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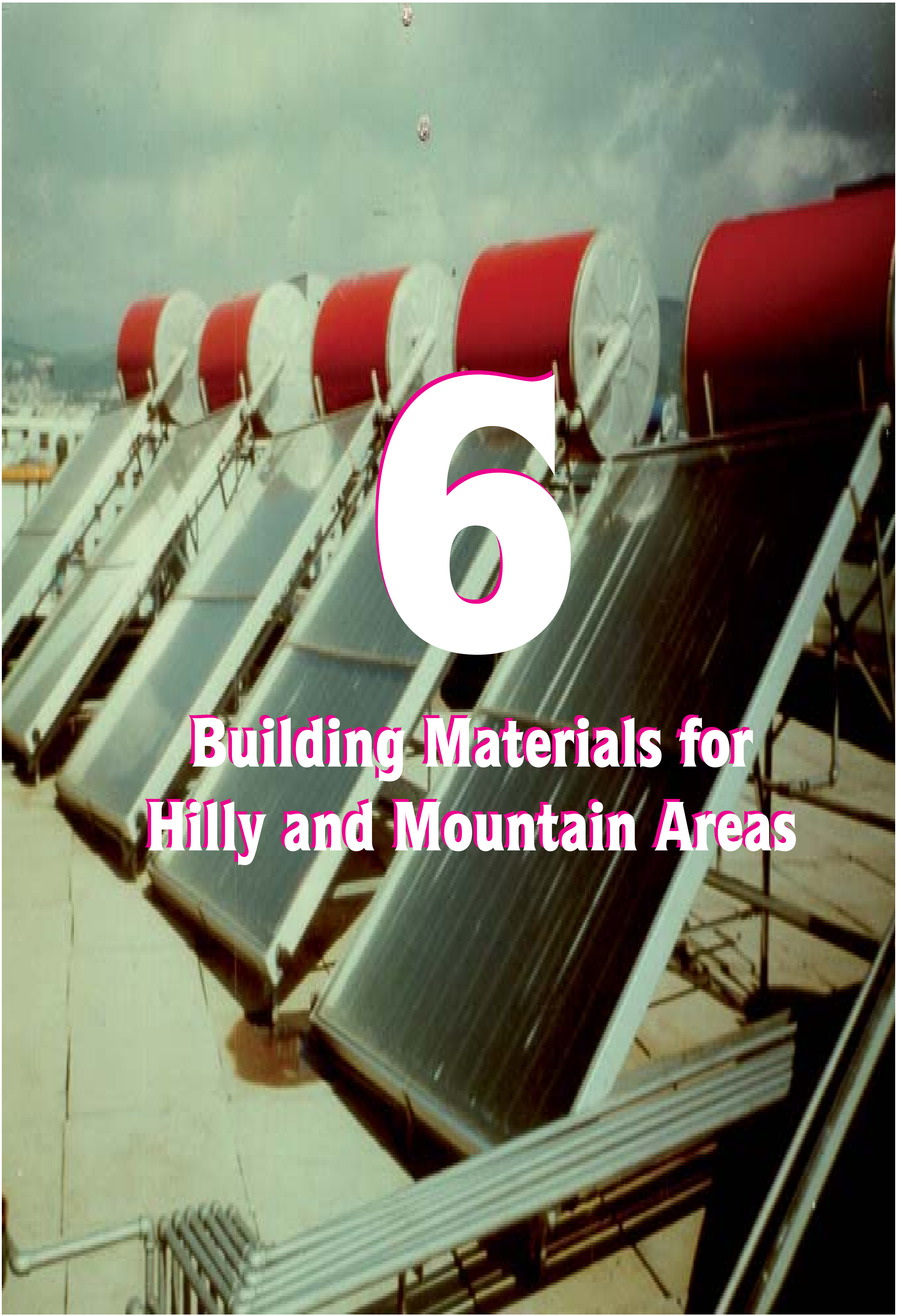
Building Materials for Hilly and Mountain Areas



6.1
Recent Developments in Materials for Solar Buildings

N.D.Kaushika

Introduction

Buildings in their own right modify climate and their main function is to provide comfortable living conditions for their inhabitants. This objective is often met by air-conditioning the building. So a building is always specified by its energy demand. The reduction of this demand is referred to as demand management. In this respect the fact that the sun's energy can be used for natural heating and cooling of buildings was realised even in ancient times and has since been pursued with an increasing degree of technological sophistication. Various concepts of and approaches to heating and cooling buildings have been proposed and tried. The factors that significantly influence the indoor temperature of the building include the following.

- Building materials
- Shape
- Orientation
- Zoning
- Sun Control
- Glazing
- Heat Storage
- Thermal Insulation

This paper presents an outline of some materials and technologies wherein more than one of such functions as sun control, thermal insulation, glazing, and heat storage are performed in the same configuration.

Transparent Insulation Materials

Transparent insulation materials (TIM) represent a class of materials wherein air gaps are used to reduce unwanted heat losses. TIMs consist of a transparent cellular structure immersed in an air layer. They are solar transparent and yet provide good thermal insulation and are similar to conventional insulation materials insofar as the placement of air gaps in the solid mass is concerned. TIMs hold great promise for application in increasing the solar gain of outdoor thermal energy systems (Kaushika 1998). The solar transmittance and heat loss coefficients are the two main parameters characteristic of the performance of TIMs. They can be classified based on various parameters such as the manufacturing process, the materials, and the geometry of cell wall etc, but the following four types, based on cellular geometry, describe them in detail (Figure 6.1).

a) absorber-parallel,
b) absorber-vertical,
c) cavity structures, and
d) homogeneous.

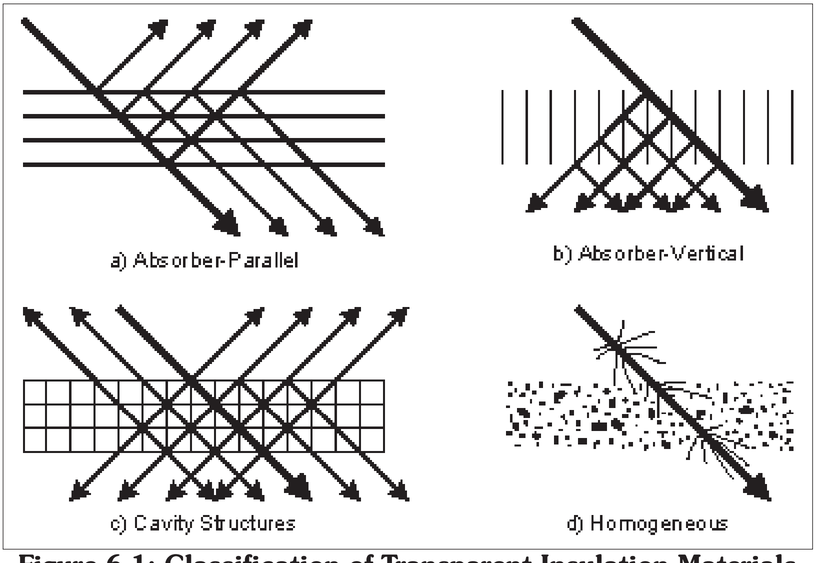


Figure 6.1: Classification of Transparent Insulation Materials

The absorber-parallel structures are multiple-glazing or plastic films which are placed parallel to the absorber. The main problem associated with this structure is that the number of parallel covers has to be increased to reduce heat loss, and this reduces solar transmittance drastically.

In vertical absorber structures, cell walls are placed perpendicular to the absorber plane. The principal advantage of this orientation is the forward reflection of solar radiation by the vertical walls, and thus the maximum amount of radiation reaches the absorber.

If the vertical wall sheets have a low extinction coefficient, the solar transmittance becomes almost independent of cell depth. The convection and radiation heat losses can be suppressed significantly by proper design of the cell dimensions. These materials are also called transparent insulation of the forward reflection type.

The cavity structure is a combination of absorber-parallel and absorber-vertical structures. It includes duct palates and foams. The problem associated with this type is the increase in optical losses, but heat losses are suppressed significantly.

Homogeneous materials include the TIM of glass fibres and aerogels. These materials can be used for higher temperatures than ordinary glass panels. The scattering and absorption are a little more in these materials than in other TIMs.

The most documented version of a TIM is the absorber vertical structure, and it includes honeycombs, capillaries, and parallel states. To optimise the performance of transparent honeycomb insulation materials maximisation of solar transmittance and minimisation of heat losses are the two main parameters to be considered. Heat is transferred through the TIM by one or more of the following modes:

- conduction and radiation through the solid cellular media and
- conduction, convection, and radiation across the air cell

To minimise heat losses, the convective heat transfer across it must be suppressed. The convective stability of the fluid (air) in the honeycomb cell depends on the value of the critical Rayleigh Number (Ra_c) which depends on the physical shape, aspect ratio ($A = L/d$), and thermophysical properties of the walls of the cell. The fluid mechanical treatment of this type of problem of the square cells has been given, amongst others, by Edward and Catton (1969), following which Ra_o may be expressed as :

$$R_o = \frac{(a_o^2 + 2.9)^3}{(a_o^2 + 7.9)} \qquad (6.1)$$

Where a_o = p m $(5)^{0.5}$ A and 0.75 £ m £ 1

The Rayleigh number is given by:

$$R = \frac{g\hat{\imath}\,\Delta T^{3}}{\alpha} \qquad (6.2)$$

so for convection suppression

$$(\Delta T)_{max} = \frac{R_c\,\alpha}{g\hat{a}\,L^3} \qquad (6.3)$$

The $(\Delta T)_{max}$ values of air layer as obtained from Eqn. (6.3) are illustrated in Figure 6.2. It shows that for a cell width of ≤ 4.5 mm, convection is suppressed for a range of temperatures from 50 - 100°C.

Fabrication of a thick-walled device is rather simple (Kaushika 1989). The materials chosen for temperatures of up to 70°C could be polymethylacrylate (PMA) often referred to as perspex. Sheets 1 mm in thickness or less may be used. For the fabrication of honeycomb models in sizes of 50 x 50 x 10 cm, the material is cut into slats of 50 x 10 cm. The slitted slats are then interwoven to form a square cell of 3 x 3 cm. The cells are then interwoven to form a square cell array. To fabricate thin-walled devices, the film of material such as polycarbonate, polyester, and teflon of Fluorinated Ethylene Teraphithlate (FET) could be used. Straight fabrication of a square cell device from film materials poses problems in glue dispensing. A relatively costlier but technically convenient method of constructing a square honeycomb has been devised and adopted by Ar El Energy Ltd., Israel. This method involves the profile extrusion process. The device is encapsulated in tempered glass which protects it from UV degradation. The TIM of Ar El Energy Ltd. costs about US$ 100 per square metre.

The cellular honeycombs were developed as convection suppression devices in the early days to improve the efficiency of solar flat collectors. Subsequently, in the early eighties a new concept of a non-convective solar pond using the honeycomb as transparent insulation was proposed as an attractive alternative to salt gradient solar ponds (Ortabassi *et al.* 1983 ; Kaushika *et al.* 1983). Results of simulation of the honeycomb solar pond have predicted solar collection efficiency of up to 40-50 per cent at 70°-80°C. More recently, several architectural configurations for the solar passive heating of buildings and a transparently insulated face element for daylighting on the working face of buildings have been proposed and tested to date.

Phase Change Materials

Phase change storage involves the change of phase of suitable materials for absorption and release of solar thermal energy at a constant temperature equal to the melting and vaporisation temperature**.** Telkes (1974) has compared the thermophysical and other properties of various latent heat storage materials. One of the suitable materials for space heating applications is sodium sulphate decahydrate. It undergoes phase change at 32°C and stores heat of 369,472 KJ per cubic metre. Yet another material is calcium chloride hexahydrate. It undergoes phase change at 28°C and can store heat of 368,660 KJ per cubic metre.

A solar architectural configuration of a transparent insulated PCM storage wall demonstrated in Melbourne is portrayed in Figure 6.3.

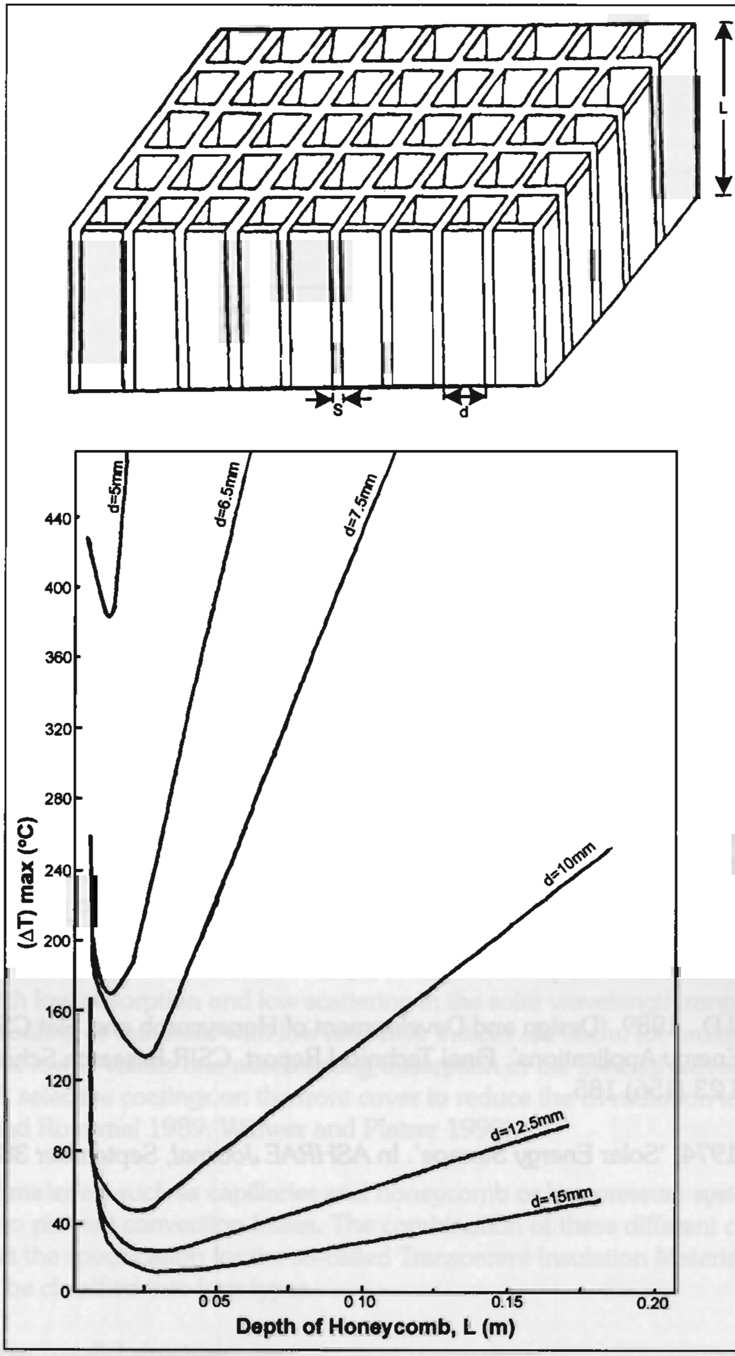


Figure 6.2: Variation of $(\Delta T)_{max}$ for Air Filled Honeycomb with Its Depth and Cell Size

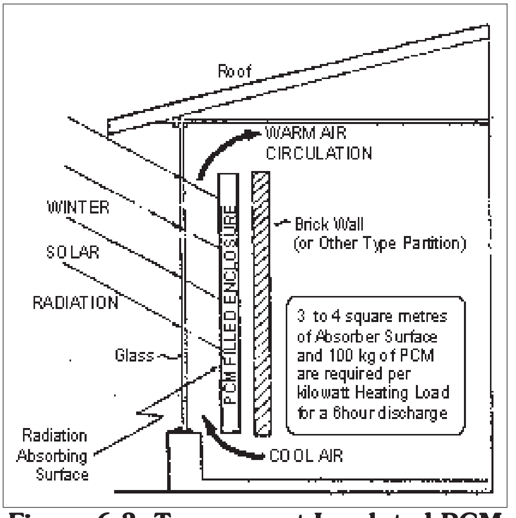


Figure 6.3: Transparent Insulated PCM Storage Wall

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6.2
Solar Heating of Buildings in Hilly Areas Using TIMs

G.M. Singh

Introduction

For high energy efficiency of a thermal system, there are two critical characteristics: the fraction of the solar input which can be absorbed by the system depending on solar transmittance (i) of the cover and the absorptance (a) of the absorber and the portion of the heat absorbed by the system which can be stored and used depending upon the thermal insulation of the system (U-value). For high solar inputs one needs cover systems with low absorption and low scattering in the solar wavelength range. Anti-reflection coating or materials with low refractive indices are useful for multicover systems. For low U values one needs strong absorption in the thermal wavelength range or IR selective coatings on the front cover to reduce the IR radiation losses (Wittwer and Ro mmel 1989; Wittwer and Platzer 1990).

Structured materials such as capillaries and honeycomb or low pressure systems are necessary to prevent convection losses. The combination of these different characteristics gives us the specification for the so-called Transparent Insulation Materials (TIMs). They may be classified into four types.

- Absorber parallel structure
- Absorber perpendicular structure
- Cavity structure
- Quasi homogeneous structure

TIM represent a class of new materials for application in solar thermal conversion. U- values are below $1W/m^2K$ and energy transmittance greater than 70 per cent is the main characteristic of TIM. Experiments, simulation calculations, and results from demonstration projects have shown the space heating potential of transparently insulated walls. It can save energy up to 200 Kwh/m^{2}yr.

Geometry of the TI Element

A transparently insulated building wall is a combination of conventional insulation and a solar collector. Figure 6.4 gives a sketch of the application for walls. Solar radiation is transmitted through the transparent insulation and absorbed on the black wall; depending on the quality of transparent insulation, part of the energy is conducted through the wall into the building. A shading device may be used to control the solar radiation flux and prevent the wall from overheating in daytime. At night this device may be used to increase insulation.

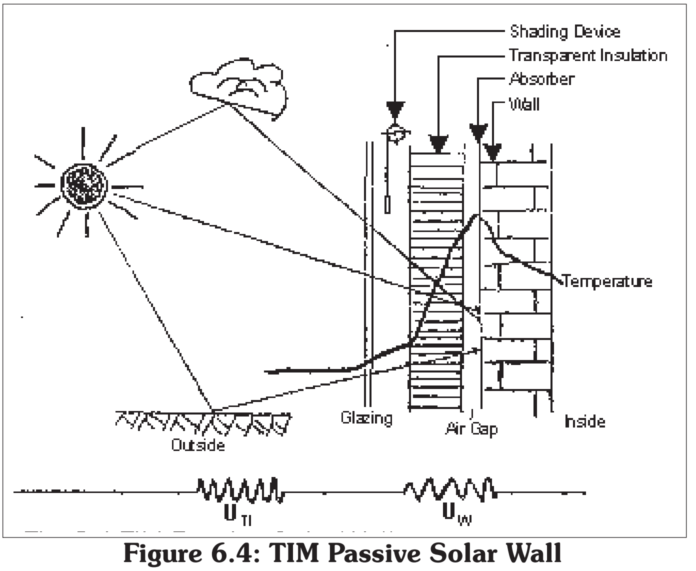

Figure 6.4: TIM Passive Solar Wall

Buildings Using TIM

Out of all demonstration projects using TIM, Strathclyde University's residences in Glasgow, Scotland, are the world's largest demonstration of transparent insulation. This demonstration project is supported by the European community and Scottish Enterprises (Braun *et al.* 1992). These residences have four separate blocks to acco mmodate a total of 376 students in flats with individual study - bedrooms (Figure 6.5). The solar fraction of useful gain in winter is 20 per cent of the total energy. The south faces of the building have a monthly net gain of energy into the building throughout the year even in mid-winter in Glasgow.

The two houses (TIM house, i.e., reference house) built in front of the Shanghai Institute of Energy Research (SIER) have identical floor plans but use different insulation techniques. The so-called TIM house has transparently insulated walls and additionally

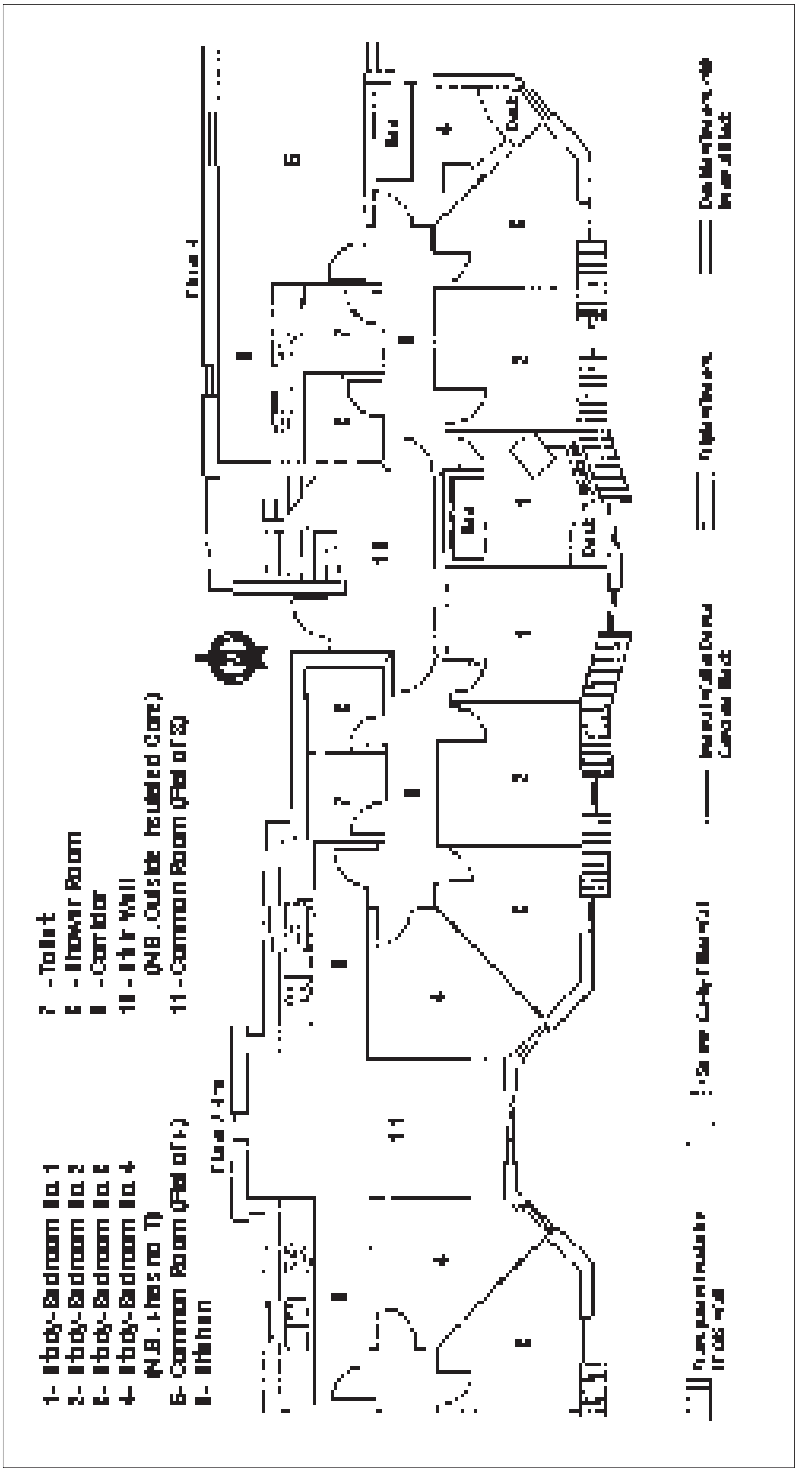

Figure 6.5: Plan of Strathclyde University's Residences in Glasgow

improved insulation values. The modules were prefabricated in Shanghai using locally available materials: wood for frame construction, venetian blinds, and 3 mm glazing; PC-honeycombs were sent from Germany.

Further material research will enhance solar conversion efficiency. New materials are being developed, e.g., a capillary structure made from glass tubes appears very promising. The commercial production of TI elements is in its infancy. TI walls are a new component in solar architecture. Contrary to conventional opaque insulation, a TI wall not only reduces the transmission losses from a building's wall to zero, but also heats the room behind the TI wall. Architectural constraints to reducing heating demand by minimising the ratio of the building surface to building volume are removed. The solar residences have been a brave and successful demonstration for large-scale use of TI in a site at higher latitudes and where winter insolation is poor, as, for example, in hilly areas.

6.3
Appropriate Design, Construction Techniques and Building Materials for Thermal Efficiency of Buildings

A. Maher, R. Rahooja, P. Brohi, & Z. Shaikh

Introduction

Buildings have a primary function of shielding occupants and their goods and possessions from the unpleasant aspects of nature. As a rule, they should be so planned that satisfactory levels of comfort are maintained indoors against the constantly changing outdoor climate. Heat gain or loss in a building as a result of external conditions is primarily caused by three mechanisms of heat transfer, i.e., conduction, convection, and radiation. Another factor concerning heat gain within a closed space arises from the internal heat generated within the space by occupancy, use of equipment, and use of artificial lighting. However, 90 per cent of the heat gain/loss is caused by conduction, convection, and radiation.

Previous studies carried out at the National Building Research Institute (NBRI) and elsewhere show that, under typical summer conditions in Pakistan, most of the heat is transmitted through rooves and walls by the processes of conduction and radiation. The areas of exposed glass surface and openings also play a vital role in determining the heat gain or loss by convection.

The heat gain in a single-storeyed building through the roof alone can be about 50 per cent of the total heat gained by the building during a typical summer day in Pakistan.

In such a case, it is evident that the provision of indoor thermal comfort entirely by mechanical means is extremely uneconomical. Building form, proper designs, and proper choice of building materials not only serve to improve and control thermal performance but also reduce the energy loads required to maintain comfortable levels within a closed environment.

Design Variables Affecting the Thermal Performance of Buildings

Accurate information about a number of variables is needed to plan, design, and construct a thermally efficient building. The combination of these parameters with internal factors helps to predict the optimal comfort level for inhabitants.

Among the vital design variables affecting thermal performance are :

i) meteorological data,
ii) shape/form/massing of buildings,
iii) orientation of buildings,
iv) size of openings, areas of glass surface, and type of shading used in the buildings,
v) surface rendering (treated surface) employed buildings,
vi) thermal properties of construction materials,
vii) type of occupancy, and
viii) acceptable limits of thermal comfort/comfort —indices for buildings of various categories.

Construction Materials and Techniques for Rendering Buildings Thermally Efficient

The roof and walls are the two main building components through which heat is gained from the external environment during summer and through which it is lost from the internal environment during winter. Designers and planners have to focus on making these two important building elements thermally efficient, not only to reduce the energy needs but also to eliminate the use of mechanical heating/cooling systems.

The value of auxiliary cooling/heating loads depends on the thermal properties of the building materials used. However, there is not a wide choice of alternative building materials in Pakistan. In such a case, the building's form and suitable construction techniques can be used in such a way that the roles of rooves and walls become more efficient in terms of heating .

Here, special mention should be made of bio-climatic architecture, which basically is an indigenous form of architecture not unco mmon in Pakistan. This type of building was used by the Moghuls, to build the Pyramids, and to build wind catchers in buildings in Sindh and other lower regions of Pakistan. However, presently, this type of architecture is becoming more popular in cold and western countries to conserve as much solar radiation during the day and use it to keep down heating loads.

Since most of the heat gain/loss in a building is due to conduction and radiation from walls and rooves alone, heat transmission coefficients or thermal transmittance values of these building elements are of vital importance. These values must be reduced to minimise heat transfer from external to internal surfaces (or vice versa) of walls and rooves.

Rooves and walls can be made into thermally efficient components of buildings in the following ways:

- increasing the thickness of walls and rooves exposed to direct external environment,
- introducing hollow cavities in rooves and walls,
- using composite materials for construction of rooves and walls,
- using insulation materials and techniques on rooves and walls,
- using lightweight aggregates in concrete and by achieving air inclusion in concrete,
- making appropriate opening sizes for maximum natural ventilation, and
- providing external faces of buildings with sunshades, facades, and surface rendering which contribute to blocking summer radiation gains from external surfaces.

At the National Building Research Institute a number of configurations for rooves and walls has been developed that are not only low in cost but improve the thermal efficiency of building components. Some of the elements developed at NBRI are listed in Table 6.1 A software programme has also been developed at NBRI that helps to predict the thermal response of a building for given variables and design parameters.

Table 6.1: Low-cost Building Elements Developed at NBRI for Improving Thermal Efficiency of Buildings

Name of Building Component	Description of R&D Products
Rooves	1. Lightweight RCC hollow-cored slab 2. Lightweight ferro-cement hollow-cored slabs 3. Ferro-cement waffle slabs 4. Ferro-cement - clay-tile hollow deck slabs 5. Ferro-cement barrel shell rooves 6. Hollow clay-pot RCC roof 7. Clay-tile waffle slabs
Walls	1. Interlocking concrete hollow blocks 2. Lightweight blocks using bagasse clinkers 3. Stone block masonry 4. Block from aggregate waste 5. Hollow concrete blocks made of aggregates from crusher sand 6. Cement-*surkhi* sandwiched mud blocks 7. Lime-*surkhi* sandwiched mud blocks 8. Soil-cement stabilised blocks 9. Mud plaster using bitumen and wheat straw 10. Mud plaster stabilised with cement
Floors	1. Thermally comfortable mosaic flooring 2. *Surkhi*-cement or *surkhi*-lime, plain and mosaic flooring

Recommendations and Conclusions

Construction materials, design, and detailing play a significant role in the success of an efficient cooling or heating system within a building. These factors should be thoroughly investigated and exploited to their optimum values in the planning stages. This will enable us to control the parameters influencing thermal efficiency and thus improving comfort levels at a much reduced cost compared to the costs incurred later on, i.e., in terms of energy consumption or additional costs required for improvement of different building components to improve thermal efficiency.

Further Reading

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6.4
Focus on Heat Pumps and Heat Pipes

D. Kaushik

Introduction

The aim of this paper is to present various energy efficient systems of centralized heating as a back-up to, and in tandem with, passive/active solar building technologies. The systems proposed in this paper are not at present popular for centralized heating in India but have been in use in colder countries all over the world for over a decade. The concepts behind these are certainly not new in India and have long been used in applications other than central heating. Chemical process plants use heat pumps, and heat pipes are an integral part of cooling systems in our space programmes at the Indian Space Research Organization (ISRO).

The reasons behind this lag in technology in the field of central heating compared to the rest of the industry are not difficult to comprehend. If one lists the areas that are very cold in our country and that need central heating as an essential facility rather than a luxury, we end up with areas that are not very thickly populated or are otherwise economically and technically backward. As a result there are no government statutes that enforce energy efficient systems, nor are there any incentives to install more efficient systems or penalties on inefficient ones that use high grade energy.

The result of this is that no private sector enterprise is prepared to invest in the development of these systems to make them viable at the user's level. Some companies have been manufacturing these products in collaboration with foreign companies that have developed them. Other companies are in a position to import these products directly. But both these alternatives end up with costs so high that the products become unviable. Absence of penalties on inefficient technologies and lack of incentives and subsidies or depreciation benefits on better products further compound the problem. The aim of this paper is to highlight these systems and their potentials.It also urges interdisciplinary interaction between architects and heating system designers so that the two endeavours are not treated as independent activities. Building and even city planners should involve system designers in the very early stages of planning so that there is a maximum degree of freedom to incorporate energy efficient systems.

Only very broad possibilities for use are presented and detailed technicalities are avoided.

Sources of Heat and What Heat Pumps Are

The sources that any heating device or system use to heat up a given space could basically be categorised as follow.

Direct Solar energy

This needs very little explanation. Solar energy can either be used directly by appropriately locating windows appropriately or through Trombe Wall or glass-enclosed sun spaces. This energy can also be absorbed during the day and stored in high thermal mass substances such as stone or water masses for use at night. This type of use needs elaborate planning in the building conceptualisation stage, and this needs an enlightened architect for the best results. Usually its effective implementation will pay back more than the architect's professional fees.

Conversion of Other Forms of Energy to Heat

This normally involves burning fossil fuels such as wood, diesel, coal/coke, and kerosene oil. to generate heat. Conversion of electrical energy to heat also falls into this category. Unless the electricity is generated through hydropower, it is not wise to use it to generate heat. Efficient burning of fossil fuel may be the lesser of two evils. However, environmentally speaking, the third option of pumping heat through what are called heat-pumps ought to be the best option.

Pumping Heat from a Lower to a Higher Level

This option is an attractive alternative to the consumption of fossil fuels and is already used widely in American and European countries where the science (or art) of comfort heating is fairly advanced.

In India, since comfort heating is isolated to relatively less developed areas, not much effort has gone into this field.

What Are Heat Pumps?

Some time back, before the quantum nature of energy was postulated, heat was compared to any other fluid and many properties of heat were very well explained with the help of this fluid analogy. Thus, if heat was like a fluid, temperature was like its potential or the height or gravitational head of heat. So, just as fluids naturally flowed down from a greater to a lower height but needed a pump and some expenditure of energy to flow from a lower to a higher level, similarly heat naturally flowed from a higher temperature to a lower temperature.

Heat pumps are devices that pump heat from a lower temperature to a higher temperature using energy in the process. The amount of energy used to pump one unit of heat, of course, depends on the height to which this unit of heat is raised, or in other words the temperature difference between the two bodies between which this unit of heat is pumped. In all practical applications of comfort heating, this ratio could typically be 1:8 on (a coefficient of performance [COP] of 8)—meaning that, by spending say 100 Watts of electricity one could pump up about 800 Watts of heat into a room. Compare this to the case of burning fossil fuel when you would have to burn fuel with a calorific value of at least 1,000 Watts to get 800 Watts of heat inside a space (considering an overall thermal efficiency of as high as 80%, not many systems have such high efficiency).

All refrigeration cycles, such as the vapour compression cycle and absorption cycle are essentially heat pumps. Examples of heat pumps used in applications other than space heating are numerous and virtually every household has a heat pump operating in it in the form of a refrigerator or an air conditioner. These devices also pump heat up from the cold interior to the warm/hot exterior, the only difference being the operating temperatures and the end use. A vapour compression cycle- based heat pump could typically pump up heat from a cold outdoor temperature of minus 10°C to an indoor space at 20°C (similar to the performance of a deep freezer in the plains). The problem of defrosting the outdoor coil needs to be taken care of, but this can very easily be done. Such heat pumps have been in use the world over for the last decade and a half.

Typical sources of heat for heat pumps are ambient air, year-round river water, groundwater, earth, direct solar radiation, thermal energy stored in rock beds for the night, and so on

More on Heat Pumps

Property

- Heat pumps can extract useful heat for space heating from sources having temperatures as low as minus 10°C.

Potential Applications

- It extracts more heat out of thermal storage such as rock beds by chilling them to lower temperatures, hence increasing their storage capacity.
- It improves the collection efficiency of solar collectors by lowering the operating temperature of water heated by solar collectors with a solar coupled heat pump. Collectors can then absorb heat even from diffused light and on ‘not too bright days’.

- In the case of district heating systems, lower centralized hot water temperatures result in lesser transmission losses and local heat pumps coupled to this centralized hot water can upgrade the temperature to comfort levels.
- 'Attic space coupled heat pumps' can extract heat from warm attics. Attics become warm as a result of solar heat on the roof and also because of the fact that warm air from the house rises to the top. Keeping the attic cool but the ceiling insulated results in collection of solar radiation incident on the roof.
- Heat pumps with their heat absorbing coils embedded in the earth about 13-14 feet below ground level pump heat up from the earth to the space inside. This is another example of indirect, solar heat coupled heat pumps.
- Groundwater coupled heat pumps have a very high coefficient of performance as groundwater temperatures are fairly warm compared to other typical sources of heat for heat pumps. An added benefit of these pumps is that they can reject heat to the same groundwater in summer during the air cooling cycle, if any.
- Heat pumps coupled to year-round river water also have a high COP. When the river is a little far, then two stage heat pumps may be used to feed a cluster of buildings: the first stage providing slightly warm water to the individual buildings after extracting heat from the river water and the second stage upgrading this warm water to hot water to be supplied to individual houses for space heating or washing. This reduces the transmission heat losses if the river is a little far away from the cluster of houses.
- Heat pumps need electricity for the compressors, pumps, and blowers and if this is not available in remote areas in winter then diesel generating sets with waste heat recovery systems on both the radiator heat rejection and flue gases can provide high overall efficiency.

Heat Pipes

Heat pipes are super conductors of heat. They are hollow, closed, and sealed vessels (not necessarily of a pipe-like shape) with a porous wick-like lining on the inside on a working fluid wetting the wick. Their most popular configuration is in the shape of a pipe, hence their name. Choice of material for the wick, external envelope, and the working fluid depends on the operating conditions and use.

Well-designed heat pipes can have equivalent thermal conductivities more than 1,000 times that of an equivalent sized solid bar of copper.

Heat pipes were invented very long ago but were revived in the sixties by the NASA space programme for dissipating heat from spot heat generation points such as electrical devices and missile nose tips, wind tips, and so on. Now heat pipes are used in a wide variety of applications, e.g.,mould cooling of plastic injection moulds, electrical panel heat dissipation, heat dissipation from high power electrical devices, and so on . Heat pipe heat exchangers are even being used in heat recovery applications in HVAC systems which involve high percentages of fresh air and exhaust air.

Heat pipes are passive heat dissipation devices working on the principle of evaporation, capillary action, and condensation. The mode of heat transfer is by latent heat of evaporation and condensation, and hence they have very large heat transfer rates. A portion of the pipe (one end) acts as an evaporator and the other end as the condenser. Usually the central portion is the adiabatic portion. This portion is best insulated. The evaporator absorbs heat from the heat source and the working fluid, which wets the wick and evaporates. The vapour fills the entire tube. The condenser end rejects heat to the heat sink, resulting in the condensation of vapour. The liquid then travels to the evaporator end by capillary action as the evaporator end will be dry. This travel could also be assisted by gravity. The liquid turns into vapour again in the evaporator end by absorbing heat and the vapour fills the tube. Thus, there is an effective transport of liquid from the condenser end to the evaporator end by capillary action and gravitation and subsequently transfer of vapour from the evaporator end to the condenser end.

The process is absolutely passive with no moving parts and the unique point about heat pipes is a very long maintenance-free life only limited by physical corrosion.

Salient Features and Potential Application of Heat Pipes

- Heat pipes can operate either in a reversible manner by merely changing the source and sink temperatures or, by incorporating certain features, can be made to act as thermal diodes or switches in a non-reversible manner. This means that these pipes transmit heat only in one direction, and if, because of some reason or another, the temperatures of the heat source and sink reverse, the heat flow will stop. Flow will resume as soon as the source and sink temperatures are back to the desired form. The application of this property can be for transferring heat from solar collectors effectively to the storage tanks during sunshine time and stopping the reverse heat flow at night.
- It has extremely high rates of heat transfer. This translates into the use of heat pipes as heat dissipating devices. Applications could be the warming up of rear side rooms through solar heat gain by the front sun-facing rooms with heat pipes embedded in the floor. Another application could be the dissipation of localised heat generation on a floor, either by a furnace or by day-time thermal storage in rock beds, etc via heat pipes embedded in the floor. These only transport heat one way and not the other.
- Because of the near constant temperature across the heat pipe, extremely high heat transfer does not need a very high temperature gradation; this means that very high heat transfer rates can be achieved between source and sink temperatures not very different from each other. Application could include transfer of heat upwards from the ground into an occupied room by a vertical heat pipe going down about 40-50 feet into the earth. Such heat pipes embedded in the earth, if coupled to indoor heat pumps, would use less pipe footage embedded per unit of heat pumped inside.
- These can be made in any convoluted shape and hence heat can be made to flow along any convoluted route.

Thermal Comfort in Cold Climates

As in hot weather situations, temperature, humidity, fresh air, and human metabolic activity play an important role in thermal comfort in cold climates as well. Although higher humidity (within reasonable limits) is more comfortable, care must be exercised to keep the humidity levels low enough so as not to induce sweating, as this can prove very detrimental to health. In addition, the moisture level inside any building should be low enough to avoid condensation of moisture on the window panes and cold walls. To ensure this, the dew point of the indoor air must be well below the inside surface temperatures of the coldest surface (usually the window panes).

Air motion, however, does not play an important role in thermal comfort in cold climates, unlike in hot climates. Hence, heating systems tend to have lower overall air flow quantities per cubic foot of conditioned space than cooling systems.

A critical parameter in system design in heating systems is the hot air outlet temperature which, to a great extent, is related to the relative location of the outlets in relation to the space occupied. High outlets ought to be avoided but, if inevitable, should have low air outlet temperatures and high outlet velocities.

Cool air return should, as far as possible, be taken from the lowest point (preferably at the floor level). This is more critical in areas in which people are mainly seated or otherwise at rest in lounges and lobbies than in areas in which people would be walking; a slight compromise can be made if absolutely necessary.

Perimeter heating, floor heating, and radiant heating are preferred to the conventional complete air heating. For large halls, an intelligent combination of the above could produce a very pleasant heating system. Perimeter heating usually involves heat ingenuity of a convective kind placed along the exposed wall or beneath an exposed window. This takes care of the heat loss. Some wall units combine convective as well as radiative heating if the heat source is a high-temperature source like steam or a gas burner. This meets the internal space heating requirement while also countering the inflow from the cold surface.

Floor heating is, without doubt, the most luxurious of the heating methods, but it needs very elaborate planning at the building construction stage. This is usually achieved either by burning logs of firewood in a small room called a ‘Haman’, which is specially constructed beneath the occupied space, or, in more modern and well-planned buildings, by circulating hot water or antifreeze fluid in pipes imbedded in the floor. Either way, the method of heating from bottom up is the best method from the perspective of human comfort.

Radiant Heating

Other factors permitting, this is one of the most energy efficient methods of achieving thermal comfort in cold climates. Ever wondered why one feels good standing close to a window with sunshine streaming in, even though the room air may otherwise be very cold, or why it feels very good to have the red hot electric wire-type heater facing you, but a slight turn of the heat to the side removes the comfort almost completely or, in very cold weather, when one sits facing a fire, the front part of the body gets warm but the back stays quite cold, and one has to keep turning around to keep uniformly warm? Yes, it is radiant heat showing its effects.

Sun, the universal energy supplier, sends its energy in the form of short wave radiation. This radiation heats up the earth or any other body on which it is incident. This body in turn heats up the air surrounding it by conduction, convection, and a little radiation. This is how the earth's atmosphere is heated, apart from the direct absorption of sun's radiation due to atmospheric dust and other suspended matter. Since air is thinner at higher altitudes (meaning less thermal capacity), it stays cooler than at lower altitudes where the air is denser. This is why hill stations are cooler than the plains. Thus, if at a hill station one stands in the sun, it is comfortable, while in the shade it can be quite cool. The reason is that even though the air temperature would be the same in the sun and in the shade, it is the sun's radiant heat that warms the body in the sunshine.

Applying this principle to active space heating produces similar results. A radiant heat source, such as an electric wire-type heater, a fire, a steam radiator, a gas-burning radiator, and a radiating floor or radiating ceiling, sends out radiation, heating the body on which it is incident—a human body for example. Conventionally, the air in the space is first heated and then the people in the space receive the warmth, but, with radiant heating, the people become warm directly without the intervening air being heated. This saves on the amount of energy required to maintain comfort and keeps the heat loss through the building low also, as the same comfort is achieved at lower surrounding air temperatures. Nevertheless, radiant heating has its merits for localised spot heating or heating spaces with very high ceiling areas.