#2323

Document

D25:1985

Passive indoor-climate regulation for buildings in hot climate

Per-Olof Carlson
Per-Olof Nylund
Burtom L M Mwamila

Swedish Council for
Building Research

D25:1985

PASSIVE INDOOR-CLIMATE REGULATION FOR BUILDINGS IN HOT CLIMATE

Per-Olof Carlson
Per-Olof Nylund
Burton L M Mwamila

This report refers to research grant no. 821269-9 from the Swedish Council for Building Research to Arne Johnson Consulting Engineers, Stockholm.

D25:1985

ISBN 91-540-4491-X
Swedish Council for Building Research, Stockholm, Sweden

Spångbergs Tryckerier AB, Stockholm 1985

CONTENTS

PREFACE

At the initiative of ARNE JOHNSON Consulting Engineers a project has been formulated for the purpose of studying the possibility of improving indoor climate in hot countries without the use of fans and/or airconditioners. This climate regulation technique is here termed passive climate regulation.

In the present report the results of the first stage in a series of studies are presented and discussed. In this stage the principles involved are outlined and the computational techniques are demonstrated for relatively simple cases. These are then supported by experiences from practical applications to one of a number of similar construction projects carried out in Saudi Arabia by Saudi Chemical Company (Nitro Nobel). The experiences have been communicated by Anders Eklund of the same and the project manager Göran Landberg.

The project has been carried out jointly by two leading Swedish consulting engineering companies, ARNE JOHNSON Consulting Engineers and TYRÉNS. The computer work has been performed by Arne Sahlström and Sune Häggbom of the two companies respectively. The project has also been supervised by a consultative group. We would like to express our gratitude to all who have contributed to the accomplishment of the project so far.

This report is a revised English version of the original Swedish report by Per-Olof Carlson et al, of ARNE JOHNSON Consulting Engineers and TYRÉNS .

Stockholm, August 1985

Per-Olof Carlson	Per-Olof Nylund	Burton Mwamila *
ARNE JOHNSON Consulting Engineers	TYRÉNS	ARNE JOHNSON Consulting Engineers

* On leave from the Department of Civil Engineering, University of D'Salaam, Tanzania, up to Sept. 1985.

1 INTRODUCTION

1.1 Objectives

Swedish building export plays an important role in Swedens external trade. Building projects often occur in connection with turn-key deliveries. The governing philosophly in this case should, therefore, be to conceive modern buildings in a traditional environment incorporating local experiences and resources. The approach is particularly important in countries with hot climate and no industrial resources. Resource and climate adaptation of building techniques to local conditions can improve the competitive power of the Swedish contractor and reduce running and maintenance expenses to the owner.

After consultations with Swedish industrial companies and contractors within the framework of projects in countries with hot climate, ARNE JOHNSON Consulting Engineers and TYRÉNS have come to the conclusion that where the attainment of desired indoor climate is concerned simple building techniques should be preferred to complicated mechanical installations. The investment costs inherent in the adoption of such techniques are lower and installation and maintenance simple. Local and traditional building techniques provide the starting ground for the development of such systems for passive climate regulation.

In order to promote possibilities for export of buildings incorporating passive climate regulation techniques, it is necessary that clear instructions, with examples on how the techniques function, are worked out. Thus this project was initiated with the aim of achieving that goal. In this introductory stage the work is limited to the conception of the principles governing passive climate regulation, demonstration of computational techniques based on simplified assumptions on climate and local building traditions, and the provision of practical examples of the possibilities of passive regulation.

Computations have been made for a building type that can be considered to be common in many countries with hot climate.

The building type is of general form and is not tied to any kind of utility. It is in principle applicable for housing, schools, halls for industries, storages and the like. The climate data used describes a typical summer day in Baghdad, which is taken to be representative for the hot-dry climate.

Results of the computations show that passive climate regulation is a technique which yields comfortable indoor climate using simple solutions and at low cost. Compared to the traditional building, a single storey building adapted for natural ventilation enhanced by the provision of chimney and limited air movement in the attic, figure 3.3 D, the following improvements of climate in the occupied area are achieved:

- temperature variation during the day is reduced by about 9°C (from 11°C to 2°C)
- the maximum temperature decreases by about 9°C (from 46°C to 37°C)
- air movement is significantly improved.

In Saudi-Arabia Saudi Chemical Company have constructed magazines and related facilities for the storage of explosives. The ventilation of these magazines is by passive climate regulation. From measurements performed over a period of several months it has been verified that the objective of keeping the indoor temperature below 32 °C has been fulfilled though the outdoor day temperature has exceeded 40 °C.

1.2 Passive climate regulation

Climate regulation using natural phenomena is not a new venture. A characteristic example is natural ventilation, which is still in use in many of the old Swedish buildings. This technique has not, however, been developed further because of the evolution of modern installation technology which then overtook it and won over the market. Since then, the building's own climate regulation potentials have been neglected and people have become more reliant on mechanical solutions for climate regulation. That tendency is, to a great extent, also true for countries with hot climate. Unfortunately, machine oriented techniques have serious problems, a short-list of which is as follows:

- mechanical installations tend to be increasingly complicated
- users possibilities to run and maintain the installations are very limited
- the service-life of mechanical installations is short
- the quality of the indoor climate achieved varies greatly
- investment, running and maintenance costs are high
- mechanical installations depend on supply of electricity

These problems are a result of too rapid a development from the old building traditions using simple techniques to the present advanced and complicated installation techniques.

Old building traditions allowed buildings to provide improved indoor climate. Consequently, the resulting experience led to certain building forms and massiveness. The intention was not only to provide a protective climate cover but also to yield a comfortable indoor climate. What was eventually accomplished was climate regulation using natural phenomena, passive climate regulation.

Passive climate regulation is based on physical and empirical laws of nature for air exchange and heat transfer. It utilises ventilation as well as heat transfer mechanisms in buildings. The computation technique for a well conceived passive regulation system is complicated. It is also not wholly possible to revive the old experiences and knowledge which have long been forgotten.

Recent developments in building techniques have led to increased possibilities for revival of passive climate regulation. Also the present development in computer technology has enabled the solutions of problems which earlier could only be dealt with using common sense, practical experience and intuition.

Because of the drastic increases in energy prices in the seventies, and other problems inherent in machine-dependent climate regulation, interest in passive climate regulation has increased in recent years. Experiences from different applications in Sweden have shown that passive climate regulation utilising new technical innovations is an attractive alternative for the Swedish climate as well. Experience from foreign projects suggests that passive climate regulation is even more interesting in countries with hot climate, because:

- temperature differences between days and nights are often great
- running and maintenance of machine-oriented systems is a big problem in developing countries
- the need and use of short-term (about half a day) heat storage is greater in hot countries than in this country. Short-term storage can be advantageously exploited by use of simple building techniques employing local materials and well adapted traditions
- for reasons of safety, costs and availability electrial supply is often not possible

1.3 Project realisation

The project is intended to be done in stages. In this first stage the intention has been to outline the principles underlying passive climate regulation, demonstrate the computation techniques and illustrate practical possibilities for passive climate regulation. In subsequent stages it is intended to develop a more complete reference material for general use in real projects, apply it to a practical case, follow-up and evaluate some reference projects.

2 BASIC CONSIDERATIONS

2.1 Some possible configurations.

Passive climate regulation implies the control of indoor climate using building technological measures. These measures fall into two main categories, namely, those which reduce the effect of the external heat load on the indoor climate and those which modify the ventilation system.

Measures that reduce the heat load effect have something to do with the materials used, the configuration and orientation of the building, and include screening devices (e.g. large overhang), absorbent surface materials, insulation and heat storage. It is a matter of choice regarding the type of building design and that of building materials and their properties. There is a lot to learn from local traditions because a number of problems can be avoided through adoption of a humble attitude to traditions. In a given project the following are some of the important questions to be asked:

- how does one design and build houses?
- what materials does one use?
- why that way and those materials?

Local building traditions are a result of long periods of development which have often led to good solutions. Through experience a certain amount of knowledge, which can not be understood or dealt with mathematically, has been acquired. Because of our ignorance of the knowledge thus acquired there is a risk that we disregard factors that are of great importance.

As mentioned earlier it is not within the context of this report to examine these questions more closely. For the computational example presented in the next chapter, use of easily available information has been made. We have especially made use of information obtained from a few SIDA-projects and the experiences of the project members. Only to a very limited extent we have surveyed the literature (see ref.list). Based on the information thus obtained, approximate data has been worked out for the example.

The other category of technical solutions refers to those dealing with the ventilation system. The air volume enclosed in a building is a heat carrier and, depending on how the ventilation system is designed, heat transfer can occur in different ways. In all cases heating up and cooling as well as ventilation can occur. A very simple ventilation principle is shown in figure 2.1A below. Ventilation principle A is one where during the day, heat transmission, direct solar radiation and the heat generated by activities in the building, is utilized advantageously to induce ventilation. During the night the day heat stored under the roof is utilised for the same purpose.

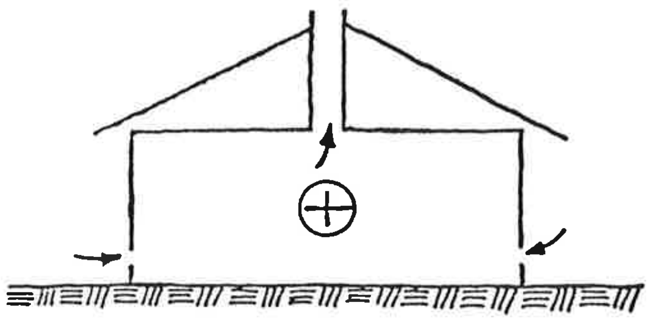


Figure 2.1A Ventilation principle A.

The greatest disadvantage of this ventilation principle is that air temperature in the occupied area and the air flow are interdepent. Air flow occurs only if the air temperature in the occupied area is different from the outside air temperature. The air flow increases with increasing temperature difference. The principle is thus insufficient when both air temperature and air flow have to be regulated. The principle can of course be reshaped so as to allow wind to contribute to air flow, but the system should function even when there is no wind. Consequently, one has to accept a certain increase in air temperature in the occupied area in order to ensure air flow. Thus, during the hot season it may be difficult to maintain room temperatures within the comfort zone.

Obviously, the problem is less serious if the room height is big because then temperature stratification in the room can lead to comfortable air temperature in the actual occupied area, up to two metres from the floor.

To avoid inconveniences inherent in ventilation principle A, it is necessary that the required thermal ventilation induction force is acquired independently of the air temperature in the occupied zone. In that case, the roof offers many possibilities. Examples of some of the possible ventilation principles are shown in figure 2.1 B

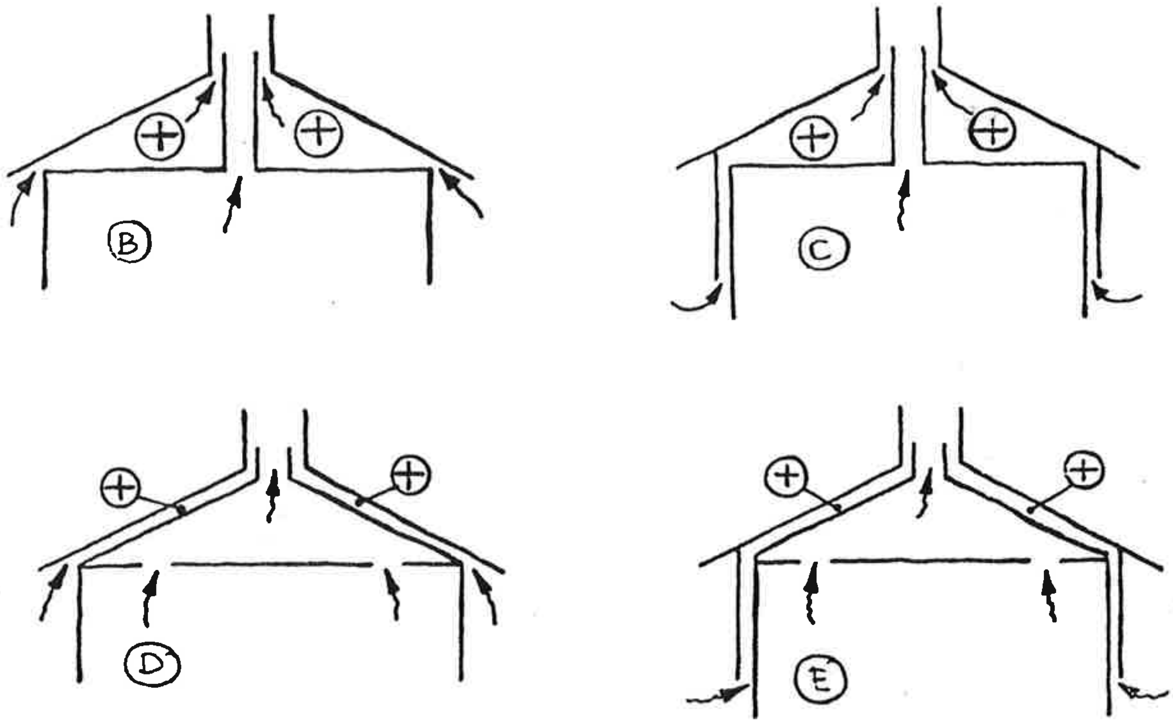


Figure 2.1B Ventilation principles B, C, D and E.

It need be mentioned here that the figure presents only a few of the numerous possibilities and which are not necessarily the best. The best possibilities will tend to vary with the particular case in question. In fact the configuration shown in fig. 2.1C might prove to perform better in certain cases.

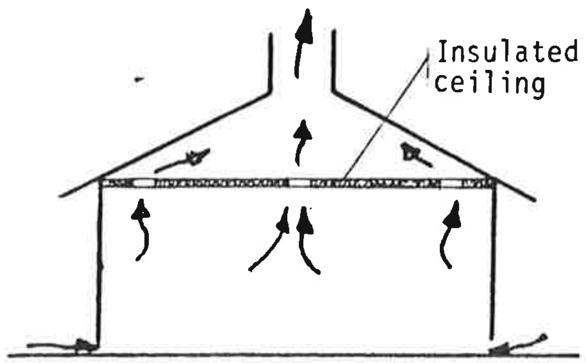


Figure 2.1C Another possible configuration
not studied further in this report.

The required ventilation induction force is created either in the attic or in the air column in the outer roof construction. In either case the air stream along the external wall can be exploited by providing eaves with suitably designed overhangs. As an alternative, the outer walls can be furnished with an air column which in turn offers many more possibilities.

The ventilation system's air outlet terminal device is situated at the ridge. Through the creation of lower pressure in the vicinity of the air outlet terminal device, an air current arises which then ventilates the occupied zone.

Principles B and C restrict the attic from being part of the occupied area whereas principles D and E include no such restrictions. On the other hand, principles B and C offer greater possibilities for regulation of air flow.

Further enhancement of the induction force can be derived if the incoming air temperature can also be regulated. Probably, one of the simplest solutions is one where underground air transmission canals are constructed in the surrounding area, viz as shown in figure 2.1 D.

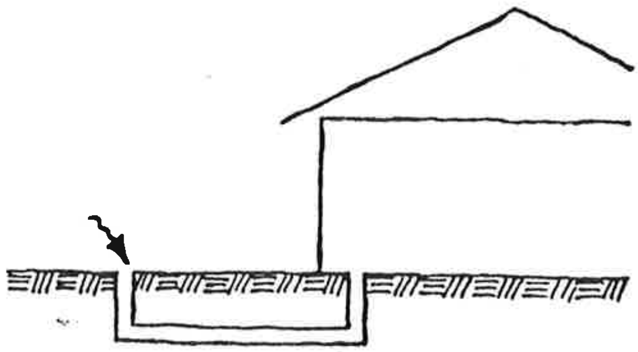


Figure 2.1D Underground air inlet canal.

The air transmission canals should be located at such depth that the temperature of the air in the canals can be brought down to the level of the annual average atmospheric in air temperature in the area. The result is that incoming air is warmed up during the cold part of the year, and cooled down during the hot part of the year.

After some discussions it was decided that ventilation principle B is very interesting, simple and does not demand high investment-costs. Even principle C is interesting in areas where facing walls are common. Principle B has therefore been adopted for the present study.

2.2 Assumptions and limitations

The quality of indoor climate in a building is generally a function of the following factors:

- outdoor climate
- activities in the building
- desired indoor climate
- quality of the building
- ventilation system.

Outdoor climate is known and can vary very much. For a building in a hot climate one can distinguish between two extreme types of climate conditions:

- hot and humid
- hot and dry

The hot-humid climate is characterised by high relative humidity (55-100 %) and heavy precipitation (in the order of 2000 mm per annum). In general the sky is cloudy and hazy. Annual temperature variations are small - only a few degrees. Even the diurnal ranges are small.

In the hot-dry climate, the sky is mostly clear. The direct solar radiation during the day, like re-radiation at night, is very high. Thus temperature differences between day and night are substantial, viz between 11 and 23 °C. Day temperatures can be as high as 38 °C in the shade and in exceptional cases even higher. Annual temperature variations are smaller, 11 - 17 °C. Air humidity is comparatively low the year round, viz relative humidity below 70%. The total amount of annual precipitation is less than 250 mm.

Between these extremes occur all conceivable variants (1). Of importance in this context is the fact that passive climate regulation utilises temperature differences during the day and solar and sky radiations as ventilation induction forces. Passive climate regulation in general is therefore more suited to the hotdry than the hot-humid climates.

In the present study the following limitations have been made:

- the investigations refer to hot-dry climate
- the effect of longwave re-radiation has not been considered because of lack of data.
- no consideration has been given to the energy generated by activities within the building.
- the configuration of a building in accordance with principle B (figure 2.1 B) is compared with both the traditional configuration, viz with no provision for ventilation, and with a configuration according to principle A (figure 2.1 A).

2.3 Computation models

As mentioned earlier building quality and ventilation system are the two factors that govern the passive climate regulation system. In the selected example (principle B), there exist two air spaces of great significance, the occupied area and the attic. The average temperature in the occupied area depends on the incoming air temperature. The average temperature in the chimney is a function of the heat exchange between the attic and the chimney. In order to achieve high heat exchange and therefore greater induction force, the temperature in the attic ought to be high and the air flow in the attic low.

Computations have been performed using two models, PASLEB developed by ARNE JOHNSON Consulting Engineers and VIP produced by TYRÉNS in cooperation with Lund Institute of Technology. In the next chapter, results of computations based on the latter model are presented and discussed.

3 WORKED EXAMPLE

3.1 Climate data

Computation for a passive climate regulation system demands climate data which clearly depict variations that occur during the day. Such very detailed data is sparse in the literature. In this project we have, through contacts with the Building Research Centre in Baghdad, succeeded in getting climate data on temperature and solar radiation. Unfortunately, it has not been possible to get data on re-radiation during the night. The effects of this have therefore not been considered.

For the worked example, we have selected Baghdad as a typical example of the hot-dry areas and adopted its climate data. Variations of air temperature during the day are shown in the diagram (5) in figure 3.1.A. Data for solar and sky radiation is derived from (6). In figure 3.1.B climate data for a typical summer-day is shown. As can be seen, the air temperature during the day varies from 25 °C to 40 °C, with about 15 °C difference. Solar radiation reaches a maximum intensity of almost 1100 W/m2.

3.2 Type of building

As a basis for the worked example, a simple building form of general validity and not bound to any type of use has been selected. It is in principle applicable for residential houses, schools, storage, handcraft and industrial buildings and the like. The actual configuration of the building is shown in figure 3.2 A. In short, it is characterised by the following features:

- roof consisting of un-insulated sheet metal on timber trusses, and un-insulated ceiling composed of timber panels or the equivalent
- outer walls consisting of 230 mm brick masony, concrete or the like, covered with about 20 mm plaster, the total thickness of the wall being about 250 mm

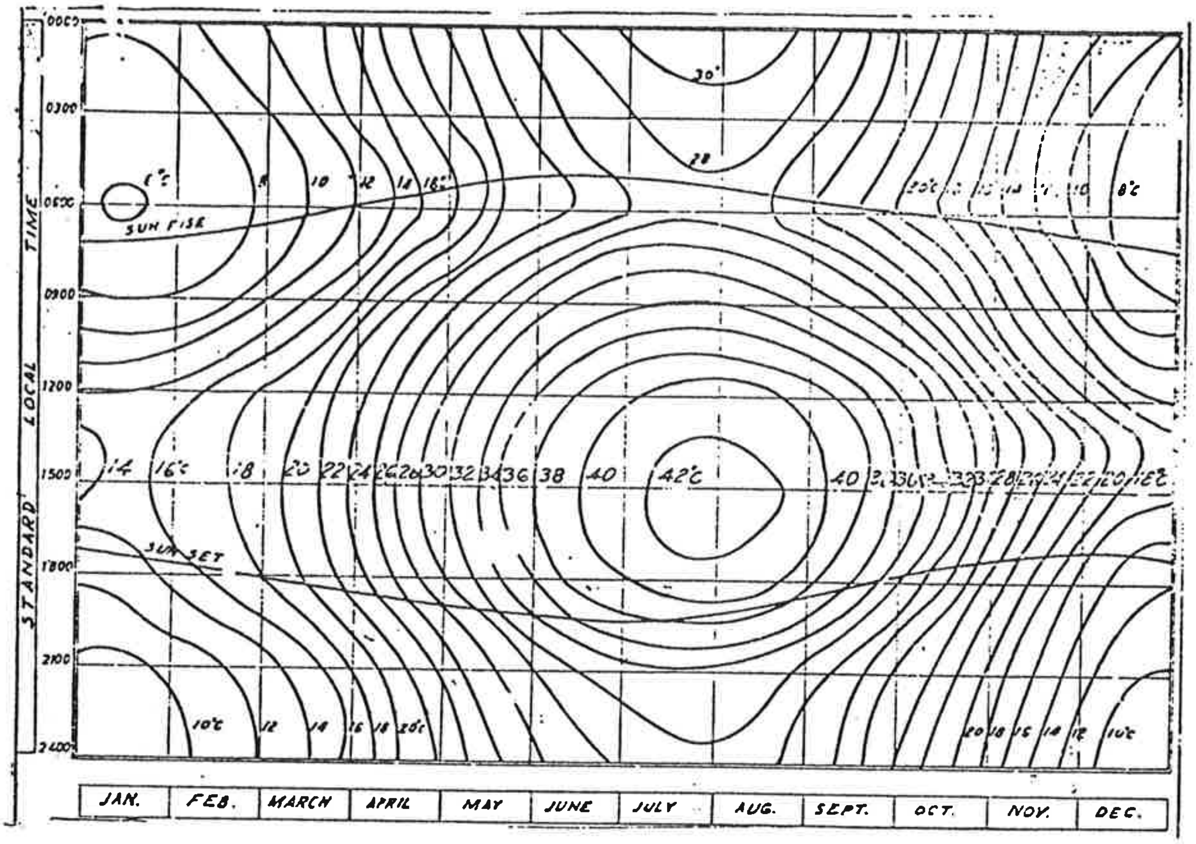


Figure 3.1A Air Temperature for Baghdad during the day over the whole year.

Time	Outdoor temp. (^oC)	Solar and sky radiation (W /m2)	Time	Outdoor temp. (^oC)	Solar and sky radiation (W /m^2)
00	29.50	0	13	40.00	1046
01	28.80	0	14	40.50	949
02	28.00	0	15	40.50	794
03	27.20	0	16	40.50	596
04	26.70	0	17	40.00	379
05	26.00	0	18	39.00	0
06	25.20	0	19	38.00	0
07	28:00	379	20	35.00	0
08	31.00	596	21	32.50	0
09	33.00	794	22	31.50	0
10	35.00	949	23	30.50	0
11	37.20	1046	24	29.50	0
12	39.00	1082			

Figure 3.1B Climate data.

- floor consisting of about 100 mm non-reinforced concrete on well compaected hardcore
- roof provided with a chimney of about 0.02 m2 in area

In the example, we have started with the traditional type of building and then modified it to suit the principles outlined earlier. Among the modifications are the provision of insulation to the ceiling and that of extra air inlet and outlet devices.

3.3 Computation results

Temperature and air-flow in the attic and the occupied area have, as earlier mentioned, been studied for the following configurations:

- the "traditional"
- ventilation principle A
- ventilation principle B

In figures 3.3 A-D the results of the computations are shown.

Figure 3.3 A shows how the temperature in the attic varies. A low air flow in the attic yields high temperature and therefore a great driving force for the passive temperature regulation. High air flow in the attic has the opposite effect.

Figure 3.3 B shows a building of "traditional form", viz no provision for ventilation. The attic has high temperature and relatively low air flow. The ceiling is un-insulated and the occupied area has no ventilation. The diagram reveals two important features regarding the room temperature. First, that the temperature becomes very high, viz reaching 46 °C and second, that it varies greatly during the day, the diurnal range being about 11 °C. No regulation of the ventilation in the occupied area is achieved. The "traditional" configuration is therefore very unfavourable.

Figure 3.3 C shows a building ventilated according to principle A, viz independent natural ventilation in the occupied area. The variation of room temperature during the day is much smaller, about 5 °C instead of 11 °C, with a substantially lower maximum

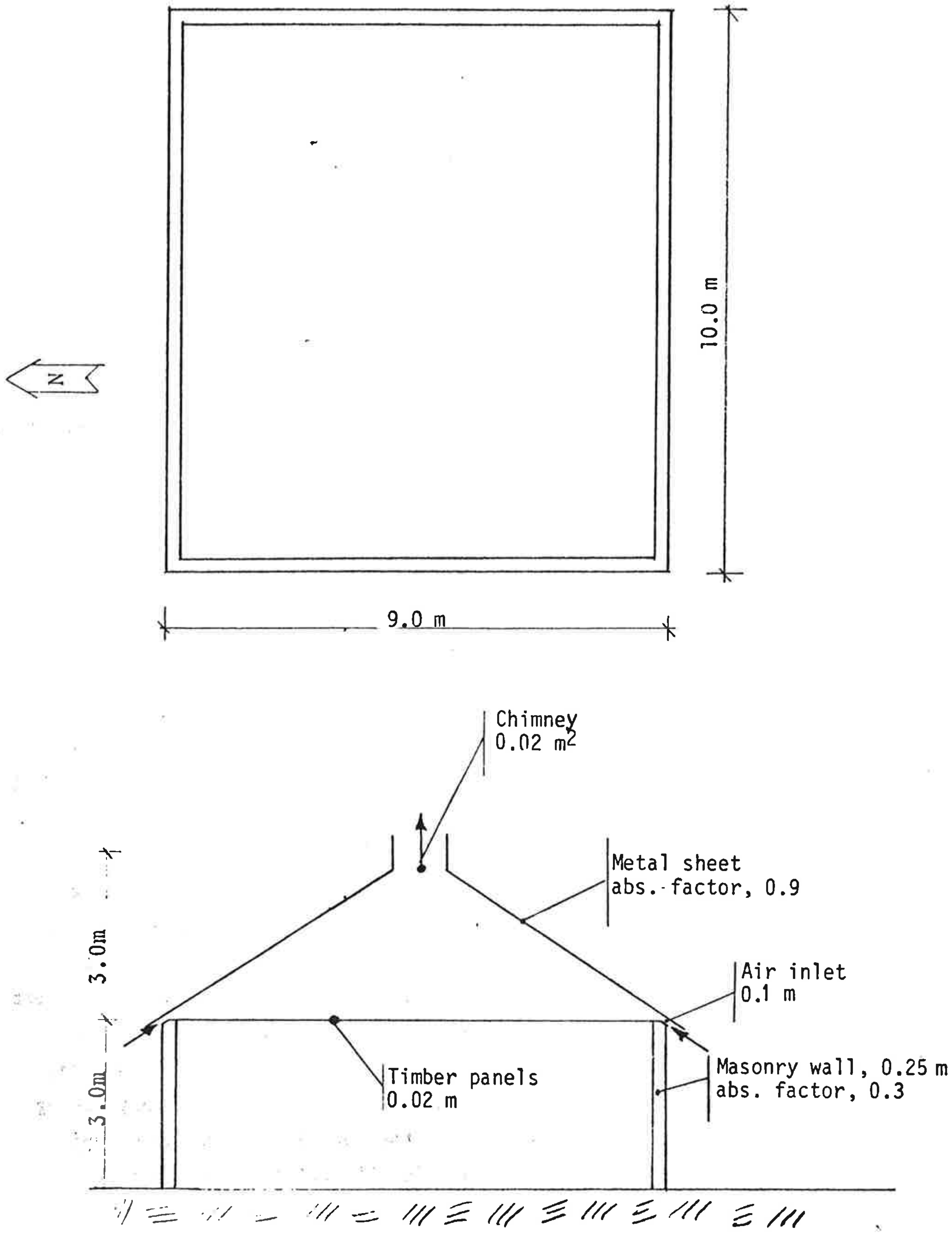


Figure 3.2A Plan and section with the relevant details.

value of about 38°C instead of 46°C. The indoor temperature is lower than the outdoor temperature during a significant part of the day, during which ventilation flow is thus reversed.

Figure 3.3 D shows a building in accordance with principle B, viz where natural ventilation is enhanced by the extra thermal effect that occurs when the air passes through the chimney in the hot attic. The extra thermal effect is also intensified by maintaining low air-flow in the attic. Further, the occupied area is separated from the hot attic by a 250 mm thick insulation on the ceiling. The diagram shows that the room temperature is very evenly distributed during the day,ie with a maximum value of about 37 °C. At the same time air flow is improved. However, even in this case air will flow backwards through the chimney, for a short period of the day. In order to prevent hot air from being sucked down into the occupied area, the chimney should be provided with a reverse valve.

In all the computations the absorption factor for the outer walls has been taken to be 0.3. This low value has been adopted in order to simulate partial shading by roof overhangs. Ground reflection has been taken to be 0.5. Further, the cooling effect of the concrete floor into the occupied area has been neglected.

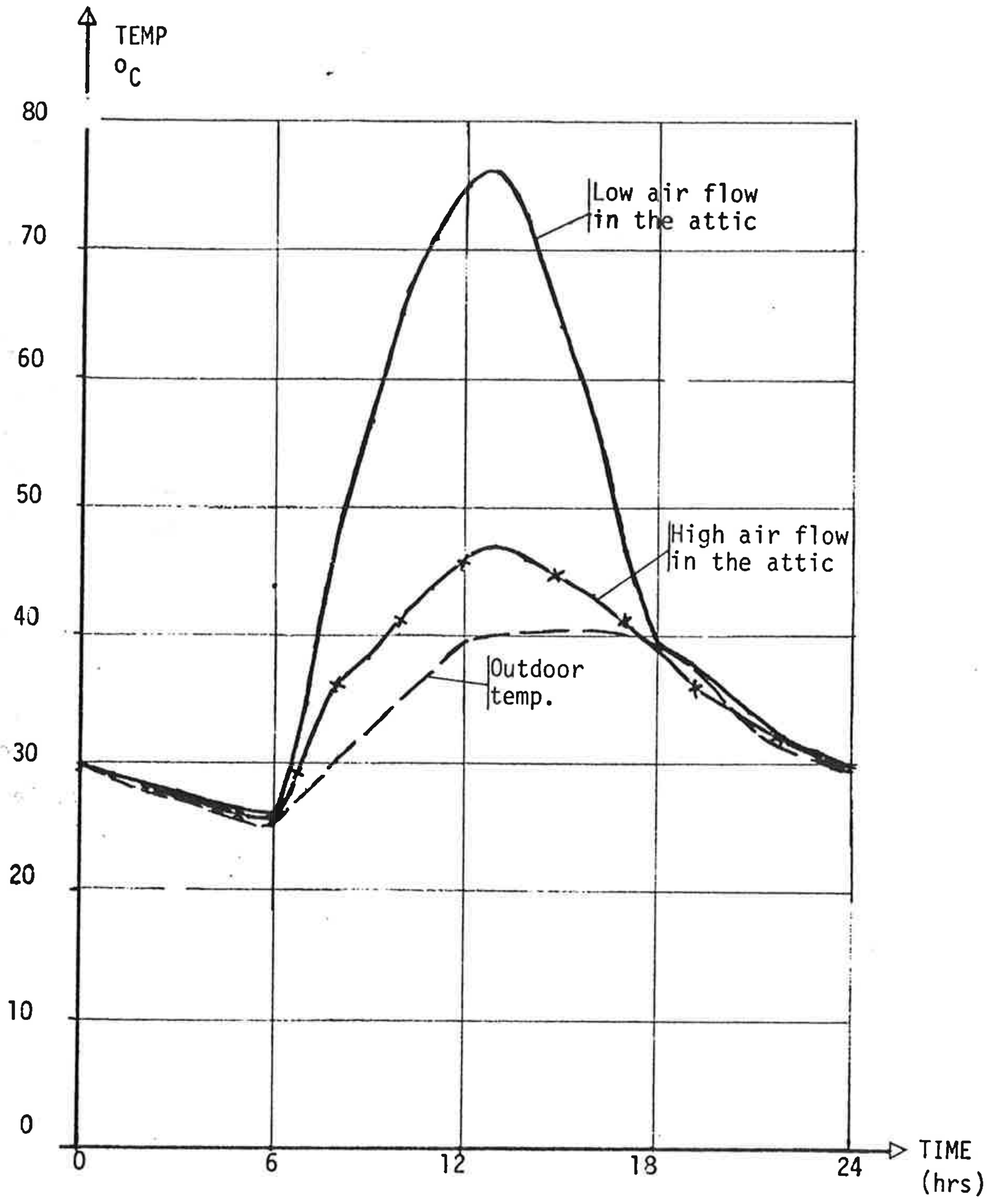
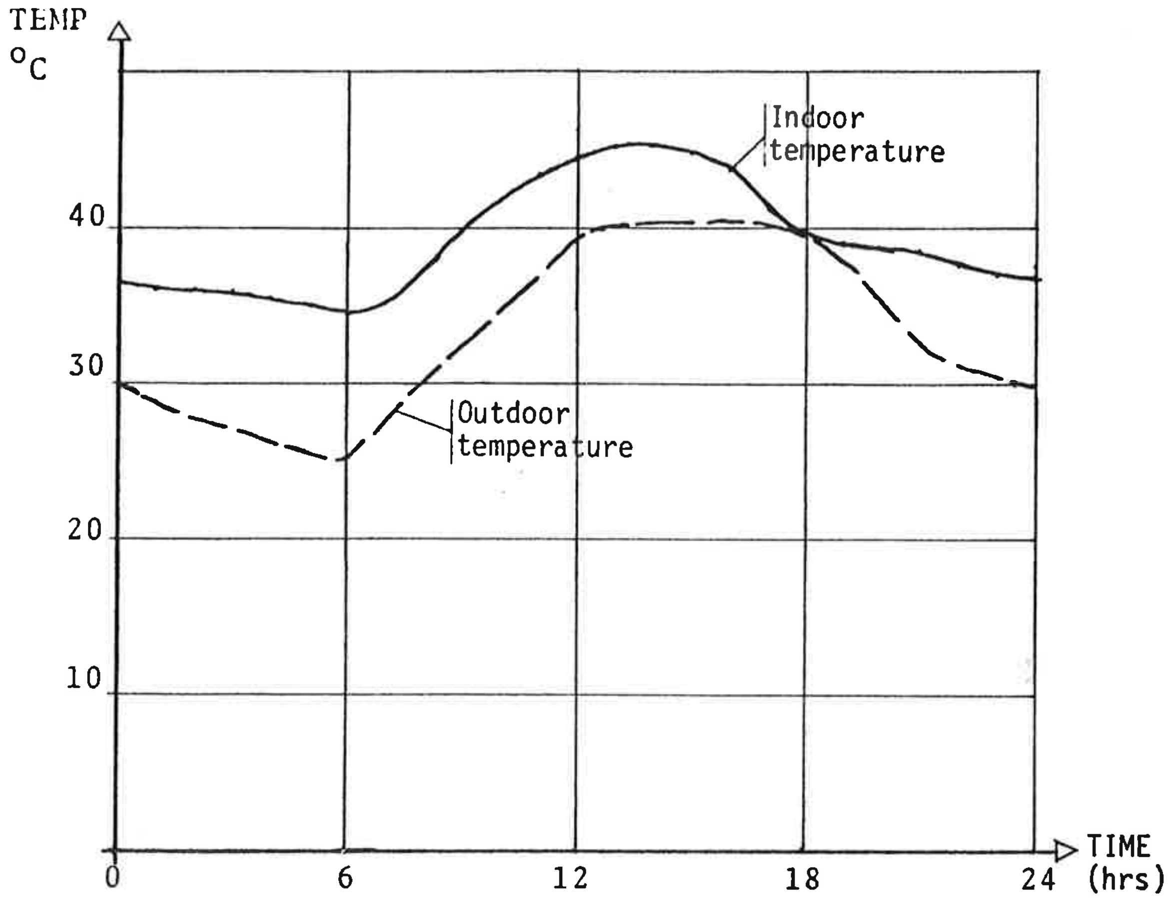


Figure 3.3A Temperatures in the attic for low and high air flows compared with the outdoor temperature.



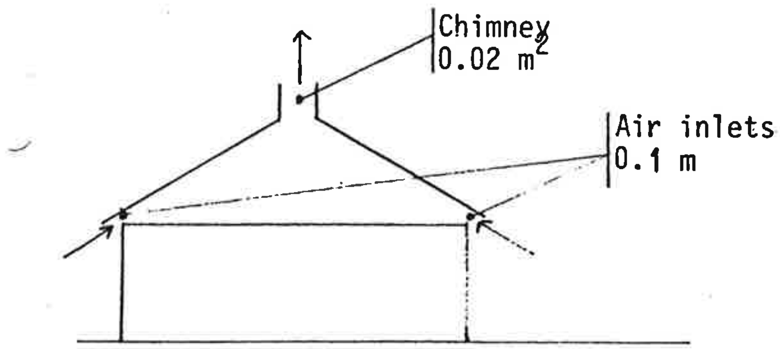
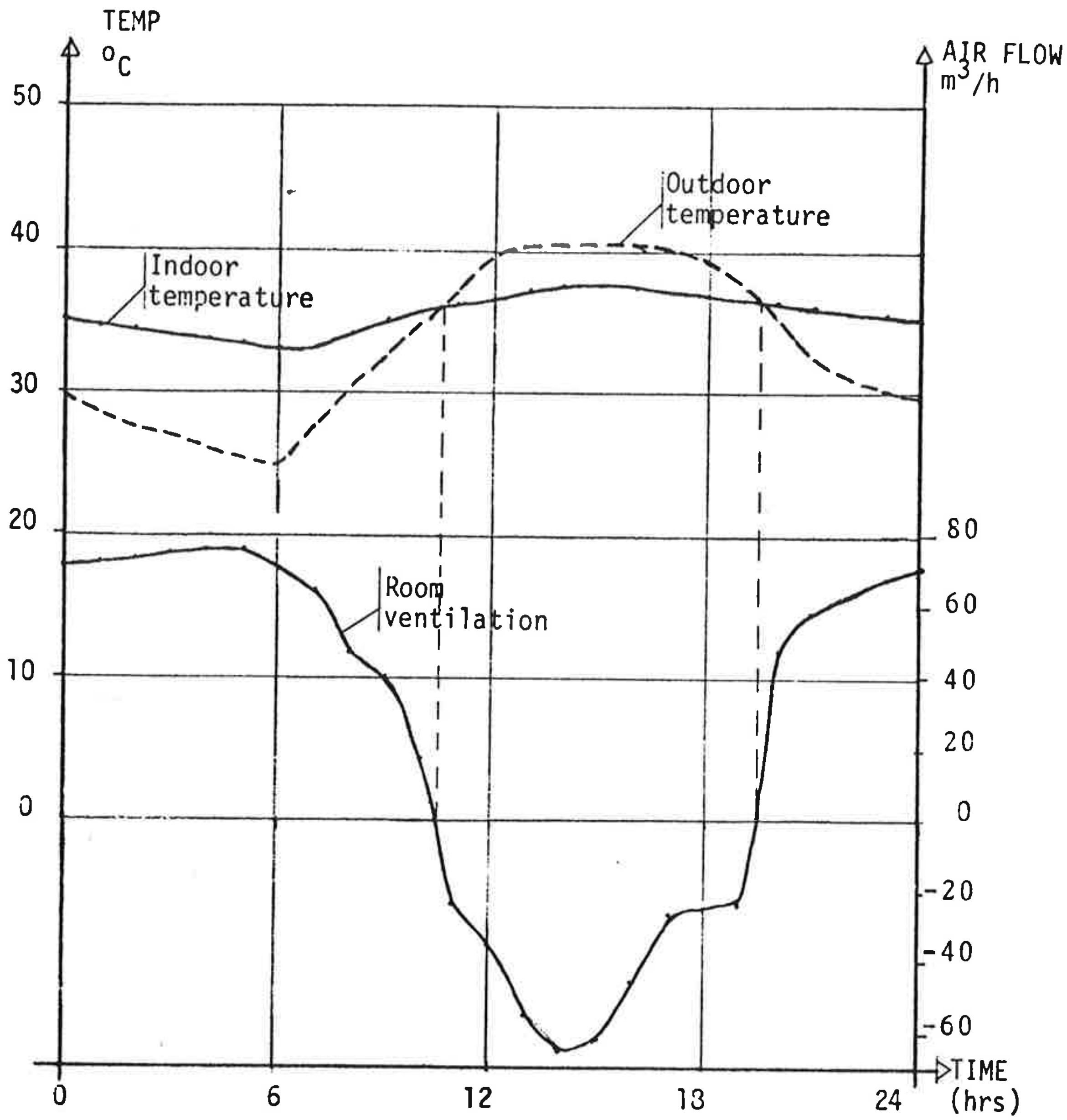


Figure 3.3B **Traditional construction without ventilation in the occupied area and with low air flow in the attic.**



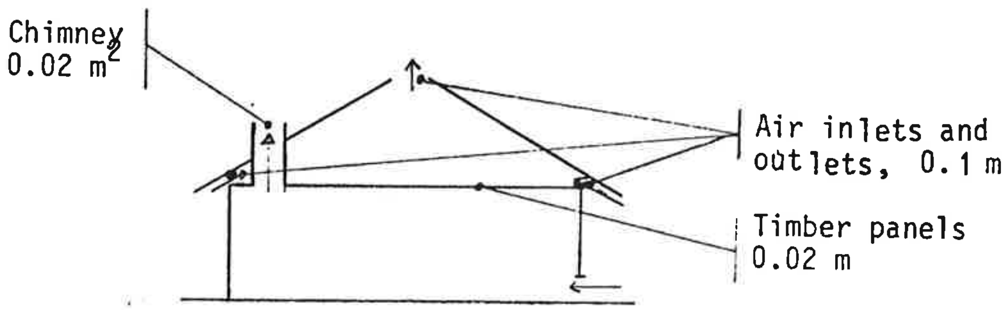
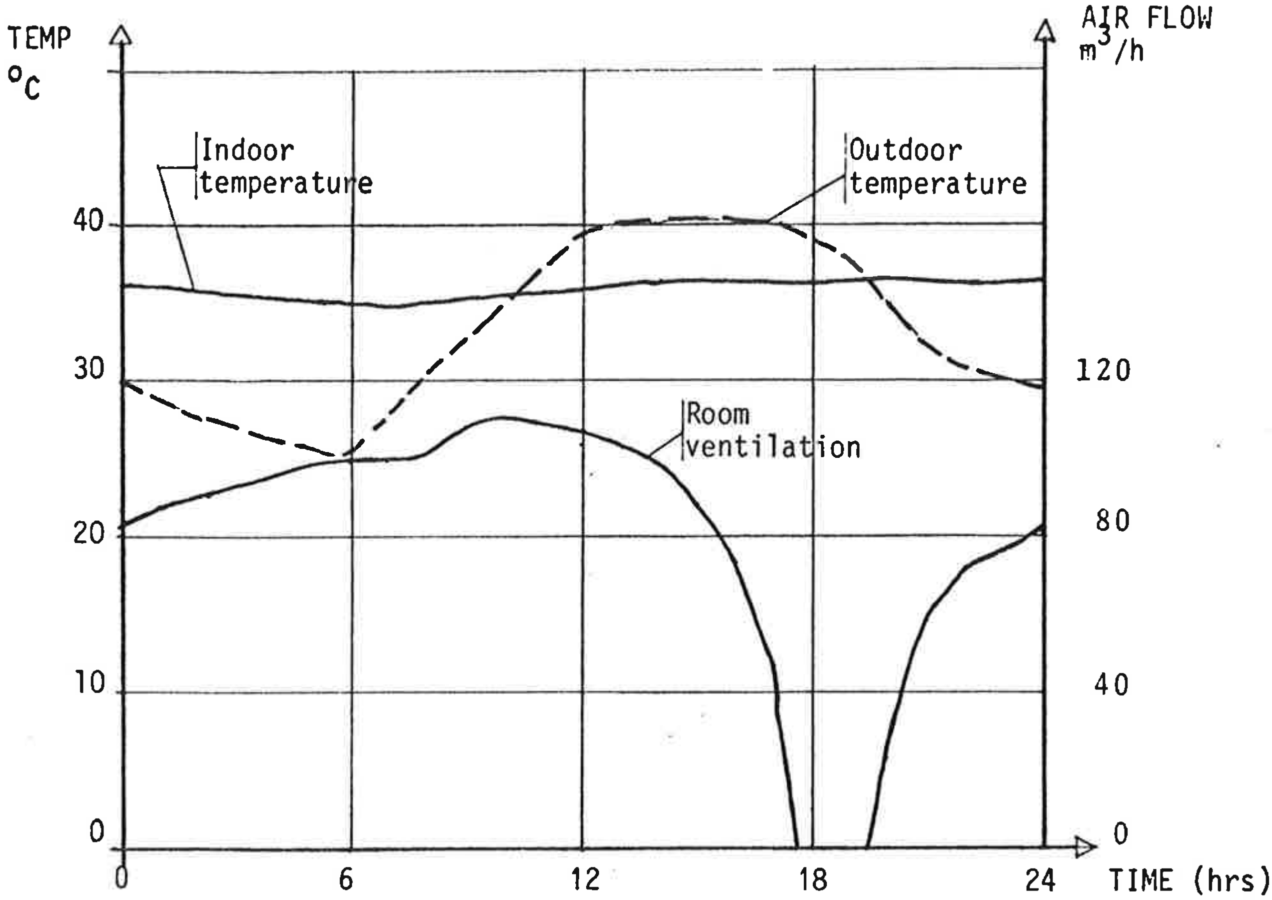


Figure 3.3C Ventilation principle A - natural ventilation of the occupied (living) space.



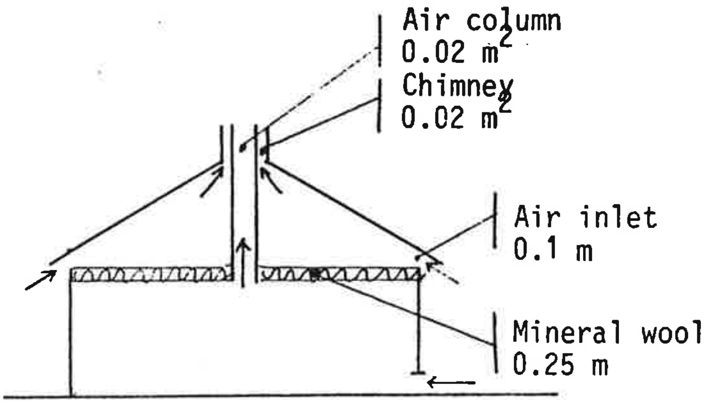


Figure 3.3D Ventilation principle B - natural ventilation amplified by the solar heated chimney and low air flow in the attic.

4 A PRACTICAL CASE – THE SAUDI ARABIAN PROJECT

4.1 Introduction

The project deals with the construction of magazines and related facilities owned by Saudi Chemical Company (Nitro Nobel) for the storage of explosives. It is one of many of its kind that have been undertaken in Saudi Arabia. This particular one is located in the suburbs of Riyadh.

The ventilation of the storage building is by passive climate regulation. Because of the risk for accidental detonation mechanical ventilation is not possible.

Saudi Arabia belongs to the hot-dry regions with very high day temperatures (exceeding 40 °C) and big diurnal ranges. The relative humidity is very low, in the range of 10-50%. Riyadh, being located in the interior of the country, amidst the desert, is a true representative of the hot-dry areas.

In the construction of storage facilities for explosives two very important conditions have to be strictly observed and adequately provided for:

- that the storage temperature does not exceed a prescribed value (in this case 32 °C) in order to inhibit deterioration of the explosive material
- that the construction is able to sustain the shock wave effect resulting from an accidental detonation of the stored explosives in a neigbouring magazine

It is outside the scope of this report to look at how the construction is of the magazines adapted to satisfy the latter. This chapter is intended to illustrate how the concepts of passive indoor climate regulation set out in the foregoing chapters can be put into practice. It shows the achievements that can be made and reveals the practical problems that have to be tackled.

4.2 Description of the project.

In the context of this report, the project can be described as dealing with the construction and the provision of temperature and ventilation regulation systems in storage magazines for explosives.

A total of 7 magazines of similar sizes but belonging to two different categories, have been constructed in this project. The general layout comprises the storage building with a 35 x 9.5 x 2.5 m storage space, a 1.7 m high attic and a 1.2 m diameter air transmission pipe underneath the ground floor. At the sides and the rear, the building is earthfilled as indicated in the accompanying diagram (figure 4.2). At the front there is a loading platform to the front of which is constructed a retaining wall to hold back a mound of earth fill. The storage space is enclosed by 250 mm thick walls on the sides, a 200 mm thick ground floor slab and a 250 mm thick roof slab stiffened, by very deep upstand beams, against explosion waves.

4.3 Adaptation to passive climate regulation.

The main features in the construction that are meant to promote passive climate regulation include the following:

- the concrete chimney
- the mounds surrounding the magazine and the vertical part of the pipe
- the underground concrete pipe
- the attic
- the steel chimney

The concrete pipe, diameter 1.2 m, runs from above the mound, in front of the magazine, below the loading platform to underneath the storage building. The concrete pipe opens into the storage space through two inlets near the front and rear walls. On the surface, these two openings are protected by grilles. The vertical end portion of the pipe protrudes beyond the top of the mound and is insulated all round. The open top of the pipe is also provided with a protective steel grating. The portion of the

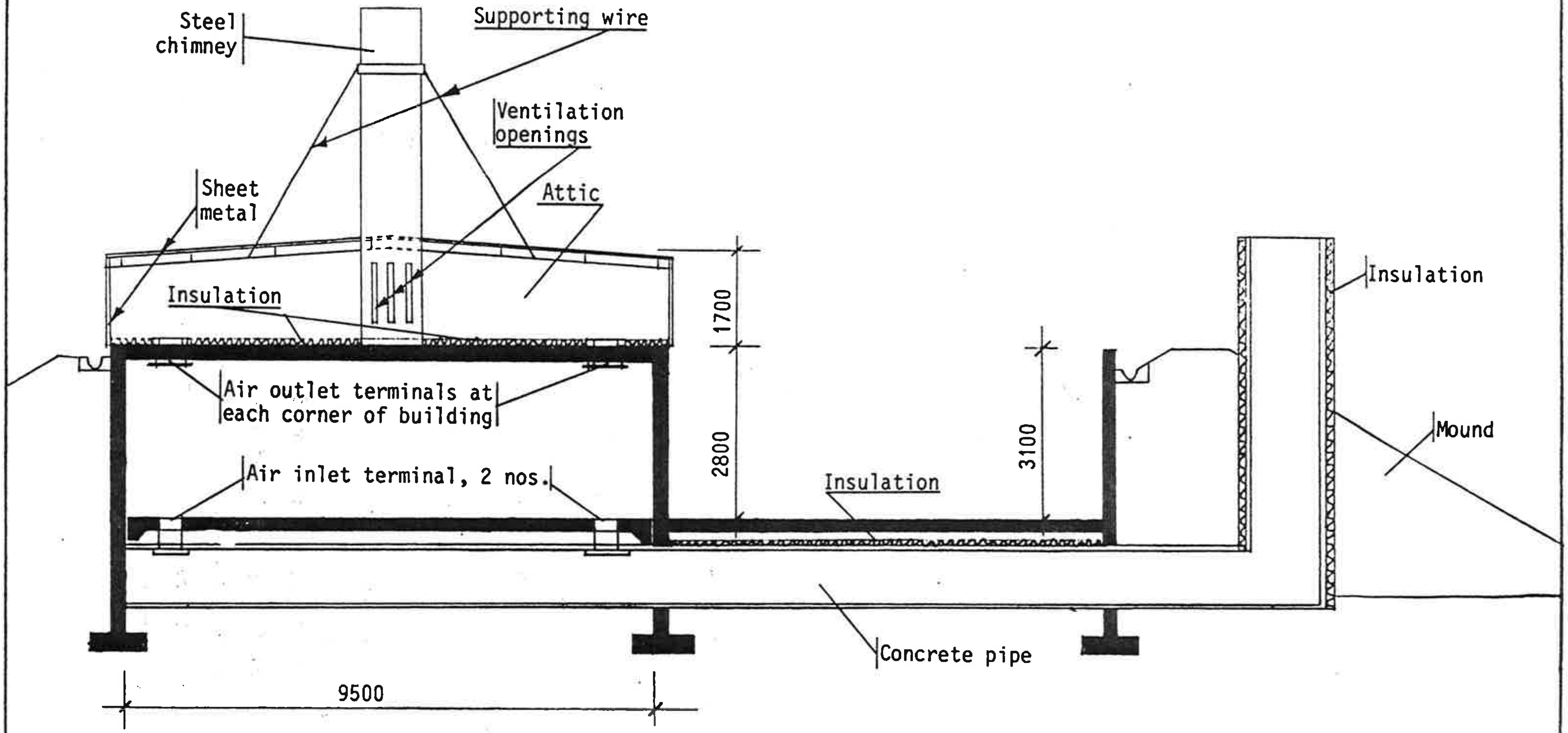


Figure 4.2 A section along the centre of the storage complex for explosives, showing features related to passive climate regulation, in Riyadhi, Saudi Arabia.

pipe beneath the loading platform is insulated on the upper semicircle of its section.

The mounds surrounding the magazine and the pipe comprise compacted earth, erosion protected by bitumen stabilized surface topped by a fine layer of clean sand.

The chimney comprises a steel pipe of diameter 1.2 m held in position by welding to a base of a stabilising angle bolted to the floor slab at the bottom, and by four stabilising wires at the top. The chimney is provided with ventilation openings around its circumference. The open (upper) end of the chimney is provided with a dense grating consisting of welded flat steel bars at 50 mm centres.

The attic is enclosed by the insulation on the roof floor slab at the bottom and tightly connected metal sheeting on the sides and the top. The roofing sheeting is supported on purlins.

The driving power for the ventilation system is derived from the temperature difference between the attic and the storage space below the slab. It is amplified by a tendency to increased temperature difference between that of the air in the chimney and the average of that of the air in the attic. The high temperature in the chimney leads to upwards movements of air in the chimney. Thus air is drawn in from the attic to the chimney through the ventilation openings. The resulting tendency to partial vacuum in turn leads to air being sucked in from the storage space to the attic and subsequently from the concrete pipe to the storage space and from the atmosphere to the concrete pipe through the relatively cool earth mound. The insulation around the pipe is intended to protect the air from being heated up and otherwise reducing the efficiency of the system. The insulation on the roof slab is to restrict the heat in the attic from reaching the storage space.

While the chimney and the attic ensure the provision of adequate driving power for ventilation, the mounds and the cold underground through which the pipe runs provide the cooling effect required to keep the temperature in the storage space sufficiently low. Thus both ventilation and cooling is achieved by passive means.

4.4 Achievements and problems.

From the climate regulation point of view, the Saudi Arabian project has been a test as to the practical feasibility of the passive climate regulation principles outlined earlier. Accordingly, therefore, the objective has been to design and construct a building system capable of reducing temperature fluctuations and their levels to below 32 °C the passive way. From measurements performed over a period of months it has been verified that this objective has been achieved satisfactorily. Figur 4.4 shows part of the results of temperature measurements made during the month of July to assess the performance of the passive indoor-climate regulation system employed. Further the great reliability of the system is yet another very important achievement.

The problems encountered in this project are more related to its peculiar nature and the inherent precautions than to the passive climate regulation requirements. The additional costs imposed by the provisions for passive climate regulation are thus relatively insignificant, and relate to

- the concrete chimney and pipe
- the steel chimney
- insulation material

Further, there are no running costs for the passive ventilation system.

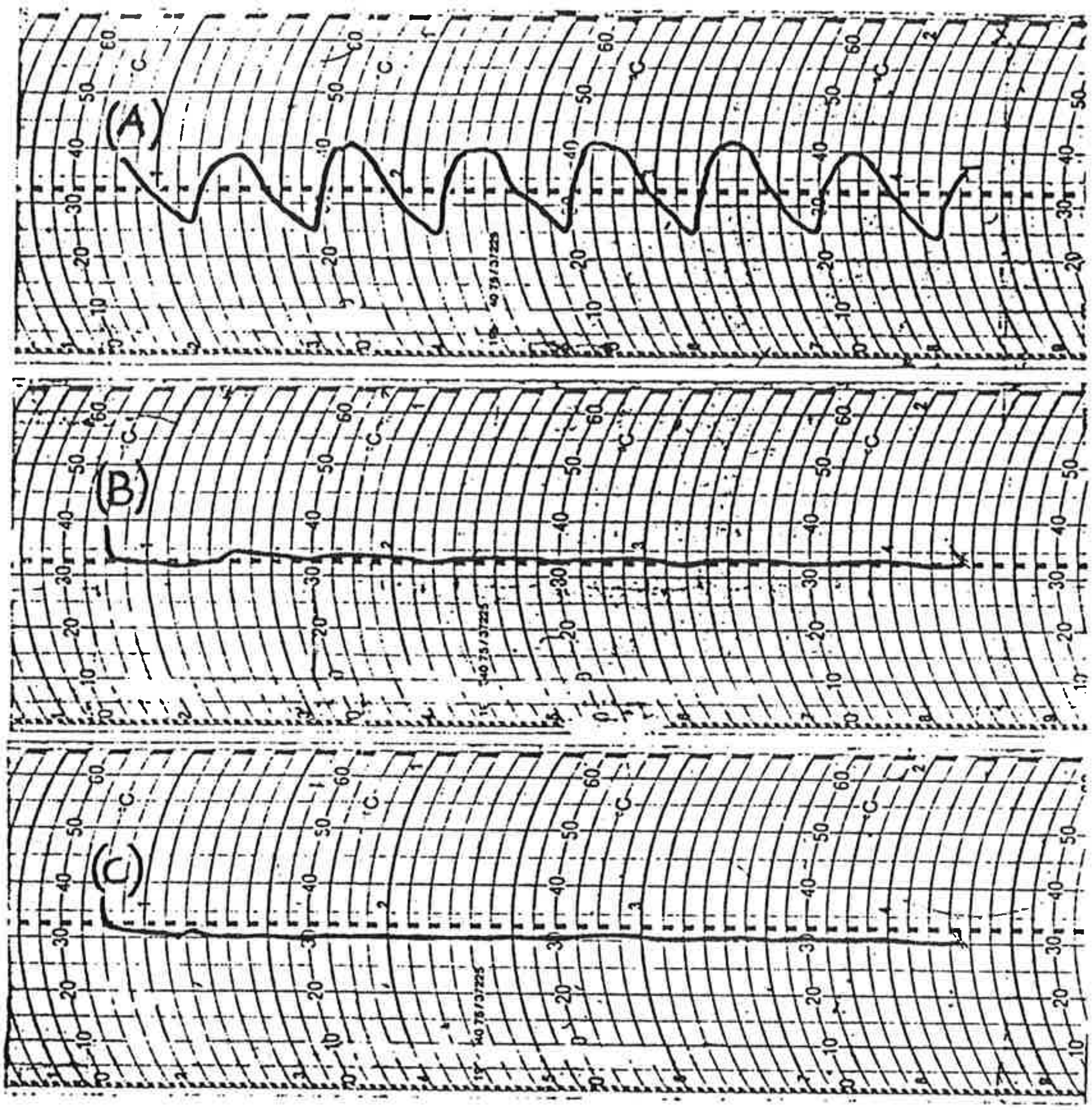


Figure 4.4 Part of the results of temperature measurements made, during the onth of July, to assess the performance of the passive indoor-climate regulation system employed.

(A) Outdoor temperature

(B) Indoor temperature close to the gable wall exposed to direct sunshine.

(C) Indoor temperature close to the gable wall not exposed to direct sunshine.

5 CONCLUSIONS

The results, based on the theoretical computations on simplified models of measures adopted to bring about passive climate regulation have been presented in one of the previous chapters. The results reveal two important achievements, namely the almost total elimination of temperature fluctuations and the enhancement of ventilation in the occupied area. These results are summarised in figure 5.1 in terms of temperature. In the same diagram, the required comfort (temperature) zone corresponding to the acquired air flow, humidity, etc, on this summer day in Baghdad, is indicated (2),(5). It is evident from the diagram that in this case ventilation alone fails by only a maximum of 3 °C to bring about comfortable climate in the occupied area. Moreover, it ought to be noted that the theoretical computations have not included certain factors which positively contribute to improved climate for principles A and B. These include:

- the long wave re-radiation from the relatively heavy construction
- the cooling effect of the concrete ground floor.

The important conclusion to be drawn from this project is that passive climate regulation, as defined earlier, is a technique which can easily bring about comfortable indoor climate, especially for buildings in hot-dry regions. The efficiency of the technique greatly improves when passive ventilation is complemented by passive cooling of the inflowing air in the manner shown in figure 2.1 D and demonstrated by the Saudi Arabian project, described in the previous chapter. The improved efficiency makes the technique very suitable even for the hot-humid regions, where the cooling ingredient is very important. The additional costs inherent in the adoption of the techniques will depend on the individual case. In the worst case, it is a question of some insulation on the ceiling, air inlet canals, etc. In the best case very little supplementing is required. In any case the additional installation costs remain very low. Furthermore, the running and maintanence costs are negligible.

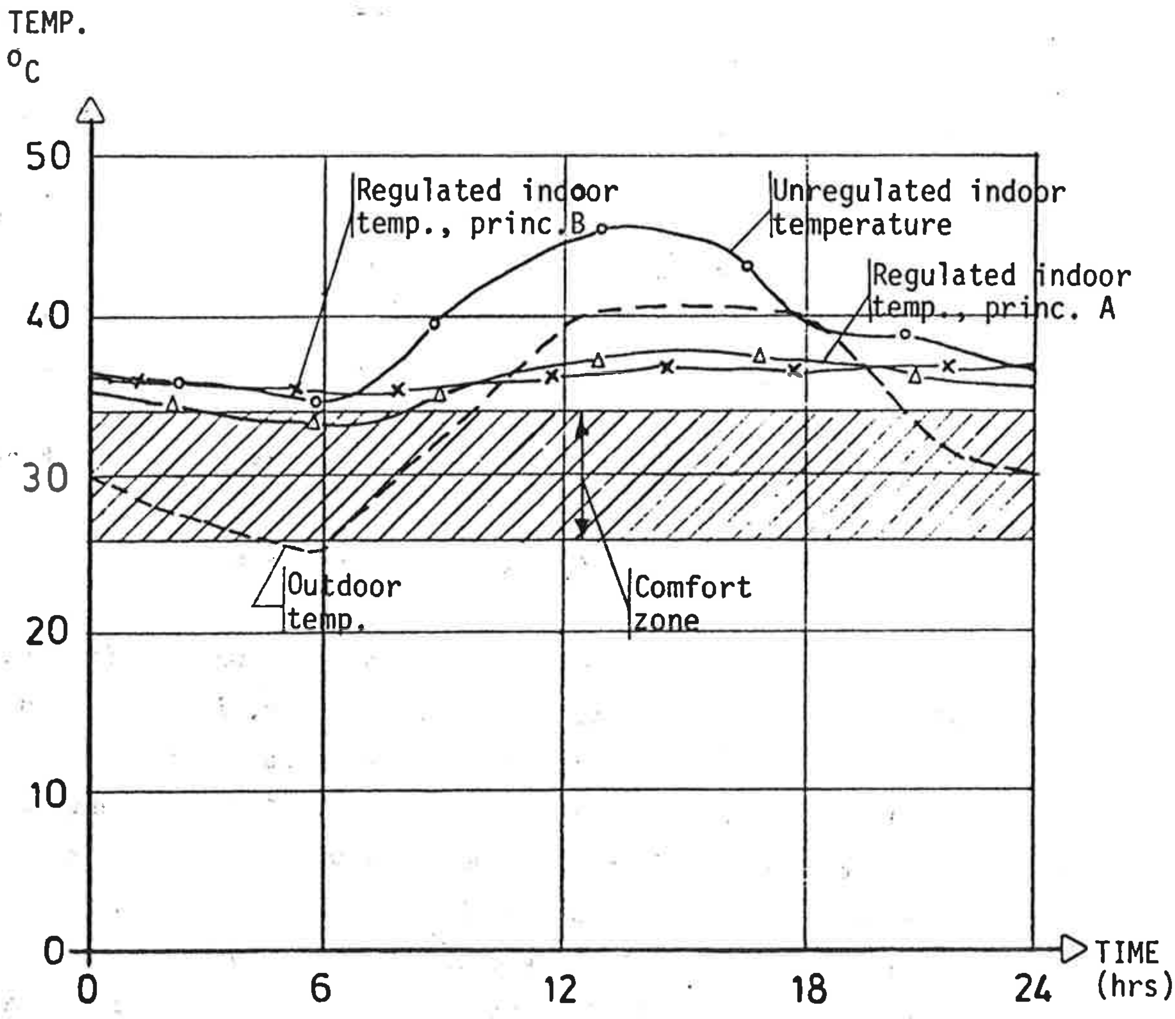


Figure 5. Comparison between outdoor temperature, the unregulated indoor temperature, the regulated (principles A and B) indoor temperatures and the comfort zone during the summer day in Baghdad.

The configurations adopted in this project have only been meant to serve as examples. There are unlimited possibilities of how buildings can be shaped to promote passive indoor climate regulation. For efficient functioning, the configuration adopted should accommodate the following features:

- an attic well adapted to contribute towards the effi ciency of the passive ventilation system
- a ceiling construction capable of inhibiting the transmission of heat from the attic to the occupied (or living) area
- large roof overhangs and construction materials of low absorption capacity for short-wave radiation
- air inlet so channelled as to promote cooling of the inflowing air.

The passive climate regulation technique described in this report can be applied to residential buildings. The technique is also suited for halls, closed markets, churches and mosques, godowns and warehouses and, of course, for storage buildings of different kinds (explosives, food) and for farm buildings (chicken farms, animal stables). In certain extreme conditions it may, however, be advisable to have a simple mechanical system as a complement.

In conclusion, the work done so far shows that there are promising possibilities that through passive climate regulation the following achievements can be made:

- comfortable indoor climate
- low investment costs climate regulation installations
- negligible running and maintenance costs of the installations
- techniques adaptable to local conditions.
- an alternative where mechanical ventilation is not possible for safety reasons.

REFERENCES

1. GLAUMAN M. och WESTERBERG U. /1971/
"Klimat och byggande i tropikerna"
Rapport 1/1971
Institutionen för konstruktionslära
Kungl. Tekniska Högskolan, Stockholm.

2. ELAWA S. /1981/
"Housing Design in Extreme Hot Arid Zones with Special Reference to Thermal Performance"
Department of Building Science
University of Lund, Sweden

3. BAHADORI M.N. /1978/
"Passive Cooling Systems in Iranian Architecture"
Scientific American 2/1978

4. NYLUND P.O. /1979/.
"Tjuvdrag och ventilation"
Rapport T4:1979
Statens råd för byggnadsforskning

5. SHAABAN A.C och JAWADI M. /1973/
"Analysis of the Climate of Iraq"
Report 21/73
Building Research Centre, Baghdad

6. HADITHI A.E. /1975/
"Availability of Solar Radiation on Building Surfaces"
Report 38/75
Building Research Centre, Baghdad.