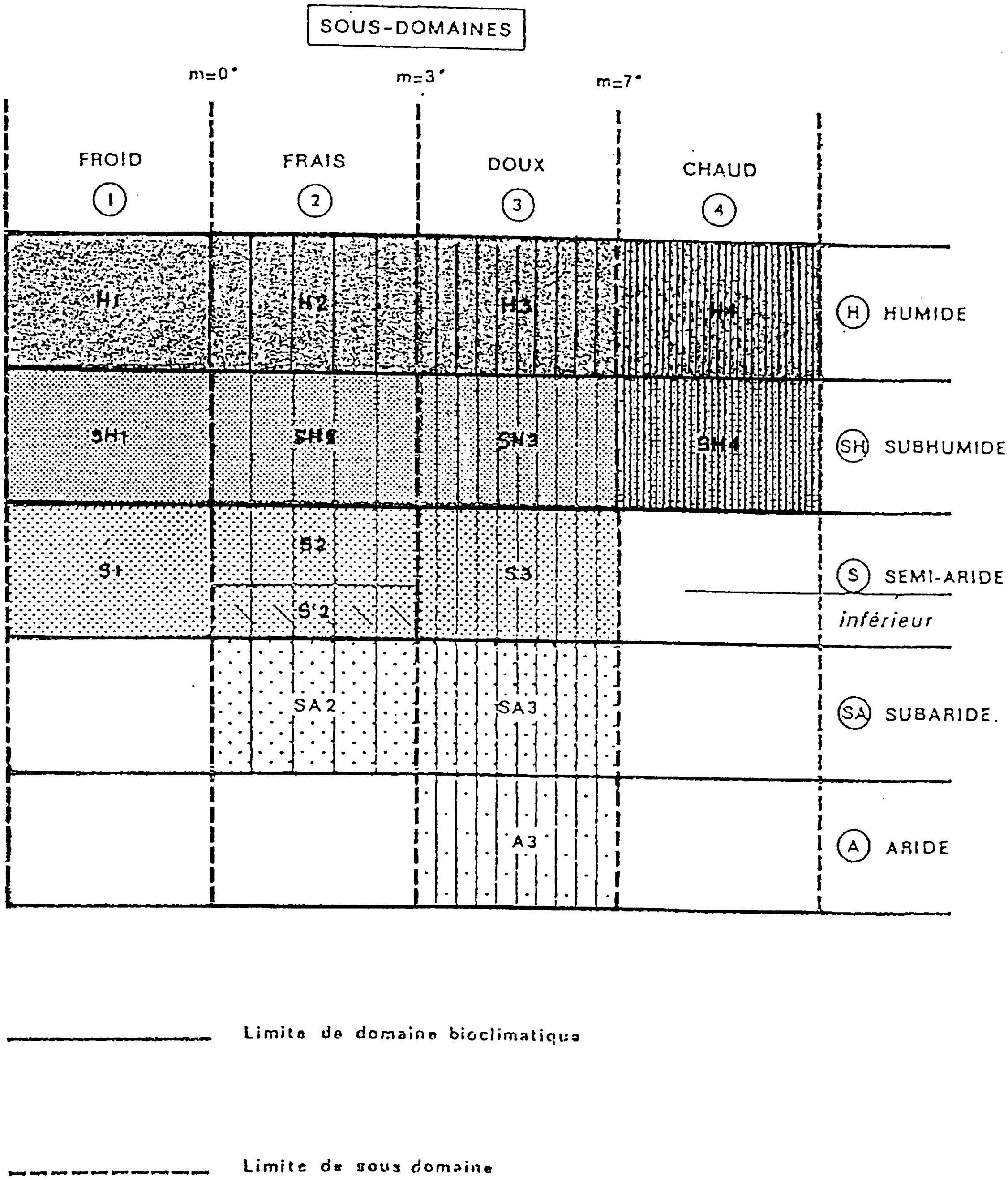


Figure 2.5 Bioclimatic map legend of the Eastern Algeria.

Source: Cote, Mutation Rurales En Algerie, 1979.

Mediterranean and forms a region of high pressure. Meanwhile over the Mediterranean low pressure systems are generated due to proximity to the cold Atlantic oceans. This causes cold, cloudy and wet winter weather. In summer the position is reversed. The Mediterranean is colder than the Sahara, creating a region of high atmospheric pressure, with hot dry air and clear skies for long periods. The mean annual temperature is 15.96°C [4] and mean relative humidity is 67.19%. [4]

2.2 Climatic elements analysis.

The analysis of the climate of this region was made on the basis of the meteorological data collected from the meteorological station (Ain.El.Bey) at the airport of the city.

2.2.1 Temperature.

The annual variation of temperature in the city of Constantine is influenced by altitude and relatively short distance from the sea. Therefore the winter varies from cold to mild and the mean monthly temperature in January, usually the coldest month of the year is around 6.9°C, whilst the summer is hot and dry with the highest mean monthly temperature of 27.03°C [5] in July. The temperature increases steadily reaching an average maximum of 35.3°C in July, figure 2.6. It may reach 40-44°C [6] for short periods when the excessively hot 'siroco' wind occurs. In

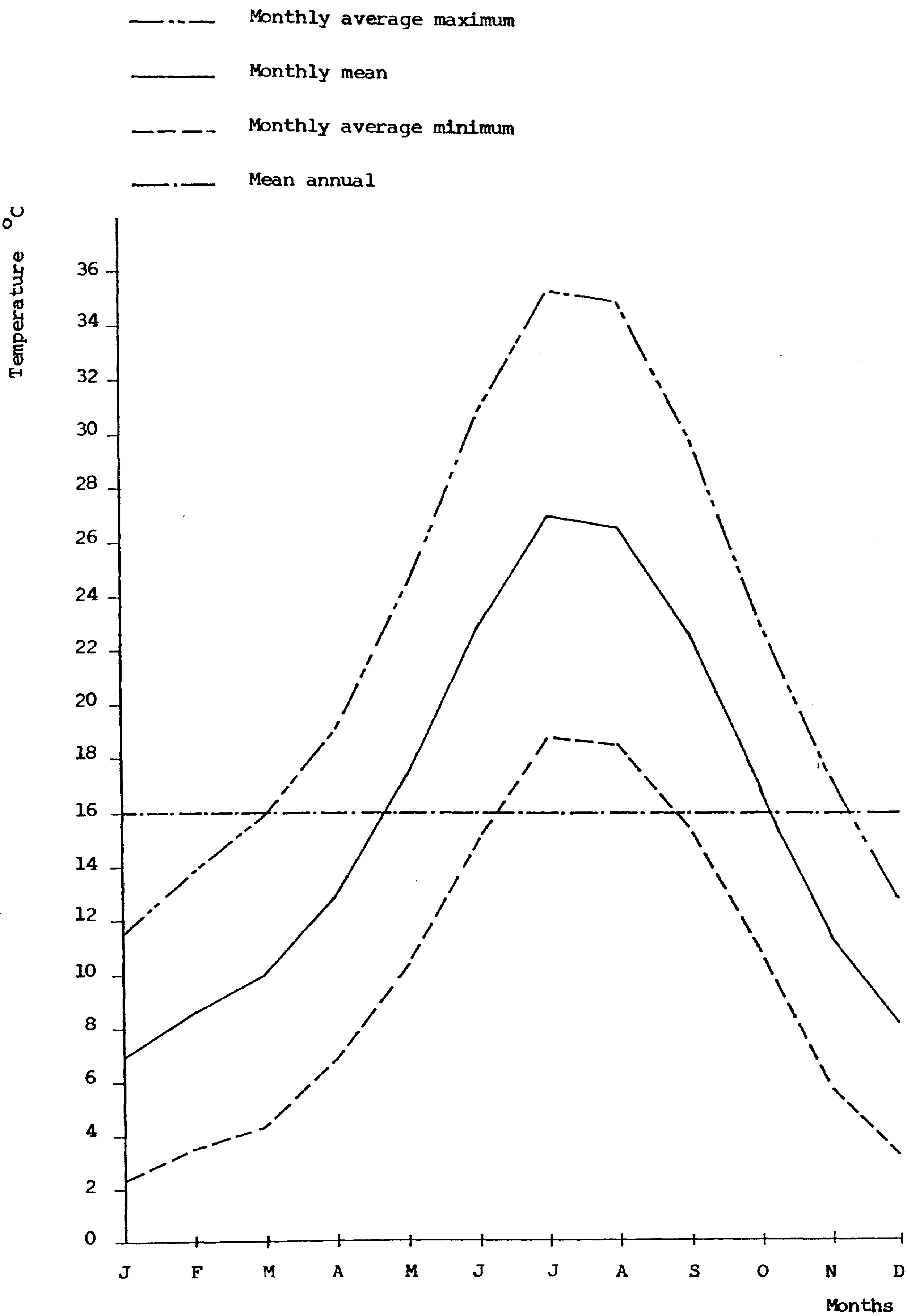


Figure 2.6 External air temperatures over 16 years.

Source: Meteorological Station - Ain Bey - Constantine.

summer, from April to October, day time maximum temperature may range between 17°C and 35°C, and is commonly higher than the skin temperature (31°C to 34°C). But at night the minimum may range between 6°C to 19°C, because of the losses of the heat from the surface of the earth to the clear sky. In summer there is a significant increase in diurnal/nocturnal swing compared to winter from December to February. The summer has a mean daily swing of about 7.5°C whilst the winter period has a mean daily swing of about 5°C. From table 2.1 and figure 2.6 it can be observed that the cooling season may last from April to October, preceded and followed by intermediate seasons, March and November, and with a short heating season lasting from December to February.

2.2.2 Solar radiation and sunshine hours.

With respect to building design, there are three solar radiation components that need to be considered:

- The direct component - clear sky and directional.
- The diffuse component - scattered by cloud, aerosol, etc.
- The reflected component - mainly from the ground albedo - see figure 2.7.

The intensity of solar radiation in Constantine is influenced partly by the solar geometry and partly by 'macro' and 'meso' climate characteristics. Figure 2.8 illustrates the variation from season to season of predicted

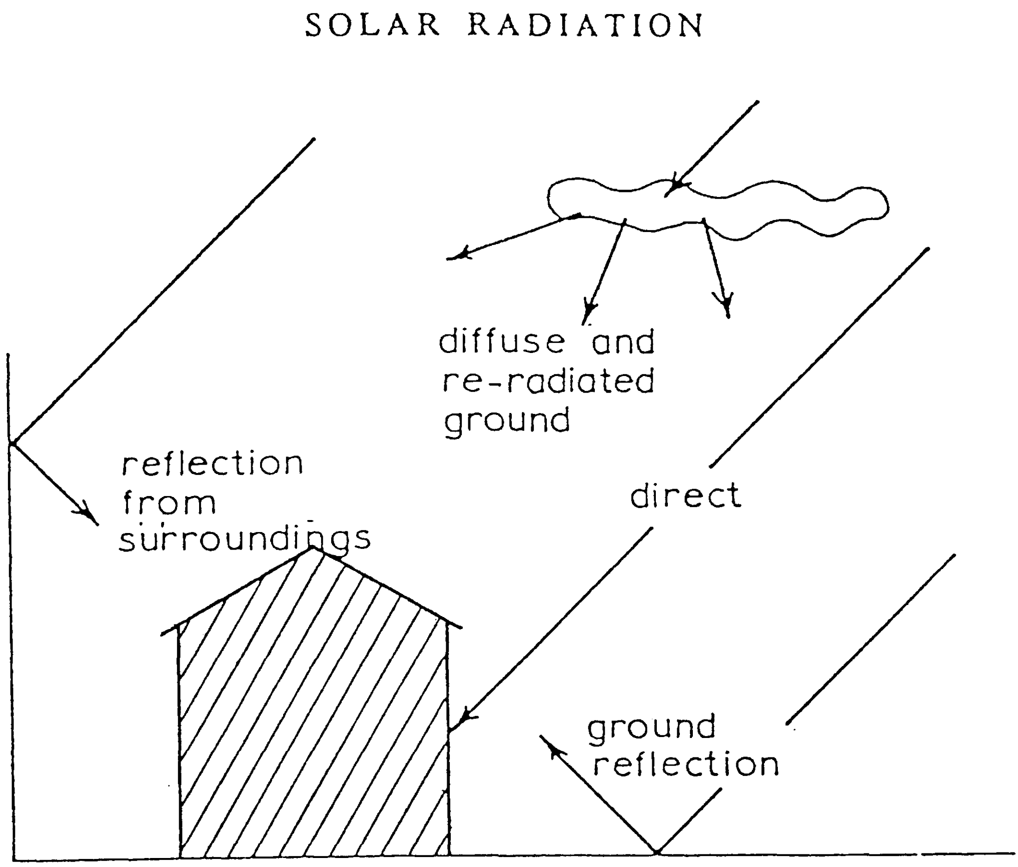


Figure 2.7 Sources of reflected solar radiation.

Source: Down, P.G., Heating and Cooling Load Calculations 1969.

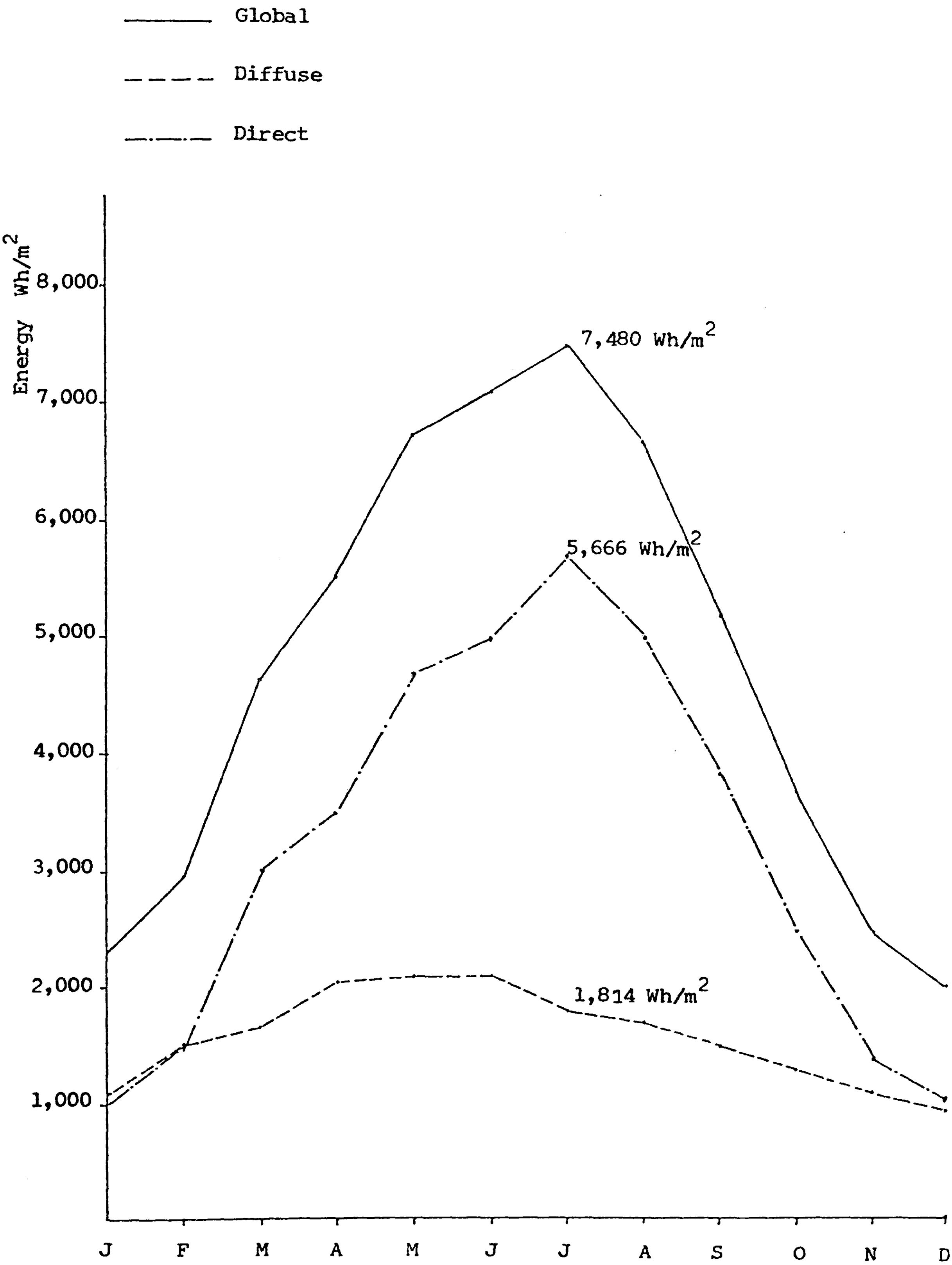


Figure 2.8 Monthly mean daily Solar irradiation on Horizontal surface.

Source: Atlas Solaire de l'Algerie - Constantine.

direct, diffuse and global irradiation on a horizontal surface. The global irradiation on horizontal and vertical surfaces can be seen in figure 2.9. The figure shows that the horizontal surface receive the greatest amount of solar energy in summer, whereas the south facing vertical surface receives less than the east and west. Solar radiation is direct and strong during the day due to clear skies, but permits easy release of the heat stored during the day time in the form of long wave radiation to the night sky. Monthly duration of bright sunshine, measured in hours and illustrated in figure 2.10, table 2.2 appendix 2, show an average annual sunshine hours of 2,959 (6) hours, with an average daily maximum of 12.4 hours occurring in July and an average daily minimum of 5 hours in January, the coldest month. From figure 2.11 it can be concluded that predictably the intensity of global irradiation varies relative to sunshine hours, increasing during dry and hot summer, and decreasing during wet and cold winter. Hourly solar intensities incident on horizontal, different vertical and inclined surfaces are illustrated in table 2.3 to table 2.9 appendix 2; and the hourly variation of global, direct and diffuse intensities over the coldest month and the hottest month are shown in figure 2.12.

2.2.3 Cloud cover.

Corresponding to sunshine hours in summer, the sky is often completely cloudless, with 0.5 octas (7) during July.

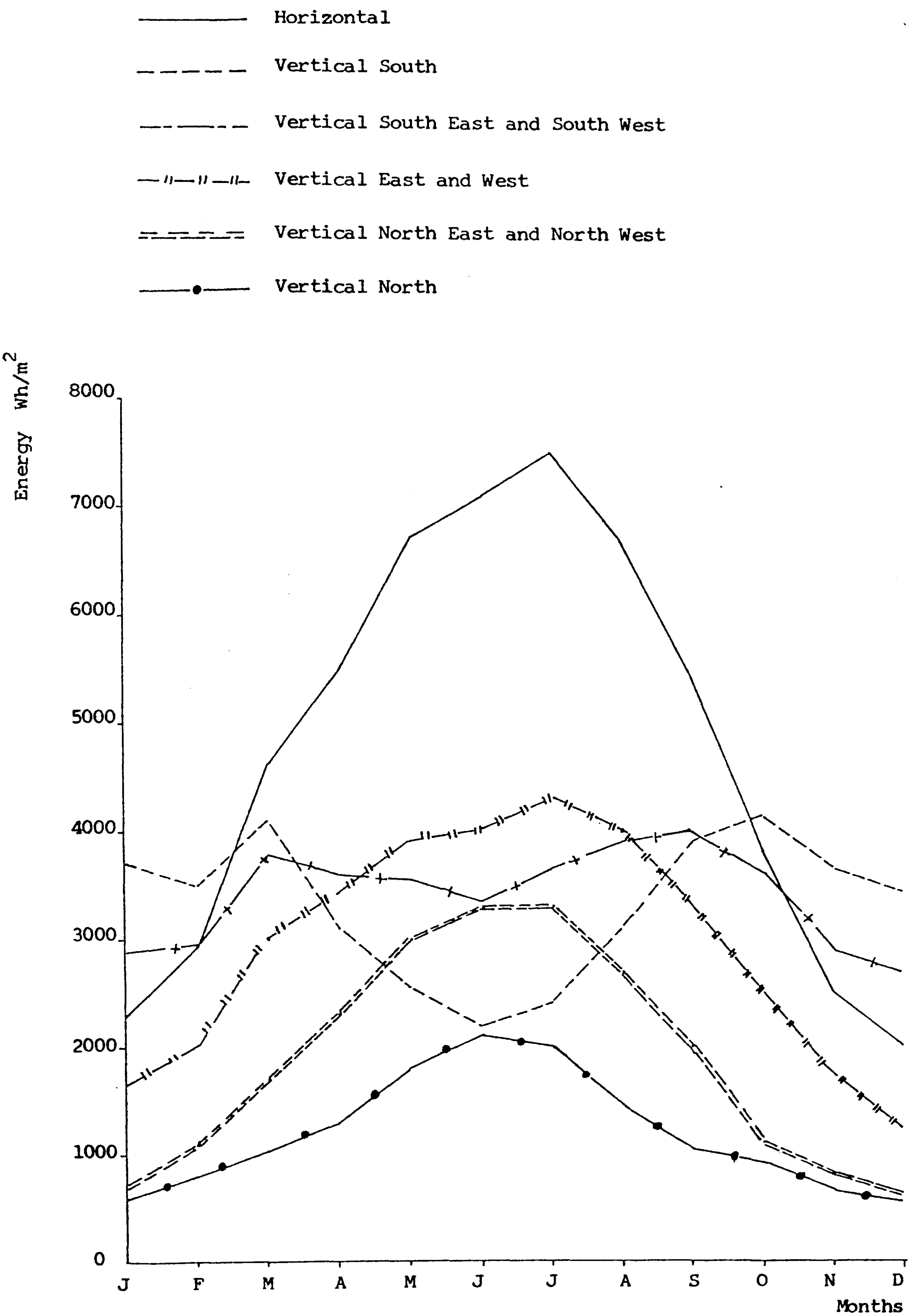


Figure 2.9 Monthly mean daily global irradiation on different orientation.

Source: Atlas Solaire de l'Algerie, Constantine.

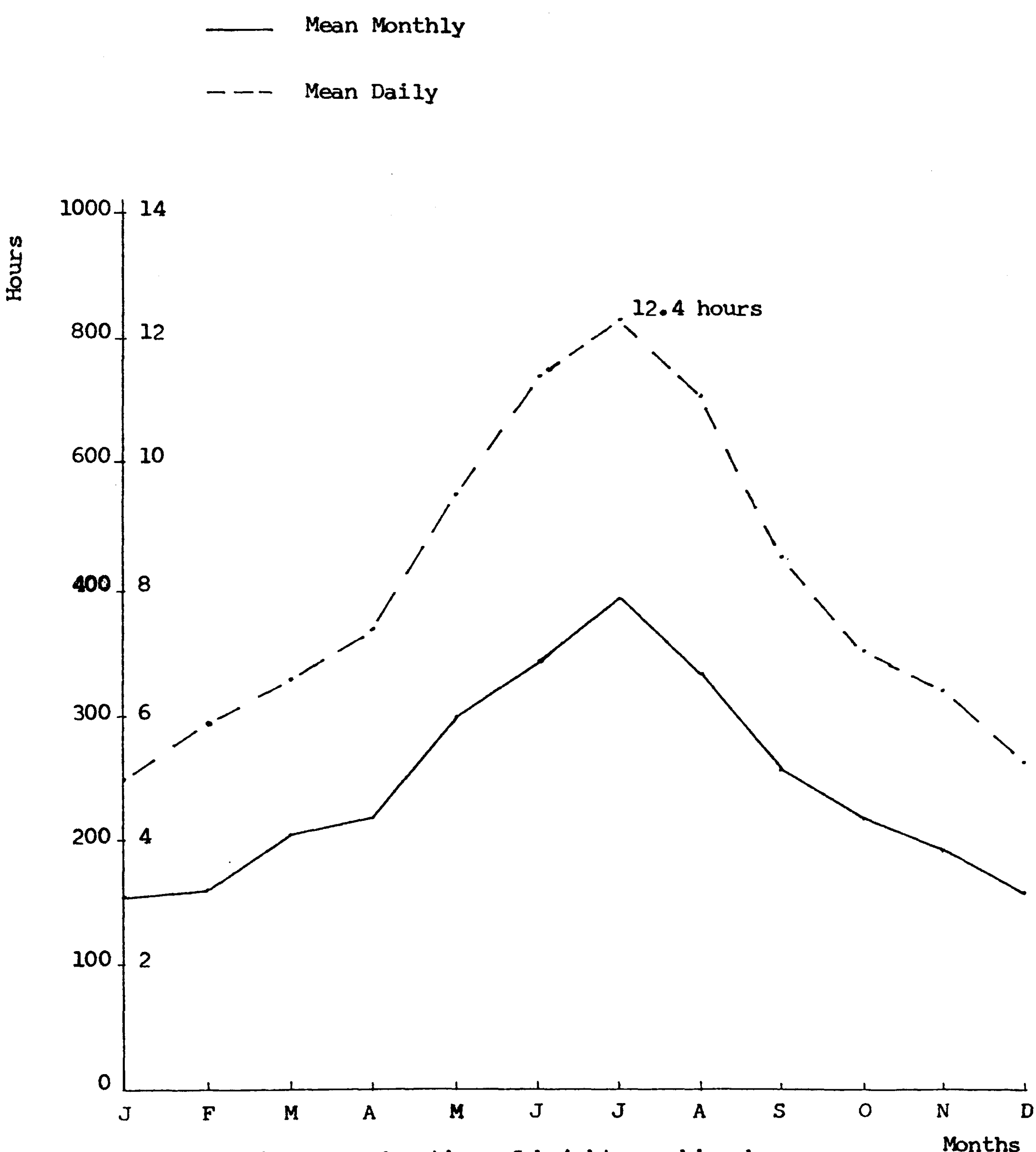


Figure 2.10 Mean duration of bright sunshine hours over 12 years (1970 - 1981).

Source: Meteorological Station - Ain Bey - Constantine

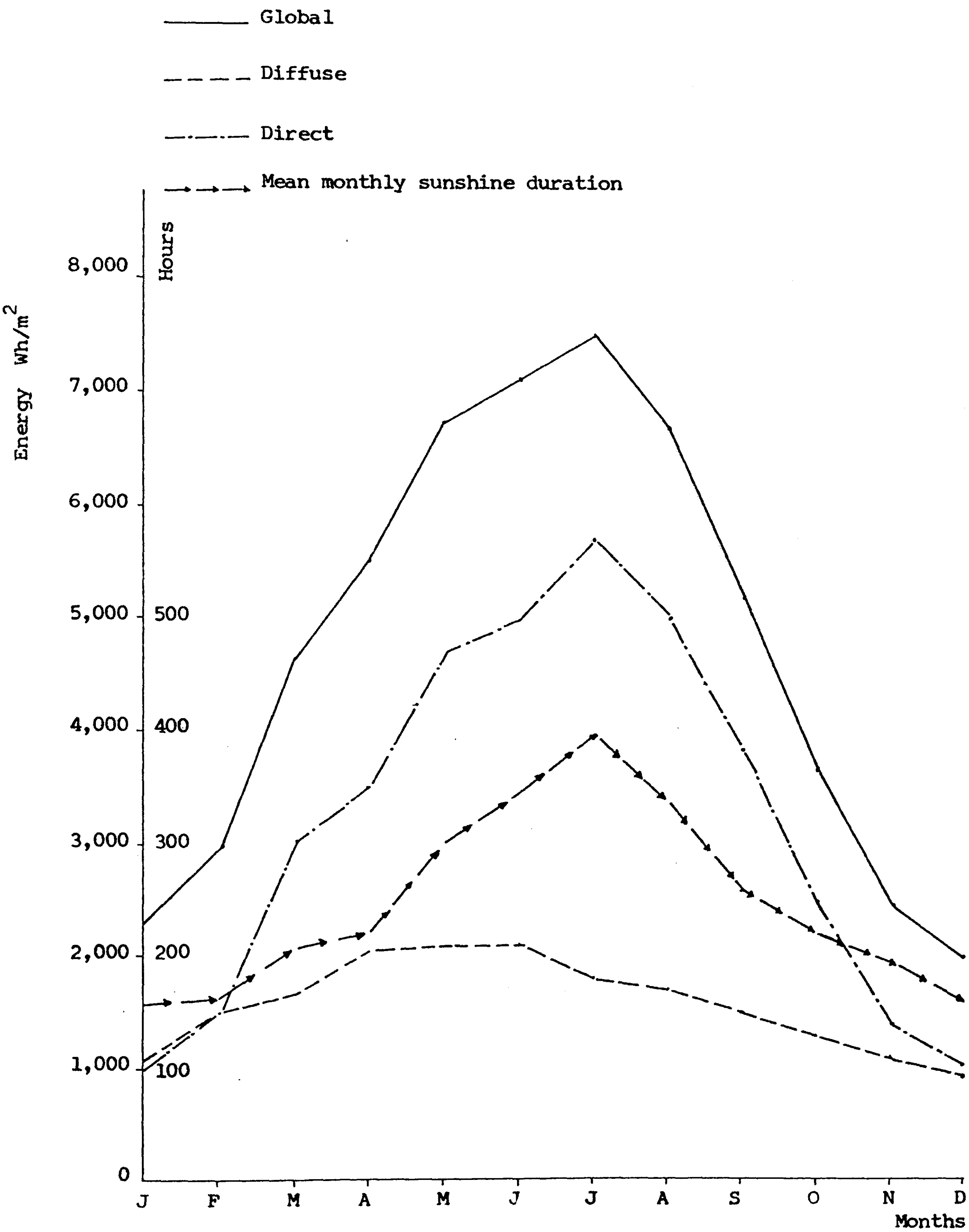


Figure 2.11 Solar radiation on Horizontal plane and sunshine duration variation.

Source: Atlas Solaire de l'Algerie, Constantine.

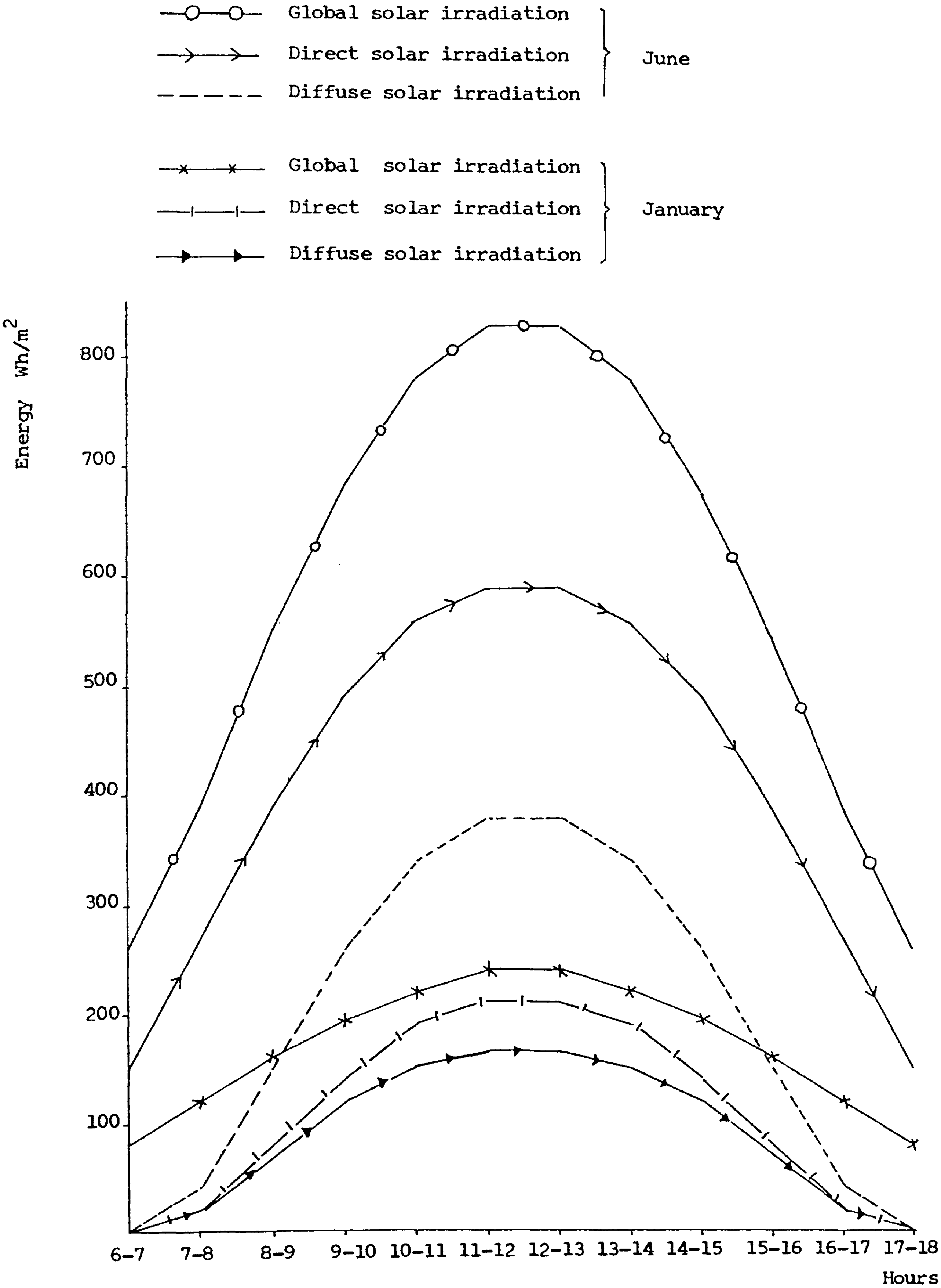


Figure 2.12 Hourly variation of global, direct and diffuse intensities on Horizontal surface over January and June.

Source: Atlas Solaire de l'Algerie - Constantine

A few clouds may appear during the day but disappear quickly after sunset, giving clear nights during which radiation of heat from the surface continues without interruption. The degree of cloudiness is also small in winter with an average from November to April of 1.5 octas. Cloud cover seasonal variation is illustrated in figure 2.11 and table 2.10 appendix 2.

2.2.4 Solar radiation related to temperature, sunshine duration and cloud cover.

Figure 2.13 confirms that the monthly global intensity of solar radiation on a horizontal surface correlates closely to sunshine duration and temperature, peaking in July, whereas cloud cover peaks coincide with solar troughs. It can be also observed that the hourly intensity of solar radiation reaches its peak at noon, local apparent time, whilst the temperature peaks later due to the earth time lag effect.

2.2.5 Relative humidity.

Most of the west and north west winds, which dominate during the winter period, having crossed the Atlantic are laden with moisture and bring considerable rainfall. But they are interrupted by the Tell Atlas which reduces the bulk. They contribute to the increase of relative humidity in winter, whilst the southern dry winds towards the equator contribute to its decrease in summer. This seasonal

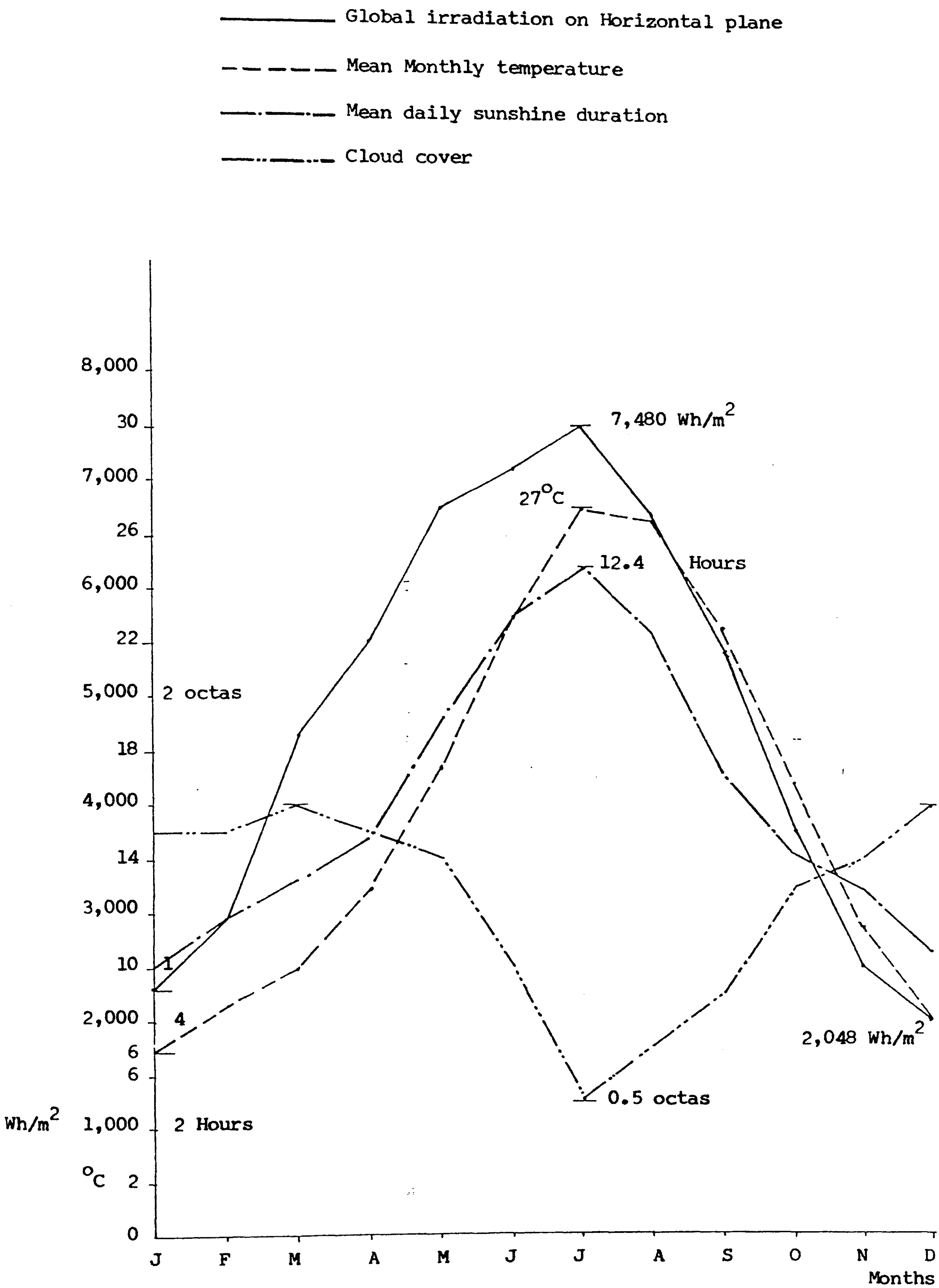


Figure 2.13 Solar radiation related to temperature, sunshine duration and cloud cover.

Source: Meteorological Station - Ain Bey - Constantine.

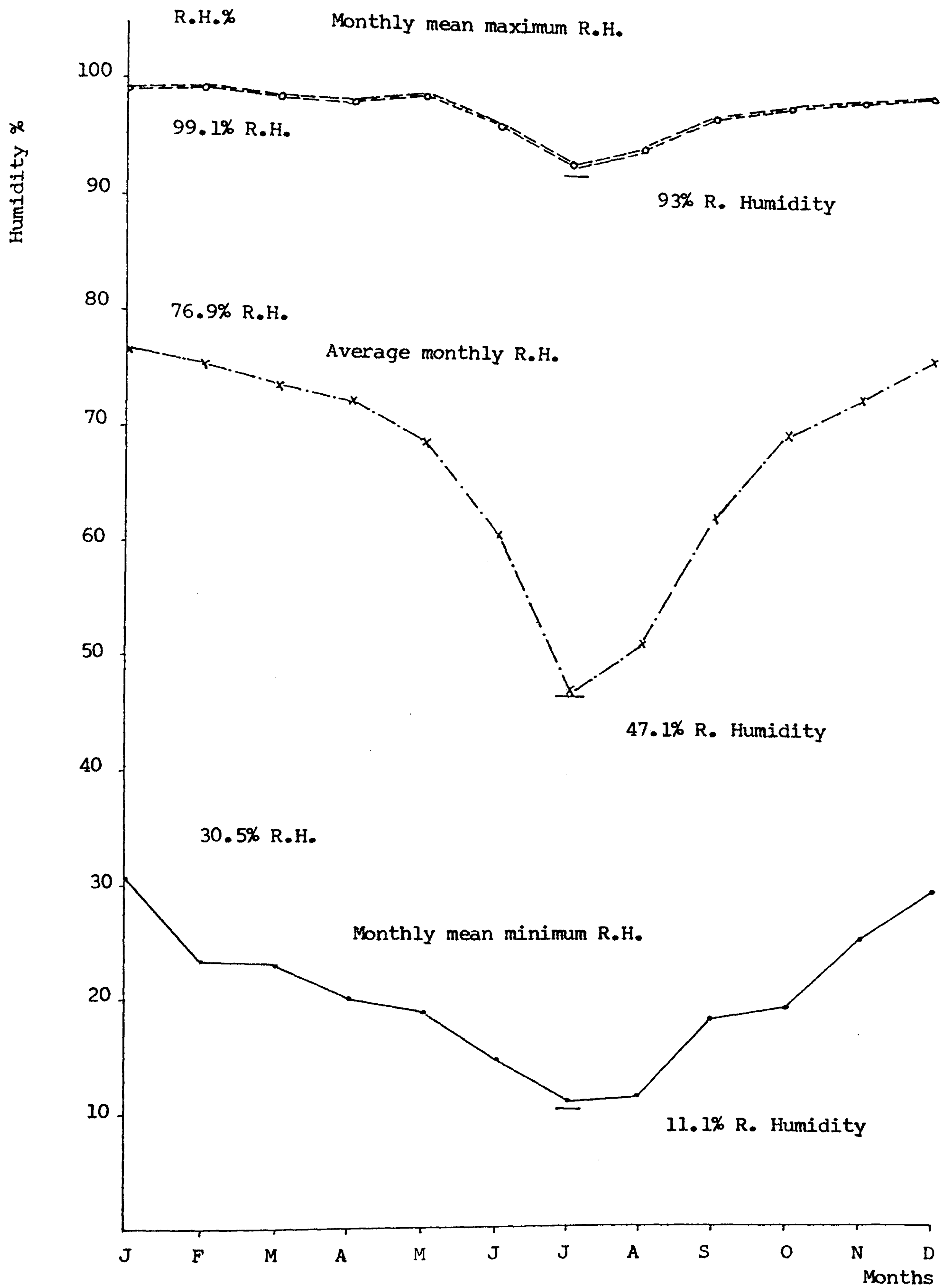


Figure 2.14 Monthly mean Relative Humidity - Constantine 1970-1985.

Source: Meteorological Station - Ain Bey - Constantine.

variation, increased also by evaporation, ranges from 77%[6] in January to 47% in July, see figure 2.14. Table 2.11 appendix 2.

2.2.6 Rainfall.

Despite its height, the Constantine region receives a mean monthly annual rainfall of about 44.5 mm[6]. This is because it is sheltered from the north by the high Kabylie mountains, on which wet winds deposit most of their rainfall. From figure 2.15 and table 2.11 appendix 2, it can be observed that the distribution of rainfall is irregular during the whole year. The dry season lasts from June to August with an average rainfall of 10.5 mm., whilst the 'humid' season is denoted by two periods, September to November and May, and the period from January to April is regarded as the wet season. The relationship between the rainfall, relative humidity, wind speed and cloud cover is illustrated by figure 2.16.

2.2.7 Winds speed and direction.

The prevailing winds depend upon the distribution of pressure and change with the seasons. Measured wind speed and direction data collected over 10 years at Constantine meteorological station (Ain.El.Bey) illustrates in figure 2.17. and table 2.12 appendix 2, the prevailing winds are west from the period - October to April, and north west

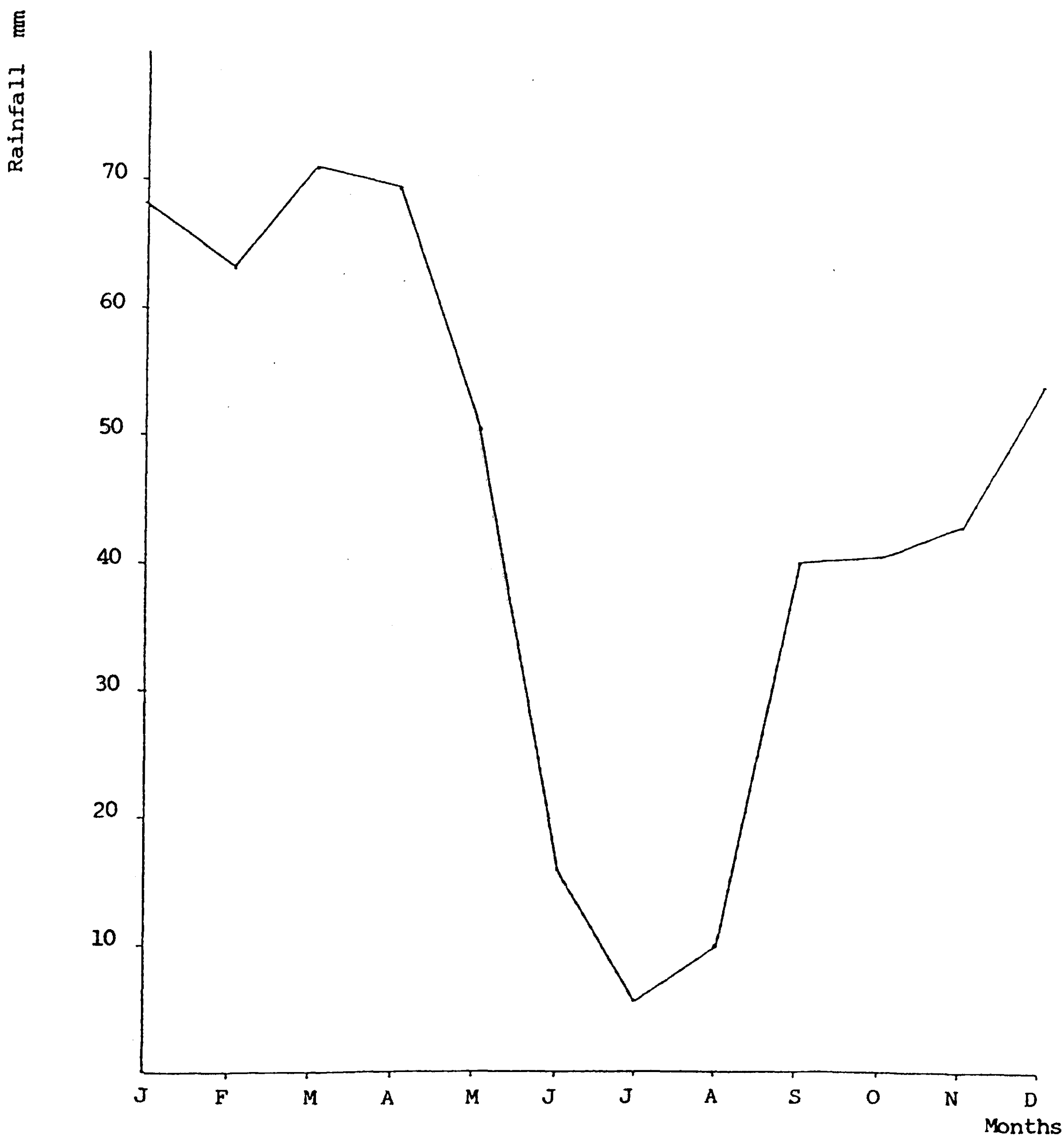


Figure 2.15 Mean monthly rainfall over the period 1970-1985.

Source: Meteorological Station - Ain Bey - Constantine.

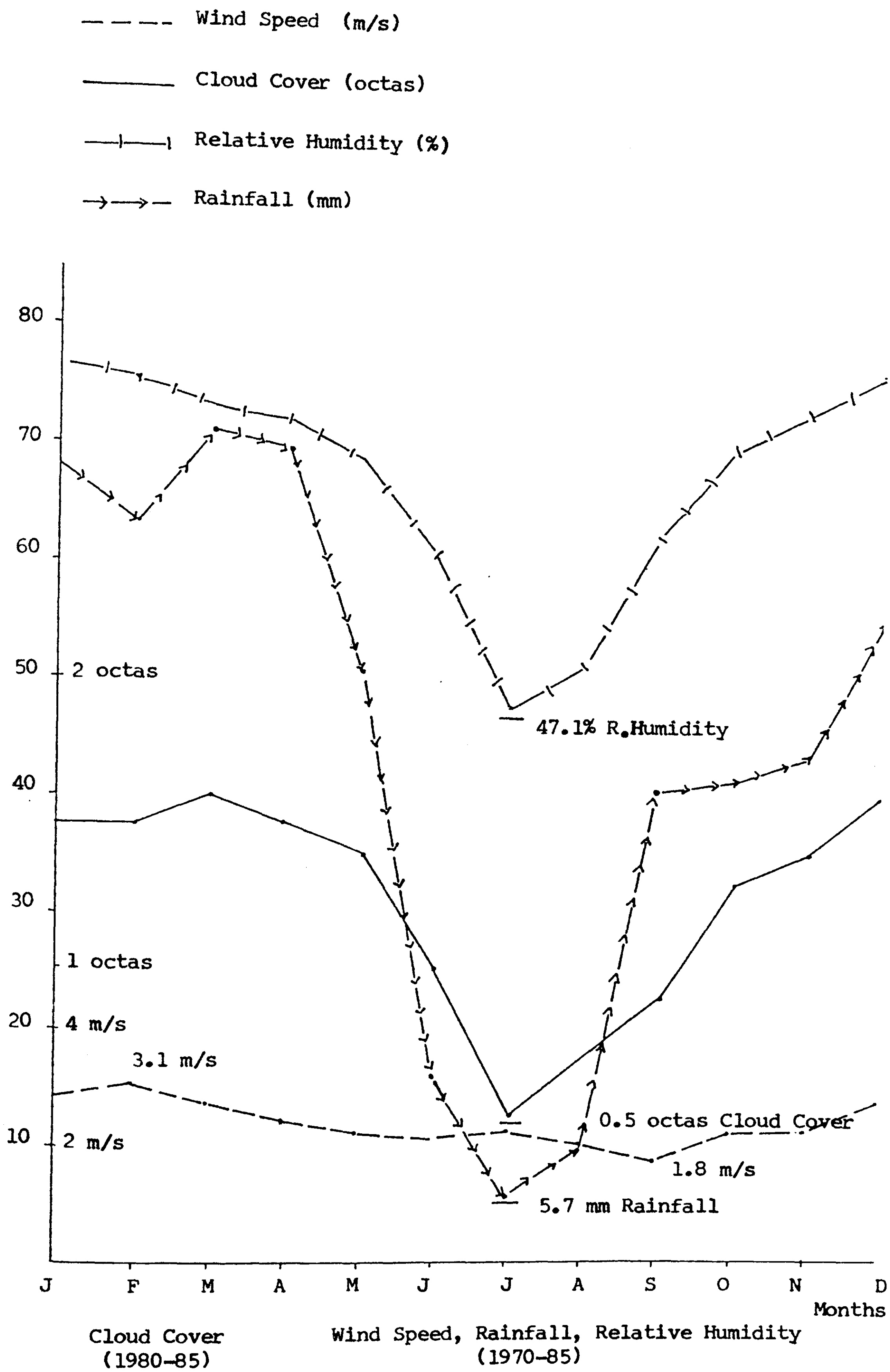


Figure 2.16 Characteristic climate relationships, Constantine.

Source: Meteorological Station - Ain Bey - Constantine.

from May to September. However the meteorological data for the period 1913-1937[8], table 2.13 appendix 2 and figure 2.17, confirms that the prevailing winds are mainly north east during winter and summer, followed by a south east wind and an excessively hot dry and dusty wind from the desert termed 'Sirocco'. This apparent contradiction may be due to local factors affecting the respective anenometers.

2.2.8 Temperature related to relative humidity, evaporation, rainfall, cloud cover and wind.

It can be observed from figure 2.18 that as one might expect the temperature peak correlates closely to the evaporation peak, but is coincident to the troughs of rainfall, cloud cover, wind and relative humidity.

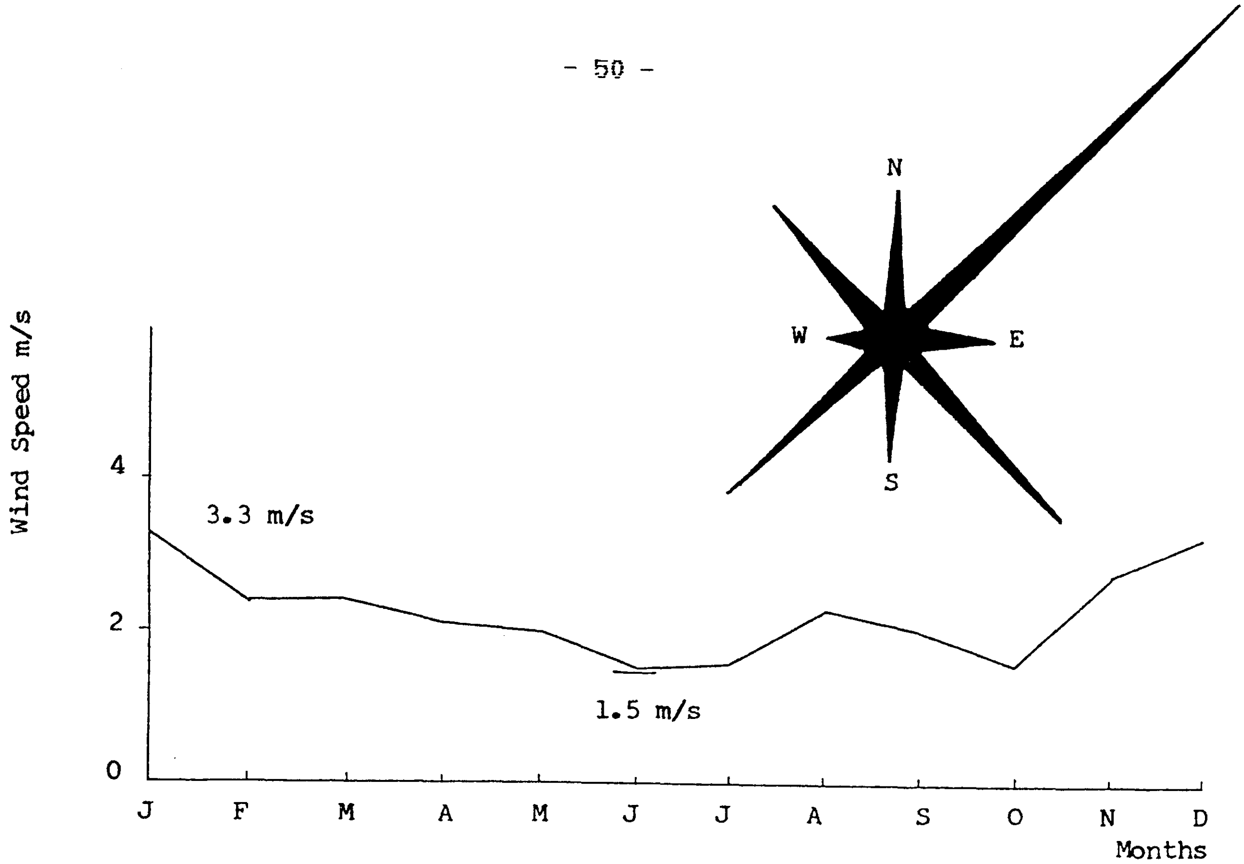


Figure 2.17 Average wind speed and direction over the period 1913-1937.

Source: Seltzer, Alger - Constantine.

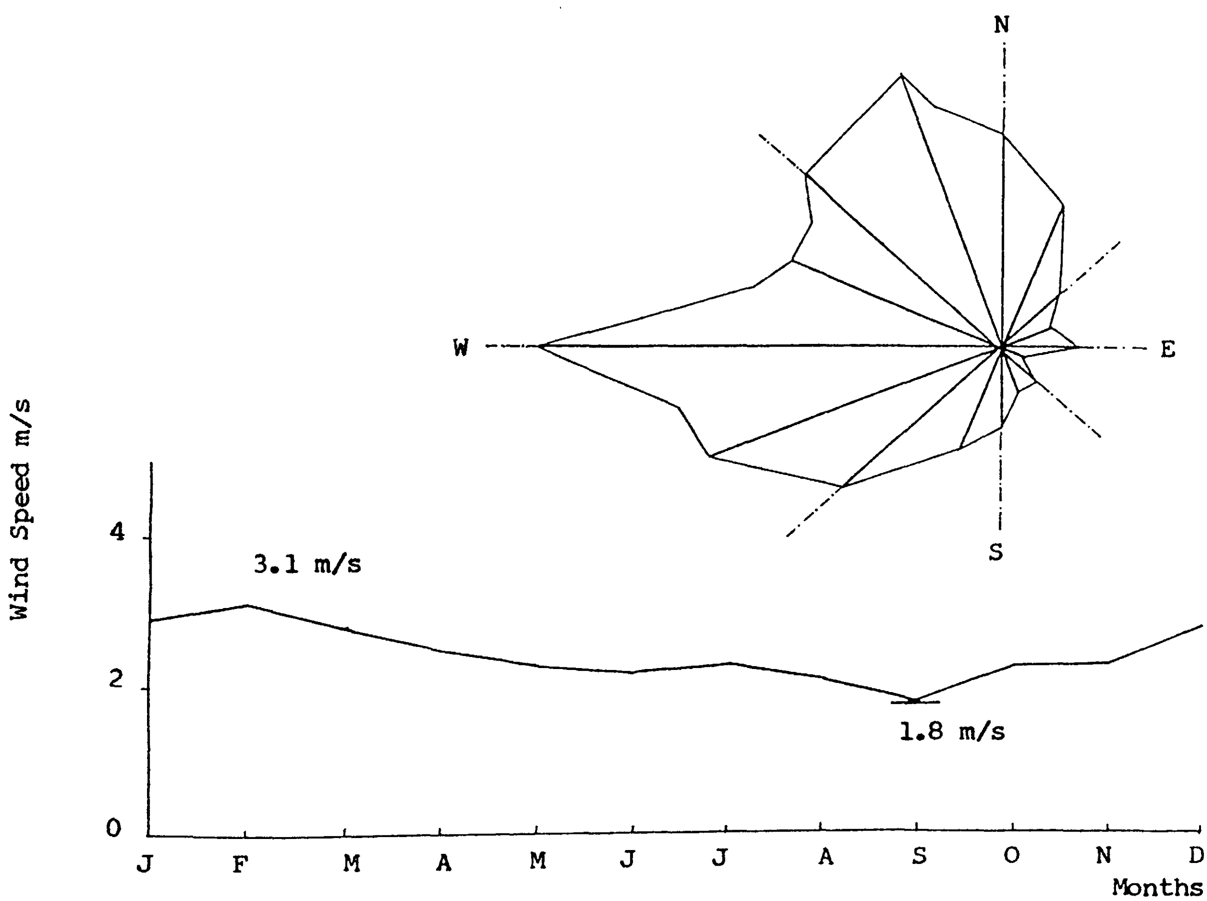


Figure 2.17 Average wind speed and direction over the period 1970-1985.

Source: Meteorological Station - Ain Bey - Constantine.

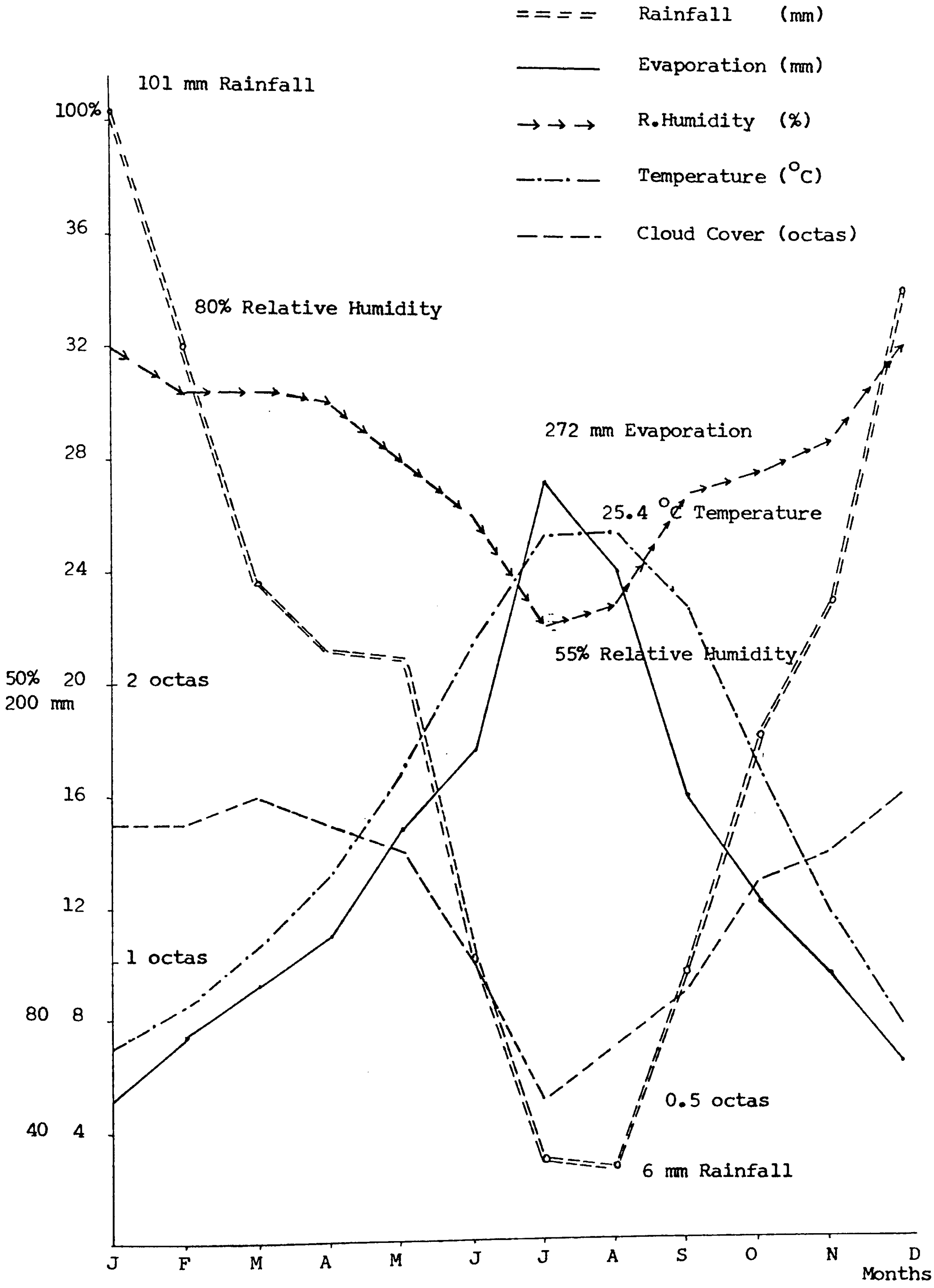


Figure 2.18 Evaporation, Rainfall, Temperature, Relative Humidity, Cloud Cover, Characteristic climate relationships, Constantine (1962-1972).

Source: Seltzer, Alger Constantine.

2.3 Conclusion.

The climate of Constantine has a great effect on the social and cultural activities of people, and has shaped the style and architecture of their buildings. From the climatic analysis of the region, it can be deduced that physical comfort depends on the reduction of energy input due to intense solar irradiance and high summer external air temperatures. To achieve this, the basic principles being applied are quite simple: by using heavyweight walls and roofs with large thermal capacity in order to slow the rate at which indoor temperature adjusts to extreme outdoor temperatures, by using enclosed plan and inward - looking buildings, and/or by providing various means of shading to admit sunlight during winter months and block it during summer. However, the situation is different in buildings where high levels of daylighting and ventilation are required, such as schools. There the windows have to be much larger than in residential buildings. Hence, the indoor temperature cannot be reduced below those outdoor on account of a significant portion of the heat gain penetrating through the window either by conduction, solar radiation or hot outdoor air infiltration. Accordingly thermal capacitance and cooling of ventilation air assumes much greater importance.

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Section 3

PREDICTION OF THERMAL PERFORMANCE OF THE STRUCTURE

PREDICTION OF THERMAL PERFORMANCE OF THE STRUCTURE

3.1 Introduction

The aim of environmental control has been and still is human thermal, visual, and acoustic comfort. This study is not concerned with acoustics but rather with thermo-physically determined heating/cooling aspects of school design, which recognises the influence of natural daylighting.

The building envelope can be considered as a barrier or filter, which separates the indoor space from the external environment, the dividing surfaces normally comprising two distinct classes of material - opaque and transparent. In the case of school buildings, the balance between the two is very important because it affects both natural lighting and thermal performance.

With respect to ambient environmental conditions, whilst realising that a specific study will be subject to localised 'meso' and 'micro' climatic factors, for the purpose of this study 'macro' climate data has been used: wind, temperature, humidity, rainfall (from 1970-1985) cloud cover (1980-1985), are provided by measured data at Ain.El.Bey - Constantine Airport (1970-1985), whilst solar radiation values are computer generated.[1]

The essence of this study is to drive a balance between building design and climate in order to determine better environmental design approaches. In order to suggest improvement, a classroom in a typical school building subject to the Constantine climate provides a suitable model for analysis. The investigation has been carried out for two periods of the day - an unoccupied period from 6 a.m. - 8 a.m., for preheating during winter, and the occupied school period from 8 a.m. - 6 p.m. A periodical dynamic analysis is used in order to emphasise the role of thermal mass in buildings with specific occupancy timetables.

3.2 Steady State Conditions

The heating/cooling load is the amount of energy needed to heat or to cool a space in order to maintain an internal temperature profile within comfort limits. Under steady state conditions the cancelling of thermal capacitance gains and losses over 24 hr periods is assumed. Heat transfer between a building and its surrounding is expressed by: [2]

$$\Phi_h + \Phi_i + \Phi_s = (\Sigma AU + 0.33nV)(t_i - t_o) + \delta t \quad (W) \quad --(1)$$

where:

Φ_h = heat output (heating/cooling load) (W)

Φ_i = incidental or casual internal heat gain (W)

Φ_s = useful or unavoidable solar gain (W)

AU = transmission heat loss per degree (W/K)

where: U = thermal transmittance coefficient (W/m^{2}K)

(U - value)

A = areas corresponding to thermal transmittance (m^2)

0.33nV = ventilation heat loss per degree °C temperature difference (W/K)

where: n = number of air changes/hour

V = volume of air (m^3)

t_i = internal temperature (°C)

t_o = external temperature (°C)

δt = rate of heat storage within structure (W)

All terms in the equation of heat transfer between the building and its surroundings will normally vary continually with the time. This variation is broadly represented by a daily cycle superimposed on a seasonal trend. When the heat requirement for 24 hours days is totalled over a heating season, the thermal capacity effect will cancel and the heat storage term δt may reasonably be dropped from the equation.

The equation (1) may then be written in terms of 24 hour values, and giving a steady state rate of transfer between mean values of t_i and t_o:

$$\Phi_h + \Phi_i + \Phi_s = (\Sigma AU + 0.33nV)(t_i - t_o) \quad (W) \quad \text{---(2)}$$

The terms of the equation (2) may also be expressed

$$\Phi_h + G = H(t_i - t_o) \quad (W) \quad \text{------(2a)}$$

where: $H = AU + 0.33nV$ (W/K)

$G = \Phi_i + \Phi_s$ (W)

and G is the sum of the incidental and useful/unavoidable solar gains, taking an average rate over a 24 hr period. The mean daily output required from the space heating system to maintain an internal temperature is then

$$\Phi_h = H\ (t_i - G/H - t_o) \qquad (W) \qquad \text{------(2b)}$$

The expression $t_i - G/H$ is called the base temperature, t_b, a concept which makes allowance for the temperature rise generated by solar and incidental gains. Thus the residual space heating/cooling load is given by:

$$\Phi_h = H\ (t_b - t_o) \qquad (W) \qquad \text{------(2c)}$$

3.3 Heat loss calculation

In order to find H, apart from building geometry we require to know the thermal conductivity (λ - W/mK) of each boundary layer and the rate of air changes. The constant 0.33[3] is derived from $\frac{c\rho}{3600}$ where c is the specific heat capacity taken as 1000 (J/kgK) and ρ is the air density taken as 1.2 kg/m^3 assuming air at 21°C. The transmission or fabric loss element AU is found by

$$U = \frac{1}{\Sigma R} \qquad \text{or} \qquad \frac{1}{R_{si} + R_1 + \ldots + R_n + R_{so}}$$

where:

U = thermal transmittance coefficient (W/m^2K)

R_{si} = inside surface resistance (m^2K/W)

R_1, R_n = thermal resistance of each layer of structure (m^2K/W)

R_{so} = outside surface resitance (m^2K/W)

The thermal resistance of unit area of the homogeneous materials forming the element of composite construction is

$$R = \frac{L}{\lambda} \qquad (m^2K/W)$$

where: L = thickness of the layer (m)

λ = thermal conductivity (W/mK)

To find t_b we require to estimate useful solar and casual gains.

3.4 Heat Gain Calculation

3.4.1 Useful solar gain Φ_s

The envelope of the building is usually composed of two types of material, opaque and transparent. Therefore solar heat transfer must be considered through these two distinct heat paths.

a) Solar heat gain through the fabric

The rate of solar gain through the fabric of the building is given by the equation

$$\Phi_{sf} = AU\ (t_{so} - t_i) \qquad (W) \qquad --(3)$$

where: Φ_{sf} = solar heat gain through the fabric (W)

A = areas corresponding to thermal transmittance (m^2)

U = thermal transmittance coefficient (W/m^2K)

t_{so} = solair temperature

t_i = internal temperature

The solair temperature t_{so} is a convenient concept to express the energy of solar irradiation in terms of a temperature increase. It may be defined as the increased external air temperature which produces the same increased internal temperature rise as would be obtained with the solar radiation acting in conjunction with the actual external air temperature and can be calculated from the following equation:

$$t_{so} = t_o + \alpha I R_{so} \qquad (^\circ C) \quad ---(4)$$

where: t_o = external air temperature ($^\circ$C)

α = absorptivity of surface (dimensionless)

I = Global solar irradiation (W/m^2) incident on the surface of the fabric

R_{so} = external surface resistance (m^2K/W)

So equation (3) and (4) may be combined

$$\Phi_{sf} = AU\,(t_o + \alpha I R_{so} - t_i) \qquad (W) \quad --(3/4)$$

A positive value resulting from the equation must then be taken into account when considering the useful portion of gain through windows.

b) Solar gain through the windows Φ_{sg}

The prime function of glazed areas is to admit daylight and sunlight into a building. However windows also transmit heat gains and losses which require to be carefully controlled to ensure comfort and energy efficiency.

Modern architecture is characterised by the wide spread use of glazing on the building facade. This increases the overheating problem particularly in hot climates such as that of Constantine. But even in temperate and cold climates, it also increases radiative clear sky losses during winter. Solar heat gain through the glazing depends on the shading provided and thermal properties of the glass.

The thermal property which characterises glass is the ability to transmit short wave radiant energy directly. The incoming irradiation is divided into three components:

- A part is reflected having no thermal effect on the material.
- A further component is absorbed by the material, than dissipated to either side by conduction, convection and longwave radiation.
- The third component is directly transmitted through the material see figure 3.1.

The proportion of the three components depends on the angle of incidence with the surface and the spectral properties of the glass.

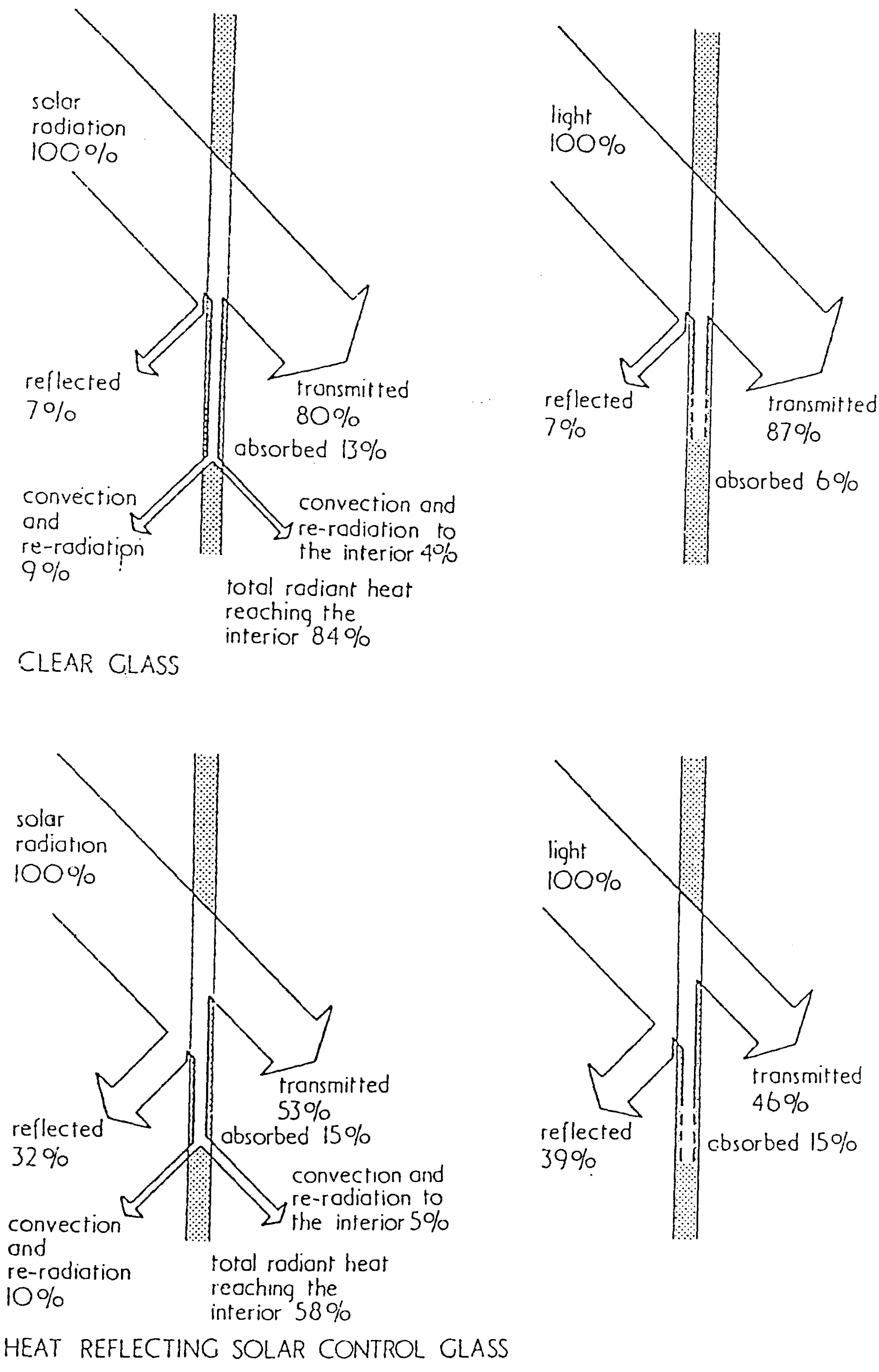


Figure 3.1 Heat flow through the glass.

Source: Evans, M. (1980) Housing, climate and comfort the Architectural Press Limited London.

The rate of heat flow through the glass is given by the equation

$$\Phi_{sg} = A_g \ (I_d + I_{df}) \ HGF \qquad (W) \quad ----(5)$$

where: A_g = area of the glass (m^2)

I_d = direct radiant energy (W/m^2)

I_{df} = diffuse and ground reflected radiant energy (W/m^2)

HGF = heat gain factor

The general formula for heat gain factor is

$$T + \alpha . \frac{c_o}{c_o + c_i}$$

where: T = transmittance value of glass (dimensionless)

α = absorptivity of glass

c_o and c_i = respective external and internal convection coefficients (W/m^2K)

For clear glass and for angles of incidence of $0^\circ \pm 60^\circ$, since T is usually about 0.82, d is 1.5 and

$\frac{c_o}{c_o + c_i}$ is approximately 1/3, HGF = 0.87

However, since the Algerian Solar Atlas[1] gives hourly values of both irradiation incident on the glazing and behind the glazing for various orientations/tilts in hourly time steps, the ratio of the latter to former will yield heat gain factor.

If any external shading devices are used, the quantity of incident radiation is reduced. For example if we find that a particular building configuration gives an average of 80% shading to a glazed facade, a factor of 0.2 is applied to the direct component I_d, before adding it to the diffuse component I_{df} to give the net incident irradiation. We then apply the heat gain factor to find the net transmitted irradiation.

We must now test for overheating to ascertain what proportion of this insolation is useful. The standard Pilkington[4] method is used to determine peak solar gains, taking account of mass characteristics, and splitting the gain into short and long wave components. Then setting an upper comfort limit, t_{imax}, above which cooling is required, we can find the corresponding base temperature, t_{bmax}, substituting in equation (2c) together with the mean t_{omax} for the peak period. A negative values for Φ_h signifies a cooling load. In order to find useful solar gain we must assume $\Phi_h = 0$ and hence $t_{bmax} = t_{omax}$.

Since we have $t_b = t_i - G/H$, in this case

$$t_{omax} = t_{imax} - \frac{(\Phi_{sg} + \Phi_{sf} + \Phi_i)}{H}$$

or reorganising;

$$\Phi_{sg} = H\,(t_{imax} - t_{omax}) - (\Phi_{sf} + \Phi_i) \qquad \text{(W)} \qquad \text{------(6)}$$

(assuming Φ_{sf} is a positive value)

If Φ_{sg} is positive value, this is the useful solar gain Φ_s in equation (1); if a negative value none of the solar gain can be considered useful since it simply adds to the cooling load. However, having taken reasonable architectural measures, bearing in mind daylight requirements, the residual or unavoidable solar gain must be included in the energy balance.

3.4.2 Internal heat gain Φ_i

In additional to solar gain there are internal gains. Their importance vary with the type of the building and its use. These gains are from occupants, lighting appliances ...etc.

a) Heat gain from occupants

Thermal comfort is the maintenance of thermal equilibrium between the heat production of the body and the loss of heat to the surrounding. The rate of metabolic heat gain to the surrounding depends upon the degree of activity age and sex and typical values are available from many sources. In this case a metabolic rate of 55 W per child is assumed.

b) Heat gain from lighting and appliances

The amount of heat produced by any lighting installation or electrical appliances depends upon the choice of light source and the equipment used. In this case, this has been assumed negligible due to the use of natural lighting.

3.5 Degree days calculation DD

We have now determined all the terms necessary to calculate base temperature t_b for the unoccupied and occupied period in any month. To obtain the annual space heating requirement for a building with 24 hour occupancy, equation (2c) is integrated over the heating season. In this integral there are firstly two cases to consider:

- (a) Days for which $t_b > t_o$

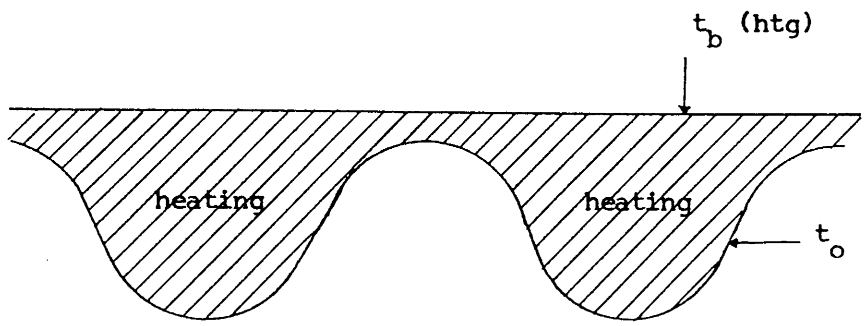
  In this case the internal and solar gains are insufficient to obtain the required internal temperature t_i and heating is required.

- (b) Days for which $t_b < t_o$

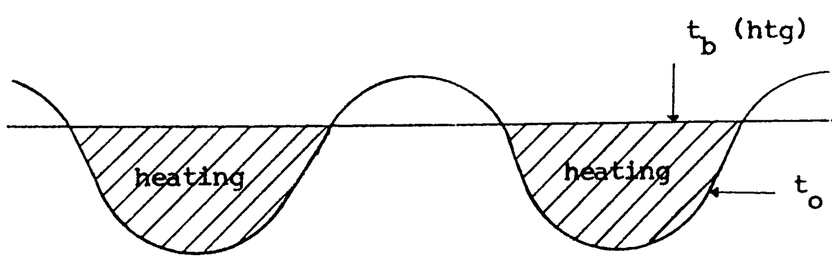
  In this case the internal and solar gains exceed the heat losses. So either t_i or the ventilation component of H must be increased.

In practice there may be relatively few occasions when base temperature t_b, is either wholly above or below a fluctuating outside temperature, t_o. Taking first the heating condition where t_b is derived from a heating demand temperature t_i (htg), the calculation adopted for the degree days is the one used by the Meteorological office of the U.K.

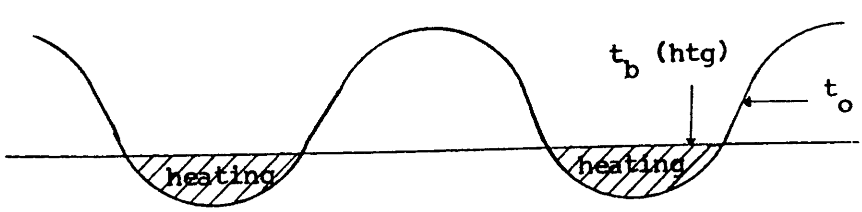
1. If $t_b > t_{omax}$ $\quad DD = t_b - 0.5(t_{omax} + t_{omin})$



2. If $t_{omax} > t_b$ and $t_b > t_{omin}$ and $(t_{omax} - t_b) < (t_b - t_{omin})$ $\Rightarrow DD = 0.5(t_b - t_{omin}) - 0.25(t_{omax} - t_b)$

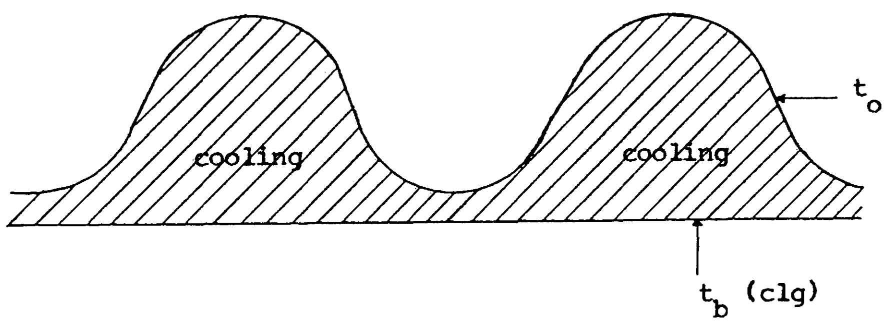


3. If $t_{omax} > t_b$ and $t_b > t_{omin}$ and $(t_{omax} - t_b) > (t_b - t_{omin})$ $\Rightarrow DD = 0.25(t_b - t_{omin})$

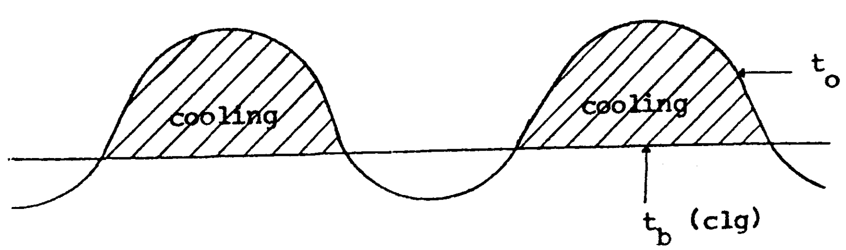


It is assumed that the heating demand temperature t_i (htg) will not normally coincide with the cooling demand temperature t_i (clg), since there is a comfort band between t_i (htg) and t_i (clg) where no heating or cooling is required. Taking the cooling condition the degree day calculation procedure is simply reversed.

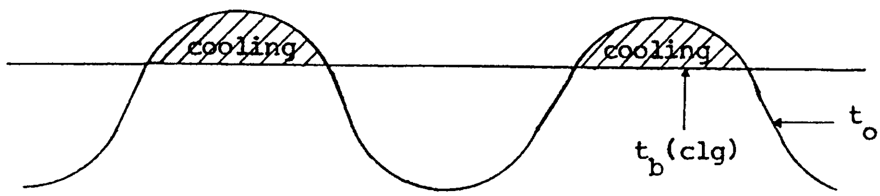
1. If $t_b < t_{omin}$ $\quad DD = 0.5(t_{omin} + t_{omax}) - t_b$



2. If $t_{omax} > t_b$ and $t_b > t_{omin}$ and $(t_{omax} - t_b) > (t_b - t_{omin})$ $\Rightarrow DD = 0.5(t_{omax} - t_b) - 0.25(t_b - t_{omin})$



3. If $t_{omax} > t_b$ and $t_b > t_{omin}$ and $(t_{omax} - t_b) < (t_b - t_{omin})$ $\Rightarrow$ $DD = 0.25(t_{omax} - t_b)$



The total heating or cooling load required to maintain the lower or upper comfort condition may be written:

$$\Phi_h = H \times DD \times \text{No. of days} \times 0.024 \quad \text{(kWh)} \quad \text{-----(7)}$$

3.6 Dynamic conditions

While the use of a steady state mean 't_o' value as above may be adequate to determine heating and cooling loads for some building types - say an old person home with a 24 hour occupancy, it cannot be considered adequate for a school where occupancy is for a specific diurnal period on weekdays only. The simplest way to reintroduce the storage element of equation (1) is to express it through a theoretical temperature difference, which will convey thermal damping and time lag effects in much the same way that sol-air temperature translates as energy gain to a temperature rise.

This 'equivalent external temperature' is dependent on the thermal diffusivity of the construction, denoted D, and found by dividing the thermal conductivity by the volumetric thermal capacitance.

$$D = \frac{\lambda}{\rho c} \qquad (m^2/s)$$

This ratio controls time lag defined as the time delay for a temperature change on the outside surface to affect a temperature variation on the inside.

The time lag in hours assuming a 24 hours periodical cycle for a single homogeneous layer can be found from the equation:

$$T_{24} = L \times 0.023 \sqrt{1/D} \qquad \text{(hours)} \qquad \text{--------(8)}$$

It can also be found from the graph in figure 3.2. However the time lag for a multilayer construction is more complex and can be found using the time constant method by Raychaudhury and Chaudhury[5]. The time constant ϕ/U is the time taken for the amount of stored heat to flow through the wall, assuming a constant rate of heat loss and linear distribution of temperature inside the external element or wall.

The ϕ/U ratio (s/m thickness) of a multilayer structure is defined as the sum of the individual ϕ/U values of the separate layers where ϕ is the volumetric thermal capacitance, ρc, and U is the transmittance. Then thermal time constant, TTC, is given by

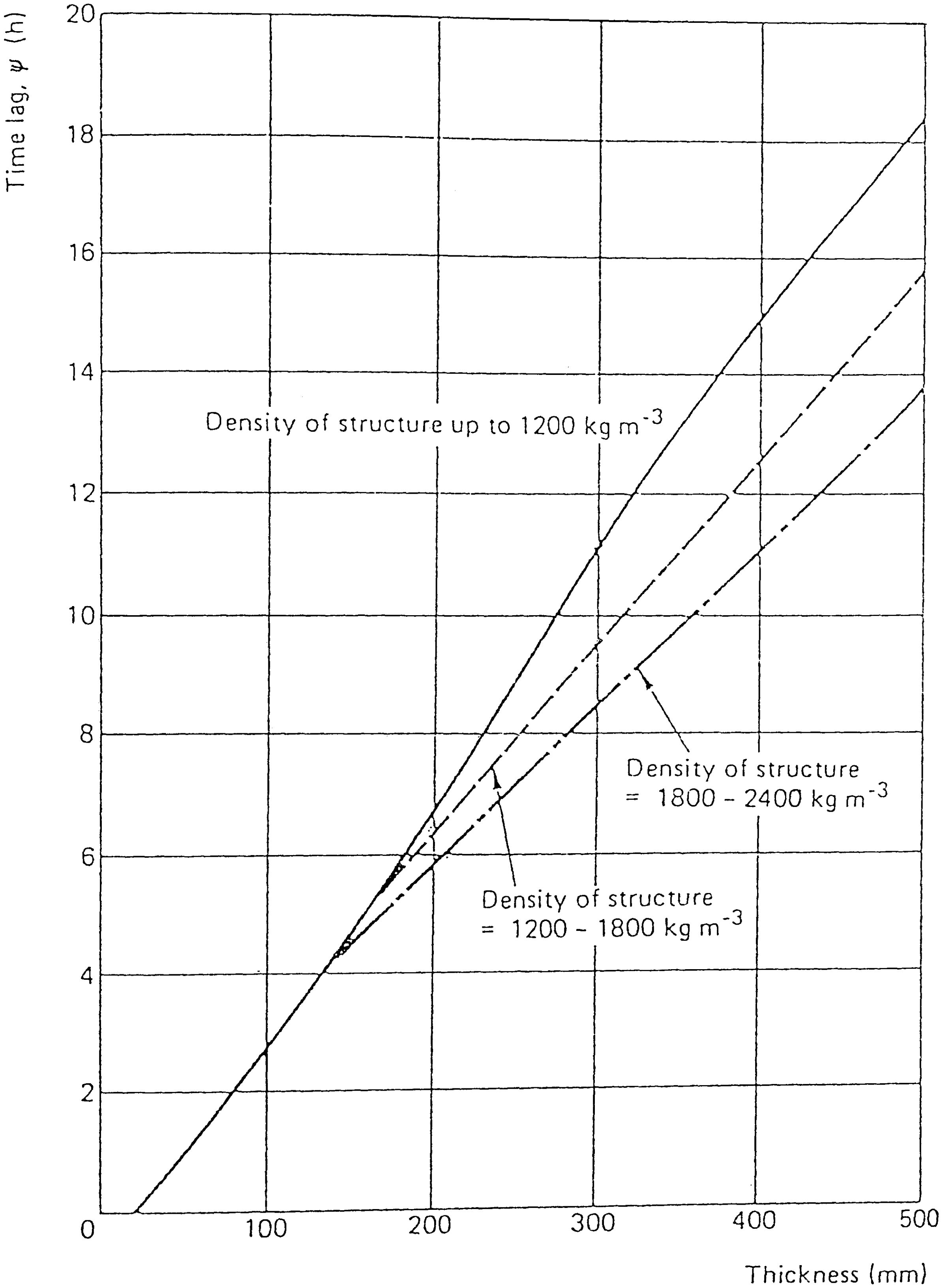


Figure 3.2 Value of time lag.

Source: I.H.V.E. Guide - Institute for Heating and Ventilating Engineers - Book A London 1971. A 8.6

$$TTC = \phi/U = \Sigma_i \ (\phi/U)_i \qquad \text{(seconds)} \qquad \text{------(9)}$$

where:

$$(\phi/U)_i = (R_{so} + L_1/\lambda_1 + \ldots L_i/2\lambda_i)(L_i\rho_i c_i) \qquad \text{-----(9a)}$$

where: ϕ/U = time constant of the structure (s)

R_{so} = external surface resistance (m^2K/W)

L_i = thickness (m)

λ_i = thermal conductivity (W/m^2K)

ρ_i = density (kg/m^3)

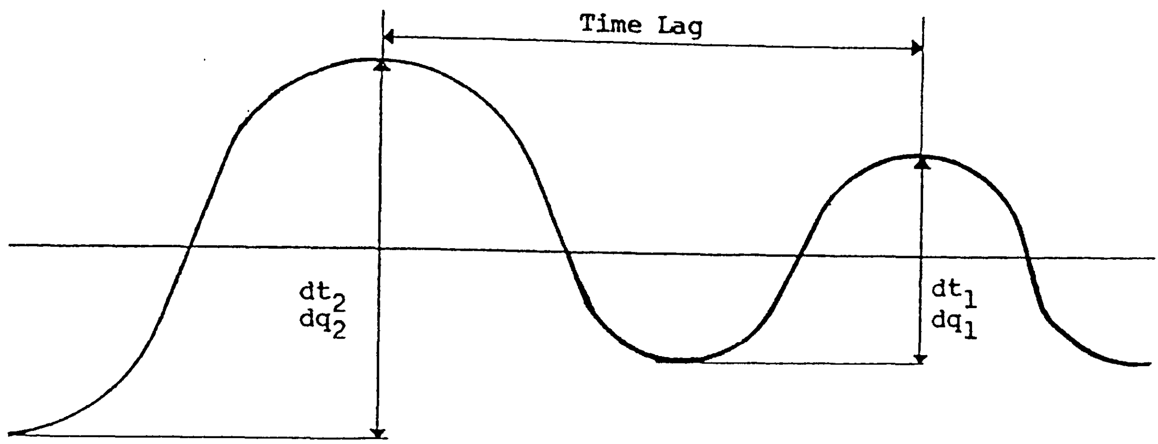
c_i = specific heat (J/kg)

The relationship between the time lag and time constant is expressed by the following equation

$$T_{24} = 1.18 + \frac{2\pi}{24}\frac{\phi}{U} \cdot \frac{1}{3600} \qquad \text{(h) ---(10)}$$

where: T_{24} is the time lag in hours with a 24 hour periodic cycle.

Thermal diffusivity also controls the 'damping factor' and the 'decrement factor', which are respectively the ratio of internal/external temperature and heat flux amplitudes - $\frac{dt_1}{dt_2}$ and $\frac{dq_1}{dq_2}$ - see figure below.



For single homogeneous layers the damping factor, D_t and the decrement factor, μ, are found respectively

$$D_t = \exp^{[-\text{thickness} \times 0.00603 \sqrt{1/D}]} \qquad \text{-------(11)}$$

$$\mu = \exp^{[-\text{thickness} \times 0.00219 \sqrt{1/D}]}$$

A graphical example of decrement factor is shown in figure 3.3. However, again the multi-layer construction is more complex and to find μ, the CIBS[6] standard admittance procedure using matrix algebra has been utilized on a micro-computer, together with the time constant equations (9) and (10) and the following equation to obtain the equivalent external temperature profile:

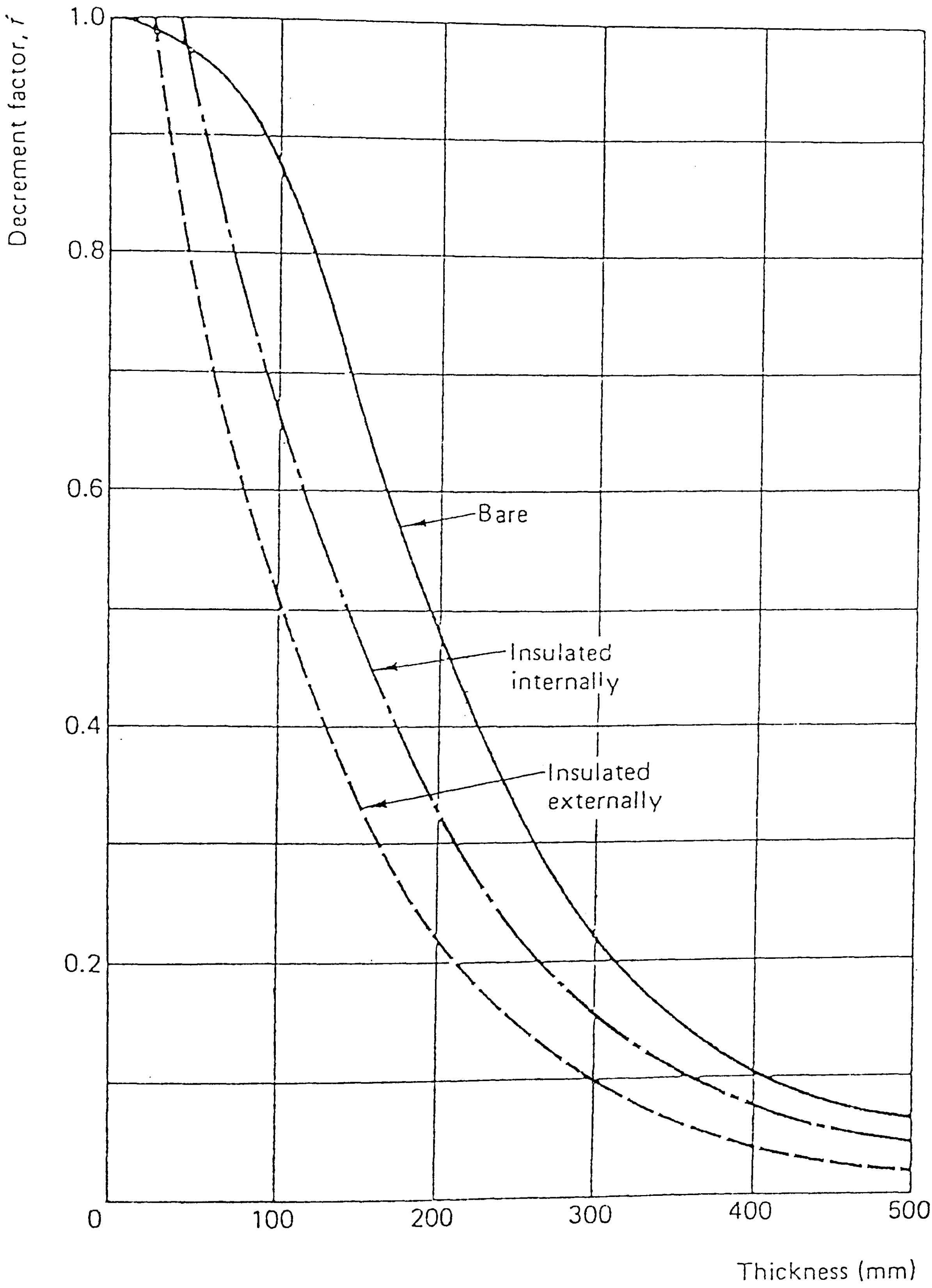


Figure 3.3 Value of decrement factor.

Source: I.H.V.E. Guide - Institute for Heating and Ventilating Engineers - Book A London 1971. A 8.6

$$t_e = \mu(t_\theta - t_o) + t_o \qquad °C \qquad \text{----------(13)}$$

where: t_θ = external temperature 'time lag' hours before the time in question.

t_o = mean external temperature for the period

The equivalent external temperature 't_e' for each construction can now be substituted in equation (2c) for any slice of the 24 hour period where H is now ΣH_{1-x} corresponding to $t_{e_{1-x}}$ for each consruction. In the case of a thin construction such as a window, 't_e' will equal 't_o' and the same applies to the ventilation component of H.

Equation (2c) thus becomes:

$$\Phi_h = \Sigma H_{1-x} (t_b - t_{e_{1-x}}) \qquad (W) \qquad \text{----(2d)}$$

Where t_b (htg) or t_b (clg) may be derived from either a heating or cooling demand temperature.

3.7 Conclusion

Thus we are able to investigate dynamic thermal performance during the unoccupied or preheat period and during the occupied period; calculating seasonal heating and cooling loads using the degree - day method outlined in 3.5, but substituting 't_e' for 't_o' throughout. By altering building design parameters we can then attempt to passively reduce heating and cooling loads to a minimum.

The following section therefore summarises the analysis of the existing model following this procedure. From this analysis guidelines for improved climate sensitive school design will emerge.

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Section 4

ANALYSIS OF THE EXISTING SCHOOL MODEL

ANALYSIS OF THE EXISTING SCHOOL MODEL

4.1 General Description

In addition to the school building situation and needs discussed in section 1, the rapid growth of school age population encouraged a standardisation of architectural style. The school building to be analysed is therefore representative of current building programmes.

The school building considered for the thermal analysis is situated in a new settlement or large spontaneous residential area-see figure 4.1. It is an urban structure for housing development sited some distance from the city of Constantine and taken as one of the measures contributing to the housing crises in the region. It is an exposed hilly site, south-east of the town, and nearly at the same latitude as Constantine Airport where the climatic data used for analysis has been measured. The school is situated on the hill top dominating the residential area in which houses are one storey, lightweight and pitched roof buildings.

The school was built in 1983 to accommodate 960 pupils but it actually accommodate 1,066[1] pupils due to the lack of schools. The building is three storey, rectangular shaped and each floor contains four classrooms, terminated at the south-east and north-west by staircases, - see figure 4.2a and 4.2b. It has a total gross floor area of about 1,305 m^2. Each classroom has two walls subjected to

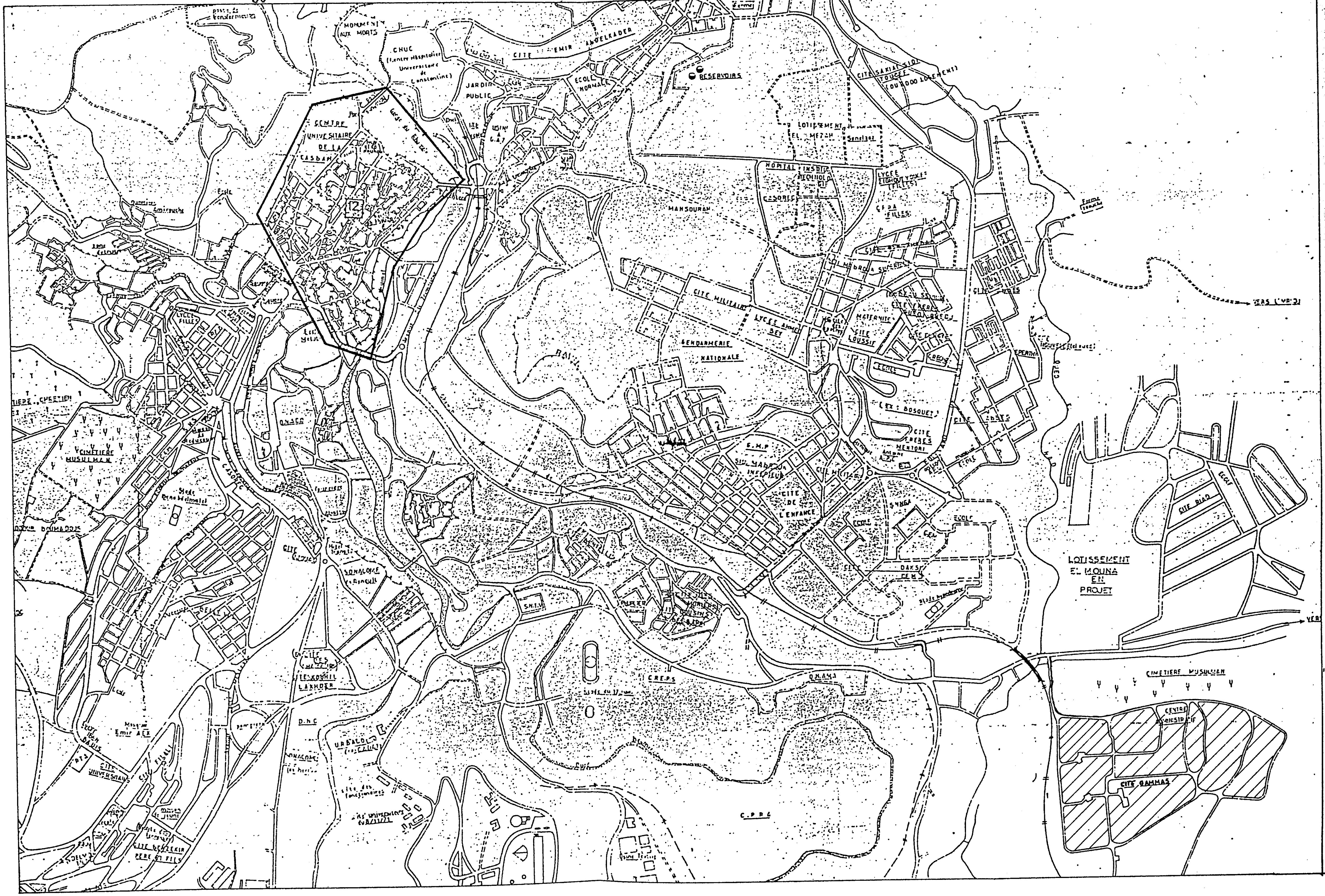


Figure 4.1 The location of the school analysed in relation to the Constantine City Centre.

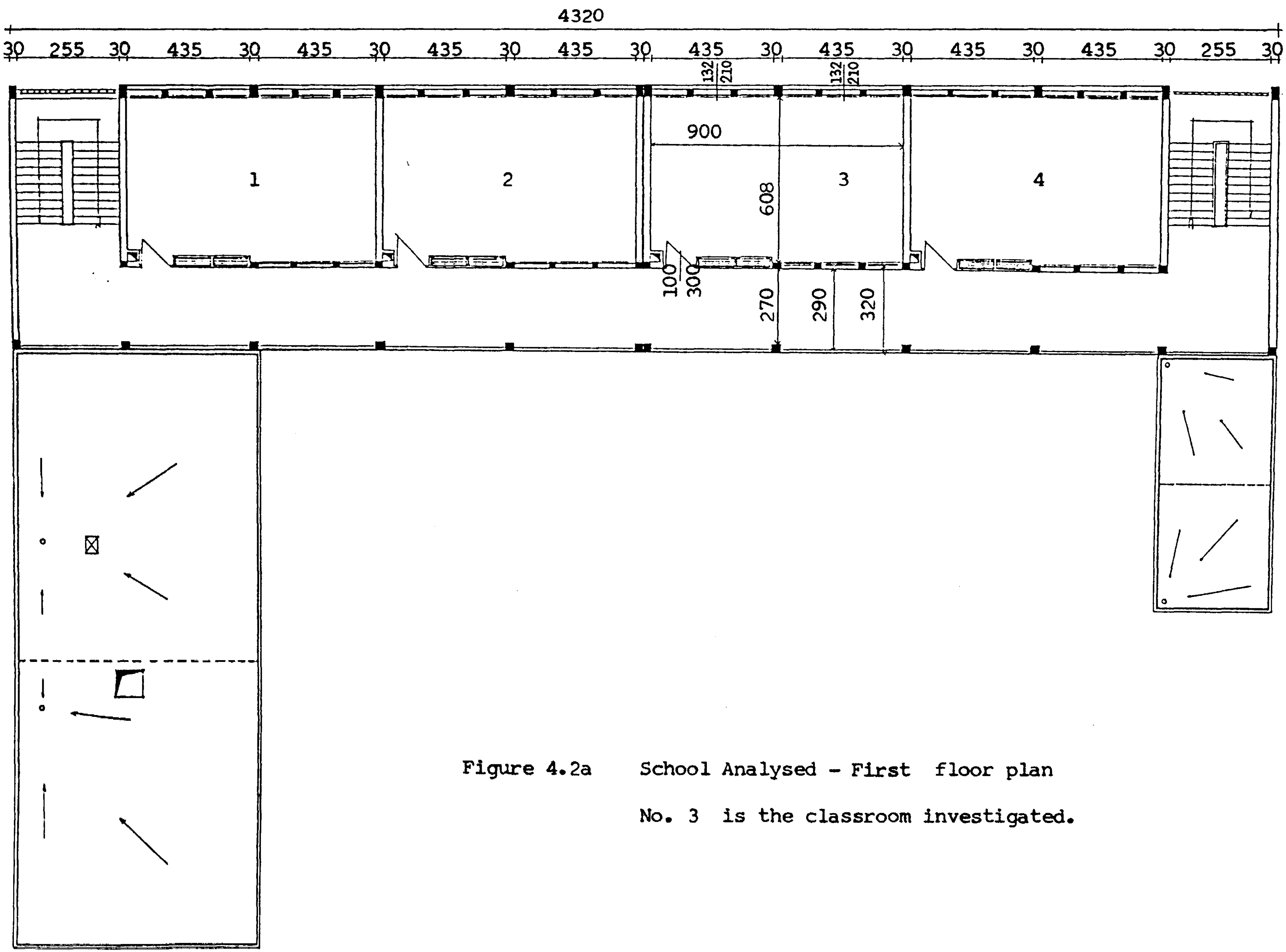
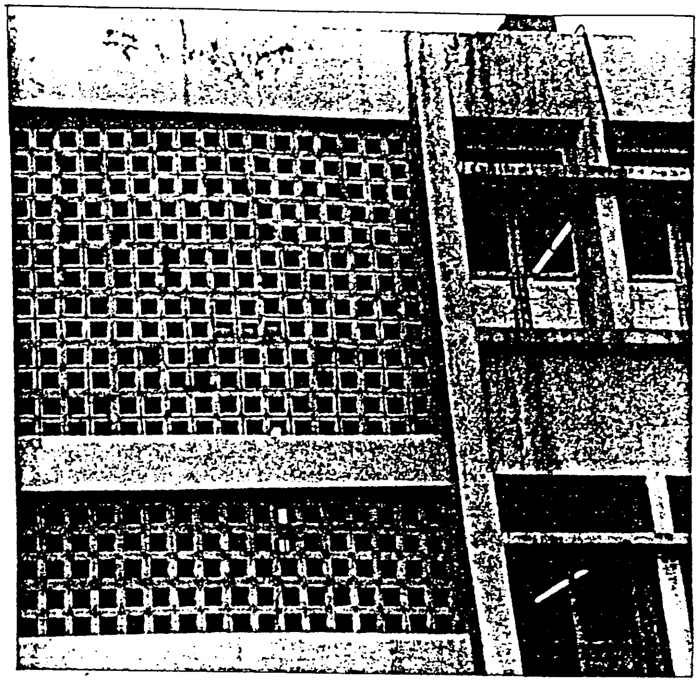
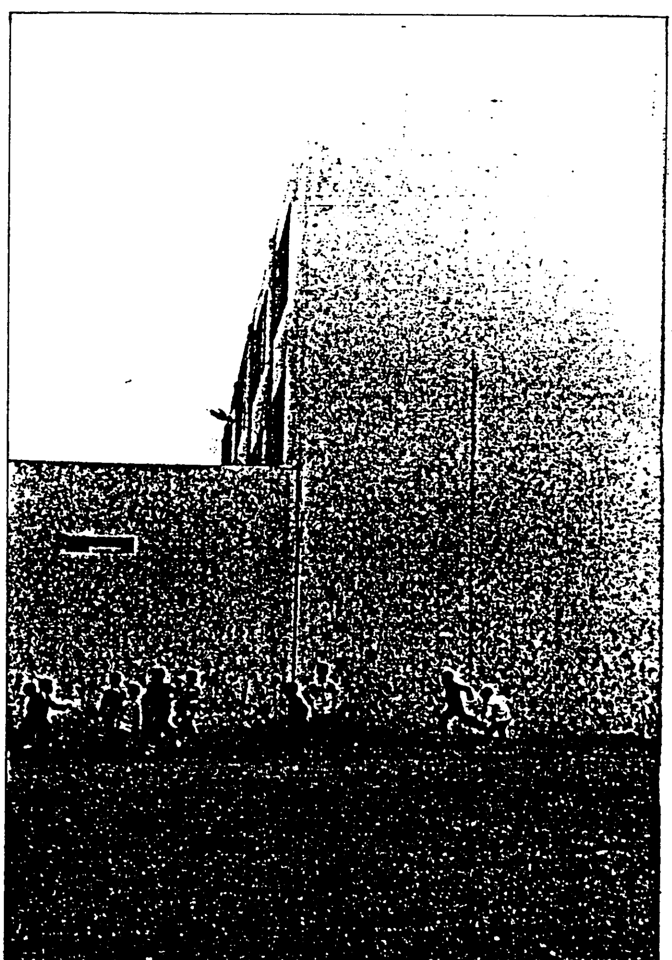


Figure 4.2a School Analysed - First floor plan

No. 3 is the classroom investigated.



Staircase from the north-east facade



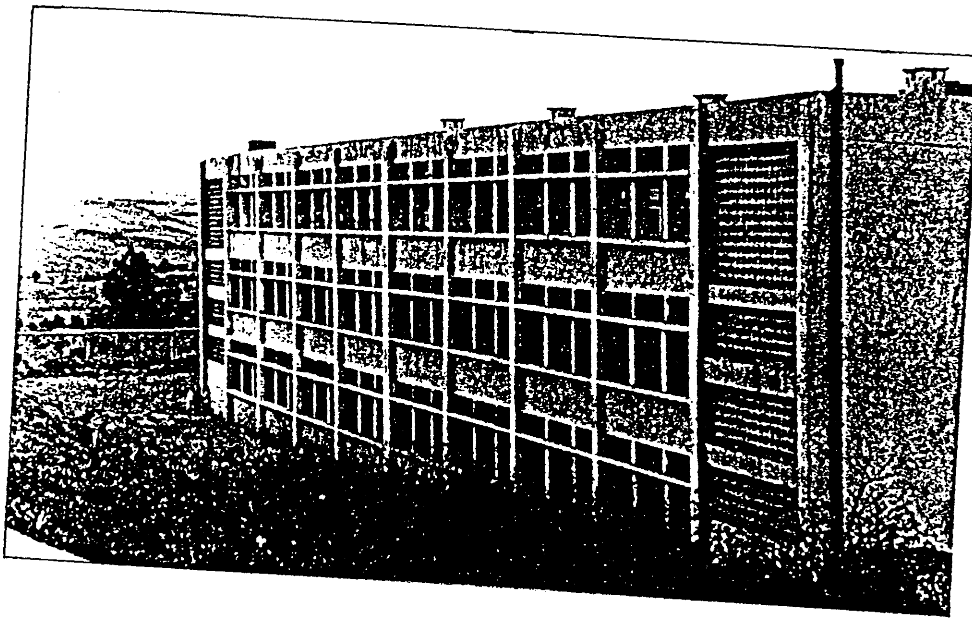
South-east facade

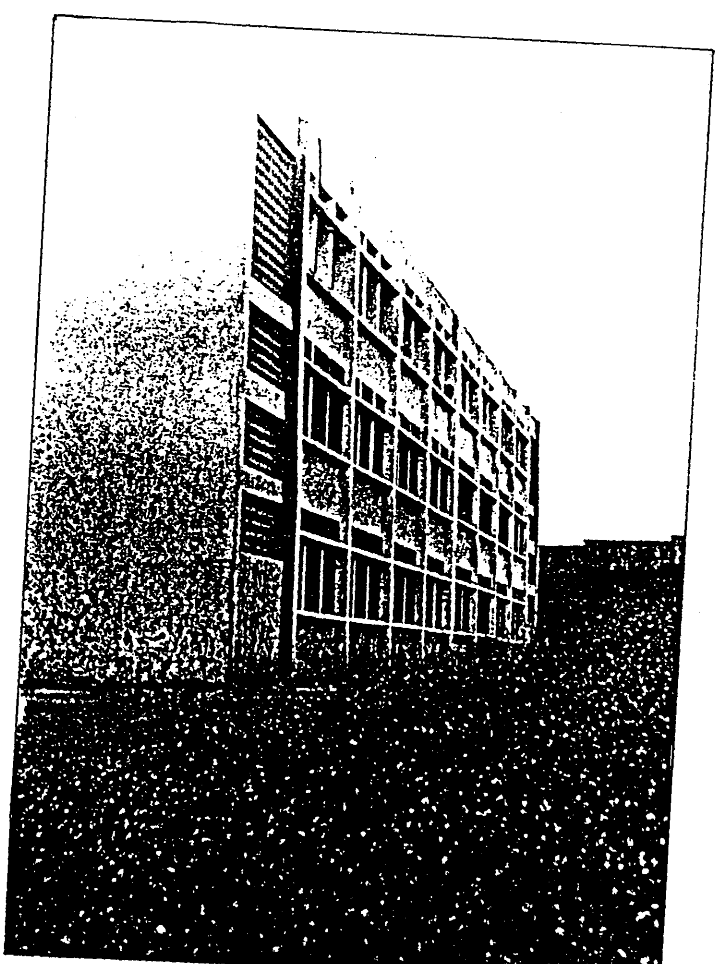
Figure 4.2b

the external environment and oriented north-east and south-west. The north-east facade has a glazing to wall area ratio of about 35.5% and protected from the direct sunlight by fixed fins of 40 cm, see figure 4.3.

The south-west facade has a ratio of glass to wall area of 20%. It is also protected by a 3.2 m wide overhang which covers an open corridor - see figure 4.4. This eliminates the penetration of sunlight during summer but permits some of it during the winter. It has a solid flat roof exposed to the most dominant incident solar radiation. Its construction and thermo physical properties of material are 'illustrated in table 4.1, appendix 4 and figure 4.5.

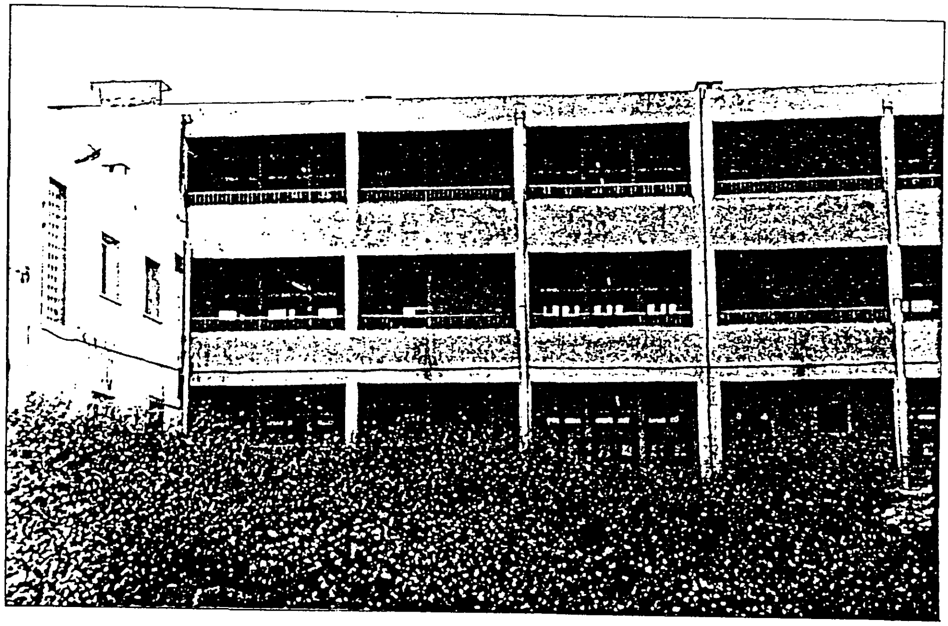
The external opaque part of the building envelope is white washed (absorptivity = 0.8) and mainly built of two layers of hollow brick, with the exception of the south-west wall at the back of the fixed cupboard, see fig 4.6. The external layer is three times thicker than the internal one. The transparent part is mainly constituted of wooden frame single glazed windows with a U-value estimated to be 4.14 W/m^2K [2]. The thermal diffusivity, that is ratio of conductivity to volumetric thermal capacity, and the wall thermal transmittance, U = 0.88 W/m^2K, contribute to achieve a time lag of 9 hours and estimated fabric losses of 136.32 W/K in addition to ventilation losses of 168.17 W/K, based upon a recommended value of three air changes per hour. It should be noted that this exceeds the minimum Ministry of Education requirement by a factor of 3 (see 1.3.4), but is considered necessary to provide satisfactory environmental





North-east facade showing fins and staircases position

Figure 4.3 North-east facade.



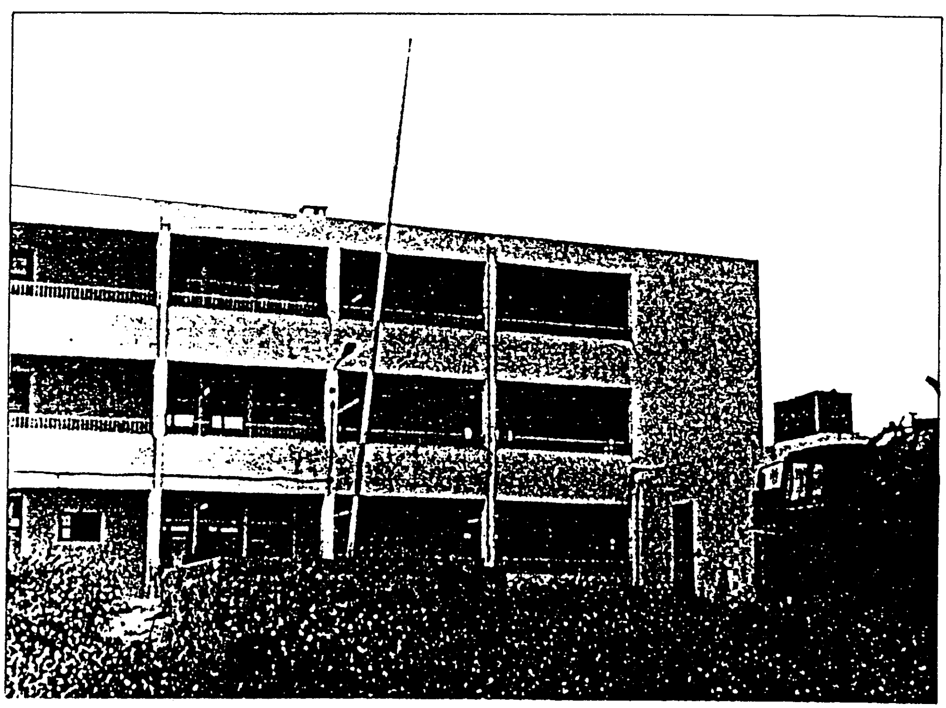


Figure 4.4 South-west facade showing the open corridor and overhang.

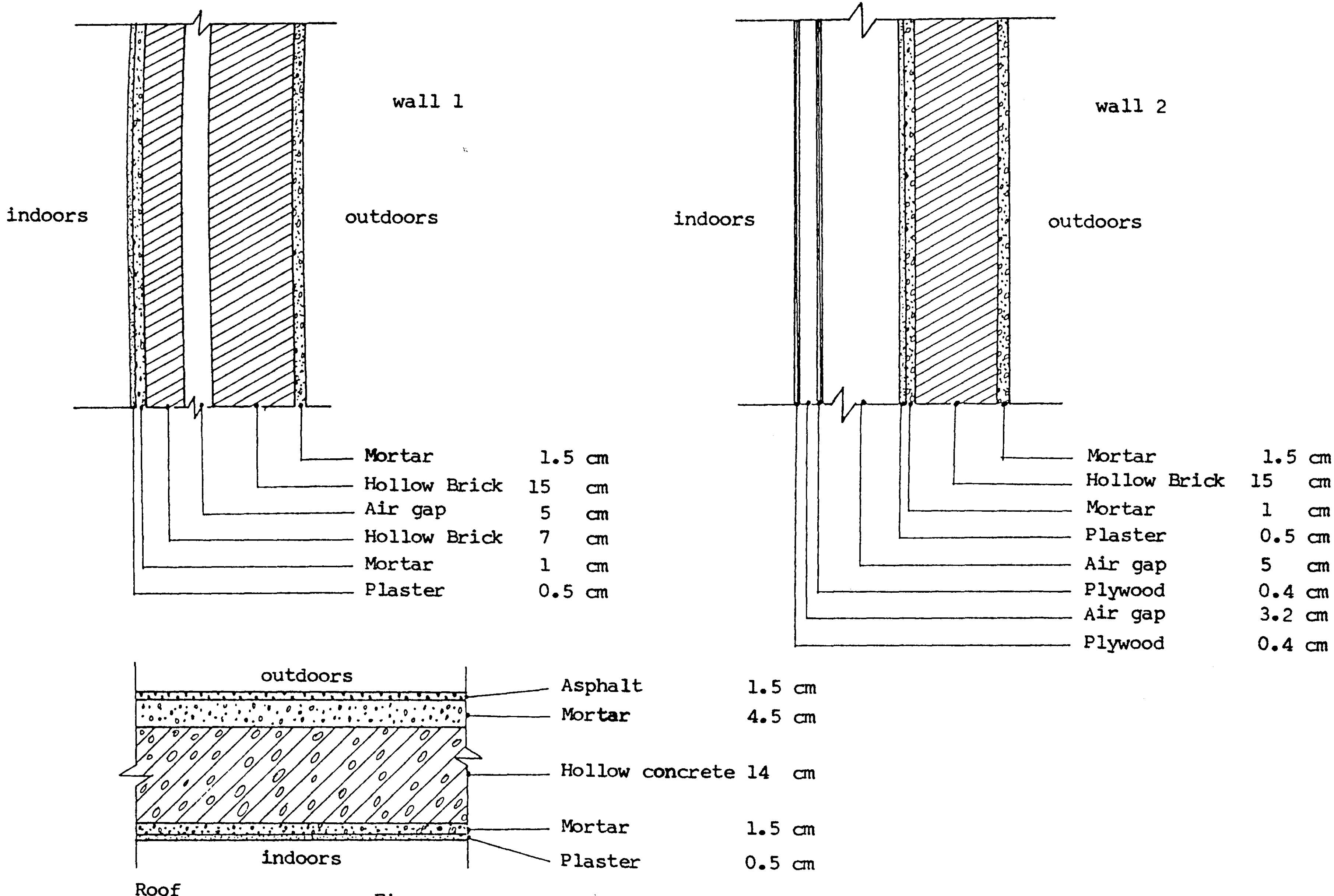


Figure 4.5 Roof and walls construction of the model analysed

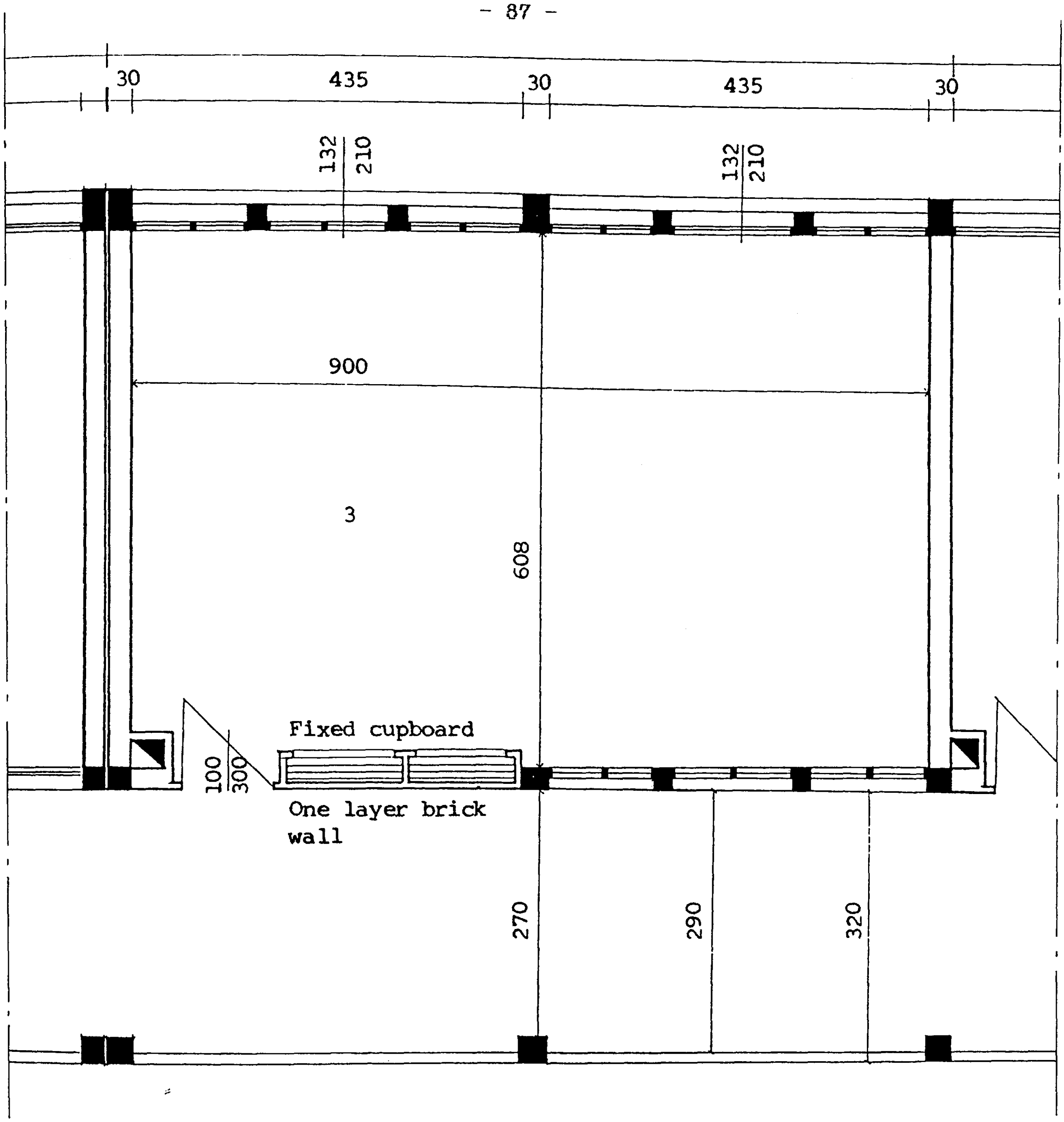


Figure 4.6 Classroom investigated - First floor plan.

conditions taking account of the nature and size of the occupancy - see sub-section 4.3.3 below. Wall thickness, type of building material, physical properties, thermal admittance and decrement factor are listed in table 4.2, appendix 4, and illustrated by figure 4.5.

The classroom investigated is in the first floor, bounded on the north-west and south-east by two other classrooms. The investigation has been carried out for two periods of the day - an unoccupied period from 6 a.m. to 8 a.m. assumes a design temperature of 21°C where none of the incidental heat gain input is considered. The occupied period is from 8 a.m. to 6 p.m. when an estimated 2,200 W of metabolic gain is generated by 40 pupils and the design temperature has been assumed within a range of 18 - 25°C.

The investigation has been carried out for the working period of the year which lasts from mid-September until the end of June. There is an interruption during winter and spring for about 15 days during each period, but the school still funtions for the staff, while it stops completely for the summer holiday period of two and a half months.

4.2 Heating and Cooling Loads - Preliminary Observations

From the analysis of the model it has been found that a considerable amount of energy is needed to cool an occupied and unoccupied classroom depending on the period of the year. The school working day has been divided into occupied and unoccupied periods and each period is investigated separately.

The results also show that a significant heating load is required to preheat this unoccupied classroom for 2 hours of about seven months - say from October till April. It peaks in January reaching 329.18 kWh and reaches a minimum of 26 kWh in April. A small amount of cooling during the same time of the day is required for a short period of the year (May, June and September) - see fig 4.7 and table 4.2. The amount of energy required for cooling in this period is only 6% of that required for heating, but mounts up considering the whole school or 12 classrooms to 957 kWh. The reduction or even the elimination of this amount can be met using night and/or morning cross ventilation.

It has been deduced that a large amount of cooling is required during the occupied period in order to maintain the classroom at the maximum comfort temperature - 25°C. This is the case even during winter, with the exception of January and December, where neither heating nor cooling is required - see table 4.3. The principal factor which governs the extent of the overheating problem is the heat generated

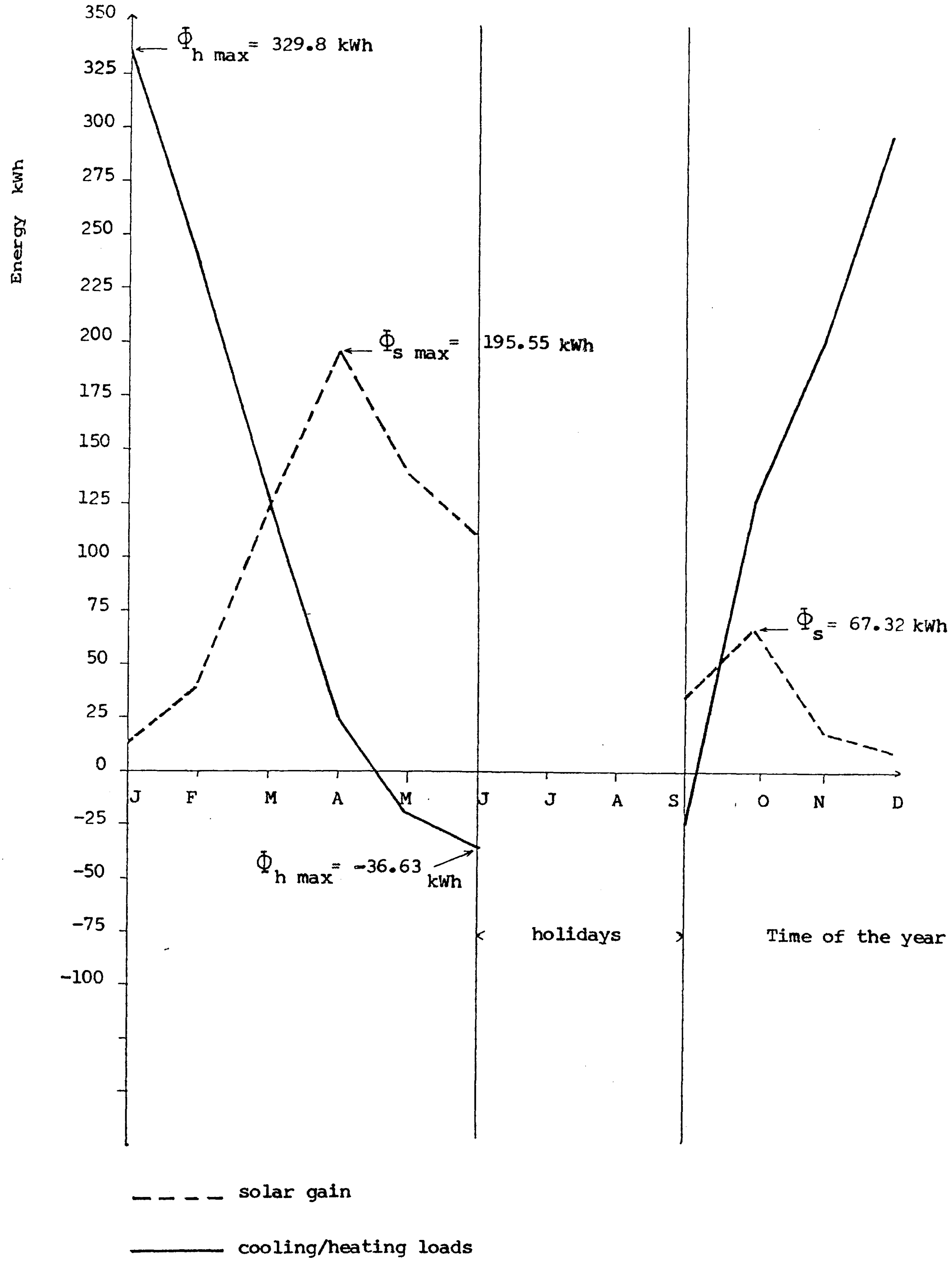


Figure 4.7 Unoccupied period: Monthly solar gain and cooling/heating loads.

	North East Facade			South West Facade					
Month	$T_{so1}/^{o}C$	Φ_{sf1}/W	Φ_{sg1}/W	$T_{so2}/^{o}C$	Φ_{sf2}/W	Φ_{sg2}/W	$T_b/^{o}C$	Φ_s/kWh	Φ_h/kWh
January	4.6	-	182.26	3.3	-	29.75	20.3	12.72	329.18
February	8.42	-	645.23	4.97	-	80.33	18.6	40.63	231.05
March	16.3	-	1874.72	6.99	-	154.7	14.34	125.82	152.43
April	23.87	36.85	2974.23	10.67	-	246.93	10.34	195.55	26.07
May	32.66	149.71	1964.01	14.8	-	147.23	13.57	140.19	-20.68
June	39.1	232.39	1281.8	20.07	-	321.3	14.97	110.13	-36.63
July	SCHOOL HOLIDAY								
August									
September	30.84	127.6	331.76	18.69	-	42.84	19.4	30.13	-22.45
October	18.6	-	987.66	13.26	-	98.18	17.4	67.32	76.27
November	9.55	-	293.58	7.64	-	41.65	19.9	20.11	213.84
December	5.4	-	116.22	4.5	-	20.83	20.62	8.5	295.77

Table 4.2 Results of analysis for the unoccupied period $t_i = 21^{o}$

	North East Facade			South West Facade							
Month	$T_{sol}/^{o}C$	Φ_{sf}/W	Φ_{sg}/W	$T_{so2}/^{o}C$	Φ_{sf}/W	Φ_{sg}/W	$\Phi_{sg}+\Phi_{sf}/W$	t_i ^{o}C	$T_b/^{o}C$	Φ_s/kWh	Φ_h/kWh
January	12	-	529.95	21.9	-	712.1	1242.05	18/25	6.4/13.7	372.6	0*
February	15.1	-	618.04	24.13	-	622.91	1240.95	25	13.72	347.47	-125.43
March	18.7	-	554.57	29.93	107.03	409.46	1071.06	25	14.26	298.85	-113.06
April	23.46	-	899.4	31.64	144.15	720.7	1764.25	25	11.9	486.03	-338.32
May	30.96	76.52	1141.97	37	260.52	748.15	2227.16	25	10.4	690.42	-913.2
June	38.7	175.9	1212.76	42.85	387.52	718.46	2494.64	25	9.6	748.39	-1573
July	SCHOOL HOLIDAY										
August											
September	33.18	105.02	835.94	44.47	422.7	716.66	2080.32	25	10.9	624.1	-1342.47
October	25.3	3.85	595.16	36.6	251.8	655.25	1506.06	25	12.8	466.88	- 664.06
November	18.27	-	193.52	28	65.18	180.45	439.15	25	16.3	131.75	- 105.64
December	13.62	-	495.68	22.65	-	764.86	1260.54	18/25	6.6/13.6	390.77	0*

Table 4.3 Results of analysis for the occupied period $t_i = 25^{o}$

Nomenclature Table 4.2 and 4.3

T_{so1} = Sol-air temperature on the North-East Facade.

T_{so2} = Sol-air temperature on the South-West Facade.

Φ_{sf1} = Solar gain through North-East Wall.

Φ_{sf2} = Solar gain through South-West Wall.

Φ_{sg1} = Solar gain through North-East Window.

Φ_{sg2} = Solar gain through South-West Window

Footnote:

* In January and December, when the internal temperature required is 18°C, there is a cooling requirement. But when the internal temperature is 25°, there is a heating requirement. So it can be concluded that, these two requirements are negligible, and the temperature of the occupied classroom is within a comfort range, 18°- 25°C.

by occupants plus solar heat gain as shown in figure 4.8. Even assuming the total obstruction of direct solar gain, the cooling load is very high and reaches a maximum of 1573 kWh in June. Averaging 647 kWh over 8 months, it is 3.5 times larger than the heating required during the unoccupied period, averaging 189 kWh for 7 months. It is also clear that a diurnal increase of ventilation rate during summer increases the cooling load, due to the high external temperature; whereas a decrease can be achieved during November, February and March when the external temperatures are less than the minimum design temperature '18°C'.

The effectiveness of nocturnal ventilation in summer to lower the following day's start temperature would be very dependant on a reasonable differential between structural temperature reached during the preceding day and the external temperature profile. In June, for example, the average temperature during the period 18.00 (school closed) to 8.00 (school open) is 19.7°C, starting at 28°C and falling to 15°C by 6.00 a.m. Thus the cooling effect would be marginal in the period after the school closed, but would be of some value during the early morning prior to opening. From figures 4.9 and 4.10, and table 4.4, appendix 4 it can be seen that the building envelope, with a time lag of 9 hours, starts to heat up at 6.00 a.m. and dissipate the stored heat at 15.00 p.m., which coincides with the maximum outside temperature. Consequently, the heat absorbed contributes to an increase of the school day overheating problem. It may be concluded that since maximum natural

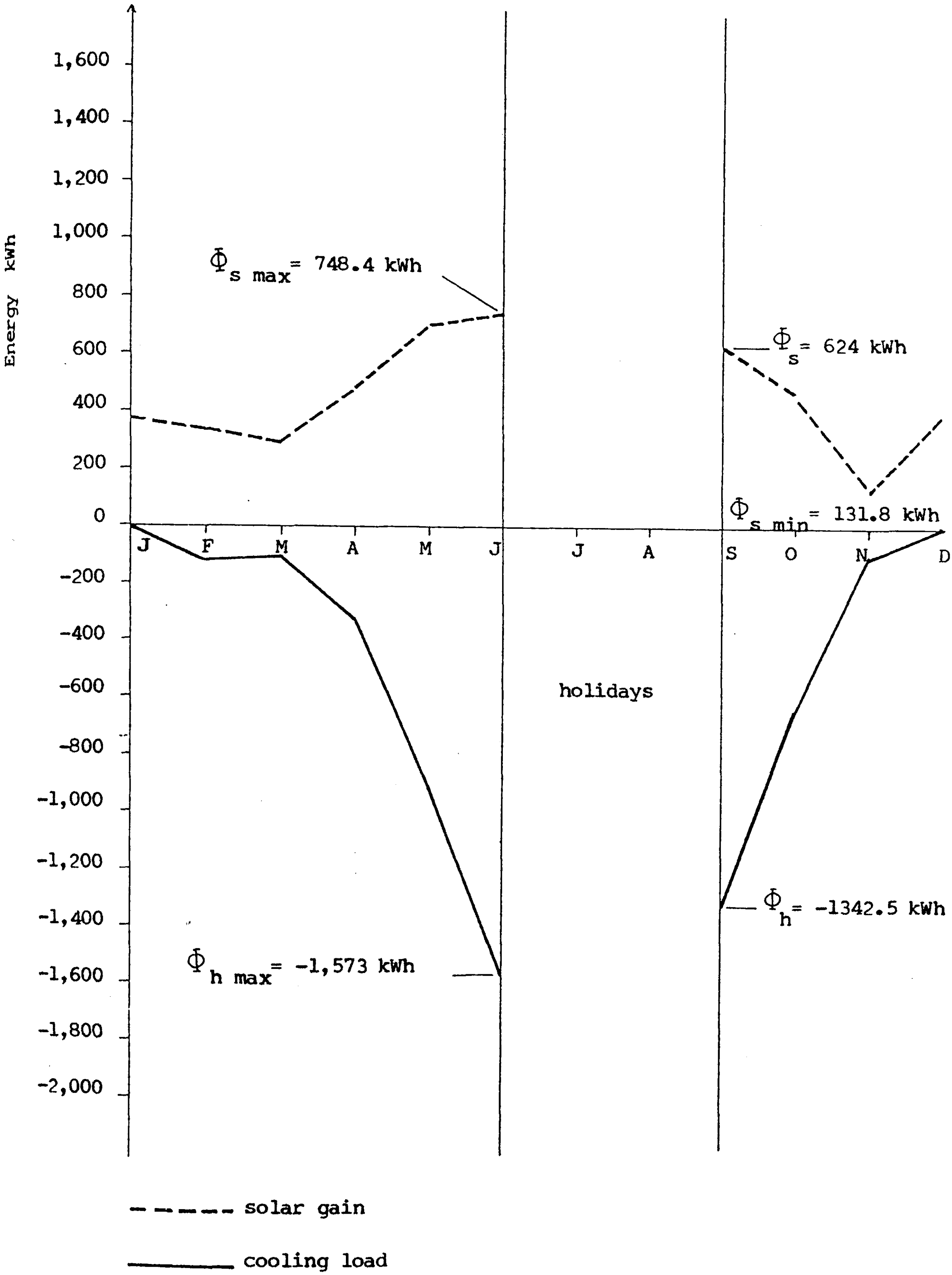


Figure 4.8 Occupied period: Monthly solar gain and cooling load.

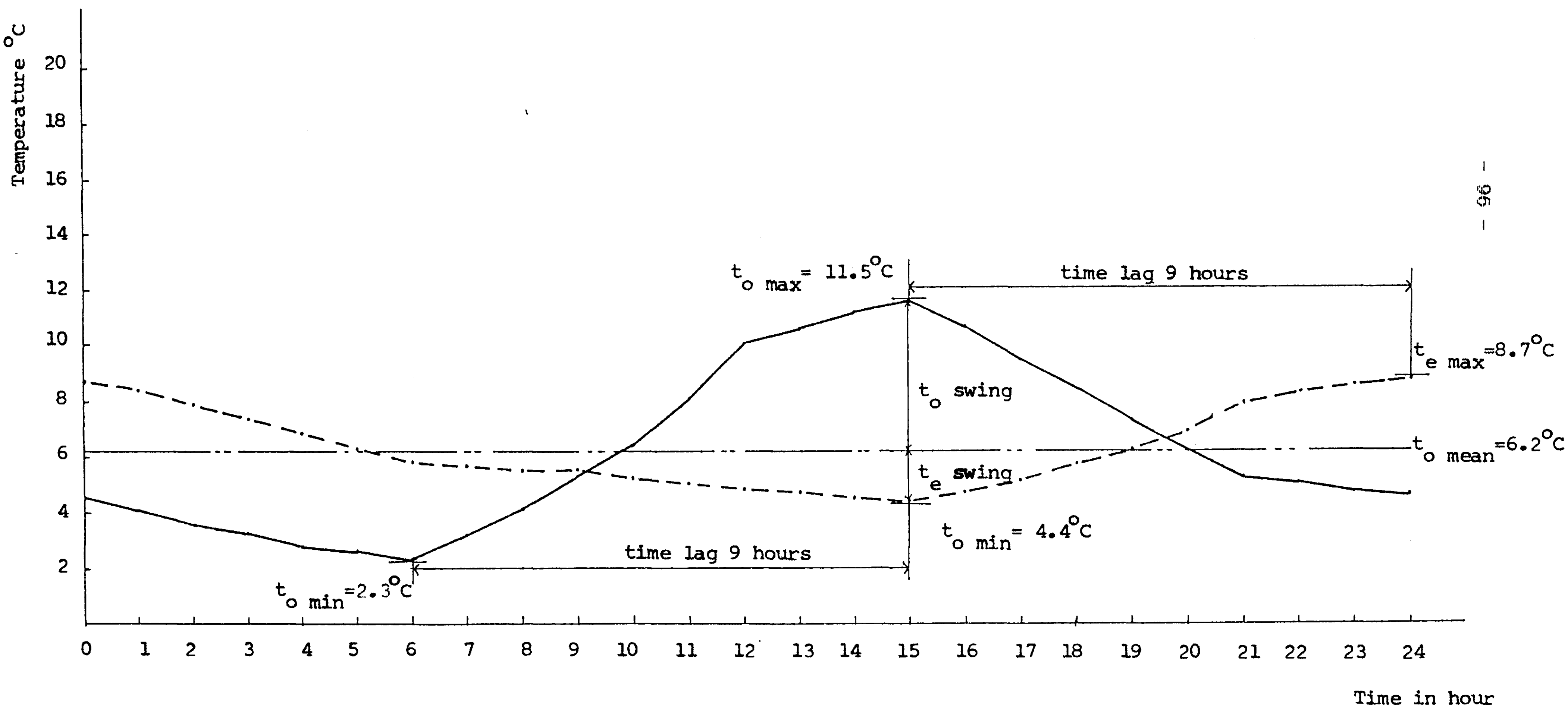


Figure 4.9 External and equivalent external temperature fluctuation in January for the wall of the existing school.

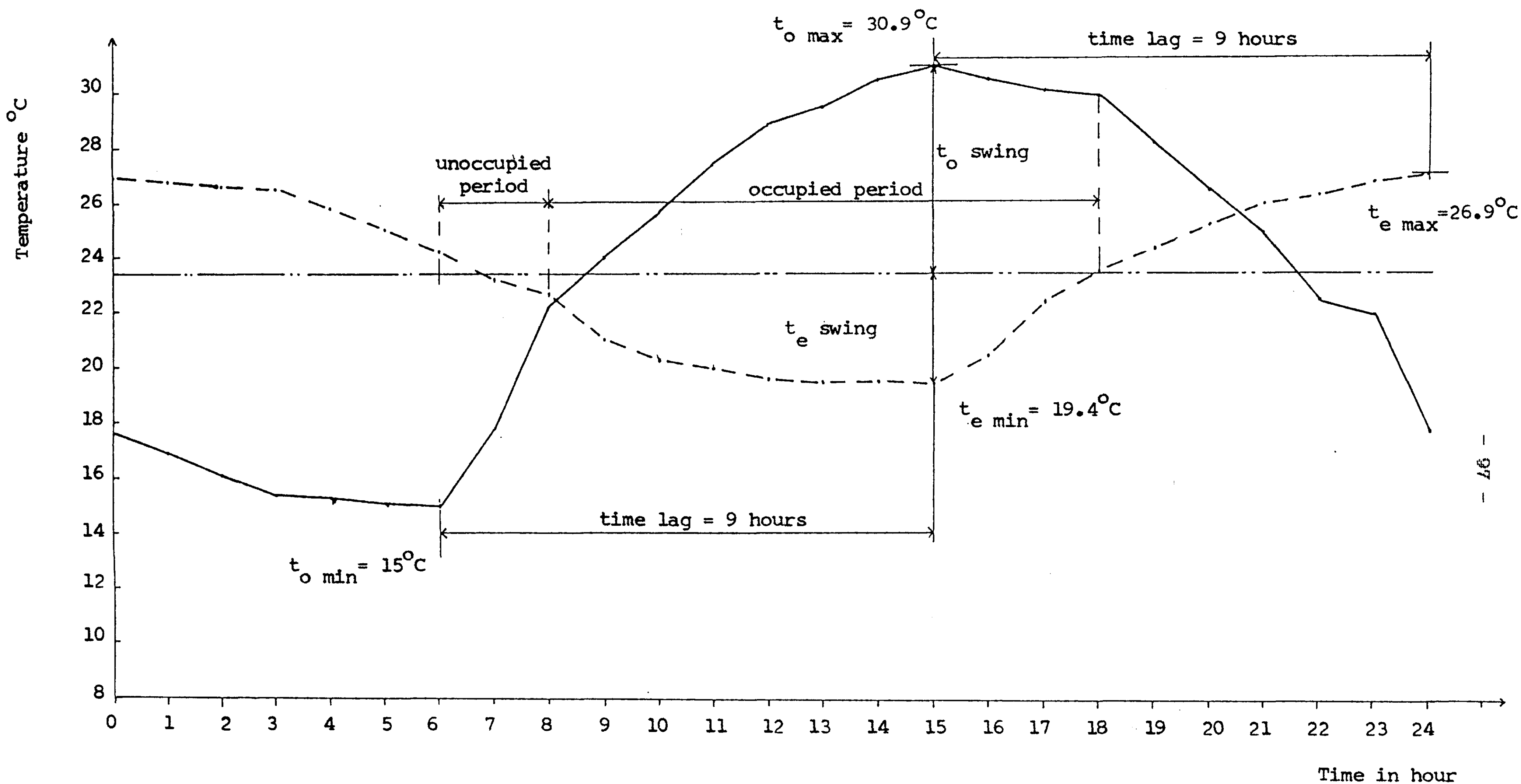


Figure 4.10 External and equivalent external temperature fluctuation in June for the wall of the existing school.

cooling occurs during the night and early morning, a building envelope with longer time lag could have a beneficial effect on daytime temperature.

Cooling would also be assisted in summer by having the occupied period ventilation held to the minimum requirement, in this case 1 air-change/hour. But although this might satisfy current standards it is likely to induce a rather stuffy/smelly environment for teaching purposes. The target is to achieve both lower temperature and reasonable ventilation during the day by passive means.

When the cooling is assumed equal to zero permitting the internal temperature to float above the desired level, The temperature in June is calculated to rise to 23.68°C during the unoccupied period, a value which is somewhat in excess of the design temperature taken as 21°C. However, the temperature during the occupied period rises to 43.4°C, a level which could not be tolerated even outside and for short periods.

From the analysis it has been found that the contribution of casual gain is critical in relation to comfort inside the classroom. In June during the occupied period and when pupils are in the classroom, the amount of cooling is 2.3 times that required during the same period with pupils outside. Also this amount of casual gain generated from pupils displaces potentially useful solar energy during the winter period.

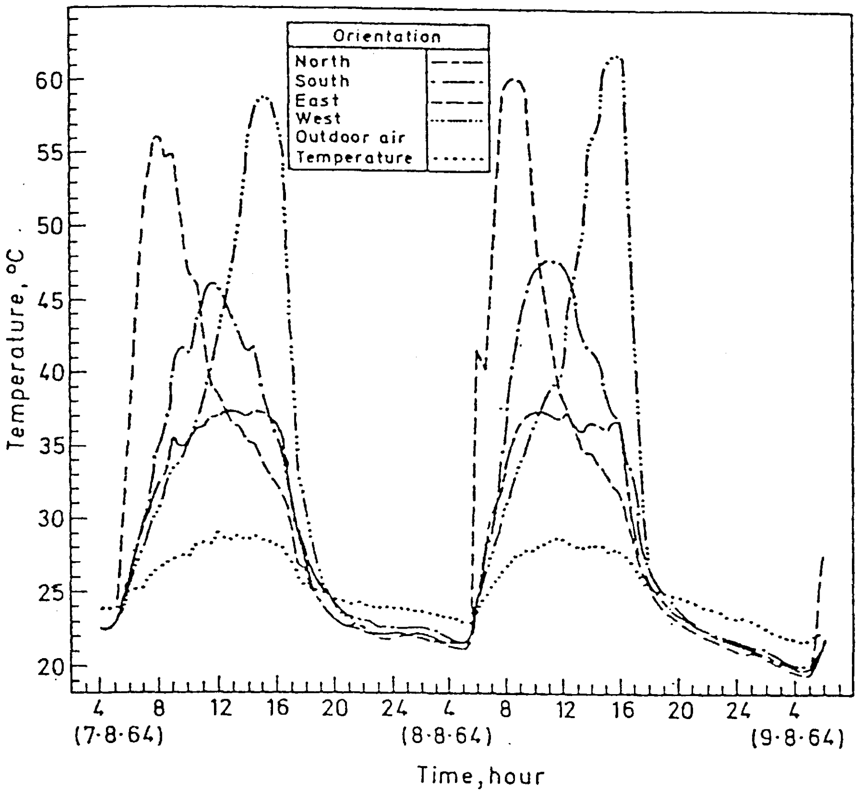
It can be concluded from the result that winter preheating and summer cooling cannot be solved without modification of the present design. So in order to arrive at an effective solution, the influence of relevant climate/building design factors on the internal comfort conditions has to be analysed. Although these features must be analysed separately, it is then necessary to synthesise to an integrated climate sensitive building design.

4.3 Climate Sensitive Design Parameters

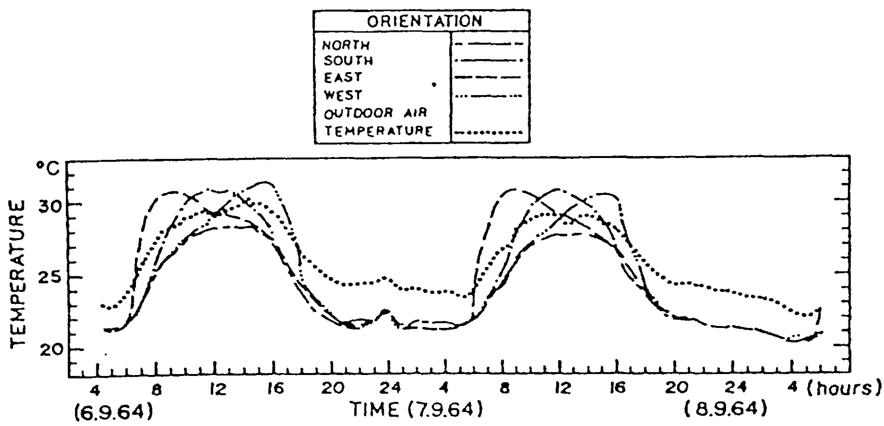
4.3.1 The opaque shell

The total amount of solar radiation or insolation received at any surface depends on the duration, intensity and orientation. The transmission of solar energy to the interior of the building depends on the thermophysical properties of the multi-layer envelope including the external colour. When the colour of the surface is light, its absorptivity is low and the effect of shortwave solar radiation is less significant than with a dark colour, where the influence is dominant. This is confirmed by the experimental study at the BRS in Haifa. Figure 4.11 illustrates the interaction between the colour and orientation of external surfaces.

From figure 2.9, section 2, it is noticeable that there are large variations between the amount of solar radiation falling on different surfaces of the building. In this case it is the roof and to some extent the south-west facade which are most exposed to the sun. For example, in June horizontal surfaces receive 2.3 times more than the average of north, south, east and west facades and 1.75 times the



External surface temperature of grey wall with different orientations.



External surface temperature of white coloured walls with different orientations.

Figure 4.11 Interaction between the effects of orientation and External colour.

Source: Givoni, B. 'Man, Climate and Architecture', 1976, p. 218.

amount on east or west facades. It is also interesting that the difference between south and north facades in June is very small - 2,210 Wh/m^2 compared to 2,102 Wh/m^2 - due to solar geometry and the consequent dominance of the diffuse component.

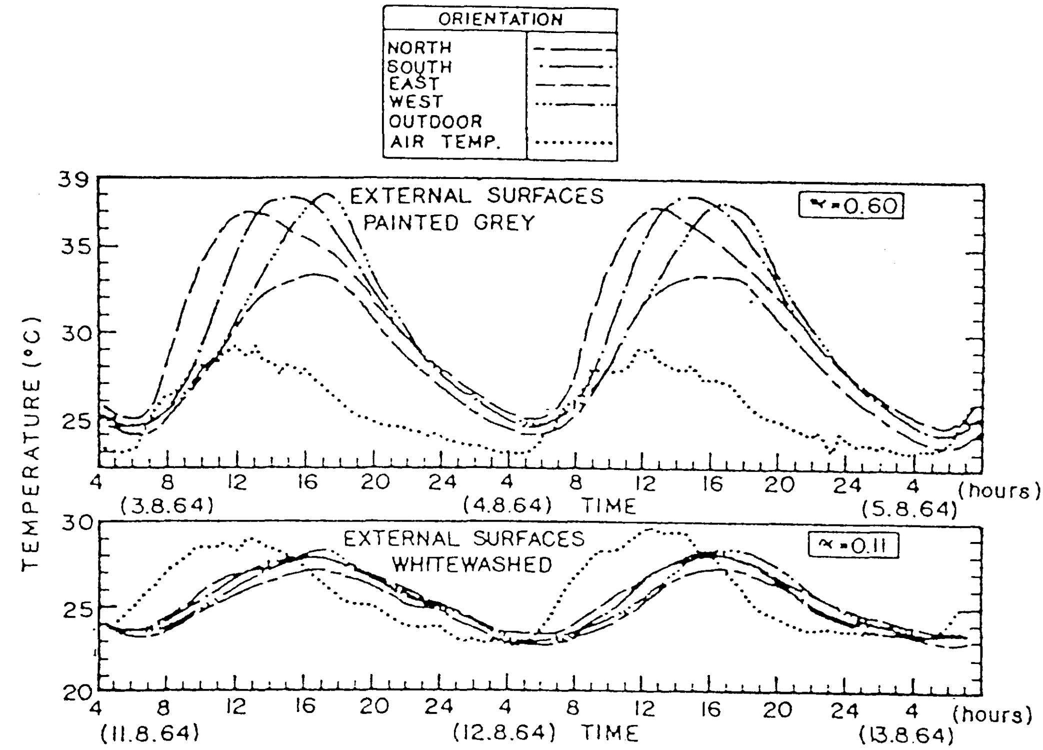
Different attempts have been made to determine the optimum orientation for buildings. For example Olgay[3] promotes the use of 'solair temperature' to determine the optimal orientation. But Givoni[4] concluded that not enough is known on the orientation problem with respect to ventilation in school buildings and offices to enable definite recommendations to be made - see sub-section 4.3.3 below.

The amount of solar radiation input will thus initially be the function of geometry. Considering the differences in exposure to solar radiation, a rectangular plan tends to give better results than a square one, since long south and north facades self-shade to a large extent. It is clear in the model that orientation and shading have been considered, but overheating and consequent pupil discomfort is still a problem.

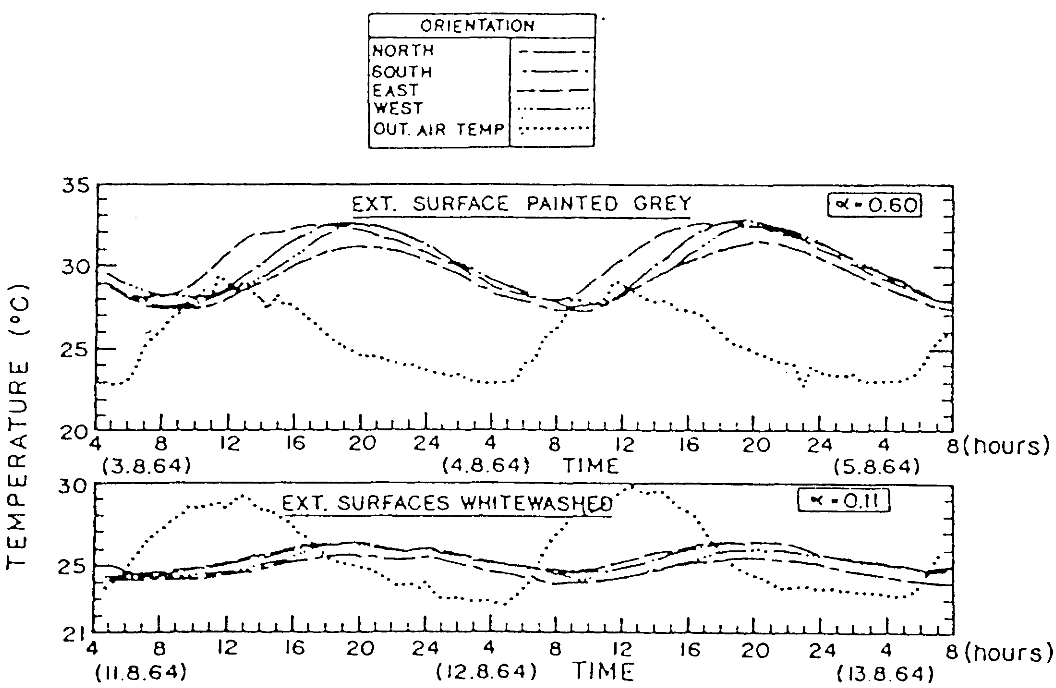
The process of heat flow through the opaque shell of the building is comparable to the absorption of moisture by porous materials. The successive layers of the structure become 'saturated' with heat until finally the effect is felt on the inside surface. The sinusoidal fluctuating daily temperature/heat flux through the structural element becomes diminished in amplitude and delayed in time, creating dynamic daily patterns of the energy flow into and out of any building - see figure 4.12. As shown in section 3 this flow is controlled by thermal diffusivity 'D' which is inversly proportional to volumetric thermal capacity. Hence materials with high heat capacity have great advantage in Constantine regions since they take a long time to absorb the received solar energy before passing to the inside. This can be explained as follows. The outdoor temperature is at its minimum before sunrise, afterwards increasing to reach its maximum in the afternoon, then declining slowly to reach its minimum during the very early morning. The same cyclic process is followed by the internal temperature, but its amplitude is smaller and its maximum and minimum are delayed by the time lag. This effect is well illustrated by the results of the analysed model comparing the 't_e' to the 't_o' profiles, figure 4.13 and 4.14.

When windows are large as in the analysed classrooms, or the shading is not effective and the portion of heat penetrating through the window is significant, the heat capacity assumes much greater importance. In this case, a wall of bricks, dense concrete or adobe with a thickness of about 20-30 cm could exhibit a better thermal performance.

The time lag of 9 hours of the principal part of the classroom wall has been stated to be on the low side. As the sun starts to heat the building early in the morning - 6.00 am - the heat flow reaches the interior of the building at 15.00 pm. This coincides with the maximum external temperature and the working hours of the classroom. Hence a



d = 10 cm.



d = 20 cm.

Figure 4.12 **Internal surface temperature of walls of different orientation thickness and external colour.**

Source: Givoni, B. 'Man, Climate and Architecture', 1976, p. 223.

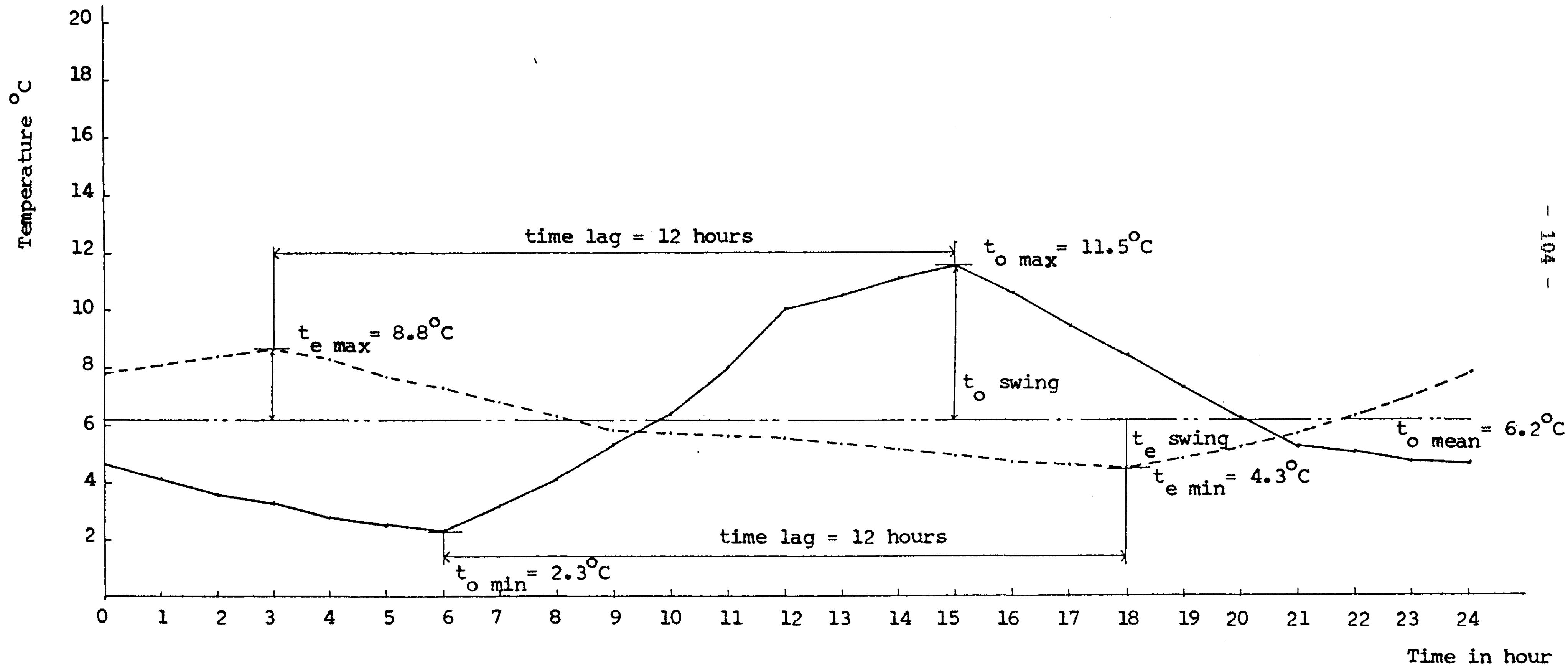


Figure 4.13 External and Equivalent external temperature fluctuation in January for a wall of 12 hours time lag.

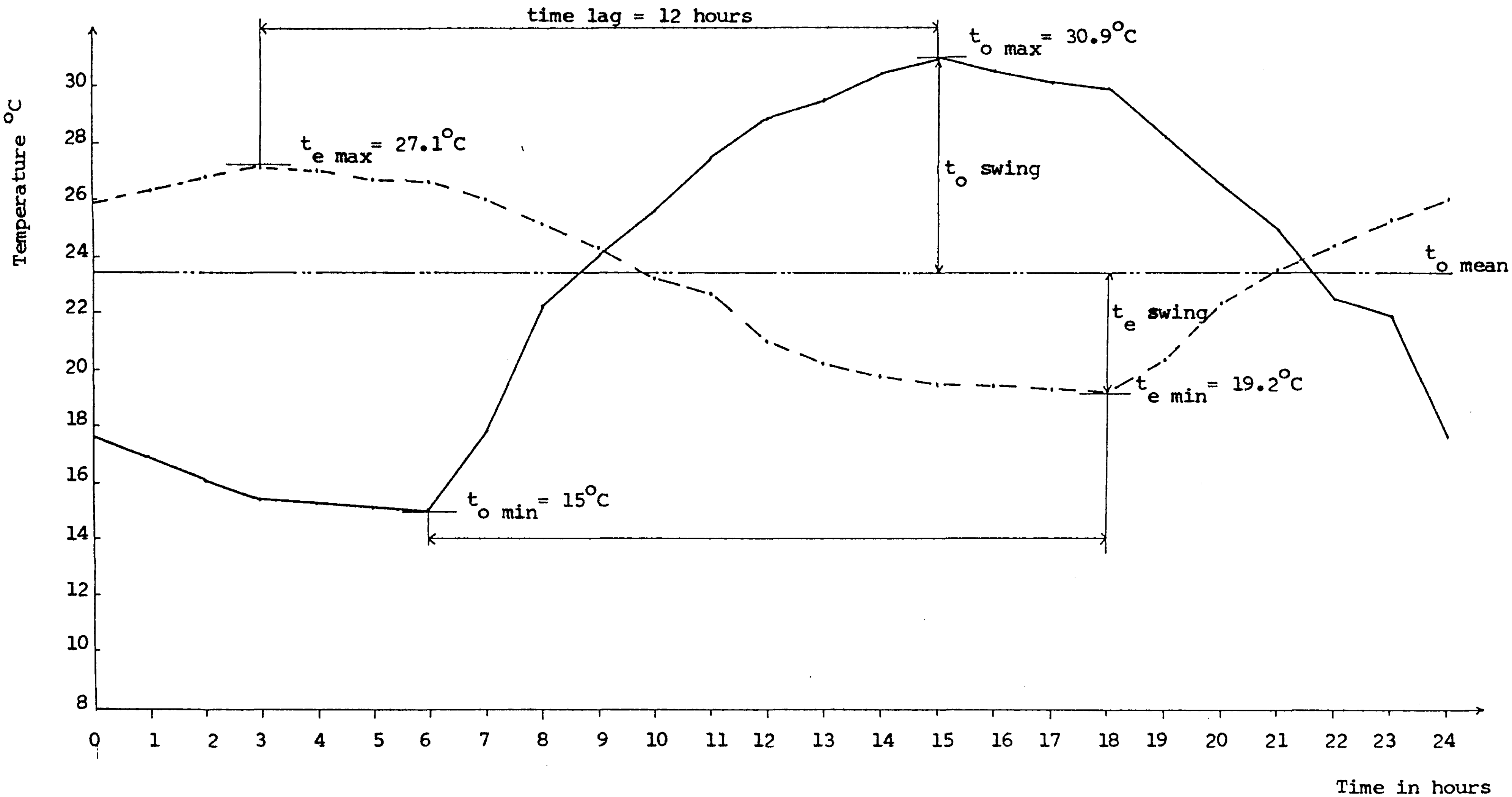


Figure 4.14 External and equivalent external temperature fluctuation for June for a wall of 12 hours time lag.

structure with a time lag around 12 to 14 hours will perform better in the case of school buildings as the school is unoccupied after 18.00 pm when the heat reaches the interior.

The location of insulation layers is important in thermal control of heat flow through walls. The thermal mass of building fabric is effective for heat/coolness storage, when it is not insulated from the room air. If this were the case, the energy absorbed by the outside mass will pass through after the particular time lag for that material, say 4.5 hours for 20 cm of concrete, and on reaching the insulation this will heat up fairly rapidly and dissipate heat to the interior. Also solar gain through glazing, in long wave exchanges, will achieve a rapid response and dissipation of heat to the air, if the bounding surfaces are insulated.

But if the insulation is external to the mass, the time lag of the wall will be much greater. The exposed insulation will heat up rapidly and dissipate most of this gain back to the external air. The much reduced heat flux that does pass through the insulation then has to heat up the large mass before reaching the interior - hence severely damped and with a considerable time lag.

For example, a dense concrete wall with cork insulation has been investigated with the insulation position reversed. It shows that the time lag in the case of an externally insulated dense concrete wall is 4 times the internally insulated one, with a decrement factor of 0.2 and admittance value of 6.0 compared to 0.3 and 1.8 respectively. These results show the influence of insulation to mass in affecting the temperature and heat flux, see figure 4.15 and tables 4.5 and 4.6, appendix 4, with external insulation having a clear advantage in a combined construction.

Mackay and Wright[5] studied the thermal effect of the location of an insulation layer. A grey coloured concrete panel of 5 cm thick brought about by the addition of 0.5 and 5 cm thick layers of expanded polystyrene was measured with insulation placed internally and externally. With internal insulation, the maximum were reduced by 3.2 and 13.3°C, and with external insulation the respective reductions were 7.5 and 15.5°C. Thus the relative effect of location of insulation is greater as the insulation is thinner. The interaction between the effect of thermal resistance and external colour is shown in figure 4.16.

Danby[6] observes that in hot dry climates, the mass might be more effective if it could be confined to the interior of the building where, of course, it will not be subject to the impact of solar radiation. Consequently the space closing walls should be of high thermal resistivity material to reduce the inward flow of heat, and to prevent storing at high temperatures, they should have low thermal capacitance i.e. they should be made of light weight material figure 4.17.

In hot climates it is apparent that the roof is the critical part of the whole structure. Its design is very

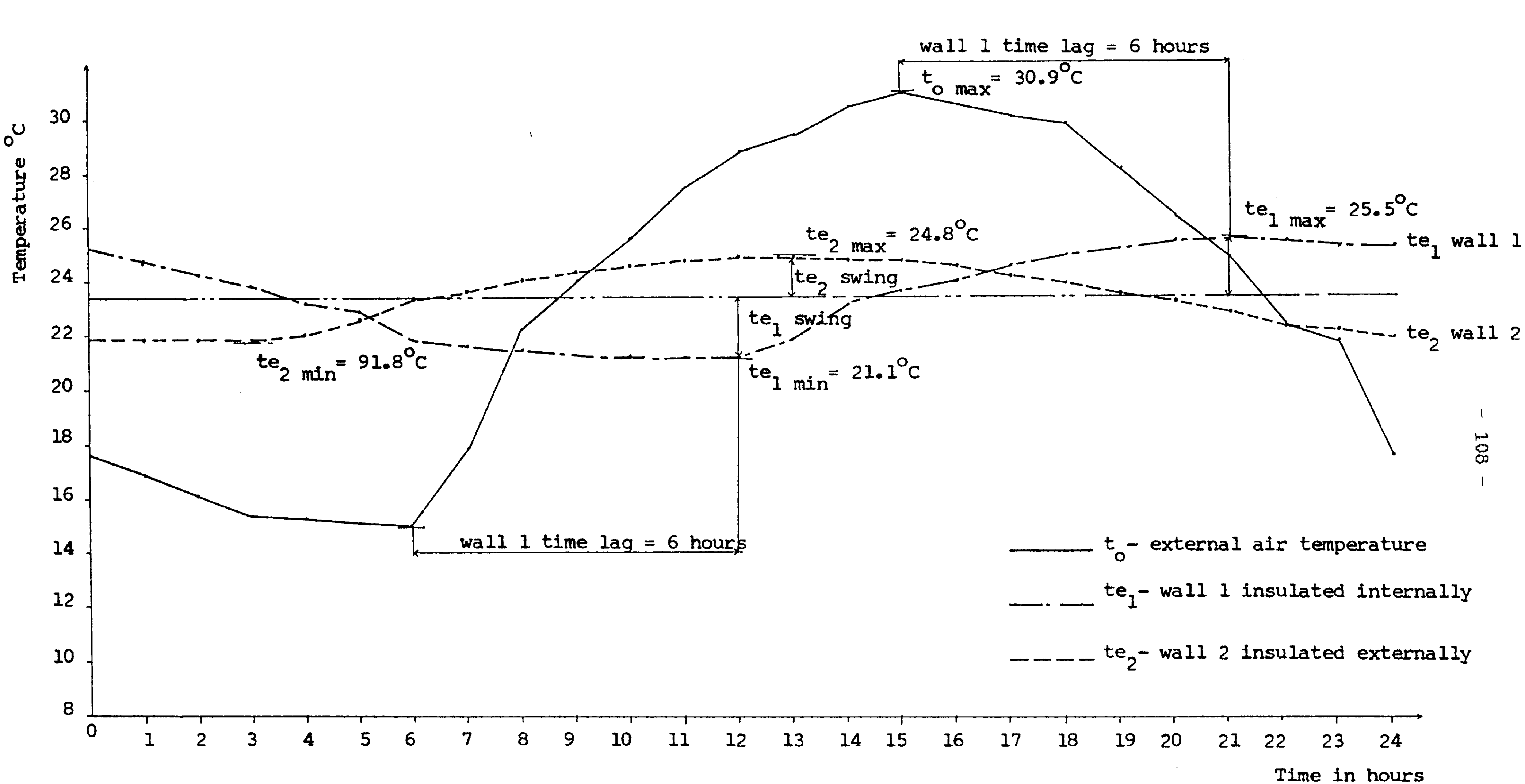


Figure 4.15 Effect of insulation position on the Equivalent external temperature.

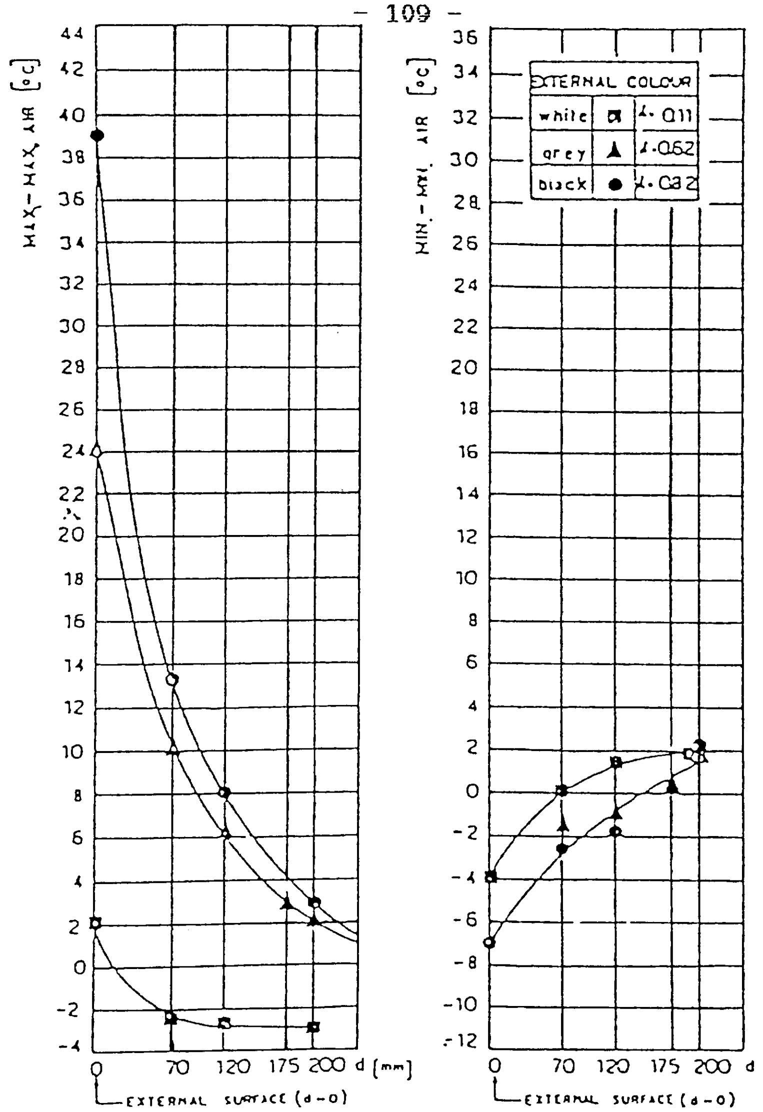


Figure 4.16 Difference between maximum and minimum internal temperature and corresponding air temperatures as function of insulation thickness of light horizontal panels.

Source: Givoni, B. 'Man, Climate and Architecture', 1976, p. 131.

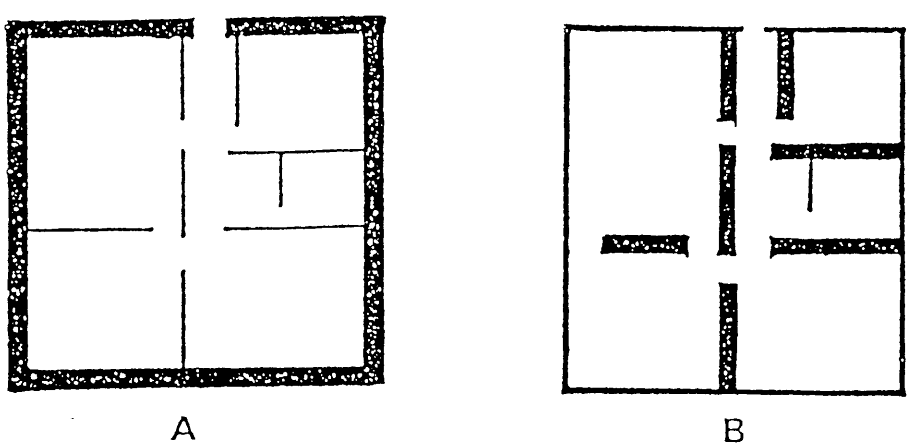


Figure 4.17 Customary arrangement of heavy masses in traditional type building (A) and the ideal arrangement of masses for space naturally cooled by stored low temperatures in hot dry climates (B).

Source: M. Danby, the Design of Buildings in Hot dry Climates and the Internal Environment.

important if the internal thermal environment is to be improved. Roofs receive the greatest amount of heat during the day and release the greatest amount to the clear sky during the night. To mitigate overheating problems there are several passive methods which may be used separately or in combination:

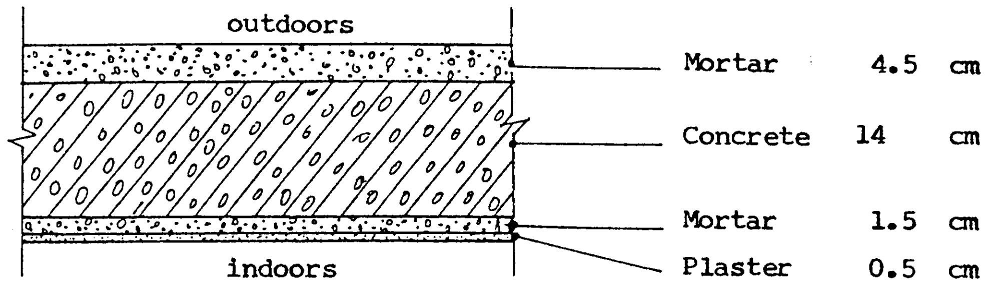
- solar reflective and light coloured surfaces
- increased time lag
- increased insulation
- ventilating the roof air space

As in walls, the external colour of roofs plays an important role in their thermal performance, as it determines the pattern of the ceiling temperature and consequently the internal comfort conditions. A white colour is considered the most effective of all in roofs. Although it has a higher solar absorptivity than bright metals - see table 4.7, appendix 4, its advantage over bright metal is its ability to emit most of the heat absorbed. But its disadvantage is the rapid deterioration of its reflecting power with age and weather. However whitewash mixed with a suitable binder such as tallow has been found to last longer.[7]

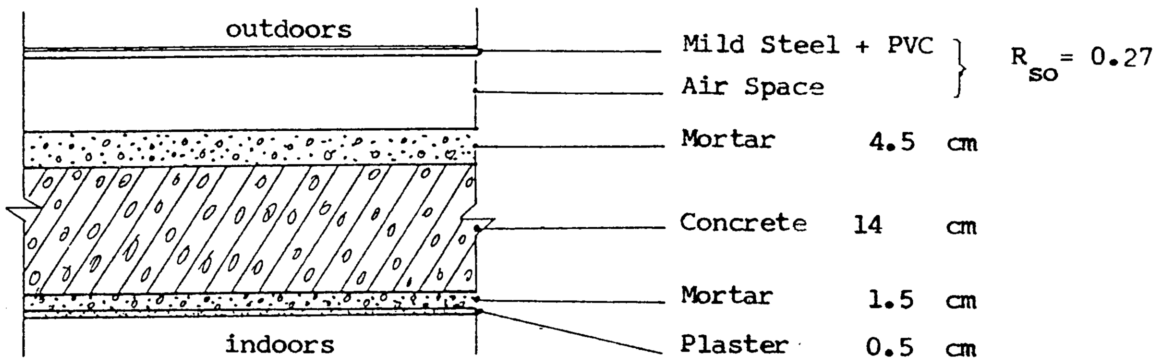
Roofs of high heat capacity warm up and cool down slowly. Hence they will not only reduce the amplitude of the diurnal range of the external temperature, but also the internal surface temperature. An advantage of such structures is that its time lag effect will vary the time of maximum internal surface temperature with respect to time of maximum external surface temperature. Hence to delay the heat in a classroom, a time lag of more than 12 hours will give adequate results, as the school is occupied only 10 hours a day. Consequently, the use of roofs with high capacitance could significantly reduce the overheating in school buildings in Constantine, as the temperature difference between day and night is high. External insulation material, as shown above, retards the heat flow through the structure. As a result of low thermal conductivity they can be used in hot climates to reduce the heat gain in summer, but at night any heat that has been stored in the mass will not dissipate so quickly to the outside. Then night ventilation could be utilised to provide structural cooling. The degree of insulation could also be increased by dividing the air space with bright metalic surfaces.[8] This is confirmed by the following roof investigation using the computer programme " μ - t_e"

1. The investigation of the roof of the studied model, without "Asphalt", shows that it has only 6.4 hours time lag which is insufficient to prevent the flow of heat to the classroom during the working day. Roof construction and thermophysical properties of material are illustrated by figure 4.18 and tables 4.8 and 4.9, appendix 4.

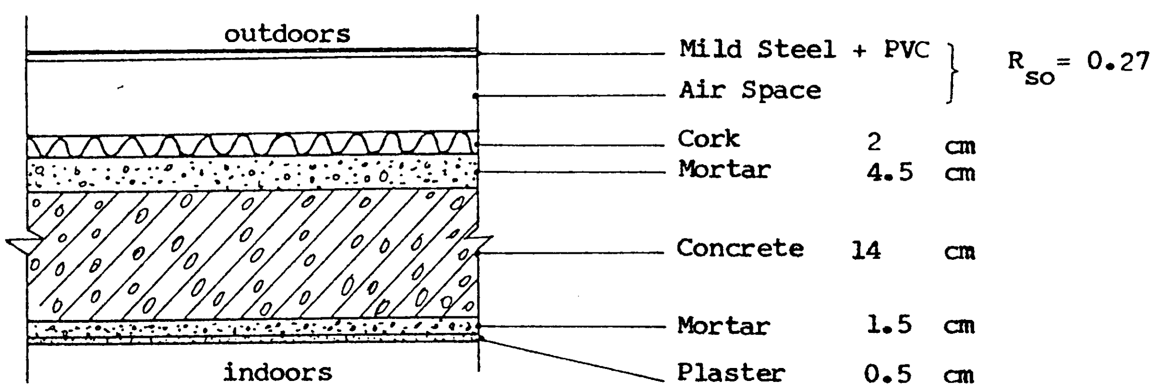
2. A layer of mild steel sheeting above an air space is added to the same roof. The steel is covered



Roof No. 1



Roof No. 2



Roof No. 3

Figure 4.18 Construction of the three first analysed roofs.

externally with white P.V.C. and has a dull finish internally, i.e., the side facing the air space. This increaes the time lag to 12 hours which may be acceptable in the case of schools.

3. A layer of 2 cm thick cork is added to the roof in (2) at the top of the mortar layer. This doubles the time lag to 25 hours. In this case, the "t_e" profile is almost level, see figure 4.19. In other words, steady state conditions are approached.

4. The same construction as in (2) but substituting a reflective aluminium for the steel, increasing resistance from exterior to the concrete to 0.43 mK/W, has given a time lag of 17 hours. The same roof construction with a layer of *"Alreflex" dividing the air space gives 39 hours time lag. The resistance of the layers up to the concrete in this case is assumed 1.13 mK/W -see tables 4.10 - 4.11 appendix 4.

Figure 4.19 suggests that construction (2) might outperform (3). However this does not take into account solar gain in the air space, which would effectively convert (2) to (1), but with an even higher outside temperature. The conclusion drawn from this investigation is that a concrete roof of 20-25 cm thick, insulated from the air space created by the use of double roof construction corresponding to (3) is efficient for hot climates, particularly when the air space is ventilated during summer.

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* **Footnote** "Alreflex" is a combined air and radiative insulant comprising aluminium foil on each side of a layer of plastic bubbles.

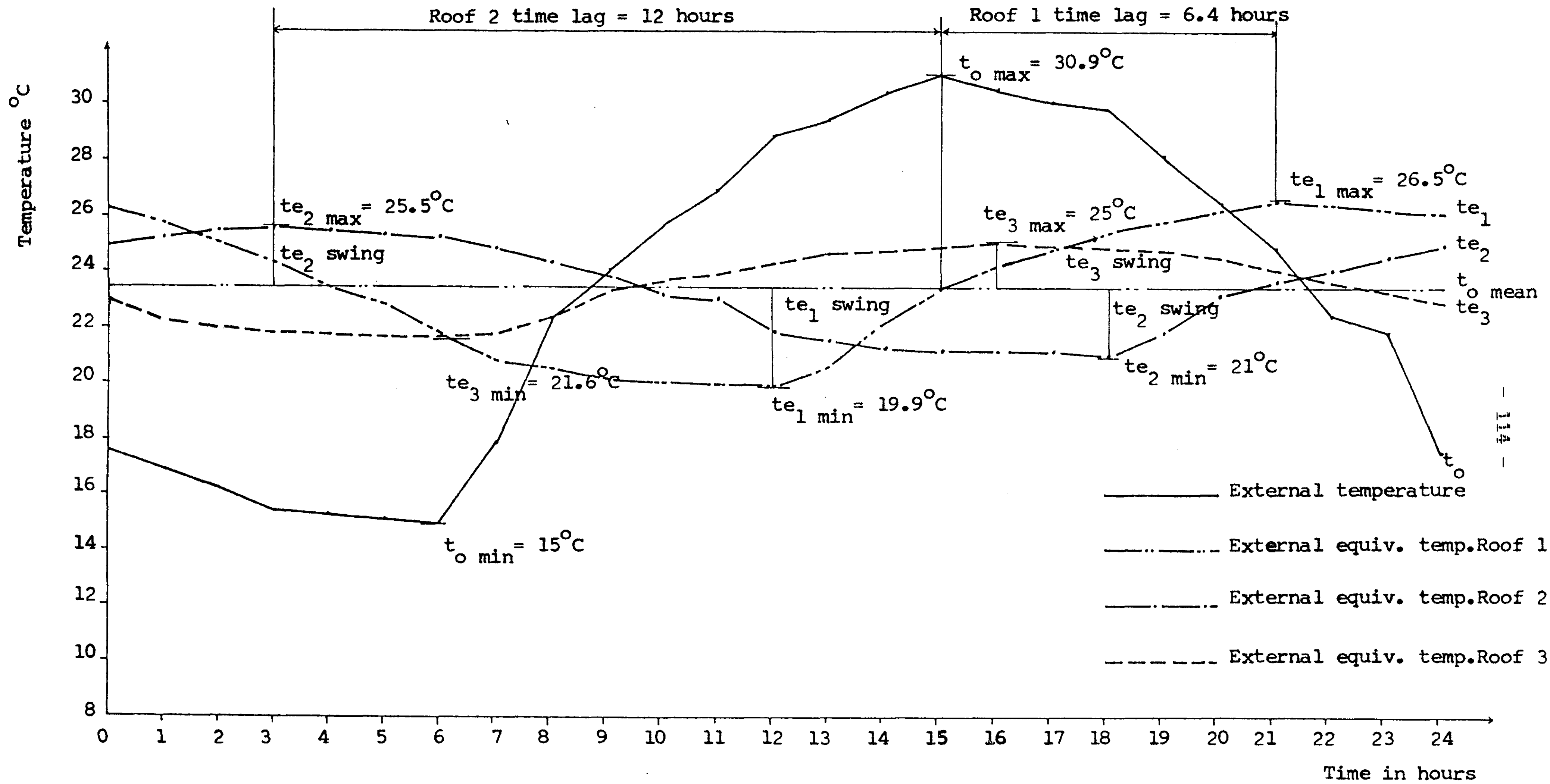


Figure 4.19 Comparison of Equivalent external temperature of three roof construction.

4.3.2 The transparent shell

When direct sun's rays enter the building through window openings, they may contribute a disproportional amount of energy to the building heat balance. In the case of the intermediate classroom analysed, with white external colour and relatively small areas of opaque wall exposed to the sun, it is the windows which dominate solar gain.

However, windows are an essential feature of schools, performing many different functions. They play a vital role in relation to the visual environment by admitting daylight as well as sunlight, and providing a visual link with the outside. Also they are openable, and serve as ventilators in an easily controllable way. Unlike other building elements usually they are adjustable, enabling them to perform different functions. Particular thermal properties of windows may be either favourable or unfavourable, and it is the purpose of window design techniqes to make use of favourable properties and minimise the effects of the unfavourable.

The effect of heat gain through the window in particular is felt almost immediately without any appreciable time lag. The unique property of the glass which is responsible for their specific thermal effect, is the differential transparency to the shortwave and longwave radiation - see section 3. When conditions might otherwise be within the comfort zone, the greenhouse effect can cause an increase of discomfort. This is specially the case in schools where openings to provide required daylight and ventilation tend to be larger than in residential buildings. Therefore, openings should be protected to prevent the penetration of direct solar radiation at times when temperatures are within or above the comfort zone. In the case of the classroom analysed, it has been determined that the north-east facade will only receive a minimal gain during the preheating period, 35.85 W in April, and from the end of spring to autumn, morning sun will cause overheating if left unshaded. The south-west window, although well shaded, receives significant quantities of diffuse gain and dominates during the occupied period - 387.5 W in June and 107.3 W in March.

The glass material can be divided into several types according to their spectral transmission. Figure 4.20 shows the absorption and reflection characteristics. The amount of energy transmitted through it is dependent on the angle of incidence of incoming direct radiation - see figure 4.21. This amount decreases when the angle of incidence is over 45°, and when over 60° there is a sharp progressive reduction. Hence, as the angle of incidence increases, the energy transmitted decreases. In our model, the angle of incidence of morning sun striking the north-east window during winter will be large, and thus the transmitted component is small, e.g., in January at 8.00 am when the direct is 42 Wh/m^2, the global is 72 Wh/m^2 and the transmitted is 42 W/m^2; while at 3.00 pm, when there is no direct, the global is 98 W/m^2 and the transmitted is

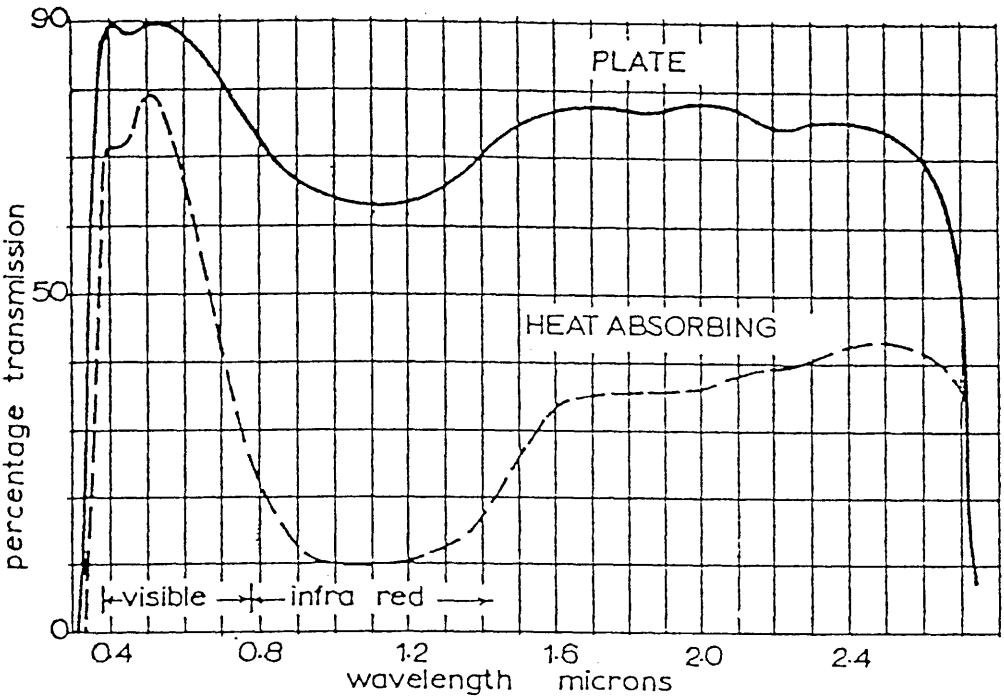


Figure 4.20 Spectral transmissivity of glass for solar radiation.

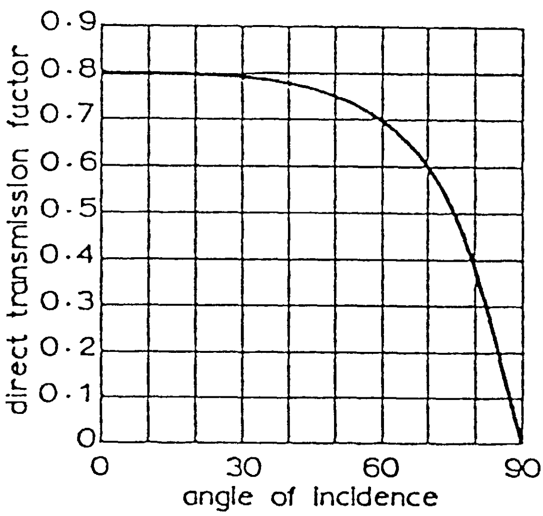


Figure 4.21 Correlation between solar incident angle and transmissivity of glass.

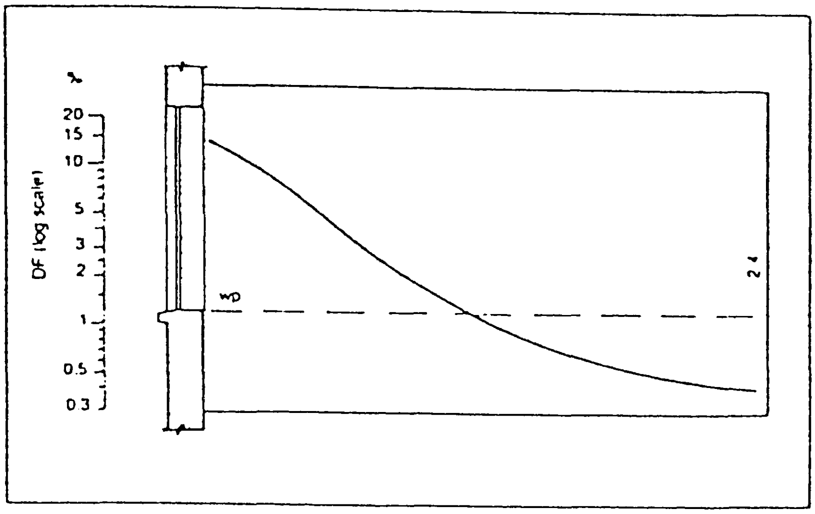
Source: Down, P.G. 'Heating and Cooling Load Calculations', 1969, p. 147.

78 Wh/m^2, emphasising the diffuse contribution on both the shaded and unshaded facades.

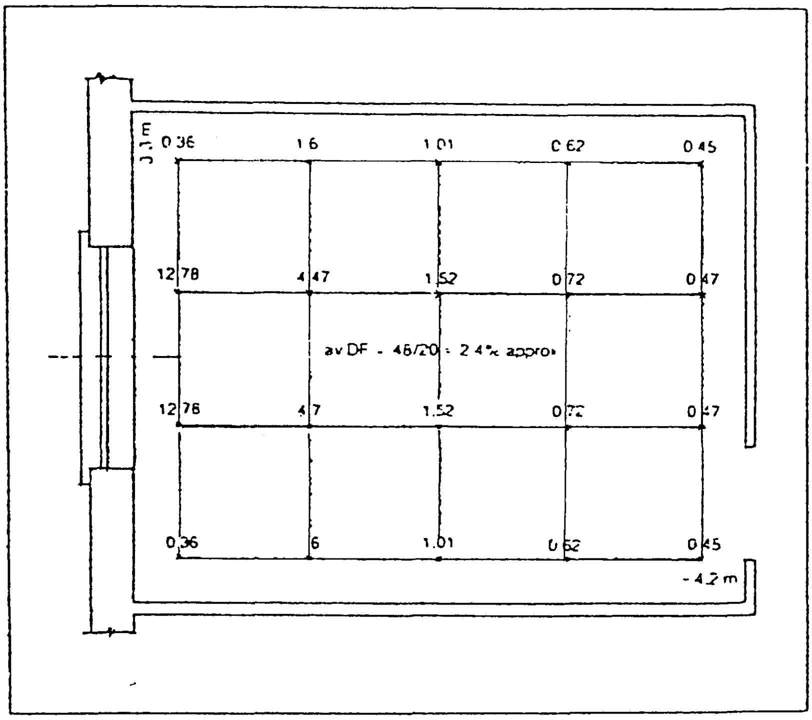
In Constantine, large openings are not desirable unless the building requires it, but limits to the percentage of glazing of the building facade also place a constraint on the provision of daylighting. Daylighting, heat flow through glazing and ventilation cannot be treated separately.

In schools where occupancy patterns coincide with daylight hours, daylight should as far as possible be the main source of illumination. Artificial lighting is then required only when natural lighting is not available. If the occupancy hours are longer or where more complex relationships between various activities exist, requirement for lighting will be more complex. Where it is not possible to use daylighting, artificial lighting can be used to supplement it. In this case windows should be sized and provided to give a satisfactory view out. The Ministry of Education in the regulation for schools, has stipulated glazing to floor area ratios of 15%[9]. The Architects Department of Gloucestershire County Council[10] in studying the methods of improving the environment in schools have concluded that glazing area should not exceed approximately 20% of the facade area in the arc south of the east-west axis. Within this limit, single glazing in timber frames will generally be adequate. The window area recommendation to provide adequate daylight is usually made in terms of minimum daylight factor - DF - which has been determined for the classroom 2%[11] at working plane - see table 4.12. Figure 4.22 shows the distribution of daylight in a room. The distribution of daylight within a side-lit classroom, figure 4.23, is such that illumination levels on the working plane close to the window are light when compared with the level at the back of the room, particularly if it is more than 7 m deep. The quantity of daylight reaching the rear of the room, appears gloomy in comparison with the area adjacent to the window and artificial light is often used to reduce this luminance contrast. There are various expedients for reducing the contrast between a bright sky and the dark window surrounding, and so reducing the associated disability glare. A light coloured window wall, splayed reveals and tapered glazing all help to reduce glare, but it is better to light from several sides. Moreover multi-lateral lighting gives a more even distribution of daylight and reduces the danger that pupils near the window will be obliged to suffer discomfort glare, and can ensure that those remote from the window can receive a bare 2% daylight factor. Hence, unless the site or economy restricts windows to one wall, lighting should ideally flow from more than one side.

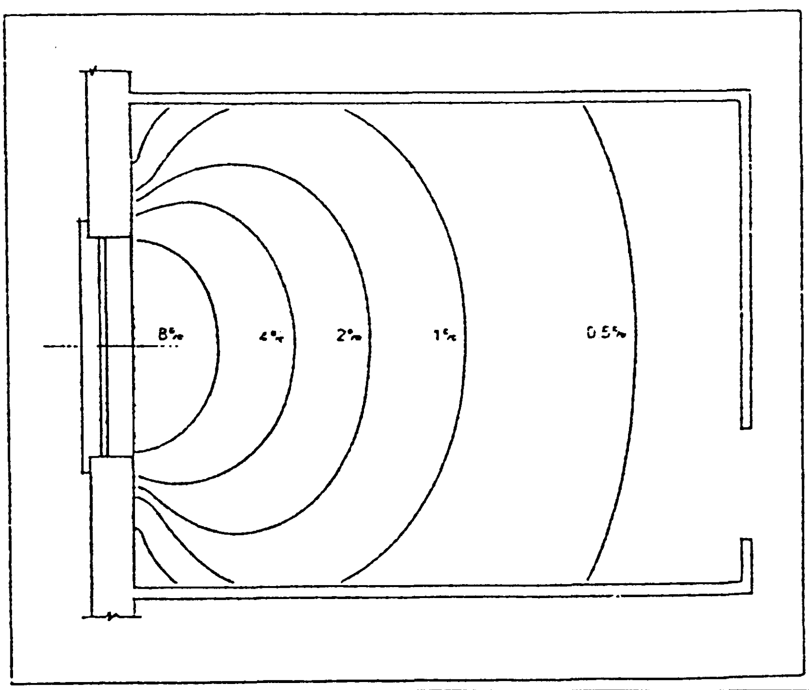
In the school analysed, where the classroom is lit from two sides, the lighting is well distributed, because the internal face of each window wall receives light from windows in other walls. Hence natural lighting, is solved with regard to window position and size. However, it is



1. Gradient of illuminance on centre line of window



2. Distribution of daylight over horizontal plane.

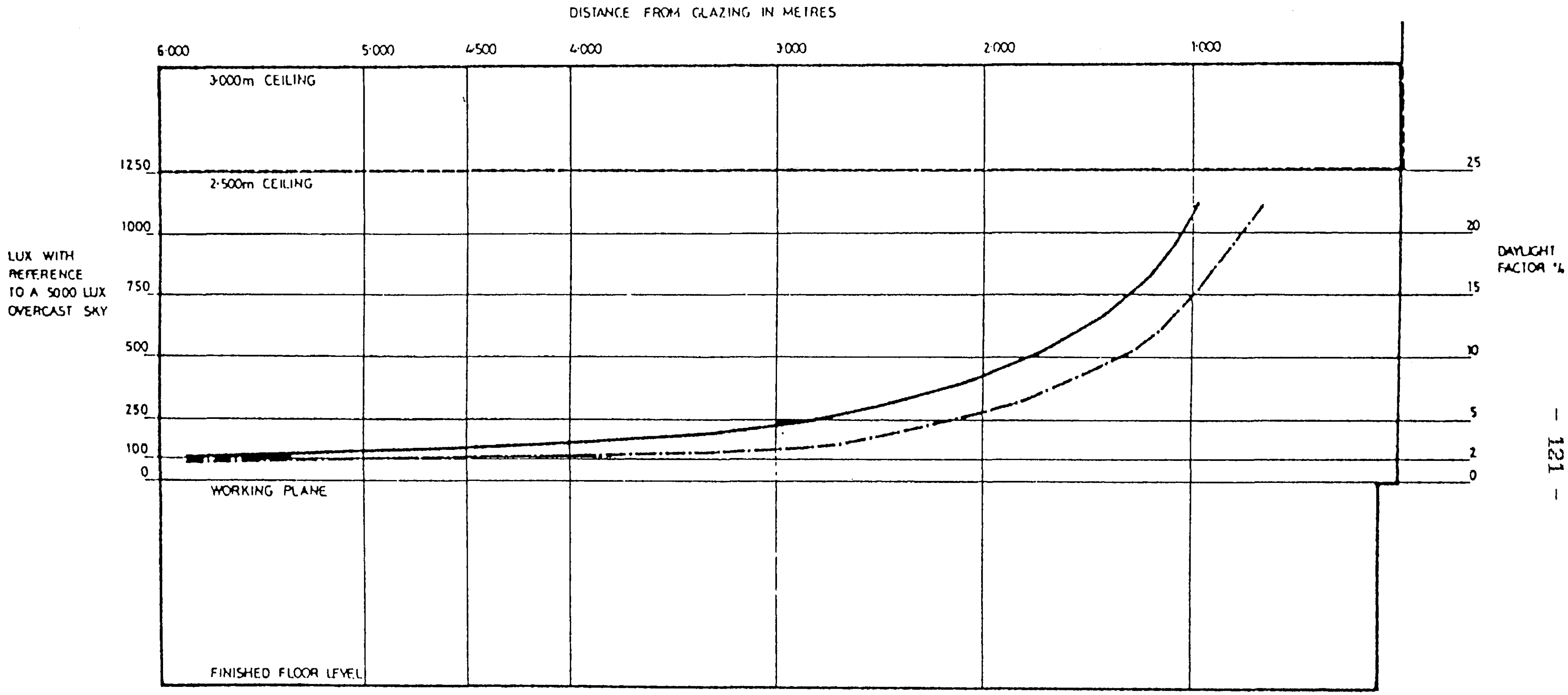


3. Distribution of daylight on horizontal plane shown by contous of equal D.F.

Figure 4.22

Daylight Distribution.

Source: Neufert, E. Architect's Data second (international) English Edition, Canada, Publishing 198.



DISTRIBUTION OF DAYLIGHT ON THE HORIZONTAL WORKING PLANE WITHIN A ROOM 3·000m WIDE AND 6·000m DEEP WITH 2·500m AND 3·000m CEILING HEIGHTS THE GLAZING IS FROM CILL TO CEILING AND WALL TO WALL WITH AN UNOBSTRUCTED SKY

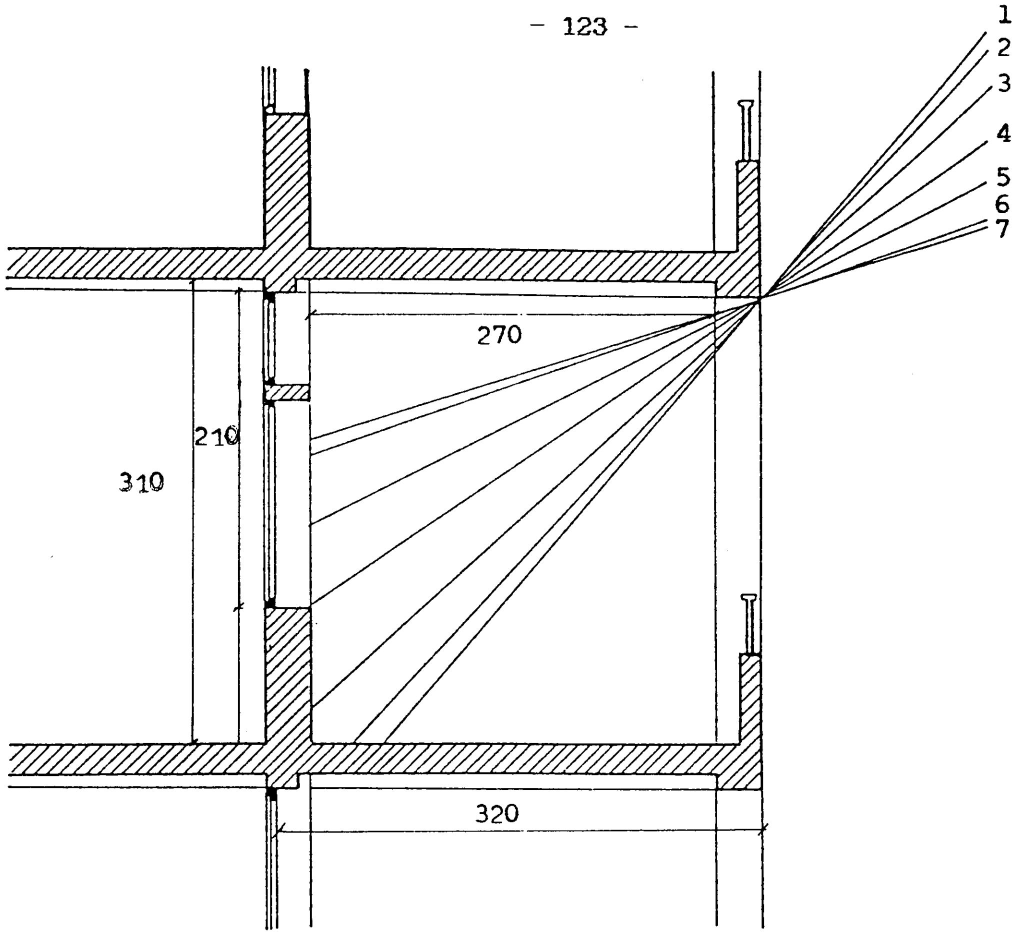
Figure 4.23 DIAGRAM ILLUSTRATING HOW DAYLIGHTING REQUIREMENTS CAN LIMIT ROOM DEPTH

Source: Integrated Environment Design : A Feasibility study for school buildings, 1971.

clear that windows cannot be designed in isolation, but must be a part of the integrated design of the building which is itself subject to the restriction imposed by the climate. So the design has to be balanced in order to have good lighting, good ventilation, good view and good contribution in terms of heating and cooling the classroom. In the model, the conflict of opposing requirements has not been entirely resolved, since solar gains are admitted, contributing to unsatisfactorily high temperatures. If daylight is accepted as a prequisite, severe restrictions are placed on shading techniques - i.e. conopies and fins, but not shutters. Thus this analysis is more concerned with external fixed shading and more precisely with the effect of the overhang on the south-west facade and fins on the north-east facade, both of which obstruct solar radiation. External shading is the most efficient technique, since it obstructs passage of radiation through the glass, hence reducing its effect before entering the building.

a. Fixed horizontal shading devices

Although a wide overhang of 3.2 m shown in figure 4.24a and 4.24b, has been used to protect the south-west facade of the classroom analysed, and offers an average annual shading of 90.5%, the part of the window left unshaded when the sun is hotter, coincides with the occupied period of the classroom. Taken together with the diffuse component that cannot be shaded out without sacrificing daylight, the south-west window gain is still smaller than the metabolic



1.	June	AL = 49^{o}	AZ = 85^{o}	at 1500 local apparent time.
2.	July - May	AL = 47^{o}	AZ = 81^{o}	
3.	August - April	AL = 42^{o}	AZ = 71^{o}	
4.	September - March	AL = 32^{o}	AZ = 59^{o}	
5.	February - October	AL = 22^{o}	AZ = 46^{o}	
6.	January - November	AL = 19^{o}	AZ = 45^{o}	
7.	December	AL = 17^{o}	AZ = 38^{o}	

AL = Altitude, AZ = Azimuth

Figure 4.24a South west facade shading device designed to eliminate summer sun and admit the maximum in winter.

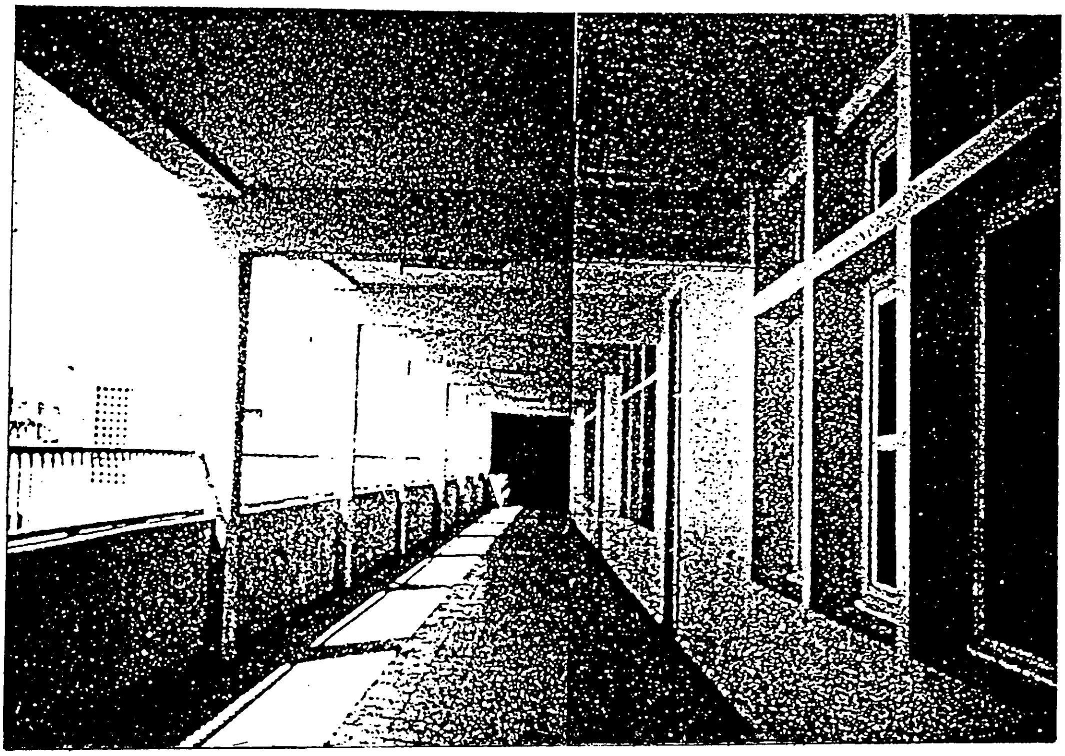
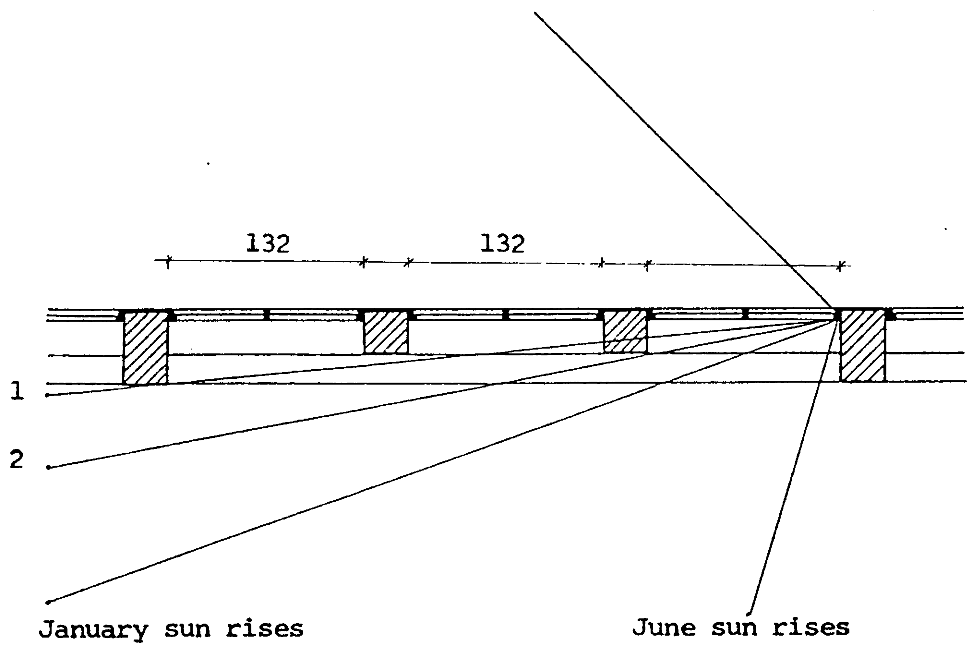


Figure 4.24b Shading of windows and corridor provided by the overhang (2.00 p.m. in September).



1: Wide fin total shading at an Azimuth of 51^{o}

2: Small fin total shading at an Azimuth of 56^{o}

Figure 4.25 North-East facade shading device.

heat gains - e.g. the largest amount from south-west window in June is 718.46 W. However the total solar gain through all windows and fabric exceeds the metabolic gain in May and June.

b. Fixed vertical shading devices

Vertical obstructions block out direct incident sun rays from the sides. They are most effective in excluding the low sun, particularly easterly and westerly orientations. In order to acheive maximum efficiency, they should be perpendicular to the azimuth of maximum direct solar radiation on that facade. In the north-east facade, fins of 0.4 m provide average shading of 42% during the winter period when the sun is needed to contribute to the increases of temperature during the preheating period. On the other hand, they allow the penetration of the sun to the classroom during the early summer morning, providing only 4.2% shading in June, when the structure needs to be cooled. So it can be concluded that widely spaced vertical devices on east or west facades of schools provide very poor shading in summer, while cutting off almost all radiation in winter - see figure 4.25.

The efficiency of various types of fixed shading devices for varying orientations has been analysed by Givoni and Hofman[12], and is illustrated in figure 4.26. The figure shows the effect of the projection depth of the various shadings on the total radiation impact in east and

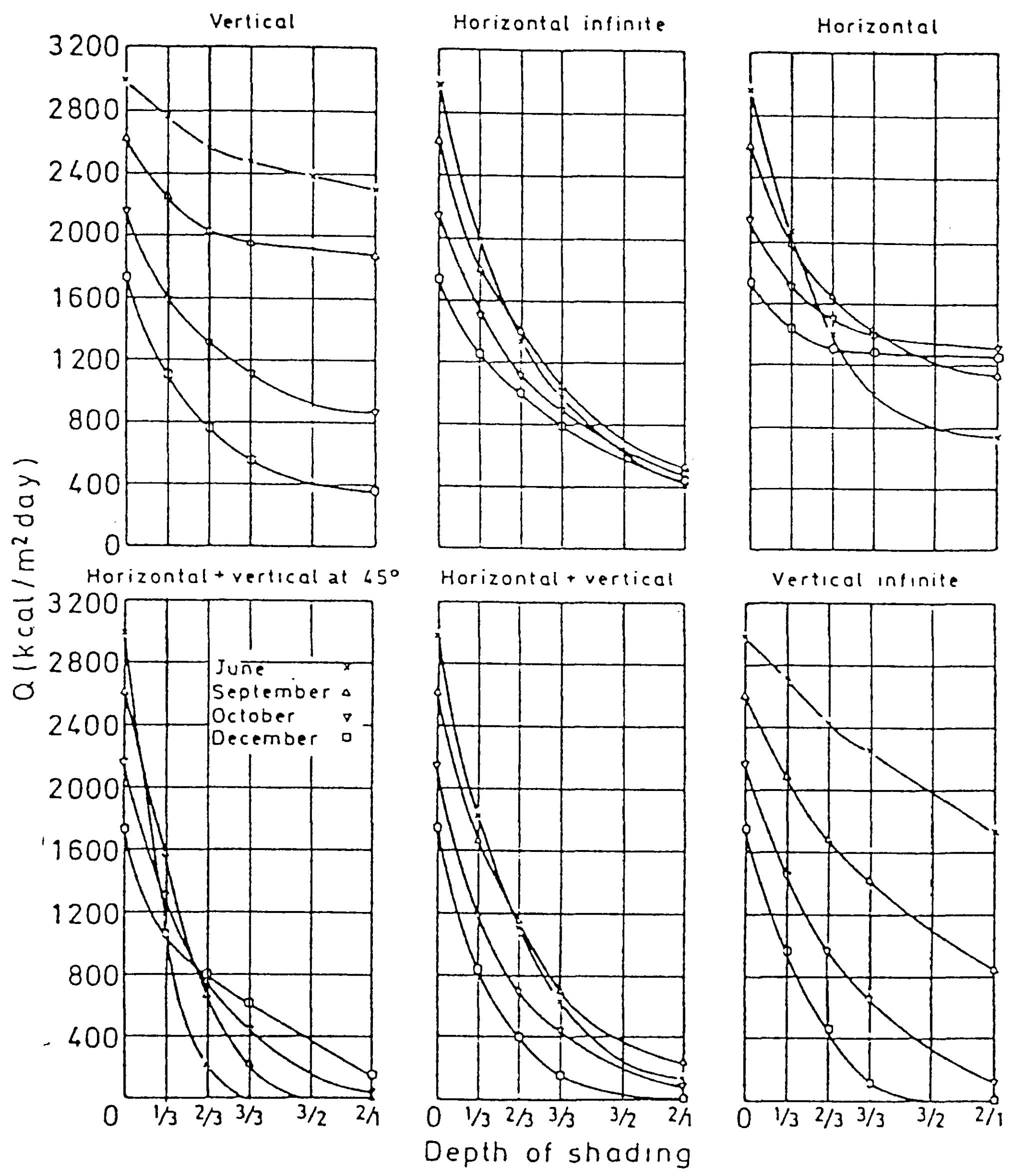


Figure 4.26 Effect of projection depth of various fixed shading devices on total radiation impact in east and west orientations.

Source: Givoni, B. 'Man, Climate and Architecture', 1976, p. 247.

west orientation.

c. **Movable shading devices - window size control**

The thermal effect of window size depends mainly on the shading condition. Indeed when shaded and kept open, an increase of window size will bring the indoor temperature closer to the outdoor level. This is caused by both the higher level of ventilation rate and the lower thermal resistance of glass areas as compared with opaque walls.[4]

Loudon[13] in the U.K. has studied the effect of window size on indoor temperature, under different ventilation rates and with various types of construction. Table 4.13 summarises the effect of different sizes of unshaded south window in an office building in summer in London.

Considering schools in Constantine, window size is more related to lighting and ventilation. Therefore openings should be well protected from the sun, but in a way to permit enough natural lighting. In most part of Algeria, as in all Mediterranean countries, shutters are the oldest and most widely used external sun protection device.

However as they impede air movement inside the room and substantially reduce the amount of daylight, their use is not recommended and irrelevant in the case of classroom shading, at least during the occupied period. On the other hand they could have a useful role during the morning unoccupied period on an east oriented facade, particularly if they also encouraged cross ventilation flow during a period of cool air temperatures.

	Maximum perpendicular depth of the teaching space from an external wall (in metres)			
	less than 8m	8-11m	11-14m	more than 14m
Minimum percentage of internal elevation of the external wall area	20%	25%	30%	35%

Table 4.12 Minimum Area of Glazing to A Working Space as a Percentage of the External Wall Area as the Depth of the Space Varies.

Source: 'Guidelines for environmental design and fuel Conversation in Educational Buildings', Department of Educational and Science, Design Note 17, April 1981, p. 8.

Construction type	Ventilation rate (air change per hour)	Window size relative to wall area					
		0.0	0.2	0.4	0.6	0.8	1.0
Lightweight	2	-4.6	+1.4	+6.4	+11.0	+15.3	+18.0
	10	-2.9	0.0	+2.7	+ 5.3	+ 7.4	+ 9.3
Heavyweight	2	-5.7	-1.4	+2.8	+ 6.7	+ 9.7	+12.1
	10	-4.6	-2.6	-0.7	+ 1.2	+ 2.6	+ 3.8

Table 4.13 Computed deviation of indoor maximum air temperature from outdoor maximum as function window size, ventilation and constructions, deg C (after Loudon [12.10]).

Source: Givoni, B. 'Man, Climate and Architecture', 1976, p. 250.

4.3.3 Natural ventilation

Natural ventilation inside buildings has a direct and indirect effect on the human body. The direct effect is through the physiological interaction of moving air, and the indirect through influence on the temperature and humidity of the indoor air and surfaces. It has three different distinct functions:

- Provide a healthy supply of fresh air and prevent disagreable odours. It is essential in all climatic conditions.
- Ensure thermal comfort by increasing the heat loss from the body and preventing discomfort due to moist skin in hot climatic conditions.
- Structural cooling of the building when the indoor temperature is above that outdoor, also applicable to hot climatic conditions.

The relative importance of each of these functions depends on the climatic condition and the buildings pattern of use and occupancy. The first of these requirements is particularly dominant in schools taking into account the density of occupancy. As stated above the recommended value of one air change/hour translated from 4-5 m^3/person, is not sufficient to provide the necessary fresh air and prevent disagreeable odours. Hence the rate of three air changes per hour has been estimated to provide an adequate quantity of fresh air.

The second function of ventilation may be met by air movement at a sufficiently fast speed to be felt at a body level. The cooling effect is not only due to the coolness of the air but to the cooling effect of the velocity of the air as it increases evaporative and convective heat loss. This relation between flow rate and velocity depends also on the geometry of the space and the location of openings.

The third function deals primarily with reducing temperature of the indoor air and internal surface. This can only be done when there is a favourable difference in temperature between inside and outside air. This form of ventilation may be termed 'structural ventilations' as the cooling of the structure is the significant end product of lowering air temperature.

These three basic functions of ventilation can be achieved in three different ways - firstly by stack effect, a consequence of differences in pressure of air at different temperatures; secondly by wind pressure and thirdly by mechanical means. This analysis is most concerned by stack effect since wind velocities are relatively low and the aim is to avoid 'active' solutions.

For the Constantine model during the winter period, analysis has shown that when the school is occupied, air movement within a classroom can substantially reduce the cooling load and increase the condition of thermal comfort. In other words air movement inside a building will help in keeping the internal air temperature at a comfortable level. During a summer day as the external air temperature is hotter than the internal, infiltration will contribute to overheating. But during summer nights when the temperature drop occurs, especially during the early morning, a precooling can be provided naturally by simply opening the window. This can help to keep the internal air temperature within a band of comfort, its efficiency depending on the thermal capacitance of the building envelope. In the case study, 9 hours time lag are insufficient as the classroom is occupied 10 hours a day and the structure starts to heat up as soon as the sun rises. However it can be concluded that structural cooling contributes to some extent in solving the overheating problem. In this climatic condition, it may be assumed that a building with externally white colour, medium thermal resistance and heat capacity, and relatively small, shaded window, will have a summer daytime air temperature lower than the outdoor. This is not the case of the analysed model as it has large window openings.

Air entering a building can be due to air flow through ventilation openings or infiltration through cracks round buildings caused by wind pressure and/or stack effect. In either case air flow will depend on inside/outside pressure differences and resistance of cracks and openings. In the first case the pressure difference is produced by the action of wind flow around the building, whereas in the second case the pressure is caused by a difference in the density of the internal and external air, this difference in pressure being due to the phenomenon that warm air is less dense than cool air.

Even with low temperature differences and small differences in height, the stack effect can provide adequate ventilation for health and structural cooling. In order to maximise the cooling power of stack effect when it is required, the inlets should be placed on the windward side of the building, so that stack and wind forces can reinforce each other. In the Constantine climate openings should therefore be arranged to promote a cooling effect but avoid exposure to hot and dusty winds.

When the wind blows against the building, it is arrested and as a result produces higher pressure than the atmosphere on the windward face. The straight motion of the air is disturbed and deflected around and above the building and gives areas of suction on the roof and leeward sides of the building, as indicated in figure 4.27. The first graph shows that low pitched and flat roofs are subject to the suction effect. The difference in the high and low pressure zones determines the potential air flow velocity through the internal space.

In common architectural practice the best orientation of openings to give optimum ventilation conditions, is that facing the prevailing wind. But Givoni [4] in his recent study has shown that it is not always so, and in some cases better conditions can be achieved when the wind is oblique to the inlet window, particularly where good ventilation conditions are required in the whole room such as a classroom. When window are in opposite sides of the room, if the inlet faces the external wind, the main air stream

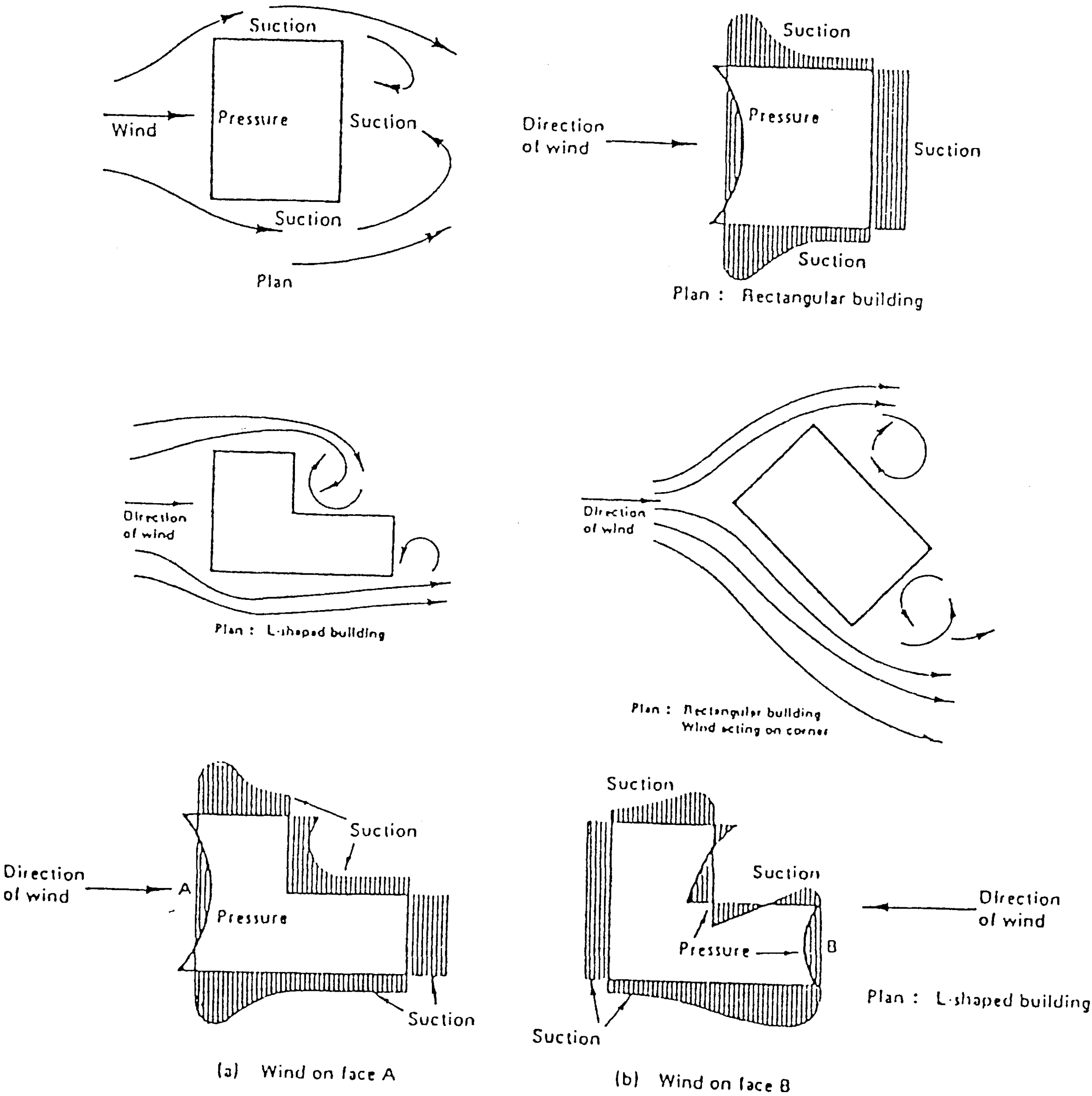


Figure 4.27 **Wind pressure and suction on buildings.**

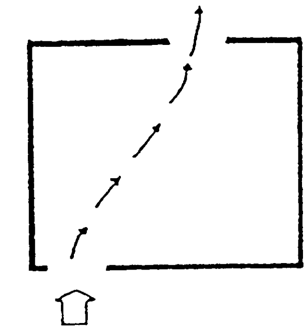
Source: **Markus, T.A. and Morris, E.N. 'Building, Climate and Energy'.**

flows straight from inlet to outlet, creating local turbulance at the corner of the outlet, but the rest of the room is only slightly affected. However when the wind is oblique to the inlet, higher indoor air velocity and a better distribution of indoor air movement occurs. This is illustrated in figure 4.28. His findings are of importance particularly in regions where prevailing winds are westerly and easterly in the warmer months, assuming a noth-south building orientation.

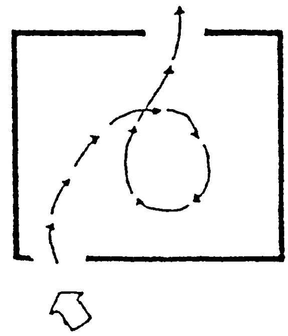
The size of window has a small effect on the internal air velocity if the window is only one side, but in cross ventilated rooms its effect is significant. This is illustrated in table 4.14. It may be seen that with a wind oblique to the windows there is an appreciable effect as window size is increased.

The air velocity inside the room depends also on the window location and wind direction - see table 4.15. The air velocity close to the floor is higher than at upper levels near the window because of the formation of two main air streams, initially through the inlet and secondly along the surfaces of the room. Therefore, in the classroom care should be taken since the air movement required for comfort might disturb work, by lifting papers from desks, etc. Hence the most satisfactory solution could be to direct the air flow in such a way to achieve decrease at the desk level - about 70 cm. (4)

Different types of inlet window produce characteristic air flow patterns at various level in a room space and thus

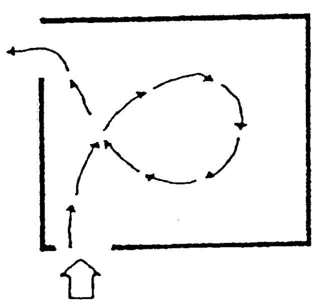


Most of the space is slightly affected when wind is perpendicular.

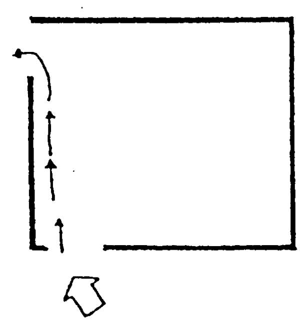


Better internal distribution of air is achieved when wind is oblique.

(a) Window in opposite wall.



Well cross ventilated room when wind is perpendicular.



Rest of the room is slightly affected when wind is oblique.

(b) Window in adjacent walls

Figure 4.28 Window orientation and wind direction.

Direction of the wind	Width of window		
	1/3	2/3	3/3
Perpendicular to window	13	13	16
Oblique in front	12	15	23
Oblique from rear	14	17	17

Table 4.14 Effect of window size in room without cross-ventilation on average air velocities (% of external wind velocity).

Source: Givoni, B. 'Man, Climate and Architecture', 1976, p. 291.

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

Table 4.15 Effect of window location and wind direction on average air velocities(% of external velocity)

Source: Givoni, B. 'Man, Climate and Architecture', 1976, p. 290.

the window and the way in which it is openable and oriented have considerable influence on the ventilation of spaces. The effect of fly screens and mosquito nets has been studied by Koenigsberger[14] who indicates that a cotton net can give a reduction of 70% in air velocity, while a smooth nylon gives the result with a reductin of only 35%.

Cross ventilation occurs when the building is connected by apertures to both pressure and suction areas of the exterior. As result of the pressure difference, a flow of air will move through openings on both sides of the building, from the windward to the leeward sides. In rooms with a single window and a closed door, i.e. without cross-ventilation, wind flow is less than 10 percent of the external wind speed. But if the cross-ventilation is provided such as in the classroom analysed with windows on opposite sides, the air flow is about 30 percent[15] of the outside wind.

In a cross ventilated room the size of the opening has an influencial effect in determining the velocity of the air flow. From table 4.16 it can be deduced that the largest air velocity is obtained through a small inlet opening with a large outlet and when the wind is oblique to the external facade. In a room with windows on one side, the ventilation is very poor because the internal external pressure gradient accross the openings is very small. However, when the wind direction is oblique to the external facade, air flows from the high to low pressure, due to the build-up of pressure along the external wall. Consequently, the benefit from

Wind direction	Outlet size	Inlet size 1/3 Av.	1/3 Max.	2/3 Av.	2/3 Max.	3/3 Av.	3/3 Max.
Perpendicular	1/3	36	65	34	74	32	49
	2/3	39	131	37	79	36	72
	3/3	44	137	35	72	47	86
Oblique	1/3	42	83	43	96	42	62
	2/3	40	92	57	133	62	131
	3/3	44	152	59	137	65	115

Table 4.16 Effect of inlet and outlet width on average and maximum velocities (% of external wind speed)

Source: Givoni, B. 'Man, Climate and Architecture', 1976, p. 292.

this pressure gradient can be realised by two laterally located small windows.

In the studied model, as the windows are in two opposite sides and the size of ventilation openings can be modified, cross ventilation can be provided. Nevertheless, this is not desirable when the classroom is occupied and when the external air temperatures are high. Hence night ventilation to induce structural cooling is of great importance. Evans[illegible] indicates that cool night air may contribute to achieve temperature difference between 5° to $10^{\circ}C$ in a building with a heavy structure, but this is clearly dependent on the extent of diurnal/nocturnal swing.

4.4 Towards a Solution

As demonstrated above, openings in buildings subjected to a semi-arid climate should be kept closed during summer days. However in schools where the required daylight is more important than in residential buildings, some form of cool air supply to the interior is necessary to aid the structural cooling process.

Several methods have been used for passively cooling the air before entering the building, such as storage mass for cooling/heating, fountains inside traditional arab houses, water streams connected to a wind tower, orientation of the building to benefit from the air passing over the water. It can be deduced from the analysis that a high thermal capacity structure performs much better than a light weight structure, especially when the heavy material is insulated externally. A time lag of 9 hours has been found to be too short. On the other hand a time lag between 14 hours and 20 hours in the case of schools may contribute to winter morning preheating, but may also increase overheating during summer by providing a heat input during the early hours of the morning. Consequently, it is proposed that an externally insulated 'Double-envelope' structure with a thermo-syphon loop, in conjunction with an external cool air intake and hot exhaust, may offer an effective solution. This is detailed in the following section.

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Section 5

PROPOSED SOLUTION - PASSIVE HEATING/COOLING MEASURES

PROPOSED SOLUTION - PASSIVE HEATING/COOLING MEASURES

5.1 Background

Different principles of climate sensitive design have been understood and used in different types of buildings for many centuries all over the world. Furthermore, different climatic regions dictate a different emphasis on winter heating relative to summer cooling. Traditional buildings in hot climates use a combination of shading and mass in order to provide a tolerably cool internal environment. The school configuration with relatively large windows essential to the function, identifies a need to concentrate on structural cooling by ventilation as a passive cooling strategy. A winter morning preheating load is also predicted. The aim is to achieve one passive system that can satisfy both requirements with the minimum of manual operation.

The basic components of all heating and cooling systems based on natural energy are: collection areas with careful selection of location and orientation; storage, generally consisting of dense heavy material that captures heat/coolness and later releases it to the interior of the buildings when needed; and a distribution system, either directly by radiant and conduction/convection exchanges at building surfaces, or indirectly through ducts using a fluid such as air or water as the transport medium. Various control mechanisms, for example shutters or vents, may be associated with any or all of the three components.

The definition of passive solar design whether "Direct" "Indirect" or "Isolated" has been based on the different relationships between the sun, collector, storage mass and the occupied space. Also they may be categorised as heating systems, cooling systems and combined cooling and heating sytems. As stated above, the aim is to provide a solution of winter preheating and summer cooling by the use of a combined system.

In pure passive solar systems, the thermal storage absorbs solar energy and releases it to the building spaces without mechanical aids. Generally, this requires the thermal storage to be present in the building along the south side of the structure as in a Trombe-Michel solid or fluid mass wall, or at the roof as in a roof pond system - see figures 5.1 and 5.2. However, in hot climates the storage mass may have to be present in all parts of the building. The effectiveness of mass to maintain coolness has been shown to be dependant on time lag, related in turn to occupancy requirements. At certain periods the mass can also become a disadvantage, releasing heat when it is not wanted. In this case evaporative cooling may offer a solution - For example, marble fountains and Salsabil of old Arab houses. These passive means were used in public buildings as well, Gorna school in Egypt presents a good reference. The system is a combination of a very thick structure with domed roof in conjunction with a wind catcher. The latter consists of a chimneylike air passage with a large opening high up facing the prevailing wind, and

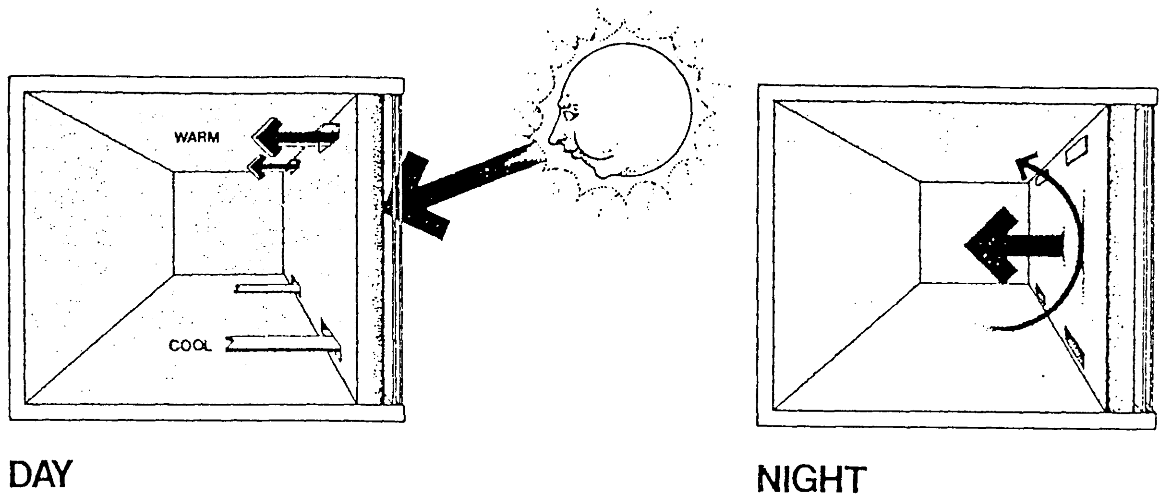


Figure 5.1a Indirect gain - masonry thermal storage.

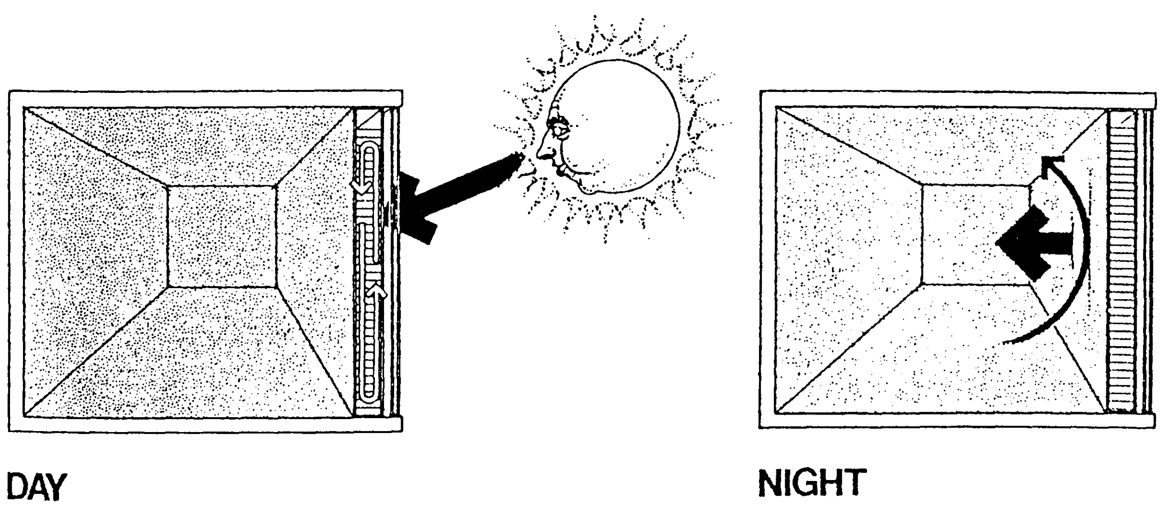


Figure 5.1b Indirect gain - water thermal storage wall

Source: Mazria, E. The Passive Solar Energy Book, 1979, p. 44,51.

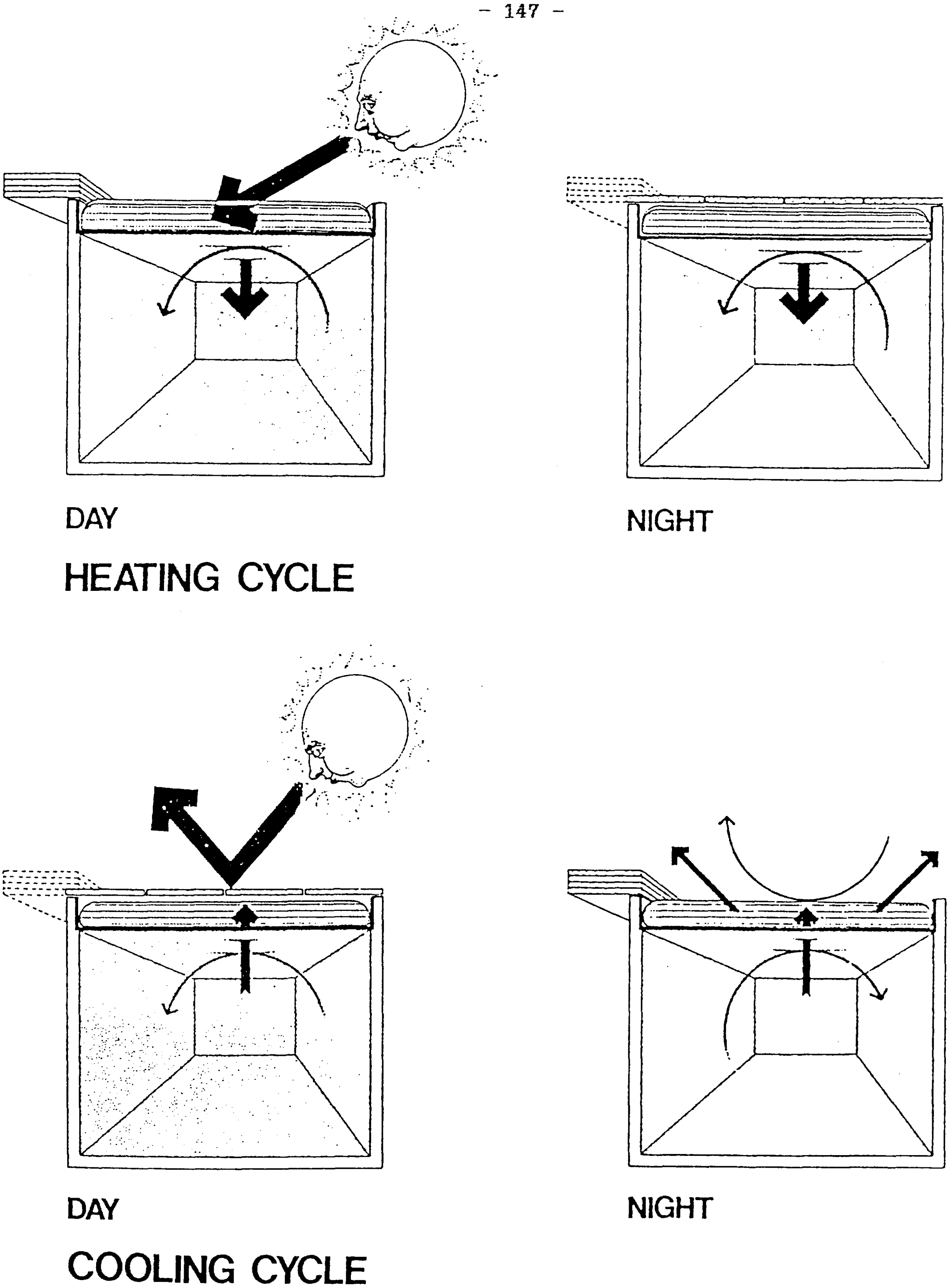


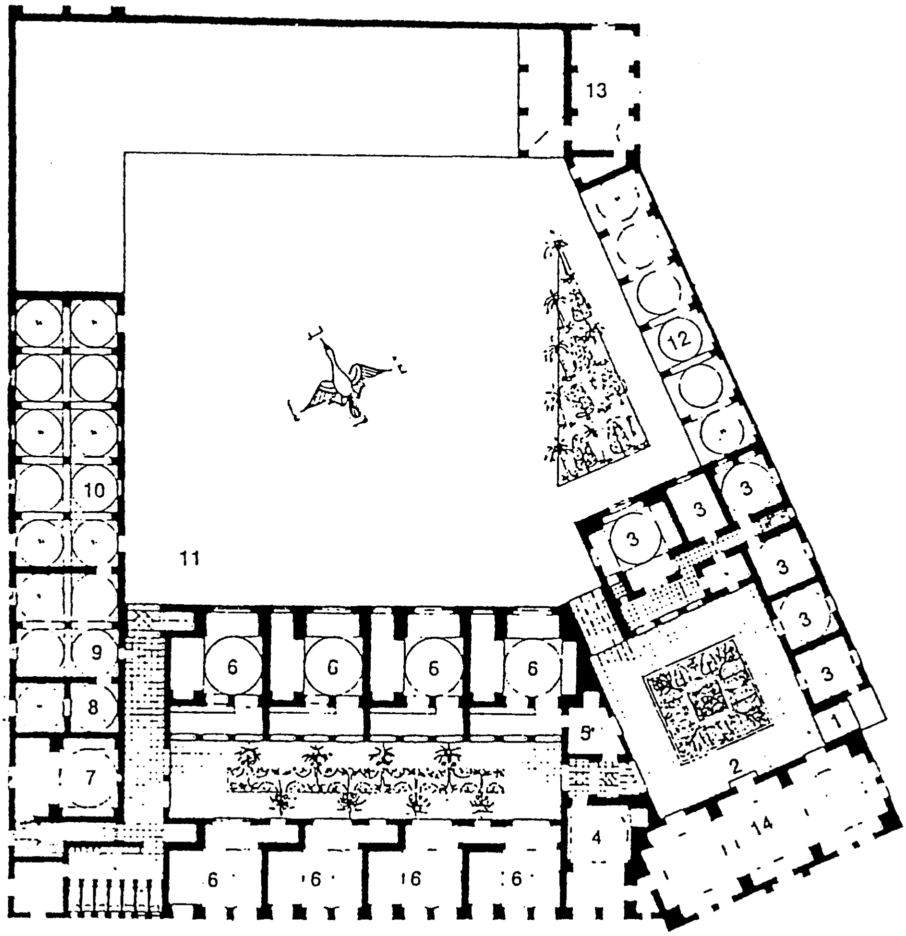
Figure 5.2 Indirect gain - Roof Pond.

Source: Mazria, E. The Passive Solar Energy Book, 1979, p. 57.

set inside it was a sloping metal tray filed with charcoal that could be wetted by a tap. Hence the air entering the wind catcher is cooled before entering the classroom. This is illustrated with two schools types - see figures 5.3, 5.4 and 5.5.

In some cases it may be desirable to have the thermal storage located in another part of the building, for rooms that do not have direct access to the south, or need more opening area rather than storage area, such as classrooms. The thermosyphon loop system provide an opportunity to achieve such a result. It has been widely used for passive solar domestic water heating, but there are also several examples of thermosyphon collectors being used for space heating. One of the earliest and most published is the Paul Davis house at Aberquerque, New Mexico U.S.A. - see figure 5.6. Although the emphasis of thermosyphon solutions is generally on heating, the rock bed storage element of such a system may also be adapted for cooling. A source of cool air is introduced to the rock bed and the system may then either by simply reversed, with the collector losing heat to night sky, or the collector element may be disconnected. The latter would be necessary, for example, if the system were to be utilised during the day for cool air delivery to the interior, or if night-time ambient conditions prevented reverse thermo-circulation.

For the storage part, Hughes[1] has analysed the performance of rock bed storage for heating, while Rizzi and Fumogali[2] have constructed a small prototype to



Plan of boys' primary school. Legend:
(1) Entrance. (2) Entrance courtyard.
(3) Headmaster and administration offices.
(4) Masters' room. (5) Supervisor's room.
(6) Classroom. (7) Mosque and ablutionaries. (8) Storage. (9) Kitchen.
(10) Dining room. (11) Main courtyard.
(12) Shed. (13) Manual works workshop.
(14) Assembly-lecture room

Figure 5.3 Heavy mass construction of boy's primary school in Egypt.

Source: Fathy, H. Architecture for the Poor 1969.

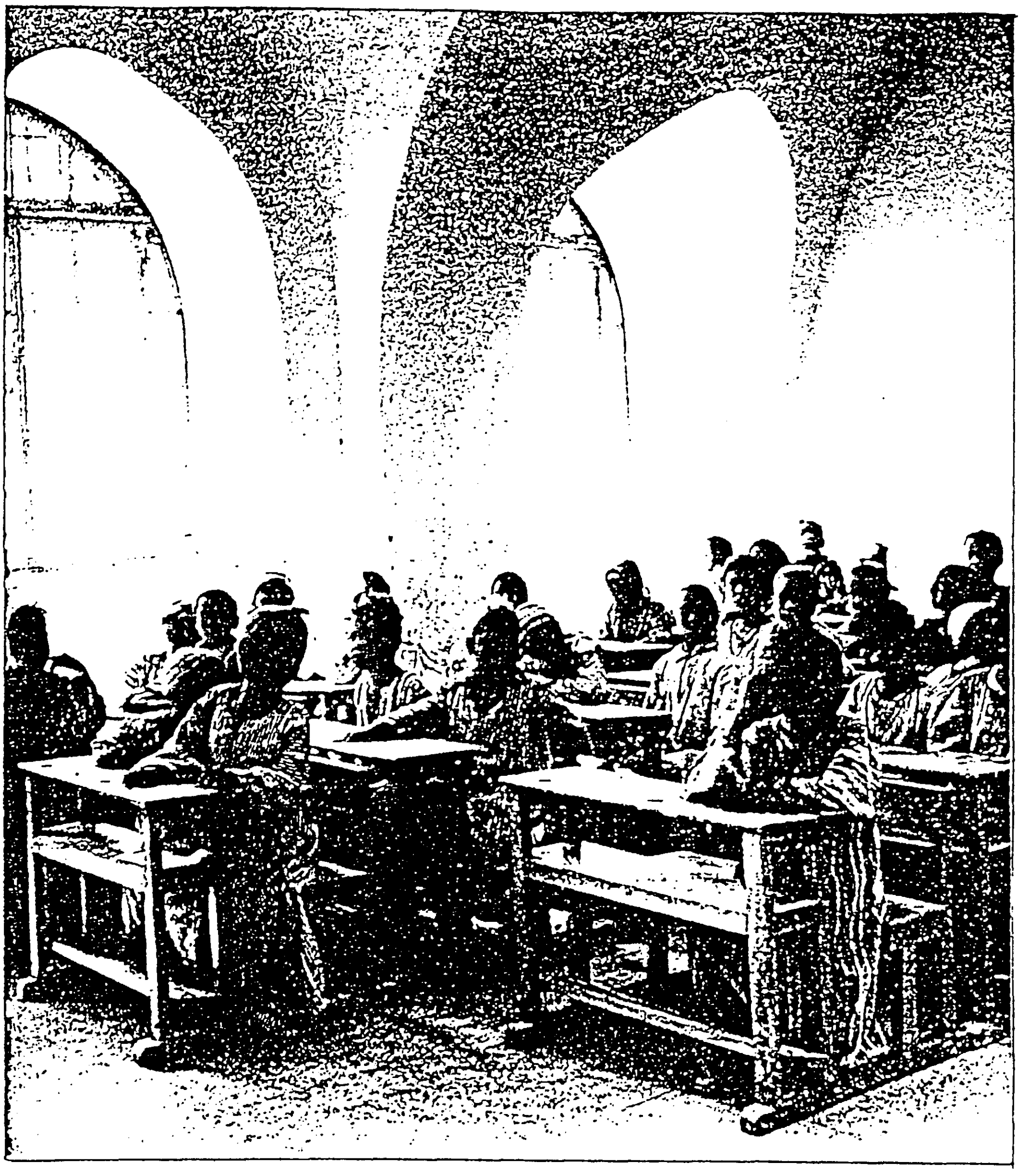


Figure 5.4a Boy's Primary School : Thickness of wall and lighting.

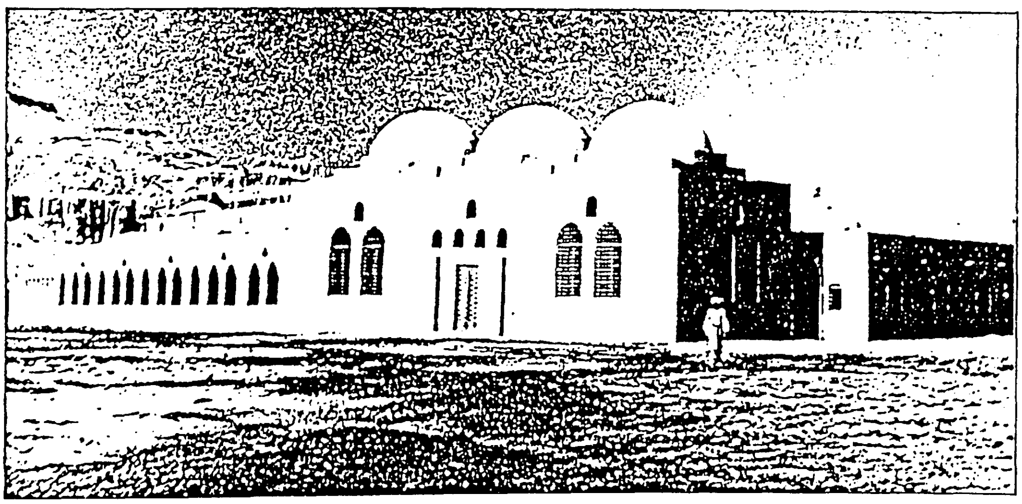
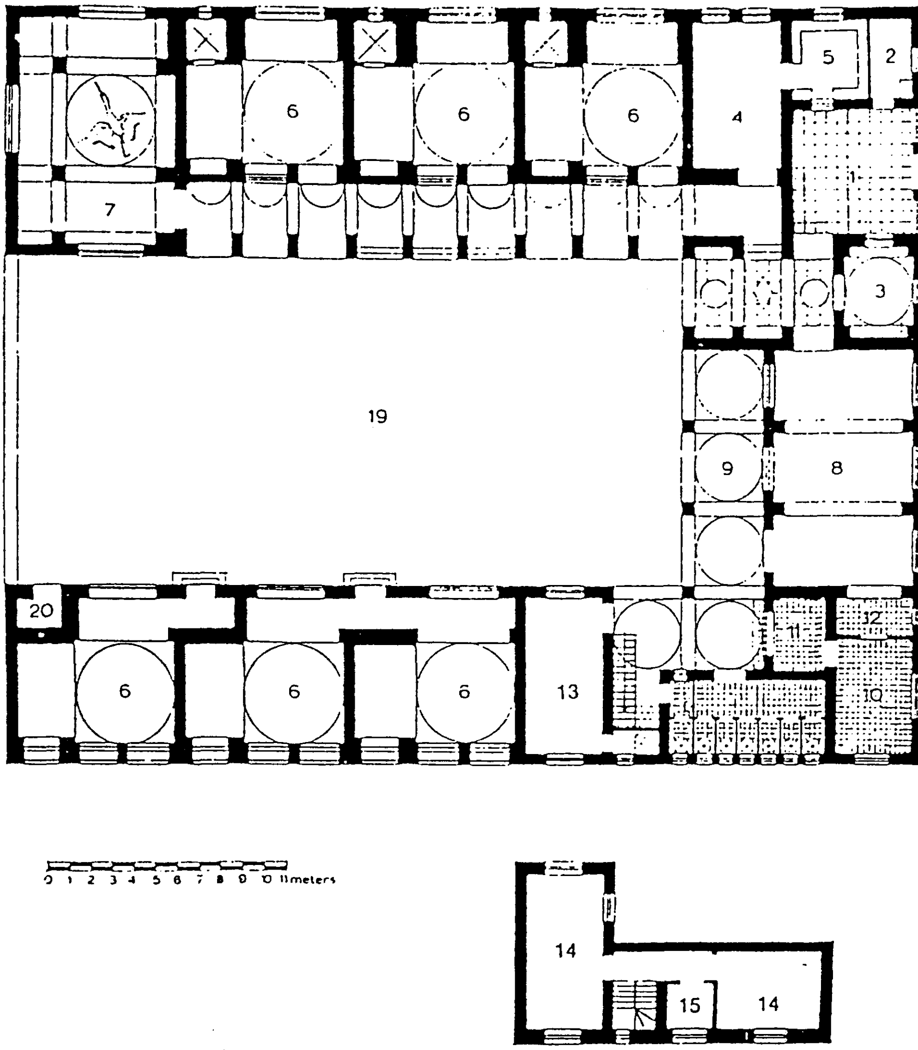
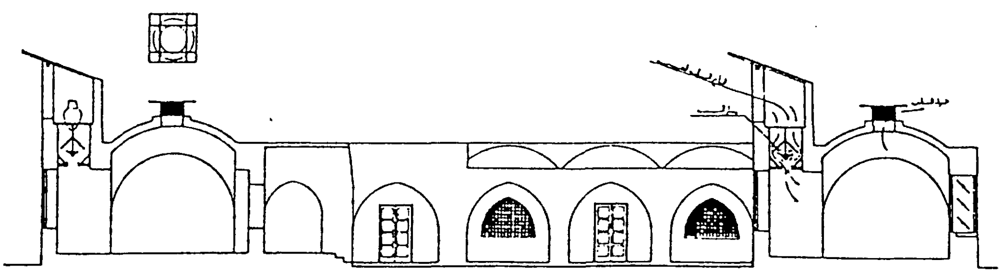


Figure 5.4b External Facade.

Source: Fathi, H. Architecture for the Poor 1969.



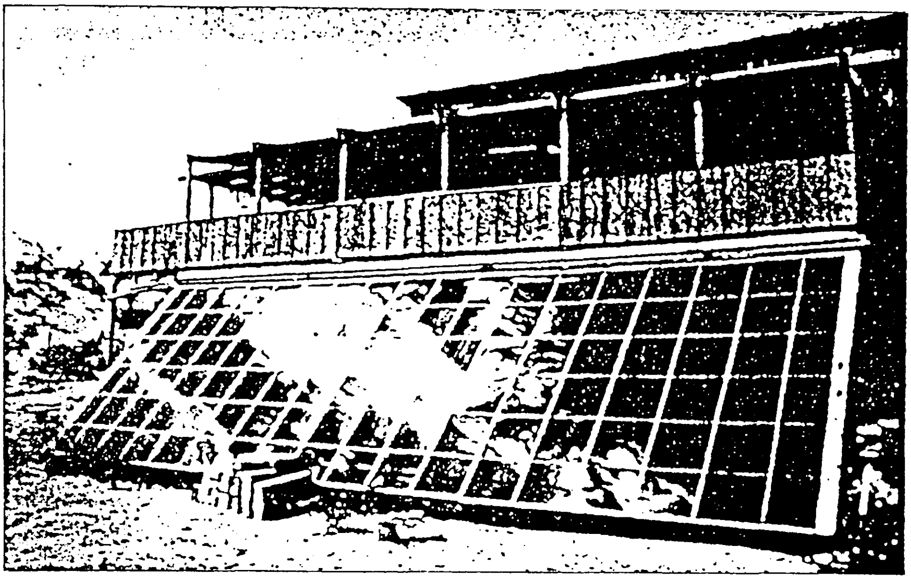
. Plan of girls' primary school. Legend: (1) Entrance. (2) Porter. (3) Supervisor. (4) Book storage. (5) Book distribution. (6) Classroom. (7) Art room. (8) Dining-exhibition room. (9) Shed. (10) Kitchen. (11) Storage. (12) Serving. (13) Mistresses' room. (14) Mistress's bedroom on upper floor. (15) Bathroom



Ventilation system at girls' primary school

Figure 5.5 Girls' Primary School in Egypt : Heavy mass and evaporative cooling.

Source: Fathy, H. Architecture for the Poor 1969.



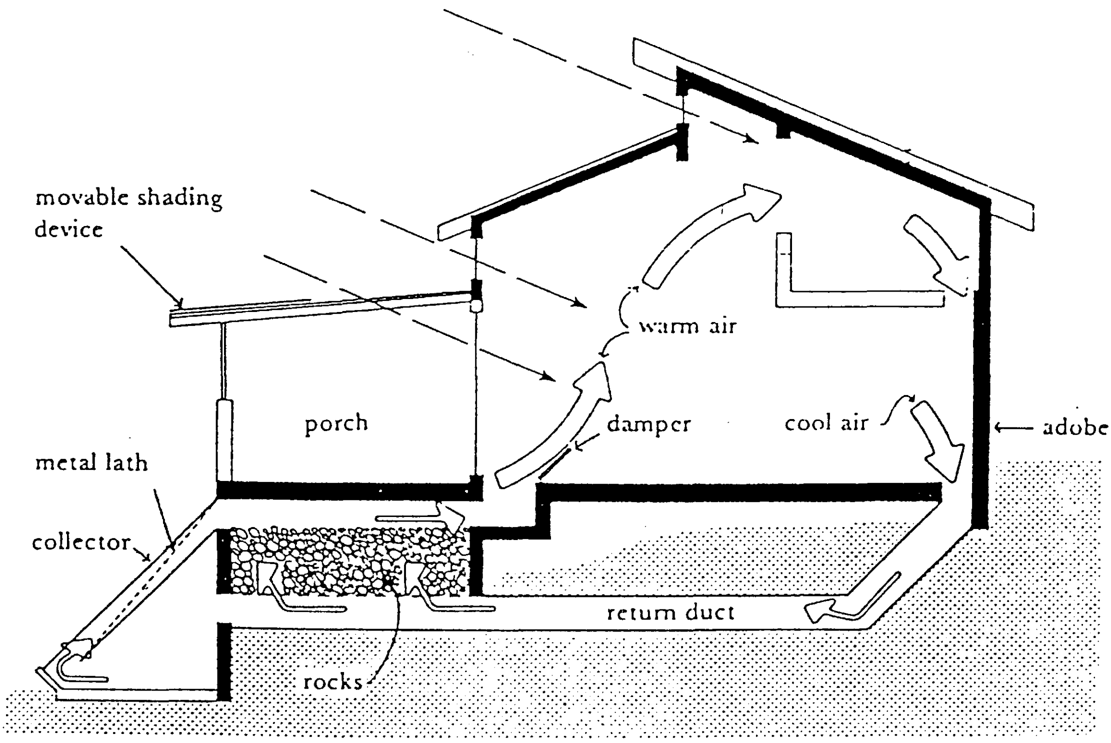


Figure 5.6 The Paul Davis house, Corrales, Albuquerque, New Mexico.

Source: Lebens, R.M. Passive Solar Heating Design 1980.

experimentally verify some design parameters - see figure 5.7.

According to Anderson[3] rock beds integrated as part of the building can be advantageous for cooling in regions where night time temperatures drop below maximum comfort limits. He shows the fluctuation in inside air temperature of a night air cooled office building near Davis, California over a 4 day period in the summer. The indoor temperature fluctuated from a low of 18.3°C to a high of 25.7°C whereas daytime external temperature during the same period soared well over 37.8°C. His findings are illustrated in figure 5.8.

Among the various combined cooling/heating systems were those developed under the general heading of 'Double Envelope', where the loop encloses the whole building. Figure 5.9 illustrates such a system where the collector is a sunspace and the rock bed is in indirect contact with the living space, providing delivery by radiation and conduction/convection transfer. It can be categorised as "isolated" since the collector and the storage mass have been separated. Shurcliff[4] has described a number of examples. Dodson[5] stated that Butler is generally credited with being the first to propose the idea, and the first well known example appears to be the Smith house on Lake Tahoe near San Fransisco late 1977.

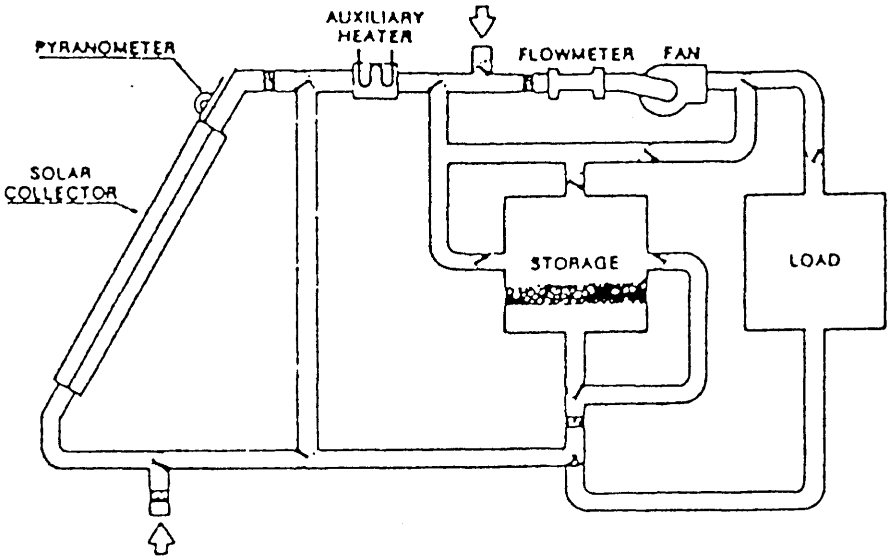


Figure 5.7a Schematic Illustration of The Experimental Facility.

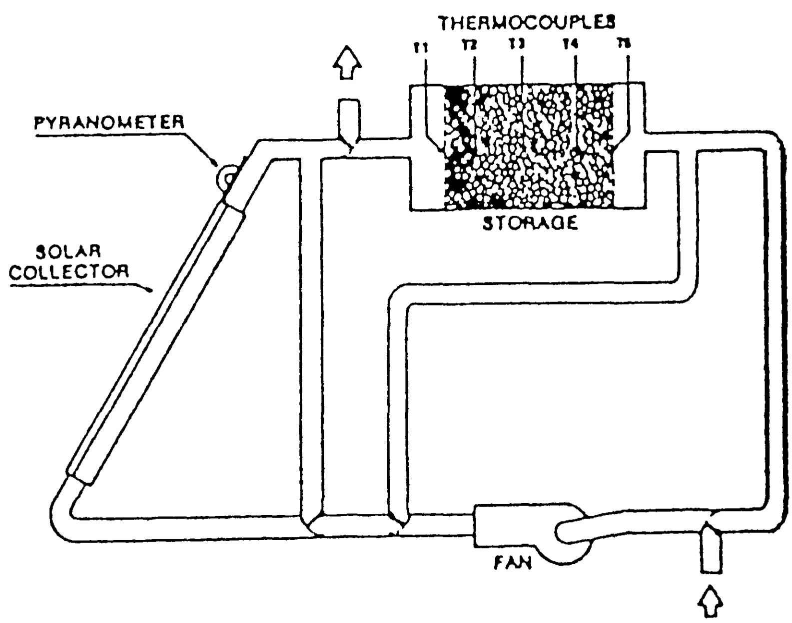


Figure 5.7b Schematic Illustration of The Small Scale Facility.

Source: Szokolay, S.V. Solar World Congress 1983 Volume 2, p. 906.

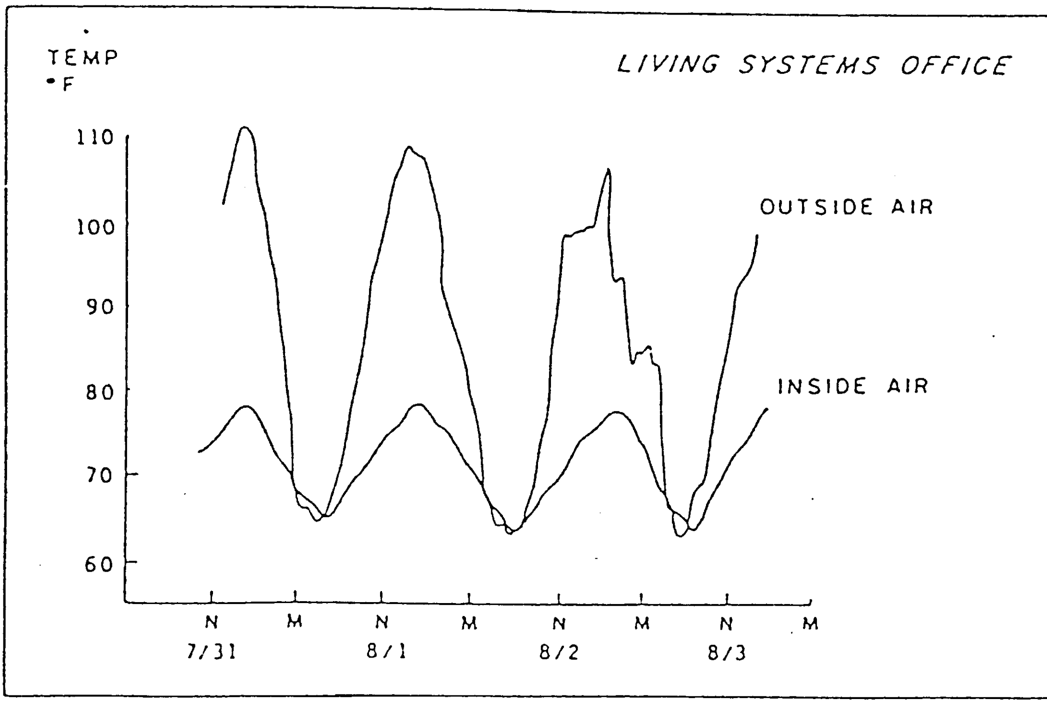


Figure 5.8 Indoor temperature fluctuation over 4 day period in an office building in Davis, California, that is cooled by the circulation of night outdoor air.

Source: Anderson, B. Total Environmental Action, Inc. Passive Solar Design Handbook 1984.

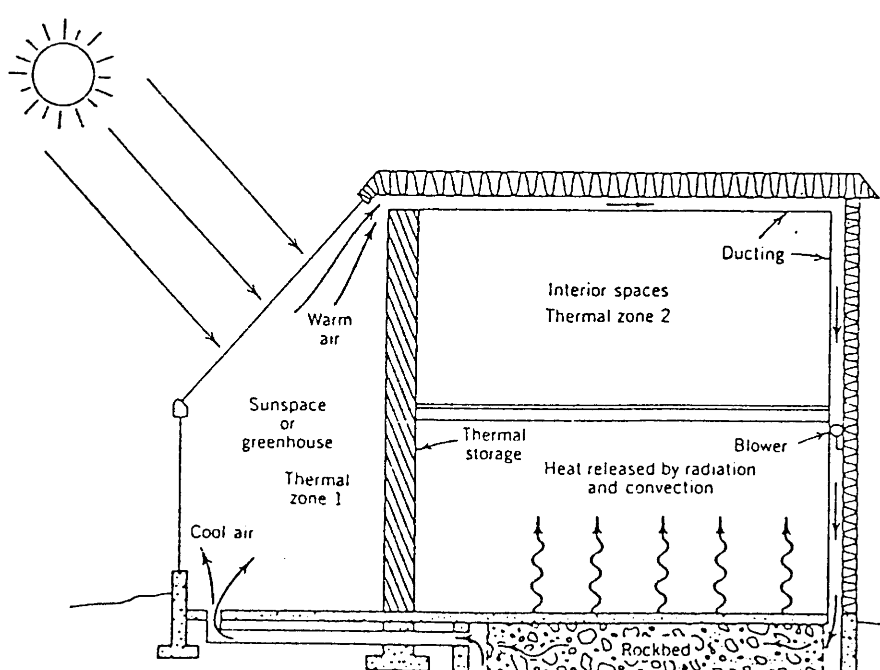


Figure 5.9 A two-zone hybrid system has the rock bed placed outside the sunspace. The typical location is under the floor slab of northern rooms. A fan is used to circulate warm air from the sunspace through the rock bed.

Source: Harris, Miller, Thomas. Solar Energy Systems Design 1985.

5.2 Application to School Model

In Constantine buildings are concerned with relatively short periods of heating compared to cooling. Thus, combined heating/cooling is a potentially effective approach which can be accomplished by a storage mass integrated with a partly reversible passive solar double-envelope, incorporating hot exhaust and cool air intake.

It is firstly recommended that the school should be oriented as near North/South as possible rather than North-east/South-west as in the model. The principle then employed in the proposed system is to create a hollow space on the four sectional faces of the building - walls at back and front, roof and under floor - interconnected in such a way that a convection current can flow. During winter days two south facing glazed vertical air collectors initially drive air flow up to a void between the roof and ceiling. This in turn picks up insolation through the opaque roof surface, continuing the flow down the north wall via two ducts to a rock-bed store below the floor - see figure 5.10. The air gradually cools as it passes round the loop, with a return at the base of the south collection device. At the end of a school day, manual dampers will close the system between the store and the south collector at A and at the top of the north ducts at B - see figures 5.11a and 5.11b. This will prevent night losses, with the flow reversing from the rock bed up the north face. Vents from the north ducts to the classroom will ensure overnight delivery of stored

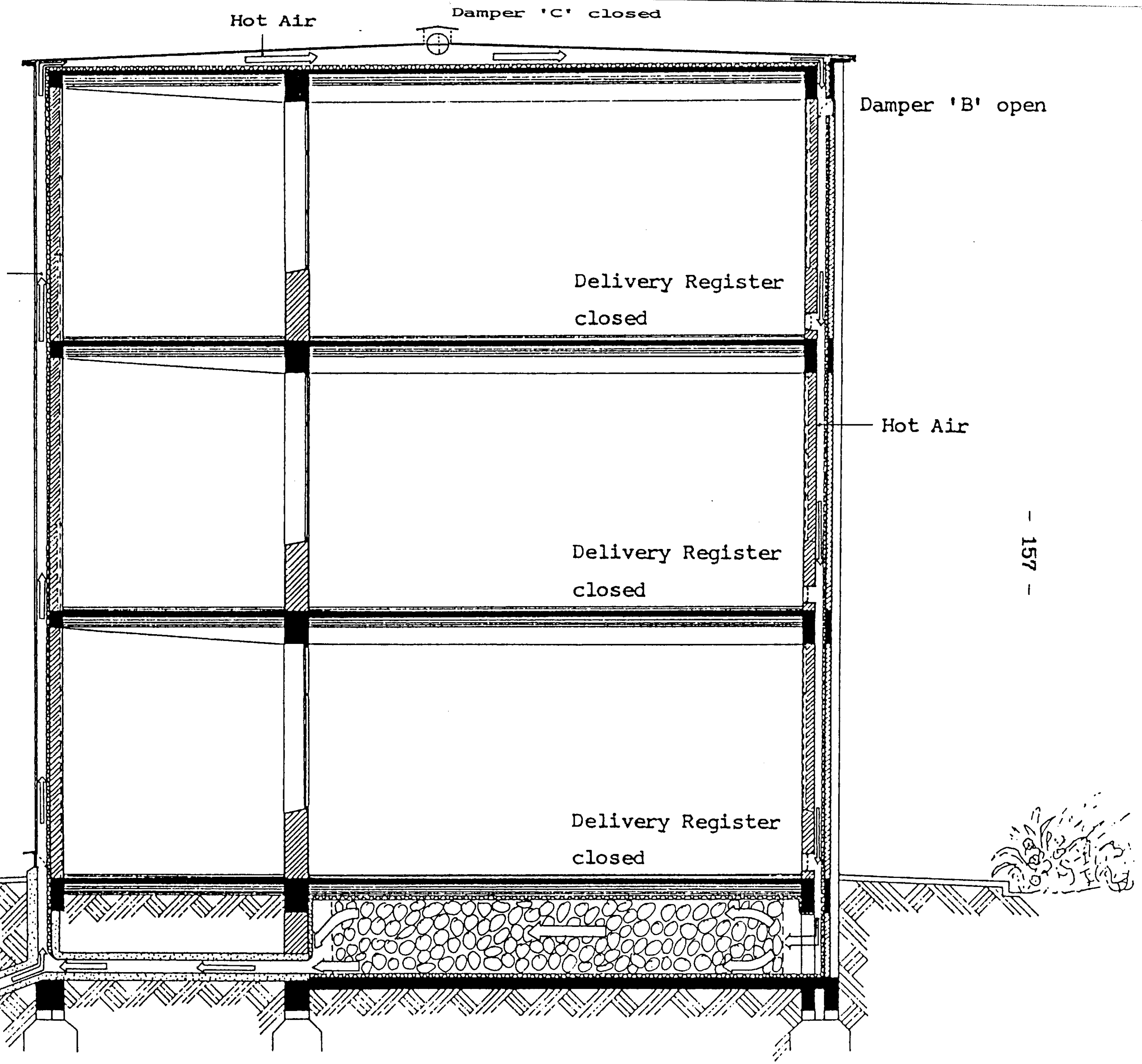


Figure 5.10 Winter day - Charging Mode

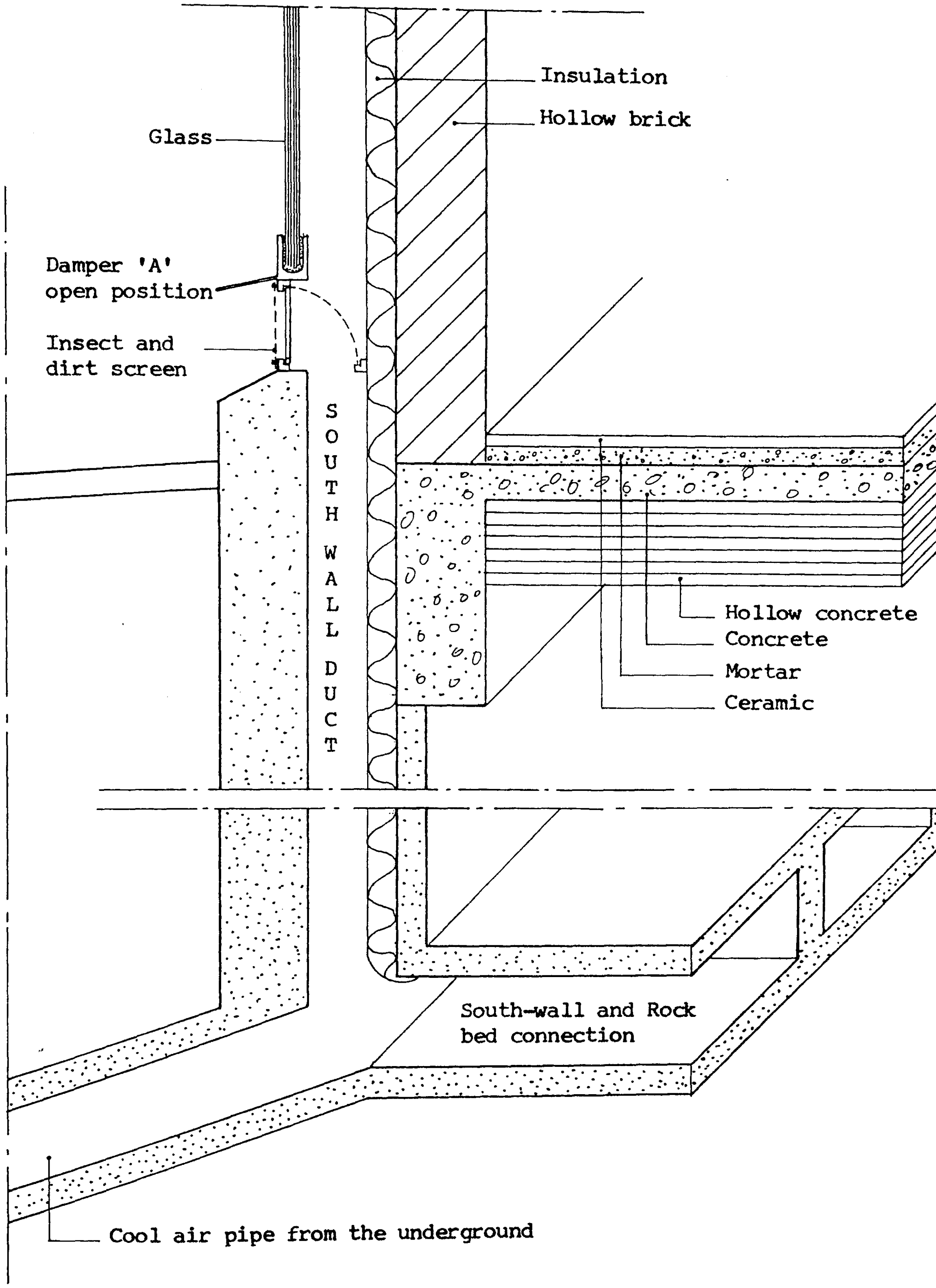


Figure 5.11a South Wall Duct Detail

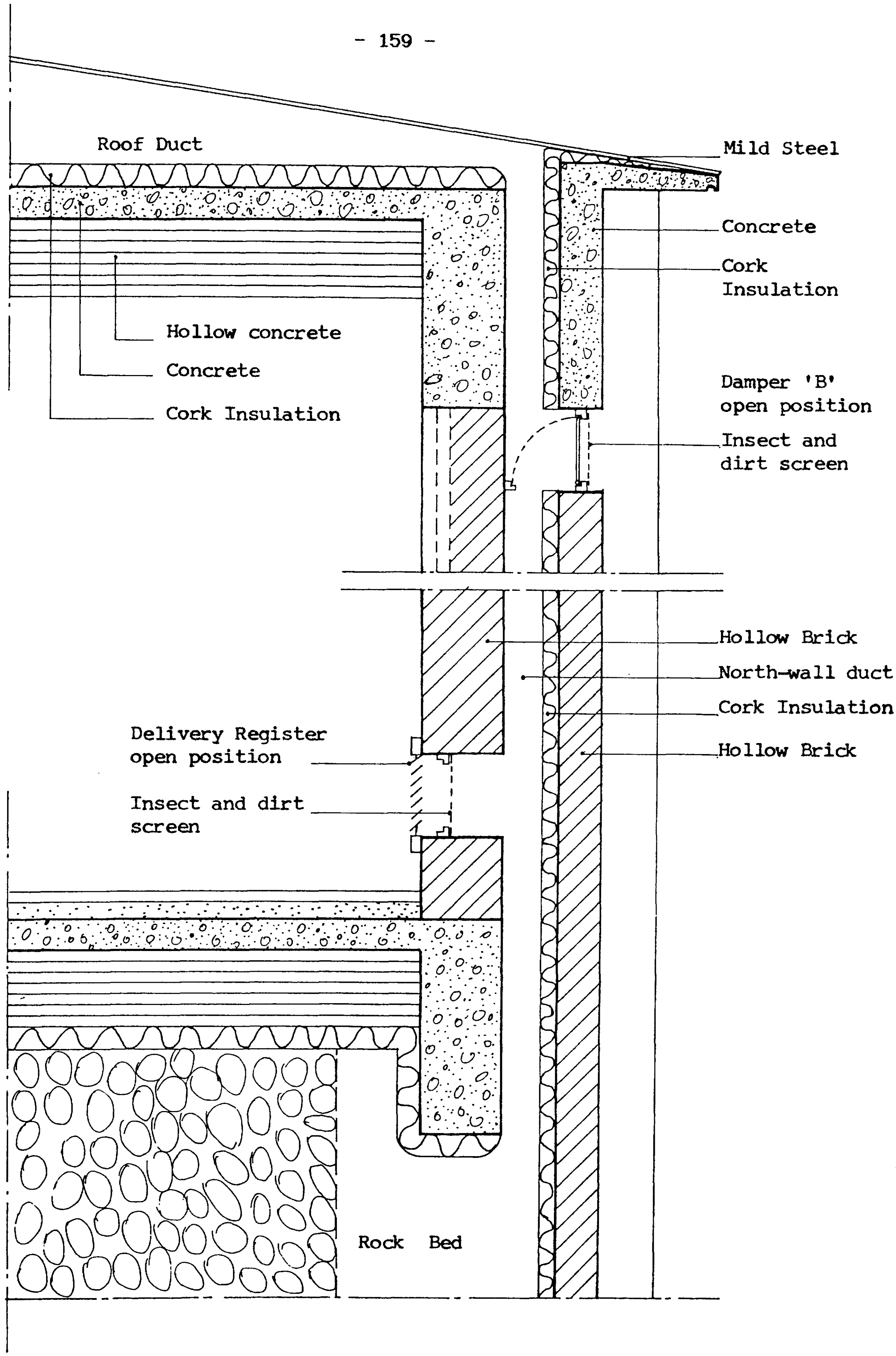


Figure 5.11b North-wall duct detail

heat, in order to fulfil the identified preheating demand. In summer the warm air system is vented and cool air is introduced by an underground intake to the south side of the rock bed, and hence to the same delivery vents on the north wall. Thus dampers A and B are both closed in the heating and cooling delivery mode, but open during the heat charging mode - see figure 5.10. In the case of heating there is a planned delay between charge and delivery, while with cooling, charging and delivery may be simultaneous, operating during both day and night.

5.2.1 Collection elements

a) South facing vertical element

The south facing collection devices are mounted on 1.25m wide and 3.2 m floor-high panels between columns, which support the open corridor and are located so as to minimise daylight loss to windows - see figure 5.12. Their construction and the thermal properties are shown in figure 5.13 and table 5.1 appendix 5. Air collectors of this type differ from a Trombe wall since the absorbent surface behind the glass is well insulated. Consequently the irradiation collected is not stored in this area. The air gap between the glazing and the inner layer of the wall should be wide enough to produce a green-house effect, and not smaller than 5 cm in order to permit easy air circulation. To prevent summer stagnation of hot air in the gap, the collector has a damper at A permitting direct air intake at the lower part

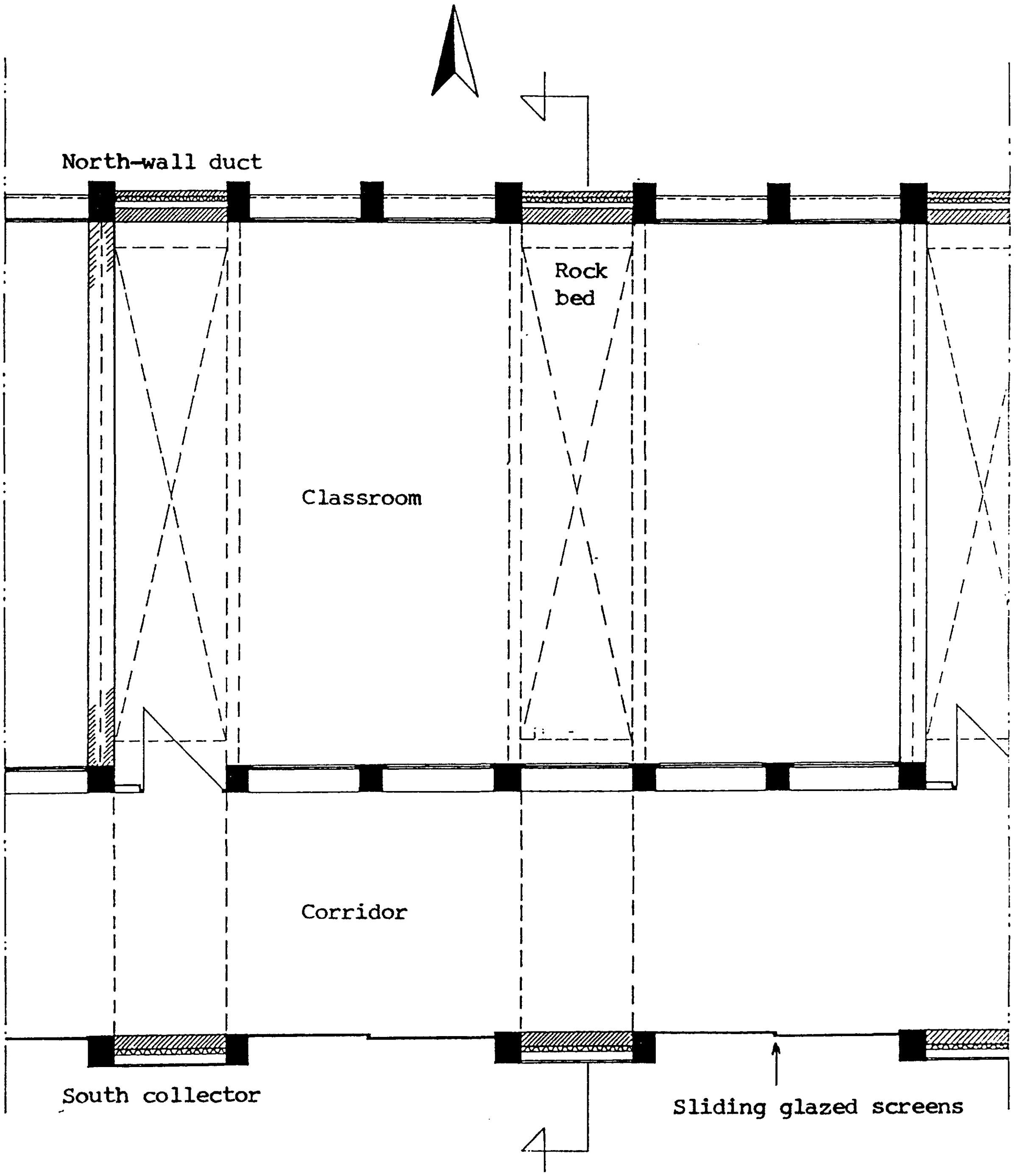


Figure 5.12 Proposed solution - classroom ground floor plan.

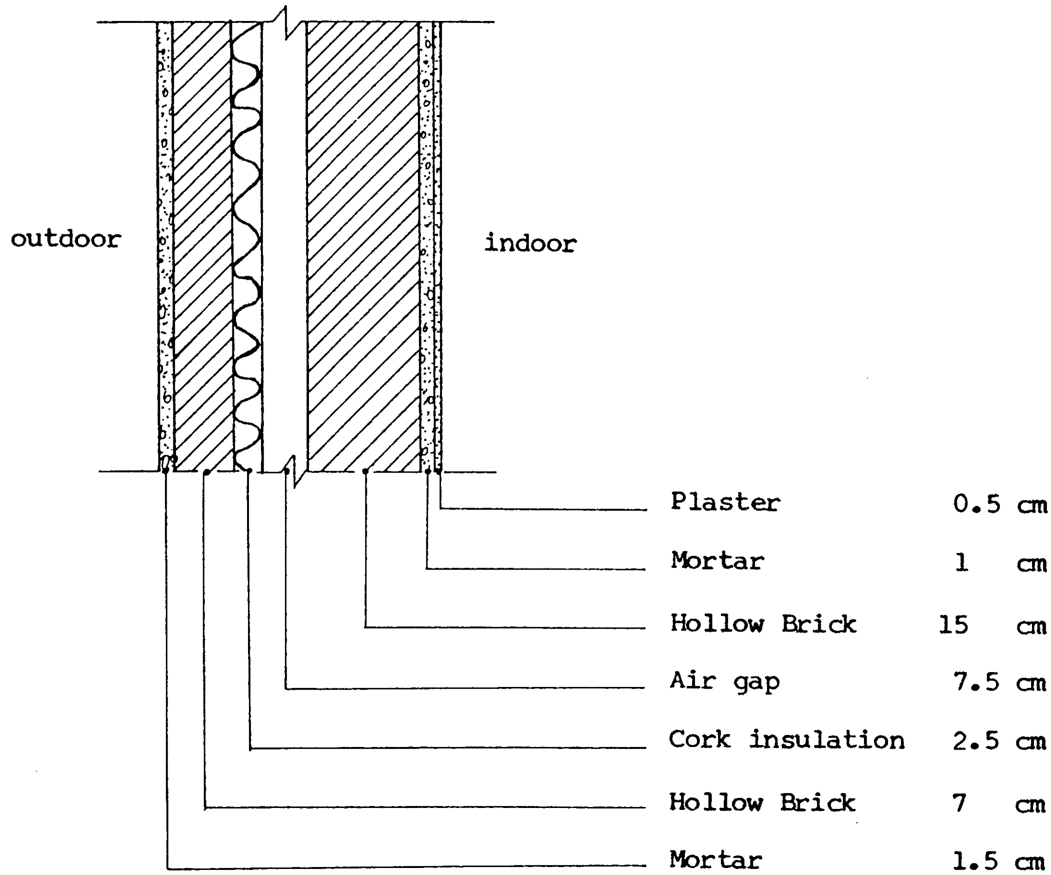


Figure 5.13a Proposed North-wall Construction.

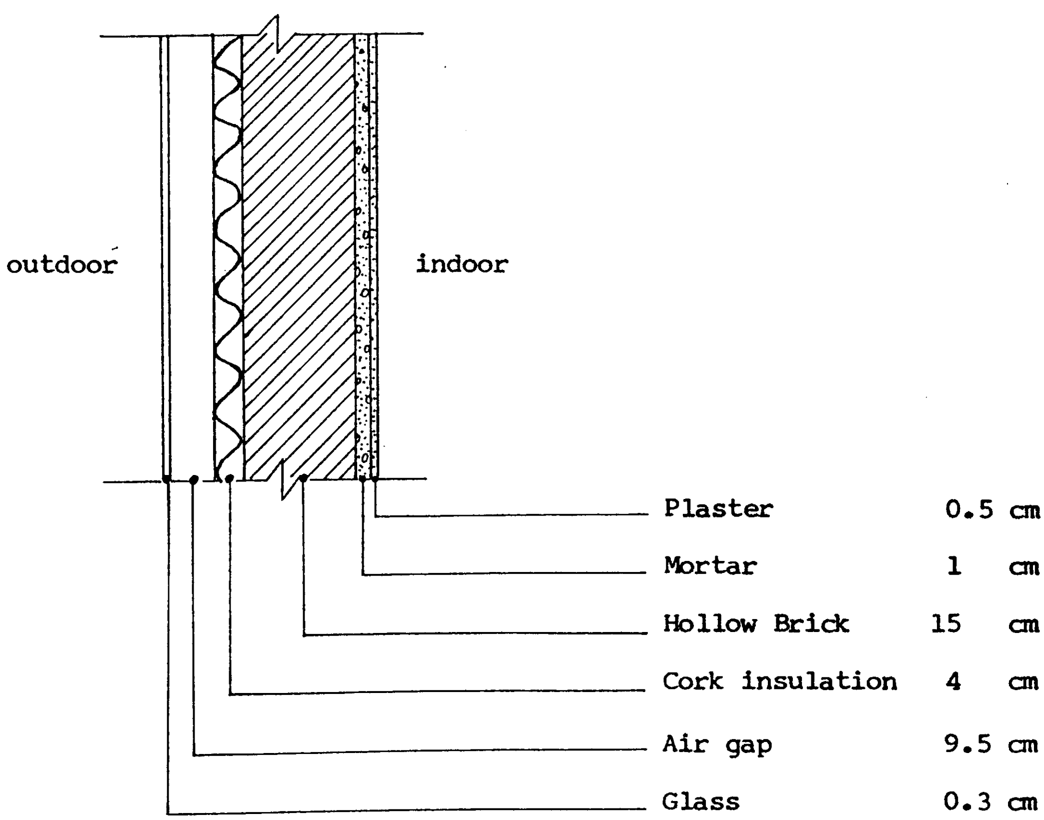


Figure 5.13b Proposed South-wall Construction.

of the outer skin, and simultaneously closing the loop. The proposed construction is hollow brick wall 35 cm thick, the absorbent surface insulated with a layer of black coloured cork. The lightweight black insulant will promote rapid conduction/convection transfer, with hot air in the gap, thus driving the loop. The glazing may be translucent plastic rather than glass for practical/economic reasons.

b) Roof element

The ceiling duct is a space between the solid inner part of the roof and the lightweight pitched external surface. The inner surface is a hollow concrete slab, well insulated from the circulating air. Its construction and thermal properties are illustrated in figure 4.18, roof no. 3. As in the south wall, the void should permit free air flow from the south wall to the north wall. This space also requires a vent or "hot exhaust" C for use in conjunction with damper vents at A and B, for summer relief to help cooling of the structure.

5.2.2 Circulation and distribution element : North wall ducts.

These are located in two sections of 1.25 m wide wall between the north facing windows. The air gap, between the outer insulated skin and inner high mass skin of the north wall permits the downward circulation of gradually cooling hot air to the storage mass during winter afternoons. Opening vents in the inner skin at floor level will then permit the distribution of the stored hot air for preheating the unoccupied space during the night and early morning, with ducts closed at A and B - see figure 5.14. In summer daytime the same delivery system permits the circulation of cool air from the storage to the occupied classroom while vents at A and B are again closed. Hence, we have a separate hot air exhaust and cool air delivery system. Construction of the wall and vents are illustrated in figure 5.11b and 5.13a.

During the summer night, as the exposed surface of the roof is light, the night cooling effect would take place more rapidly than the cooling of walls. Conversely the daytime heat build up will be more rapid. Consequently vent C should be open day and night to assist roof cooling, while A and B are closed to permit cool air delivery and cross ventilation to classrooms. Louvred shutters to windows will permit both security and cross ventilation at night, but will be opened during the day - see figure 5.15a and 5.15b.

5.2.3 Cool air intake

As far as we know, the use of water as a cooling medium in hot areas is as old as the Egyptian Pharaohs who employed slaves to fan the air over large porous earthenwar jars. As it flows past the wet surface of the jars the air is cooled by evaporation - see figure 5.16. Building of Babylon and many parts of Iraq were located on the Euphrates and the Tigris to obtain the cooling effect of the river surface. They also use water in a more sophisticated way for cooling

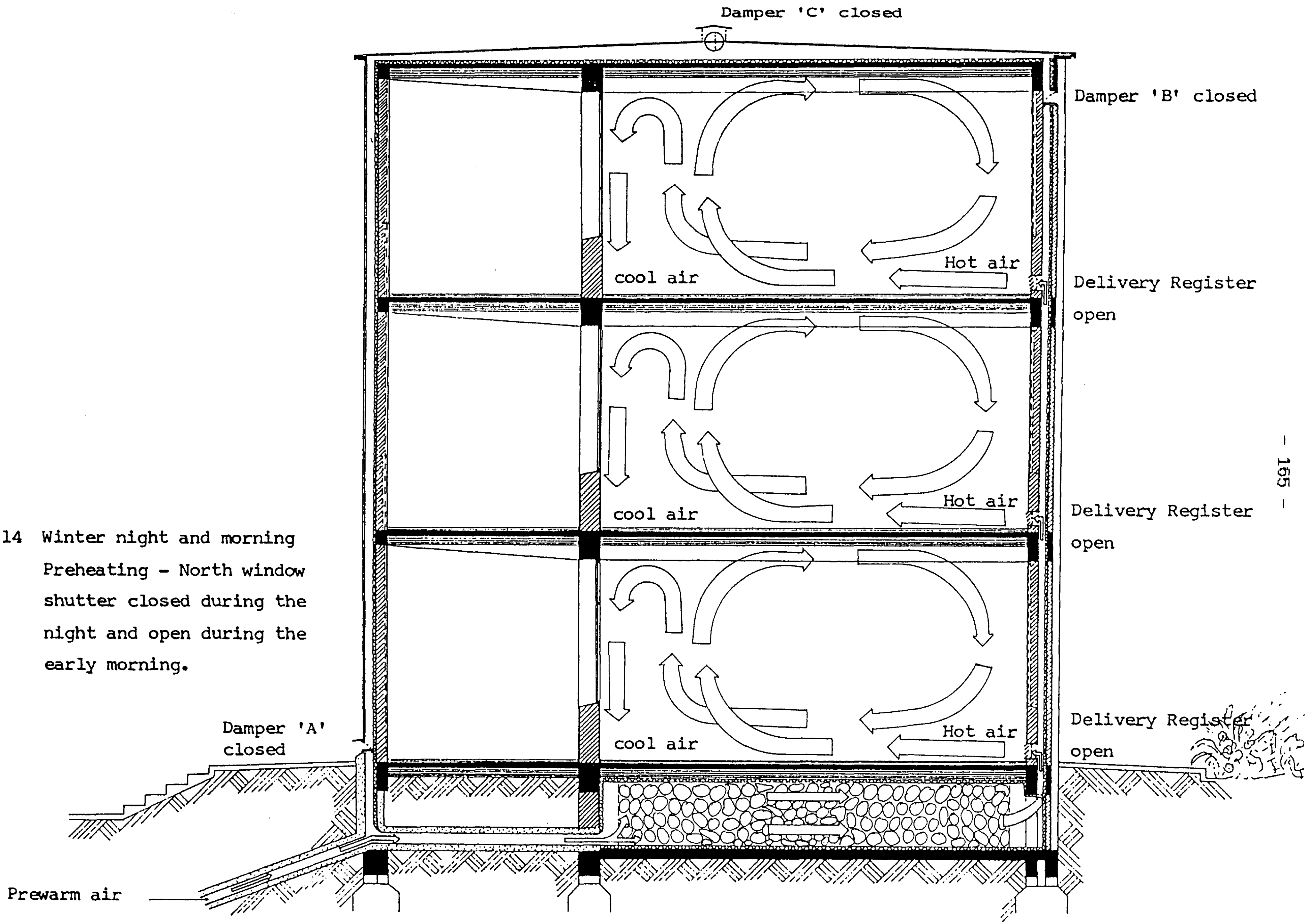


Figure 5.14 Winter night and morning Preheating - North window shutter closed during the night and open during the early morning.

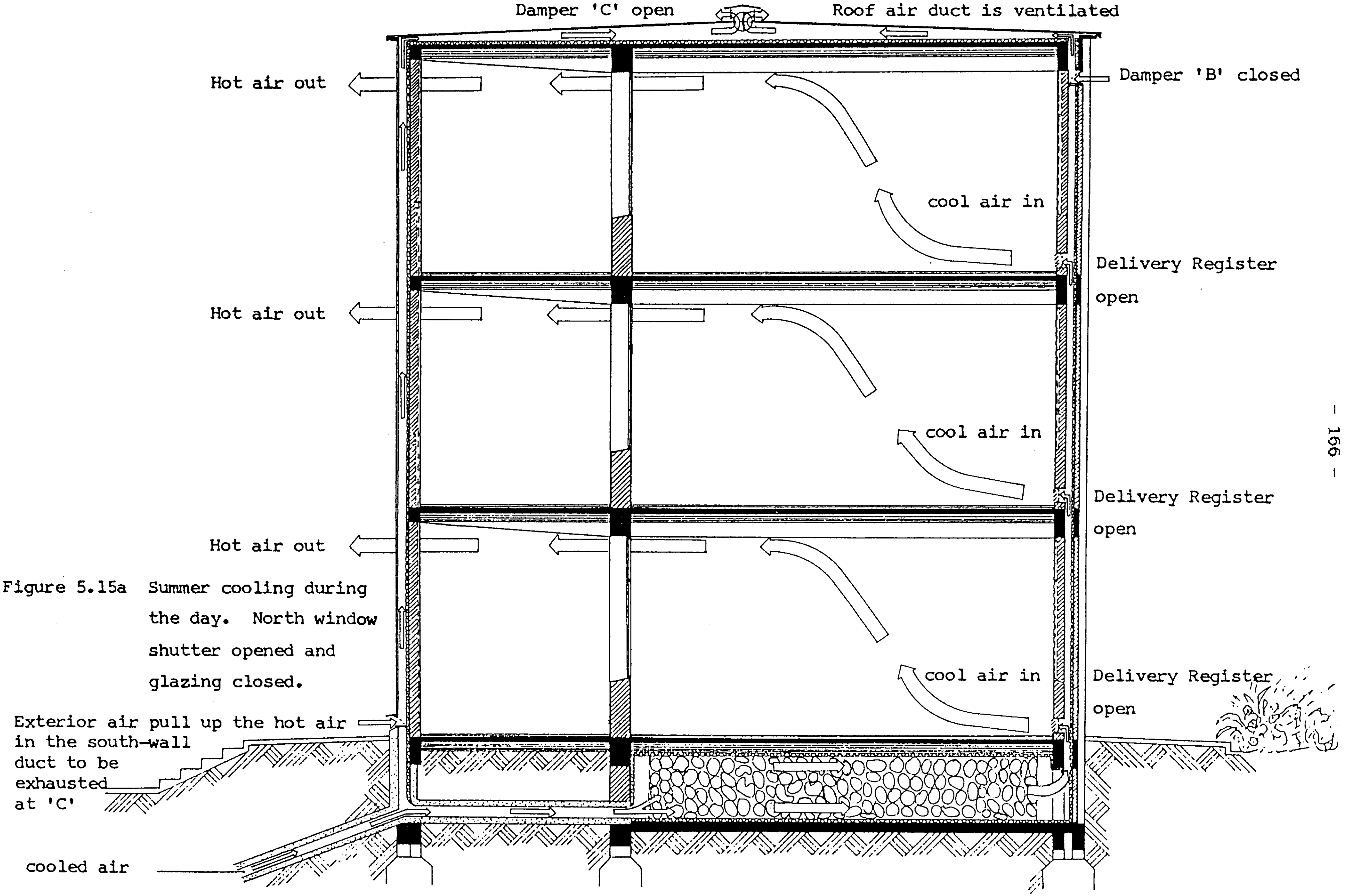


Figure 5.15a Summer cooling during the day. North window shutter opened and glazing closed.

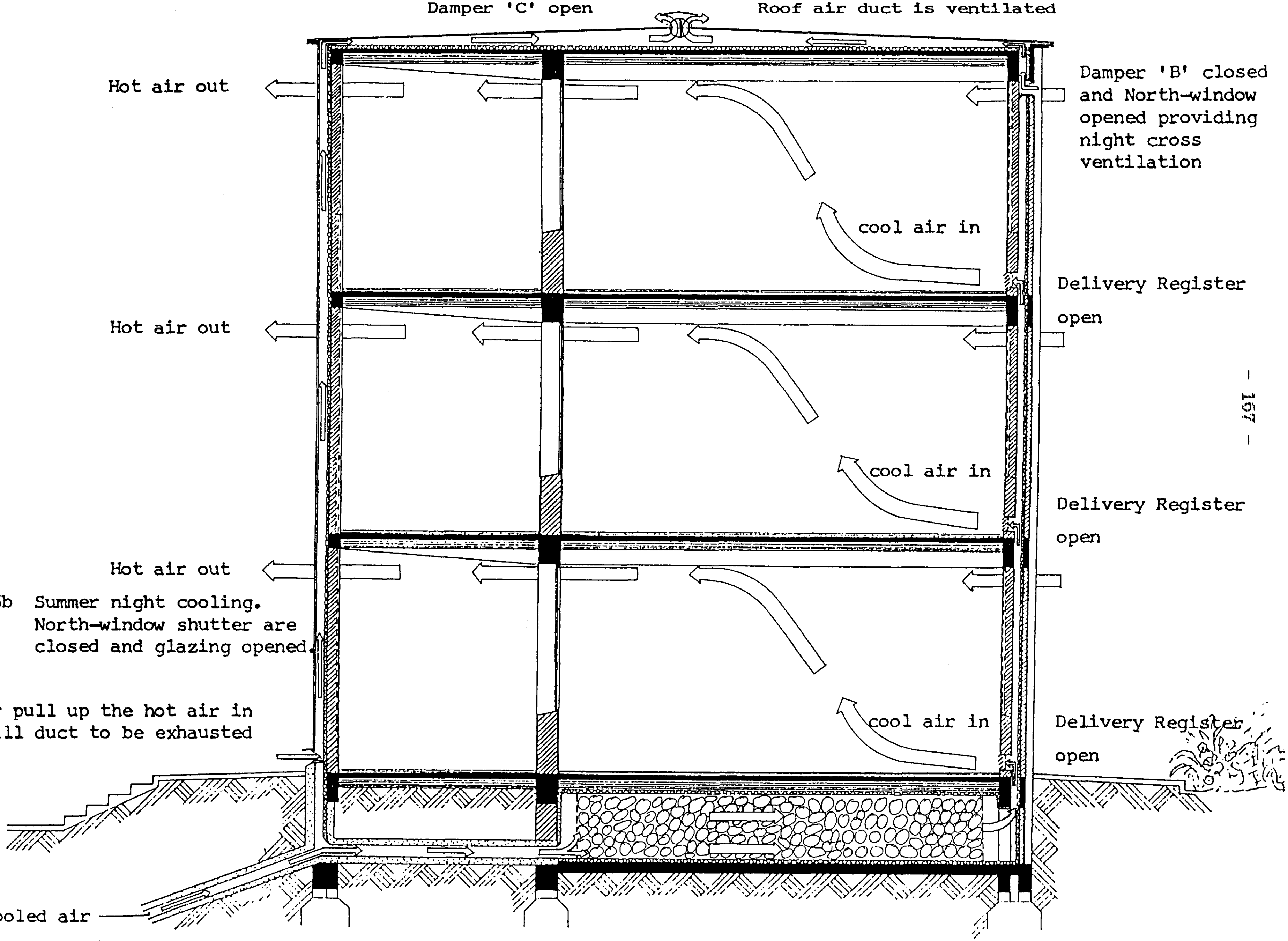


Figure 5.15b Summer night cooling. North-window shutter are closed and glazing opened.

- ie the underground tunnel system which is commonly called "Serdab", in conjunction with wind catchers or wind towers provide an effective cooling - see figure 5.17. Traditional arab houses as in Constantine old town which contain a fountain and artificial cascades to cool the air, also act as a thermal regulator. Most of these cascades or Salsabil- name of a river in the paradise according to the Koran - utilise marble slabs. Thus the Salsabil may be seen as a fountain, placed at the upper level where the water trickles, then flows through a corrugated marble surface to the basin at the lower level, to increase the effect of evaporative cooling - see figure 5.18. This concept of cooling, although based on empirical rather than theoretical scientific knowledge, worked successfully.

Consequently a fountain or Salsabil in the middle of the school play-ground would make an attractive and refreshing place, shaded with trees and decidious plants which help the water to keep its coolness from the night over´ day. This fountain can be related to an underground water collector, which in turn is connected to an underground cool air tunnel. This tunnel is a clay conduct which can transmit cool air from the fountain to the rock storage mass. The cooling affect is due to the two following principles:

- Evaporative cooling as the air passes through a duct inside a group of thin water jets to the underground void.

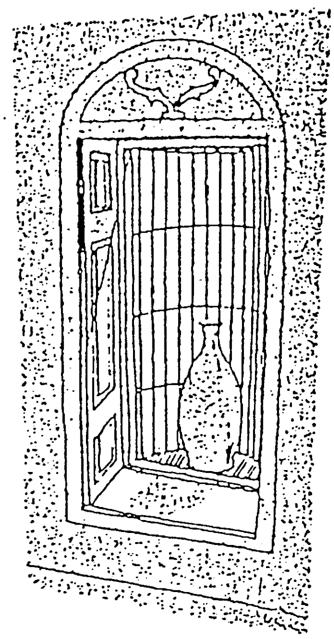


Figure 5.16 Elaborate Window. Air is cooled by evaporation as it passes over surface of water-filled porous pot.

Source: Warren, J. and Fethi, I. Traditional houses in Baghdad.

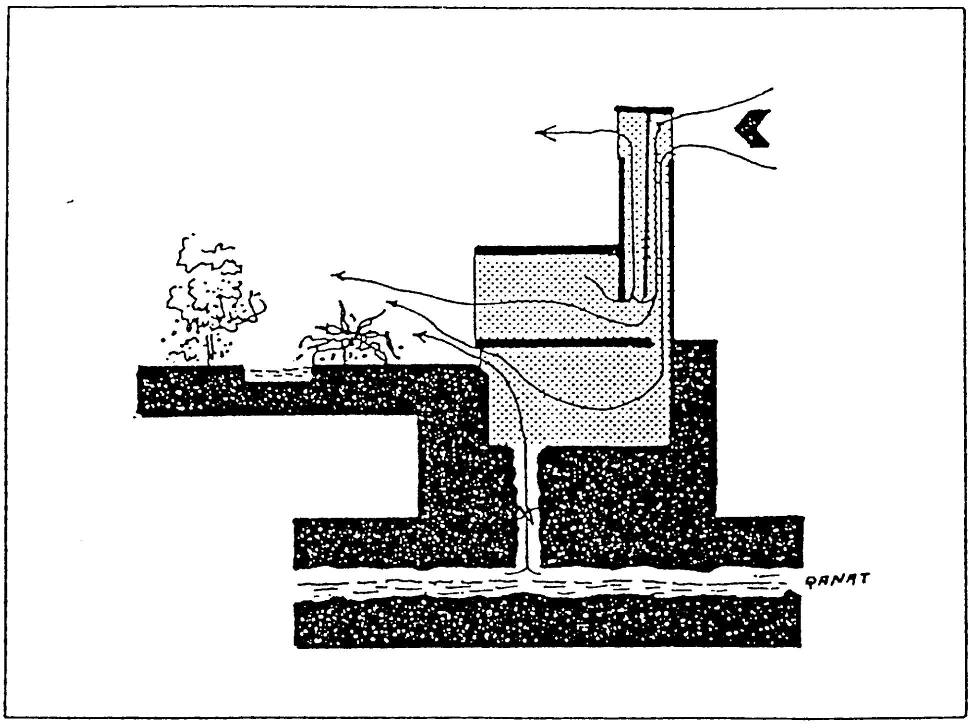


Figure 5.17 Section showing the wind tower associated with an underground stream.

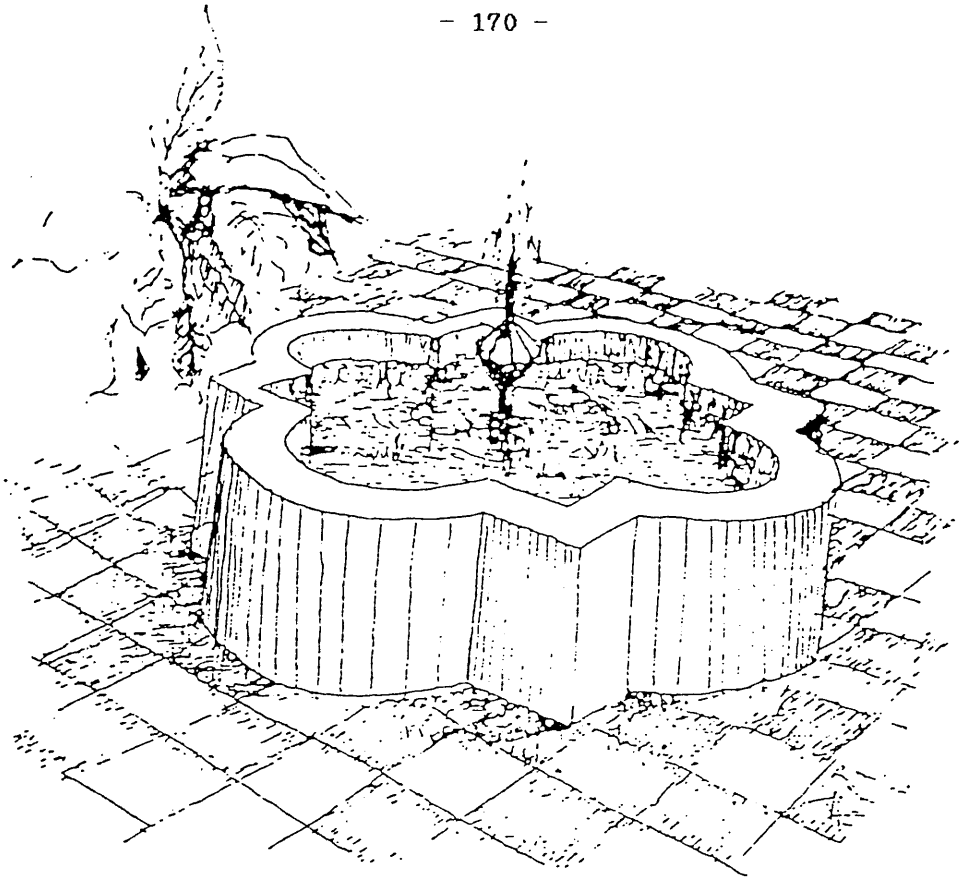


Figure 5.18a Fountain in the middle of courtyard playing into basin provide evaporative cooling.

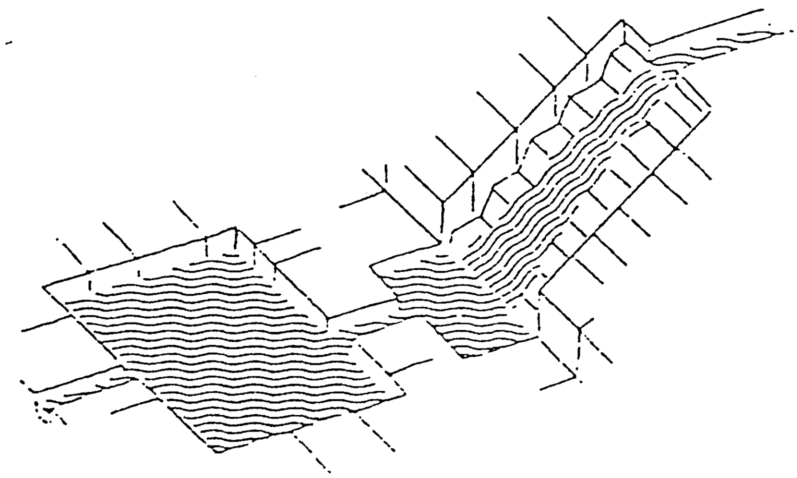


Figure 5.18b Evaporative cooling increased if water has to flow over corrugated surfaces.

- Temperature difference (stack effect) between the tunnel of cool air and the storage which loses its coolness to the classroom.

5.2.4 Storage mass

A common hybrid system utilises a fan to achieve greater control of air flow through the loop to the rock bed. In this case the cool air intake serves both heating and cooling mode. In summer it will be always cooler than the ambient external temperature, while in winter, under certain circumstances it could provide a slightly prewarmed supply to the collector. The rock bed is usually located under the floor of the building as in this case. The storage consists of an underground void filled by river pebbles. The pebble dimensions and density are chosen with reference to the Rizzi and Fumagali[2] experiment, where they have taken pebbles of 2,500 kg/m^3 volumetric density and 3 cm diameters. The void fraction was assumed 36% measúred by water displacement method, which gives a rock bed density of 1,600 kg/m^3. The void combines the function of completing the loop and acts with the storage mass. The air flow can be controlled by placing small air impelled fans operated automatically by the temperature difference between collecting area and storage mass, but in this case the system is designed to operate by natural thermo-circulation.

5.2.5 Sizing rock bed

Rock bed size is dependent upon the desired amount of heat to be stored. Generally transferring large amounts of energy to the store requires a large air flow rate, which is dependant upon exterior energy sources and the air circulation system. In this case, in January, the mean daily energy to be transferred to the pebble bed is estimated at 62.7 kWh, supplied from south vertical collecting area of 24 m^2 (3 floor classroom unit) and horizontal opaque roof area of 93.84 m^2. The average temperature in the air gap is assumed 25°C during the collection period and the circulation losses are assumed 25%. If we wish to raise the pebble bed store through 10 K, the above value give a volume of 14.87 m^3 with a length of 6.3 m corresponding to classroom depth and a width of 2.5 m corresponding to 2 rock beds, one at each collector/duct location and with a depth of 0.94 m. The volumetric thermal capacity of the two rock beds, ρc, taking specific heat capacity as 950 J/kg K is 1,520 kJ/m^3K or 0.422 kWh/m^3K. To raise the pebbles through 10 K we then require 4.22 kWh/m^3. Since we have an input of 62.7 kWh, we require a total volume of 14.87 m^3. It has been shown in section 4 that the preheating load in January is 330 kWh or 10.6 kWh per day per classroom. This is then 31.8 kWh for a 3 storey unit served by two rock stores, and would give an input/output efficiency of approximately 50% in relation to the 62.7 kWh charging the store.

Thus the heating demand is used to size the store, and the cooling will adjust according to the load and temperature drop.

Reference section 5

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3. Anderson, B. Passive Solar design Handbook - Part one: Total environmental action, Inc, 1984 p.75.

4. Shurkliff, W.A. suprinsulated and double envelop houses 2nd edition; Wm A. Shurcliff, Cambridge, Ma, USA 1980.

5. Dodson, C. Review of Hybrid and Double Envelope Solutions, Proceeding Second U.K. Passive Solar Conference C 27, UK-ISES London 1981, p. 53.

GENERAL CONCLUSION

The investigation of cyclical thermal performance of a classroom unit in a typical Constantine school during winter and summer conditions, showed the heating load to be small compared to the cooling load.

The model analysis showed that southerly orientation and its appropriate shading were suitable strategies, contributing to a reduction of direct incident solar irradiation, which together with the external air temperature, are the most influential climatic features. On the other hand, double-lit classrooms which provide the required daylight and night cross ventilation, simultaneously permit considerable heat transfer from the dominant diffuse component. It has also been determined that shutters on north facades perform better than fins in reducing or eliminating the penetration of direct radiation to the classroom during the early summer morning and permitting it during winter. Hence they can contribute to precooling in summer and to winter preheating. With respect to opaque wall surfaces, the thermal mass, giving a 9 hour time lag, failed to sufficiently delay the heat flow with respect to classroom pattern of use and occupancy. Thus, even though thermal strategies were considered in the existing model, the summer cooling load remained highly significant due to both unavoidable solar radiation and casual gains from occupants.

From the investigation of walls and roofs, it has been determined that increasing time lags to between 14 and 20 hours, may still contribute to the increase of overheating in summer by providing a heat input during the early morning.

It has also been deduced that with respect to building shell capacitance/resistance, heavy mass insulated externally has clear potential in increasing the time lag without increasing the thickness of the heavy mass. For example, light coloured PVC coated mild steel sheeting, separated by a ventilated air space from a cork insulation layer on the heavy mass concrete roof, has been shown to give a satisfactory performance for this climate - a time lag in excess of 24 hours providing virtual steady-state conditions. The air space also permits transfer of warm air around a thermosyphon loop in the winter preheating mode, and permits venting in summer.

Passive cooling of buildings in hot regions requires an effective storage of coolness. The most commonly used material for the storage of thermal energy is the structural material of the building. The building structure may be cooled internally at night by circulating cool night air, and externally by allowing the outside surface to lose diurnally stored heat to the air by convection and to the clear skies by radiation. The latter is accelerated by the use of a white-wash colour which has low absorption/ emittance in shortwave, but high in longwave permitting rapid radiation loss on cool clear nights.

The high rate of ventilation required in schools cannot be achieved during the day by simply opening the window as this raises the indoor temperature. Night cross-ventilation provided by windows in opposite walls may provide effective structural cooling if the outside night air temperature is sufficiently low, especially during the early morning. In relation to mass characteristics, this may provide precooling of the unoccupied clasroom during the summer period.

To enhance cooling by ventilation, there are various passive methods available to precool incoming air. For example, air may be evaporatively cooled by water in underground ducts, possibly in conjunction with a fountain. The cooled air may then pass through pebble storage beds below the ground floor, further lowering the temperature and be introduced to the classrooms by thermo-circulation through vertical ducts.

Thus, since both winter preheating and summer cooling loads are identified, simple modifications to the existing configuration have been proposed to perform both functions. The roof construction is designed to avoid transmission of summer gain, but integrated with a thermosiphon loop, it enables heat storage in winter. The rock bed also assists in both heating and cooling, and delivery ducts may deliver warm air or cool air.

Such duality of roles in construction techniques which can be utilised in conjunction with existing school morphology to increase comfort and/or displace auxiliary fossil fuel based energy, is considered to be an appropriate economic strategy for the current Algerian situation.

Appendix 1

ANALYSIS OF THE DEVELOPMENT OF EDUCATION AND EDUCATIONAL BUILDING

Period	School number	Classrooms number
before 1904	2	-
1904	3	30
1904 - 1916	6	85
1923 - 1933	11	127
1935 - 1942	6	69
1943 - 1954	10	81
1955 - 1959	12	125
1960 - 1966	10	120
1967 - 1977	22	206
Total	82	843

Table 1.1 Development of School Buildings and Classrooms Number from 1904-1977.

Source: Inspection Academic, Direction de l'Education - Constantine.

School academic year	Number of Pupils	Growth Rate %
62 - 63	20,265	-
63 - 64	35,734	76.82
64 - 65	45,451	26.83
65 - 66	47,163	5.96
66 - 67	49,821	3.44
67 - 68	53,308	6.99
68 - 69	56,070	5.18
69 - 70	60,830	4.84
70 - 71	64,386	5.84
71 - 72	65,874	2.31
72 - 73	70,926	7.66
73 - 74	73,888	4.16
74 - 75	74,454	0.76
75 - 76	75,999	2.07
76 - 77	77,849	2.43

Table 1.2 Development of Pupils Number and Growth Rate, 1982-1977.

Source: Inspection Academic, Direction de l'Education - Constantine.

School year	Government budget	Education budget	Indices	Percentage of The national budget
1963	2,912,737	322,719	100	11.0
64	3,740,900	719,338	223	19.2
65	3,956,040	731,867	227	18.5
66	4,945,715	660,000	205	13.3
67	4,707,000	880,000	273	18.6
68	5,076,200	892,850	277	17.5
69	7,899,000	1,454,000	453	18.5
70	11,020,000	1,634,000	506	14.9
73	10,620,000	2,094,900	649	19.7
74	20,695,000	2,276,450	705	11.0
77	29,061,400	3,796,900	1,175	13.1
80	50,897,837	5,186,797	1,607	10.2

Table 1.3 Budget allocated to education during the 1963/80 in Thousand A.D.

Source: Source Ministry of Education 1980, p. 32.

Footnote: Recent figure also confirm the considerable support allocated to education 10.6%[5] of the national budget during the first five years plan and 8.18%[6] for the second five year plan

School Year	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86
Number of Pupils	132,148	133,228	134,706	136,194	102,424	103,789
Number of Schools		266	281	300	194	197
rate of occupancy %		62	60	57	62	62
Number of Classrooms		2,148	2,245	2,389	1,652	1,674

Table 1.4 Fundamental Education (Primary)
Number of Pupils and Number of Schools allocated
During the creation of Fundamental School 1980-86
Constantine (wilaya)

Source: Sous Direction De La Planification et Des Realisations Information Statistiques Enseignement elementaire et Moyen.

Appendix 2

CONSTANTINE CLIMATE ANALYSIS

Months	Monthly average maximum	Monthly average minimum	Summer and winter amplitude	Mean monthly	Mean annual
J	11.47	2.34	9.13	6.9	
F	13.87	3.5		8.68	
M	15.7	4.3		10.0	
A	19.05	6.8		12.92	
M	24.3	10.29		17.29	
J	30.87	15.0		22.9	15.96
J	35.3	18.76	16.54	27.03	
A	34.9	18.45		26.67	
S	29.8	15.4		22.6	
O	23.13	10.73		16.93	
N	17.24	5.87		11.53	
D	12.87	3.27		8.1	

Table 2.1a External air temperature over 16 years

hours \ months	J	F	M	A	M	J	J	A	S	O	N	D
00.00	4.6	6.4	7.40	9.90	13.65	17.6	22.45	22.40	18.65	13.95	8.0	5.
01.00	4.05	5.70	6.80	9.25	12.80	16.85	21.90	21.80	18.1	13.2	7.55	4.
02.00	3.60	5.0	6.15	8.60	12.10	16.1	20.50	20.80	17.4	12.55	7.05	4.
03.00	3.25	4.40	5.65	7.90	11.40	15.4	19.9	20.0	16.8	12.0	6.7	4.
04.00	2.85	4.0	5.15	7.60	11.2	15.3	19.20	19.65	16.35	11.60	6.4	3.
05.00	2.6	3.7	4.75	7.20	11.0	15.15	19.0	19.1	15.85	11.05	6.0	3.
06.00	2.34	3.5	4.30	6.85	10.29	15.0	18.76	18.45	15.4	10.73	5.83	3.
07.00	3.2	4.4	5.9	8.9	12.6	17.8	20.7	21.0	17.25	13.0	8.0	4.
08.00	4.10	6.0	7.5	11.2	14.8	22.2	23.3	24.1	20.1	15.4	10.0	6.
09.00	5.25	7.1	9.0	13.1	16.8	24.0	25.9	26.6	22.4	17.2	11.2	7.
10.00	6.4	8.6	10.4	14.6	18.8	25.6	27.95	28.5	24.10	18.5	13.0	9.
11.00	8.0	10.2	12.10	16.0	20.6	27.4	29.5	30.6	26.2	20.4	14.7	10.
12.00	10.0	11.4	13.3	17.3	21.9	28.8	31.1	32.1	27.9	21.8	16.2	11.
13.00	10.5	12.2	14.4	17.9	22.8	29.4	32.6	33.0	28.6	22.3	16.3	12.
14.00	11.1	13.0	15.0	18.5	23.8	30.4	34.2	34.15	29.2	22.8	17.1	12.
15.00	11.47	13.87	15.70	19.05	24.3	30.87	35.3	34.9	29.8	23.13	17.24	12.
16.00	10.6	12.8	15.5	17.4	24.0	30.2	35.0	34.4	29.0	22.4	16.3	11.
17.00	9.40	11.9	14.4	15.8	23.4	30.0	34.4	33.9	28.3	21.3	15.2	10.
18.00	8.0	11.0	13.8	14.3	23.0	29.8	33.4	33.2	27.75	20.3	14.0	9.
19.00	7.35	9.8	12.6	13.9	21.6	28.15	30.8	31.75	26.4	19.2	13.6	8.
20.00	6.15	8.55	11.3	13.5	20.0	26.4	29.1	29.8	24.95	18.0	13.0	6.
21.00	5.20	7.20	10.0	13.0	18.45	24.85	27.6	28.0	23.8	16.85	12.5	6.
22.00	5.0	7.0	9.2	12.0	16.75	22.4	25.95	26.10	22.2	15.9	11.0	5.
23.00	4.7	6.75	8.2	11.0	15.30	21.85	24.1	24.7	20.4	14.9	9.3	5.

Table 2.1b Predicted mean hourly temperature/Constantine.

Source: Meteorological Station - Ain-El-Bey - Constantine.

months / years	J	F	M	A	M	J	J	A	S	O	N	D
1970	141	208	179	225	298	355	376	328	263	196	237	140
1971	149	157	157	212	287	358	357	338	241	207	174	154
1972	106	145	176	185	285	262	348	296	196	171	207	129
1973	96	110	125	211	304	255	340	304	258	195	179	148
1974	161	152	201	151	283	310	359	349	260	164	160	101
1975	167	170	172	198	253	340	377	332	269	257	157	130
1976	150	115	176	209	252	300	310	317	106	146	136	149
1977	155	175	269	229	280	335	301	285	266	243	166	176
1978	157	152	214	212	253	335	383	323	273	181	182	195
1979	131	110	205	181	255	251	360	296	205	180	156	187
1980	167	173	197	191	214	361	368	339	255	242	166	127
1981	133	137	193	230	301	338	360	312	252	242	226	161
Mean monthly	155,7	164	205,8	22,3	296,8	345,5	385,3	347,2	258,5	220,4	195,1	163,4
Mean daily	5,0	5,9	6,6	7,4	9,6	11,5	12,4	11,2	8,6	7,1	6,5	5,3
Mean annual	8,10 hours											
Total	2959 hours											

Table 2.2 The duration of bright sunshine.

Source: Meteorological Station-Ain-El-Bey-Constantine.

******************** Energie (en Wh/m2) =================== ASA/m.c.*epau
* 06 - CONSTANTINE * incidente sur le PLAN HORIZONTAL -- (jen) -------------
******************** par tranche horaire =================== 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	19	80	142	187	211	211	187	142	80	19	0	1278
-	Glo G	0	42	154	259	336	376	376	336	259	154	42	0	2334
-	G /vitr	0	20	98	190	263	301	301	263	190	98	20	0	1744
-	Glo G *	0	60	236	404	527	591	591	527	404	236	60	0	3636
FEVR	Dir S	2	43	107	165	207	229	229	207	165	107	43	2	1506
-	Glo G	7	96	219	324	400	440	440	400	324	219	96	7	2972
-	G /vitr	3	57	157	255	327	364	364	327	255	157	57	3	2326
-	Glo G *	10	151	357	536	665	732	732	665	536	357	151	10	4902
MARS	Dir S	27	122	227	317	382	416	416	382	317	227	122	27	2982
-	Glo G	50	200	357	491	587	638	638	587	491	357	200	50	4646
-	G /vitr	24	132	277	405	495	542	542	495	405	277	132	24	3750
-	Glo G *	66	274	491	674	806	875	875	806	674	491	274	66	6372
AVRI	Dir S	68	171	272	356	417	449	449	417	356	272	171	68	3476
-	Glo G	123	281	433	561	653	702	702	653	561	433	281	123	5530
-	G /vitr	73	209	353	473	557	601	601	557	473	353	209	73	4542
-	Glo G *	169	393	607	786	915	982	982	915	786	607	393	169	7734
MAI	Dir S	127	250	368	466	536	573	573	536	466	368	250	127	4694
-	Glo G	197	367	528	664	762	814	814	762	664	528	367	197	6762
-	G /vitr	130	287	440	566	655	701	701	655	566	440	287	130	5604
-	Glo G *	251	468	671	840	963	1027	1027	963	840	671	468	251	8562
JUIN	Dir S	149	273	390	488	558	594	594	558	488	390	273	149	4992
-	Glo G	226	393	551	684	781	832	832	781	684	551	393	226	7086
-	G /vitr	155	312	462	585	672	717	717	672	585	462	312	155	5884
-	Glo G *	284	493	688	851	968	1030	1030	968	851	688	493	284	8818
JUIL	Dir S	160	304	443	559	642	685	685	642	559	443	304	160	5666
-	Glo G	225	408	582	729	837	894	894	837	729	582	408	225	7480
-	G /vitr	150	322	488	625	722	772	772	722	625	488	322	150	6220
-	Glo G *	262	470	666	829	948	1010	1010	948	829	666	470	262	8524
AOUT	Dir S	111	252	392	510	595	639	639	595	510	392	252	111	5024
-	Glo G	163	346	523	674	784	842	842	784	674	523	346	163	6712
-	G /vitr	99	263	433	575	675	726	726	675	575	433	263	99	5562
-	Glo G *	193	406	609	779	903	967	967	903	779	609	406	193	7772
SEPT	Dir S	47	166	295	405	484	526	526	484	405	295	166	47	3948
-	Glo G	79	245	415	561	667	723	723	667	561	415	245	79	5384
-	G /vitr	41	171	331	470	568	619	619	568	470	331	171	41	4402
-	Glo G *	97	303	511	687	815	881	881	815	687	511	303	97	6592
OCTO	Dir S	8	78	178	267	332	366	366	332	267	178	78	8	2458
-	Glo G	18	135	282	410	503	552	552	503	410	282	135	18	3800
-	G /vitr	8	81	208	330	418	464	464	418	330	208	81	8	3018
-	Glo G *	23	181	383	558	685	751	751	685	558	383	181	23	5162
NOVE	Dir S	0	25	90	154	201	226	226	201	154	90	25	0	1392
-	Glo G	1	56	171	277	354	395	395	354	277	171	56	1	2508
-	G /vitr	0	29	114	209	282	321	321	282	209	114	29	0	1910
-	Glo G *	1	80	261	429	551	615	615	551	429	261	80	1	3874
DECE	Dir S	0	12	64	120	163	185	185	163	120	64	12	0	1088
-	Glo G	0	29	129	227	299	337	337	299	227	129	29	0	2012
-	G /vitr	0	14	79	163	231	267	267	231	163	79	14	0	1508
-	Glo G *	0	41	200	362	481	543	543	481	362	200	41	0	3254
A06-1::asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE / 12 heures (Midi TSV)						JOURNEE Wh/m2

Table 2.3 Solar irradiation on Horizontal surface.

Source: Atlas Solaire de l'Algerie, Constantine.

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********************     Energie (en Wh/m2)      ====================          ASA/m.c.*epau
* 06 - CONSTANTINE *     incidente sur le PLAN   VERTICAL  SUD          (jem)  -------------
********************     par tranche horaire     ====================          p:(+000,+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	94	200	266	309	330	330	309	266	200	94	0	2398
-	Glo G	0	143	303	411	485	524	524	485	411	303	143	0	3732
-	G /vitr	0	114	251	347	412	446	446	412	347	251	114	0	3140
-	Glo G *	0	287	589	779	904	967	967	904	779	589	287	0	7052
FEVR	Dir S	18	95	161	211	246	263	263	246	211	161	95	18	1988
-	Glo G	30	162	279	374	441	476	476	441	374	279	162	30	3524
-	G /vitr	19	119	223	308	369	400	400	369	308	223	119	19	2876
-	Glo G *	69	338	561	732	852	913	913	852	732	561	338	69	6930
MARS	Dir S	29	107	187	254	303	328	328	303	254	187	107	29	2416
-	Glo G	52	183	314	426	508	551	551	508	426	314	183	52	4068
-	G /vitr	24	115	230	335	412	452	452	412	335	230	115	24	3136
-	Glo G *	80	274	461	619	732	791	791	732	619	461	274	80	5914
AVRI	Dir S	1	38	103	160	202	225	225	202	160	103	38	1	1458
-	Glo G	36	118	230	328	402	441	441	402	328	230	118	36	3118
-	G /vitr	27	69	145	231	300	337	337	300	231	145	69	27	2224
-	Glo G *	40	151	314	457	562	618	618	562	457	314	151	40	4292
MAI	Dir S	0	2	46	108	154	179	179	154	108	46	2	0	978
-	Glo G	48	83	163	263	337	377	377	337	263	163	83	48	2558
-	G /vitr	38	64	99	161	222	257	257	222	161	99	64	38	1704
-	Glo G *	52	84	185	314	411	462	462	411	314	185	84	52	3046
JUIN	Dir S	0	0	13	69	113	137	137	113	69	13	0	0	664
-	Glo G	53	83	125	214	285	324	324	285	214	125	83	53	2210
-	G /vitr	42	66	88	128	176	206	206	176	128	88	66	42	1446
-	Glo G *	57	85	132	245	336	384	384	336	245	132	85	57	2526
JUIL	Dir S	0	0	30	99	152	180	180	152	99	30	0	0	922
-	Glo G	49	79	140	243	324	367	367	324	243	140	79	49	2436
-	G /vitr	39	62	89	142	201	237	237	201	142	89	62	39	1564
-	Glo G *	55	83	150	269	360	409	409	360	269	150	83	55	2690
AOUT	Dir S	0	19	98	174	231	260	260	231	174	98	19	0	1564
-	Glo G	38	93	213	326	412	458	458	412	326	213	93	38	3092
-	G /vitr	30	59	122	211	288	332	332	288	211	122	59	30	2094
-	Glo G *	44	103	244	375	473	526	526	473	375	244	103	44	3544
SEPT	Dir S	15	88	177	255	311	341	341	311	255	177	88	15	2374
-	Glo G	38	161	295	413	501	548	548	501	413	295	161	38	3914
-	G /vitr	20	91	200	310	394	439	439	394	310	200	91	20	2908
-	Glo G *	50	205	372	518	625	681	681	625	518	372	205	50	4904
OCTO	Dir S	24	119	210	284	335	362	362	335	284	210	119	24	2668
-	Glo G	38	185	325	440	523	567	567	523	440	325	185	38	4156
-	G /vitr	22	129	252	358	434	474	474	434	358	252	129	22	3338
-	Glo G *	61	286	486	648	763	823	823	763	648	486	286	61	6134
NOVE	Dir S	6	96	189	254	297	319	319	297	254	189	96	6	2322
-	Glo G	10	150	292	398	471	510	510	471	398	292	150	10	3662
-	G /vitr	7	117	239	334	399	433	433	399	334	239	117	7	3058
-	Glo G *	22	293	547	729	852	914	914	852	729	547	293	22	6714
DECE	Dir S	0	76	183	250	292	313	313	292	250	183	76	0	2228
-	Glo G	0	121	279	386	458	495	495	458	386	279	121	0	3478
-	G /vitr	0	97	233	327	390	422	422	390	327	233	97	0	2938
-	Glo G *	0	254	565	762	889	953	953	889	762	565	254	0	6846
A06+0::asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE	/	12 heures	(Midi	TSV)		JOURNEE Wh/m2

Table 2.4 **Solar irradiation on South vertical surface.**

Source: **Atlas Solairede l'Algerie, Constantine.**

********************	Energie (en Wh/m2)	====================		ASA/m.c Mepau
* 06 - CONSTANTINE *	incidente sur le PLAN	VERTICAL SUD-OUEST	(jem)	-------------
********************	par tranche horaire	====================		p:(+045,+000)

TRANCHES HOR.		6- 7	7- 8	8- 9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	TOTAL JOURNEE
JANV	Dir S	0	0	1	41	121	200	268	316	335	308	174	0	1764
-	Glo G	0	13	47	125	245	355	443	494	499	442	256	0	2919
-	G /vitr	0	10	36	76	170	280	369	420	428	381	222	0	2392
-	Glo G *	0	15	50	180	406	621	801	923	962	882	524	0	5364
FEVR	Dir S	0	0	0	15	82	155	218	265	289	280	217	52	1573
-	Glo G	2	31	66	112	221	328	414	467	477	438	330	83	2969
-	G /vitr	2	25	52	78	147	251	340	393	407	375	285	72	2427
-	Glo G *	2	34	64	131	353	581	774	911	970	929	730	200	5679
MARS	Dir S	0	0	0	2	72	183	281	356	400	401	346	179	2220
-	Glo G	14	52	85	114	218	368	492	575	606	577	477	250	3828
-	G /vitr	11	41	67	87	137	262	391	479	514	492	409	215	3105
-	Glo G *	16	53	81	109	265	498	697	841	913	897	768	416	5554
AVRI	Dir S	0	0	0	0	20	113	205	277	320	330	298	211	1823
-	Glo G	35	71	101	125	166	296	415	497	531	513	439	303	3572
-	G /vitr	27	56	80	98	117	194	310	399	440	431	370	253	2840
-	Glo G *	38	70	97	119	177	383	576	718	794	793	704	504	5109
MAI	Dir S	0	0	0	0	3	74	179	262	314	330	303	229	1793
-	Glo G	48	80	108	130	148	246	378	471	516	507	443	325	3556
-	G /vitr	38	63	85	102	114	154	259	358	413	413	362	260	2740
-	Glo G *	52	81	106	128	149	281	463	597	670	675	607	459	4492
JUIN	Dir S	0	0	0	0	0	47	149	231	284	300	276	212	1613
-	Glo G	53	83	109	130	145	211	339	431	477	471	413	307	3359
-	G /vitr	42	66	86	102	114	136	221	315	371	375	329	238	2532
-	Glo G *	57	85	110	131	147	234	404	532	603	609	548	419	4143
JUIL	Dir S	0	0	0	0	0	65	187	285	345	362	331	249	1949
-	Glo G	49	79	105	126	142	230	377	483	535	529	464	341	3649
-	G /vitr	39	62	83	99	111	143	249	358	421	426	374	267	2769
-	Glo G *	55	83	108	129	145	248	421	549	618	621	556	419	4194
AOUT	Dir S	0	0	0	0	11	122	245	343	402	413	369	261	2247
-	Glo G	38	70	98	120	149	291	441	546	596	582	501	349	3901
-	G /vitr	30	55	77	94	109	179	315	429	468	484	413	287	3061
-	Glo G *	44	75	101	123	155	325	506	637	705	701	618	443	4593
SEPT	Dir S	0	0	0	0	55	183	299	368	438	438	375	217	2408
-	Glo G	20	56	86	109	191	356	497	594	632	605	502	297	3971
-	G /vitr	16	44	67	86	120	241	385	489	533	515	428	252	3197
-	Glo G *	25	61	88	110	214	428	615	748	812	794	676	415	5024
OCTO	Dir S	0	0	0	11	101	209	303	373	408	393	306	84	2188
-	Glo G	5	36	68	106	234	377	494	570	591	548	419	124	3572
-	G /vitr	4	29	54	76	147	280	402	480	505	470	361	107	2915
-	Glo G *	6	41	71	114	306	524	709	837	891	849	669	204	5221
NOVE	Dir S	0	0	0	32	111	191	260	309	327	301	190	14	1735
-	Glo G	0	18	50	116	234	345	434	487	492	437	283	24	2920
-	G /vitr	0	14	39	72	159	270	360	413	421	376	245	21	2390
-	Glo G *	0	20	53	158	376	587	764	882	920	843	566	52	5221
DECE	Dir S	0	0	2	45	118	191	253	296	309	275	137	0	1626
-	Glo G	0	9	42	122	234	337	417	462	462	399	210	0	2694
-	G /vitr	0	7	31	73	164	267	348	394	396	344	182	0	2206
-	Glo G *	0	10	48	190	407	614	786	898	926	826	449	0	5154
A06+i::asa		17-18	16-17	15-16	14-15	13-14	12-13	VERTICAL	SUD-EST		<<<---	TR.HOR.		JOURNEE Wh/m2

Table 2.5 Solar irradiation on South-West and South-East vertical surface.

Source: Atlas Solaire de l'Algerie, Constantine.

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

Table 2.6 Solar irradiation on West and East vertical surface.

Source: Atlas Solairede l'Algerie, Constantine.

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********************     Energie (en Wh/m2)       ===================          ASA/m.c.*epau
* 06 - CONSTANTINE *     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	26	42	0	68
-	Glo G	0	13	46	72	90	98	98	90	72	79	72	0	730
-	G /vitr	0	10	36	57	71	78	78	71	57	46	42	0	546
-	Glo G *	0	15	48	70	85	93	93	85	70	118	138	0	815
FEVR	Dir S	0	0	0	0	0	0	0	0	5	52	83	27	167
-	Glo G	2	31	66	92	110	119	119	110	99	135	146	44	1073
-	G /vitr	2	25	52	73	87	94	94	87	74	83	102	34	807
-	Glo G *	2	34	64	86	102	110	110	102	101	226	299	106	1342
MARS	Dir S	0	0	0	0	0	0	0	0	42	137	195	138	512
-	Glo G	14	52	85	111	128	137	137	128	163	253	292	197	1697
-	G /vitr	11	41	67	87	101	108	108	101	104	168	225	162	1283
-	Glo G *	16	53	81	104	120	129	129	120	190	360	457	325	2084
AVRI	Dir S	0	0	0	0	0	0	0	10	94	184	244	234	834
-	Glo G	35	71	101	125	141	149	149	153	243	331	373	333	2313
-	G /vitr	27	56	80	98	111	118	118	113	155	245	303	283	1800
-	Glo G *	38	70	97	119	136	145	145	157	316	486	589	557	3042
MAI	Dir S	0	0	0	0	0	0	0	47	162	265	335	340	1344
-	Glo G	48	80	108	130	145	153	153	203	328	428	481	459	2999
-	G /vitr	38	63	85	102	114	121	121	132	220	332	400	392	2365
-	Glo G *	52	81	106	128	145	154	154	225	407	563	663	657	3750
JUIN	Dir S	0	0	0	0	0	0	2	71	187	287	356	365	1546
-	Glo G	53	83	109	130	145	153	155	233	358	456	509	491	3282
-	G /vitr	42	66	86	102	114	120	120	145	248	359	425	420	2598
-	Glo G *	57	85	110	131	147	156	159	265	441	589	682	682	4086
JUIL	Dir S	0	0	0	0	0	0	0	70	206	323	401	403	1677
-	Glo G	49	79	105	126	142	150	150	225	370	483	545	521	3334
-	G /vitr	39	62	83	99	111	118	118	140	250	378	455	446	2833
-	Glo G *	55	83	108	129	145	154	155	245	420	566	655	645	3863
AOUT	Dir S	0	0	0	0	0	0	0	28	155	274	348	330	1267
-	Glo G	38	70	98	120	136	144	144	169	304	419	476	433	2742
-	G /vitr	30	55	77	94	107	113	113	115	193	316	392	369	2139
-	Glo G *	44	75	101	123	139	148	148	180	348	499	586	551	3199
SEPT	Dir S	0	0	0	0	0	0	0	2	78	189	250	198	734
-	Glo G	20	56	86	109	125	134	134	128	202	309	354	274	1959
-	G /vitr	16	44	67	86	98	105	105	99	122	215	281	230	1491
-	Glo G *	25	61	88	110	127	135	135	130	235	392	472	383	2334
OCTO	Dir S	0	0	0	0	0	0	0	0	18	96	137	51	302
-	Glo G	5	36	68	93	110	118	118	110	114	186	208	77	1243
-	G /vitr	4	29	54	73	86	93	93	86	78	114	152	61	923
-	Glo G *	6	41	71	93	109	117	117	109	127	261	323	125	1499
NOVE	Dir S	0	0	0	0	0	0	0	0	1	35	55	6	97
-	Glo G	0	18	50	75	92	100	100	92	76	94	95	10	802
-	G /vitr	0	14	39	59	73	79	79	73	59	55	60	7	597
-	Glo G *	0	20	53	75	91	98	98	91	78	144	180	21	949
DECE	Dir S	0	0	0	0	0	0	0	0	0	17	29	0	46
-	Glo G	0	9	39	65	82	91	91	82	65	62	52	0	638
-	G /vitr	0	7	31	51	65	72	72	65	51	37	28	0	479
-	Glo G *	0	10	43	66	81	88	88	81	66	93	104	0	720
A0b+3::asa		17-18	16-17	15-16	14-15	13-14	12-13	VERTICAL	NORD-EST		(((--- TR.HOR.			JOURNEE Wh/m2

Table 2.7 Solar irradiation on North-West and North-East vertical surface.

Source: Atlas Solairede l'Algerie, Constantine.

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********************     Energie (en Wh/m2)         ===================        ASA/m.c xepau
* 06 - CONSTANTINE *     incidente sur le PLAN      SUD / INCLIN.=LATIT.  (jem)  -------------
********************     par tranche horaire        ===================        p:(+000,+054)
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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	71	183	272	334	366	366	334	272	183	71	0	2452
-	Glo G	0	113	287	426	525	577	577	525	426	287	113	0	3856
-	G /vitr	0	82	233	359	448	493	493	448	359	233	82	0	3230
-	Glo G *	0	215	526	765	933	1019	1019	933	765	526	215	0	6916
FEVR	Dir S	12	91	182	258	312	341	341	312	258	182	91	12	2392
-	Glo G	22	162	318	449	543	593	593	543	449	318	162	22	4174
-	G /vitr	12	118	259	378	462	505	505	462	378	259	118	12	3468
-	Glo G *	48	313	600	838	1007	1095	1095	1007	838	600	313	48	7802
MARS	Dir S	39	161	294	406	487	529	529	487	406	294	161	39	3832
-	Glo G	66	252	444	608	729	792	792	729	608	444	252	66	5782
-	G /vitr	35	183	364	516	623	678	678	623	516	364	183	35	4798
-	Glo G *	96	367	643	876	1044	1132	1132	1044	876	643	367	96	8316
AVRI	Dir S	45	160	280	382	456	495	495	456	382	280	160	45	3636
-	Glo G	95	272	449	602	715	775	775	715	602	449	272	95	5824
-	G /vitr	54	197	367	509	610	662	662	610	509	367	197	54	4804
-	Glo G *	126	385	644	866	1026	1111	1111	1026	866	644	385	126	8322
MAI	Dir S	56	188	323	439	523	567	567	523	439	323	188	56	4192
-	Glo G	115	299	485	646	765	828	828	765	646	485	299	115	6304
-	G /vitr	65	214	393	545	653	709	709	653	545	393	214	65	5180
-	Glo G *	135	376	617	823	973	1052	1052	973	823	617	376	135	7976
JUIN	Dir S	56	187	320	434	517	560	560	517	434	320	187	56	4148
-	Glo G	118	297	477	633	749	811	811	749	633	477	297	118	6214
-	G /vitr	67	210	385	533	639	694	694	639	533	385	210	67	5090
-	Glo G *	136	365	593	789	933	1009	1009	933	789	593	365	136	7690
JUIL	Dir S	64	216	373	509	607	659	659	607	509	373	216	64	4856
-	Glo G	118	315	515	690	819	889	889	819	690	515	315	118	6724
-	G /vitr	64	222	416	583	701	763	763	701	583	416	222	64	5522
-	Glo G *	133	361	589	787	932	1008	1008	932	787	589	361	133	7652
AOUT	Dir S	60	212	374	514	616	669	669	616	514	374	212	60	4890
-	Glo G	106	307	514	696	830	902	902	830	696	514	307	106	6724
-	G /vitr	57	220	420	591	712	775	775	712	591	420	220	57	5560
-	Glo G *	124	361	603	811	964	1044	1044	964	811	603	361	124	7828
SEPT	Dir S	46	186	342	477	575	626	626	575	477	342	186	46	4504
-	Glo G	78	273	479	659	791	861	861	791	659	479	273	78	6284
-	G /vitr	42	198	394	560	678	740	740	678	560	394	198	42	5226
-	Glo G *	100	348	605	826	986	1071	1071	986	826	605	348	100	7874
OCTO	Dir S	21	134	268	383	466	509	509	466	383	268	134	21	3562
-	Glo G	35	206	395	558	676	739	739	676	558	395	206	35	5218
-	G /vitr	19	149	324	473	579	633	633	579	473	324	149	19	4354
-	Glo G *	53	304	575	804	969	1055	1055	969	804	575	304	53	7520
NOVE	Dir S	4	77	184	274	338	371	371	338	274	184	77	4	2496
-	Glo G	7	127	293	432	531	583	583	531	432	293	127	7	3946
-	G /vitr	4	92	238	364	453	498	498	453	364	238	92	4	3298
-	Glo G *	14	233	519	754	919	1005	1005	919	754	519	233	14	6868
DECE	Dir S	0	55	160	245	304	335	335	304	245	160	55	0	2198
-	Glo G	0	91	255	388	483	532	532	483	388	255	91	0	3498
-	G /vitr	0	66	206	327	411	454	454	411	327	206	66	0	2928
-	Glo G *	0	181	484	723	889	974	974	889	723	484	181	0	6502
A06+5::asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE	/	12 heures	(Midi	TSV)		JOURNEE Wh/m2

Table 2.9 Solar irradiation on Tiled surface.

Source: Atlas Solairede l'Algerie, Constantine.

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

TRANCHES HOR.		6- 7	7- 8	8- 9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	TOTAL JOURNEE
JANV	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	0	13	46	72	90	98	98	90	72	46	13	0	638
-	G /vitr	0	10	36	57	71	78	78	71	57	36	10	0	504
-	Glo G *	0	15	48	70	85	93	93	85	70	48	15	0	622
FEVR	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	2	31	66	92	110	119	119	110	92	66	31	2	840
-	G /vitr	2	25	52	73	87	94	94	87	73	52	25	2	666
-	Glo G *	2	34	64	86	102	110	110	102	86	64	34	2	796
MARS	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	14	52	85	111	128	137	137	128	111	85	52	14	1054
-	G /vitr	11	41	67	87	101	108	108	101	87	67	41	11	830
-	Glo G *	16	53	81	104	120	129	129	120	104	81	53	16	1006
AVRI	Dir S	18	0	0	0	0	0	0	0	0	0	0	18	64
-	Glo G	58	71	101	125	141	149	149	141	125	101	71	58	1338
-	G /vitr	32	56	80	98	111	118	118	111	98	80	56	32	1012
-	Glo G *	78	70	97	119	136	145	145	136	119	97	70	78	1370
MAI	Dir S	78	25	0	0	0	0	0	0	0	0	25	78	342
-	Glo G	143	110	108	130	145	153	153	145	130	108	110	143	1786
-	G /vitr	81	69	85	102	114	121	121	114	102	85	69	81	1280
-	Glo G *	192	124	106	128	145	154	154	145	128	106	124	192	1998
JUIN	Dir S	108	56	5	0	0	0	0	0	0	5	56	108	570
-	Glo G	183	151	115	130	145	153	153	145	130	115	151	183	2102
-	G /vitr	112	86	87	102	114	120	120	114	102	87	86	112	1490
-	Glo G *	243	180	117	131	147	156	156	147	131	117	180	243	2444
JUIL	Dir S	109	49	2	0	0	0	0	0	0	2	49	109	534
-	Glo G	177	136	107	126	142	150	150	142	126	107	136	177	1990
-	G /vitr	103	77	83	99	111	118	118	111	99	83	77	103	1400
-	Glo G *	215	153	110	129	145	154	154	145	129	110	153	215	2220
AOUT	Dir S	49	4	0	0	0	0	0	0	0	0	4	49	180
-	Glo G	97	75	98	120	136	144	144	136	120	98	75	97	1452
-	G /vitr	49	56	77	94	107	113	113	107	94	77	56	49	1056
-	Glo G *	121	81	101	123	139	148	148	139	123	101	81	121	1578
SEPT	Dir S	1	0	0	0	0	0	0	0	0	0	0	1	4
-	Glo G	22	56	86	109	125	134	134	125	109	86	56	22	1068
-	G /vitr	16	44	67	86	98	105	105	98	86	67	44	16	834
-	Glo G *	27	61	88	110	127	135	135	127	110	88	61	27	1102
OCTO	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	5	36	68	93	110	118	118	110	93	68	36	5	860
-	G /vitr	4	29	54	73	86	93	93	86	73	54	29	4	678
-	Glo G *	6	41	71	93	109	117	117	109	93	71	41	6	874
NOVE	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	0	18	50	75	92	100	100	92	75	50	18	0	670
-	G /vitr	0	14	39	59	73	79	79	73	59	39	14	0	528
-	Glo G *	0	20	53	75	91	98	98	91	75	53	20	0	674
DECE	Dir S	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Glo G	0	9	39	65	82	91	91	82	65	39	9	0	572
-	G /vitr	0	7	31	51	65	72	72	65	51	31	7	0	452
-	Glo G *	0	10	43	66	81	88	88	81	66	43	10	0	576
A06+4.:asa		17-18	16-17	15-16	14-15	13-14	12-13	SYMETRIE / 12 heures (Midi TSV)						JOURNEE Wh/m2

Table 2.8 Solar irradiation on North vertical surface.

Source: Atlas Solairede l'Algerie, Constantine.

Nubulosite en Octas

hours / months	0.00	3.00	6.00	9.00	12.00	15.00	18.00	21.00	mean daily
January	4.1	3.9	4.5	4.8	5.05	5.01	4.6	4.3	1.6
February	3.86	3.9	4.5	4.9	5.15	5.01	4.7	4.13	1.5
March	3.9	3.6	4.6	5.05	5.4	5.6	5.06	4.2	1.6
April	3.9	3.8	4.5	4.75	4.9	5.1	5.03	4.3	1.5
May	3.4	3.3	4.3	4.4	5.1	5.15	4.6	3.8	1.4
June	2.35	2.0	2.7	2.5	3.15	3.5	3.4	2.8	1.0
July	0.9	1.2	1.4	1.45	1.4	2.23	1.9	1.35	0.5
August	1.7	1.46	1.9	1.7	2.0	2.5	2.45	2.2	0.7
September	2.0	1.7	2.7	2.7	3.1	3.7	3.4	2.7	0.9
October	3.4	3.1	3.5	4.0	4.7	4.6	3.5	3.6	1.3
November	3.4	3.3	4.16	4.5	4.8	4.8	4.3	3.4	1.4
December	4.3	4.3	4.5	4.8	5.0	5.0	4.9	4.6	1.6

Table 2.10 Cloud cover over the period 1980-1985.

Source: Meteorological Station - Ain-El-Bey - Constantine.

Relative humidity in % 1980 - 1985

element \ month	J	F	M	A	M	J	J	A	S	O	N	D
Mean monthly maximum	99.1	99.2	98.5	98.3	98.8	96.2	93.0	94.3	97.1	98.1	98.9	99.1
Mean monthly minimum	30.0	23.4	23.1	20.0	18.9	14.9	11.1	11.7	18.1	19.1	25.2	29.3
Mean monthly	76.9	75.2	73.4	72.3	68.8	60.5	47.1	51.2	62.1	69.8	72.7	76.0
	Rainfall on mm, 1970 -1985											
Mean monthly rainfall	68.2	63.1	71.0	69.6	50.5	15.9	5.7	9.9	40.5	41.2	43.6	54.5

Table 2.11 Relative Humidity and rainfall over the period 1970 - 1983.

Source: Meteorological Station - Ain-El- Bey - Constantine.

element \ month	J	F	M	A	M	J	J	A	S	O	N	D
Mean monthly wind speed	2.9	3.1	2.8	2.5	2.3	2.2	2.3	2.1	1.8	2.3	2.2	2.8

Table 2.12 Mean monthly wind speed 1970 - 1985.

Source: Meteorological Station - Ain-El-Bey - Constantine.

months	Atmospheric pressure mbars	Mean wind speed m/s	North %	North-East %	East %	South-East %	South %	South-West %	West %	North West %
January	1020.0	3.3	23.3	23.6	6.0	11.6	8.3	13.3	4.2	16.3
February	1017.6	2.4	11.3	24.3	8.3	10.6	10.7	14.0	4.8	16.3
March	1017.2	2.4	9.3	27.3	7.0	15.0	10.3	17.0	3.3	10.0
April	1015.1	2.1	11.3	30.9	6.0	12.0	9.3	15.0	5.3	9.6
May	1016.0	2.0	14.1	28.6	10.0	14.3	10.3	12.3	5.0	8.0
June	1015.8	1.5	12.6	12.6	10.3	13.6	11.3	13.17	5.6	7.0
July	1015.8	1.6	10.6	21.8	10.6	15.6	1.3	10.3	5.0	6.3
August	1014.8	2.3	10.3	27.6	10.3	16.6	11.0	11.6	4.3	-
September	1017.1	2.0	9.3	56.6	10.3	15.3	10.6	13.0	7.0	8.3
October	1017.9	1.6	14.6	22.3	7.6	18.3	8.3	12.6	6.0	11.5
November	1017.5	2.7	15.0	25.3	6.3	15.3	10.6	13.6	5.3	8.0
December	1017.3	3.3	18.3	20.6	8.0	10.6	10.6	15.3	6.3	10.0
Mean Annual	1016.9	2.2	12.75	28.3	8.3	14.3	10.3	13.3	5.2	10.1

Table 2.13 Mean Monthly of Atmospheric Pressure/Wind Speed and Direction.

Source: Seltzer, op. cit., p. 20, 1913-37.

Appendix 4

ANALYSIS OF THE EXISTING SCHOOL MODEL

Layer Number	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	1.400	1000	0.010
3 Hollow Concrete	2200	1.200	1000	0.140
4 Mortar	2130	1.400	1000	0.045
5 Asphalt	1700	0.580	1140	0.015

Number of layers = 5
No. Construction = 2
Construct Name - **Roof 1**

Surface Resistances
Internal <.12> : 0.100
External <.06> : 0.090

Properties
u-value : 2.566
Decrement factor : 0.370
Admittance value : 5.799
Surface Factor : 0.478

Time Lag Out/In 7.414

Layer Number	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	1.400	1000	0.010
3 Hollow Brick	864.62	1.200	1066.31	0.070
4 Air gap	1.2	1.400	1180	0.050
5 Hollow Brick	540,84	0.580	1108.95	0.150
6 Mortar	2130	1.400	1000	0.015

Number of layers = 6
No. Construction = 1
Construct Name - **Wall 1**

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

Properties
u-value : 0.882
Decrement factor : 0.480
Admittance value : 3.660
Surface Factor : 0.687

Time Lag :- 9.245

Layer Number	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plywood	555.55	0.140	1400	0.004
2 Air gap	1.2	0.150	1180	0.032
3 Plywood	555.55	0.140	1400	0.004
4 Air gap	1.2	0.280	1180	0.050
5 Plaster	700	0.280	840	0.005
6 Mortar	2130	1.400	1000	0.010
7 Hollow Brick	540.84	0.295	1108.95	0.150
8 Mortar	2130	1.400	1000	0.015

Number of layers = 8
No. Construction = 3
Construct Name - **Wall 2**

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

Properties
u-value : 0.854
Decrement factor : 0.533
Admittance value : 1.490
Surface Factor : 0.833

Time Lag :- 4.854

Table 4.1 Constructional material of roof and walls of the analysed model.

	January		June	
Time	T.o	T.e	T.o	T.e
1.00	4.1	8.4	16.9	26.8
2.00	3.6	7.9	16.1	26.6
3.00	3.3	7.4	15.4	26.5
4.00	2.8	6.9	15.3	25.8
5.00	2.6	6.3	15.1	25.0
6.00	**2.3**	5.8	**15.0**	24.2
7.00	3.2	5.7	17.8	23.2
8.00	4.1	5.5	22.2	22.7
9.00	5.3	5.5	24.0	21.0
10.00	6.4	5.2	25.6	20.3
11.00	8.0	5.0	27.4	20.0
12.00	10.0	4.8	28.8	19.6
13.00	10.5	4.7	29.4	19.5
14.00	11.1	4.5	30.4	19.5
15.00	**11.5**	**4.4**	**30.9**	**19.4**
16.00	10.6	4.7	30.4	20.4
17.00	9.4	5.1	30.0	22.4
18.00	8.4	5.7	29.8	23.5
19.00	7.3	6.2	28.1	24.3
20.00	6.2	6.9	26.4	25.1
21.00	5.2	7.9	24.9	25.9
22.00	5.0	8.2	22.4	26.2
23.00	4.7	8.5	21.9	26.7
24.00	4.6	**8.7**	17.6	**26.9**

Table 4.4 External equivalent temperature - compared to the external temperature (Wall 1).

Internal Insulation

Layer Number	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (m)
1 Cork	120	0.049	1800	0.020
2 Concrete	2400	1.500	1100	0.200

Number of layers = 2
No. Construction = 0
Construct Name - **Wall 1**
Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.055

Properties

u-value	:	1.390
Decrement factor	:	0.282
Admittance value	:	1.736
Surface Factor	:	0.785
Time Lag Out/In		5.975

External Insulation

Layer Number	Density kg/m³	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Concreat	2400	1.500	1100	0.200
2 Cork	120	0.049	1800	0.020

Number of layers = 2
No. Construction = 0
Construct Name - **Wall 2**
Surface Resistances
Internal <.12> : 0.123
External <.06> : 0.055

Properties

u-value	:	1.390
Decrement factor	:	0.196
Admittance value	:	6.011
Surface Factor	:	0.331
Time Lag Out/In		21.605

Table 4.5 The effect of insulation position to mass

	January				June			
	Wall 1		Wall 2		Wall 1		Wall 2	
Time	T.o	T.e	T.o	T.e	T.o	T.e	T.o	T.e
1.00	4.1	6.6	4.1	5.6	16.9	24.7	16.9	21.8
2.00	3.6	6.2	3.6	5.6	16.1	24.2	16.1	21.8
3.00	3.3	6.0	3.3	5.5	15.4	23.8	15.4	21.8
4.00	2.8	5.9	2.8	5.6	15.3	23.1	15.3	22.0
5.00	2.6	5.8	2.6	5.7	15.1	22.9	15.1	22.6
6.00	2.3	5.8	2.3	5.9	15.0	21.8	15.0	23.3
7.00	3.2	5.6	3.2	6.1	17.8	21.6	17.8	23.6
8.00	4.1	5.5	4.1	6.4	22.2	21.4	22.2	24.0
9.00	5.3	5.4	5.3	6.8	24.0	21.2	24.0	24.3
10.00	6.4	5.3	6.4	7.0	25.6	21.1	25.6	24.5
11.00	8.0	5.2	8.0	7.1	27.4	21.1	27.4	24.7
12.00	10.0	5.2	10.0	7.2	28.8	21.1	28.8	24.8
13.00	10.5	5.4	10.5	7.2	29.4	21.9	29.4	24.8
14.00	11.1	5.7	11.1	7.0	30.4	23.1	30.4	24.7
15.00	11.5	6.0	11.5	6.8	30.9	23.6	30.9	24.7
16.00	10.6	6.3	10.6	6.6	30.4	24.0	30.4	24.5
17.00	9.4	6.8	9.4	6.4	30.0	24.5	30.0	24.2
18.00	8.4	7.3	8.4	6.2	29.8	24.9	29.8	23.9
19.00	7.3	7.4	7.3	6.0	28.1	25.1	28.1	23.5
20.00	6.2	7.6	6.2	6.0	26.4	25.4	26.4	23.2
21.00	5.2	7.7	5.2	5.9	24.9	25.5	24.9	22.8
22.00	5.0	7.5	5.0	5.9	22.4	25.4	22.4	22.2
23.00	4.7	7.1	4.7	5.8	21.9	25.2	21.9	22.1
24.00	4.6	6.8	4.6	5.7	17.6	25.2	17.6	21.9

Wall 1 = internal insulation

Wall 2 = external insulation

Table 4.6 The influence of insulation to mass in affecting the temperature and heat flux.

Surfaces	Absorptivity/ Emissivity Solar Radiation	Absorptivity/ Emissivity Terrestrial Radiation
Black, non metallic surfaces, Red brick and tile, concrete and stone, rusty steel and	0.85 - 0.98	0.90 - 0.98
Iron, dark paints	0.65 - 0.80	0.85 - 0.95
Yellow and buff brick and stone	0.50 - 0.70	0.85 - 0.95
White or cream brick, tile, paint or paper, plaster whitewash	0.80 - 0.50	0.85 - 0.95
Fresh white wash	0.12 - 0.88	0.80 - 0.95
Window glass	Transparent	0.80 - 0.95
Bright aluminium paint, gilt or bronze paint	0.30 - 0.50	0.40 - 0.60
Dull brass, copper or aluminium, galvanised steel, polished iron,	0.40 - 0.65	0.20 - 0.30
Polished brass, copper	0.30 - 0.50	0.02 - 0.05
High polished aluminium, template, nickel chromium	0.10 - 0.40	0.02 - 0.04

Table 4.7 Absorptivity and emissivity for solar/ terrestrial radiation.

Source Dr. Younis Abdalla Muktar "An Investigation into the Thermal Performance of Roofs in Hot Dry Climates, 1976.

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	1.400	1000	0.010
3 Hollow Concrete	2200	1.200	1000	0.140
4 Mortar	2130	1.400	1000	0.045

Number of layers = 4
No. Construction = 0
Construct Name - Roof 1
Surface Resistances
Internal <.12> : 0.100
External <.06> : 0.090

Properties
u-value : 2.749
Decrement factor : 0.421
Admittance value : 5.791
Surface Factor : 0.481

Time Lag Out/In 6.392

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	1.400	1000	0.010
3 Hollow Concrete	2200	1.200	1000	0.140
4 Mortar	2130	1.400	1000	0.045

Number of layers = 4
No. Construction = 3
Construct Name - Roof 2
Surface Resistances
Internal <.12> : 0.100
External <.06> : 0.270

Properties
u-value : 1.839
Decrement factor : 0.285
Admittance value : 5.866
Surface Factor : 0.470

Time Lag Out/In 11.995

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	1.400	1000	0.010
3 Hollow Concrete	2200	1.200	1000	0.140
4 Mortar	2130	1.400	1000	0.045
5 Cork	120	0.049	1800	0.020

* As the resistance of the steel is considered negligible
.27 = .18 + 0.09

Number of layers = 5
No. Construction = 3
Construct Name - Roof 3
Surface Resistances
Internal <.12> : 0.100
External <.06> : 0.270*

Properties
u-value : 1.050
Decrement factor : 0.218
Admittance value : 5.886
Surface Factor : 0.466

Time Lag Out/In 24.851

Table 4.8 Constructional material of the investigated roofs

January

	Roof 1		Roof 2		Roof 3	
Time	T.o	T.e	T.o	T.e	T.o	T.e
1.00	4.1	6.9	4.1	7.5	4.1	5.0
2.00	3.6	6.4	3.6	7.6	3.6	5.8
3.00	3.3	6.0	3.3	7.7	3.3	5.7
4.00	2.8	5.8	2.8	7.5	2.8	5.6
5.00	2.6	5.6	2.6	7.1	2.6	5.5
6.00	2.3	5.6	2.3	6.9	2.3	5.4
7.00	3.2	5.4	3.2	6.6	3.2	5.4
8.00	4.1	5.2	4.1	6.2	4.1	5.6
9.00	5.3	5.0	5.3	6.0	5.3	5.8
10.00	6.4	4.9	6.4	5.9	6.4	6.1
11.00	8.0	4.8	8.0	5.8	8.0	6.3
12.00	10.0	4.6	10.0	5.8	10.0	6.7
13.00	10.5	4.8	10.5	5.6	10.5	7.1
14.00	11.1	5.2	11.1	5.5	11.1	7.2
15.00	11.5	5.6	11.5	5.4	11.5	7.3
16.00	10.6	6.1	10.6	5.3	10.6	7.4
17.00	9.4	6.7	9.4	5.2	9.4	7.2
18.00	8.4	7.5	8.4	5.1	8.4	6.9
19.00	7.3	8.0	7.3	5.4	7.3	6.7
20.00	6.2	8.2	6.2	5.6	6.2	6.5
21.00	5.2	8.4	5.2	6.0	5.2	6.2
22.00	5.0	8.2	5.0	6.3	5.0	6.0
23.00	4.7	7.8	4.7	6.8	4.7	6.0
24.00	4.6	7.3	4.6	7.3	4.6	5.9

Table 4.9a Equivalent external temperature compared to external temperature for the 6.4, 12 and 25 time lag.

June

	Roof 1		Roof 2		Roof 3	
Time	T.o	T.e	T.o	T.e	T.o	T.e
1.00	16.9	25.7	16.9	25.1	16.9	22.1
2.00	16.1	25.0	16.1	25.4	16.1	22.0
3.00	15.4	24.3	15.4	25.5	15.4	21.8
4.00	15.3	23.4	15.3	25.4	15.3	21.7
5.00	15.1	22.8	15.1	25.3	15.1	21.6
6.00	15.0	21.7	15.0	25.2	15.0	21.6
7.00	17.8	20.8	17.8	24.8	17.8	21.7
8.00	22.2	20.5	22.2	24.3	22.2	22.3
9.00	24.0	20.1	24.0	23.8	24.0	23.2
10.00	25.6	20.0	25.6	23.1	25.6	23.6
11.00	27.4	20.0	27.4	23.0	27.4	23.9
12.00	28.8	19.9	28.8	21.8	28.8	24.3
13.00	29.4	20.6	29.4	21.5	29.4	24.6
14.00	30.4	22.2	30.4	21.3	30.4	24.7
15.00	30.9	23.4	30.9	21.1	30.9	24.9
16.00	30.4	24.1	30.4	21.1	30.4	25.0
17.00	30.0	24.8	30.0	21.1	30.0	24.9
18.00	29.8	25.4	29.8	21.0	29.8	24.8
19.00	28.1	25.8	28.1	21.8	28.1	24.7
20.00	26.4	26.2	26.4	23.1	26.4	24.4
21.00	24.9	26.5	24.9	23.6	24.9	24.0
22.00	22.4	26.4	22.4	24.0	22.4	23.6
23.00	21.9	26.2	21.9	24.5	21.9	23.2
24.00	17.6	26.1	17.6	24.9	17.6	22.9

Table 4.9b Equivalent external temperature compared to external temperature for the 6.4, 12 and 25 time lag.

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	1.400	1000	0.010
3 Hollow Concrete	2200	1.200	1000	0.140
4 Mortar	2130	1.400	1000	0.045

Number of layers = 4
No. Construction = 5
Construct Name - Roof 4

Surface Resistances
Internal <.12> : 0.100
External <.06> : 0.430

Properties
u-value : 1.421
Decrement factor : 0.246
Admittance value : 5.881
Surface Factor : 0.468

Time Lag Out/In 16.976

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	1.400	1000	0.010
3 Hollow Concrete	2200	1.200	1000	0.140
4 Mortar	2130	1.400	1000	0.045

Number of layers = 4
No. Construction = 3
Construct Name - Roof 5

Surface Resistances
Internal <.12> : 0.100
External <.06> : 1.130

Properties
u-value : 0.712
Decrement factor : 0.200
Admittance value : 5.895
Surface Factor : 0.465

Time Lag Out/In 38.769

Table 4.10 Constructional material of the two last investigated roof.

	January				June			
Time	T.o	T.e	T.o	T.e	T.o	T.e	T.o	T.e
1.00	4.1	5.7	4.1	5.0	16.9	23.1	16.9	18.7
2.00	3.6	6.0	3.6	5.0	16.1	23.6	16.1	18.7
3.00	3.3	6.3	3.3	5.0	15.4	24.0	15.4	18.7
4.00	2.8	6.7	2.8	5.0	15.3	24.4	15.3	18.7
5.00	2.6	7.2	2.6	5.1	15.1	24.7	15.1	18.8
6.00	2.3	7.3	2.3	5.0	15.0	24.9	15.0	18.8
7.00	3.2	7.5	3.2	5.0	17.8	25.1	17.8	18.8
8.00	4.1	7.5	4.1	5.0	22.2	25.2	22.2	18.7
9.00	5.3	7.3	5.3	5.0	24.0	25.1	24.0	18.7
10.00	6.4	7.0	6.4	5.0	25.6	25.0	25.6	18.7
11.00	8.0	6.8	8.0	5.0	27.4	25.0	27.4	18.7
12.00	10.0	6.5	10.0	5.0	28.8	24.6	28.8	18.7
13.00	10.5	6.2	10.5	5.0	29.4	24.1	29.4	18.7
14.00	11.1	6.0	11.1	5.0	30.4	23.7	30.4	18.7
15.00	11.5	5.9	11.5	5.2	30.9	23.2	30.9	19.5
16.00	10.6	5.9	10.6	5.8	30.4	23.0	30.4	22.1
17.00	9.4	5.8	9.4	5.7	30.0	22.0	30.0	21.9
18.00	8.4	5.7	8.4	5.6	29.8	21.8	29.8	21.8
19.00	7.3	5.6	7.3	5.6	28.1	21.6	28.1	21.8
20.00	6.2	5.5	6.2	5.5	26.4	21.4	26.4	21.7
21.00	5.2	5.4	5.2	5.5	24.9	21.4	24.9	21.9
22.00	5.0	5.4	5.0	5.7	22.4	21.4	22.4	22.5
23.00	4.7	5.3	4.7	5.9	21.9	21.4	21.9	23.2
24.00	4.6	5.5	4.6	6.1	17.6	22.2	17.6	23.6

Table 4.11 External Equivalents temperatures compared to the external temperature for 17 and 39 time lag.

Appendix 5

PROPOSED SOLUTION - PASSIVE HEATING/COOLING MEASURES

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	0.140	1000	0.010
3 Hollow Brick	548.84	0.295	1108.95	0.150
4 Cork	120	0.049	1800	0.040
5 Air gap	1.2	0.280	1180	0.050
6 Glass	2600	0.720	900	0.003

Number of layers = 6
No. Construction = 1
Construct Name **No.3 south** w

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

Properties
u-value : 0.563
Decrement factor : 0.427
Admittance value : 3.020
Surface Factor : 0.716

Time Lag Out/In 13.129

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1 Plaster	700	0.280	840	0.005
2 Mortar	2130	0.140	1000	0.010
3 Hollow Brick	548.84	0.295	1108.95	0.150
4 Cork	120	0.049	1800	0.025
5 Air gap	1.2	0.280	1180	0.050
6 Hollow Brick	864.62	0.300	1066.31	0.070
7 Mortar	2130	1.400	1000	0.015

Number of layers = 7
No. Construction = 2
Construct Name **No.2 north** w

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

Properties
u-value : 0.585
Decrement factor : 0.361
Admittance value : 3.014
Surface Factor : 0.717

Time Lag Out/In 13.355

Table 5.1 Thermal properties of material of south and north wall.

	January				June			
	South wall		North wall		South wall		North wall	
Time	T.o	T.e	T.o	T.e	T.o	T.e	T.o	T.e
1.00	4.1	7.7	4.1	7.4	16.9	25.6	16.9	25.2
2.00	3.6	8.0	3.6	7.7	16.1	25.9	16.1	25.5
3.00	3.3	8.3	3.3	7.9	15.4	26.3	15.4	25.8
4.00	2.8	8.5	2.8	8.1	15.3	26.6	15.3	26.0
5.00	2.6	8.2	2.6	7.9	15.1	26.4	15.1	26.0
6.00	2.3	7.7	2.3	7.5	15.0	26.2	15.0	25.8
7.00	3.2	7.2	3.2	7.2	17.8	26.1	17.8	25.7
8.00	4.1	6.8	4.1	6.8	22.2	25.5	22.2	25.3
9.00	5.3	6.3	5.3	6.4	24.0	24.8	24.0	24.7
10.00	6.4	5.9	6.4	6.0	25.6	24.1	25.6	24.1
11.00	8.0	5.7	8.0	5.8	27.4	23.1	27.4	23.4
12.00	10.0	5.6	10.0	5.7	28.8	22.8	28.8	22.9
13.00	10.5	5.6	10.5	5.7	29.4	21.2	29.4	21.9
14.00	11.1	5.3	11.1	5.5	30.4	20.6	30.4	21.1
15.00	11.5	5.1	11.5	5.4	30.9	20.3	30.9	20.9
16.00	10.6	5.0	10.6	5.2	30.4	20.0	30.4	20.6
17.00	9.4	4.8	9.4	5.1	30.0	20.0	30.0	20.5
18.00	8.4	4.7	8.4	5.0	29.8	19.9	29.8	20.4
19.00	7.3	4.6	7.3	4.9	28.1	19.8	28.1	20.4
20.00	6.2	4.9	6.2	5.0	26.4	20.9	26.4	21.0
21.00	5.2	5.3	5.2	5.4	24.9	22.6	24.9	22.4
22.00	5.0	5.8	5.0	5.7	22.4	23.6	22.4	23.4
23.00	4.7	6.3	4.7	6.2	21.9	24.3	21.9	24.0
24.00	4.6	6.9	4.6	6.7	17.6	25.0	17.6	24.6

Table 5.2 Effect of time lag of South and North walls on the external temperature.