Development Workshop

Human Settlements in the Third World
Etablissements Humains dans le Tiers-Monde

MISSION TO PAKISTAN TO ADVISE THE AGA KHAN HOUSING BOARD OF PAKISTAN

16th to 23rd May 1988

MISSION REPORT

by

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CONTEXT

The Aga Khan Housing Board for Pakistan has existed since 1980. Its objective is to improve the life of people, and notably those living in rural areas. The Board is active in the Sind and the Northern areas of Pakistan.

On behalf of the Development Workshop, John Norton was invited to visit the Housing Board and its project area in the region of Gilgit, in order to examine the area, the project activities, and to discuss possibilities of some form of collaboration. This visit took place from the 16th to the 23rd May 1988.

Unfortunately, unrest broke out in the Gilgit area at the time of the visit, and this meant that it was impossible to enter the project area. The comments in this report are therefore based on our discussions during the time spent in Pakistan; the examination of slides, the Housing Board video and other documents related to the project; and an examination of housing made during the abortive journey to the area, which was curtailed only 60 miles short of Gilgit.

It is very much hoped that a future visit to the Gilgit area will be possible.

The alteration to the programme made a short visit to the Sind area possible on Monday the 23rd May. In addition to the Board's request for comments on the Northern areas project, some specific issues were also raised following this latter visit.

For the visit, John Norton was joined by Hugo Houben of CRATerre.

1. THE NORTHERN AREAS

At present the Aga Khan Housing Board's activities appear to have concentrated on three main aspects:

* improving living conditions through a programme focussed for the time being on health related improvements to dwellings: a toilet unit, a simple water filtration system used in water containers, an improved stove with flue, and the introduction of high level openings to improve ventilation and lighting;

* training programmes, which now focus on improving present techniques of building and house organisation - ventilation, lighting, heating;

* building construction management, which includes a self help school building programme, and the construction of more substantial building projects including the Aga Khan Academy at Hunza and the Shah Kerim Hostel at Gilgit.

Although many aspects of the work already undertaken have touched on building technology, there has apparently as yet been no work specifically related to the way people achieve their housing. The Housing Board requested that the following points be specifically considered:

1. village planning;
2. use of local materials;
3. comments and suggestions for training;
4. roof construction.

1.1 VILLAGE PLANNING

No detailed practical propositions can be made without a visit to the area. However, it is already possible to make the following observations.

The Board has expressed particular concern about the pollution of water, and one aspect that would seemingly merit more detailed study in the near future would be the heirarchy of water use as it passes through each settlement. Simple facilities could be planned to enable water to be either kept pure or purified immediately prior to water collection points, and to ensure that drinking water collection preceeded (i) washing, and (ii) animal contamination. Although the water source in the example presented in Annexe 1 is different, the same problem of planning a rational sequence to water use was encountered by Development Workshop in Oman, and the approach used there (but not the specific solution) might be relevant.

Water flow through the settlement would also relate to the choice of sites for certain public facilities. It would be worth examining more closely how and where people wash clothes, and the possibilities of incorporating some aspects of water collection and washing into a public facility, creating fixed points for these activities.

In an earthquake prone area, settlement planning has a direct bearing on seismic risk. In sloping settlements, siting of buildings should become part of the training programmes.

With increased used of vehicles in the area, access and communication needs both to and within settlements is likely to change and needs to be considered in future planning.

1.2 USE OF LOCAL MATERIALS

Houses in the area just south of Gilgit are built with rubble stone walls similar to that shown in photographs examined of the Gilgit area. Timber horizontal and vertical framing within the wall structure is still extensively used, and this is a tested and proven method of earthquake resistant construction, often giving extremely good results. The reported shortage of timber in the Gilgit area means that this technique will become less common, and an alternative needs to be found.

The AKHB experience has shown that making use of the local granite boulders is expensive, with high costs and labour involved particularly for dressing the boulders. This tallies with our own experience of these techniques in neighbouring countries. Additionally, rubble stone construction is in general seismically unstable*[1], and can consume large amounts of mortar. Mud mortars provide no chemical bond with stones, and are thus unable to resist movement induced by an earthquake. A cement based mortar is almost certainly a necessity.

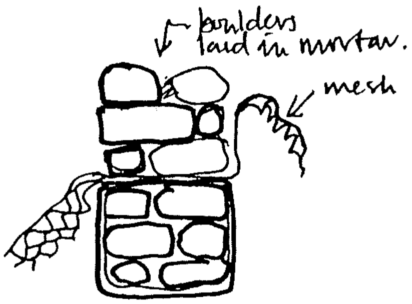
Judging from the large distances involved and the general transport difficulties, moving away from rubble stone wall building to cement block wall building is, however, likely to remain expensive for many private house builders. It would seem likely that for many people local stone, gathered by the people concerned, will remain a comparatively low cost material. If this is the case, options which allow one to build with the same materials but with greater seismic safety are worth presenting. It is perhaps worth noting here that the training materials and techniques used in the Dhammar/Yemen programme make use of semi-dressed stone which is not exactly the case assumed in the Gilgit area.

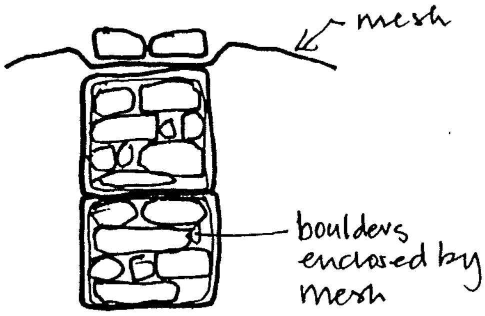
The Board have been experimenting with the production of boulder blocks: photographs examined shown would suggest that the boulders used are quite small, and that a large proportion of concrete is still used to achieve a regular shaped block. Once again, no specific comment is possible without seeing the blocks produced, but for reference a paper on the Jamaican experience of producing stone masonry blocks is included in Annexe 2. Here the results at an average of 30% stone content were extremely favourable.

Secondly, techniques of bonding units of rubble stone wall together with heavy guage galvanised wire mesh are already well

1. Development Workshop: "A strategy for developing indigenous building in earthquake resgions: case studies of the Bandar Abbas 1977 and the Zarand 1978 earthquakes", 1978.

known for retaining wall construction. There have been successful applications of this technique for house wall building. Stones still need to be laid with a cement mortar, and as much attention paid as possible to bonding, especially through the wall. However, the wire mesh, fixed around units of wall as the construction proceeds, serve as an efficient reinforcing system. Fig. 1 below shows the theory.





Choices between building with stone, earth, or cement blocks depend upon a closer evaluation of (1) the quality and source of materials available in the area (both local and external), and (2) preferences in choice of building expressed by the local population, and the resources that they feel they are able to devote to building.

A policy also needs to be established regarding the choice of material made for public facility building relative to the influence that this can have on choices in domestic building. In the long term it would seem desirable to demonstrate faith in (and the correct methods for) materials and techniques which are suitable for both domestic and public building. Local people participating in public building projects are consequently able to transfer the experience directly to domestic building. Choices made for long term development may not necessarily seem the most expedient and cheapest in the short term. Quality control when using local materials is sometimes difficult to ensure without some form of preliminary and on the job training. This in the short term raises costs, but is often necessary if replicability is a key issue in the project.

In policy making, the seismic risk factor in the area imposes different considerations for public and private building. Public buildings play an important role after an earthquake, hopefully providing essential shelter when weaker buildings have failed. It is realistic to invest more resources towards ensuring their structural integrity. This is less realistic in domestic building - the cost of ensuring that houses remain undamaged in a medium earthquake is frequently too great. A more common approach is to aim to ensure that there is sufficient time for the occupants to escape from the building without loss of life or injury, and this should be regarded as a minimum requirement for dwellings.

Photographs of contemporary building in the Gilgit area ("guest houses") showing different wall and roof building techniques to those used in the older houses would suggest that the problems and apparent deficiencies in traditional techniques of building are not necessarily due to a lack of technical skills. It is important to establish the reasons for these differences in material choice and techniques used in different types of local self help construction. Household surveys and, most particularly, participatory research as an integral part of builder training - where trainees themselves examine the available techniques and options and the local preferences - would be an essential part of developing a house construction improvement programme.

In addition, if older houses do present deficiencies, it is nevertheless unlikely that people will leave these houses and build new homes. Survey work should therefore examine the ways that existing structures can be made more stable in the event of earthquakes. Earthqauke damage surveys in Iran on rubble stone walls have shown that butresses can increase stability. However, the configuration of the house is of utmost importance, and recommendations depend on the specific layout of rooms, openings and partition walls.

1.3 TRAINING

Training is already an integral part of the project. The themes of the existing training modules seem to cover the main overall technical issues. However, training can be seen essentially as (1) an opportunity to exchange ideas, and (2) for the participants to make choices about the materials and techniques that they think suit the local context and the means and habits of the local population. Training is therefore a two way process, where the trainer has a role of presenting the structural and environmental performance of potential techniques and materials (based on preliminary investigation of the local situation), and the parameters which may influence their choice, and where the trainees participate by (1) presenting and explaining their own techniques, (2) evaluating the available options, and (3) choosing those that they feel best suit the local situation. Discussion is thus as important (and sometimes more important) as practical exercises and "on the job training".

The detailed content of future training programmes should be determined in the light of the evaluation of the resources available. The range of materials and techniques which might eventually be adopted should allow for different levels of affordability. Several solutions may be necessary for each element of the building.

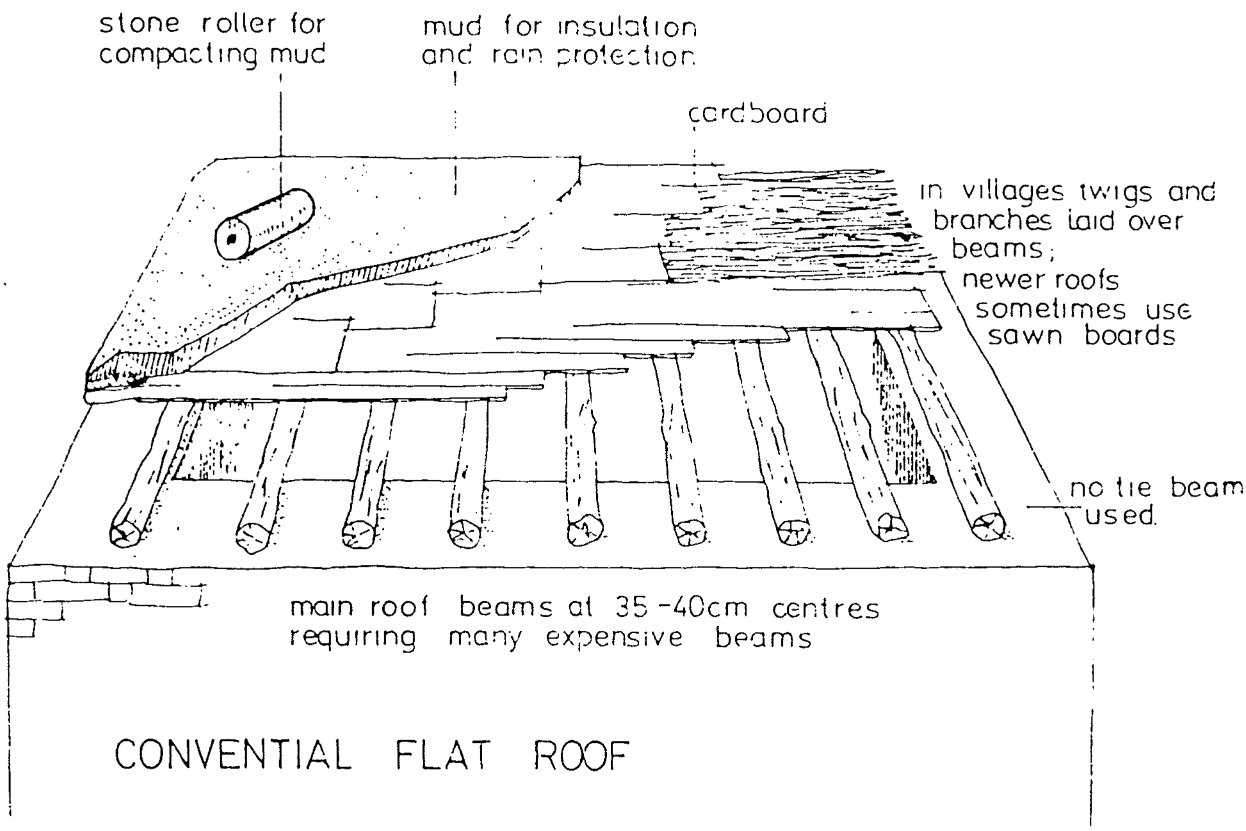
1.4 ROOF CONSTRUCTION

Traditional roofs appear to use very large amounts of timber for their structure. More recent roofs (shown in the "guest houses") appear to use slightly less timber, but in both cases an analysis of roof structure is necessary to see in what ways the amount of timber could be reduced without diminishing its load bearing capacity. Earth remains one of the best low cost insulators against the cold of the winter, and it would therefore be realistic to continue its use. Bitumen provides a good waterproofing agent, but will last longer if applied to a fibre backing, typically hessian or jute sacking work well. A single coat of bitumen is usually insufficient for a long life, and two coats would be a more realistic minimum. A protective finish over the bitumen will help to preserve the surface, especially when snow is being removed from the roof.

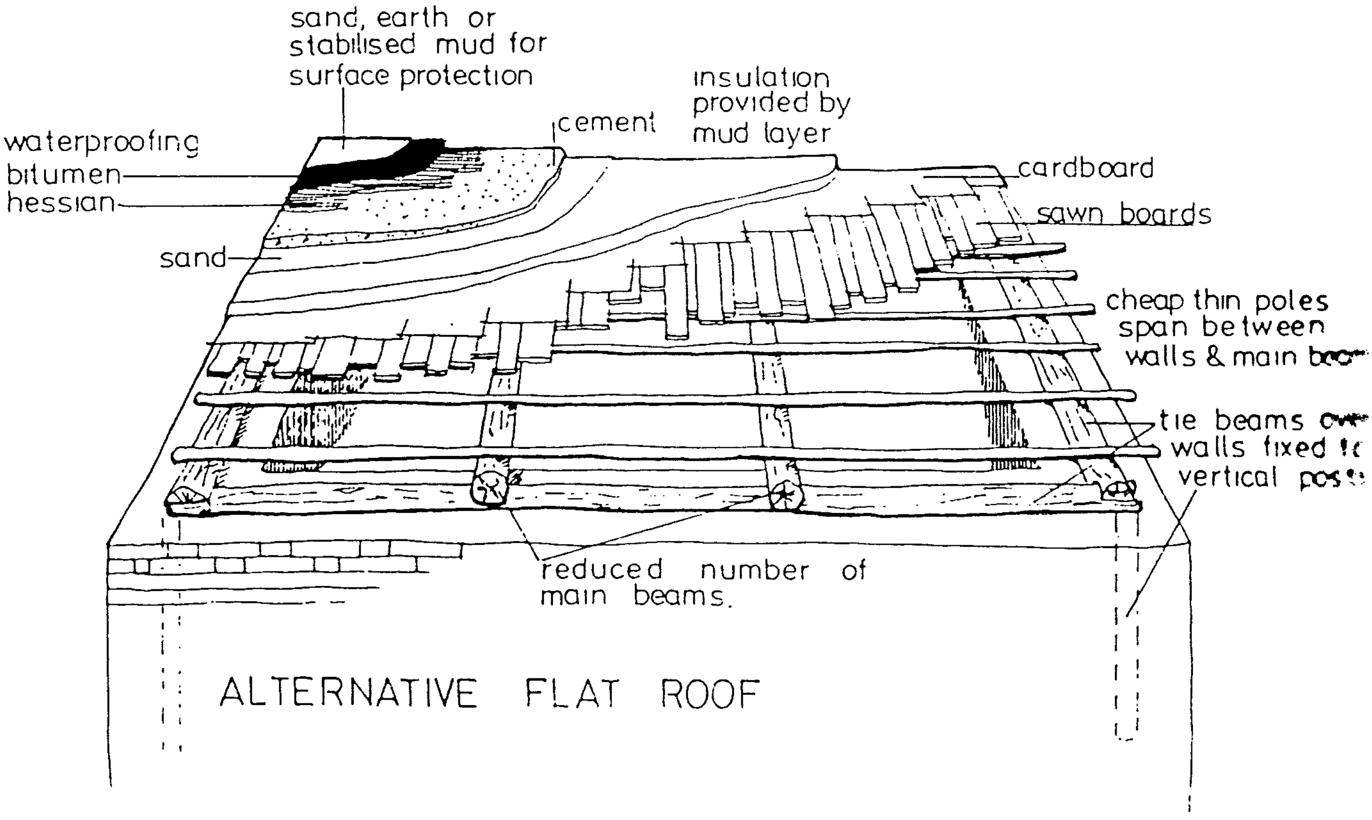
Timber is likely to remain the principle material for the roof structure in the near future, and it would be beneficial to promote techniques which make better use of the wood available in each tree felled. The illustration on the following page shows one way of reducing the amount of timber used in flat roof construction, by using progressively smaller profiles of wood*2.

2. Development Workshop: "Report on builders training programmes in Luristan, Iran, 1977".

Fig 2 FLAT ROOF EXPERIMENTS



CONVENTIAL FLAT ROOF



ALTERNATIVE FLAT ROOF

RECOMMENDATIONS

Although it was not possible to visit the project area, the visit to the Aga Khan Housing Board for Pakistan has been most fruitful, allowing an understanding of the objectives of the project and an overview of the context and potential problems.

It is now recommended that a further visit estimated at two weeks in the project area be undertaken with the following specific terms of reference:

1) Preparation of the detailed content and programming for a builders training programme, for (i) new construction, and (ii) strengthening of existing construction, and based on:

a) the evaluation of the materials available for use in the area;
b) the evaluation of existing skills;
c) the clarification of reasons for present choices in material and building techniques for dwellings.

2) Preparation of guidelines for village planning, including detail proposals for water management and public facility planning (see the need for a policy on public facility building noted above), based on physical and socio-cultural surveys.

2. SIND

Three aspects regarding the projects in Sind area were raised:

1. performance of windcatchers;
2. insulation of concrete roofs;
3. sewage disposal

The following comments and the information included in the annexes may be of interest.

2.1 WINDCATCHERS

In the housing project close to Thatta windcatchers have been included in each of the two room units. Whilst a considerable amount of air is entering the room served by a large opening from the windcatcher, the second room in each case has a small opening high up in the wall. Where this opening is in the wall opposite the prevailing wind, and opposite a window open to the prevailing wind, the effect of the windcatcher may well be minimal, and might conceivably work in reverse. It would be worthwhile trying out (1) a division of the windcatcher inlet so that each room had a seperate supply, and (2) a larger inlet in the wall. Since the orientation of the houses varies (although the windcatcher remains orientated to the prevailing wind) one single solution is unlikely to produce the optimum results. A difference between the present arrangement and the more traditional one is that in the latter the windcatcher opens onto a hole in the ceiling, whilst for one of the rooms in the two unit house the opening is through a hole in the wall. In all events a shutter will be necessary to allow the occupants to close the windcatcher when cooling is not needed.

Raising the level of the intake on the windcatcher would serve to reduce the risk that at low wind speeds air entering the building would be heated by passing over the hot roof.

The papers on traditional cooling presented in Annexe 3 are for general interest. In all cases it will be seen that the relationship between inlet and outlet is important. Modifying their relative sizes alters the distribution and the amount of air passing through a room. An optimum performance can be achieved through experimentation.

2.2 INSULATION OF CONCRETE ROOFS

The simplest method for reducing heat transfer through a concrete roof slab is by ensuring that the external surface is not exposed to direct sunshine. This typically involves placing a second layer of covering over the roof, the object of which is to provide shading. Although not very long lasting, reed matting achieves this result cheaply and efficiently. More durable and perhaps more presentable results are provided using a corrugated cement fibre sheet or other rigid panel. In all cases the principle is simple. The sheets should be raised at least 20cms (8") above the slab, and it is essential that air can move freely between the two. The reed matting technique could be tried on one unit for a short period to assess the difference between a protected and unprotected roof. Some attention is necessary to detailing to ensure that the covering does not look like an afterthought.

The paper included in Annexe 4 presents the results of research carried out in Sudan on the same problem, and may be of interest.

2.3 SEWAGE DISPOSAL

In two of the settlements visited, sewage disposal was raised as a major issue. Two factors seem worth taking up here: firstly, a water born sewage sytem to a septic tank will require sufficient water to transport the solids. To ensure this, it helps if any waste domestic water is added to the system, including sullage from clothes washing, bathing, food and kitchen activity. Where water is in short supply, aqua privies will be more suitable, as they function on much less water - 15-20 litres per day is ample, as opposed to higher quantities desirable for septic tanks, the amount being related in part to the fall of the outflow pipe and the diet of the household.

Effluent from the septic tank will normally be relatively clear and have a low concentration of organic matter. However, the effluent will be rich in bacteria and other organisms, and thus the outlet should particularly be kept away from the wells and streams. (A recommended distance for soakaways is 30 metres). These recommendations should apply even when the outflow passes into a filtration tank. However, it will help to add a filter tank to the outlet end of the septic tank, or, where space and conditions permit, arrange that the outlfow passes into a soakage pit or tranch. Whichever method is adopted, it remains important that the eventual outflow (or ground water penetration) should not be close enough to contaminate a water source.

ACKNOWLEDGEMENTS

My thanks are due to the following people who gave generously of their time during our visit:

Dr Tajuddin A. Manji	Chairman	Aga Khan Housing Board of Pakistan
Ashiq Ali Panjwani	Hon.Secretary	Aga Khan Housing Board of Pakistan
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Kamil Tharani	Convenor	
Amir Ali Moolji	Convenor	Construction Management & Living Condition Improvement Programme
Pyarali Bhayani	Convenor	Housing Cooperatives Motivation Committee
Amir N. Jivrat	Convenor	Technical Advisory & Appropriate Technology
Naser G. Noorani	Member	Finance
Saleh Mohammad Damani	Convenor	Skill Development & Technical Training
Salim Rajan	Projects Engineer	
Nooruddin Panjwani	Architect	

ANNEXE 1

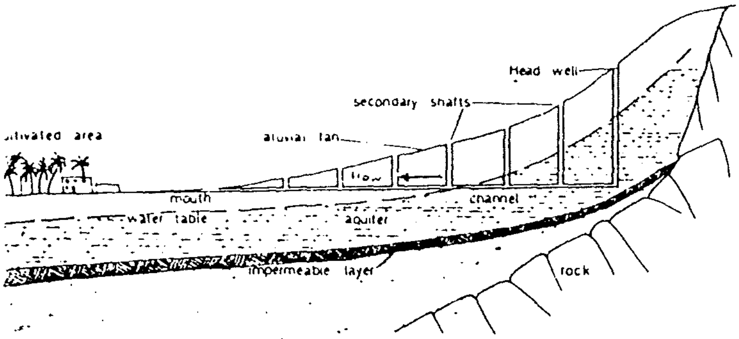
WATER SUPPLY

Extract from an article by Development Workshop

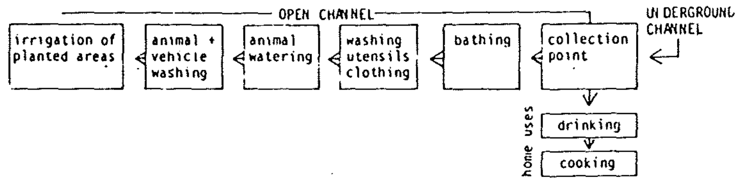
Architectural Design

April 1975

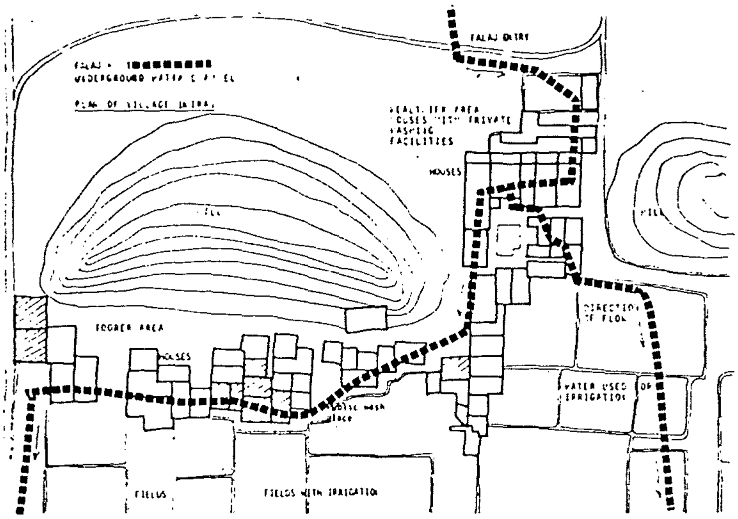
Water supply



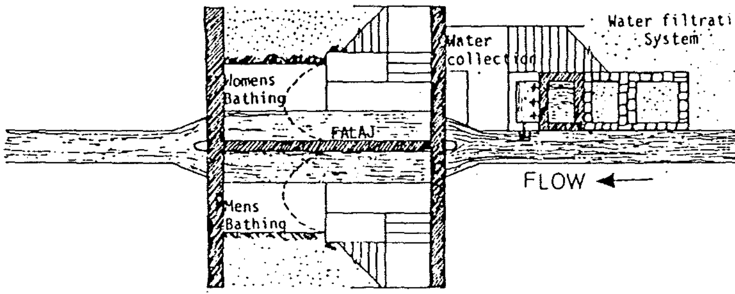
Falaj — water supply system



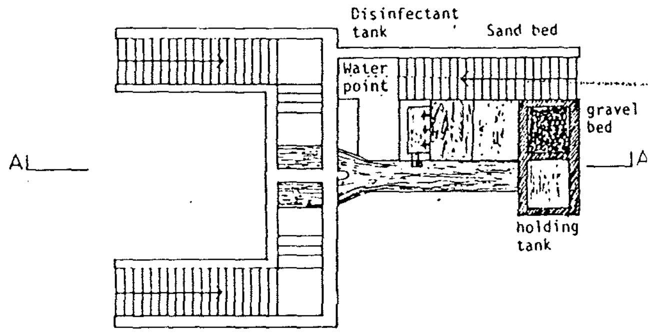
Falaj water distribution.



Plan of Iranian village with hierarchical use of water channel system



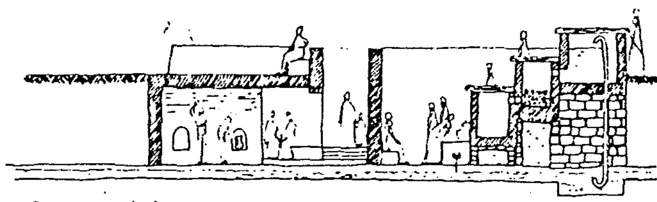
Falaj Level Plan



Ground Level Plan

Falaj. Note that drinking water is supplied in jars to protect people from contaminated water.

Domestic bathing area.



Falaj Section A A

Falaj — water purification and bathing area improvements.

.vailability of water is a prime etermining factor for settle- ent since agriculture and umans require sufficient applies of fresh water. In areas here average annual rainfall is egularly less than 100mm, ater must be obtained from elow the surface of the ground.

One method of obtaining ater has been developed in arious Middle Eastern ountries, the Falaj (Oman), r Qanat (Iran). The system volves the tapping of the quiter or water table in high round or hillsides, and bringing ne water down through man- nade underground channels to ie cultivated areas in the valleys nd plains. Vertical shafts are ug to allow access to the nannel, used in the original xcavation and for maintenance f the horizontal channel. By sing a horizontal channel, the ater is easily brought to the reas of settlement and agricul- ure. The underground channels re noted for their reliability.

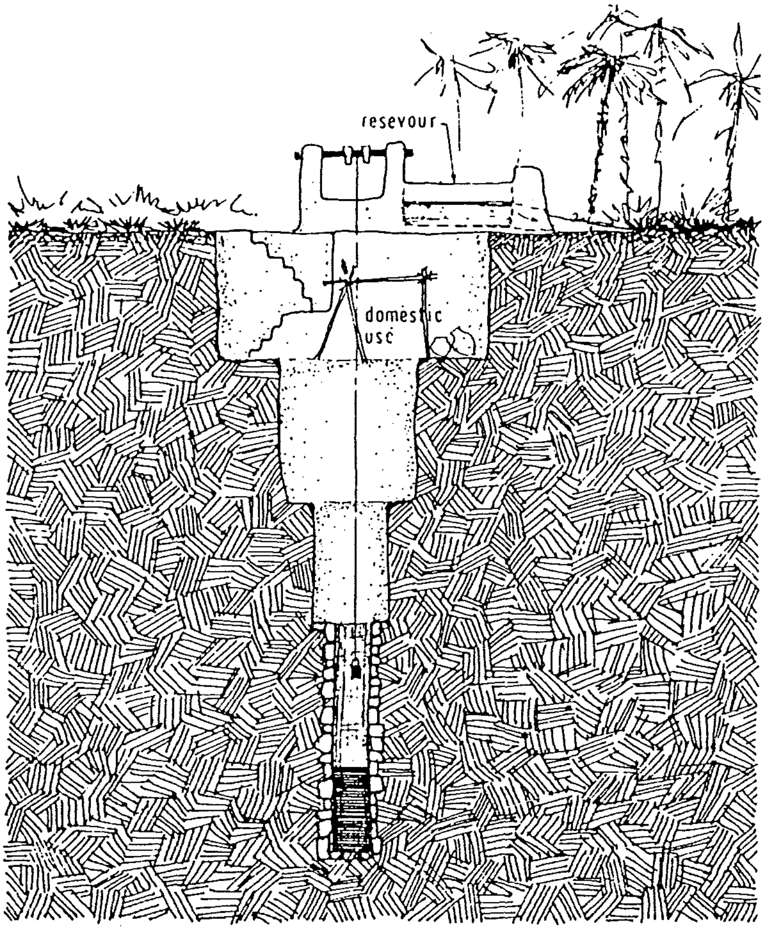
The actual distribution of alaj water is organised in such a ay as to minimise the chance f contamination. A definite near utilization is held to, as ie water flows through the ettlement, ensuring clean water or drinking before con- amination by washing and nimals.

It can be seen that drinking ater is always taken from the Falaj' at the point that it merges from the ground. 'ater is often collected from is point and deposited in pots urther down channel, for ublic drinking,. Some houses f richer families (in the best ositions) have private wash eas built over the channel, ut washing for the poorer nembers of the community is one in public wash houses. 'ater is also distributed to rivate plots of land in return or a proportionate tax, the ioney from this being used for ich things as educating the nildren. Improvements in the ierarchy of water use and the esign of facilities, is often ecessary, and an outline iggestion is shown here. Sand lters and disinfectant tanks can introduced for purification, id the organised sequence of e (such as the design of public ithing facilities) can be refined conjunction with education in ealth and hygiene.

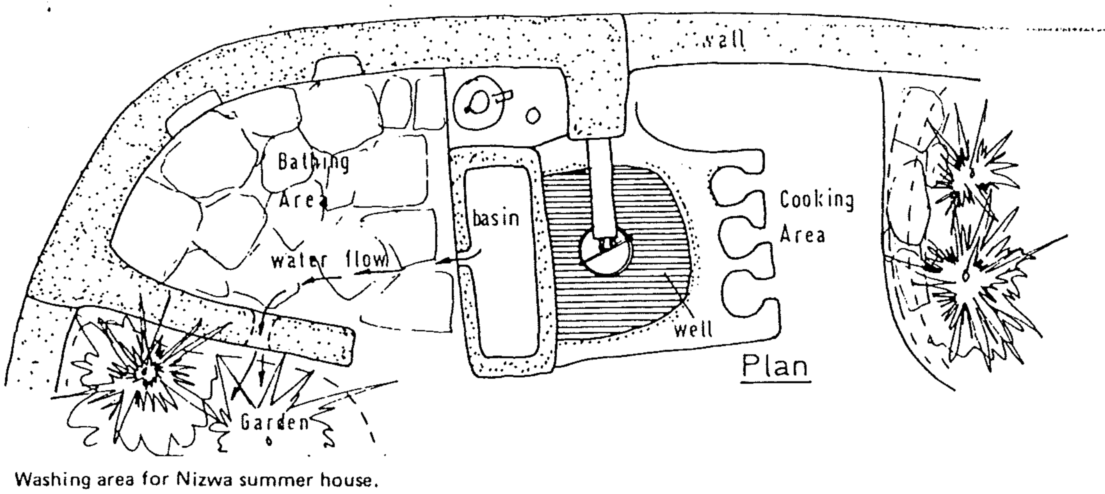
In town centres it is not always possible to have direct access to a water source, so drinking water is sometimes distributed by tanker. Water is also obtained from wells, but because the water table is usually at great depth, a great deal of energy is expended in raising the water (by hand or animal power). To facilitate this and initial excavation, wells are often built in a series of steps of decreasing diameter for people to descend the shaft.

Domestic indoor washing areas should be designed in such a way as to conserve water. Indigenous examples demon- strate the concern to cut down wastage. The example here shows an integrated drinking, cooking, bathing and washing area. The water runoff from washing is used to irrigate a fruit tree.

This example illustrates how washing areas and water use in general can be designed to harmonise with traditional customs, and yet be acceptable in health terms and inexpensive and simple to construct for the average house owner.



Stepped well.



Washing area for Nizwa summer house.

ANNEXE 2

STONE MASONRY BLOCKS

Jamaican Building Research Institute

Technical Notes

STONE MASONRY BLOCKS

INTRODUCTION

Jamaica has an abundance of stone and a large unskilled labour force. The Building Research Institute has developed a technique to combine these two resources using uncomplicated machinery to produce a standard walling material. The Stone Masonry block combines simple manufacture and laying with economy of material to produce a useful alternative to cut stone and hollow block masonry.

The advantages are:—

1) It uses stone, a plentiful natural resource, to form a standard building product;
2) It is suitable for self-help production, having a low capital requirement for the production equipment, and it does not require a high level of skill for production;
3) The overall cement content of the wall is low compared with normal stone masonry;
4) Construction time and skill is reduced compared with stone masonry;
5) No rendering or painting is required for external surfaces since this is an exposed stone face;
6) There are no block pockets to be filled with concrete;
7) There are savings in Steel; reinforcement is normally required at corners and openings and in unbraced wall lengths.

MATERIALS

AGGREGATE

A clean, crushed, ½" down aggregate can be used in the concrete. If clay particles are present, the stone must be washed to remove the majority of them, as these will reduce the concrete strength.

SAND

Any clean, well graded sand can be used.

CEMENT

Bagged ordinary Portland cement can be used.

EQUIPMENT — MOULD

At the Building Research Institute's Laboratory steel gang moulds are used to produce six blocks 11½"x 5½" x 7½" each and a combination of ¼, ⅓, ½, ⅔ and ¾ blocks for bonding purposes. Lifting handles are provided at the ends of the moulds and a matching "pressing bar" is made for each type of mould with plates the size of the top of each block. Single or gang moulds may be constructed in timber or steel, with steel likely to be more durable. For single moulds a rectangle of wood can be used to hold down the block while lifting.

Special moulds have been made to produce a ½ block with a 3" diameter semicircular cutout to allow the inclusion of reinforcement in the wall.

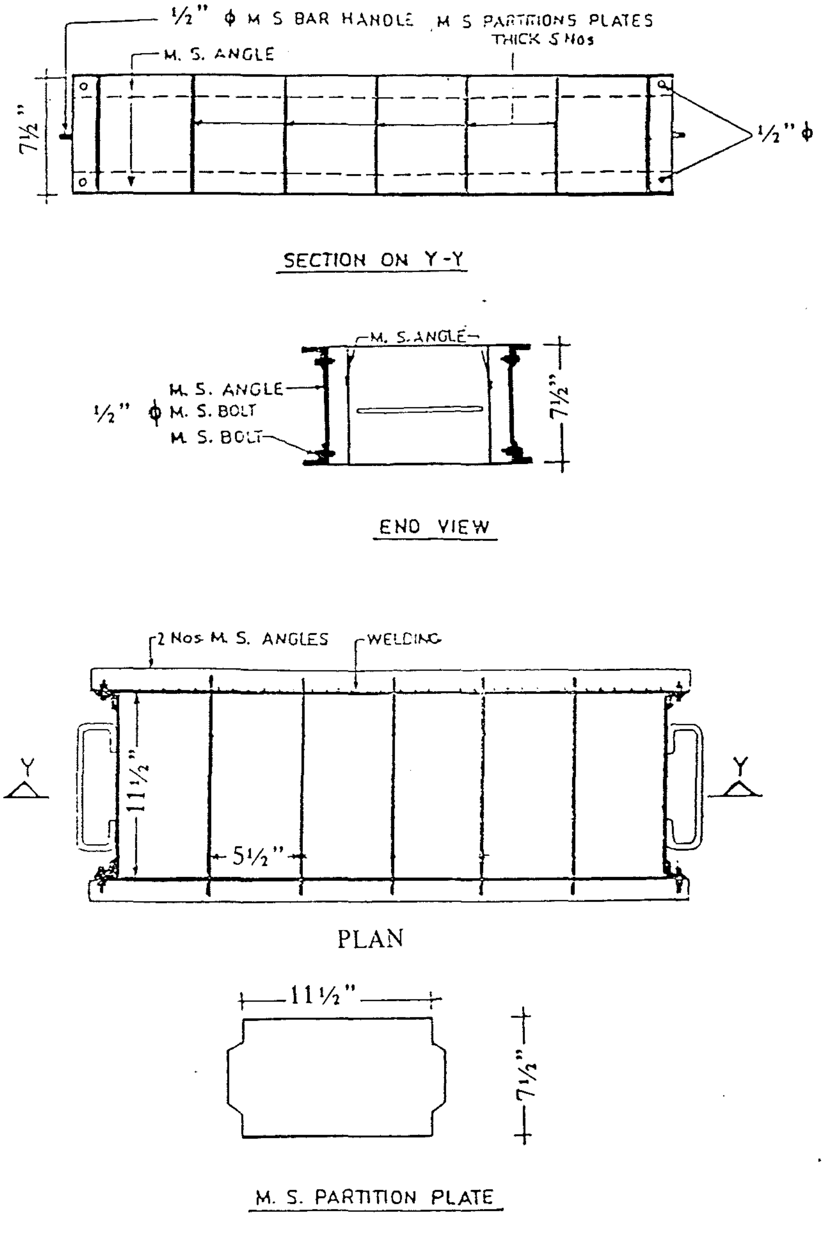


FIG. 1. GANG MOULD DETAILS

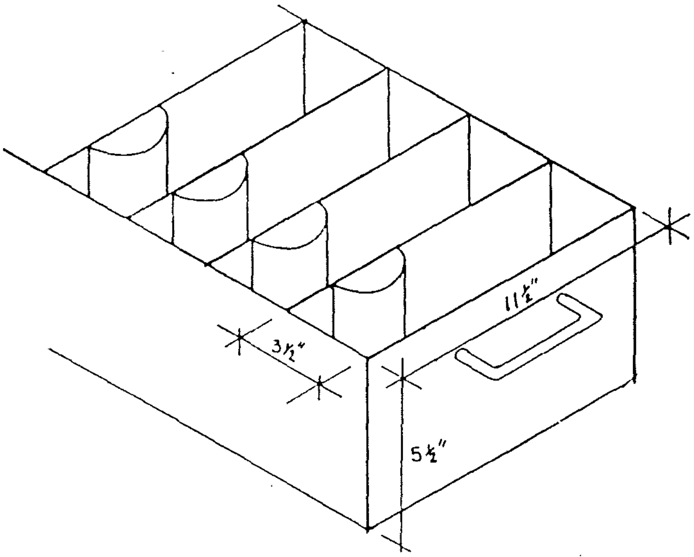


Fig. 2. Reinforcement block mould.

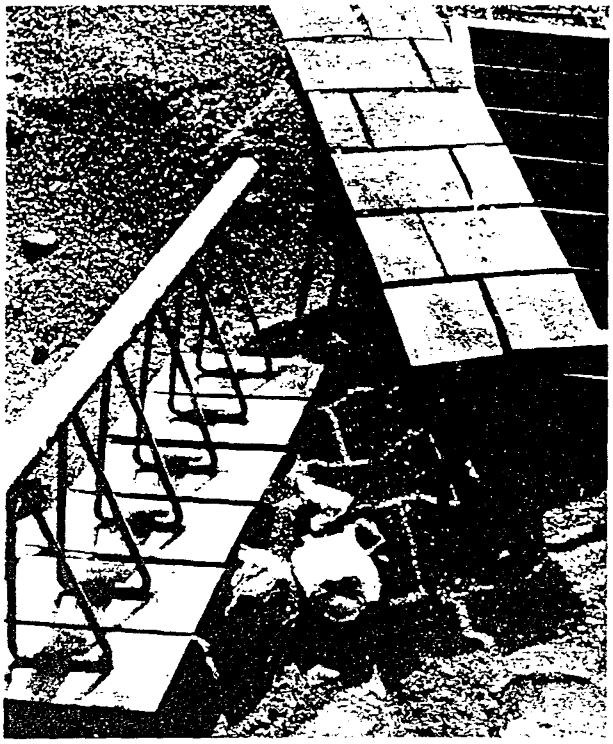


Fig. 3. Top plate.

Fig. 4. Stones being added to mould.

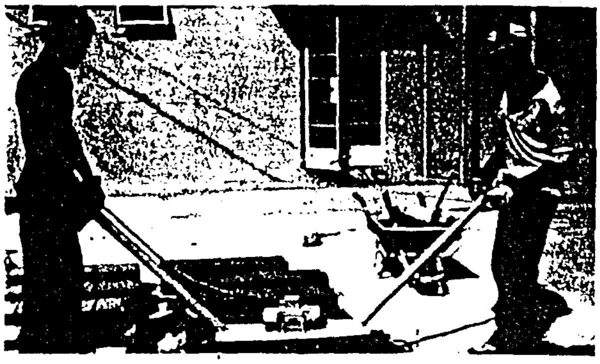


Fig. 5. Compacting with plate vibrator.

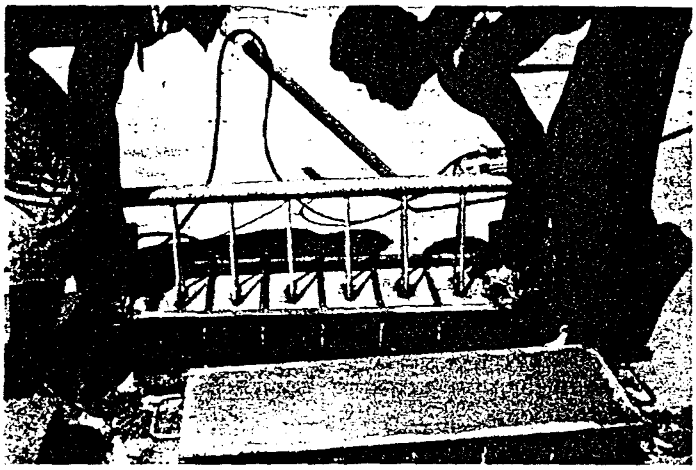


Fig. 6. Lifting mould using presser bar.

Fig. 7. Finishing tops of blocks.

Fig. 8. Casting yard.

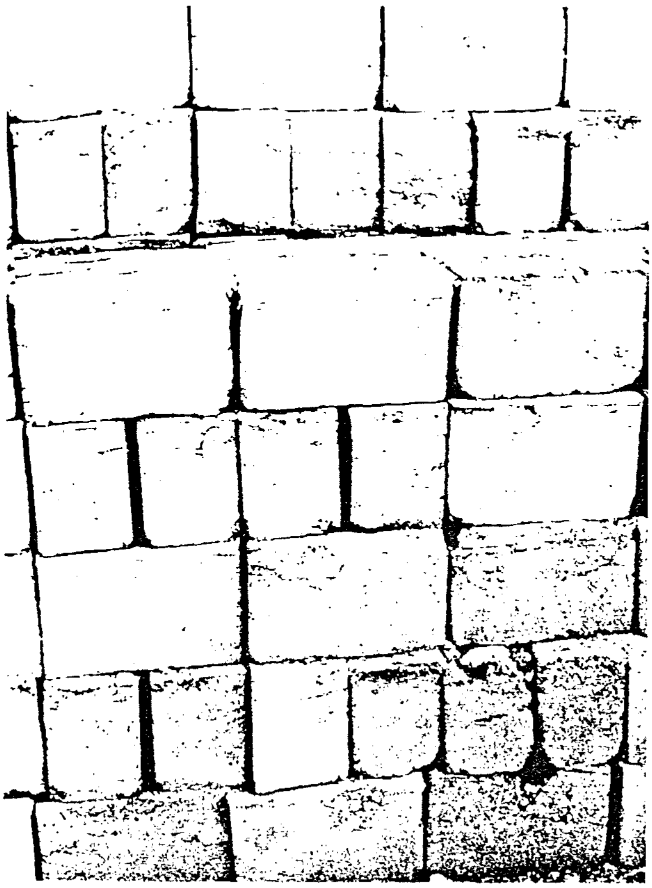


Fig. 9. Blocks stacked for use.

VIBRATOR

A 3000 RPM Shutter Vibrator is being used, mounted on a steel plate with handles at both ends, allowing it to be lifted on to the moulds. Rated at 220 watts, this vibrator requires 3 phase power. A flat bottomed rammer can be used to compact the concrete by hand. This gives similar results to the electric vibrator but requires more labour.

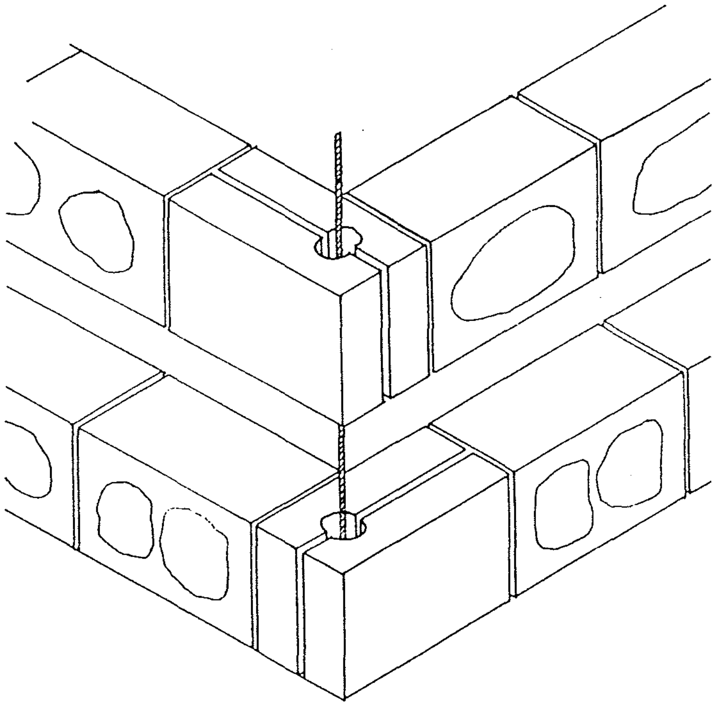
CASTING AREA

A flat concrete surface of some 500 square feet is required for production of 200 blocks per day. It has been found desirable to let the blocks set for 48 hours before stacking them to lessen damage from handling, which increases the necessary area. Output is dependent on the number and type of mould being used, the organization of the production method and the number of workers available.

A thin membrane is needed to prevent the block adhering to the casting surface. Polyethylene sheeting, mould oil or newspaper will do. Wheelbarrows, shovels, buckets, and stiff broom and a hose are also required for production.

USE OF BLOCKS

The blocks are laid in simple bond with the top and bottom as cast forming the inside and outside of the wall respectively.



Reinforcement in the corner block.

A ½" (10mm) mortar bed is used. Blocks intended for reinforcement are laid as cast, enclosing the steel in the hole formed by semi-circular cutouts.

Stone Masonry Blocks are used in design like any other masonry wall. The required strength of the concrete in the block will be determined by the design used. Provision for reinforcement by use of special blocks enables steel to be incorporated where required to properly tie to foundation, tie beams and floors.

BLOCK SIZE AND MODULE

Block production at the Building Research Institute has concentrated on a 12" long x 8" wide x 6" high module.

As these blocks cannot be cut, part blocks of ¼, 1 / 3, ½, 2 / 3 are required when forming openings, corners and junctions. Use of a modular block reduces this need for part blocks to ½ and 3 / 4 blocks.

Recommended dimensions for stone block modules are:

	NOMINAL	
Length	Breadth	Height
12"	8"	6"

	ACTUAL	
Length	Breadth	Height
11½"	7½"	5½"

METHODS AND MIXES PREPARATION

Before the start of a day's production:

1) The moulds must be clean and oiled;
2) The casting platform must be clear of stone and debris and a sheet of paper or plastic laid under the moulds.
3) The large stones must be broken to enable them to fit the moulds.
4) The gang moulds must be placed side by side in a row with gaps for demoulding.

MIXING

For the concrete, a nominal mix of 1:5:7 is used. This produces 55 blocks per bag of cement at a stone content of 30%, and would produce proportionally lesser or more with lower or higher stone content. Only sufficient water is added to give a dry, low slump mix. A standard slump of less than one inch is required. It is suggested that the stone pieces used cover volume between 30 to 50 percent of the block. The ingredients are thoroughly mixed dry and with the water added. Adjustment of the water content may be necessary if the mixed batch has lost moisture while block making is in progress.

PRODUCTION OF BLOCKS

The flat face of one or two large stones are placed in the bottom of the mould, ensuring that there is about ½" gap between the stones and between the sides of the moulds.

Concrete is placed around the stones and to fill the mould so as to cover them. This is trowelled into place to ensure no large voids at the sides or corners of the blocks. More pieces of stone are placed on top of this layer and tapped into place, the mould then being filled with concrete to approximately one inch above the sides. The vibrator is then placed on the concrete to tamp it into the mould. When cement paste is visible at the top and the concrete if flush with the mould the vibration is stopped and top trowelled flat. A smoother surface is obtained if a dry cement sand mix is dusted over the surface and trowelled in.

The mould is then immediately removed by placing a device to press down on top of the blocks while the mould is lifted. Care must be taken to lift vertically so as not to damage the blocks.

CURING

The blocks are left to harden for at least 24 hours before stacking and breakage is less if they are left longer. They should not be stacked more than five blocks high while curing. They are kept damp for two weeks to cure, and allowed to dry for two weeks. They are then ready for use.

PHYSICAL PROPERTIES

Compressive Strength

Stone Masonry Block is hetrogenious consisting stone pieces of different sizes and shapes and lean cem concrete. Further, the bond of the lean concrete with t stone pieces is very much influenced by the grading a type of the sand and coarse aggregate as well as t surface texture of the stone pieces. Added to this, t quality and position of placement of the stone pieces h great influence on the performance of the stone masor blocks under load. Therefore, depending upon the qual of cement, the type and grading of sand and coa aggregate, the quality and quantity of the stones used large variation in the strength of the blocks can expected. To know the actual strength of the blocks, it necessary that blocks be made by using the local materi and tested.

The average compressive strength values of the bloc tested in the Laboratory was 1000 p.s.i. For qual control, three blocks out of every 1000 blocks or a da production, which ever is less, be tested for compressi strength after providing proper capping as per t procedures laid down by codes.

Tolerance

The maximum variation in the length of the block sh not be more than ± ¼ inch and maximum variation height and width of the blocks not more than ± 1 / 8 in

STRUCTURAL DESIGN

The Stone Masonry Block Wall is designed like a other masonry wall. The provision of vertic reinforcement at corners and on either side of the openi can be easily provided by using special blocks with rece Necessary tie beams shall be provided at the lintel a roof levels.

COST ECONOMICS

There is a savings in cost of approximately 30% walling compared to cost of block and steel constructic The stone masonry block walling consumes less ceme since more than 30 percent of the volume of the blc consists of large and small stone pieces and the rest is le concrete. No rendering or painting is required for exter surface, since the outside face of the wall is a stone fa There are no block pockets to be filled with concrete.

COST ANALYSIS

ᴛONE MASONRY BLOCKS
OSTS – AUGUST 1985)

ost of Ingredients at the Building Research Laboratory, ngston, August 1985 prices:

ones	–	$40.00/yd^3
nd	–	$28.00/yd^3
ravel	–	$32.00/yd^3
ment	–	$27.00/bag (94lb.)

ix of 13 cu. ft. makes an average of 55 blocks with average ne content 30% i.e. 55x0.28x0.70 cu. ft.

= 10.78 cu. ft.

st of concrete/cu. ft. (1:5:7 mix) (Materials cost only)

= $3.77/cu. ft.

st Per Block

aterials

ne	0.30 x 0.28 x $\frac{40}{27}$	=	0.12
ncrete	0.70 x 0.28 x 3.77	=	0.74
ater Charges	(3% of 0.74)	=	0.022
ıbour	3 workers @ 36 blocks /hour x 6 hours @ $25.00 per day $\frac{3 \times 25}{36 \times 6}$	=	0.35

ndling and Watering Blocks

vorkers @ 1 block/minute = 0.104

lixing Concrete, 2 labourers @ mins./ batch and 9 batches/day

$$\frac{9 \times 10}{60} \times \frac{2 \times 25}{8} \times \frac{1}{216} = 0.043$$

eaking Stones 12m. hrs $\frac{12 \times 25}{8} \times \frac{1}{216}$ = 0.173

Other Charges

Mixer, depreciation and Diesel Oil	=	0.050
Mould, assuming 5 years usage	=	0.040
Casting Platform	=	0.002
Vibrator and electricity	=	0.020
Mould Oil	=	0.020
Total		$ 1.68 / block
		or US$0.283

Note: 1 US Dollar = 6 Jamaican Dollars
(In August, 1985)

COST COMPARISON WITH OTHER WALLING MATERIALS (In Jamaican Dollars)

Stone Masonry Block Cost Per Square Yard

18 Blocks @ $1.70	=	$30.60
Cost of 1:3 mortar in joints	=	$ 7.00
Labour Cost	=	$ 9.00
Assume½" Internal Rendering	=	$17.00
Total	=	J$63.60
		or US$ = 10.60

6" Concrete Blockwork

6" Blockwork	=	$54.00
Steel	=	$ 4.50
½" Rendering both sides	=	$34.00
Total	=	J$92.50
		or US$ = 15.42

Note: 1 US Dollar = 6 Jamaican Dollars (In August, 1985)

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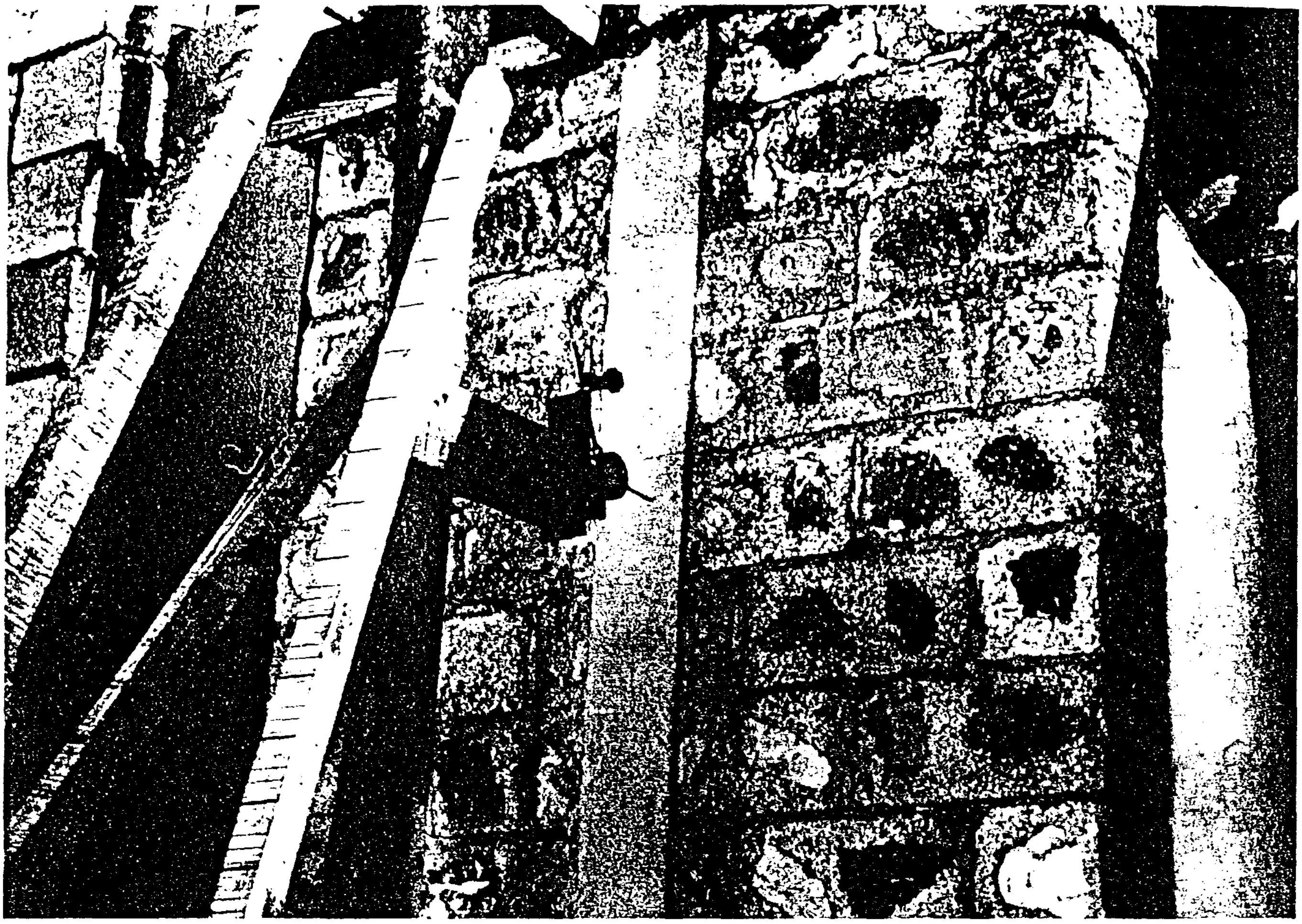
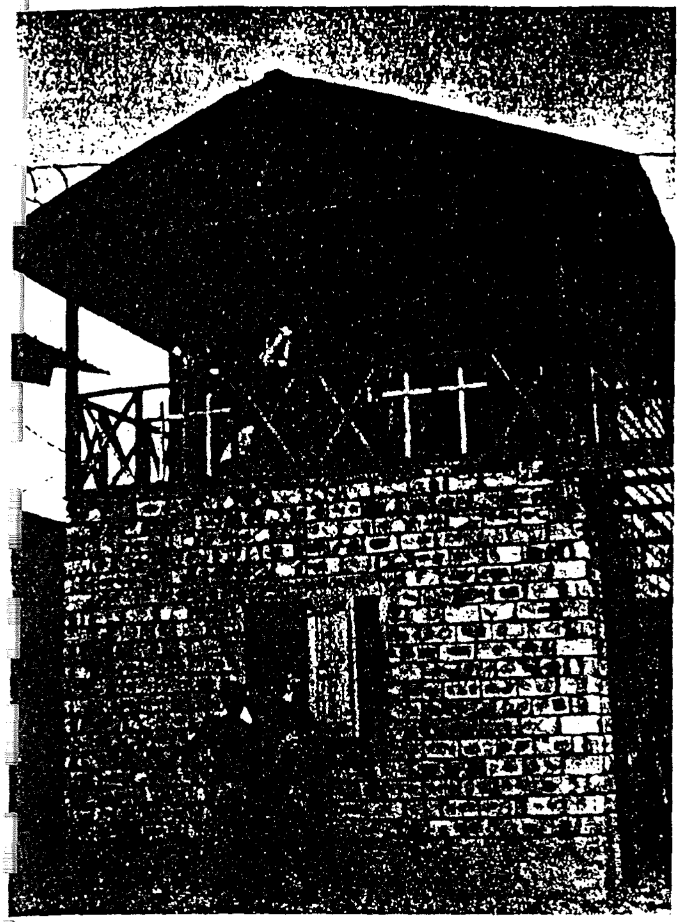
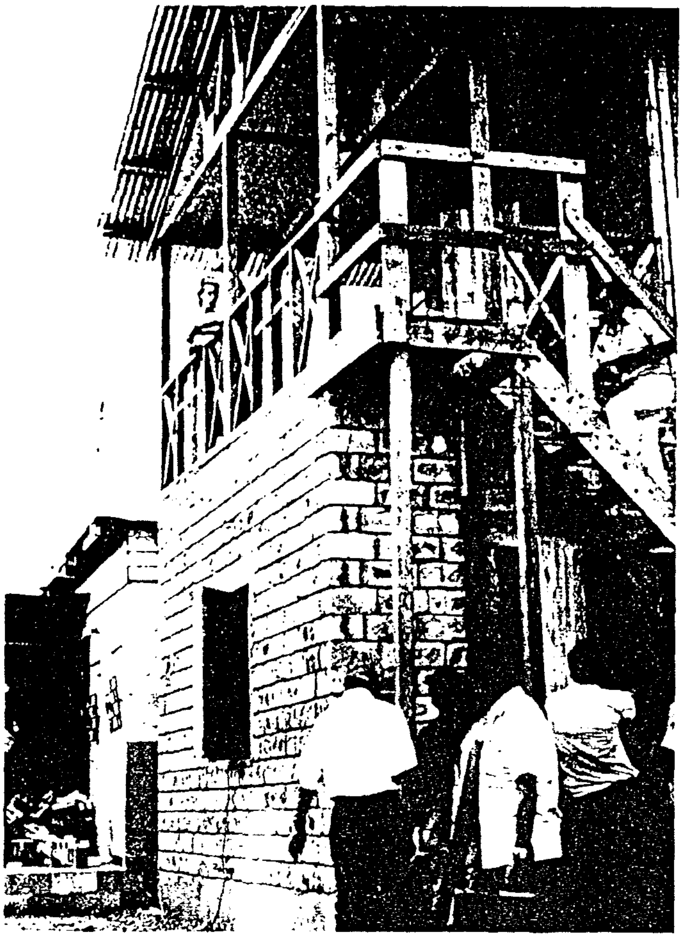


Air bag wall test arrangement

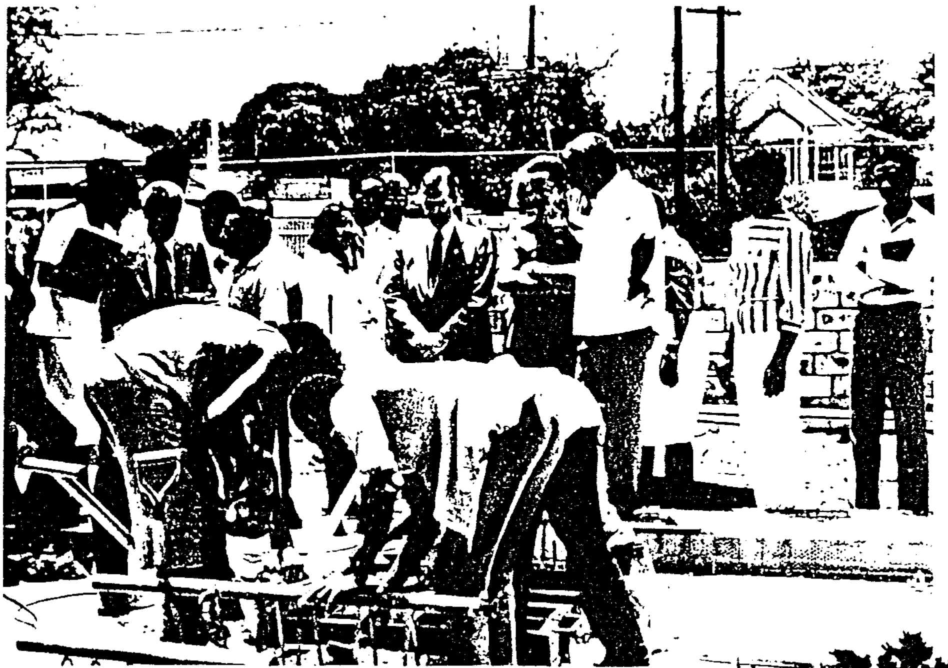
Unreinforced stone masonry wall at the time of collapse.



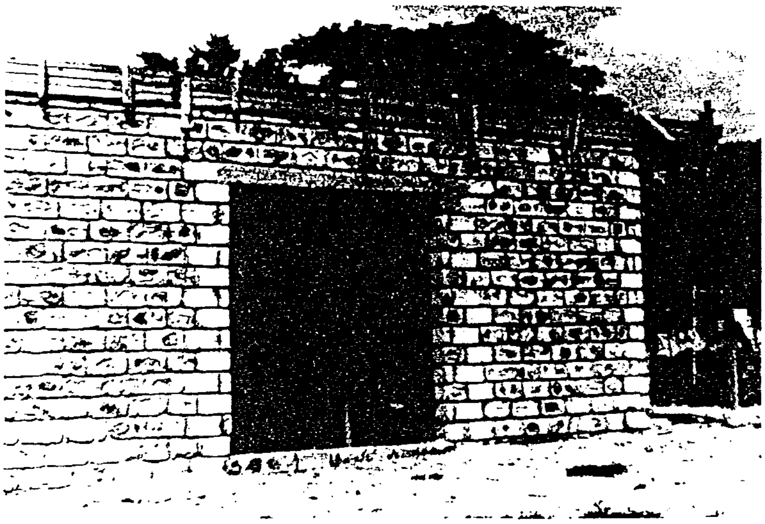
Mustard Seed workshop at Mona Commons.



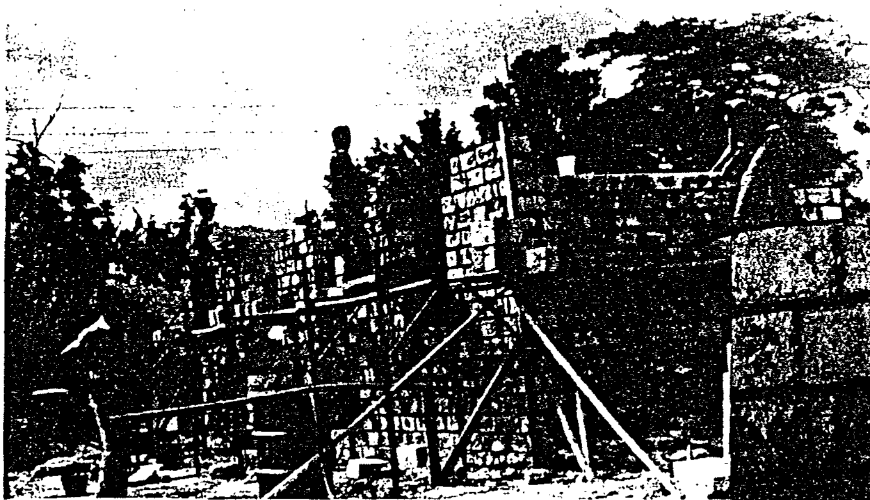
Stone block masonry walling.

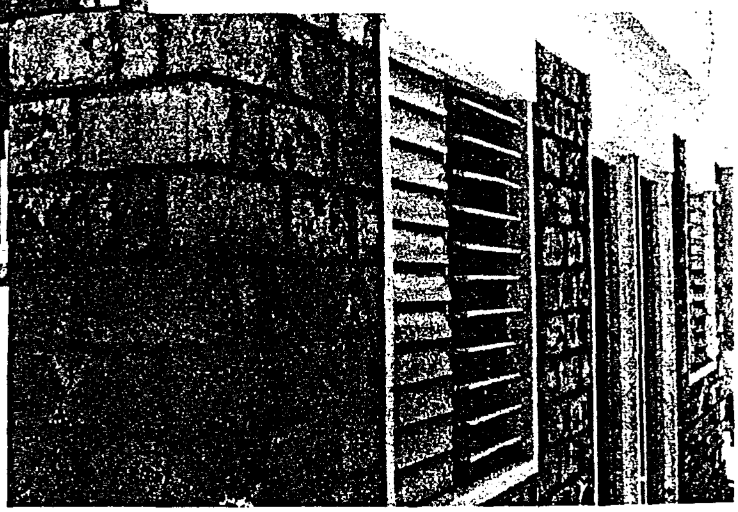


Prime Minister Edward Seaga with Minister for Construction, Bruce Golding and Director BRI Keith Gilfillan viewing stone masonry blocks production.



Basic school under construction at 100 Red Hills Road using stone masonry blocks for walls.





Demonstration Building showing stone masonry blocks at the BRI workshop at 2 Hagley Park Road.

ANNEXE 3

TRADITIONAL COOLING SYSTEMS

Articles by Development Workshop

Traditional Cooling Systems in the Third World

by
Allan Cain,
Farroukh Afshar,
John Norton
&
Mohammad-Reza Daraie

Today more than ever the technology of the industrialised world is being exported intact to the developing world. Western industries depend on marketing their wares to the Third World in order to buoy up their own countries' failing economies. For example, in Britain now 50 per cent of the building industry is dependent on foreign contacts.[1] The West's technological development was founded on the cheap raw materials and energies taken from the colonial world. Developing countries today do not have a world of resources to freely exploit and a few are now beginning, out of necessity, to look towards a more self-reliant road to development.

Agricultural technology in the United States now demands 5 calories of energy input to produce 1 calorie of food; on the other hand, in China 1 calorie input of energy produces 20 calories of food — 100 times less.[2]

There exist in the Third World a wealth of indigenous technologies which have largely been ignored, if not actually suppressed, during the era of rapid growth in the industrialised world. However large numbers of people in the rural areas and old quarters of cities and towns in the Third World rely entirely upon indigenous technologies. These technologies are almost always identified as signs of underdevelopment because they are most often employed by the poorer classes of society. Those who have never had access to large amounts of expensive energy have invented technologies which are efficient in use of local materials.

Millions of pounds are spent on the research and development of 'Advanced Technologies' — advancing them further and further away from any relevance to the majorities of the world. We believe that we must research and develop those "simpler" and not unadvanced technologies which the majority of the people in the Third World use and live within. Such a scientific reassessment of the indigenous in Third World countries could form the basis of a real development.

This article deals particularly with the indigenous technologies of cooling, using largely natural sources of energy and techniques which have been developed by people locally.

Maziara Cooling Jars

The Maziara is a traditional water cooling and purification system used in rural areas of Upper Egypt. The evaporative cooling properties of large porous ceramic water storage pots are employed. Similar methods have been used in different parts of the world to keep liquids and perishable food cool.

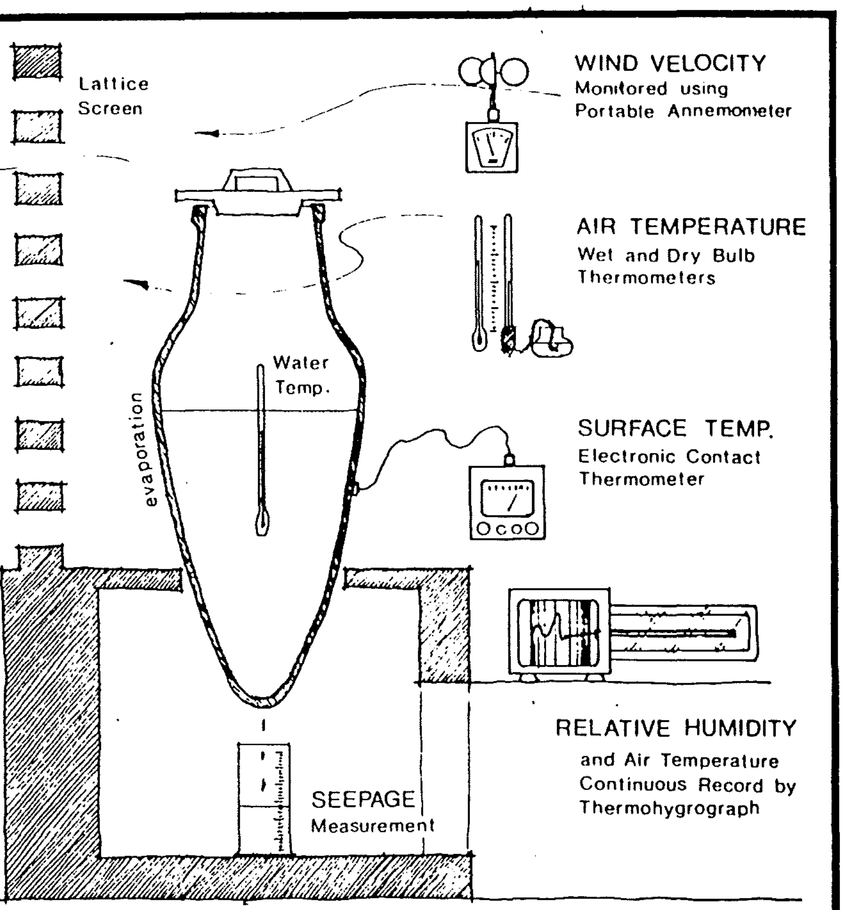
The supply of safe drinking water is a primary factor in the maintenance of public health in developing countries. Consideration must be given not only to the water source and its quality but also to the distribution and storage systems. In an Egyptian village area studied by the authors,[3] there was no modern system of piped water to individual homes. Water was available from wells or from the Nile River and its canals. Nile water and water from irrigation channels is unfit for drinking and often carries dangerous pathogens such as 'bilharzia larvae'. Shallow wells are also often polluted and clean water is only guaranteed from deep wells. Women collect water from these sources in the early morning and then carry water jars (bellas) on their heads back to their homes. Once home the water is stored in the Maziara. These large, unglazed ceramic jars hold the day's supply of water for drinking and domestic use.

The porous nature of the unglazed ceramic means that water seeps through the jar's wall, maintaining a wet outside surface. Some of the water evaporates and the rest drips down the sides of the jar and is sometimes collected. Drinking water is usually scooped out of the pot with a dipper, though it was discovered that water collected at the base after it had been filtered through the pot is much cleaner. The water in the Maziara is kept cool all day by the action of evaporation from the jar's outer surface. Evaporation, or the change of water from a liquid to a vapour, absorbs a considerable amount of heat energy (580 calories of energy for every cc. of water evaporated.) Heat is therefore continually drawn out of the water in the storage jars. The dry Egyptian climate means that the outside air can absorb a great deal of water vapour, and in turn a considerable amount of evaporative cooling can take place. The Maziara is usually situated so that it is in a draft, for air movement aids evaporative cooling.

An experiment was set up using portable meteorological testing equipment in order to evaluate the cooling action of the Maziara (Fig. 1) Water samples were taken at various stages in the system, to be measured later in the laboratory for purity.

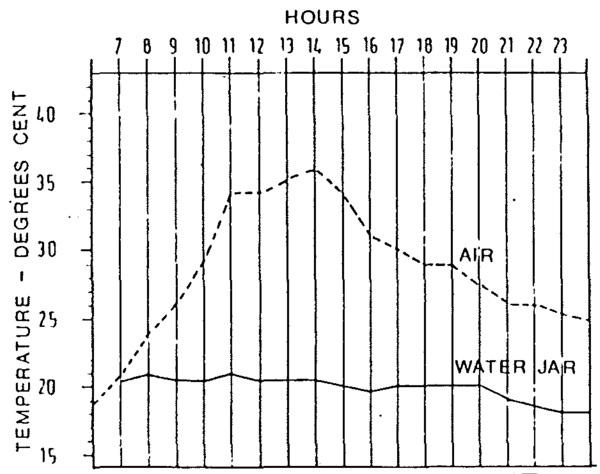
Results of the climatic tests showed that even though the outside air temperature ranged from 19°C. to 36°C. over the day, the temperature of the Maziara water remained relatively constant at 20°C. Since one feels comfortable in Egypt only between the narrow range of 21°C. to 26°C. the water feels refreshingly cool all day. The constant Maziara temperature (Fig. 2) may seem surprising with such a large air temperature range, i.e. 17°C. This can be explained by the fact that as the day progresses and the air temperature rises, the relative humidity (the amount of water vapour in the air) decreases (Fig. 3). As the air becomes drier more water evaporates from the water jar's surface and the cooling rate increases (Fig. 4).

Fig. 1



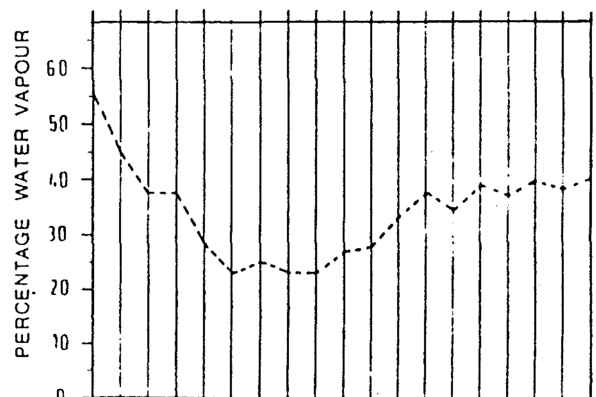
MAZIARA WATER JAR TESTING METHOD

Fig. 2



COMPARATIVE TEMPERATURES OUTSIDE AIR VS WATER JAR

Fig. 3



RELATIVE HUMIDITY OF AIR

The Maziara though mechanically simple proves to be a very sophisticated system; its temperature self-regulation is a response to local climatic changes.

Over a 16 hour test period a single jar produced 1700 k. cal. of cooling. At the hottest time of the day the jar's cooling rate was 165 k. cal./hr. or about 192 watts (Fig. 5).

In order to test the Maziara's water purification action a series of laboratory tests were made on water samples. Into the Maziara was placed water collected from the nearby Nile River. Samples were taken from the river source and from the effluent runoff after water had been allowed to filter through the Maziara system. Other samples were taken from inside the jar. Samples were tested in the Government laboratories in the Luxor hospital and it was found that the filtered outflow water was pure to the Government's drinking water standards, even though the original Nile water that was put into the jar was contaminated.

Pollutants can either be suspended in the water or chemicals dissolved in the water. The filtering action of

Fig. 4

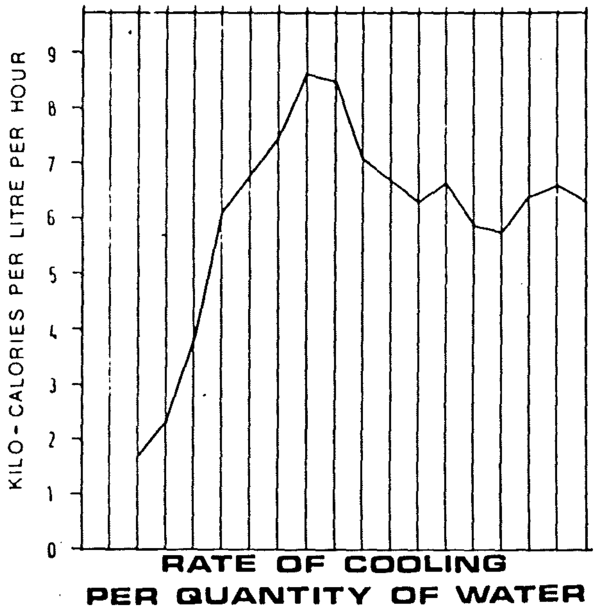
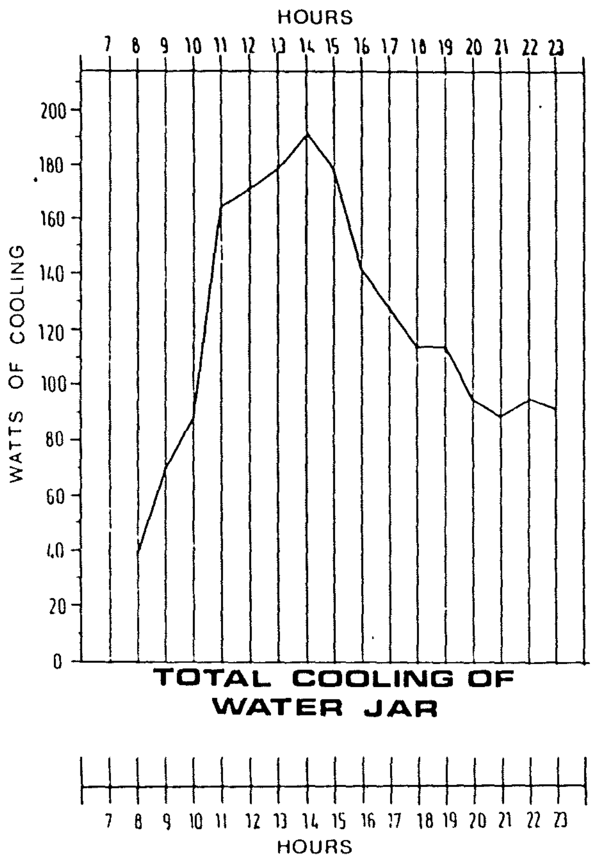


Fig. 5



the Maziara removed some of the suspended pollutants, but filtering alone cannot remove harmful chemicals or all microscopic organisms. It is therefore assumed that there were no such elements in the original samples taken. If the cleaning action of the jars is to be maintained they would have to be rinsed periodically and sterilised with boiling water.

The result of the purification tests illustrates that chances of drinking water contamination can be reduced if the Maziara's filtering action is used.

Western Technology versus the Indigenous

It is interesting now to compare the indigenous Maziara cooling jar method to its Western counterpart, the mechanical cooler.

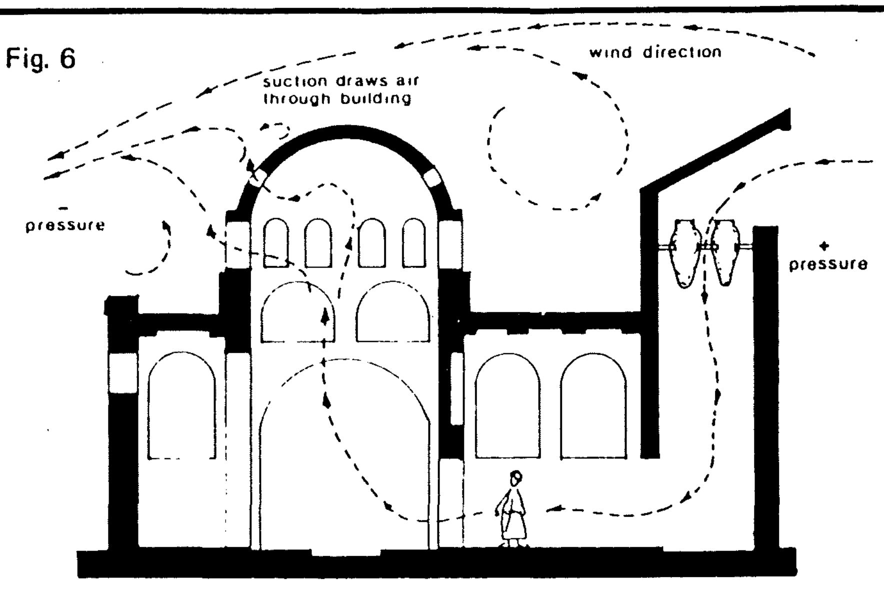
Technological sophistication is usually measured in terms of the number of transistors or moving parts. On this count the mechanical air conditioner could be called a piece of advanced equipment. If we evaluate sophistication in terms of efficiency we find the opposite. An air conditioner producing 12,000 BTU's of cooling will in turn consume 2400 watts of electrical energy.[4] This means that an equivalent of about 70 per cent of the total cooling output is required in electrical energy to run the unit. The Maziara cooling jar method, on the other hand, requires no other energy than that required to fill the jar with water in the morning. It is, as well, totally self regulatory and responsive to climatic changes without the aid of a complicated thermostat. The inefficiency of these mechanical systems is compounded and in global terms: "200 million Americans use more electricity for air conditioning than 800 million Chinese use for everything."[5]

The hazards of modern air conditioning systems are rarely advertised in the glossy brochures distributed by companies' dealers in the Third World. Mild shock sometimes occurs at the entry of an excessively cooled building, if the temperature differences between inside and outside are too great. Mechanical air conditioners often produce pools of very dense cold air in the lower parts of rooms. Such stratification of temperature over long periods affects blood circulation, respiration and other bodily functions particularly in children and old people.[6] Indigenous cooling systems by the very fact that they are usually naturally regulated, avoid these dangers.

Most of the vast rural areas of the Third World do not have access to electricity in order to power a mechanical unit, and must therefore rely on some other non-energy consuming method. The average per capital income of people in many countries, if accumulated over several years, would hardly be enough to purchase the cheapest mechanical air conditioner. On the other hand, a large unglazed jar suitable for cooling, costs less than a pound, and can be made in a village kiln, and could if developed form the basis of a small industry.

Comparative experiments are currently being planned by the authors

Fig. 6



WIND-CATCHER WITH COOLING JARS
Air is cooled as it passes over evaporative cooling jars

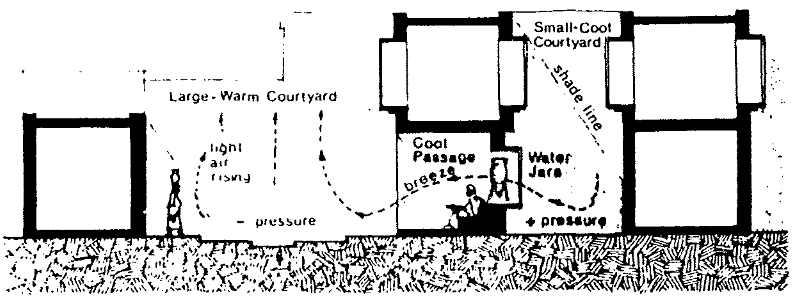
in Iran, in the use of water jars for air cooling within buildings as against mechanical cooling. In theoretical terms, five or six water jars, each producing up to 200 watts of cooling, would be equivalent to a small window-mounted mechanical cooling unit of 1000 to 1200 watts.

Development of Local Technologies
A wide variety of cooling solutions based on the principles illustrated above have been developed indigenously in Third World countries, and there is still much scope for their improvement and wider use. Porous water jugs and even simple dampened reed matting have been used in conjunction with wind catching towers, which funnel air down into rooms of houses after it has been conditioned by evaporatively cooled surfaces (Fig. 6). Professor Hassan Fathy, in a design for a wind catcher for a school in Upper Egypt, used beds of wet charcoal for air to pass over before entering rooms, and he reports a drop of 10°C. in air temperature.[7] In Iran, wind shafts often lead to basement water cisterns. Both the air and water is cooled by the effects of evaporation. The water being stored underground retains its coolness, and the air after being cooled is directed up into the rooms of the house. (More information on the wind catcher as an air cooling device can be found in *Architectural Design Magazine*, April 1975, pp 217-218, by the authors.)

The courtyard of the Middle Eastern or Mediterranean house has long been known for its cooling properties.[8] The court acts as a well to trap cool night-time air and retain it throughout most of the day. An interesting adaptation of the typical case is the two courtyard house. One court is small and deep and therefore generally shaded and cool; the other is wide and open to the heating of the sun's radiation. Air in the small courtyard, being cool and dense, has a higher pressure than the warm air of the large courtyard, which tends to be lighter and therefore rises. If an opening or passageway connecting the two courtyards is well positioned, there will be air movement induced by convection from the cool courtyard through the passage to the warm courtyard. The air's velocity is controlled by the size and nature of the passageway as well as the temperature and pressure differences between the two courtyards. Water cooling storage jars if placed in this passage will add to the cooling effect of the breeze (Fig. 7). In houses where this feature is employed, the inhabitants spend the hottest hours of the summer days in this cooled space between the courtyards.

In Muscat Oman, water jars have been mounted in specially designed window openings, not only for the provision of cooled water but to reduce the temperatures of the air passing over them and entering the room (Fig. 8). Similarly in India simple coarse woven mats over window openings when wetted cool the air passing over them into the room. Such matting usually needs rewetting by hand every 20 minutes. A recent development in India based on research into the indigenous method is an air conditioning unit (Fig. 9) using matting of khus-khus grass, which is widely available in Northern India and gives off a pleasant aroma when wet, in conjunction with a water reservoir and a small mechanical fan. The water reservoir maintains a controlled drip which is just enough to keep the matting wet. A low voltage fan, which could even be battery powered, is the only energy consuming part of the unit.[9] A development upon this could use a roof-mounted wind trap to provide air

Fig. 7



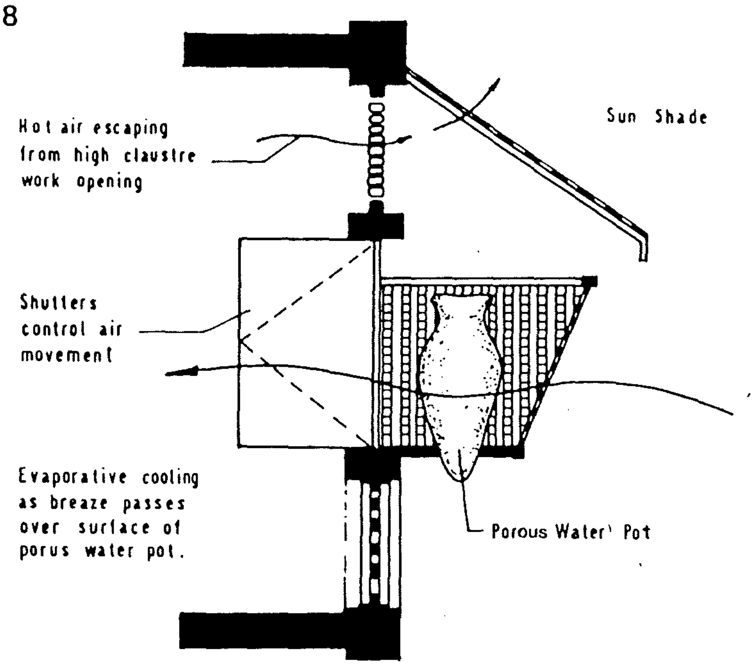
TWO COURTYARD HOUSE – AIR MOVEMENT INDUCED
Convection system between courtyards. Breeze is drawn across cooling jars

movement and the fan as only a back-up system.

Perhaps more important than air cooling is the cooling and storage of perishable foods. A large percentage of the total food produced in Third World Countries rots and is lost before it is eaten because of the lack of any cooling storage facilities. Again in India evaporative coolers have been used indigenously which could help alleviate this problem. A domestic cooler was developed using a porous outer water jar and a glazed inner jar as a dry compartment to hold the food (fig.10). The space between the two jars acts as a reservoir for water, which keeps the exterior porous jar wet. Evaporation of water from the surface of the outer jar keeps the whole system, including food stored within it, cool.

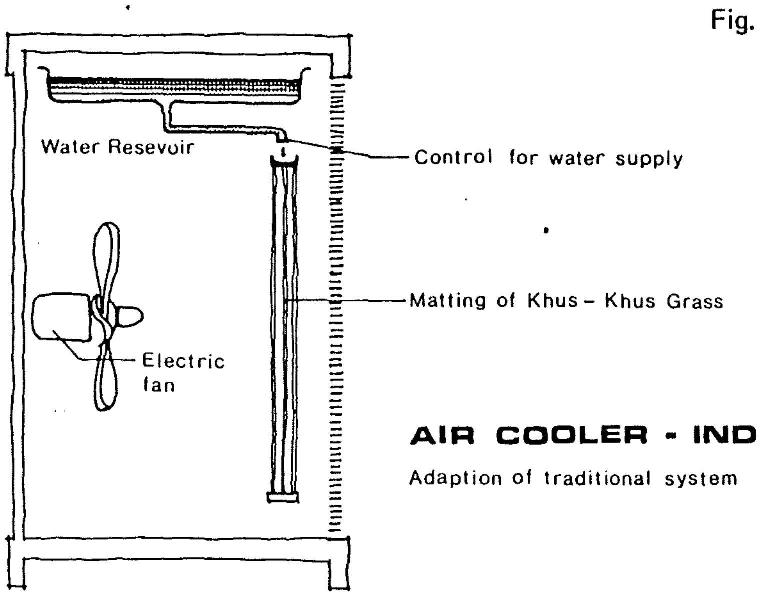
This article has dealt with some of the technological innovations that have grown out of an indigenous scientific approach to a basic problem — cooling — in many Third World countries. It should be seen as one example out of many such neglected systems which could be developed upon. Technologies adopted, as well as the approach taken to the improvement of indigenous methods of solving problems have a strong impact upon the direction of the road any society chooses towards development.

Fig. 8



WINDOW MOUNTED COOLING UNIT - MUSCAT

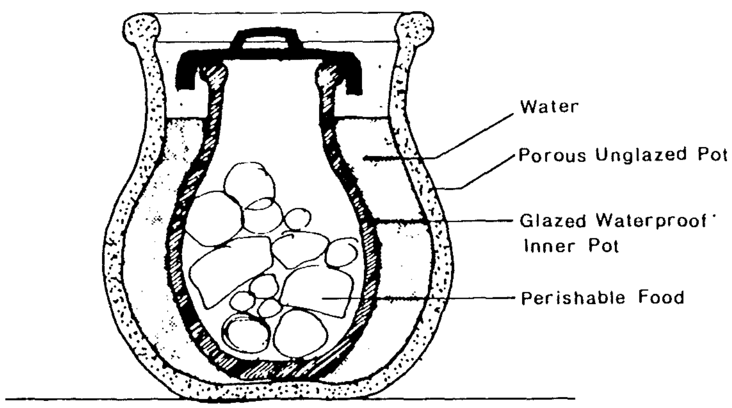
Fig. 9



AIR COOLER - INDIA

Adaption of traditional system

Fig. 10



FOOD STORAGE COOLING UNIT - INDIA

Evaporative cooling from moist exterior surface

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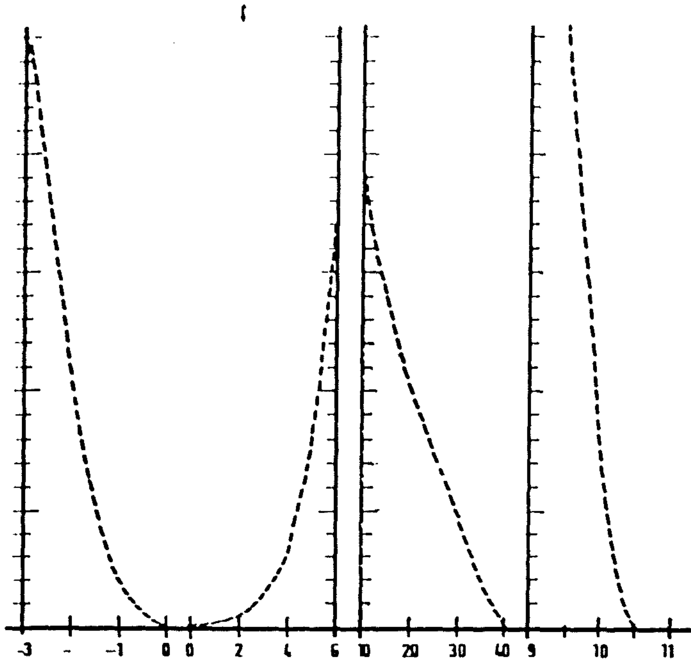
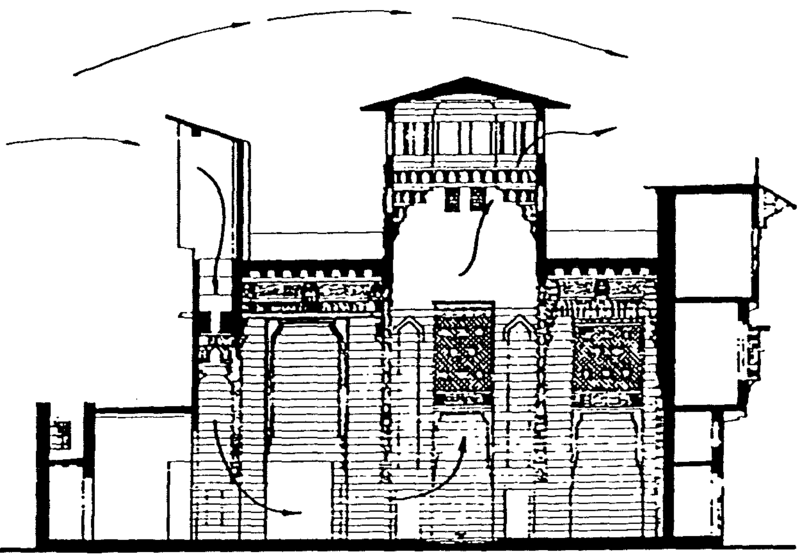
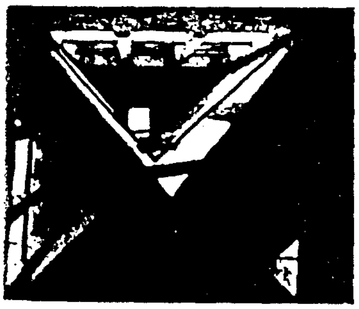




Uni-directional windcatcher. Ka Mohib al Din, Old Cairo.

Wind catchers.

Windcatchers



Looking up the shaft of a multi-directional windcatcher.

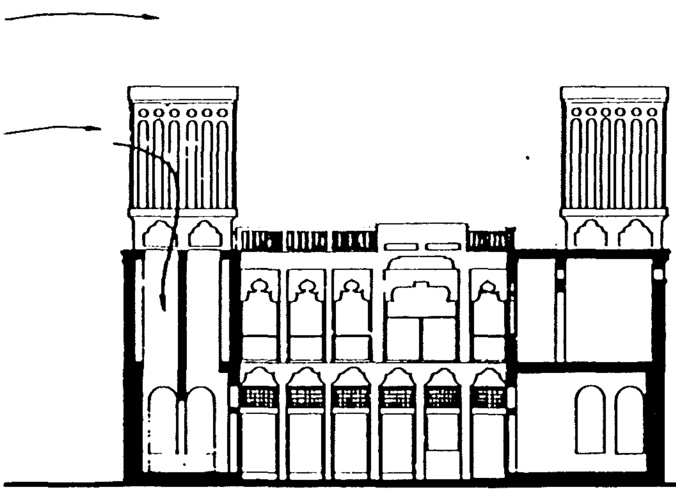
The wind catcher or wind tower as an element in the traditional house form can be found in settlements ranging from the Sind region in Pakistan, through Iran and Arabia to Egypt and North Africa. Its design form varies from region to region according to climatic conditions. In general, their use proves advantageous in hot regions where air movement can provide some degree of cooling, just as air passing over the skin's surface helps the body to lose heat through evaporation.

As shown graphically, the wind catcher, in having its intake as high above ground as possible, obtains air which is cooler and cleaner. This is even more important in dense urban areas where breezes are inhibited at ground level and the air is hot and dusty. The wind tower must be high enough above the roofs to catch an unobstructed high level air stream. It is usually oriented so as to catch favourable breezes. For example, the Egyptian wind catcher (Malkaf) has a scoop-like form and those studied in the old quarter of Cairo usually faced north to intercept the breeze off the Nile from the Mediterranean. The catch is one-directional, since winds blowing from other directions are from the desert and are hot and dusty.

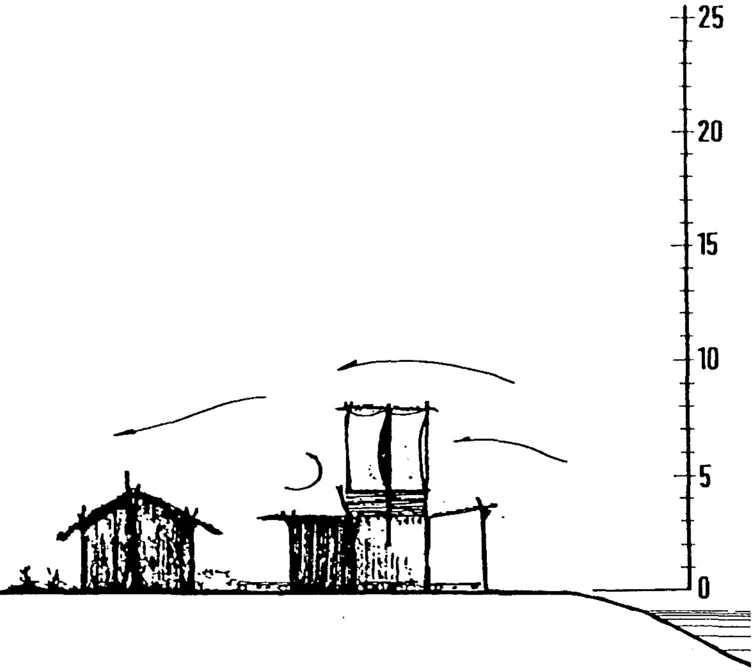
It became apparent in Cairo after making tests on the wind tower throughout a daily cycle, that its function is not dependent purely on the wind's ability to force its way into the house. In fact, during the heat of the day, a breeze will tend not to enter the house, even if the catcher is open, because the air inside the house is already cooler than outside, the temperature inside being kept down by the massive loadbearing walls which retain much of the previous night's coolness. The cooler interior air is dense and has a higher pressure than the hot, lighter, exterior air. The walls keep the inside temperature constant at about the daily average; so that in the afternoon or evening, when the outside air does fall below that average, the exterior air's temperature and pressure relative to that of the interior has reversed and air flows freely into the house. Thus the wind catcher only functions when it is needed, and only encourages cooler air into the interior. The whole house functions to control the micro-climate within, and responds to the climate in different ways at various times throughout the day.

The design of the wind catcher itself is not the only consideration. The air outlet is just as important. While wind blowing from a single direction exerts a positive pressure on the front face of the building, it also creates a suction on roof and leeward wall. If exhaust openings are located in these areas, air will be sucked or drawn through the building. The section of the Cairo house illustrates how a raised section of the roof is employed as an air exhaust. Its roof is of light construction and heats up rapidly, thus heating the air underneath it. This warm air rises and escapes, leaving a low pressure area behind, which induces more air movement upward and outward.

Thus this one example in Old Cairo teaches us that the wind catcher design depended upon not only a consideration for the prevailing wind, but also upon



Multi-directional wind catcher. Courtyard town house, Dubai.



Cloth multi-directional wind catcher. Beach house, Batina coast, Oman.

he micro-climate within the)uilding, influenced by the heat :apacity of the building naterials, as well as a concern 'or the effective escape of the :xhaust air.

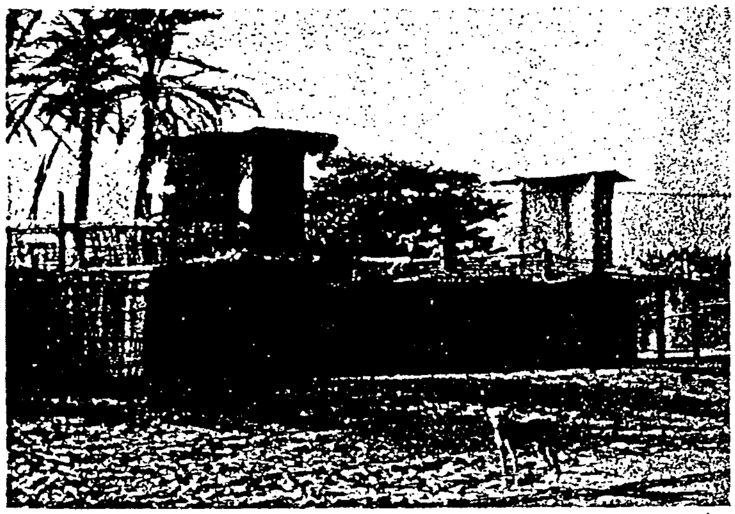
In Iraq, an ingenious solution o the problem of variable wind lirection is the incorporation of sail or fin-like projection into a)ivot-mounted scoop, to keep it acing the wind at all times.

A simpler and more common olution to shifting winds is the nulti-directional wind catcher 'badgir' in Persian) found in the \rab Gulf region and Iran. In ırban areas, these towers are laborately sculpted and lecorated. A horizontal section hrough one of them would how an X configuration. Vinds from any direction are hus admitted into the house. 'his kind of tower is found ısually on the coast where land-ea breezes are in effect. During he day the wind catcher admits ool air off the sea, while at night ›reezes blow off the land. In ooler seasons, when air novement is not needed, traps re shut and the wind catchers')penings covered.

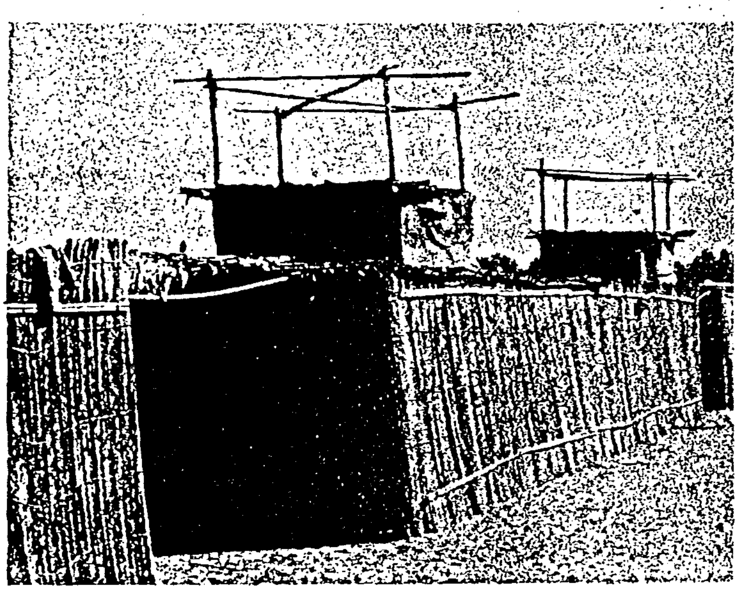
In rural areas, on the Batina Coast of Oman, cloth sails like wind catchers are used which have a similar X configuration to those of the Arab Gulf. These in some ways are more directly responsive to the climate as they are demountable and can be taken down and stored in the winter.

Some wind catchers are able to cool the air before it enters the building. Air is often drawn through a cool basement chamber, or across a bed of planting, before entering the living quarters. Evaporative cooling can be incorporated into the wind catcher in the form of porous water-filled jars, or mats of wet grasses. Hassan Fathy, in the design of a wind catcher for a school in his Gourna Village, used beds of wet charcoal for the air to pass over before entering rooms, and claims to have measured a drop of 10°C in air temperature.

With the costs of mechanical air conditioning remaining prohibitively high, the use of the wind catcher could prove advantageous today in many regions.



Cloth wind catcher



Cloth wind catcher

Study of Qa'A Mohib-al-din

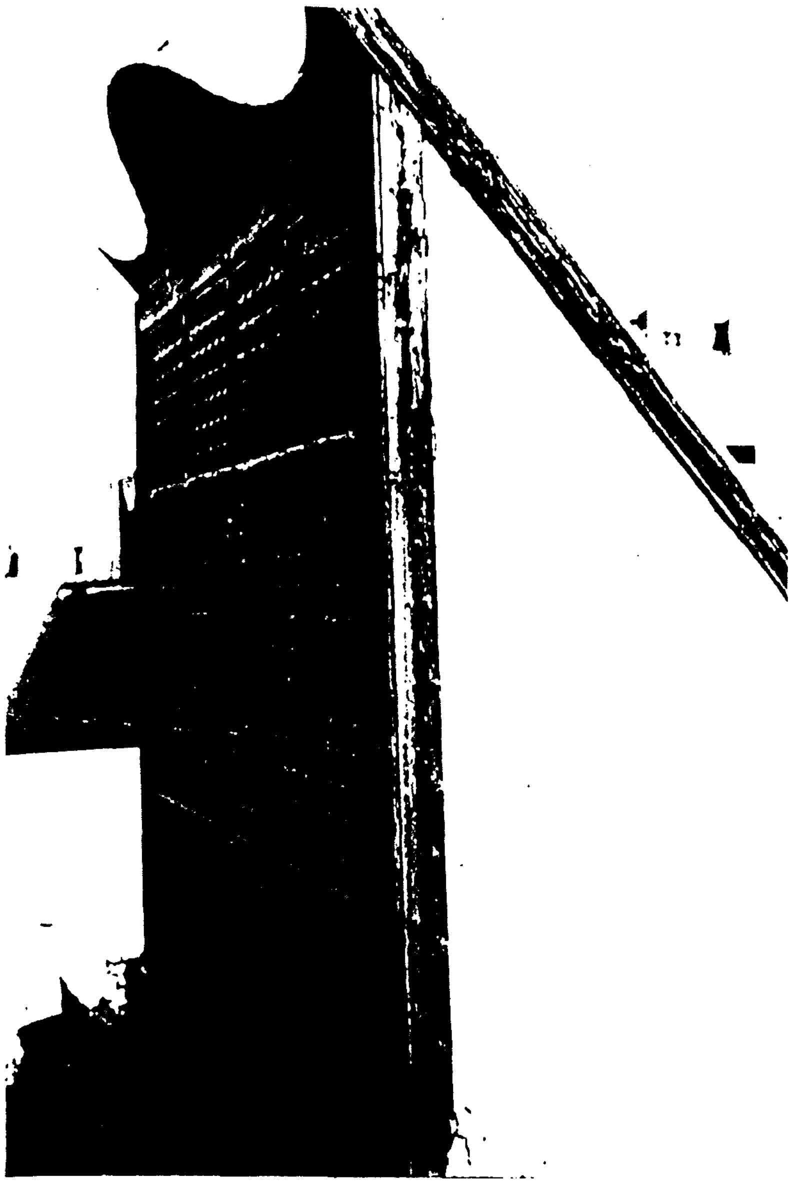
One of the buildings containing a wind catch which we surveyed was the Qa'a Mohib al Din in Old Cairo and shows the principle simply. This house was built in the 14th century and illustrates more clearly than any other that we studied, the design concept of the Qa'a which is discussed in another section of the report.

The catch itself is oriented towards the northerly prevailing winds. The air is drawn down a shaft through two gates or doors which can be opened or closed to determine the amount of air entering. The air then moves down across the floor through the useable parts of the room. The air escapes by high openings at the top of an upraised circular projection above the central Qa'a. This upper area collects hot light air by the convenction principle; therefore it is a low pressure area, helping to draw the air out that way.

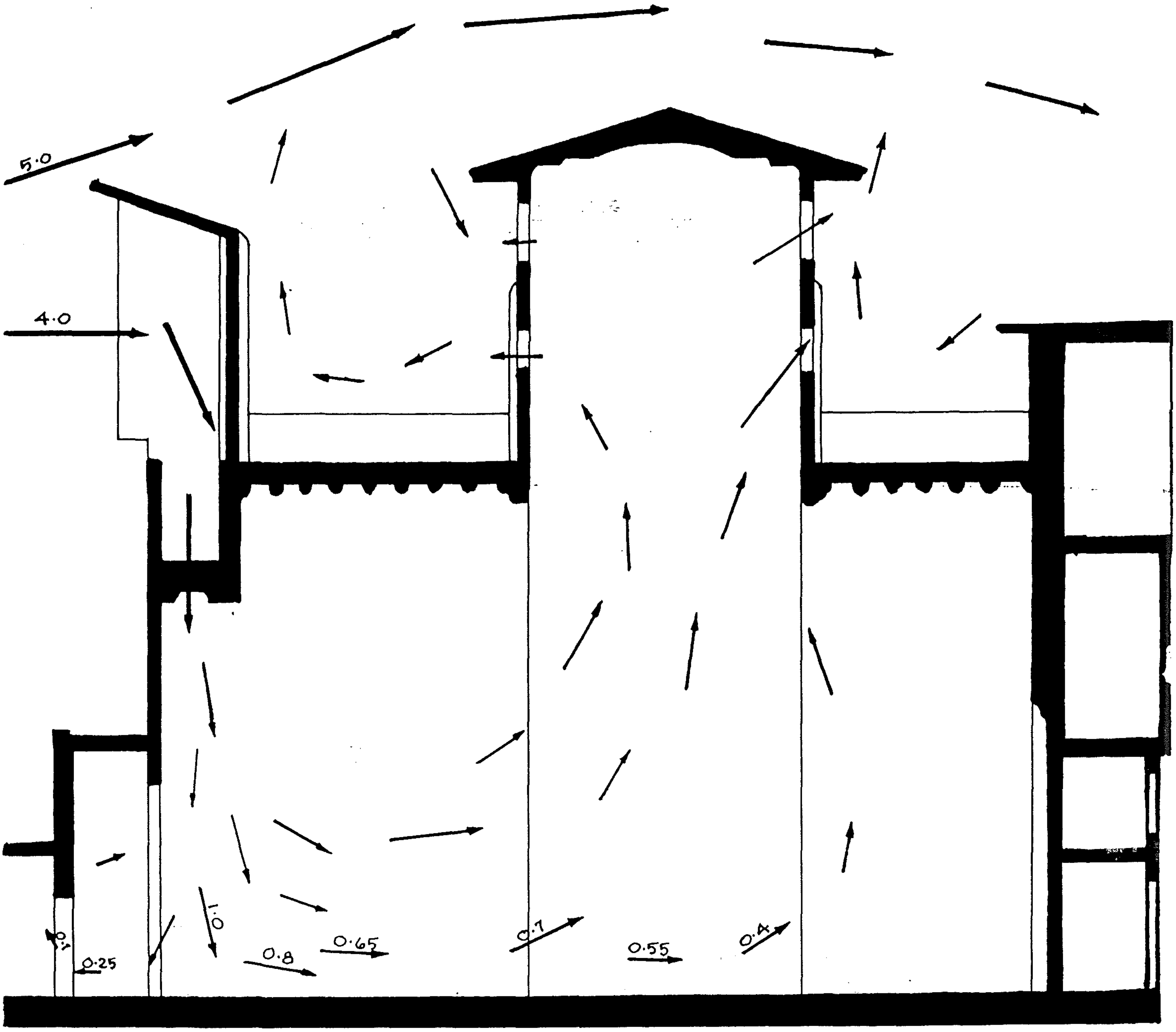
The high roof above the central Qa'a is of light construction and relatively flat, because of this it heats up quickly and in turn heats the air collecting here to a further degree aiding the air movement. We have noticed that even without a wind outside the convection system within this building works because of this particular design.

Air movement cannot be looked at alone as can be seen here. Localised temperature differences within a large building can modify the pattern. In the Qa'a Moheb al Din we were interested to find that during most of the day we were comfortable inside the building because our bodies were continually radiating heat to the cool walls (i.e. the walls were cooler than the air).

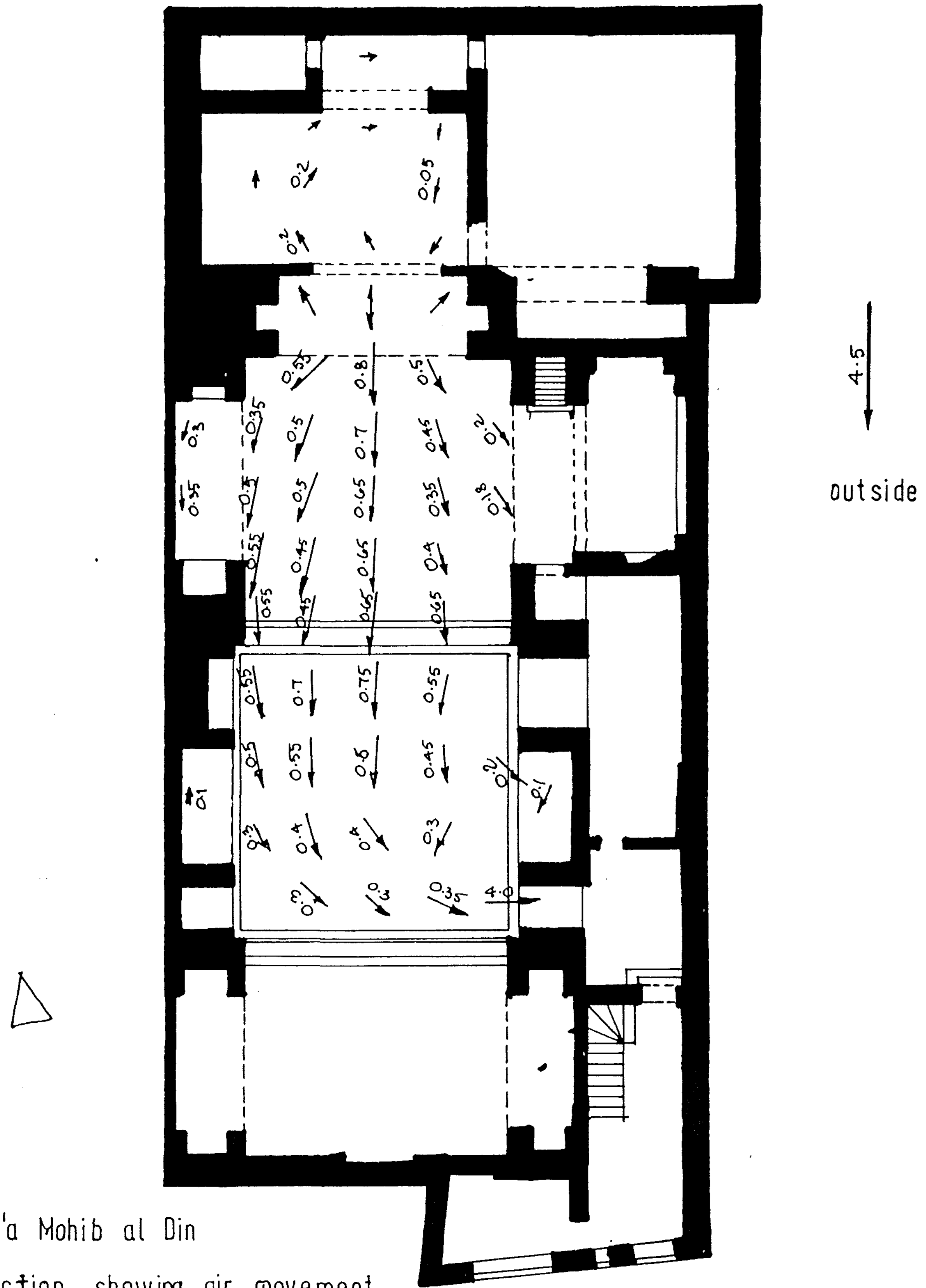
There are many ingenious variations on this basic model including multi-directional catch devices (persia) for areas where the wind often shifts directions. Systems for introducing porous water jars or wet materials into the mouth of the catch to encourage evaporative cooling of the air before it reaches a person within the building and many solutions for the design of the exit vent to produce a low pressure in that area and actually draw the air through the building.



The reason for the relative coolness will be explained in the next section. As the walls became warmer later in the afternoon this radiant cooling effect was lost and at this point the air movement, due to the system described above, increased dramatically. This increase may have been due to a slight change in wind direction outside and the fact that a cool breeze tends to blow from the north in the late afternoon and evening. This particular increase in air movement though may also relate to the relationship between indoor and outdoor temperature within the building is raising due to the fact that the walls are beginning to radiate warmth. The air within the building in this case being relatively warmer than the outside air has a lower density or pressure. Air always moves from high to low pressure hence air movement occurs here as a convection system is set up, through the building.



Qa'a Mohib al Din – section showing air movement
figures are in meters per second
arrow lengths proportional to velocity
measurements made April 2, 1973



Qa'a Mohib al Din

Section showing air movement

figures in m./sec.

1·3 m. from floor

Test Room (B.R.C.) Air Movement Study

One of the test rooms built by Hassan Fathy at the Building Research Institute in Cairo incorporates a traditional malkaf or windcatch into a simple vaulted roof design. The construction material here again is basically mud brick.

Even though the room is quite small, measuring 5 meters by 4 meters it illustrates well how an element found in vernacular architecture of urban areas of this region can be incorporated into contemporary designs such as low cost housing groupings. Although the malkaf is used often to bring air into generally inaccessable parts of the house such as rooms without windows facing the outside, it can also be employed on single story structures. In this case the windcatch stands above the rest of the building in order to draw air from above the layer of hot dusty street air. This malkaf could also protrude above the roof level of surrounding buildings in order to catch the unhindered free moving breeze. As with all wind catchers in this region the opening is fixed to catch the prevailing northerly winds.

This particular room was designed with a number of different kinds of openings. For our purposes we will classify the openings on the north wall or windward side of the building as air inlets and the openings on the south lee side as outlets. The north wall as seen from the plan and section contains the malkaf openings at the top and a window; while the south wall contains a door, a window and a large vent type opening at top.

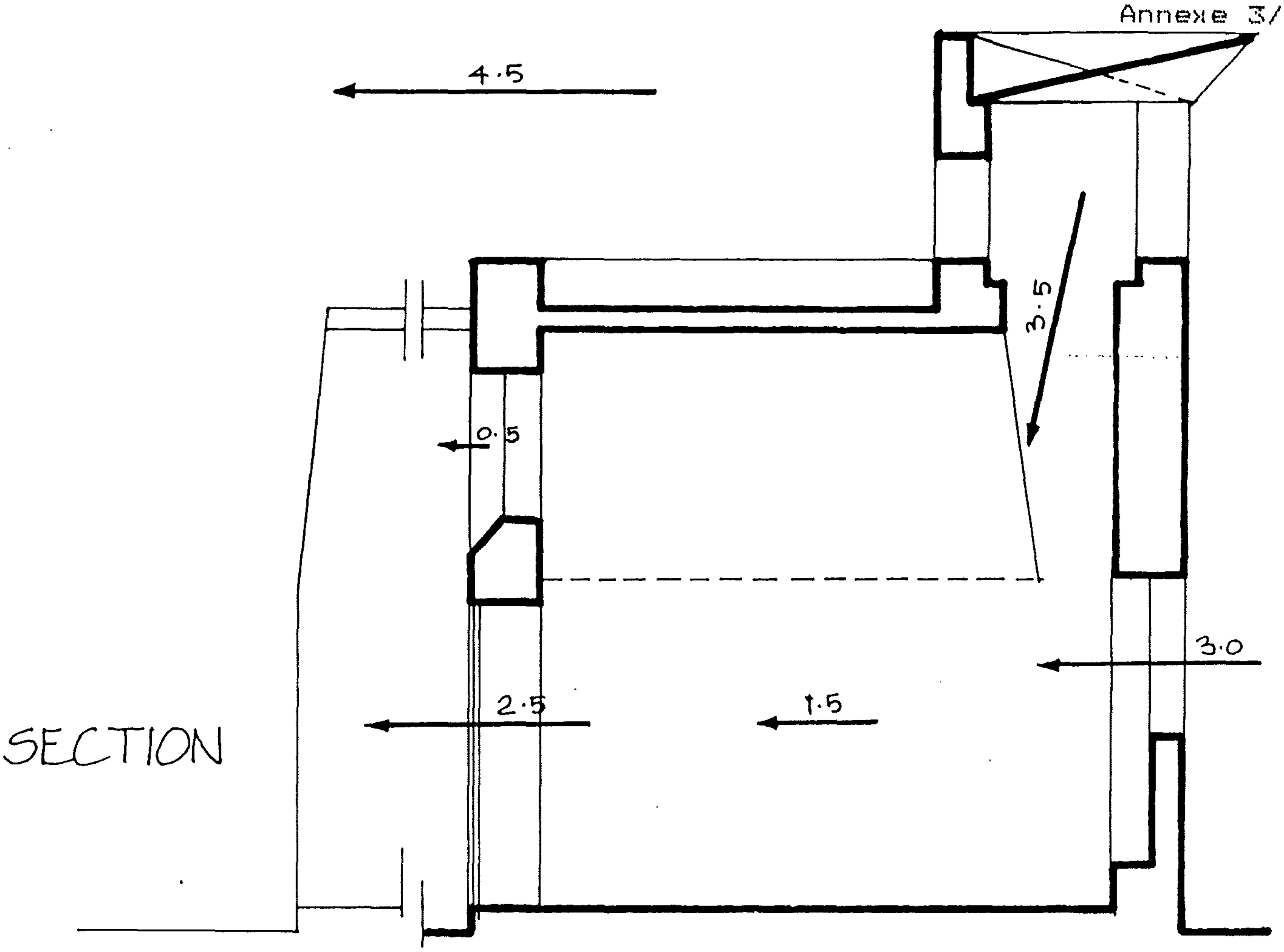
We were interested in finding the effects of opening and closing various inlets and outlets, on the air movement inside the room. We also wished to discover the relationship, if any, for the size of inlet openings and outlet openings to the air movement.

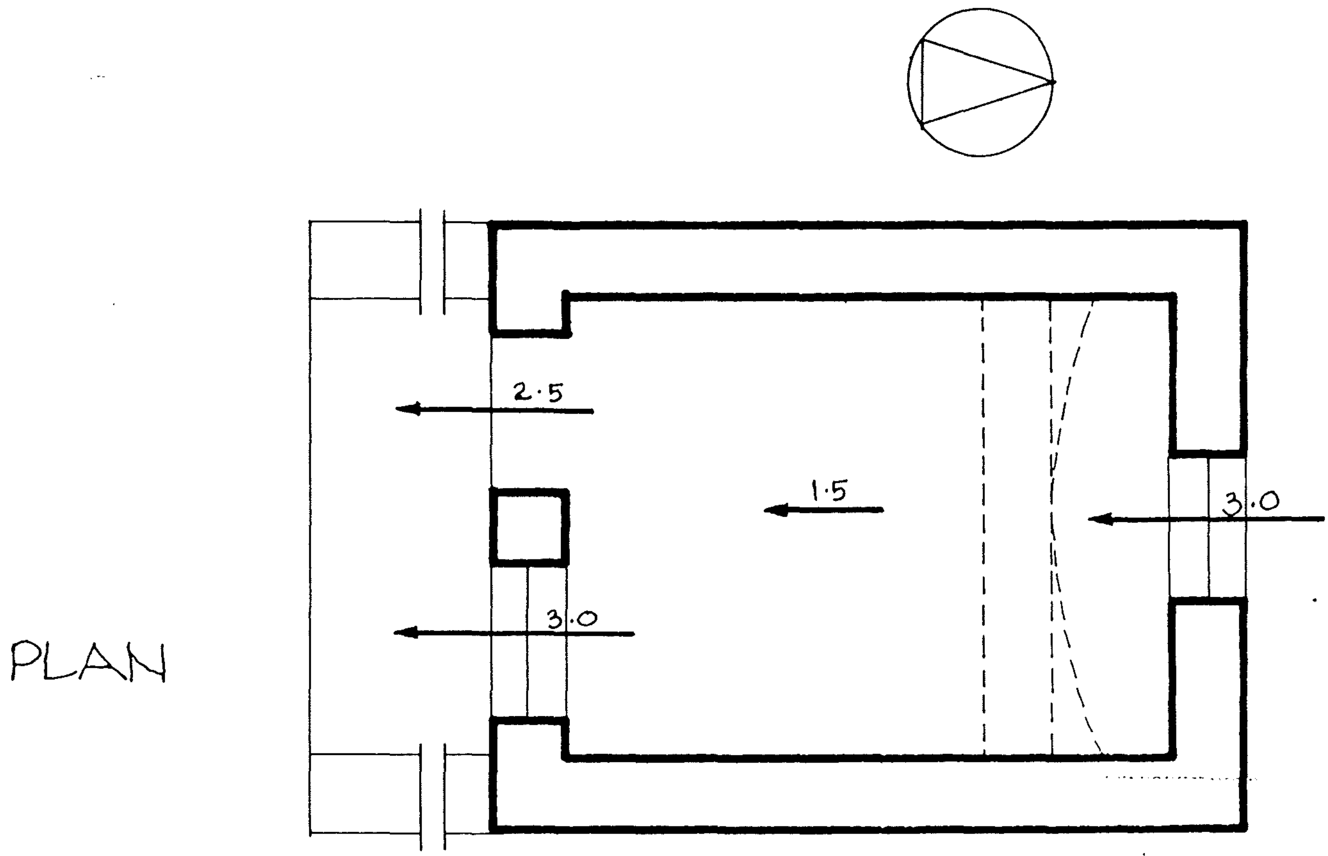
For this study we made use of a velometer which is an instrument which tells one the velocity of air moving in one given direction. The arrows and figures drawn on the plans and sections indicate the velocity of the air moving at the direction of maximum intensity.

Three different combinations of openings were tested. These experiments were made between 14:00 and 15:00 hours on March 29th 1973 when the air temperature was 28.8°C (Dry Bulb) and relative humidity was 31%. The "effective temperature" in this case considering minimal air movement is 23.5°C. It has been discussed earlier although that air movement has a definite effect on the 'effective temperature'. It is given in the following chart: (Constant 28.8°C and 31% R.H.)

Velocities (m/sec)	.08	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Effective Temp. (°C)	23.5	23.0	22.5	22.0	21.7	21.4	21	20.8	20.6	20.4	20.

To calculate ratios of inlets to outlets, the area of each opening was measured and then added to find the overall area of opening on each wall. The volume of air moving through an opening in one second can be found by multiplying the area of the opening by the velocity of air moving through the opening at that particular time.





CASE 1

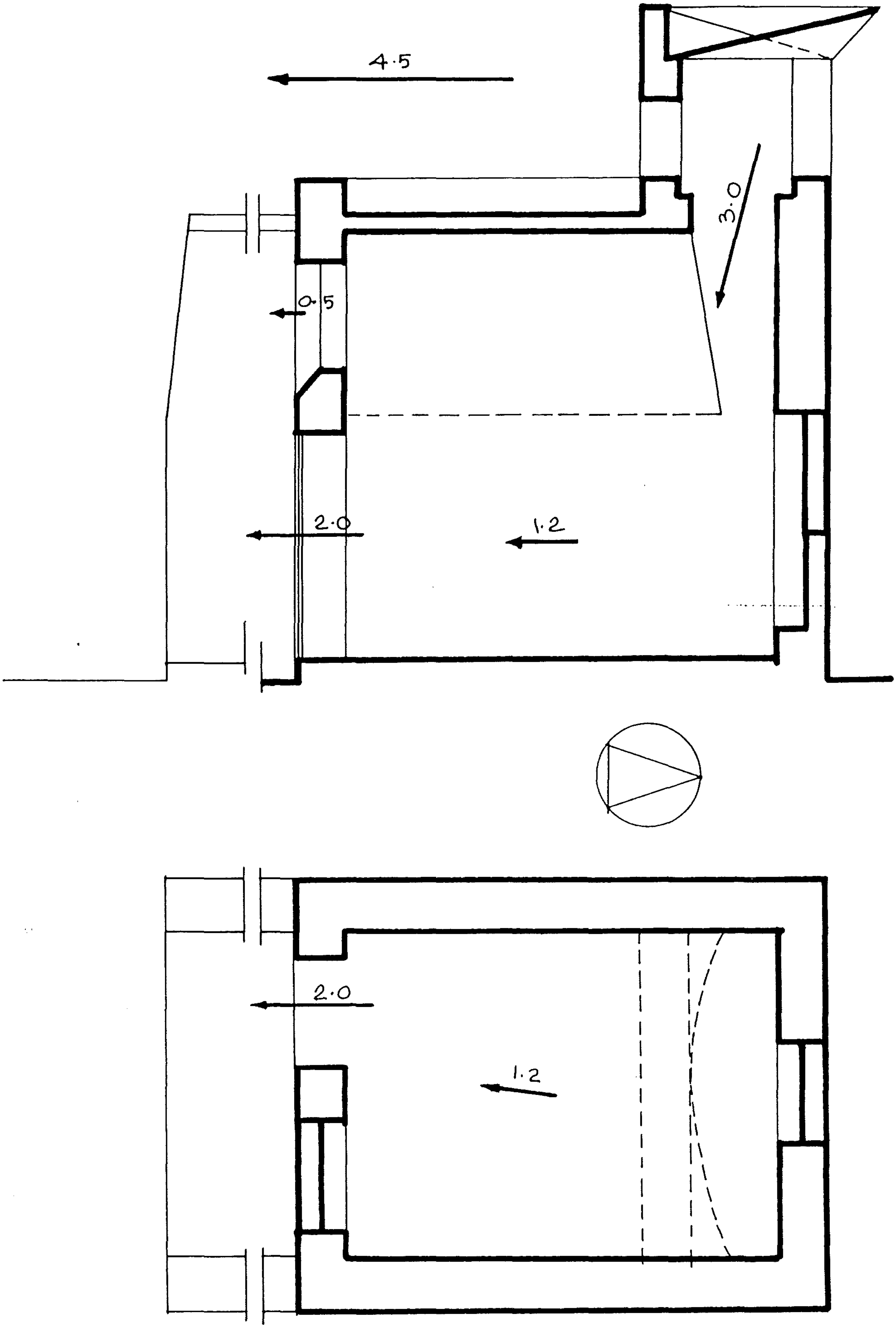
CASE 1

			AREAS	GROSS AREA	VELOCITY	VOLUME OF AIR PASSING PER SEC. THROUGH OPENING	GROSS VOLUME Cu. Meter / Sec.	AVERAGE VELOCITY THROUGH OPENINGS
INLETS	1	MALKAF	1·7	2·8	3·5	6·0	9·3	3·3
	2	NORTH WINDOW	1·1		3·0	3·3		
OUTLETS	1	DOORWAY	2·2	4·8	2·5	5·5	9·3	1·9
	2	SOUTH WINDOW	1·0		3·0	3·0		
	3	HIGH OPENING	1·6		0·5	0·8		

VELOCITY OF AIR IN ROOM CENTRE = 1·5 M/SE(

AREA RATIO OF INLET OPENINGS TO OUTLET OPENINGS = 2·8/4·8

= 1 : 1·7



CASE 2

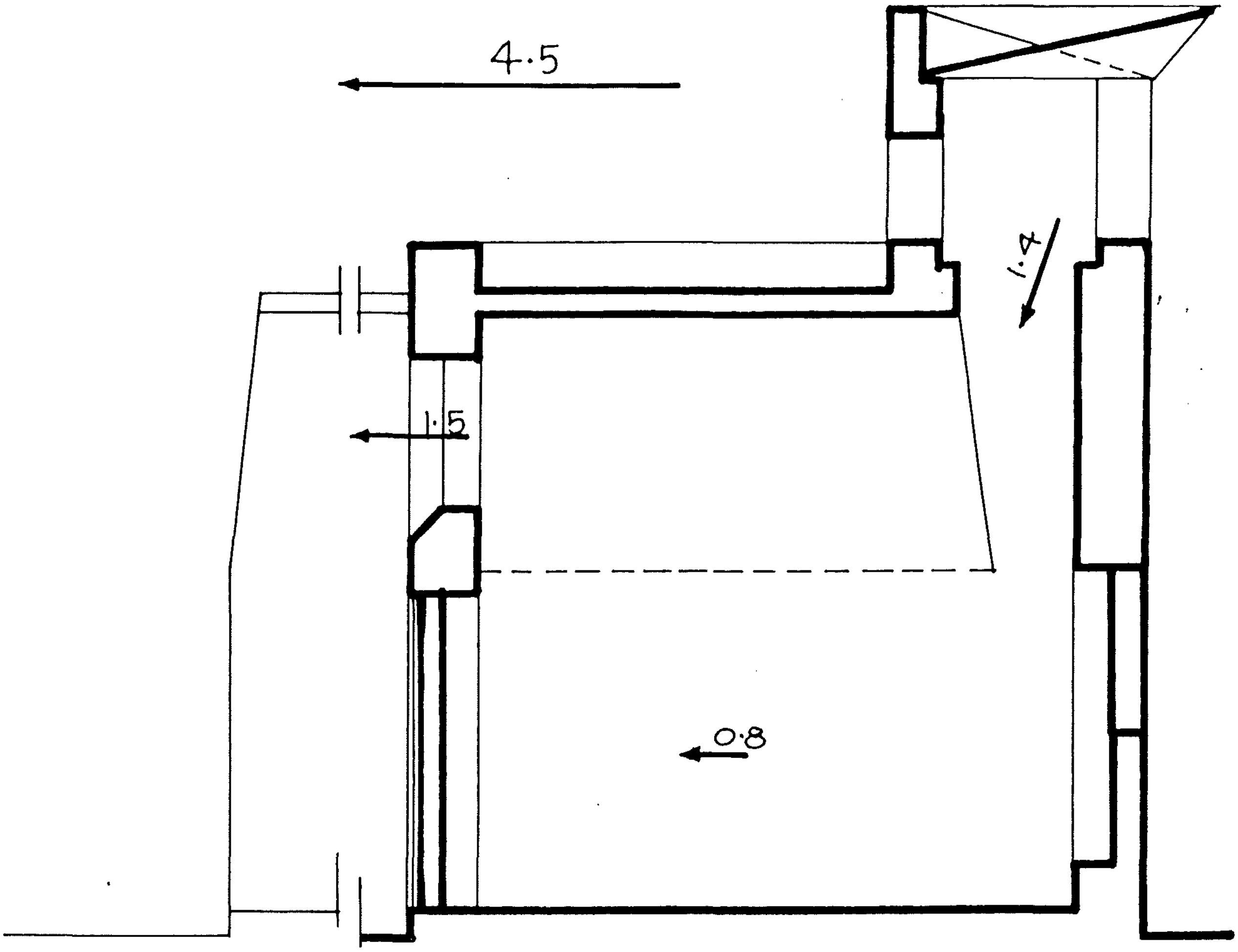
CASE 2

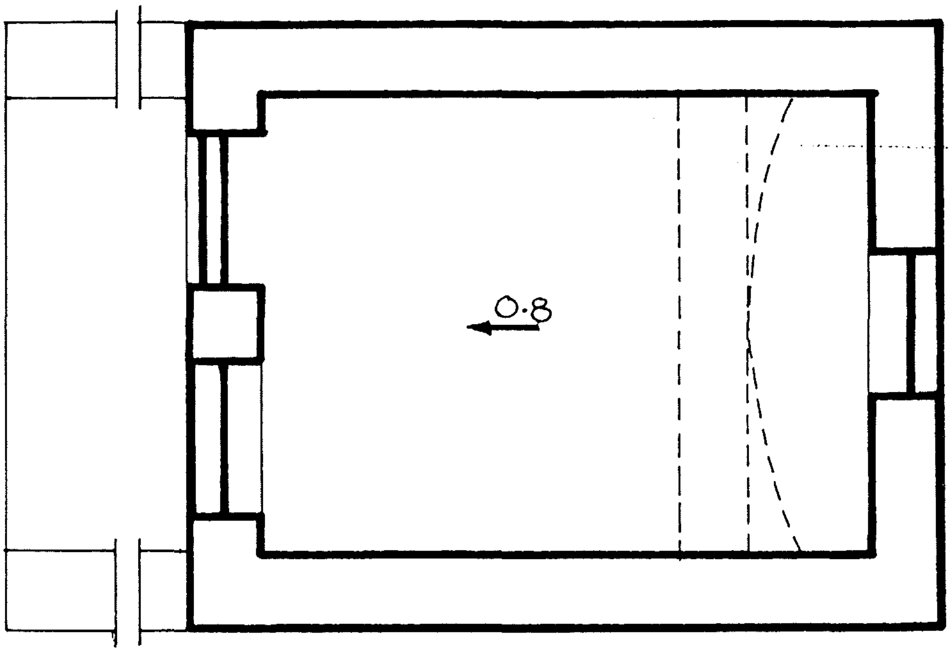
		AREAS	GROSS AREA	VELOCITY	VOLUME OF AIR PASSING PER SEC. THROUGH OPENING	GROSS VOLUME CU. Meters/Sec	AVERAGE VELOCITY THROUGH OPENINGS
INLETS	1 MALKAF	1·7	1·7	3·0	5·1	5·1	3·0
	2 NORTH WINDOW	CLOSED					
OUTLETS	1 DOORWAY	2·2	3·8	2·0	4·4	5·2	1·36
	2 SOUTH WINDOW	CLOSED					
	3 HIGH OPENING	1·6		0·5	0·8		

VELOCITY OF AIR IN ROOM CENTRE = 1·2 M/SE

AREA RATIO OF INLET OPENINGS TO OUTLET OPENINS = 1·7 / 3·8

= 1 : 2·2





CASE 3

CASE 3

			AREAS	GROSS AREA	VELOCITY	VOLUME OF AIR PASSING PER SEC. THROUGH OPENING	GROSS VOLUME Cu.Meter/Sec.	AVERAGE VELOCITY THROUGH OPENINGS
INLETS	1	MALKAF	1.7	1.7	1.4	2.4	2.4	1.4
	2	NORTH WINDOW	CLOSED					
OUTLETS	1	DOORWAY	CLOSED	1.6			2.4	1.5
	2	SOUTH WINDOW	CLOSED					
	3	HIGH OPENING	1.6		1.5	2.4		

VELOCITY OF AIR IN ROOM CENTRE = 0.8 M/S

AREA RATIO OF INLET OPENINGS TO OUTLET OPENINGS = 1.7 / 1.6

= 1 : .94

Conclusions

In the three cases tested here we have in each an example of a different area ratio of input openings to output openings. Case one for example is 1:1.7, case two is 1:2.2 and case three is 1:0.94.

We can see from the data obtained, that when the inlet outlet ratio is 1:1.7, as in case one, we get maximum velocity of air movement through the openings and through the room. That is when the outlet opening is 1.7 times larger than the inlet opening.

When the outlet opening is 2.2 times larger than the inlet opening as in case 2, the air movement through the openings and in the room is somewhat less.

In the 3rd case when the inlet opening is slightly larger than the outlet opening, the velocity of air movement through the openings and through the room is considerably less.

The actual optimum inlet/outlet area relationship requires many more tests with varying sized openings under a number of wind. conditions. Our tests although show this relationship to be in the neighbourhood of 1:1.7, and it is clear in any case that the size of the air outlets must be greater than the air inlets.

d. Windcatchers (Badgir)

The windcatcher is a device designed to funnel air from the unrestricted upper levels down into ground level rooms which might not otherwise have sufficient air movement to achieve a comfortable micro-climate.

On the Batinah coast these windcatchers are multi-directional, so that no matter from what direction the wind is blowing, air movement will be caught and channelled down into the room below. Multi-directional windcatchers are probably Persian in origin and similar examples to those found in Iran can be seen in the Bastakia area of Dubai. Those seen on the Batinah coast of Oman are not as ornate but equally effective.

Variations in the room layout and the materials used lead to differing degrees of efficiency, which are illustrated below.

Two types of windcatcher are shown here in detail. Both examples are in Sohar.

The first example channelled air into a concrete block bedroom, used all year by the owner of the house. The windcatcher is built with concrete block columns rising up above the roof of the house, a column at each of the four corners of the windcatcher. From a height of about 1¾ metres above the floor up to the top of the windcatcher, the tower is divided by an 'X' formed of palm frond stems covered over with gypsum plaster. In this way the tower can catch wind blowing from any direction (Fig. 333). The arrows on the figures indicate how wind blows into the tower and is channelled down into the room, where part is sucked back up the opposite shaft of the tower, and part enters the room. In the case of (Fig. 335) which is the case for daytime air movement, air blows down the shaft, and out across the room at low level. A small proportion of this air movement rises up the leeward side shaft; some of this air comes directly from the downward shaft. A larger proportion of the air leaves the room through the doorway and window openings. This process is advantageous for the daytime use of the room, when its central space is in use and therefore is the area requiring air movement to cool the occupants.

At night the wind direction reverses (land/sea breezes) and air blows down the opposite shaft (Fig. 336). As can be seen, only a small proportion of air actually circulates round the main part of the room, and the surface of the bed, and then back up the opposite shaft. This is beneficial in that the bed is the area that needs night-time ventilation. Air is sucked up the opposite shaft to the inlet shaft because of the negative pressure on the leeward side of the windcatch, which creates a vacuum effect (see plus and minus signs on Figs. 335 and 336). During the winter months, when air movement is unwanted, conditions being too cold or at least cool enough, the openings at the top of the windcatch can be covered with planks.

The other windcatch is constructed with four timber posts, with the tower divided up in the same 'X' form, but using sackcloth instead of plastered palm frond stems (Fig. 334). Entry of air movement into the windcatch is the same as in the previous case, but the room below is different, affecting the air movement pattern. This room is built of palm frond stem walls.

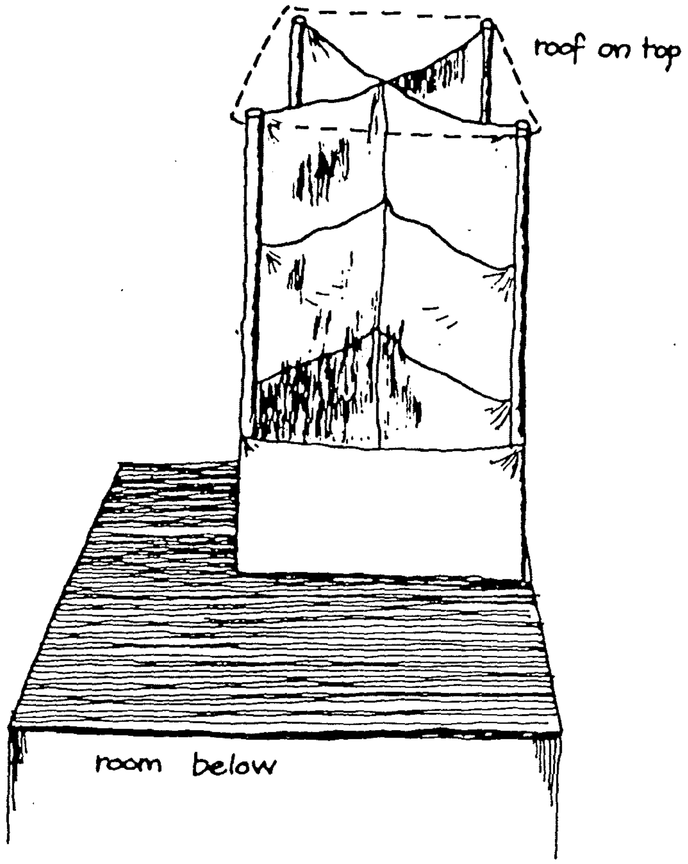


Fig 3.34
Cloth Badgir

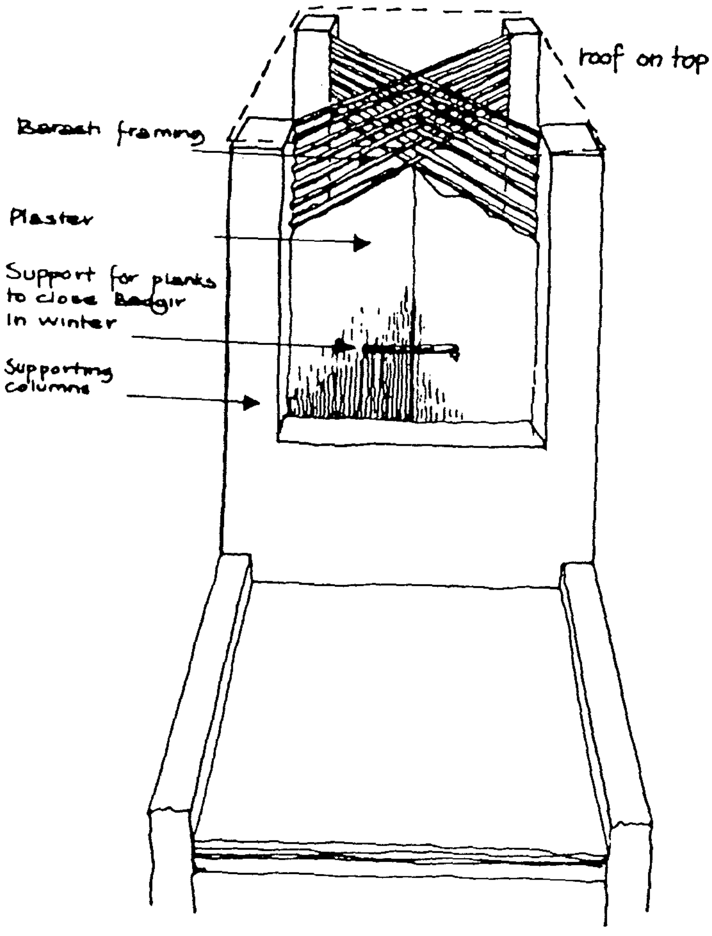


Fig 3.33
Plastered Badgir

Although the two walls on either side of the room are made of impervious or relatively impervious panels, the two end walls in line with the prevailing land and sea breezes are made of open space barasti, forming a wall which allows a free passage of air through it.

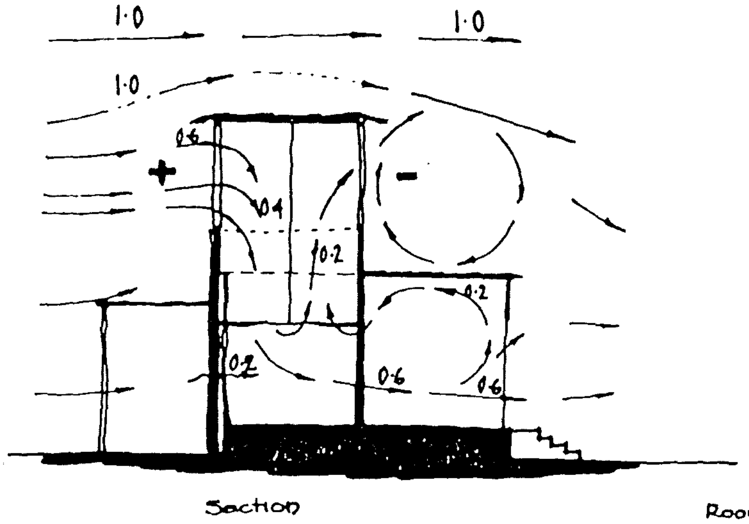
During the daytime (Fig. 337) air being channelled into the room through the windcatch is joined at the bottom by air entering through the wall. This means that whilst the area immediately below the windcatch will benefit directly from the air blown downwards, the rest of the room will be ventilated as much by direct air movement through the room from one side to the other.

At nighttime (Fig 338) the reversed wind direction blows in, in the same way as for the plastered windcatch, but at the bottom a proportion returns back up the opposite shaft, and the rest blows out through the adjacent leeward partition, both effects helped by the negative pressure zone on the leeward side of the building. None of the air from the windcatch is drawn into the rest of the room, which therefore relies upon air coming in through the windward side partition. The advantage of this is that where there is a less organised use of space and several people may sleep in the same room, there is air movement throughout the room. The windcatch helps to increase the velocity of the air movement, and therefore, in the summer, the degree of beneficial cooling. In the previous example the windcatch is the only source of air movement, but in this case an equally important proportion comes in through the walls, which gives more widespread air movement at night.

As the climate gets cooler in the late autumn, the cloth windcatch is removed and the roof opening covered over, leaving only the supporting posts (Fig 339).

The windcatchers in the Bastakia area of Dubai are far more ornate (Fig. 340) but perform in the same way as theplastered windcatch in Sohar. Rooms served by windcatchers can be equally on the ground or first floor, but in most cases have now been closed up and replaced by air conditioning units.

air movement at 16 00 hrs.



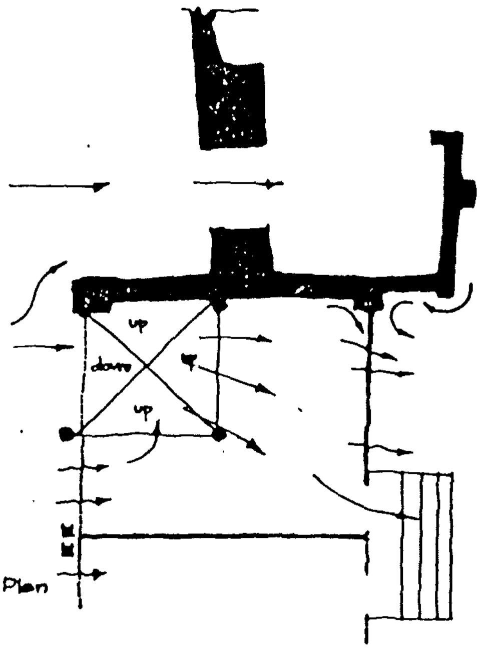
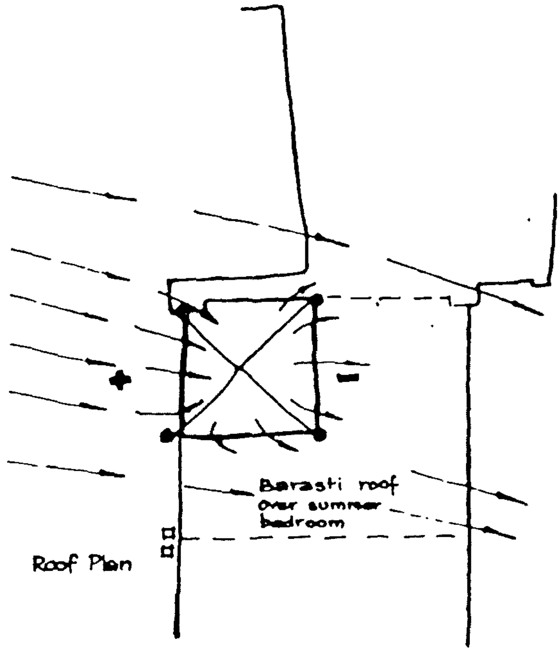
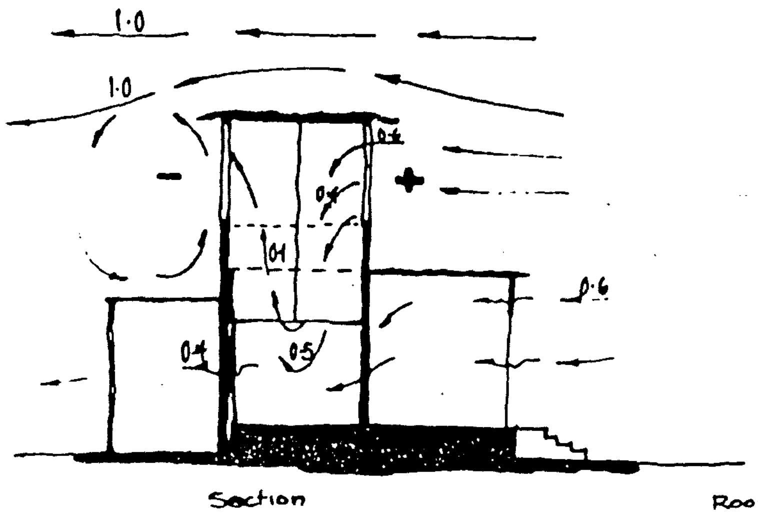


Fig 3·37 Cloth Badgir



air movement at 07·00 hrs



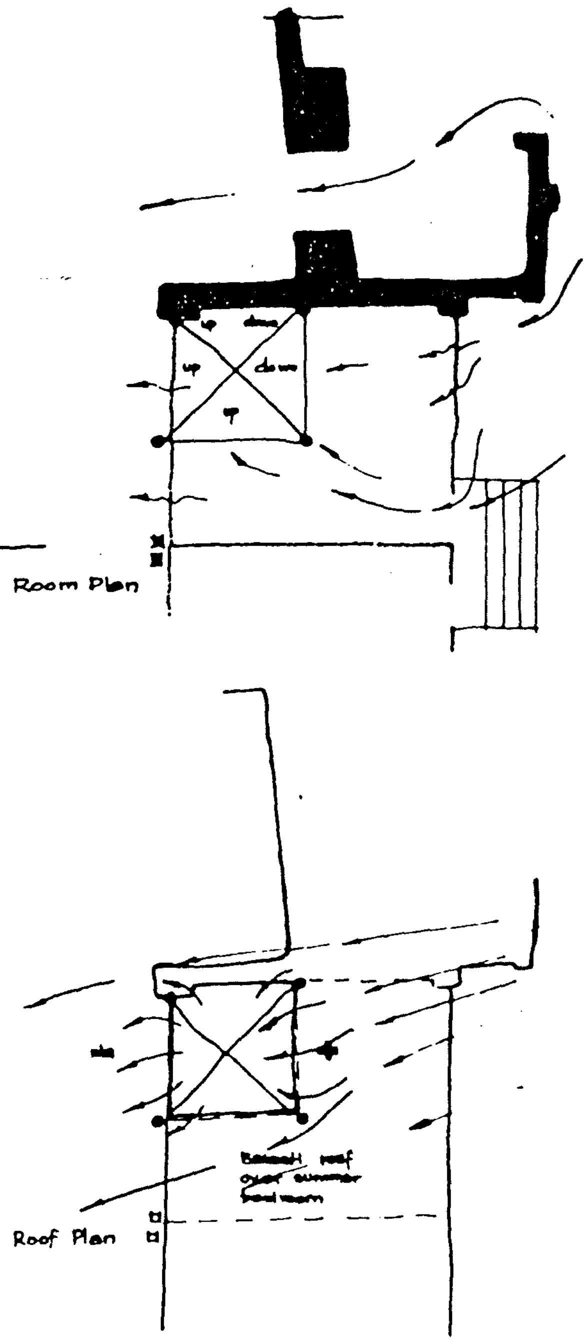
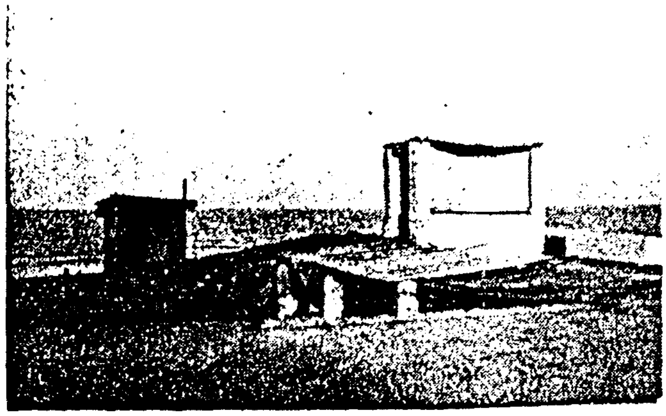


Fig 3·38 Cloth Badgir

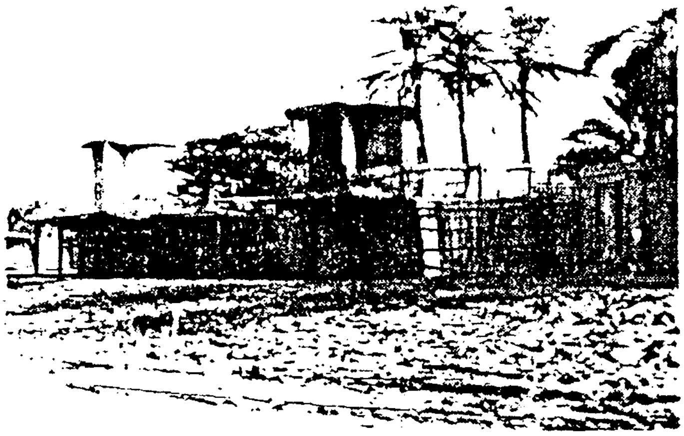
Fig 3.39

Plastered Badgir and cloth Badgir at Sohar

View from other side



Cloth Badgir in use

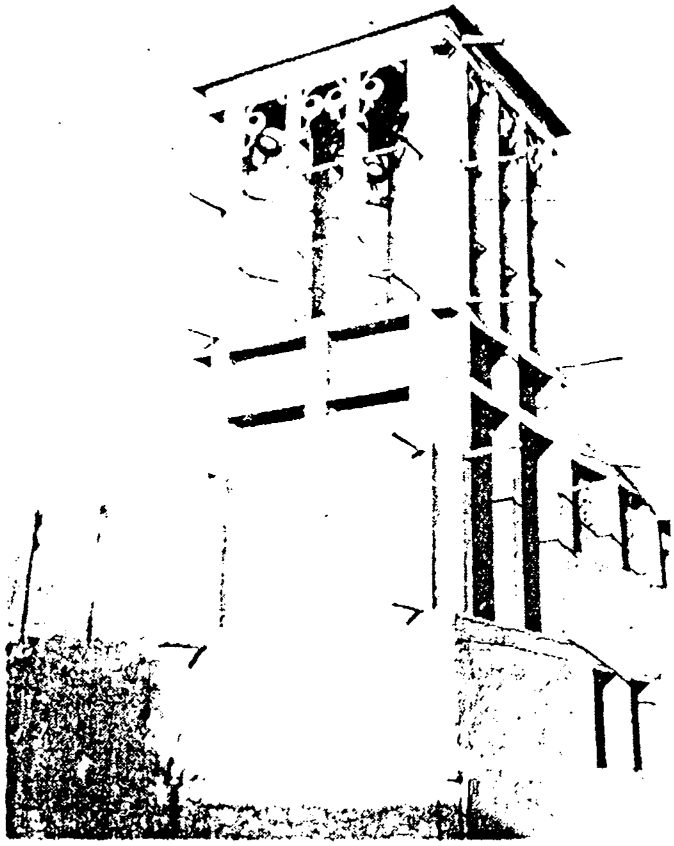


Cloth Badgir framework after adaptation to winter use.

Fig 3.40

Bastakia area of Dubai with Badgir

Dubai Badgir



View up Badgir shaft showing divisions

ANNEXE 4

ROOFS IN HOT DRY CLIMATES,
WITH SPECIAL REFERNCE TO NORTHERN SUDAN

by Y.A. Mukhtar
Overseas Building Notes No 182, 1978
BRE United Kingdom

ROOFS IN HOT DRY CLIMATES, WITH SPECIAL REFERENCE TO NORTHERN SUDAN

by Y.A. Mukhtar, PhD., AA.Dip(Trop), BSc (Arch).

1 INTRODUCTION.

Roofs, unlike other building components which are more apparent, often do not receive adequate attention to their thermal performance at the design stage. Efforts to improve the thermal performance of a building through careful designing, planning and selective use of materials for walls and openings can easily be negated by the poor design of the roof. The roof forms a considerable proportion of the external surface of the building, and is particularly exposed to the sun and the external climate.

In the Tropics the roof receives the greatest proportion of the sun's radiation because of its inclination with respect to solar altitude and its area as compared with the external walls. The roof also loses the greatest amount of stored heat by long wave radiation to night sky, for the same reason.

Apart from the requirements of structural safety and protection from the direct sun and rain the roof construction plays a major role in the attainment of thermal comfort, the capital and running cost of the building and the capacity and size of the air conditioning in an air conditioned building, in the following way:

(i) In tropical climates the effects of radiation from the internal building surfaces, especially from ceilings with high temperatures, are considered as the main causes of discomfort, loss of working efficiency and disturbed sleep(1). In South Africa it was reported that the radiation from the ceiling of a well planned building with a massive wall caused the fainting of 19 working women(2). Koenigsberger and Lynn(3) in a survey of the hot humid zone, found that less than 50% of the roofs they examined satisfied the desirable thermal conditions. Similar examples occur among the recently built housing schemes in Khartoum, Khartoum North and those for the re-settlement of Wadi Halfa people in Khashim El Girba. Unlined double pitched roofs of corrugated galvanised steel or asbestos cement are among the most common forms of roof construction in the hot dry region of Northern Sudan.

(ii) Roofs, besides their thermal weaknesses, are expensive both to construct and maintain. Examining the costs of construction of some of the buildings erected for the University of Khartoum during the last 20 years, the author found that an average of about 41% of the total cost of single storey building was taken up by the roof construction alone. The other 59% was shared by the other building elements i.e., walls, partitions, floors, windows etc. (In the case of two and three storey buildings the percentage attributable to the roof was about 17% and 14% respectively.) The variation in cost between one roof construction and another depends on both the materials and the design. The design is mostly based on the experience of the architect, as there are no building regulations as such for determining the minimum thermal insulation nor enough knowledge about the thermal performance of the different roof constructions to make design decisions relative to roof performance.

(iii) The high surface temperature of the roof increases the rate of deterioration of many roofing materials. It hastens the chemical degradation of unprotected bituminous roofing membrane and causes the formation of blisters and bubbles as a result of the evaporation of construction water which may be trapped beneath a poorly laid felt. Bituminous roofing membranes can also be damaged by the low night time temperatures which make them brittle and subject to cracking under stress. Such failures of the roofing membrane occur more frequently when it is applied over insulation.

High temperatures can cause the softening of plastic insulation and sometimes its collapse. The recommended upper working temperature for polystyrene, which is extensively used for roof insulation, is 80°C, and polystyrene sheets placed under dark roofing felt (Ruberoid) on the roof of the Faculty of Pharmacy Building in Khartoum had collapsed when it was examined after the first two years. This caused the rain water to form a pond on the top of the roof, and eventually resulted in the failure of the waterproofing system.

Thermal movements resulting from the extreme day and night temperatures are experienced, to different degrees, by nearly all the materials in roof construction. They cause cracks, distortion and sometimes failure. The most serious failures occur in concrete slab construction. Fractures along the line where walls join the roof and on parapet walls are common failures, due to thermal movement in the concrete slab.

(iv) The running cost, size and capacity of an air conditioning plant depends to a large extent on the thermal efficiency of the building envelope, in minimizing the effects of the adverse weather conditions. For walls and openings it has been possible through the available methods of accurate predictions to arrive at certain solutions. These solutions determine the shape, orientation and shading for maximum protection from the incoming solar radiation and achieve the maximum advantage of the cool weather. Roofs are difficult to protect from radiation although they are considered as the main source of solar heat gains inside buildings. Consequently the design of the roof is an important factor in determining the running cost and the size and capacity of an air conditioning plant.

The traditional form of roof construction is basically 'heavy' with thick layers of material which offer a high degree of resistance and modification to the external climate and to the diurnal variation in temperature. The application of this type of roof in urban areas is becoming impracticable due to its weight and difficulty of construction in multi-storey buildings. It may also be aesthetically unacceptable on account of its primitive detailing and finishes.

Modern forms of roof construction, like other building components, are often made of non-traditional lightweight materials. They may have a higher thermal insulation value than the traditional materials, but they lack adequate thermal capacity and as a result allow internal conditions to fluctuate rapidly with variations of the external air temperature and solar radiation. In order to provide acceptable internal conditions, and to take full advantage of the properties of the roofing materials it is necessary to know their thermal performance under local conditions. Such information does not exist for the hot dry climates. The materials, which are mostly imported from the temperate climates, show a variety of physical properties and their performance under the local climatic conditions and workmanship is very difficult to predict due to the lack of accurate climatic data and of a suitable method of prediction.

Methods of predicting heat gains and losses in buildings are mainly developed for the temperate climates, where the diurnal range of the outdoor temperature is small and the difference between the outdoor and indoor temperatures is large. The hot dry climates are characterized by their wide diurnal variations in temperature and high solar radiation intensity. These variations, which bring about non-steady state conditions of heat flow, make the calculation very complex and time consuming and of uncertain validity for the tropical conditions, as they are based on certain assumptions and approximations.

The object of the study described in this note was to investigate current forms of roof construction in Northern Sudan with respect to their influence on the internal temperature, their capital cost and the possibility of improvement in their performance. Northern Sudan could be considered as a hot dry climate.

2 FORMS OF ROOFS IN NORTHERN SUDAN

Flat and pitched roofs are both common forms in Northern Sudan. The construction techniques are based on traditional local practice and on European experience, applied with different levels of skill and little knowledge of actual performance under local climatic conditions. The current forms of roof construction could be grouped as follows:

2.1 Concrete Roofs

Solid reinforced concrete slabs are used in the Khartoum area with various forms of insulation and protection from the sun. The selection of these forms is greatly influenced by appearance rather than the function or the availability of the material or the skill. Discrepancies between the finished work and the detailed drawings are frequently noticed for these reasons. The absence of design standards has encouraged the designers to use their own judgement or the experience of others without testing their suitability to the conditions.

A common form of solid reinforced concrete slab roof is one with insulation and waterproofing membrane (Ruberoid) covering on top. Expanded polystyrene sheets, which are made locally from imported raw materials, are widely used as the insulator.

'Khafgi'*, screed and white cement tiles are sometimes applied on the above form of roof. They add much to the cost and the load of the building, but they reduce the maintenance cost and allow the use of the roof for other purposes, like outdoor sleeping or recreation. Their light colours help in reducing the range of the surface temperature but their effect on the total thermal performance of the roof is not known, neither is the cost benefit. The disadvantage of such a form of roof is the difficulty of maintaining both the insulation and the waterproofing membrane.

Roof shading (Figure 1) is used in some government and semi-government buildings. The shading materials used are either corrugated galvanised steel or corrugated asbestos cement sheets. Both are imported and expensive and the latter has a greater risk of damage by the extreme temperatures and high speed winds. The forms of the shades vary according to the designer's attitude and there is no established theory for the design or performance of the air space in between. The solution is sometimes very expensive and the structure is very elaborate.

2.2 Light or sheet roofs

They are mainly corrugated galvanised steel and asbestos cement roofs. They were introduced on a large scale in the Sudan at the beginning of this century by the Condominium Rule and since then have been used in the form of pitched roofs in almost all government buildings all over the country. The two materials are used to replace traditional roof systems in housing. Corrugated galvanised steel is the most popular and is constructed with a gentle slope (about 10°) and a very simple structure in many homes. The roof is constructed with parapet walls to conceal it, together with perforations and a small projection to shed the rain water (Figure 2).

Most homes normally have no ceilings and the indoor temperatures are well above the outdoor air temperature during the day time hours. There are many complaints about the noise of the rain hammering on the surface of the roof and also from the thermal movements of the sheets.

Whitewash, which is cheap and available, is applied on some government buildings, but its maintenance is not frequent.

2.3 Traditional or mud roofs

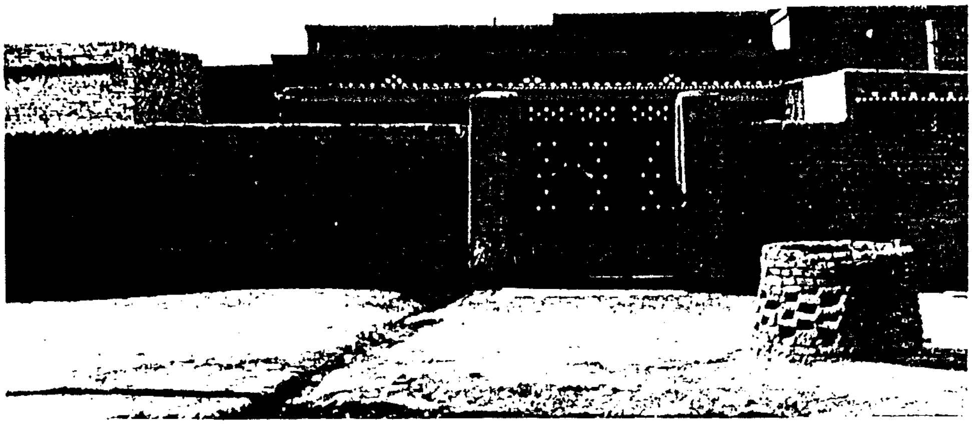
Traditional roofs are the most common in rural areas where the materials and the skill are still available (Figure 3). Materials are basically timber from the palm tree and earth finished with 'Zibala' †. The palm tree provides the

*Khafgi is a mix of cement, sand and lime with a small chipping of ordinary red brick, locally used in the same way as screed.

†Zibala, a mix of animal dung, straw and mud for rendering mud walls and roofs.

Figure 1 Double roof system – University of Kartoum, students' hostel.

Figure 2 Corrugated galvanised steel flat roof – Burri, Khartoum.



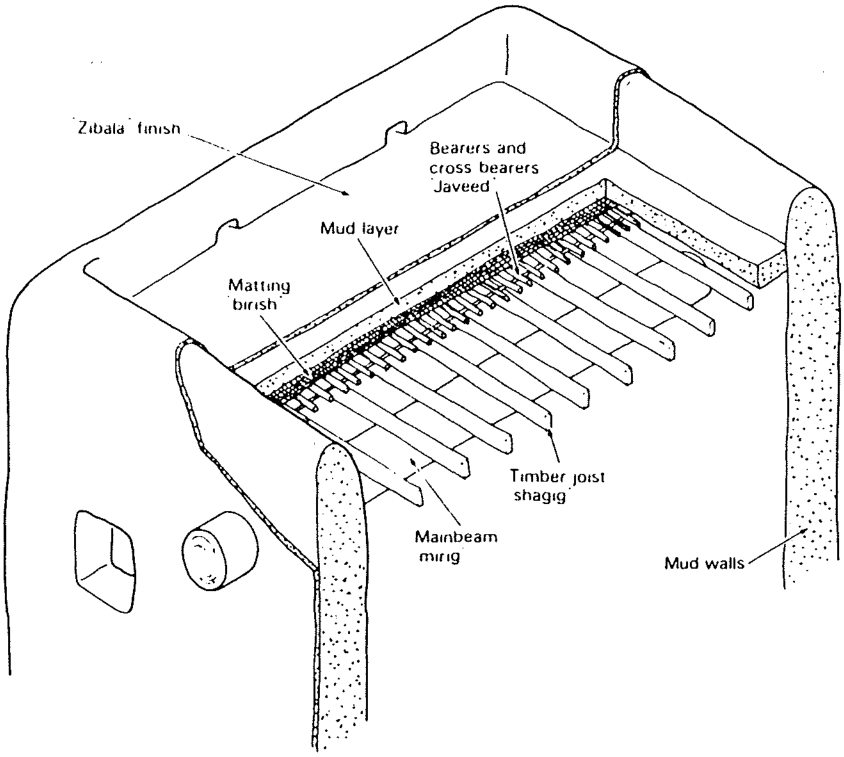


Figure 3 Traditional mud roof construction.

main beam 'murig', the joists 'sharig', the matting bearers 'jand' and the matting 'birish' which receives the mud layer. Sometimes dry leaves of the palm tree or dry grass are placed under the mud layer. The initial cost is normally small, but annual maintenance is necessary, which is in the form of another layer of 'Zibala'. The 'Zibala' is usually applied at the end of the summer to seal cracks which are caused by high temperature and dry conditions. The traditional roof, combined with customary mud walls and minimum openings, provides a satisfactory internal climatic condition, but it always leaks after heavy rain and sometimes collapses under the weight of wet mud or of the pond which is formed as the result of the roof deflection.

3 EXPERIMENTAL INVESTIGATION

Earlier studies have shown that satisfactory results can be obtained when model buildings are used to investigate problems of heat flow (4). In the Tropics models were used to test the thermal performance of buildings or building elements in order to determine their effect on the indoor conditions(5). The lack of adequate climatic data and enough information on the performance of building materials in the Tropics makes the model particularly suitable for such studies and also for studying the relevance of the theoretical methods of calculations currently used for predicting the indoor conditions.

During 1973 a half scale model building was constructed on an unobstructed site at the University of Khartoum. The model consisted of 10 rooms of equal dimensions (2m x 2m x 1.5m high), all facing the North/South traditional orientation (Figure 4). The walls were of ordinary red brick (220mm thick), plastered internally with cement sand mix. The initial construction and finish of each of the roof panels was in the manner shown in Figure 5. In the case of the traditional roof construction, timber was used to replace the traditional matting and roofing felt was added to ensure good waterproofing. This has been the practice in urban centres where traditional materials and skill are difficult to obtain.

Temperatures were recorded during May, June and July 1974, after the building had dried out. Each set of readings was for a minimum period of three consecutive days with clear skies. Readings included the external shade air temperatures, internal room air temperatures, and upper and lower surface temperatures of the roof panels. Calibrated thermistor sensors and chart recorders were used for measuring and recording the hourly temperatures.

The initial readings were taken under four different conditions of room ventilation, i.e., no ventilation at all, ventilation during night time only, ventilation during day time only and ventilation all day. The original construction was then modified and more readings were taken to determine the effect of different surface finishes on the thermal performance of the roof (Table 1).

4 EXPERIMENTAL OBSERVATIONS

Some of the findings from this investigation have been presented in Figures 6-8, and are outlined below:

4.1 Initial roof construction

(i) The reinforced concrete roof slab (No. 3) with a 50mm thick expanded polystyrene layer on top, achieved the greatest reduction in both maximum slab temperature and its diurnal variation, in spite of its highest external surface temperature. The temperature of the black roofing felt (Ruberoid) reached 79°C. The internal conditions were almost stable with very little fluctuations in temperature. The average 'delay' in the maximum internal air temperature was about four hours.

(ii) The shaded reinforced concrete roof slab (No. 5) and the roof with 'Khafgi' finish (No. 4) follow roof No. 3 in thermal efficiency. They have nearly similar temperature curves and time lag. The shaded reinforced concrete roof had a comparatively low night temperature as a result of the direct cooling of the slab by the cool night air passing over it. The 'Khafgi' roof had a slightly higher temperature, especially during daytime and its minimum temperatures were reached later than others, because the structure needs a longer time to cool. The thermal performance of the 'Khafgi' roof depends mainly on the mix of 'Khafgi' and its optimum thickness.

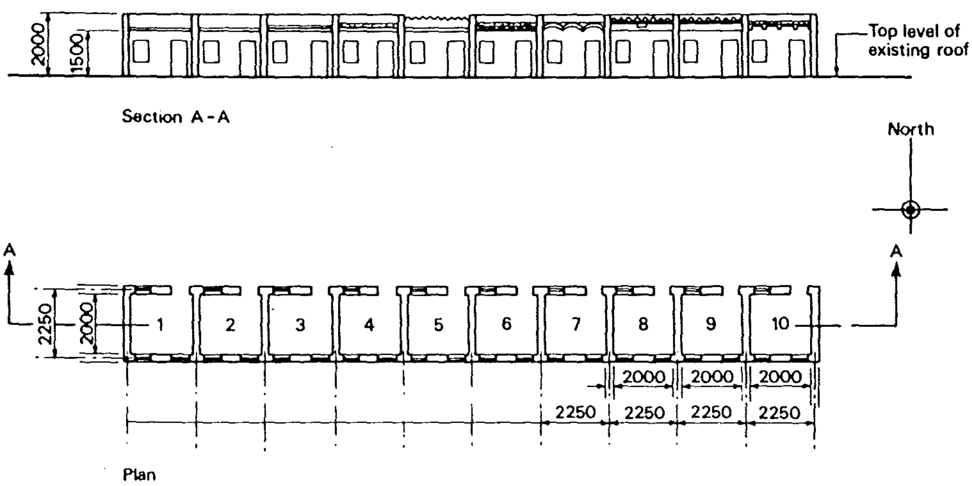


Figure 4 Plan and section of the experimental model building.

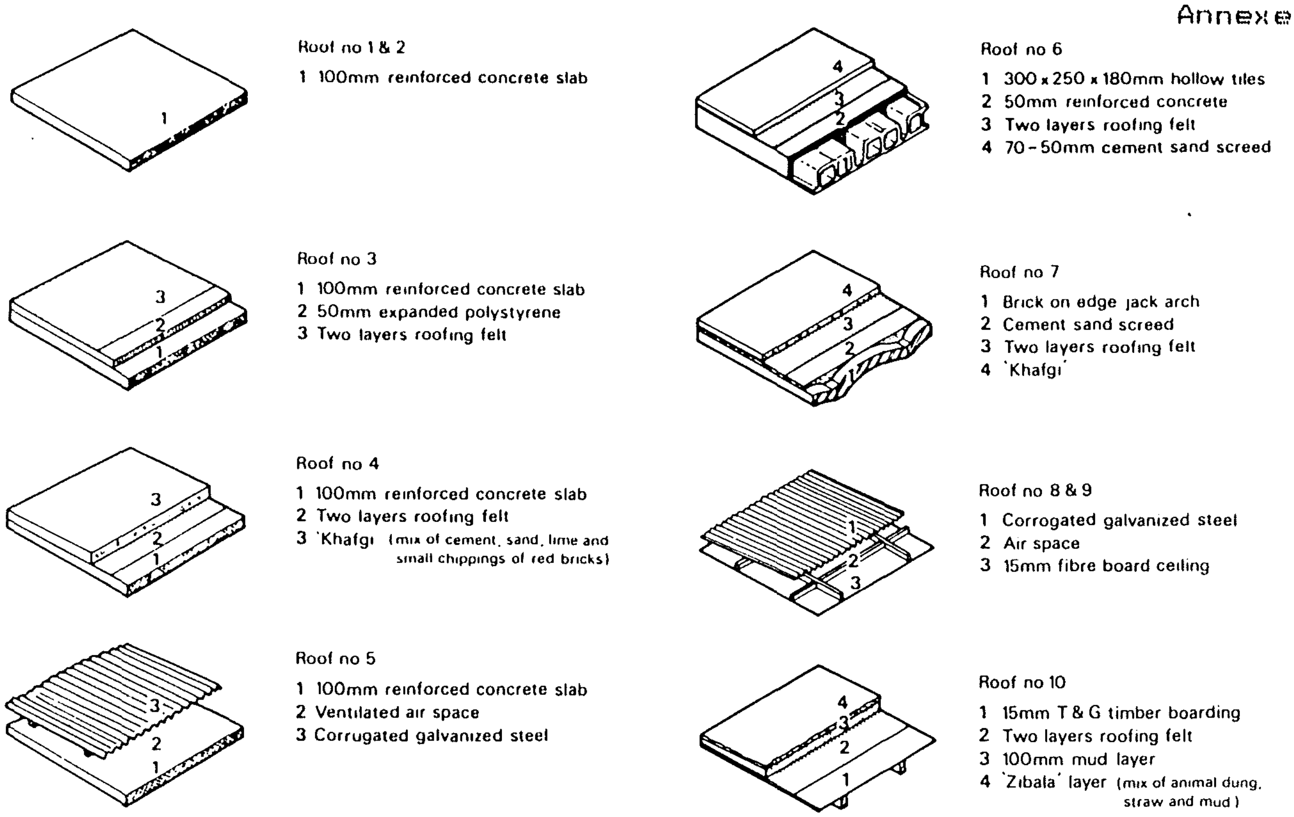


Figure 5 Isometric projections of sections of the initial construction of the experimental roofs.

Table 1 The initial roof construction and the modification during three stages of the experiment

Room No.	Stage No. 1 (Initial Construction)	Stage No. 2	Stage No. 3	Stage No. 4
1	100 mm thick reinforced concrete slab			
2	100 mm thick reinforced concrete slab	White wash	50 mm layer of white gravel	75mm layer of white gravel
3	100 mm thick reinforced concrete slab + insulation + roofing felt	White wash	White P. C. tiles	
4	100 mm thick reinforced concrete slab + roofing felt + khafgi*			White wash
5	100 mm thick reinforced concrete slab + corrugated galv. steel sheeting + (ventilated air space in between)			White wash
6	Hollow tiles + roofing felt + screed to fall (ventilated air space)		Unventilated air space	White wash
7	Jack arch roof + roofing felt + khafgi			White wash
8	Corrugated galvanised steel sheets + ceiling (ventilated air space)			Unventilated air space
9	Corrugated galvanised steel sheets + ceiling (unventilated air space)	White wash		
10	Traditional mud roof + zibala finish**			White wash

* Khafgi is a mix of cement, sand and lime with small chippings of ordinary red brick.

** Zibala is a mix of animal dung, straw and mud for rendering walls and roofs.

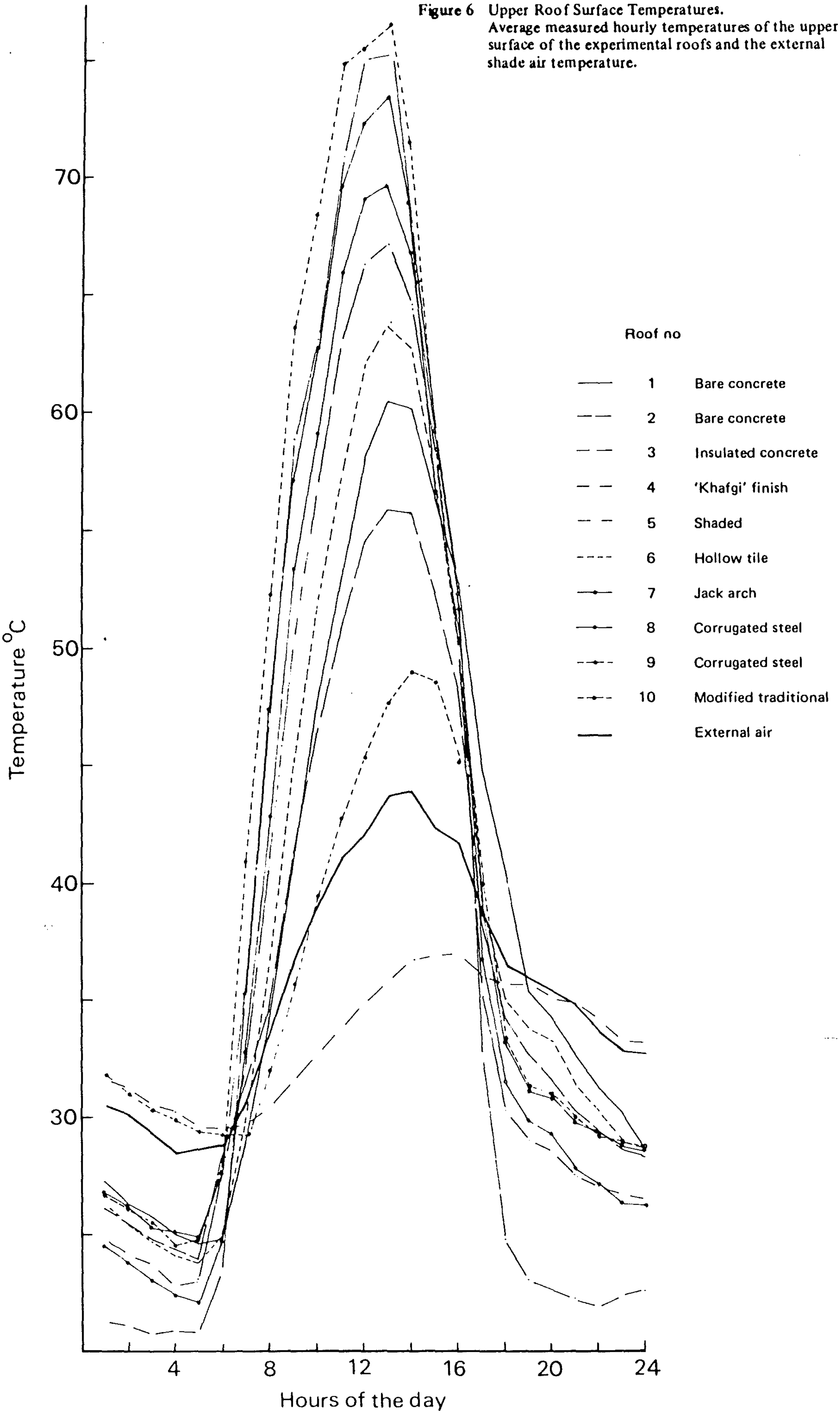


Figure 6 Upper Roof Surface Temperatures.
Average measured hourly temperatures of the upper surface of the experimental roofs and the external shade air temperature.

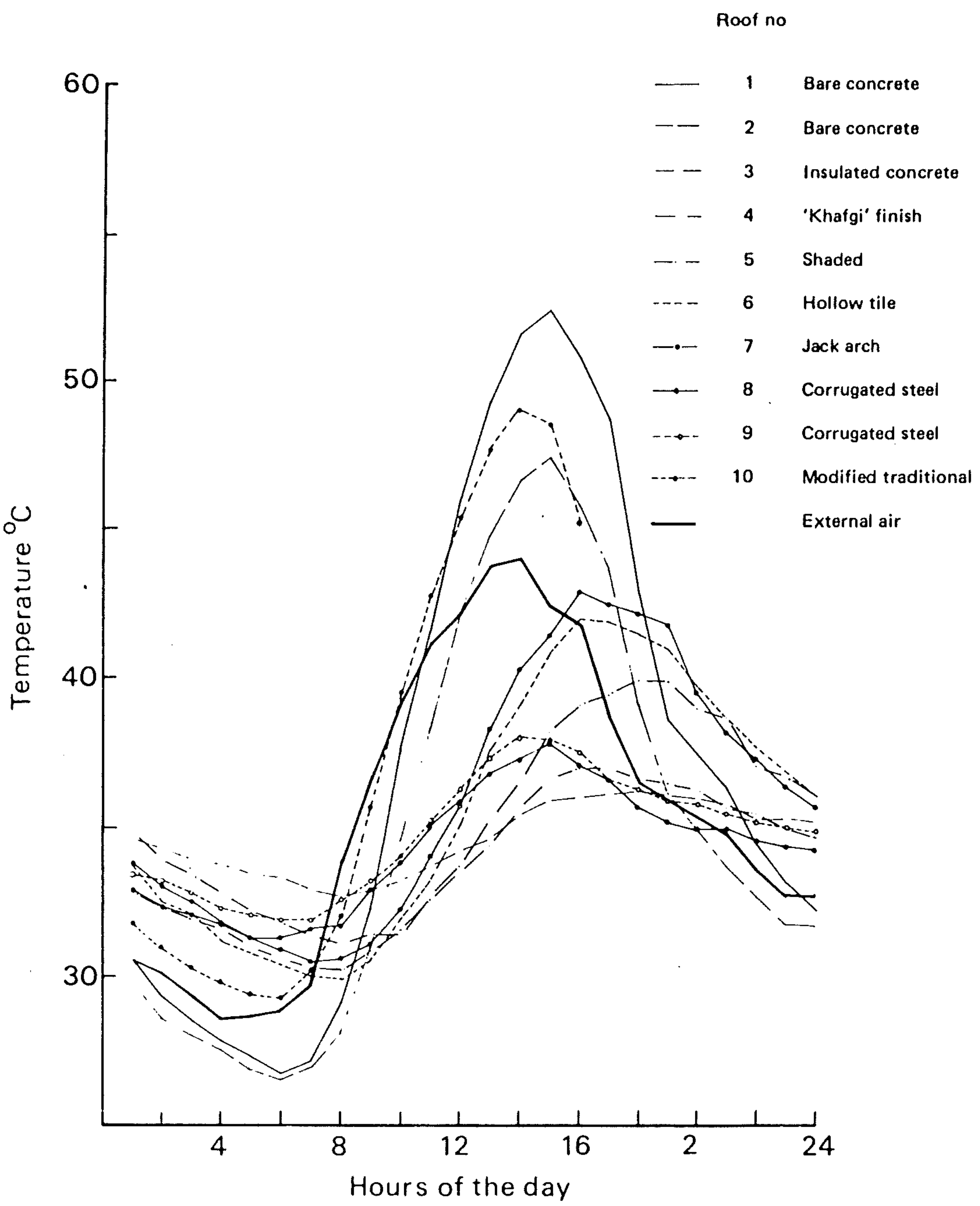


Figure 7 Lower Roof Surface Temperatures.
Average measured hourly temperatures of the lower surface of the experimental roofs and the external shade air temperature.

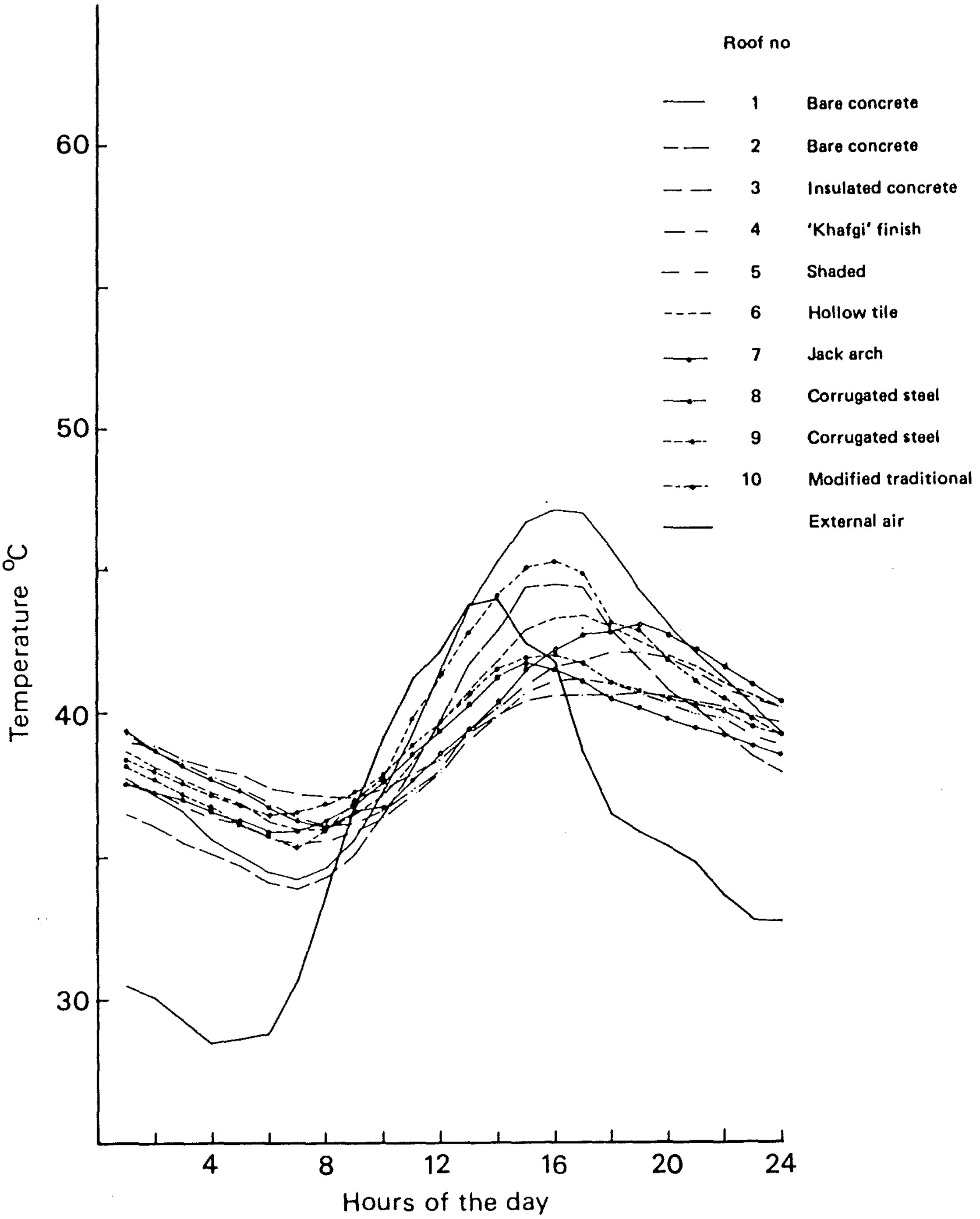


Figure 8 Internal Air Temperatures – Initial Construction. Average measured hourly temperatures of the internal air at 100 mm below the ceiling and the external shade air temperature.

(iii) The above roofs were followed with reasonable reduction in maximum temperatures and diurnal variation by the brick jack-arch (No. 7) and the hollow tiles roof (No. 6). Both are heavy and have similar temperature curves. The lower surface and internal temperatures of the hollow tiles roof were slightly higher than the other roof, but had a lower upper surface temperature. Its maximum internal temperature was also an hour earlier.

The reduction in maximum air temperatures achieved by the two types of roof construction was comparatively small and the internal temperatures during the night time remained well above average.

(iv) The corrugated galvanised steel roofs (Nos. 8 and 9) with 20mm fibre board ceilings achieved a good reduction in maximum temperatures and diurnal variations, but with very short time lag (about one hour). The internal temperatures followed the corresponding external air temperature very closely. The external surface attained a maximum temperature similar to that attained by the black roofing felt on roof No. 3. The temperature curves of the two galvanised steel roofs were similar and the effect of the ventilation of the roof/ceiling air space was insignificant. It was about 0.5°C.

(v) The bare concrete roof slab (No. 2) and the modified traditional mud roof (No. 10) both offered very small resistance to heat flow. Their diurnal range was the greatest (in the range of 10°C) and the maximum internal air temperatures were higher than the corresponding external shade air temperature. The temperature curves showed a rapid rise in temperature to maximum and a similar drop to a lowest minimum level compared with other roofs.

In the case of the traditional roof the dark colour of the 'Zibala' finish and its rough texture could have a great influence on its thermal performance. The modified traditional roof normally had less thick mud on top, which could be the reason for its poor performance. The layer of 'Zibala' which was added annually also had a significant effect on the insulation value.

Generally the upper surface temperatures reached their maxima about the same time (13.00 hours), which was almost an hour earlier than the time of the maximum external air temperature and an hour later than the time of maximum solar intensity, except in the case of roofs No. 2 and 3. Roof No. 2, which had a whitewash finish, had its maximum about the same time as that of the external air, while roof No. 3, which had a black finish, had its maximum about the same time as that of the maximum solar radiation.

4.2 Effect of Ventilation

(i) *Ventilation of rooms*

Ventilation only during the night time increased the diurnal range, reduced the maximum internal air temperatures and delayed the time of their occurance. This was found to be more effective in the case of the heavy roof construction, shaded and top insulated roof constructions (Table 2).

Ventilation only during daytime hours i.e., when the external air temperature was higher than the corresponding internal air temperature, resulted in more heat gain, so offsetting the thermal protection due to the roof itself.

When the openings were closed after sunset the heat gained by the internal structure during the day had an adverse effect on the night temperature and the temperature of the following day. It increased the rate of the temperature rise during the first half of the following day.

Continuous ventilation had little effect on the internal temperatures. The internal temperatures remained almost the same in all the rooms and they were slightly lower than the corresponding external air during the day and slightly higher during the night, except for Rooms No. 2 and 10, which recorded much higher temperatures during the daytime hours.

Generally it was noticed that continuous ventilation was a little more effective in improving the thermal internal condition, compared with the unventilated condition and with the ventilation during the daytime only.

(ii) *Ventilation of the roof/ceiling air space*

Ventilation of the roof/ceiling air space of Room No. 8 had very little advantage over the unventilated one of Room No. 9. Room No. 8 recorded about 0.5°C lower maximum internal air temperature and almost 3°C lower on the external surface compared with Room No. 9. Both rooms had the same diurnal range and time of peak temperatures. When the two rooms were ventilated the small effect due to the ventilation of the roof/ceiling air space became less significant.

(iii) *Ventilation of the roof hollow tiles.*

Ventilation of the hollow tiles air space proved to be of little advantage over the unventilated one. It helps the roof structure to cool down to a lower degree of temperature during the night. The unventilated air space may have a better insulating quality as a result of the trapped air.

4.3 Effect of the surface treatments.

(i) *Whitewash*

The whitewash applied on the external surface reduced the internal air temperatures and the external surface temperatures of the roofs. It also improved the diurnal range and delayed the time of peak temperatures. The bare concrete roof slab (No. 2) and the modified traditional roof (No. 10) were greatly improved when they were whitewashed (Figure 9 and 11).

The whitewash is cheap and available, but to remain effective it should be maintained in a clean condition. Its maintenance may offset the saving in its capital cost.

Table 2 Average temperature differences between maximum external shade air and lower surface of the roofs, and range and time of maximum temperature of the lower surface of the roofs during clear selected days for four different conditions of room ventilation.

Room No.	All openings closed			Windows opened from 1800 to 0600 (Night)			Windows opened from 0600 to 1800 (Day)			Windows opened 24 hours		
	Difference in Temperature * Deg.C	Temp. Range Deg.C	Time of Peak	Difference in Temperature * Deg. C	Temp. Range Deg.C	Time of Peak	Difference in Temperature * Deg.C	Temp. Range Deg.C	Time of Peak	Difference in Temperature * Deg.C	Temp. Range Deg.C	Time of Peak
1	8.1	25.3	1500	5.8	25.2	1500	9.5	26.0	1500	5.3	20.4	1530
2	3.1	20.3	1500	1.9	21.0	1500	3.9	21.6	1500	4.3	19.6	1500
3	-8.1	3.6	1900	-10.5	3.9	1830	-6.3	4.6	1700	-8.1	4.1	1730
4	-4.3	8.9	1830	-6.8	8.6	1730	-5.2	6.9	1630	-6.0	7.3	1600
5	-7.1	7.1	1830	-8.3	8.1	1730	-5.2	7.8	1730	-6.7	6.2	1800
6	-1.7	12.8	1700	-3.5	14.0	1700	-0.5	13.5	1700	-2.2	11.4	1800
7	-1.3	12.6	1800	-3.8	12.6	1700	-0.2	13.0	1600	-1.2	11.7	1700
8	-6.3	6.8	1500	-8.2	8.6	1500	-4.5	8.3	1500	-5.4	6.9	1500
9	-6.0	6.4	1530	-8.2	8.3	1600	-3.9	8.0	1600	-5.1	7.0	1600
10	1.1	9.7	1500	No recording						2	16.2	1500

*NOTE Negative (-) sign means that the lower surface temperature was below the corresponding external air temperature.

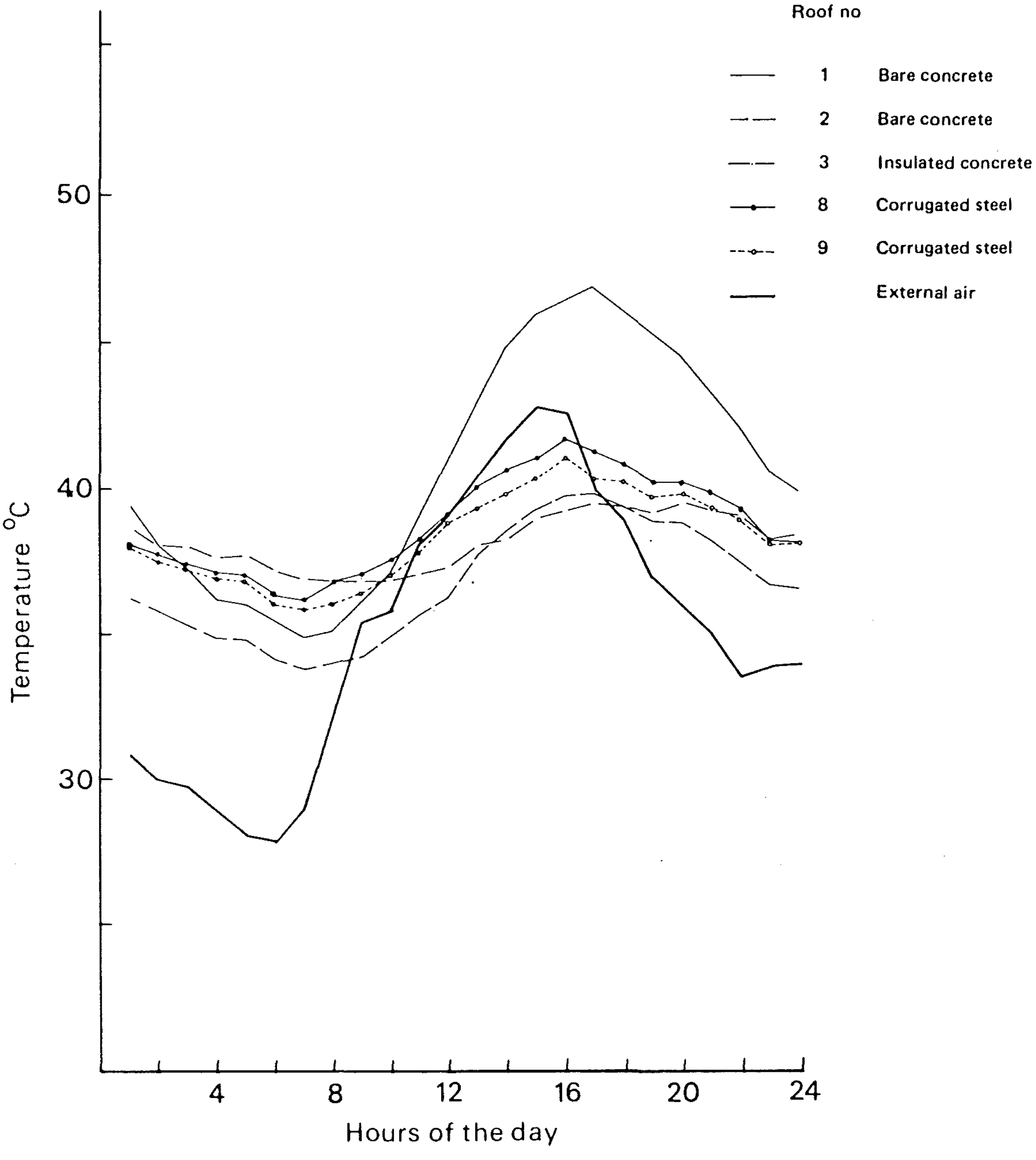


Figure 9 Internal Air Temperatures – Modified Construction. Measured hourly temperature of the internal air 100 mm below the ceiling of Rooms Nos. 1, 2, 3, 8 and 9 and the external shade air temperature.

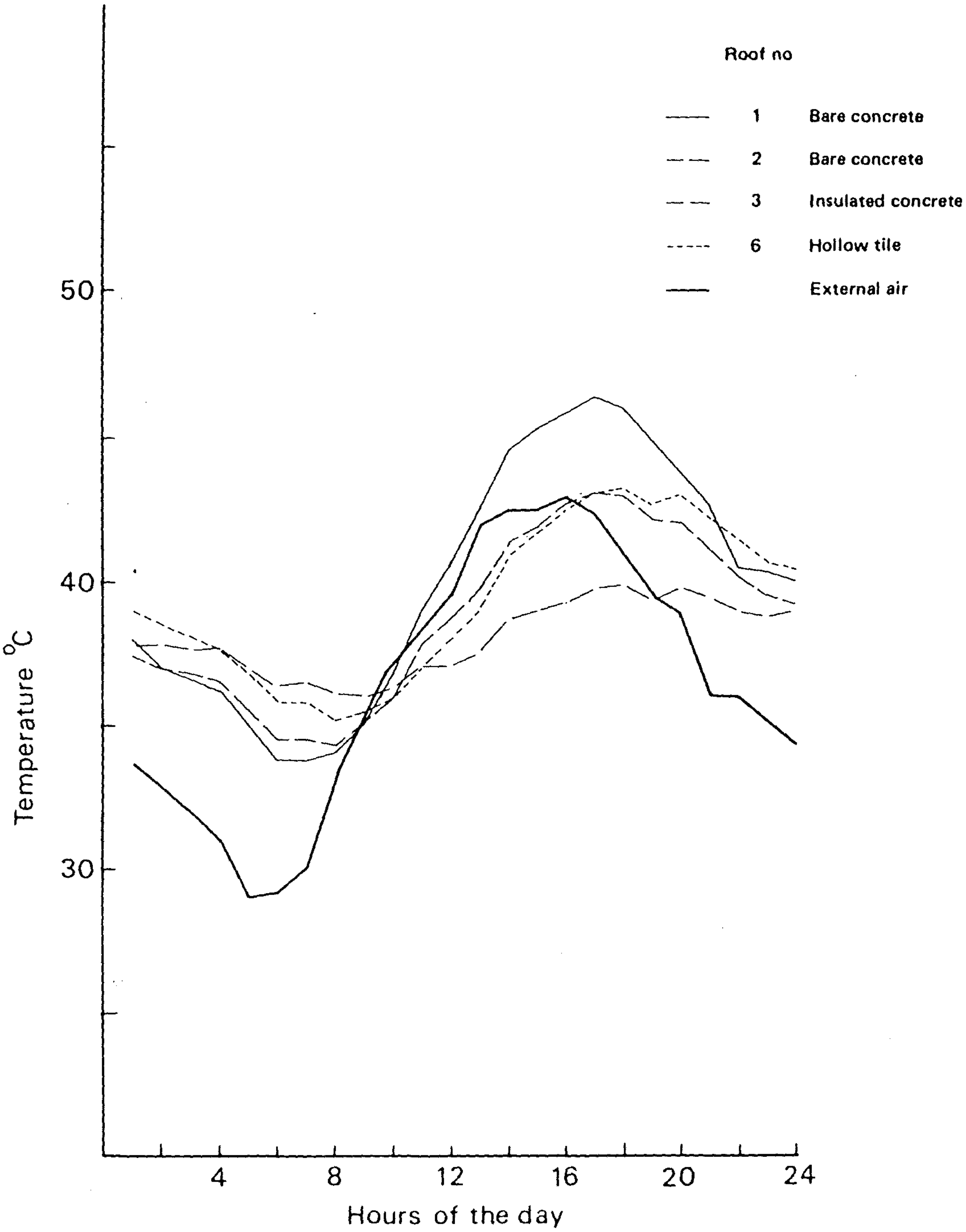


Figure 10 Internal Air Temperatures – Modified Construction. Measured hourly temperature of the internal air 100 mm below the ceiling of Rooms Nos. 1, 2, 3 and 6 and the external shade air temperature.

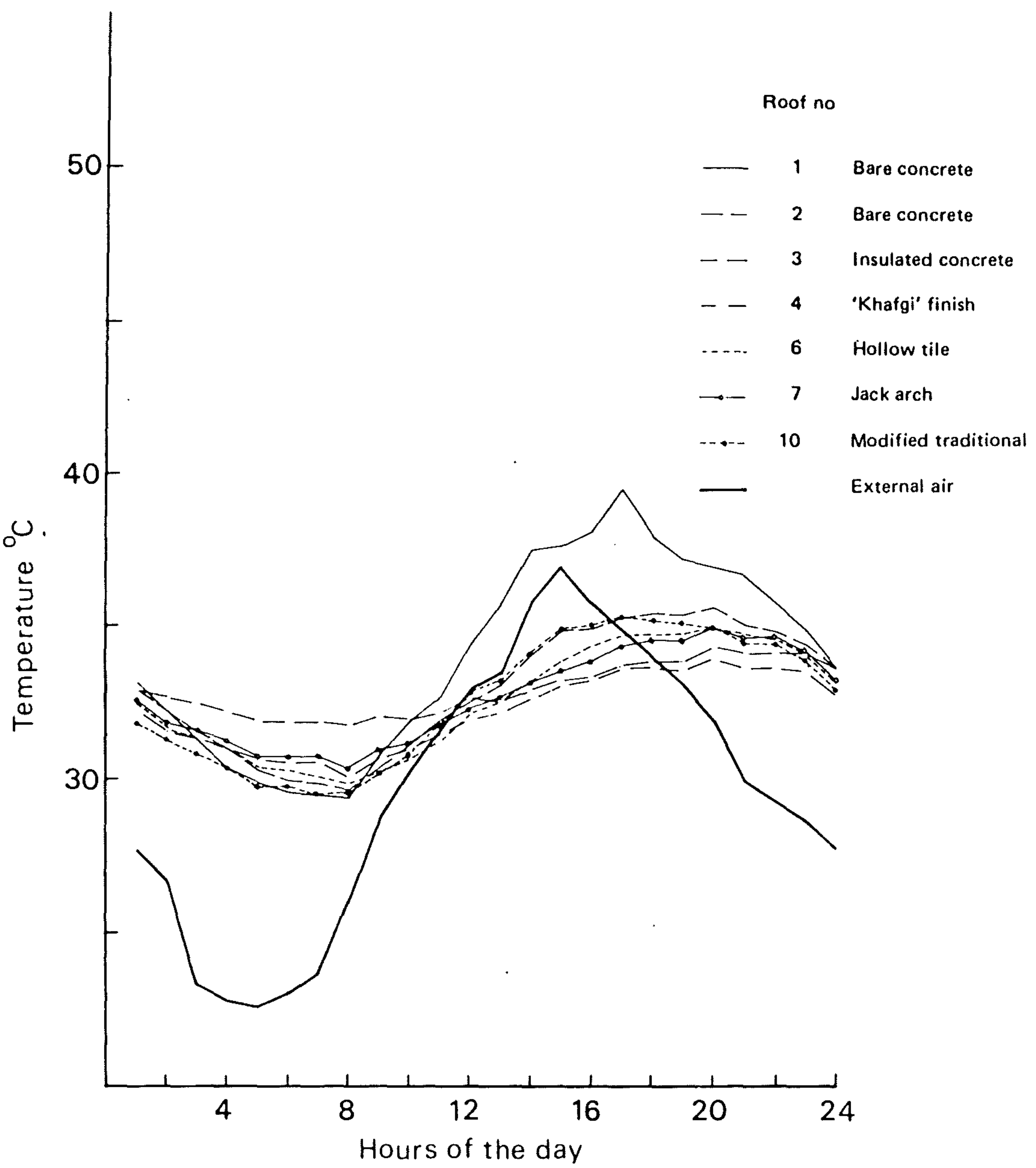


Figure 11 Internal Air Temperatures – Modified Construction. Measured hourly temperatures of the internal air 100 mm below the ceilings of Rooms Nos. 1, 2, 3, 4, 6, 7 and 10 and the external shade air temperature.

(ii) *White gravel*
A 50mm thick layer of white gravel on top of the bare concrete roof slab (no. 2) had very little effect on the thermal performance of the roof. It delayed the time of peak temperature for about an hour (Figure 10). The addition of 25mm more white gravel on top had a considerable effect. It achieved a lower temperature, minimum diurnal range and delayed the time of maximum, temperature to about the same time as the heavy roof construction. Its main disadvantages are its weight and restriction on the use of the roof surface.

(iii) *White cement tiles.*
Addition of white cement tiles (200 x 200 x 200 mms) on top of roof No. 3 had no significant effect on the thermal performance of the roof when it was white-washed. The average temperature was higher (Figure 10)'

5 COST OF THE ROOF CONSTRUCTION

The cost of the materials and labour was calculated for each individual roof of the model building, according to the current rates at the time of the construction (Figure 12). It was noticed that there was no relation between the capital cost and the thermal performance of the roof. Some high cost roof constructions performed less well than lower cost ones.

All roofs contained certain imported items, i.e., steel bars, galvanised steel, fibreboard, roofing felt, timber and polystyrene. The cost of these imported items varies from one roof to the other, i.e., Roof No. 7 was the most expensive, but it was constructed mainly from local materials, while roof No. 10, which was the least expensive, had the greatest ratio of its total cost spent on imported materials.

6 CONCLUSIONS

This series of experiments demonstrated that a concrete roof slab with a suitable layer of insulation on top, or shading of a light reflective material like galvanised steel, gives a minimum heat transfer, together with a reasonable delay of the maximum internal temperature. The combination is simple and can be achieved at a low cost if local materials are used for insulation and shading. The research also showed that the thermal performance of roofs in general can be improved by any of the following methods, used singly or in combination:
applying a coat of white paint to the external surface of the roof;
ventilating during the hours when the external air temperature is lower than the corresponding internal air temperature;
allowing the shaded roof construction to lose most of its gained heat to the cool night sky by folding or rolling away the shading device during night time.

It should be reiterated that there are further advantages to be gained from improvements in the thermal behaviour of a roof, beyond those of increasing the comfort of people in the rooms beneath. By minimising the temperature variations of the external surface, and of the roof structure, the thermal movement of the roof slab will be reduced and the life of the waterproofing membrane may be increased.

The investigation which was carried out has provided some information about the behaviour of different roof constructions. It is foolish to attempt to improve the thermal performance of a roof by simply adding more elements on top without knowing their exact effect. Such attempts may only increase the cost and the load of the roof, whilst resulting in a less efficient roof which is difficult to maintain.

ACKNOWLEDGEMENT

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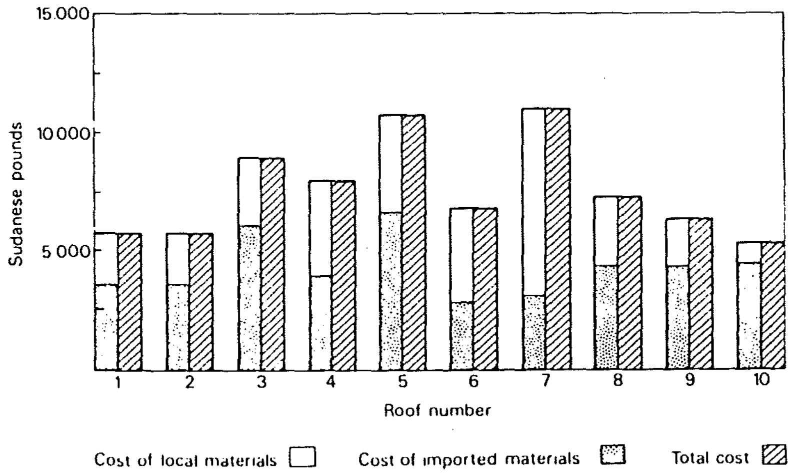

Figure 12 Construction Costs. Cost of roof construction per square metre.

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