7

Application and Design of Passive Solar Systems for Buildings

7.1
Solar Design for Hilly Areas: Proposed Hypocaust System for Indira Gandhi Hospital, Shimla

N.K.Bansal & M.S. Bhandari

Introduction

Epiphanies (Forbes 1958) gave the definition of a hypocaust as 'a heating apparatus placed under the building it proposes to heat'. In Roman hypocausts, the furnace burning wood was kept in the cellar. The hot gases were passed through the walls and escaped eventually through holes in the roof. The schematic of a hypocaust, along with a wall and floor hypocaust, is shown in Figure 7.1.

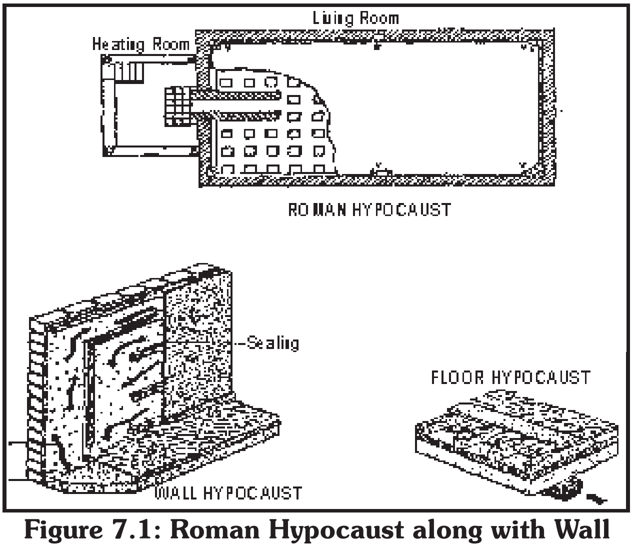

Figure 7.1: Roman Hypocaust along with Wall and Floor Hypocausts

After the energy crisis, this concept has been used in some buildings, along with other passive concepts. These buildings have been studied and their performances have been analysed; the analyses are given in the next section.

For practical use of a hypocaust, it is necessary to find out whether such building blocks are available. This paper presents the results of a survey of such a building block in India, and, finally, simulation results of a part of Indira Gandhi Hospital, which incorporates this concept, have been presented in Section 7.1.5.

Case Studies

Certain buildings that use the hypocaust concept were studied. Some of these are described below in brief (IEA 1989).

THE SCHOOL AT TOURNAI, BELGIUM

Building Type :	Educational
Surface Areas (m^2)	Opaque walls: 1,227, Glazed area: 772, gross floor area: 2,635 sq.m. and heated floor area: 1,720 sq.m.
U-Values (w/m^2k)	U_{walls} = 0.36, U_{Roofs} = 0.19, U_{Floor} = 10 and U_{window} = 1.6.
Site Data	Lat 58°38'N and altitude - 20 m
Climatic Data	Global horizontal solar irradiation (G_J): 1154 MJ/m^2 Total sunshine hrs 634 h Heating degree days (20°base): 3,060

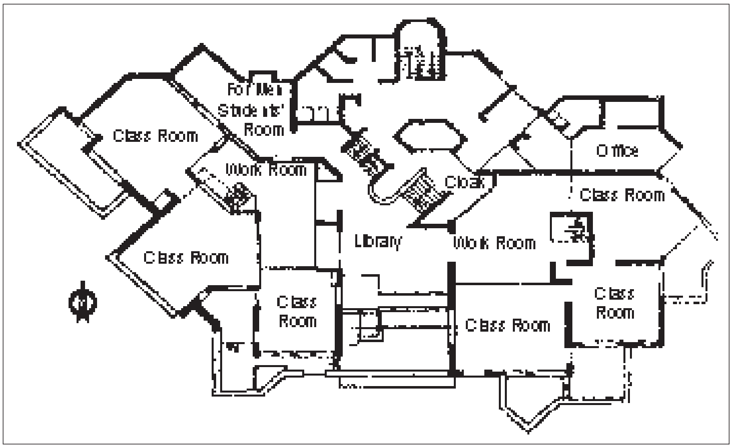

Figure 7.2: Building Plan

METEOLABOR LABORATORIES, SWITZERLAND

Floor area	Gross 640 square metres Heated 420 square metres
Volume:	Heated : 1670 cubic metres

U-Values (W/m²K)	Walls = 0.28, roof : 0.21, windows 1.98 and building 0.36
Site data	Lat. 47°20'N and altitude: 548m
Climatic data	Gh: 1425 MJ/m², sunshine hours: 643 annual degree days (base 20°C) 4,730

Figure 7.3

SOGECO OFFICE BUILDING ITALY

Floor area	Gross: 1,500 square metres Heated : 1380 square metres
Volume (m^3)	Gross : 4915 Heated : 4378
U-value (W/m²K)	Roof : 0.58, wall: 0.518 window 2.0
Site Data	Latitude: 37°24'N and altitude : 50m
Climatic data	Gh: 6257 MJ/m², sunshine hrs: Degree days (20°base): 1493

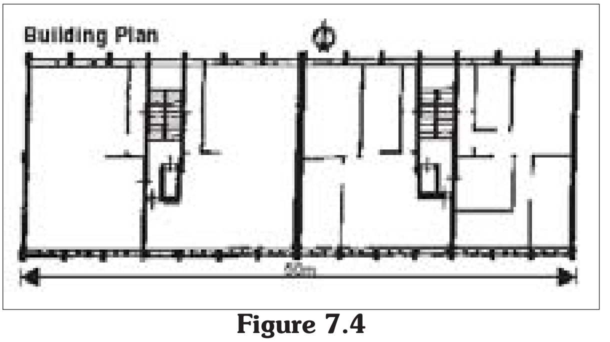

Figure 7.4

SHOPFLOCH KINDERGARTEN GERMANY

Floor area (sq.m)	Gross : 270
	Heated : 250
Volume m^3	Gross : 805
U - Value (W/m^2K)	Roof: 0.336, wall: 0.445, floor: 0.589 and windows: 3.0
Site data	Latitude - 47°50'N
	Altitude : 400 m
Climatic data	Gh : 1307 MJ/m^2
	Sunshine hrs: 598
	Degree days: 3,908

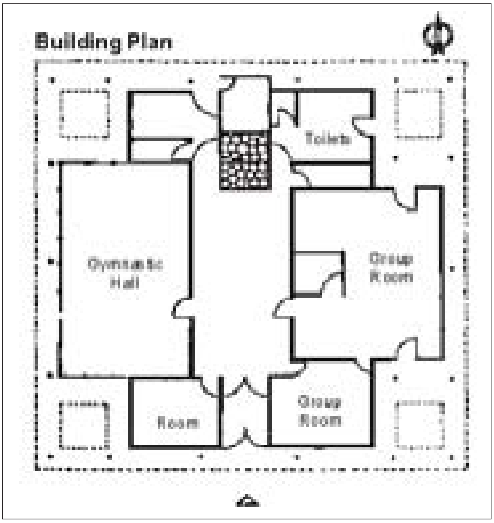

Figure 7.5: Solar Chimney

These buildings have been studied in detail and the relative performance of buildings in terms of energy performance is given in Table 7.1.

The energy requirements per m^2 per degree day show that the building with a solar chimney consumes minimum energy ($15kJ/m^2.DD$). The energy requirement in this case is minimum because it is based only on natural convection, and therefore it does not require any additional electrical energy. Moreover, the concept of a solar chimney works well, allowing a good collection of solar heat and transferring it into the building spaces.

Solar Chimney

A solar chimney is essentially a solar air heating collector integrated into the building. A building with a solar chimney is shown in Figure 7.5. The chimney is essentially a solar air heater integrated into the south facade, providing both winter heating and summer cooling. In winter, the solar air heater brings warm air into the building space, while during summer periods it provides ventilation by stack effects.

Table 7.1: Results of the Case Studies Analysed

Building Type	Solar Features	Annual Degree Days (DD)	Floor Area (M^2)		Per M^2 DD Energy Require-ment	U-Value ($WM^{-2}K^{-1}$)
			Gross	Heated		
The School of Tournai Belgium	Greenhouse Solar air collectors Warm air from solar collectors circulates through cavities in the internal double wall & in precast concrete slabs.	3754	2635	1720	65.3 kJ pa	0.57
Meteolabor Laboratories Switzerland	Greenhouse Solar air collectors Solar heated air from the greenhouse and collectors is made to flow through sheet metal tubes embed-ded in the concrete floor.	4730	640	420	22.6 kJ pa	0.36
Sogeco Office Building ITALY	Solar chimney inte-grated in the south facade with storage in the ceiling provides hot air.	1493	1500	1380	15.4 kJ pa	0.79
Schopfloch Kindergarten GERMANY	Solar air collectors Hot air from solar collectors circulates through the floor and parts of the inner wall.	3908	270	250	128.4 kJ pa	0.90

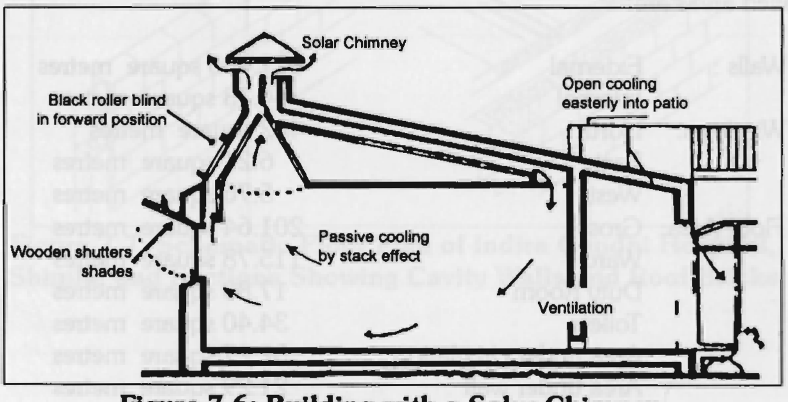

Figure 7.6: Building with a Solar Chimney

Building Blocks for Hypocaust Construction in India

Suitable hypocaust building components need a hollow conduction element that can be used to build a wall, floor, or roof. A survey of such suitable blocks was therefore undertaken (Bagley 1996) for hypocaust construction in India. The size of blocks and cavities can be varied as per requirements. This is done by making the changes required in the mould. Thermo-physical properties of some of the available blocks were measured, and these are given in Table 7.2.

Table 7.2: Material and Energy Characteristics of Cavity Blocks

(Bagley 1996)

Hypocaust Material	Cavity Type	Dry Weight (kg)	Density (kgm^{-3})	Crushing Strength (Tonnes)	Thermal Conductivity ($Wm^{-1}K^{-1}$)
Concrete Block Type I (1:3.6)	Vertical	21.07	2300	20.8	0.696
Concrete Block Type II (1:3.6)	Horizontal	10.85	2300	21.0	0.689
Precast Roof Slab (1:3.6)	Horizontal	12.64	2400	18.0	0.290
Kosi Brick	Vertical	3.18	1920	45.0	0.656

Design of Indira Gandhi Hospital, Shimla

A part of Indira Gandhi hospital has been selected for incorporation of the hypocaust concept for space heating. A model has been developed for calculating the inside room temperatures. This model also calculates the storage capacity required and the dimensions of building elements.

The selected part measuring 14.2 m x 14.2 m is exposed to the ambient on three sides and connected to the rest of the structure (Figure 7.6) on the fourth side by an inner partition wall. This part consists of a ward, duty rooms, changing room, toilets, and a staircase.

The detailed areas are:

Walls :	External	117.405 square metres
	Internal	44.73 square metres
Windows:	North	482 square metres
	East	6.21 square metres
	West	5.76 square metres
Floor Area:	Gross	201.64 square metres
	Ward	115.78 square metres
	Duty Room	17.80 square metres
	Toilets	34.40 square metres
	Area under circulation	32.27 square metres
	Area under wall	21.29 square metres
	Volume	635.16 cubic metres

The hospital has double glazed windows and a central heating system. Electricity and boilers (wood-burning) are used for central heating. In spite of the hospital having a central heating system, room heaters are needed in the cold winter months. All the three facades exposed to the ambient can be converted into cavity walls. Solar air collectors and exhaust gases from a diesel power-generating system were put to use to achieve the required temperature of hot air flowing through the cavity wall.

Before using the hypocaust concept one should have an idea about the heating requirements. The simulation has been carried out assuming a single zone building and the following construction.

a. Normal construction is a brick wall and RCC roof (U value = 2.13 W/m^{2}K)
b. Hypocaust construction without insulation (U Value = 1.78 W/m^{2}K)
c. Hypocaust construction with a 5 cm insulation of glass wool (U value = 1.36 W/m^{2}K)

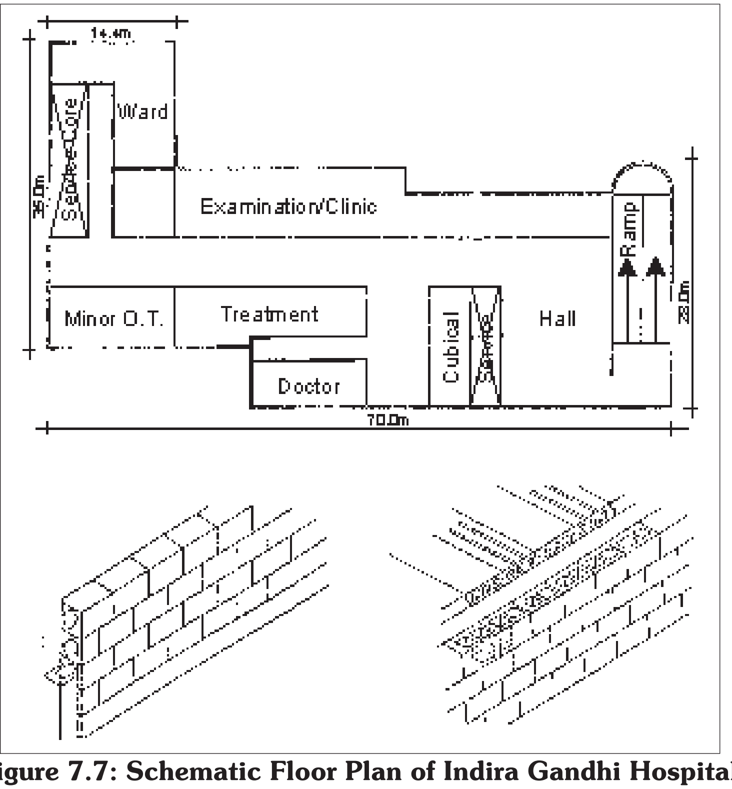

Figure 7.7: Schematic Floor Plan of Indira Gandhi Hospital, Shimla, and Sections Showing Cavity Walls and Roof Bricks

As a first estimate, the degree day method has been used for heating energy requirements and can be given by the following expression.

Heating requirement = U_B x DD x A_b x 24 x 10^{-3} kWh
Where,
U_B is the overall heat loss coefficient of the building
DD is the degree day
A_b is the area of the building envelope.

By taking the basic temperature as 20°C inside the room, the number of degree days, monthly heating requirements, and specific heating requirements are given in Table 7.3.

It is seen from Table 7.3 that, by using cavity blocks, energy consumption can be reduced to 99.06 kWh/m² a from 118.2 kWh/m²a, which can be further reduced to 75.52 kWh/m² by insulating the walls and roof.

Table 7.3: Heating Requirements(kWh/month)

Month	Degree Days	Normal Brick Wall and RCC roof	Hypocaust without Insulation	Hypocaust with 5 cm Insulation
January	458.8	4728	3995	3019
February	372.4	3837	3243	2450
March	291.4	3003	2538	1917
April	144	1484	1254	948
May	00	00	00	00
June	00	00	00	00
July	52.7	543	450	347
August	74.4	766	648	490
September	93	958	810	612
October	176.7	1821	1539	1162
November	267	2752	2325	1757
December	81.3	3930	3320	2509
Total Annual	2311	23822	20132	15211
Specific Energy Demand (kWh/m² a)		118.2	99.96	75.52

The exhaust gases from the diesel generator set or hot air from a solar air heater can be coupled to a hypocaust wall.

The temperatures obtained inside the room for a diesel generator coupled hypocaust are shown in Figure 7.7 for different mass flow rates. The room temperatures obtained are well above 20°C of the mass flow rate of 0.0708 m³/s. The temperature of the exhaust gases is 200°C. The diesel generator set was run for eight hours during the day.

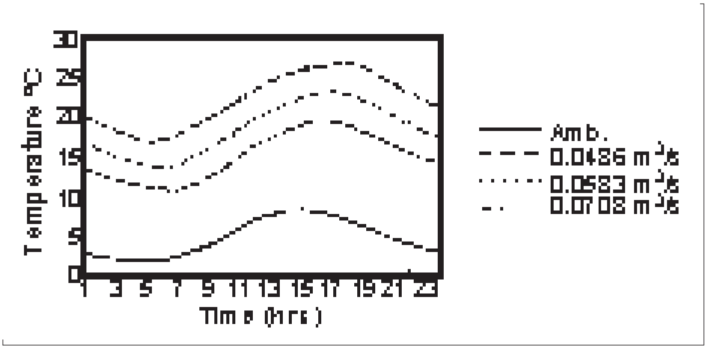

Figure 7.8: Room Temperatures Obtained from a D.G. Set Coupled Hypocaust at Different Mass Flow Rates (Continuous Flow)

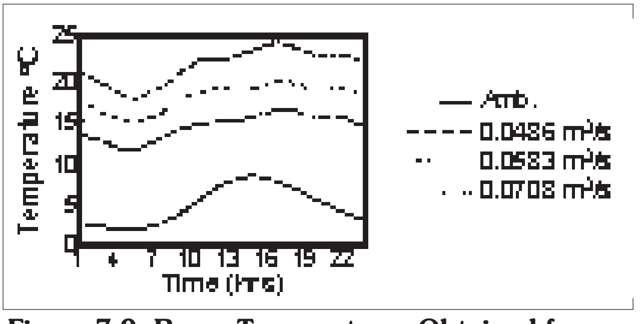

Figure 7.9: Room Temperatures Obtained from a D.G. Set Coupled Hypocaust at Different Mass Flow Rates (Intermittent Flow)

For intermittent flow, i.e., three hours in the morning, three hours in the evening, and two hours at night, the temperatures are shown in Figure 7.9. The room temperatures are more stable and in the comfortable range (18-25°C).

Alternatively even a solar air heater can be used to let warm air flow through the hypocaust cavity. Figure 7.10 shows temperatures inside the building space for such air heaters coupled to a hypocaust. The temperatures obtained for a 70 square metres collector area at the flow rate of 0.182 m^3 /s are in the range of 75-80°C above the ambient temperature. The inside temperatures are again seen to be within the comfortable range.

Conclusions

The concept of a hypocaust house evolved by tracing the history of such construction. The building materials available that are conducive to the development of a hypocaust

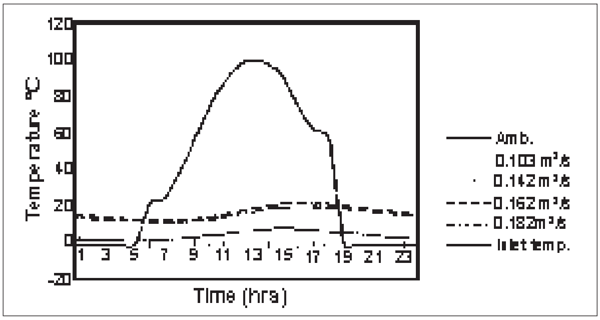

Figure 7.10: Room Temperatures Obtained from a Solar Air Heater Coupled Hypocaust at Different Mass Flow Rates

house in India are studied. Thermo-physical properties of hypocaust materials were measured and the design for a part of Indira Gandhi Hospital was conceived on the hypocaust concept by simulation. The results show that the hypocaust concept can be incorporated into buildings to achieve comfortable temperatures inside them by using exhaust gases from a diesel generator set or solar air heater.

Further Reading

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7.2
Design of a Solar Heating System for a House in a Model Village in the Hindu Kush and Himalayan Range

S. Alam

Introduction

Although the energy crisis of the 1970s had passed, the cost of heating is still a concern to householders, especially to those living in the Northern Region of Pakistan. The householder's fuel bill depends on four main elements.

1. The climate in which the house is located.
2. The amount of heat that escapes from the house in winter.
3. The cost of the fuel used in the central heating system.
4. The cost and efficiency of the central heating system.

Climate is the biggest factor determining how much heat will be needed to keep a house warm. Winter conditions in the mountain areas of Pakistan are quite harsh and building designs should take this into account. Older and larger homes lose more heat in winter and thus have to pay high prices for heating.

Although the climate and the fuel (to some extent) are out of the householder's control, they determine how the the other two elements are managed. This paper suggests ways in which (in the northern region of Pakistan) these elements can be managed effectively in order to reduce domestic heating costs.

Pakistan receives a lot of sunshine, as it is located in the latitude range between 20 and 47°N. Solar energy is clean, renewable, abundant, and distributed widely in a global sense. Solar energy is convertible into heat and electricity with reasonable efficiency. It is thus a unique source of energy that can and has been used successfully to meet domestic needs for lighting, water heating, space heating and cooling, industrial process heating, and agricultural purposes such as irrigation, crop drying, and grain/fruit cold storage. The proven technologies for use of solar energy are demonstrated and developed under local conditions in different ecological and geographical zones.

Use of passive solar energy as a means of reducing energy bills is an excellent option for poor householders in the Hindu Kush-Himalayan Region who mostly depend on fuelwood (purchased or collected) to meet their domestic energy needs . A properly designed house, taking into consideration the potential use of passive solar technologies, can offer advantages such as good environmental conditions, improvement in the standard of living, and decrease in deforestation over traditional building designs in the region.

This paper describes the basic principles of a solar heating system, a typical flat plate collector, array orientation, array size, and pros and cons of series and parallel arrays. Designs of solar hot-water supply systems and solar-assisted space heating systems are the main products of this research work. In passive solar building designs, computer simulations are also used. Two computer models are also briefly described.

Objectives

The objectives of this paper are to review the basic principles of solar heating systems and to design a solar assisted heating system for a model house (with a covered area of 600 sq. ft.) in Gilgit.

Before going into the technical details of a complete solar heating system, it is better to describe briefly the operation of heating panels, emphasising, particularly, liquid-type flat plates. commercial heating panels vary significantly from one manufacturer to another and no single theory can be applied to all systems. It is, therefore, impossible to develop a rigorous analysis of every design detail of a solar collector. In order to illustrate the essential features of flat plates and their principles of operation, a comparatively simple model is used for illustration. Although the results depend somewhat on the choice of mode, the analysis provides an understanding of the operation of a broad class of flat plate collector.

A simple liquid-type flat plate collector is illustrated in Figure 7.11. It consists of a black absorber plate with an absorptivity of near unity for solar radiation. A selective absorber coating of lower thermal emissivity is deposited on the plate. The plate is fitted with tubes or channels so that a transfer liquid can extract the heat produced in the plate when solar energy is absorbed. The plate is placed in an air-tight, insulated container and covered with glazing. Back and side thermal losses are usually negligible when compared with front losses through the glazing. Heating panels can be classified as either active or passive according to whether a pump or natural convection is used to circulate the fluid.

In particular, it will be considered how an array of heating panels is arranged and interfaced with other components to make a complete, efficient and cost-effective heating system.

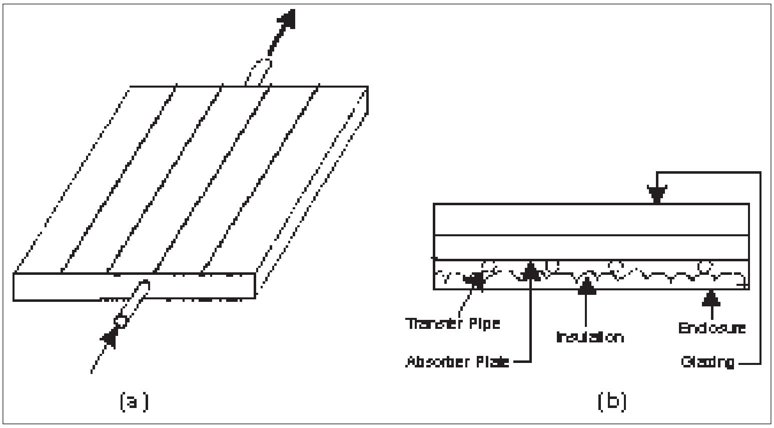

Figure 7.11: (a) A Typical Flat Plate Collector Showing Transfer Pipes (dashed lines) under the Absorber Plate, (b) A Cross-sectional View of the Same Flat Plate

Array Orientation

Unlike concentrators that normally require daily tracking, flat plate collectors can operate with a fixed orientation. Although tracking will improve the performance of a flat plate, the gains are usually more than offset by the increased costs of manufacturing and maintaining tracking apparatus. A fixed array of flat plates should be oriented so that the daily intercepted flux is largest during the operating season. Because it is difficult, if not impossible, to optimise tilt with respect to diffuse solar radiation, it will optimise with respect to the direct component only.

The daily direct flux intercepted by a fixed array with tilt coordinates can be obtained by integrating over the hours of available insolation as given below.

$$F(\Delta, \Psi) = S \int_{t_1}^{t_2} \exp[-\tau / \cos Z] \quad \cos \theta \quad d\tau \qquad (7.1)$$

Where:

S	=	1352 W/m^2 (solar constant)
i	=	optical thickness of the atmosphere
Z	=	solar zenith angle varies with solar time
q	=	obliquity angle of sun's rays to array (varies with solar time)
t_1, t_2	=	solar times in between which Cosq is positive, that is when the sun's rays strike the array on the front face
y	=	tilt and azimuth of the array.

In Table 7.4, daily fluxes obtained from equation (7.1) are reported. The values are for an array situated at latitude (L= 49°) and for an atmosphere of optical thickness equal to 0.3. For south-facing arrays the daily flux during any season is largest when the tilt is set so that the array is approximately perpendicular to the sun's rays at solar noon. At the winter solstice, a vertical south-facing array is more effective then that of a horizontal one. The opposite is true at the summer solstice. As seen from Table 7.4, an east- (or west) facing array is generally less effective than a southerly array. For an east- (or west) facing array the intercepted flux increases as the array becomes more horizontal. If a solar array, situated at (L = 49°) is to be used to provide space heating during the winter solstice, a southerly tilt of 64.5° is optimum. This tilt still provides adequate heating at the equinoxes. However, if the array is used to supply hot water in summer a tilt of 17.5° is more effective. The result is presented in Table 7.4. This is based on an oversimplified model and is for purposes of comparison only. Diffuse radiation and the radiation reflected towards the array from the underlying terrain have not been included. Also, the flux predicted by equation (7.1) assumes that the insolation pattern is sy mmetric about solar noon. Morning and afternoon insolations are often different. Consequently, east and west-facing panels do not in general receive an equal amount of sunlight. A more precise treatment would require experimental data on the daily insolation available to various inclined surfaces.

Table 7.4: Approximate Clear Day Direct Fluxes on Surfaces at Various Orientations

Season	Tilt (A) Degrees	Flux (Kw-hr/m²-day) South, = 0	Flux (Kw-hr/m²-day) (East West = 90)
Winter	0 (horizontal	1.4	1.4
Solstice	175	2.2	1.2
(D = 112.5)	41	2.2	1.2
	645	2.5	0.98
	90 (vertical	2.2	0.69
	0 (horizontal)	4.5	4.5
Equinox	175	5.5	4.2
(D = 90)	41	2.9	2.8
	645	7.6	2.0
	90 (vertical)	7.6	2.0
	0 horizontal	6.4	7.6
Summer	175	4.2	7.2
Solstice	41	1.5	6.2
(D = 665)	645		4.7
	90 (vertical		2.0

Source: Winder 1982

Array Size

The size of the array is determined by such factors as ambient conditions, heating needs, array efficiency, and available insolation. The size of an array can be found using equation 7.2.

$$A = \frac{P\,(daily)}{F\,(daily) \times n} \qquad (7.2)$$

A = Solar panel area m^2
F = useful solar energy from single collector Kwh
n = efficiency

Suppose, for example, the daily heating needs of a house during the cold weather are 100 kw-hr/day and that the available daily insolation on the array is 4 kw-hr/m^2-a day. Also assume that each panel had an area of 1.5 m^2, an efficiency of 50 per cent, and that one-third of the heating will come from auxiliary heaters. The solar heating requirement amounts to 66.7 kw-h/day. Since the array is 50 per cent efficient, the required arrayed area using equation (7.2) is found to be 33.3 square metres. Since each panel has an area of 1.5 square metres, the number of panels required is 22.

Series and Parallel Arrays

A solar array consists of heating panels arranged in either series, parallel, or a combination of the two, as shown in Figure 7.12. A large array will not produce a higher temperature than a single collector. An array of N panels, however, does have the potential for collecting N times the amount of heat than a single panel. To collect this heat, the fluid flow rate supplied to the array must be increased by a factor of N. In a series array, the outlet of one panel is coupled directly to the inlet of the next one.

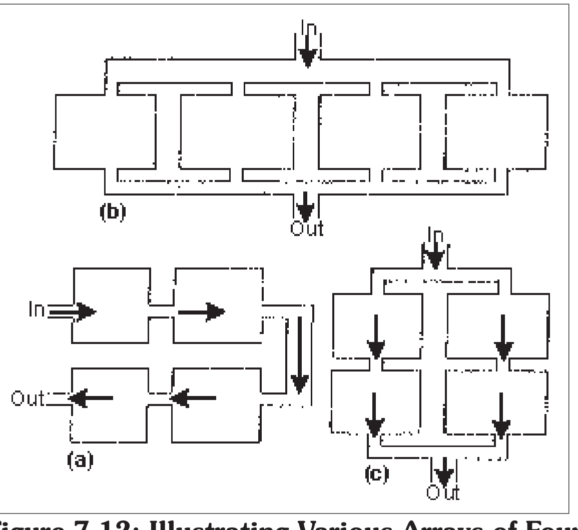

Figure 7.12: Illustrating Various Arrays of Four Panels (a) Series' Array, (b) Parallel Array, and (c) Combination Array

Consequently, the increased flow must pass through each and every panel of the array. As the fluid velocity increases, so does resistance to flow. Furthermore, the longer the overall length of the pipe through which the fluid is flowing, the greater the flow resistance. Therefore, a long series' array offers substantial resistance to the flow of the transfer fluid. To maintain the flow, the pumps must produce a large amount of pressure so that the pressure at the inlet is far greater than at the outlet. This produces a strain on both the pumps and on the panels of the array. Since, in a series' array, all the panels do not operate at the same efficiency, those closer to the inlet operate at a lower temperature and are therefore more efficient. The opposite is true for those panels closer to the outlet.

In a parallel array (Figure 7.12b), the inlets of each panel are connected to a common feeder line. The outlets are similarly connected to a common drain. A parallel array, although more difficult to implement than a series' array, offers little resistance to fluid flow. Furthermore, if the total flow rate entering the array is equally divided into the individual panels, the performance characteristics of the array can be easily deduced from those of a single panel. The efficiency and temperature increase of such an N-panel parallel array are the same as those of an individual panel, but the flow rate and the useful heat collected are N times as big. In practice, a combination array is often used to facilitate installation as shown in Figure 7.12c.

Heat Losses from Pipes

Exterior pipes that carry warm transfer fluid from the array will lose heat to the cooler surroundings. The heat transfer process can be approximated using the single-current heat exchange equation. If the heat exchange equation is applied to an exterior pipe carrying fluid from an array at a hot temperature, $T_{h.}$, the temperature of the fluid reaching the tank is:

$$T = T_a + (T_h - T_a) \exp(-U L/mC_t) \qquad (7.3)$$

Where, U_l is the overall coefficient per unit length of pipe for heat transfer from the fluid to the surrounding air and L is the length of the pipe.

The heat loss from the pipe is given by:

$$Q_{pipe\ loss} = m\, C_f\, (T_h - T_a)\, [1 - \exp(U L/mC_l] \qquad (7.4)$$

For a well insolated pipe, the product, $H^1 = U_L L$, will be small, in this case $T_{storage} \sim T_H$ and $Q_{pipe\ loss} \sim 0$.

The pipe losses represent a smaller fraction of the heat collected for large arrays than for small arrays. The smaller the array, the more important it is to keep the exterior pipe short in length.

Two Simple Applications of a Solar Heating System

A. Solar Hot-Water Supply System

One of the basic uses of solar heating is to supply hot water. Tap water heated by a solar array can be used directly or, if higher temperatures are required, the water can be heated further by an auxiliary heater.

In many applications, however, it is necessary to transfer the heat from a solar-heated transfer fluid to a cold water supply. For example, the transfer might be water to which antifreeze has been added to prevent freeze up and corrosion within the array. The transfer fluid is circulated in a closed loop, and the heat transferred through a counter current heat exchanger to a tank of water. This type of system can be used in an individual house or in health/co mmunity centres (Figure 7.13).

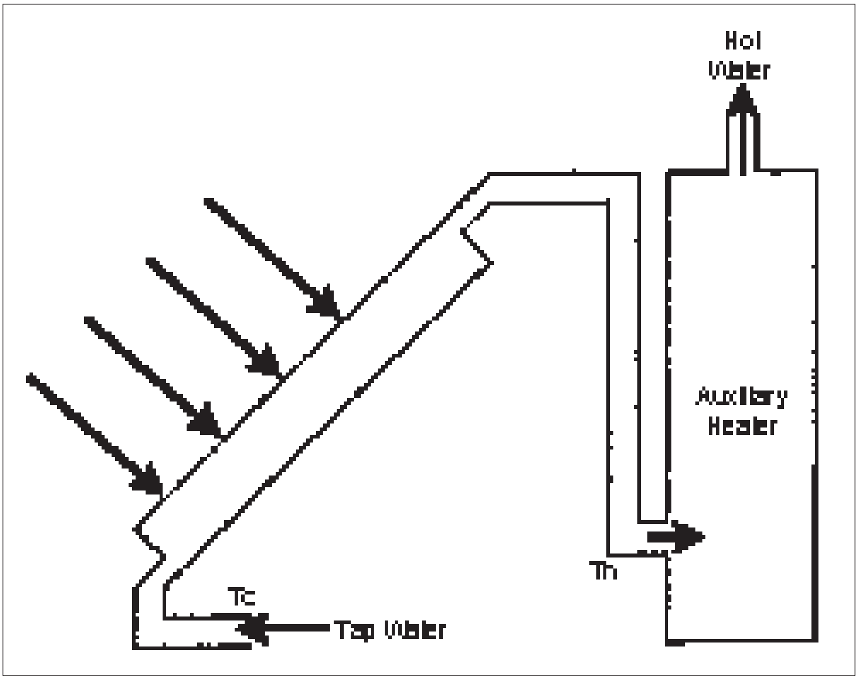

Figure 7.13: An Open Loop System in which Tap Water is Pre-heated by Solar Energy and then Heated by an Auxiliary Heater

B. Solar-assisted Space heating System

Buildings experience heat gains and heat losses depending on whether the cooling or heating system is present. Let us consider here the design of a solar assisted space heating system for a typical house built in Gilgit, in the Northern Areas of Pakistan.

Covered area of the house (or the space to be heated)	=	600 sft.
Size of household (no of occupants) average	=	eight persons

Table 7.5 provides environmental indices (climatic data) for the Hindu Kush-Himalayan Region of Pakistan (Gilgit, Yasin, and Chitral). Figure 7.14 shows the heat gain of a house in Gilgit for which a solar assisted space heating system is being designed. The excess solar heat gain during the winter month may decrease heating loads.

Table 7.5: Climatic Data for Gilgit, Yasin, and Chitral

Environmental Indices	Gilgit	Yasin	Chitral
Mean monthly Temperature, F			
January	43.30	23.00	40.10
July	86.00	68.00	83.40
Mean daily temp(minimum of coldest month), F	10.30		13.30
Absolute minimum precipitation, mm			
January	10.00	05.00	35.00
July	08.00	08.00	08.00
Mean annual Precipitation, mm	133.00	126.	448.00

Notes
1. Winter conditions are quite harsh
2. Summers are mild and if buildings are properly ventilated, oriented, and their windows properly shaded then they will be quite comfortable.
3. Gilgit and Yasin are relatively arid during summer from May to October.

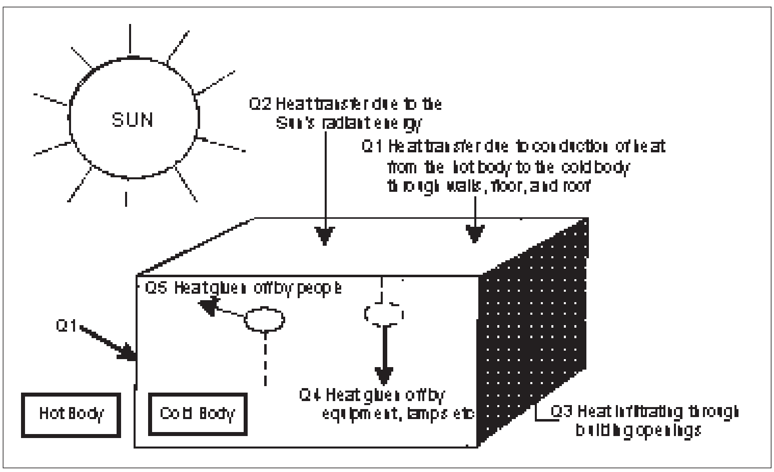

Figure 7.14: Heat Gain in a House in Gilgit

Calculations of Heat Load and Array Size

In the heat gain equation shown in Figure 7.14, the figures Q1, Q3, Q4, and Q5 are very small compared to Q2, because solar heat gain during the winter season is the major component of heat gained by a house in Gilgit and is responsible for the decreased heating load of the house.

Assume that the room /home heating is facilitated by a good quality heat exchanger made of steel (thermal conductivity 50.2 W/m-°C). The mean daily temperature (minimum of the coldest month) is –12°C (10.8° F, see Table 7.5). The temperature of the room/house has to be increased to a minimum. comfortable temperature of 20°C. This means that the temperature differential would be 32°C. The daily heat load (kW-hr/day) can be calculated using the basic heat conduction equation. To heat the whole house (600 sq.ft.), the daily heat load is estimated as 2,149 kW-hr/day. This is quite a high load and it is practically very difficult to manage solar panels to warm an area of 600 sq. ft.

It is, therefore, suggested that one bedroom of the house with a floor area of 144 sq. ft. (12 x 12) should be heated with solar heating panels (Figure 7.15).

The daily heat load (P) for the bedroom = 516 kW-hr /day.

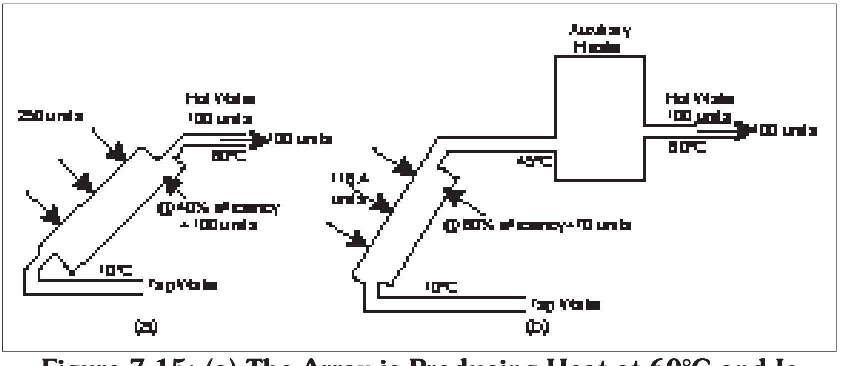

Figure 7.15: (a) The Array is Producing Heat at 60°C and Is Operating at 40% Efficiency (b) The Array is Producing Heat at 45°C and Is Operating at 60% Efficiency

In order to satisfy these heating requirements, the array area can be determined by using equation (7.2).

Assume that the available daily insolation on the array is 6.4 kw-hr/m^2-day. Also assume that each panel has an area of 1.5 square metres with an efficiency of 50 per cent. Since the array is 50 per cent efficient, the size of array needed is found to be 161.25 square metres. Since each panel has an area of 1.5 square metres, the number of panels required is 107.5.

An Auxiliary Heater Increases Array Efficiency

The efficiency of a solar heating panel decreases as its operating temperature increases, because thermal losses increase as the difference in temperature between the absorber plate and the surroundings increases. If the average operating temperature of the panel is to be $T' = (T_1 + T_2)/2$, it is required that T-T be as low as possible for maximum efficiency. For T' to be low, it is necessary for the fluid inlet and exit temperatures to be as low as possible. Let us assume for the moment that the inlet temperature (T) is fixed. For example, in a hot water supply system, T_1 is fixed by the temperature in the room. Thus to reduce T_2 and increase efficiency, the output temperature, T_2, has to be reduced by increasing the flow rate of the transfer fluid. If this temperature turns out to be too low to be useful, it can be raised to an acceptable level by an auxiliary heater. The increased operating efficiency of the array means that fewer panels will be necessary. In fact, under severe environmental conditions, the stagnation temperature may itself be below the level required to produce useful heat. In this situation the array would than be completely incapable of operating without an auxiliary system.

In order to understand the system completely, let us consider an example illustrating how an auxiliary heater increases array efficiency and reduces array size. A collector array has an efficiency of 60 per cent when heating cold tap water from 10° to 45°C. When the same water is heated to 60°C, the array efficiency decreases to 40 per cent. The system is designed to supply hot water at 60°C. Compare the size of the array of an unassisted system with that of an assisted system in which an auxiliary heater is used to raise the temperature of water from 45°to 60°C. Assume that both systems heat water at equal rates.

Let us assume that 100 units of heat are to be supplied by each system. At an efficiency of 40 per cent, the unassisted system must intercept 250 units of radiant power. In the assisted system the array raises the temperature by 35°C and the auxiliary heater raises it by 15°C. Thus the array supplies 70 per cent of the heating needs or 70 units. Since the assisted array is 60 per cent efficient, the intercepted radiation power must be 1,164 units. Consequently, the unassisted array requires more than twice the number of panels than the assisted one. In the assisted system, approximately one third of the heating comes from the auxiliary heater.

7.2.8 Computer Assisted Passive Solar Building Designs

A passive solar system is defined as one in which thermal energy flows by natural means. Examples of solar building design include:

- solar greenhouses which are built on the south side of buildings and can produce 60-100 per cent of heating and cooling requirements;
- underground buildings which use ground temperature to provide year-round temperature requirements; and
- enhanced natural ventilation though solar chimneys.

In these examples and others, passive systems accomplish work (heating and cooling) by natural means such as gravity flows, thermosiphons, etc.

To study how the building reacts to loads, its storage effect, etc. computer simulation is used. Two programmes are described below.

PEGFIX - Predicts auxiliary heat demand and excess heat available in a space with user-defined maximum and minimum air temperatures. The programme is directly useful in sizing and specifying system components and auxiliary equipment. Results stored by PEGRIX are total auxiliary heating load, excess heat available, maximum fan rate required to remove excess heat, and maximum hourly auxiliary load.

PEGFLOAT - Predicts hourly temperatures of air and storage mass in a space without auxiliary heat input or removal of excess heat. Its purpose is to evaluate temperature excursions in a 100 per cent solar-dependent operating mode. This programme can examine non-south glazing orientations with user-specified hourly values for insulation. PEGFLOAT automatically stores the maximum and minimum air and air storage temperatures of the system modelled.

Both programmes required few user-defined inputs regarding the building design and local weather heat loss coefficients, effective thermal capacity and storage surface area, solar energy available, fraction to storage and fraction to air, average outdoor temperature, and daily range. Progra mmes differentiate day and night heat loss values and can automatically proportion day-long insulation. Each can be run through a 24-hour day, without user interaction, in five to nine minutes. Hourly values of air and storage temperatures and auxiliary or excess heat can be displayed without interrupting programme execution. Optional hourly display does not affect data storage.

Conclusion and Recommendations

In this research, the application of passive solar building design was found practical if the area to be warmed is small, i.e., one bedroom of around 150 sq. ft. rather than a whole house of 600 sq ft. This is because of severe weather conditions in the Hindu Kush and Himalayan Ranges. However, if a larger area is to be considered then this technology can be used along with an auxiliary system and much energy/cost for conventional fuel can be saved. It is recommended that, before rushing out to buy a passive solar heating system in hopes of reducing heating bills, householders should first make sure that their home is adequately weatherised. If the house has leaking windows and door frames or poorly insulated walls, attics, and crawlspaces, home heating bills will be high, no matter what fuel is used or how efficient the heating system is.

Financial Assistance

The average income of the people in Gilgit and the surrounding areas is just Rs 5,000* per month. Under current circumstances, one should not expect self-financing by them for these energy projects. Either the Government of Pakistan or some NGO should take the initiative and provide the financial assistance to introduce this low cost, fuel efficient, and environmentally friendly technology in the region.

There are 52 Pakistani rupees to a U.S. dollar.

Further Reading

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7.3
Energy Efficient and Environmentally Sustainable Designing of School Building in Northern Areas Pakistan

S.Ahmed

Introduction

This paper is based on a study carried out for Sikander Ajam Associates, Architectural Consultants to the Aga Khan Housing Board for Pakistan and the Aga Khan Education Service, Pakistan, to evaluate and design a school building in the Northern Areas of Pakistan. The objective of this study was two fold: to formulate recommendations for improving the comfort of existing buildings and to prepare guidelines for designing new buildings. The results of this study were incorporated into the designs proposed for school buildings by the architectural consultants.

Methodology

The methodology adopted for this study had the following main features.

1. The parameters for thermal evaluation are:

    i. climatic data for Gilgit, Yasin, and Chitral to select the most critical conditions that the building should acco mmodate ;
    ii. thermal comfort zones based on the climatic conditions and local culture; and
    iii. ventilation requirements.

2. Based on the above parameters the existing building were evaluated. The thermal performance of different building systems was calculated using the methods explained in Appendix 7B and Appendix 7C.

3. Based on the above-mentioned evaluation, recommendations for improving thermal comfort in existing buildings and guidelines for new designs were prepared.

4. The method used for calculating auxiliary heating requirements and inside average temperatures for different types of design is explained step by step in Appendix 7B. The data required for these calculations are provided in the form of Tables and Figures (Table 7B.1 to 7B.7 and Figure7B.1). It was neither possible (in the absence of full information about all the sites, e.g., orientation, altitude, terrain, climate, and vegetation), nor within the scope of the study to evaluate each design for each possible site. The method is explained here in simple steps so that for given conditions thermal performance can easily be evaluated by just replacing the data from the tables and figurers provided.

Evaluation Parameters

Climatic Analysis

Climatic data available for the Northern Areas, especially for Gilgit, Yasin, and Chitral, were analysed and are presented in Table 7.6. These locations were selected because of their different geographical locations and climatic conditions to ensure that the study covered the different conditions pertaining in this area, e.g., Yasin is located in a valley and the conditions there are different to those of Chitral and Gilgit.

Table 7.6: Climatic Data

Environmental Indices, Gilgit		Yasin	Chitral
Mean monthly temperature			
January	42.8° F	23° F	40.1° F
July	86° F	68° F	82.4° F
Mean daily minimum of coldest			
Month	32° F		29.2° F
Absolute minimum	10.8° F		12.2° F
Precipitation			
January	10 mm	5 mm	25 mm
July	8 mm	8 mm	8 mm
Mean annual precipitation	122 mm	126 mm	448 mm

The following observations are made based on the analysis.

- Winter conditions are quite harsh and building design should be geared to take care of these conditions.
- Summers are mild and if buildings are properly ventilated and oriented as recommended in the study then buildings will be quite comfortable.

- Gilgit and Yasin have 132 and 126 mm annual precipitation respectively, whereas Chitral has 448 mm of annual precipitation. Gilgit and Yasin are relatively arid all year round, whereas Chitral is relatively humid during winter (Nov. to Apr.) and relatively arid during summer (May to Oct.)

Comfort Zone

Perceptions of comfort, temperature, and thermal acceptability are related to a person's rate of metabolic heat production, the rate of transfer of this heat to the environment, and the resulting physiological adjustments and body temperature. The heat transfer rate is influenced by environmental factors: i.e., air temperature, thermal radiation, air movement, humidity, and personal factors such as activity and clothing. Clothing, because of its insulation properties, is an important modifier of body heat loss and comfort. Clothing insulation can be described in terms of its clo value (1 clo - 0.88 sq. ft. hr. °F/Btu). A shalwar/kameez suit, with sweater, chadar, and accessories, has an insulation value of about one clo

Because of the seasonal clothing habits of building occupants, the temperature range for comfort in summer is higher than in winter. Comfort conditions for different clothing levels can be achieved by lowering the temperature by 1 °F from the comfortable temperature range for each 0.1 clo of increased clothing. The acceptable range of operative temperatures and humidities for winter and summer is defined on the psychometric chart (Figure7.16). The zones overlap in the 73-75° F range. In this region, people in summer dress would tend to be slightly cool, whereas those in winter clothing would be somewhat warm. Due to individual, clothing, and activity differences, the boundaries of each comfort zone are not actually as sharp as shown in Figure 7.16.

The maximum air movement allowed in the occupied rooms is lower in winter than in summer. In winter, the average air movement should not exceed 30 fpm. In summer, the comfort zones can be extended above 79°F if the average air movement is increased for each °F. Humidity is described in terms of dew point temperature and relative humidity. In the zones occupied by sedentary people, the dew point temperature should be between 35° and 65°F. Therefore, the acceptable temperature range with adequate clothing and proper air movement can be changed from 65°F to 60°F-83°F.

Ventilation Requirements

Proper ventilation is required to provide outdoor air for maintaining air quality in a given space and for removing excess heat from the interiors. The minimum ventilation requirements to maintain the air quality of a classroom (3,840 cu.ft.) with 30 students and a teacher are 2.5 air changes per hour (see Appendix 7A for detailed calculations). The thermal comfort conditions can be extended above 79°F, if the average air movement is increased by 30 fpm for each °F of increased temperature to a maximum temperature of 83°F.

Review of the Existing Buildings

Roof Systems

The existing three-room single storey design is a compact design which helps to reduce heat gain during summer and heat loss during winter, but the existing roof system of pre-cast T beam and hollow blocks is inefficient. This roof system has a very high U-value; because of the absence of significant insulation, excessive amounts of conduction heat gain/loss occur during summer and winter respectively. The other type of roof system currently in use is GI sheets plus 4” straw insulation plus ½ inch thick plywood. This system has excellent thermal properties and helps to save a lot more energy than the other system (T beam system). The thermal performances of these two systems are given in Table 7.7.

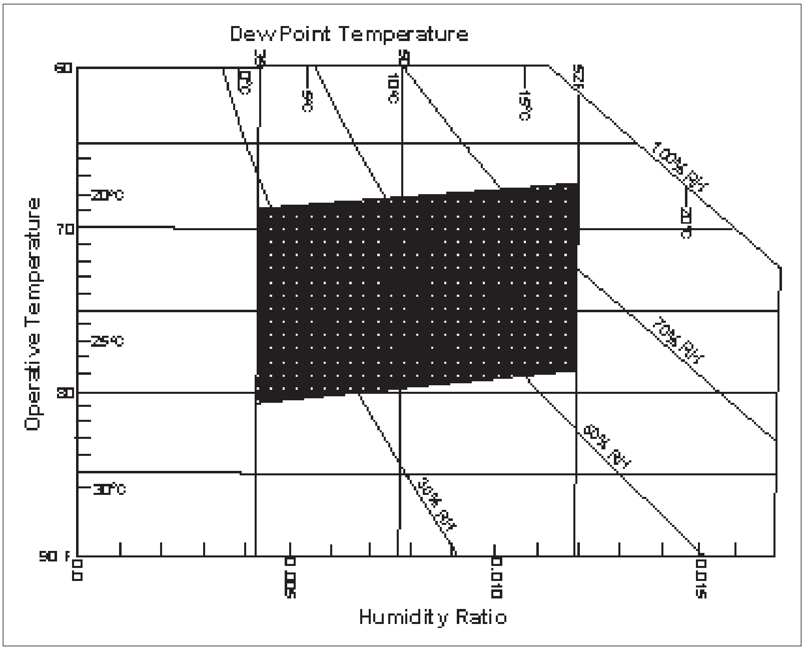


Figure 7.16: Acceptable Ranges of Operative Temperature and Humidity for Persons Clothed in Typical Summer and Winter Clothing at Light Mainly Sedentary, Activity (Adapted by Permission from ASHRAE Standard 55-81, 1981)

The existing roof system of pre-cast T beam and hollow blocks is the most inefficient system. It requires 109.6 BTUs/day per square foot to heat the building. GI sheet + 4 inch grass + 0.5 inch plywood roof gives the best thermal performance. It only requires 57.5 BTUs/day per square foot to heat the same building.

Table 7.7: Thermal Performance of Different Roof types (See Appendix 7B for detailed calculations)							
Roof Type	Roof Value (BTUs/hr-sq.ft-F)	Wall Type	Wall U-Value (BTUs/hr -sq ft-F)	Desired Temp. (F)	Heating Require-ments BTUs/ day)	Heating Require-ments per sq.ft. BTUs/ day)	Fuel Re-quirements (kg of wood/day
T-Beam + 8-inch block	0.47	8-inch thick block wall	0.51	60	205,071	109.6	144.31
GI sheet + 4-inch straw + 0.5-inch Plywood	0.06	8-inch thick block wall	0.51	60	107,560	57.5	75.61

Wall Systems

The three types of wall system currently used are the i) 8-inch thick, hollow block wall, ii)12-inch thick, teracrete wall, and iii)15-inch thick, stone wall. Out of these three wall systems the 12-inch thick, terracrete wall system has the best thermal properties, the 15-inch thick, stone wall system is the second best, and the 8-inch thick, block wall system is third. These wall types have been evaluated to determine their thermal performance. This comparison is presented in Table 7.8.

Table 7.8: Thermal Performance of Different Wall Types (for detailed calculations see Appendix - B)							
Wall Material & Thickness	Wall U-Value (BTUs/hr -sq ft-F)	Roof Materials & Thickness	Roof U-Value (BTUs/hr -sq ft.F)	Desired Temp. (F)	Heating Require-ments (BTUs/day)	Heating Re-quirements per sq.ft. (BTUs/ day)	Fuel Re-quirements (kg of wood/ day)
8-inch thick block wall	0.51	6-inch conc. Slab+mud+tiles	0.165	60	128,971	68.9	90.76
15-inch thick stone wall	0.28	6-inch conc. Slab+mud+tiles	0.165	60	76,150	40.7	53.58
12-inch thick terracrete mud conc. Gravel.	0.24	6-inch conc. Slab+mud+tiles	0.165	60	67,858	36.3	47.75

The 12-inch thick, terracrete wall gives the best thermal performance. Only 36.3 BTUs/ day per square foot is needed to heat a building built with this wall, compared to the 15-inch thick, stone wall, which requires 40.7 BTUs/day per square foot, and the 8-inch thick hollow block wall which requires 68.9 BTUs/day per square foot.

Ventilation

Although the minimum ventilation requirements (See Appendix 7A) for a healthy environment are met with the existing size and number of openings, the cross ventilation during summer is not enough to flush out the excessive heat. This results in an uncomfortable internal space during summer.

Shading Devices

There are no shading devices to protect the outside wall and windows from the direct sun during summer. This results in additional heat gain, which can be avoided.

Effects of Different Building Systems on the Environment

Wood is the main source of energy in the Northern Areas of Pakistan. The normal practice in the existing school is that each student brings with him/her some wood every morning to meet the fuel requirements of the school for the day. This wood comes from trees in the locality. Tables 7.7 and 7.8 give the effects of different building systems on the fuel requirements of the school building. Comparison of the existing wall system (Table 7.8) shows that to heat a building that has 8-inch thick, block walls, about 90 kg of wood is required each day. A normal tree provides about 150 to 200 kg of wood. This means that about 15 trees will be cut down to heat this building in one month. A comparison of the 8-inch thick wall system with the other two wall systems in Table 7.8 also shows that, if the same building has 12-inch thick, terracrete walls, only half the amount of wood is required. That means about seven to eight trees will be saved each month.

In comparing the roofing (Table 7.7), 144 kg of wood is needed to heat an existing school building with aT-beam roof for one day. This comes to about 4,230 kg of wood for a month ; equivalent to about 21 trees. The same building with a GI sheet roof needs only 2,268 kg of wood a month. This is a saving of about 10 trees each winter month.

Recommendations in the Existing System

After reviewing the existing system, the following recommendations have been made to improve its thermal performance.

Advantage should be taken of the raised roof of the central corridor and ventilators should be provided near the ceiling above the classroom roof. Ventilators should also be placed in the classroom wall adjacent to the corridor. These two types of ventilator will work together. Ventilators in the corridor above the classroom will exert a pull on the inside air and, through the stack effect, the classroom will have better air movement which in turn will effect the comfort level.

As the thermal performance of the existing pre-cast T beam roof is inefficient, it should be replaced with the proposed roof system of a six-inch concrete slab plus water- proofing plus two-inch mud plus tiles (which gives a much better thermal performance).

Recommendations for New Designs

As observed in the climatic analysis, summers are mild and, if buildings are properly oriented, have sufficient air movement, and have window shades which protect the windows during summer from the sun (but do not block the winter sun), these buildings could be quite comfortable.

After detailed study, projections have been proposed at the roof and lintel level (depending on the type of design) to shade the external openings from the direct sun. This helps to reduce the heat gain during summer. The recommended design of the projections is based on the sun angles and relevant calculation so that these projections provide maximum shade during summer but do not block the sun during winter. For the proposed projection (2'-6"wide), most of the external openings are shaded during the summer season (ventilator 100% shaded, window 72% shaded at 12.00 noon on the south side). These projections do not block the winter sun from coming in (window 100% unshaded at 12.00 noon on the south side). If the projection width is increased or decreased from the one proposed, then it will effect its efficiency accordingly in each season. Table 7.9 gives the performance of the shading devices evaluated for July 21 on the east, south, and west orientations at 8.00 a.m., 10.00 a.m., 12 noon, 2 p.m., and 4 p.m. This evaluation has been carried out for 8- and 15-inch thick walls.

Table 7.9 : Shaded and Unshaded Areas – Roof and Lintel Projections (For detailed calculations see Appendix 7D)

8-inch Thick Wall Orientation	Time	Window Shaded Area	Window Un-shaded Area	Ventilator Shaded	Ventilator Unshaded Area
East	8 am	6%	94%	62%	38%
East	10 a.m.	47%	53%	100%	0%
South	12 noon	2%	98%	100%	0%
West	2 p.m.	7%	93%	100%	0%
West	4 p.m.	6%	94%	62%	38%
15-inch Thick Wall					
East	8 am	18%	82%	81%	19%
East	10 am	77%	23%	100%	0%
South	12 noon	100%	0%	100%	0%
West	2 pm	77%	23%	100%	0%
West	4 pm	18%	82%	81%	0%

- Trees, shrubs, and creepers provide protection against the summer sun. It is recommended that deciduous trees be planted around the building, especially on the south side so that they can block the summer sun without stopping the winter sun. This will provide additional protection against excessive heat during summer.
- After evaluating the thermal performance of the existing roof systems (Table 7.7) and their effects on the heating requirements during winter, a new type of roof system is proposed to replace the existing pre-cast T beam plus hollow block roof system which is highly inefficient.
- After comparing the thermal performance of three types of wall systems (Table 7.8), it is recommended that a 12-inch terracrete wall be used wherever possible. The number two choice would be a 15-inch thick, stone wall, and the third choice would be and 8-inch thick, hollow block wall.

The proposed roof system is comprised of a six-inch thick RCC slab, plus water proofing, plus two inches of dirt, plus 0.75-inch thick, cement tiles. It has good insulation value (U-value = 0.165 compared to 0.47 of a T beam system) which helps to reduce the heating requirements during winter (Table 7.7). The existing GI sheet roof system is a good system as well and it is recommended that it should be used in areas where there is snow in winter.

Appendix 7A: Minimum Ventilation Requirements

The minimum ventilation requirements for maintaining the air quality of a classroom with 30 students and a teacher are as follow.

No. of persons in one classroom	31 persons
Classroom volume	3,840 cu. ft
Outdoor air requirements	5 cfm per person

31 x 5 cfm = 155 cfm
155 cfm x 60 = 9300 cu.ft./hr
9,300/3,840=2.5 air changes per hour

Air flow available through one window	170 cu.ft./min
(From air flow calculations)	170 x 60 = 10,222 cu.ft./hr
	10,222 / 3,840 = 2.66 air changes per hour

Appendix 7B: Calculation of Air flow through Windows

The available flow of air through a window is calculated by the following formulae.

CFM = K x A x V
Where
CFM = volume of air flow in cu. ft. per minute
K = effectiveness of opening taken as 0.5 to 0.6 for perpendicular wind and 0.25 to 0.35 for diagonal wind
A = free area of the inlet opening = 11.75 sq ft.
v = wind velocity = 2 mph = 58.66 ft/min.
CFM 0.25 x 11.75 sq ft. x 58.66 ft/min
= 172.3 cft/min.

172.3 x 60 = 10,338 cu. ft/hr

(if the total volume of one classroom is 3,840 cu.ft. then
10,338/3840 = 2.69 air changes per hour.)

Surface absorptance = the percentage of solar energy absorbed within the building (0.90 for a light interior space).

STEP NO. 6 SOLAR LOAD RATIO (SLR)
SLR = SEA /Qc
STEP NO. 7-SOLAR HEATING FRACTION(SHF)

The solar heating fraction (SHF) is taken from Figure 7B.1
STEP NO. 8. SOLAR HEATING CONTRIBUTION (Qc)
Qc = Qr X SHF
Step No 9. AUXILIARY HEATING REQUIREMENT (Qaux)
STEP No. 10- AUXILIARY HEATING REQUIREMENTS PER SQUARE FOOT
QAUX Qaux/area

In the following tables and figure, data which are required for calculations during each step of the above method are provided. These data are used for calculation in Appendix C based on the above method.

Table 7B.1: Area of Walls and Roof

Design Type	Area of walls without windows (sq. ft.)	Roof area (sq.ft.)
Existing Design	1,571	1,823

Table 7B.2: Area of Windows

Design	East	South East	South	South-west	West	North-west	North	North-east	Total
Type		Existing	92	67	92	0		0	251

Note:
All areas are in square feet
All buildings are kept at their best orientation to achieve the best thermal performance.

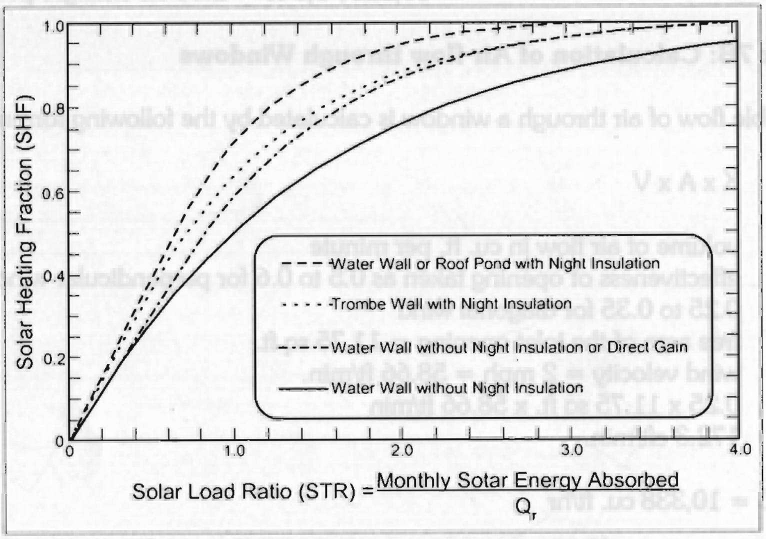


Figure 7.B1: Solar Load Ratio (SLR)

Table 7B.3: Coefficient of Heat Transfer (U-Value) through Walls and Glass

Wall Types	Composite U-Value	Effects on Heat Loss/Gain and Fuelwood Consumption
12" thick terracrete	0.24	Best performance
8" thick hollow block + 2.5 air cavity + 4" thick stone	0.28	116.66% of terracrete, 235 kg additional wood.
8" thick hollow block	0.51	212.5% of terracrete 1,582 kg of
Double glass (3 mm + 25 cavity)	0.55	additional quantity of wood.

Detailed calculations are provided in Appendix C

Table 7B.4 Coefficient of Heat Transfer (U-Value) through the Roof

Type of Roof	Composite U-Value	Effects on Heat Loss/Gain, Wood
Consumption-January G.I. sheets + 4 grass + 0.5 ply-wood (existing)	0.06	Best performance
6"conc, slab + bitumen + 2"dirt + 0.75"thick tiles (proposed)	0.165	275% of G.I. sheet system, 590 kg additional wood
8" the hollow block + precast T 0.47 beams + 2.5"screeding + water	0.47	783% of G.I. sheet system 2,304 kg additional wood

Detailed calculations are provided in Appendix C

Table 7B.5: Air Changes under Average Conditions*

Space	Number of Air Changes Taking Place Per Hour
Space with no windows or exterior door	½
Space with windows or exterior door on 1 side	1
Space with windows or exterior door on 2 sides	1-½
Space with windows or exterior door on 3 sides	2
Entrance hall	2

* This is for the schools, the number of air changes is doubled in order to account for the infiltration due to movement of people through the doors

Source:Ashrae Handbook of Fundamenatals 1977.

Table 7B.6: Volume of Space	
Design Type	Volume (cu.ft.)
Existing design	18,230

Table 7B.7: Clear Day Solar Heat Gain										
January 21th Latitude = 36./0 deg. North. Ground Reflectivity Assumed = 0.2										
Time a.m.	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NE**	**HOR**	**TIME a.m**
8	8	23	139	164	92	8	8	8	42	4
9	15	15	167	235	167	15	15	15	101	3
10	19	19	130	246	215	49	19	19	147	2
11	22	22	65	224	243	116	22	22	177	1
12	23	23	23	178	252	178	23	23	187	12
Half-day	76	91	512	958	844	276	76	76	560	
Total										

Half-day totals at given orientations are listed for the a.m. (morning hours). To find the p.m. (afternoon) total for the same orientation, read the value in the column that corresponds to the reciprocal of the a.m. orientation, about south. Add the two values to complete the daily total.

Corresponding Values

AM	PM
N	N
NE	NW
E	W
SE	SW
S	S

Source: Edward Mazria, 1997. The Passive Solar Energy Book, Rodale Press.

APPENDIX 7C

Calculations for composite coefficient of heat transfer (U-Value) for different wall systems adapted from the ASHRAE Handbook of Fundamentals 1977.

1) 12-inch Thick Terracrete

	R - Value (hr.sq.ft. - F/Btu)
Inside surface	0.68
12-inch thick terracrete	3.33
Outside Surface	0.17
Total	4.18
	1
U-Value	4.18 = 0.24 Btu hr-sq.ft. -F

2) 8-inch thick hollow block + 2.5-inch cavity + 4-inch thick stone

	R-Value (hr-Sq ft. F/Btu)
Inside surface	0.68
8-inch hollow blocks	1.11
2.5-inch air cavity	1.01
4-inch stone	0.62
Outside surface	0.17
Total	3.59
	1
U-Value	3 59 = 0.28 Btu/hr-sqft °F

3) 8-inch thick hollow blocks

	R-Value (hr-sq. ft. F/Btu)
Inside surface	0.68
Hollow blocks	1.11
Outside surface	0.17
Total	1.96
U-Value	1/1.96-0.51 Btu/hr-sq-F

Calculations for composite coefficient of heat transfer (u-value) for different roof systems adapted from the ASHRAE Handbook of Fundamentals 1977.

1) Existing G.I. Sheets + 4-Inch Grass + 2 x 4-Inch Rafters + 0.5 Plywood

AT RAFTERS (RL)	R-VALUE (hr. sq.ft. F/Btu) RAFTERS ®	BETWEEN RAFTER
Inside surface	0.61	
0.5" plywood sheet	0.62	0.61
2"x 4" rafters	4.38	0.62
4" straw insulation		
G.I sheets	0.61	14.28
Outside air surface	0.17	0.61
Total	6.39	0.17
		16.29

U-Value U1 = 1/r = 1/6.39 =0.16 U2 = 1/R2= 1/16.29= 0.06

Uav = 0.08 (0.16) + 0.92 (0.060)
= 0.07 Btu/hrs-sq.ft-F

2) Existing 8-inch thick, concrete hollow blocks + precast T beams 2.5-inch screeding + water proofing

	R- VALUE (hr. sq.ft. F/Btu) AT BEAMS (R1)	BETWEEN BEAMS(R2)
	0.61	0.61
Inside surface	0.83	
4'x 10" concrete beam		1.11
6" thick concrete hollow block	0.21	0.21
25" thick screeding	0.06	0.06
Water proofing	0.17	0.17
Outside air surface	1.88	2.16
Total		

U – Value U1 = R1 = 1/1.88 U2 = 1/R2 = 1/2.16
= 0.53 = 0.46

UaV= 0.1 (0.53) + 0.9 (0.46)
= 0.47 Btu/hr-sq. ft -F

Proposed 6-Inch Thick Concrete Slab + 2 Inches of Dirt + 0.75 Inch Thick Tiles Proposed)

	R - VALUE (hr. sq. ft. F/Btu)	
Inside surface	0.61	
6" thick concrete	0.50	
Bitumen	0.06	
2" dirt		4.50
0.75" thick tiles	0.15	
Outside surface	0.17	
Total		6.05
U-Value	1/6.05 = 0.165 Btu/hr sq. ft-F	

Appendix 7D: Calculation of Shaded / Unshaded Vent/Window Area

The following method is used for calculation of shaded and unshaded areas for summer conditions (July 21).

WALL THICKNESS = 8 inches
EAST WALL AT 8:00 P.M.
WEST WALL AT 4:00 P.M.
PROFILE ANGLE = 31 (From SUN CHART)

Calculation of Roof Projection Shade
PROJECTION = a = 2.83 (2.5 + 0.330)
SHADE = b = ?
Tan ∅ = b/a.
b = Tan ∅ x a = Tan 31 x 2.83' = 0.60086 X 2.83

Calculation of Shade Caused by Thickness of the Wall
HORIZONTAL SHADE
PROFILE ANGLE = 31 a = 4
Tan ∅ = b/a
b Tan ∅ x a = Tan 31 x 4-inch = 0.60086 x 4-inch2.4 = 0.20
VERTICAL SHADE
AZIMUTH ANGLE = 81 EAST (9 FROM NORMAL)
Tan ∅ = b/a
b = Tan 0 x a = Tan 9 x 4-inch= 0.1583 x 4-inch0.63-inch= 0.05

Shaded/Unshaded Vent/Window Area
VENTILATOR TOTAL AREA = 5.32 SQ FT.
HORIZONTAL SHADE = 1.7-inch- 0.5-inch = 1.2
SHADED AREA = 5.32 SQ FT
HORIZONTAL SHADE
SHADED AREA = 1.2-inchX 2.66 = 3.2 sq ft.
0.05 X 2inch0 = 0.1 sq.ft.

7.4
Assessment of and Improvement in the Thermal Efficiency of Standard Low cost Urban Housing in Metroville - 1, Karachi Guidelines for Improving Thermal Comfort in Existing Houses

R. Rahooja, M. Hasan, & T. Saleem

INTRODUCTION

Buildings have the primary function of shielding the occupants and their goods and possessions. As a rule, they should be planned so that satisfactory indoor conditions, which are better than the constantly changing outdoor climate,can be created.

Basic Shelter

Developing countries like Pakistan are faced with the problem of basic shelter and housing. The cost of construction is the predominant factor in the design of low cost housing, whereas thermal comfort is seen as a secondary factor. In such circumstances, emphasis on the form of the building, decisions about planning, design, and method of construction for thermally efficient building requires accurate information about the weather and climatic conditions; viz., air temperature, mean radiant temperature, air velocity, and air humidity. Combination of these parameters, with factors about the occupants, helps to predict optimal comfort for inhabitants.

Objectives

This research is directed towards forwarding proposals for improving the thermal conditions of low-cost urban houses in Pakistan. As an initial step, the scope of this study is limited to within the Metropolitan City of Karachi and considers a standard low cost urban house in Metroville-I constructed on and area of 80 square yards (see Figure 7.17).

The purpose of this case study is to assess the thermal conditions prevailing in the test model house affected by various parameters and then to check the thermal response of the model house by suggesting imeasures for improvement. The study has taken an analytical approach, and its theoretical considerations are described.

Evaluation of the thermal efficiency of a house depends on the following factors.

- Meteorological data of the environment under study
- The acceptable limits of thermal comfort/indices for urban houses
- Allowable limits of U-values for different elements of a building
- Thermal properties of various building materials

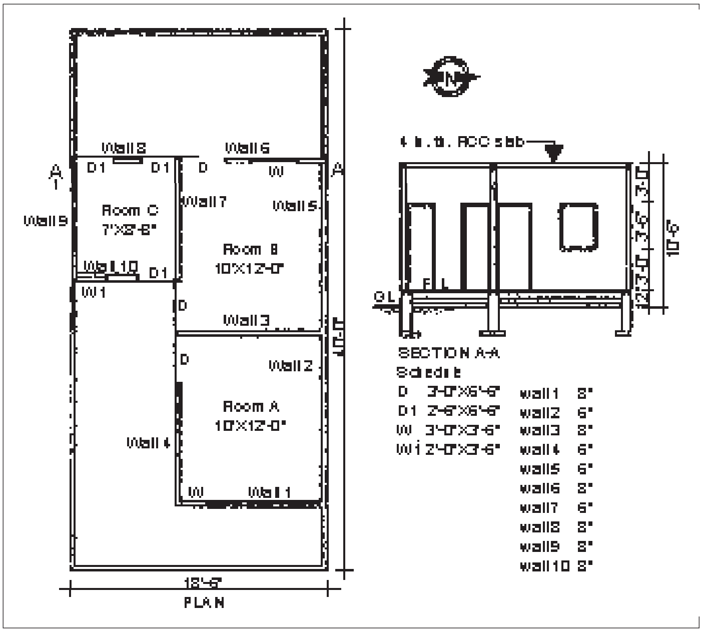


Figure 7.17: Test Model House: A Standard Low-Cost Urban House in Metroville, Karachi

THEORETICAL CONSIDERATIONS

Thermal Model Equation

The design variables that affect the thermal performance of a building are shape, massing, orientation, window sizes, glass types, shading surface finishes, material properties, ventilation, and nature of occupancy. Considering the above-mentioned variables, a model equation has been prepared to assess the thermal response of any house under study.

$$\sum Q = Qc + Qv + Qcf + Qu + Qt \qquad (7.5)$$

where, heat gains/losses caused by various factors are as follow:

Q_c = conduction
Q_v = ventilation/convection
$Q_c f$ = radiation from opaque surfaces
Q_u = radiation from glass surfaces
Q_t = internal equipment
å Q = total heat gained/lost

Thermal Analysis of the Test Model House

The thermal model equation was used to assess the thermal performance of the test model house shown in Figure 7.18. The total thermal load (in watts) as a result of heat gain by conduction, convection, and radiation from walls, roof, glass, surfaces, and openings has been calculated.

In the analysis of this test model house, heat gain from internal heat has been ignored because of the variation in occupancy rates and use of domestic equipment(a factor that varies from one house to another). However, internal heat may be considered when analysing individual cases of different houses.

The mean outdoor temperature for this study has been assumed to be 35°C, which is the average summer temperature in July for Karachi.

For warm humid conditions such as those in Karachi, in order to maintain the comfort level within a house without auxiliary cooling, the mean indoor temperature should be between 27.2 and 31.1°C. Thus, the total heat gained by the test model house should not exceed 4,182 watts.

Table 7.10 gives the details of the heat gained in watts by individual rooms in the test model house as a consequence of various factors. Table 7.11 shows the percentages of the heat gained by the test model house through conduction, convection, and radiation

Table 7.10: Efficiency of Standard Low-Cost Urban Housing

Room No	Conduction Q_c		Convection Q_v	Radiation ($Q_c\phi$)		Radiation (Qu)	Total heat Σ Q-
	Walls	Roof		Walls	Roof	Glass	$Q_c + Q_v$ $Q_c\phi + Qg$
A	622.26	426.5	122.5	742.14	1062.2	87.69	2086.29
B	498.65	522.91	159.02	607.25	1276.2	87.69	2152.72
C	460.10	274.9	82.46	578.44	669.6	58.50	2125.00
Σq	1582.01	1225.21	274.98	1928.22	3009.1	222.8	8264.11
P	18.9	14.00	4.48	22.06	26.0	2.8	100

Where,
Σq = summation of heat gain
p = heat gain with respect to total heat gain

separately. Similarly, Table 7.12 gives the percentages of heat gained by the building elements; viz., roof, walls, glass surfaces, and openings.

Table 7.11	
% heat gained due to:	
Conduction	= 22.7%
Convection	= 4.5%
Radiation	= 61.8%

Table 7.12: Percentage Heat Gained by Building Elements	
Roof	= 50.8%
Walls	= 42.0%
Glass surfaces	= 2.8%
Openings	= 4.48%

From these tables, it is evident that almost 92 per cent of heat is gained through the roof and walls through conduction and radiation alone. Thus, in order to improve the thermal efficiency of the test model house, it is imperative to improve the roof and walls by providing insulation or by using thermally efficient building materials.

Thermal Response of the Test Model House to Improvement of the Building Elements

Improvement of the Roof

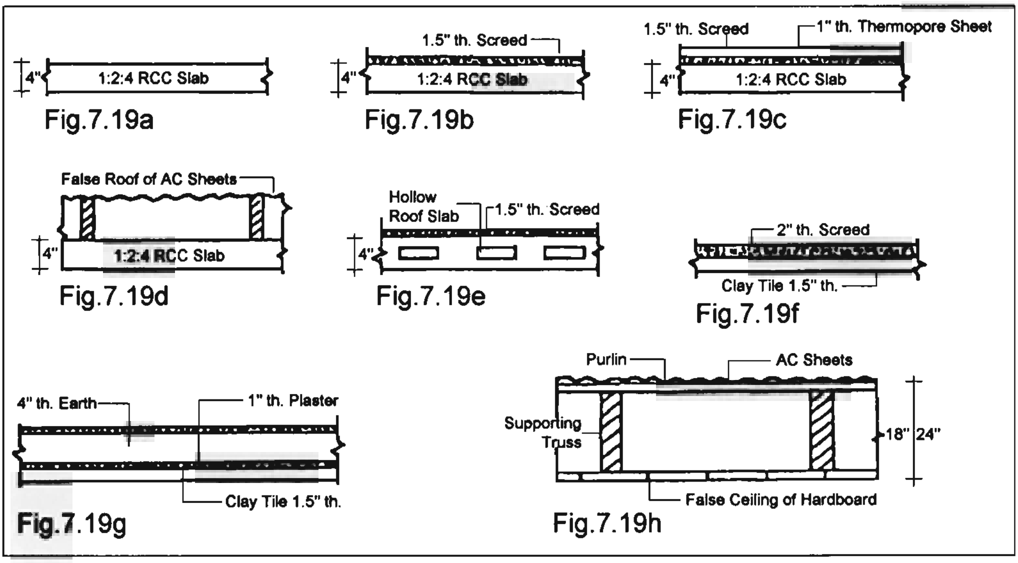
The roof of the test model house is constructed with a four-inch reinforced concrete (1:2:4) mix. As shown in Table 7.12, the heat gained by the roof alone is 50.8 per cent of the total heat gain by the model house. To reduce this, the thermal response of the roof has been studied by considering the following two cases:

Case A: by providing low cost, locally available insulation on the roof, and
Case B: by employing alternative low-cost roofing materials instead of the conventional 1:2:4 RCC slab, as provided in the test model house.

Case A: Where, the following types of insulation on the bare 4 inch thick RCC slab were tried for the study of this case (See Figs. 7.19)

- 1½ inch thick screed on the 4-inch thick RCC slab
- 1½ inch thick screed and 1-inch thick thermopore sheets on the 4-inch thick RCC slab
- false roof of A.C. sheets on the 4-inch thick RCC slab.

The thermal response to different types of insulation is shown diagrammatically in Figure 7.20.



Case B: The following alternative low-cost roofing materials were selected for comparison of their thermal response with the conventional roof slab of the model house (see Figs. 7.21, 7.22 and 7.23).

- 4-inch thick hollow roof slab (25% cavitation) with 1½ inch thick screed)
- clay tiles 1½ inch thick with mud insulation
- clay tiles 1½ inch thick with 2-inch thick conventional screed
- trussed roof (steel) with asbestos cement roof cladding sheets and false ceiling of hardboard.

The thermal response to varying the roofing materials is shown diagra mmatically in Figure 7.20.

The cost of the roof expressed in percentage increase or decrease, compared to the cost of the basic roof slab of the model house, is shown in Figure 7.22.

Improvement of the Wall

The external walls of the test model house are constructed with six inch and eight inch thick solid block masonry. As shown in Table 7.18, the heat gained by the external walls alone is 42.0 per cent of the total heat gained by the model house. To reduce the total heat gain of the model house though the external walls, the following alternative types of wall material were selected for comparison for their thermal response.

- Hollow block masonry six- inch and eight-inch thick
- Cavity brick masonry 11inch and (2-inch thick cavity)
- Cavity brick masonry $15^{1/2}$ inch and (2-inch thick cavity)

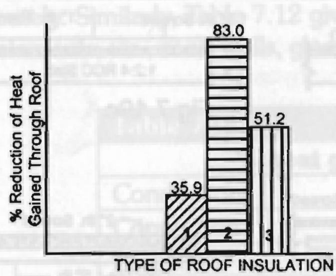


Fig. 7.20

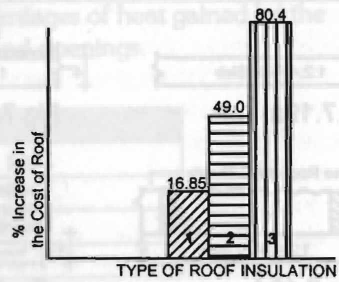


Fig. 7.21

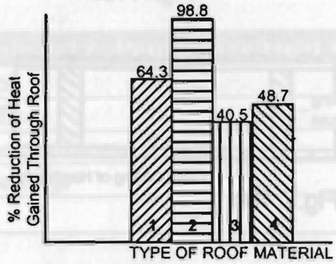


Fig. 7.22

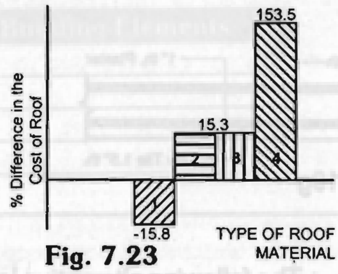


Fig. 7.23

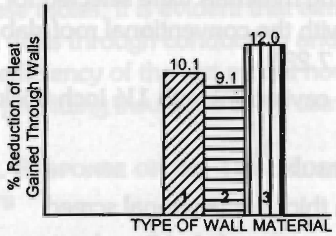


Fig. 7.24

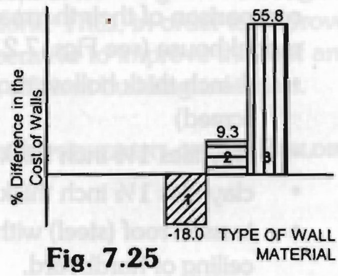


Fig. 7.25

The thermal response to varying the materials for the external walls of the model house is shown diagra mmatically in Figure 7.24.

Comparison of the cost of construction for different types of external wall is given in Figure 7.25.

(Solid brick masonry [9 and $13^{1/2}$ inch thick] has been ignored because the total heat gained increases compared to the six and eight inch solid block masonry external walls).

Combination of Different Types of Roof with Different Types of External Wall

The descriptions of different types of roof that have been combined with various types of external wall are as follow.

Four inch thick RCC slab with 1½ inch thick screed (Figure 7.17b)
Four inch thick RCC slab with 1½ inch thick screed and $1^{1/2}$ inch thick thermopore sheets (Figure 7.17c)

Four inch thick RCC slab with a false roof of asbestos corrugated sheets (Figure 7.17d)
Four inch thick hollow roof slab with 1½ inch thick screed (Figure 7.17e)
Clay tiles 12 x 6 x 1½ inches with mud insulation (Figure 7.17f)
Clay tiles 12 x 6 x 1inches with conventional screed 2 inch thick (Figure 7.17g)
Steel trussed roof with asbestos sheets as roof cladding and a false ceiling of hardboard (Figure 7.17h)

The results of the performance of various types of external wall are given in Tables 7.13 to 7.16.

Table 7.13: Different Rooves with Six Inch / Eight Inch Thick Solid Block Masonry

S.No.	Roof Types	% Reduction in ΣQ	Mean Indoor Temp°C
1	Figure 7.19b	18.22	33.57
2	Figure 7.19c	42.15	31.71
3	Figure 7.19d	25.98	33.00
4	Figure 7.19e	32.64	32.45
5	Figure 7.19f	50.15	31.08
6	Figure 7.19g	20.6	3.4
7	Figure 7.19h	24.7	33.07

Table 7.14: Different Rooves with Six Inch/Eight Inch Thick Hollow Block Masonry

S.No.	Roof Types	% Reduction in ΣQ	Mean Indoor Temp °C
1	Figure 7.19b	28.32	32.8
2	Figure 7.19c	52.25	31.0
3	Figure 7.19d	36.04	32.8
4	Figure 7.19e	42.47	31.67
5	Figure 7.19f	60.25	30.3
6	Figure 7.19g	30.7	32.6
7	Figure 7.19h	43.8	31.58

Table 7.15: Different Rooves with Eleven Inch Thick Cavity Brick Masonry

S.No.	Roof Types	% Reduction in ΣQ	Mean Indoor Temp°C
1	Figure 7.19b	22.02	33.28
2	Figure 7.19c	45.95	31.4
3	Figure 7.19d	29.78	32.68
4	Figure 7.19e	36.44	32.16
5	Figure 7.19f	53.95	30.8
6	Figure 7.19g	24.39	33.1
7	Figure 7.19h	28.52	32.77

Table 7.16: Different Rooves with Fifteen and a half Inch Thick Cavity Brick Masonry			
S.No.	Roof Types	% Reduction in Σ_Q	Mean Indoor Temp °C
1	Figure 7.19b	23.25	33.18
2	Figure 7.19c	47.2	31.31
3	Figure 7.19d	31.0	32.58
4	Figure 7.19e	37.7	32.06
5	Figure 7.19f	55.2	30.7
6	Figure 7.19g	25.6	33.0
7	Figure 7.19h	29.74	32.68

Conclusion and Summary of Results

The description of the ideal combinations of different roof/wall systems are summarised in Table 7.17. It was determined that with these roof/wall combinations, the mean indoor temperature does not exceed the acceptable limits for comfort, i.e., 31.1°C for the warm and humid climatic conditions prevailing during summer in Karachi. Table 7.17 also summarises the percentage reduction in total heat gain and the extra cost required for the test model house to make it into a more comfortable and thermally efficient dwelling.

Table 7.17: Summary of Performance of Various Wall Types			
S.No.	Description of Roof/Wall System	Q	c
1	Clay tiles 1" thick with mud insulation and 6"/8" thick hollow block external walls	60.25	9.27
2	Clay tiles 1" thick with mud insulation and 15" thick cavity brick external walls.	55.2	44.9
3	Clay tiles 1" thick with mud insulation and 11" thick cavity brick external walls.	54.0	22.5
4	4" thick RCC slab with 1" thick screed and 1" thick thermopore, with 6"/8" external walls. (hollow b.m.).	52.3	16.57
5	Clay tiles 1" thick, with mud insulation and 6"/8" solid block external walls.	50.2	18.0
where: q= % reduction in total heat gain c = increase in the cost of roof and walls (%)			

Further Reading

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