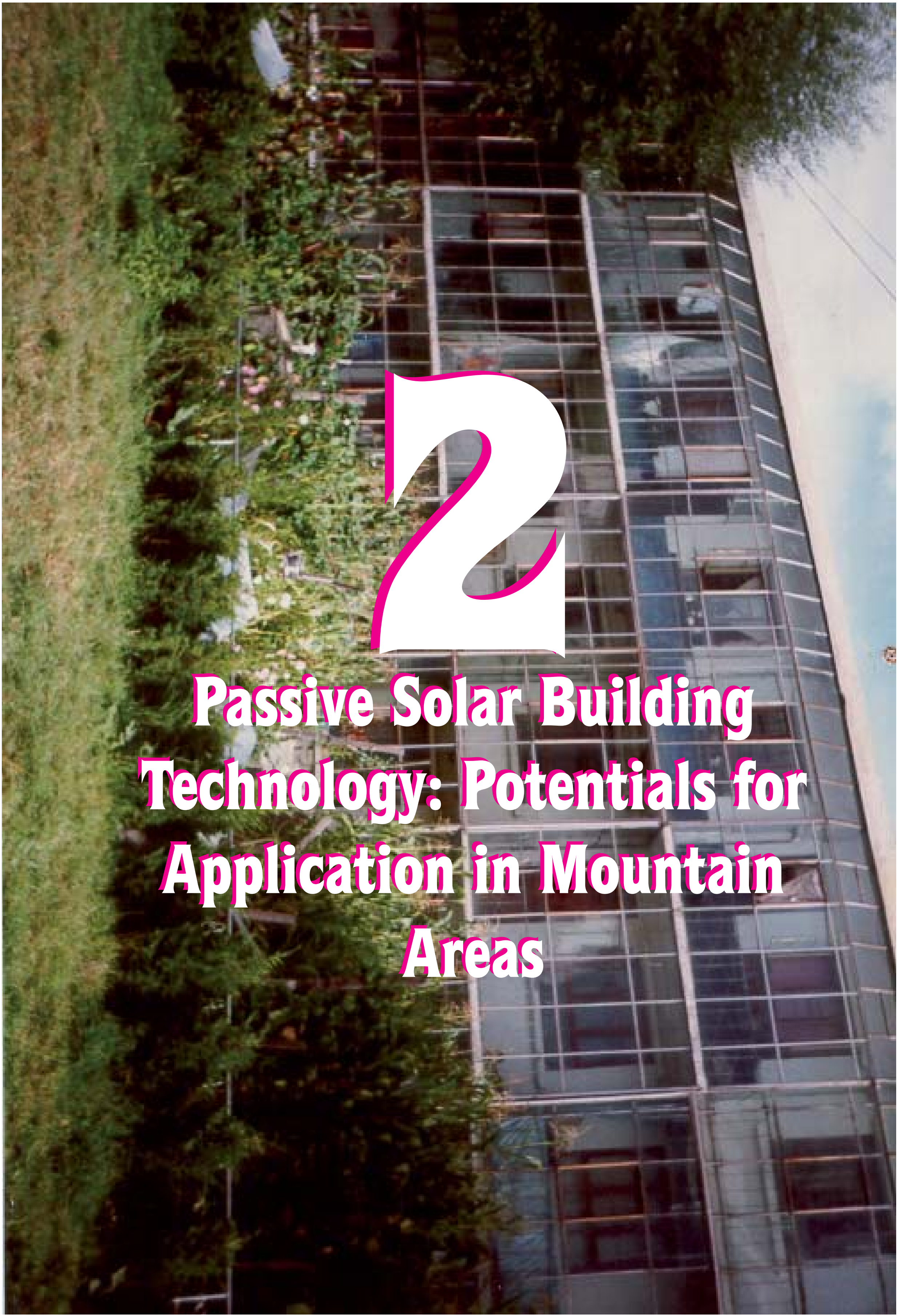


2

Passive Solar Building Technology: Potentials for Application in Mountain Areas

2 Passive Solar Building Technology: Potentials for Application in Mountain Areas

K. Rijal & N.K. Bansal

Background

In mountain regions, winters are usually harsh, and it becomes necessary to use heating to keep the temperature of indoor spaces at acceptable levels. In traditional architecture, usually wood or dung is used, whereas in urban houses kerosene heaters, electric heaters, and/or air conditioners are used. This has led to an increasing consumption of conventional energy for space heating or cooling in some areas.

The growing concern for the environment and the decrease in availability of fuelwood in the mountains have led to a search for appropriate energy options. In this respect, the promotion of passive solar building technologies is not only promising in the context of reducing energy consumption, but it also has the potential to reduce environmental hazards.

The Context

At high altitudes in the Hindu Kush-Himalayan (HKH) region, winters are severe and people need to keep themselves warm. Heating requirements have never been considered separately by energy planners/developers/promoters, and they were taken for granted along with cooking needs. Therefore, people used wood in open fires and stoves. Increasing depletion of forest resources has imposed serious limitations on use of firewood. Continuous exposure to biomass fires inside the dwellings has given rise to numerous health problems such as acute and chronic respiratory diseases.

The increasing shortage of fuelwood, the time spent on fuelwood collection, and an increased awareness of deforestation have created the need for dissemination of information about improved devices for saving fuel. Progra mmes initiated during the early 80s to propagate the use of Improved cooking stoves (ICS) were rejected mainly because they did not cater to the main need for space heating, which constitutes 30 to 70 per cent of the total, useful domestic energy consumed. Since heating is an important end–use for mountain communities, opportunities for appropriate energy technology interventions need to be explored with this in mind.

Availability of solar energy in the HKH Region and the possibility of using this free gift of nature provide the option to reduce the quantity of useful energy used for space heating in the mountains, so that less fuelwood is needed.

In this respect, solar passive building technologies (which in themselves are well studied and applied in the context of developed countries but less known in mountain areas) could help. The useful energy required for space heating, primarily for the household and commercial sectors, could be reduced substantially if old buildings were to be retrofitted or new houses designed taking the building envelope and its orientation into consideration in order to increase the heat gain inside the building through solar energy; at the same time reducing heat loss by using local materials for insulation.

Historical perspective

Ancient architecture all over the world had many characteristics to provide thermal comfort. Different parts of buildings (e.g., indoor spaces, doors, windows, etc) were located and oriented to take maximum advantage of the climate, and the role of trees, vegetation, and water around the building, located to provide thermal comfort, was well appreciated. Massive walls were built and residences clustered (to reduce the surface to volume ratio) to reduce the swing in temperature swings.

The Greeks appreciated the importance of using the southern aspect of a house, as is evident from the statement (400 B.C.):

"*Now in houses with a southern aspect, the sun rays penetrate into porticos in winter, but in summer the path of the sun is right over our heads and above the roof (so there is shade). If then this is the best arrangement, we should make the southern side loftier to get the winter sun and the northern side lower to keep out the cold winds.*"

The basic idea—that the sun describes a lower and more southerly arc in winter than in summer (and a more northern one in the southern hemisphere)– is applicable everywhere but in the tropics near the equator. It is the central principle in all passive solar design. Two to three times as much sunlight strikes a south-facing wall in winter than in summer, making that the logical side for placing the windows. The house itself then becomes a solar collector (Flavin 1980; Knowles 1996).

Conscious scientific application of solar energy for passive heating can be said to have started in 1881 when Professor E.L. Morse was granted a patent on a glazed south-facing dark wall to keep the house warm. This idea was applied by him only to one room of his house and not followed up by either Professor Morse or others for a very long time. Morse's concept was re-patented by Trombe (1972; 1974) who, starting in 1972, built a series of houses at Odeillo in the Pyrenees, France, and made an engineering success of the idea. Previously, Hollingsworth (1947) had also employed such a wall in an experimental house at the Massachusetts' Institute of Technology (MIT).

In 1947, under the sponsorship of Libbey-Owens-Ford Glass Co., a remarkable book appeared entitled 'Your Solar House' (Simon 1947). Forty-eight highly regarded architects prepared designs for direct gain solar houses. One for each of the then states of the US. As might be expected, most of the designs featured thermopane glass, but few if any recognised the importance of building mass as a means of providing storage. Overheating, even on very cold, sunny winter days, would have been a problem for most of the designs given in this volume.

In 1952, the Kech brothers designed a 24-unit solar home development in which they used double-glazing to maintain comfortable conditions despite the biting cold of northern Illinois winters. Overheating and wide temperature swings were problems encountered in these and similar designs; windows that could be opened or ventilating fans were generally required to maintain comfort in winter. Year-round air-conditioning was not contemplated in those days.

Hay and Yellot (1969) introduced the concept of a roof pond to store heat during the day in winter and deliver it to the living space in the night. The same system could be employed in hot weather to cool the building – using convection, radiation, and evaporation to cool water in the night. Moveable insulation is a special feature of the system.

The importance of structures fully or partly underground in maintaining thermal comfort had long been recognised. The pioneering work of the Underground Space Centre at the University of Minnesota (1978) should be mentioned in this connection. Passing air through tunnels deep in the earth provides a source of warm air in winter and of cool air in summer.

With the advent of the energy crisis, there was a renewed interest in those aspects of architecture that contributed to thermal comfort in a building without (or with minimum) expenditure of energy. This led to the formal recognition of the passive (or natural) heating and cooling of buildings as a distinct science. Since the sun played a predominant role in all such considerations, the science came to be known as passive solar architecture.

Passive Solar Building Technology: What is it?

For cold climates, a passive solar building can be defined as *"a building in which the various components are arranged in a manner that maximises the collection of solar heat. It is then stored and finally distributed into the space without any expenditure of conventional energy* (Flavin 1980)." This basic definition of solar passive building implies that the use of passive solar energy will have an impact on the art and science of building construction, maintaining the traditional architecture.

Ancient architects were handicapped because there was no glass (or similar material to let in solar radiation and keep the cold air out and heat in), and they were therefore unable to incorporate solar heating without letting the outside air in (currently known as the direct gain concept). After the invention of glass, it was used extensively in the west. The portions of the house that admitted sunlight through the glass were hot during the sunshine hours and cold otherwise. The cold was countered to some extent by having a double window, one of glass and the other of wood, which could be closed when there was no sunshine.

Glass and plastic are the basic materials that make modern solar heating possible. Glass has a special property that easily transmits sunlight but impedes thermal radiation, in effect trapping heat in the building. In its simplest form, passive solar heating consists of having most of a building's windows on the south in the northern hemisphere because of the relative position of the sun due to the earth's movement. Windows on the east, west, and north are kept to the minimum, because they tend to lose more than they gain and because they can cause overheating problems in the summer. Properly siting the building is almost as important as the design. Access to the winter sun and protection from cold winds can be facilitated by positioning the building correctly (More 1988; Gupta 1989).

For effective heating inside the building envelope, retention of heat is as essential as admission of sunlight. The wall, rooves, and windows of a building lose a great deal of heat during the cold weather because of radiation and convention, such a building, when heated by the sun only, cools rapidly after dark. Thus the application of an appropriate level of insulation becomes essential. Similarly, as much as half the heat loss in a conventional building occurs through direct infiltration of cold air. In order to reduce this, emphasis must be placed on tightness of construction so that the building has as few air gaps as possible.

Also integral to the success of a passive solar building is the method of storing heat. By using construction materials with a substantial capacity to hold heat, a building's ability to store the sun's energy is increased. When the sun sets, the thermal mass slowly radiates heat, keeping the building warm. Several traditional building materials - including brick, concrete, adobe, and stone - perform this task well and help reduce temperature fluctuations in both winter and summer (Schepp and Hastie 1985).

The beauty of passive solar design is that, although the basic principles are simple, there are a great number of ways to harness the sun's energy effectively.

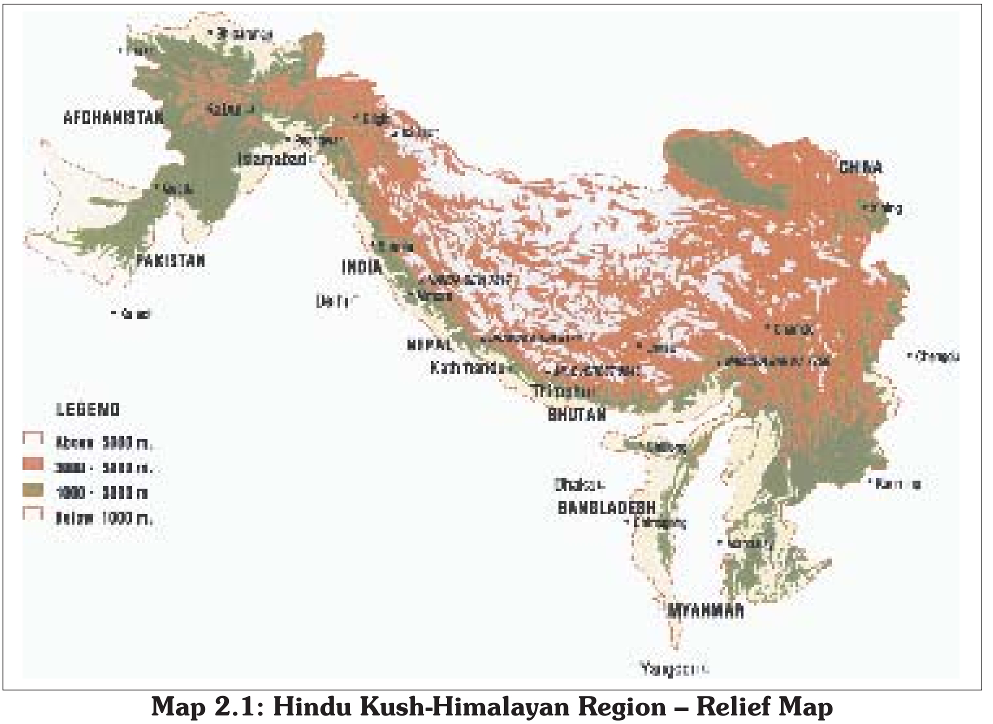
Availability of Solar energy in the HKH Region

The sun is an inexhaustible source of energy mostly composed of gases. It can be thought of as one huge thermonuclear reactor, emitting energy into space in the form of electromagnetic radiation. The total energy given out by the sun amounts to 3.8×10^{26}W (Moore 1988). This is an enormous energy flux, but the earth's outer orbit receives 1373 W/m^{2}, which is commonly known as the solar constant (Rijal 1984). This incoming solar radiation passes through the atmosphere and interacts with the matter present such as dust, ozone, carbon dioxide, and water vapour. As a result, it is partly reflected, partly absorbed, and partly scattered. The radiation reaching ground level, or global radiation, is therefore attenuated and consists of direct and diffuse radiation. The suitability of a site for solar energy use has to be evaluated not only on the basis of the average solar radiation flux available, but also on the value of the ratio of average to maximum attainable flux.

The amount of global radiation received at a particular location varies with the latitude of the place, the time of the year, and the time of day, in addition to other local conditions such as cloud and snow cover. In general, regions with dry climates within 35° latitude from the equator are much more suitable for the use of solar energy (Stambolis 1981), since the percentage of diffuse radiation is substantially less at higher latitudes and in regions with less cloud cover than at lower latitudes and in regions with substantial cloud cover. At the same time, the extent and nature of cloud cover drastically reduces the amount of direct radiation, while snow cover helps to increase the local albedo factor—thereby increasing the amount of global radiation of a particular place.

The Climatic Features

The climate of the region is characterised by four main seasons: winter (December to February); pre-monsoon or summer (March to mid-June); monsoon (mid-June to mid-September); and autumn or post-monsoon (mid-September to November) (Main 1981). As the Himalayas rise suddenly from the plains in a series of folds (Map 2.1), they cause several complexities in the micro-climatic situation in the region. There are a great number of sub-climates and small-scale subdivisions in the region due to dramatic



Map 2.1: Hindu Kush-Himalayan Region – Relief Map

changes in the orientation, altitude, and size of the mountains, slopes, valleys, and plateaux (Domroes 1979).

An interesting feature of such local climates is that the valley bottoms in the HKH are generally characterised by dry, and the adjoining slopes and peaks by wet, climatic conditions. This dry valley phenomenon is considered to be a unique feature of the Himalayas and is particularly associated with the larger valley systems in the region. This is true on the local scale as well as on the macro-scale. For example, Lumle (1,642), lying south of the Annapurna Range in the Nepal Himalayas, receives about 5,000 mm of rain per annum, whereas Jomsom (2,750 m), lying north of the same range, receives only about 250 mm per annum.

The HKH mountains act as an effective barrier between the climatic systems of the lower and middle latitudes influencing the global, regional, and local atmospheric circulations significantly (Domroes 1979; Mani 1981; Chalise 1986).

Parameters Affecting Solar Insolation and Heating Energy Demands

The availability of solar energy is primarily influenced by local climatic factors such as precipitation, sunshine hours, temperature, and seasons. A fundamental characteristic of solar energy is its intermittence. However, factors such as relief, altitude, slope, and aspect influence the availability of solar energy in mountain areas significantly and thus need careful understanding.

The terms '**relief**' and '**altitude**' are not synonymous. Altitude is an absolute term, defined with respect to sea level. In a physical sense, relief determines the kinetic energy of the mountain surface, while altitude determines the properties of the air mass surrounding the mountain. The altitudinal interval occupied by the local relief of a given mountain is a primary factor in determining differences among mountains. This, in turn, produces significant differences in terms of meteorological parameters in the mountains. In this region, both altitude and relief are at a maximum for the earth as a whole, maximising the effects of both altitude and relief (Alford 1992).

Slope determines the local relief. There are a number of areas in the region that have been identified as areas with the greatest local relief, and this will have significant effects on the climate and thus on solar insulation. For example, Hunza Valley in Northern Pakistan rises for about 1, 850 m to the summit of Rakaposhi at 7,788 m (a vertical difference of 5,939 m in 11 km) and the Kali Gandaki Valley of Central Nepal, rises from around 2,470 m to 8,167 m at the summit of Dhaulagiri I, with a difference in elevation of 5,697 m over 11 km (Alford 1992). These great changes in altitude over relatively short horizontal distances greatly increase the role played by slopes along with the nearby snow peaks which act like large reflectors, thereby raising the albedo factor and increasing the availability of solar energy in a particular place. These valleys may be suitable for the exploitation of solar energy.

Aspect - the compass direction faced by a slope plays a crucial role in modifying the pattern of precipitation and the availability of solar insulation. For example, 'windward' slopes and 'leeward' slopes will be respectively wetter and drier than regional average values, as the air mass rises and descends in its path across the mountains (Barry

1981). The second factor associated with aspect involves the maximum amount of sunlight possible during a year, or season, for any given latitude. North-facing slopes receive the least with east-and west-facing slopes receiving an intermediate value. This difference between north-facing and south-facing slopes increases with distance from the equator and with increasing altitude in any mountain range, as the importance of sunlight increases. The windward-leeward relationships will be most in the eastern portion of the region, at least at lower altitude, while orientation with respect to solar angle will be more important in the western portion of the region (Geiger 1966).

Temperature Profile

The complexity of the climatic phenomena within the HKH region is obvious from the above discussions. Such complexity is caused by the relief features as well as the differential effects of the weather systems in different regions. However, a certain effect on temperature is visible from these monsoonal effects within the region. For example, if one compares the temperatures at stations in the east and west of the HKH at the same altitude (Table 2 in Appendix A), the differences are striking. The summers are warmer and winters colder in the west (e.g., Leh, Skardu, Srinagar) and on the Tibetan Plateau (e.g., Chamdo, Lhasa, Xigagje), while the annual range of temperature is comparatively lower in the east (e.g., Gangtok, Darjeeling, Shillong) (Mani 1981; Domroes 1988).

The main variation in the temperature between the eastern and western part of the region is caused by the difference in the duration and strength of the monsoon in summer and the passage of western disturbances in winter. The arrival of monsoon in the west is sudden, with an abrupt change in cloudiness, temperature, humidity, winds, and rainfall. In the east, the transition is gradual and restricted mainly to an increase in cloud, fog, and rain and with little change in humidity and temperature. It is in winter that snow accumulates around the Himalayan peaks and the snowline comes down to about 1,500 m in the western Himalayas, whereas it is at 3,000 m or above in the eastern Himalayas (Mani 1981)

Solar Insolation and Sunshine Hours

Figure 2.1 compares solar radiation in selected places of the HKH region. The difference in temperatures at stations in the east and west of the HKH at the same altitude is striking. The summers, are warmer and winters colder in the west (e.g., Leh, Skardu, Srinagar) and on the Tibetan Plateau (e.g., Chamdo, Lhasa), while the annual range of temperature is comparatively lower in the east (e.g., Gantok, Darjeeling, Shillong); therefore, there is a substantial variation in the solar insolation and heating energy requirements. For example, the maximum average temperature in Leh during summer is 22°C and the minimum average temperature during winter is –10°C, while in Gantok, maximum average temperature in summer is 13°C and the minimum average temperature during winter is –6°C. The variation is due to the prolonged foggy mornings that prevail as a result of the micro-climatic conditions of a particular place. Variation in the summer months is due to the extent of cloud cover. The lowest variation is observed in the month of April, as the sky is clearest during this month all over the region.

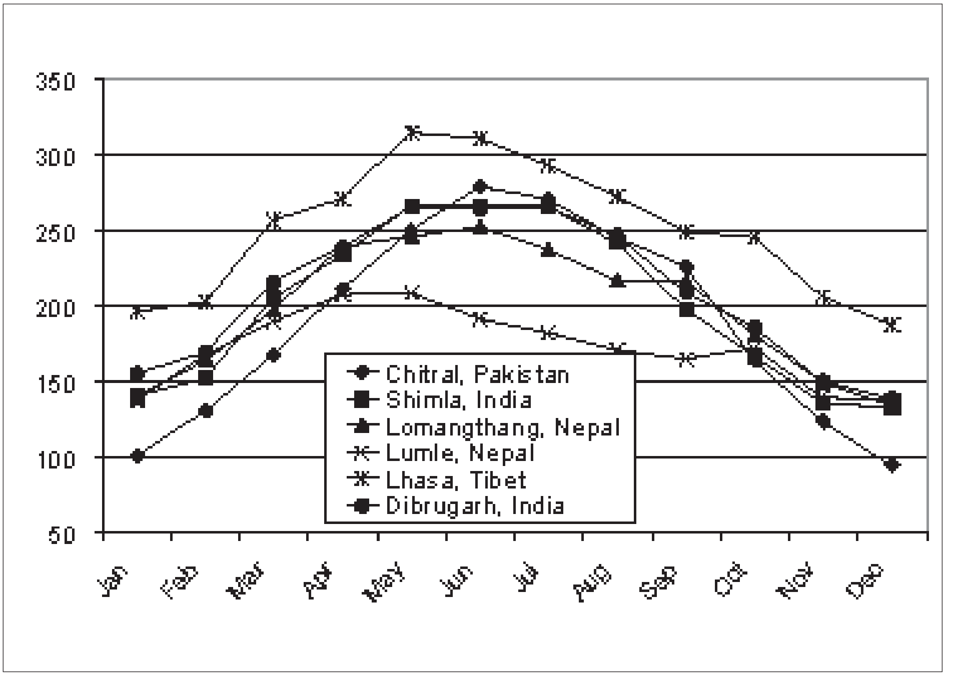
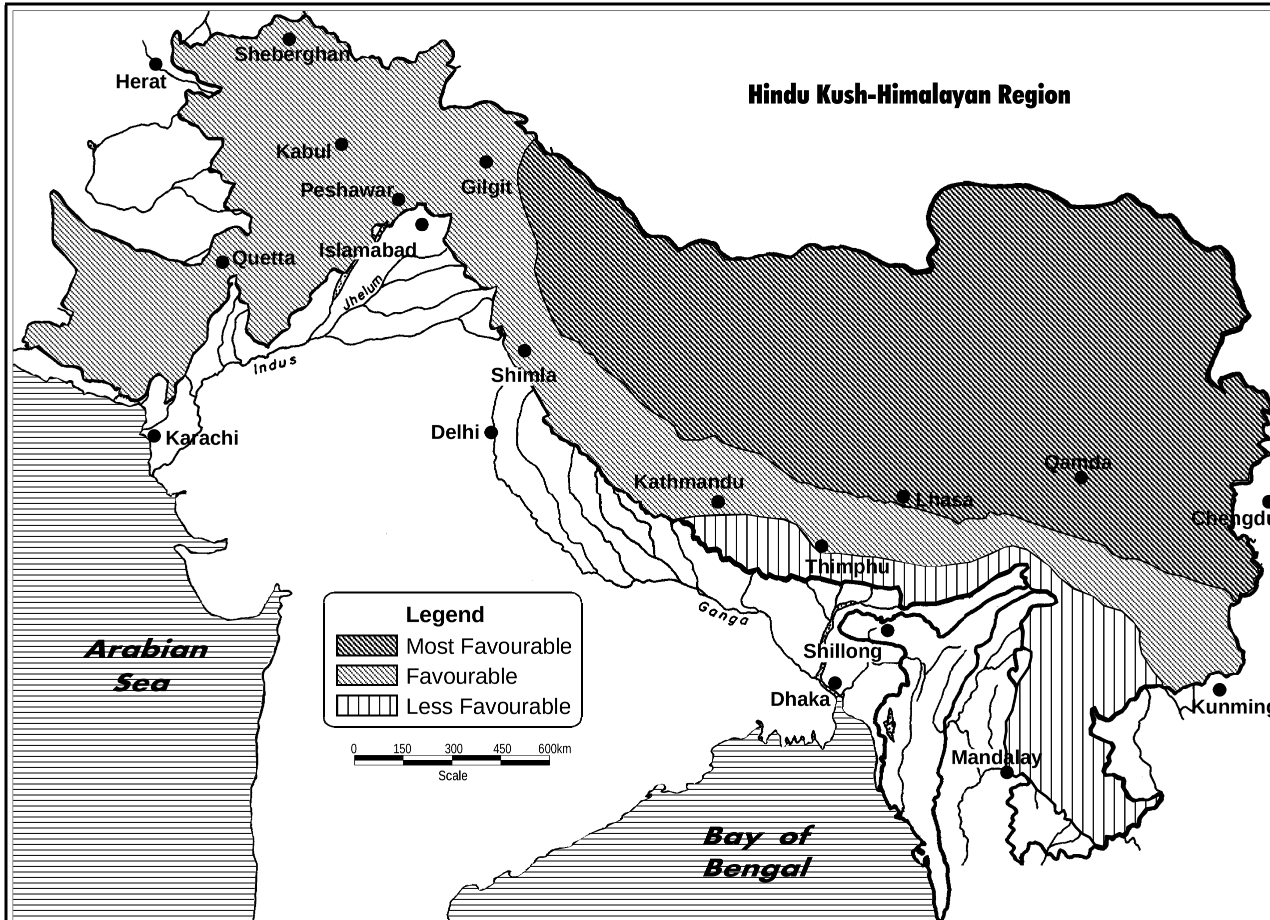


Figure 2.1: Monthly Average of Daily Global Solar Radiation in Selected Areas of the HKH

The central and eastern parts of the region primarily consist of the Tibetan Plateau and Himalayan Range. In Lhasa (Tibet) the annual mean, daily global radiation is about 250W/m^2, with an average of about 285 W/m^2 during summer and 198 W/m^2 in winter. The southern parts of the central and eastern regions (South of the Himalayas) experience less hours of bright sunshine due to a high percentage of cloud cover with a few exceptions as a result of local climatic conditions. For example, Kakani, Lumle, and Syangboche in Nepal receive less than 2, 200 hours of bright sunshine hours with an annual mean global radiation of less than 175 W/m^2, while in Kathmandu Valley it is almost 200 W/m^2 — comparable to the radiation value of Mustang and Jumla (Trans-Himalaya*) and Dadelhura (Himalaya) in Nepal and Leh (Trans-Himalaya), Shimla (Himalaya), Shillong Valley, and Dibrugarh (about 100 masl) in India.

Generally speaking, within the HKH Region, the Tibetan Plateau is most favourable in terms of the availability of solar radiation (Map 2.2). The Trans-Himalayan Zone, Hindu Kush, western part of the Himalayas, and valleys in the Hindu Kush and Himalayas can be considered favourable, the eastern part and central part of the Himalayas are less favourable than the places mentioned for solar energy resources.

N.B. The use of Himalaya-Trans-Himalaya is maintained for specific geological zones, whereas Himalayas is the general term.



Map 2.2: Availability of Solar Radiation in the Hindu Kush-Himalayan Region

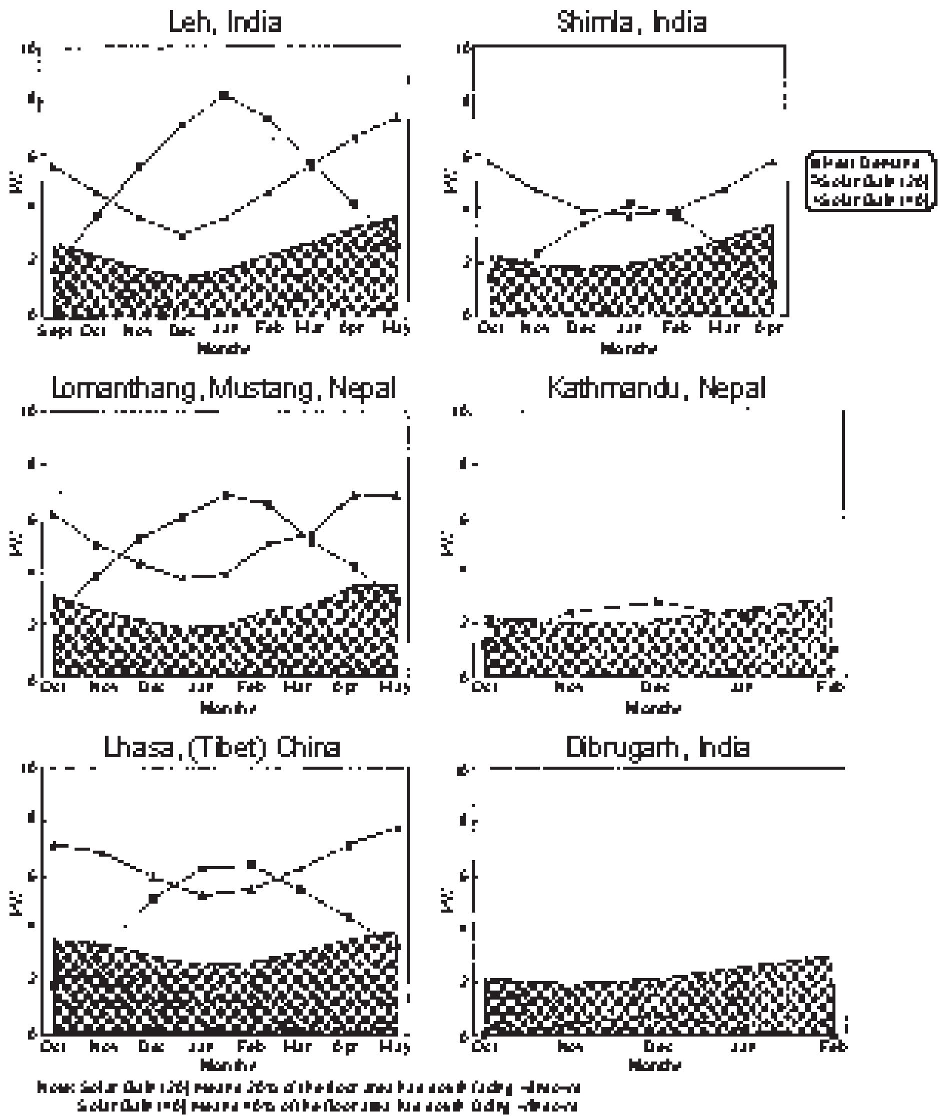


Figure 2.2: Heating Energy Demand and Solar Gain in Selected Places of the HKH

Potentials for Application to Meet Demands for Heating

The demand for heat during various months, as depicted in Figure 2.2, clearly indicates a greater demand in places such as Leh in India, Lhasa in Tibet, and Lomangthang in Nepal than in Shimla in India and Kathmandu in Nepal, depending upon the outside temperatures of these places.

It is interesting to note that the availability of solar radiation during the winter is comparatively higher in places where the demand for heating is also high. For proper

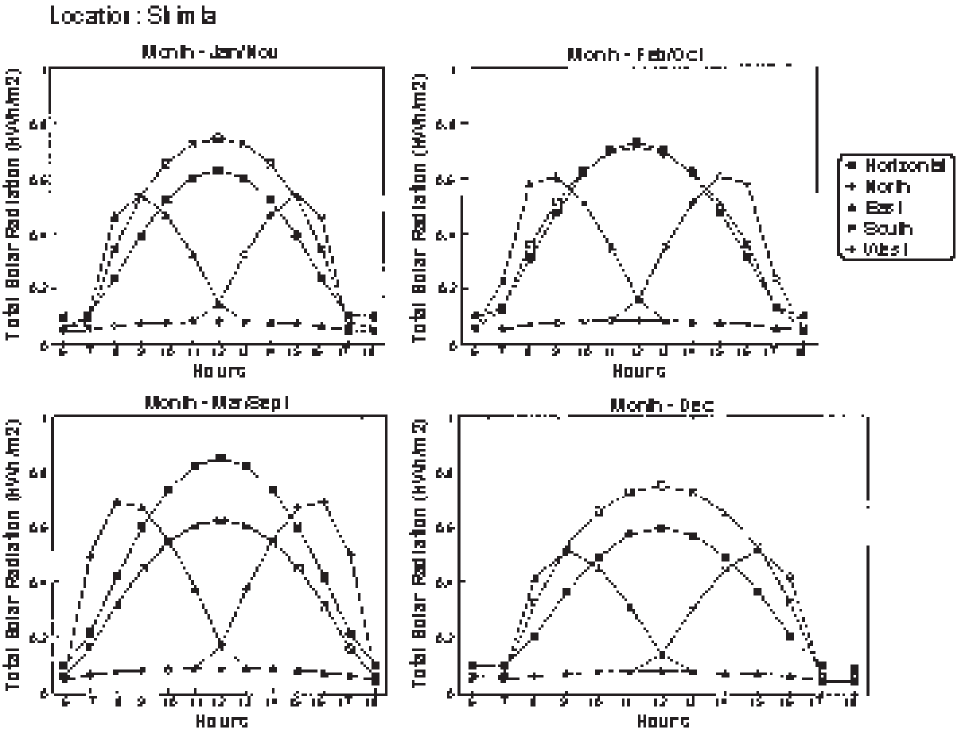


Figure 2.3: Total Solar Radiation of Surfaces of Different Orientation

exploitation of the potential of incoming solar radiation it is extremely important to register the amount of solar radiation falling on different surfaces of a building. The horizontal and south-facing walls receive the most radiation during winter compared to the north-, east-, and west-facing walls. It is also important to realise that the value of incoming solar radiation varies during the hours of the day in a particular month, and this is primarily as a result of the latitude of the place. These phenomena are exemplified with a case example of incident solar radiation in Shimla (Figure 2.3).

In places like Kathmandu, almost all the heating for buildings during winter can be provided by trapping the incoming solar radiation with the provision of 20 per cent of the total floor area as an opening on a south-facing wall (Figure 2.2). In places like Lhasa, for the same reason, more than 40 per cent of the floor area is required as an opening on a south-facing wall. These examples have been cited to clarify the potential for the application of solar energy in mountain areas to provide heating.

Principles of Passive solar Building Design for Cold Climates

There are four basic steps for capturing the sun's energy to increase thermal comfort inside the building envelope in the mountains during winter. First of all, the location, orientation, shape, external colour, and opening of the building should be such that the maximum amount of solar energy is trapped inside the building (Rosenlund 1995).

Secondly, the solar energy trapped should be retained within the building envelope by reducing heat losses and by increasing the heat storage capacity of the building. This is done by using appropriate insulating materials and operating ventilation and openings to reduce the heat loss from the building in winter properly. In order to reduce the fluctuation of temperature within the building envelope walls, the floors and rooves should act as thermal storage centres, and appropriate materials and thickness are needed for this purpose (Chepp and Hastie 1985).

Thirdly, air movement inside and outside the building envelope is also important. Proper air movement inside the building must be ensured in order to reduce the cold and hot pockets that may exist as the level and location of heat generation and incoming solar radiation may vary. The building also needs to be protected from the wind blowing outside the building envelope in cold climates, as this influences the rate of heat transfer from inside to the atmosphere (Erat 1985; Bansal and Minke 1995).

Fourthly, the building should be designed in such a way that over-heating does not occur; and this is important specifically during summer months and in day time. Appropriate shading may be required for this purpose.

Layout, Orientation, Shape and Opening

Knowledge of the sun path and intensity of global solar radiation falling on rooves and different walls at different times in a day at a particular location is essential for determining the location and orientation of the building. The building should be located where shade is not imposed on it by adjacent buildings or tree cover. As explained earlier, the roof and the south-facing wall receive maximum solar radiation in the northern hemisphere during winter. Therefore, the plan of the building should be rectangular with its length running east-west so as to allow for maximum opening on the south face.

The surface and roof area of the building should be at a minimum in order to reduce heat loss and also the area from which snow will have to be removed. For example, double storied buildings are preferable to single-storied ones. The emphasis should be given to minimising internal volume, i.e., the height between floor and ceiling should be as little as possible to lessen the heating load. It is also desirable to identify heated (kitchen), unheated (staircase, store, bathrooms), and transition zones (bedrooms) and locate them so as to maximise thermal comfort and minimise heat loss (Moore 1988; Erat 1985; Gut and Ackerknecht 1996). Windows should be on the south-facing walls and the percentage of opening required in terms of floor area depends on the outside temperature during winter. Windows on the north side should be kept to the minimum.

Reduction in Heat Losses

Heat loss from a building occurs mainly due to ventilation and conduction through windows and the ceiling. The conductive heat flow through a wall, window, door, ceiling, or floor decreases with resistance in the path of the heat flow. Improving the insulation of a house, therefore, means increasing the thickness of the construction or applying new material with better insulation properties. Hence, proper insulating materials can be used to reduce heat loss through walls, rooves, and floors. Double-glazed windows are appropriate for reducing heat loss from large openings on the south wall. Also, provision of weather stripping will substantially reduce heat loss through the openings. Additional insulation (insulation shutters or thick curtains) should be used at night. Placement of the door should be primarily based on the direction of the wind and preferably it should not be placed towards the wind so that infiltration loss is minimised. Double doors at entrances and exits will create air locks, thus reducing heat loss (Scheep and Hastie 1985; Hopman and Bachman 1984).

Heat loss can be reduced effectively by dividing the house according to its functions into zones with more heating needs and zones with less heating needs. These are called thermal zones. The following principles should be considered while planning the thermal zones; a) the thermal flux from the warm area towards the cool area further outside should be as slow as possible; and b) the rooms should be located according to their heating needs. As a result of the thermal zoning the heating needs of the house drop considerably because heat moves more slowly to the outside;i.e., heat remains longer inside.

Increase in Heat Retention Capacity

The choice of appropriate materials for walls, rooves, and floors and their thickness play important roles: these components can act as a thermal flywheel. Generally, heavy building materials, such as bricks, concrete, sand, gravel, and adobe (mud), possess the best heat retention capacities. Also, it is important for heat retention materials to have suitable heat conduction properties as well as the ability to absorb sunlight. Since absorption depends on the colour and texture of the exposed surface of the mass, darker, duller colours and rougher surfaces absorb heat the best. There are also a number of products available that are used as coatings on thermal storage walls (Erat 1985; Gut and Ackerknecht 1996). This means that while the materials absorb heat well, they should also release the heat slowly so that heat can be stored when it is available and released to the rooms when needed. In other words, solar energy can be collected and partly stored during the day, the heat being released during the night and possibly during the next day as well.

The best building materials with regard to the building as a whole should possess all of the essential properties of good insulation, suitable thermal conduction, and good heat Retention Capacity. Moreover, the materials should be inexpensive, easily available, and easy to work. Mud, which is traditionally used as a construction material in the rural areas of the HKH, has all these features and therefore it constitutes a good building material when used along with the application of passive solar building concepts.

Of all the building mass inside the building envelope, only a part can be used for storing heat. Areas where the sun strikes directly are effective for heat storage. Therefore, buildings should be planned so that much of the area of the floor and wall is exposed to direct sunlight during winter. Floors should not be covered with carpets which, being good insulators, prevent the heat from entering the heat storage (i.e., concrete floor) and thus reduce the heat capacity considerably (Schepp and Hastie 1985). An evaluation should be made of how much of the walls, floors, and ceilings can actually be used for heat storage.

Control of the Heat Flow

Control of the heat flow in a passive solar building must include control of the sunlight passing through the glass. The simplest and most effective method of controlling the amount of sunlight passing through the glass is to use overhangs. The winter sun is generally lower in the sky than the summer sun. A roof can be extended beyond the end of a wall in such a way as to block most of the higher summer sun from striking the glass (Hopman and Bachman 1984; Bansal and Minke 1995). In winter, the lower sun can pass under this overhang unobstructed. The method is crude but effective, and it requires no constant attention. It is a part of the building design.

The Passive solar heating system

One can differentiate between the two basic types of solar heating system - active and passive –by the way they retain heat once it has been converted from sunlight. Active systems use an additional source of energy to pump a liquid or blow air over the absorber. The passive system has absorbers that also store heat, but they require no additional energy source (Scheppp and Hastie 1985). Passive solar systems are not bought as products but are designed, built, and made with careful planning of measurement and sizing.

This section deals with how sunlight can be used to heat a home in cold climates and describes various types of passive solar heating system.

Basic Principles

The greenhouse effect is the basis of passive solar heating. Light travels through glass (or plastic) and is changed to heat when it strikes a dark - coloured object. Since heat has a longer wavelength than light, it cannot pass back out through the glass. This phenomenon is known as the greenhouse effect. To get out, it must heat up the glass, and the glass must then radiate the heat to the outside. Passive solar heating, however, is more than the process of sunlight being changed to heat behind glass. A solar heating system must store that heat in some way and control its distribution. For this the thermal storage mass and the glass work together. Glass brings the energy in and the mass stores it.

Passive solar systems use a material to both absorb and store solar energy. This material is commonly referred to as **thermal storage mass** and is usually heavy, dense, and dark brick, stone, cement, or containers of water are often used. When struck by sunlight, the surface of the thermal storage mass begins to heat up, heating the air around it. Depending on the design of the passive system, this heat is used to warm the living space. Much of the heat from the surface of the mass is slowly conducted inward, penetrating deeper and deeper, gradually warming up the cooler interior of the mass. When the mass becomes hot, it starts radiating and convecting heat to the surroundings slowly in the same manner in which it was heated by the sunlight. Lightweight, lowdensity materials, even if darkly coloured, do not work well as thermal mass. A material that heats up quickly will also cool down quickly. In a building, lower mass materials, such as rugs and wall hangings, absorb the light and change it to heat but have no capacity to store it for use later. The principal role of thermal storage mass is to keep temperatures more or less constant, minimising the drastic temperature change in temperature between day and night.

Once heat begins to be transferred from the thermal storage mass, it does so randomly and in all directions, whenever and wherever the surrounding air or surfaces are cooler. In order to use this heat, it must be directed in the direction desired. One way to do so is to use insulation to block the heat flow to the outside whenever the mass is located near the exterior of the building. For thermal storage walls that are exposed to sunlight directly behind glass, movable insulation can be used. Vents can be used to move air heated by the thermal mass to colder areas of the building. Appropriate movement of heat is facilitated by providing minimal resistance to air flow, thus allowing the natural convection of warm air rising and cool air falling to distribute heat evenly throughout the house.

How these basic concepts can be put together to form passive solar systems is discussed in the forthcoming paragraphs. These systems can be combined in different ways or used singly, depending on the amount of heat required and the availability of solar radiation in a particular place. In addition, the selection of a passive solar system also depends on the investments needed, the kind of materials available, and the choice of the user.

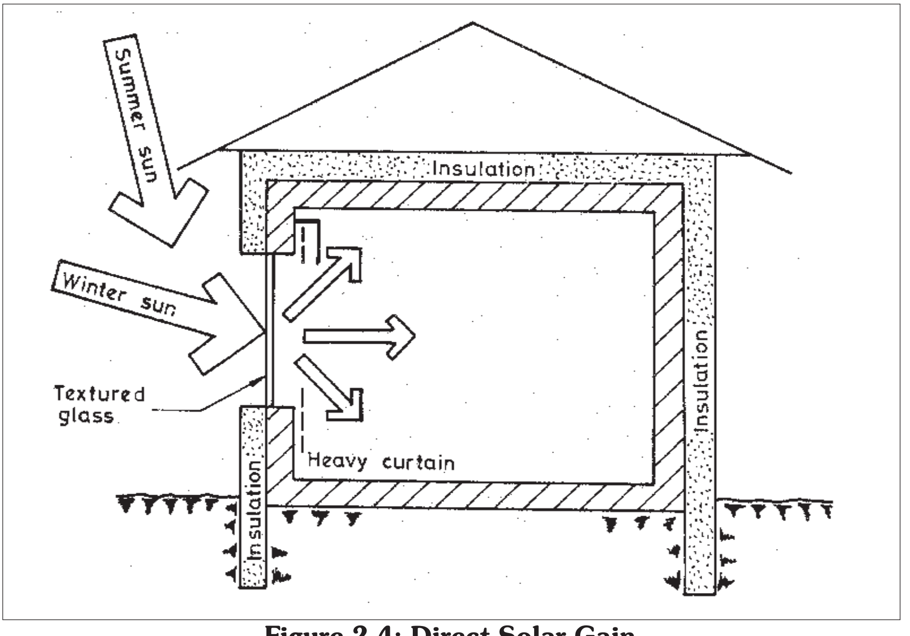


Figure 2.4: Direct Solar Gain

Direct Solar Gain Systems

The easiest way to heat a building with solar energy is to place glass on a south-facing wall allowing in the solar radiation. This method is called direct solar gain. Heat is gained by the living space directly (Figure 2.4), though some kind of dark-coloured thermal mass needs to be exposed directly to the incoming solar radiation to convert sunlight into heat as well as to control the heat flow within the building envelope (Erat 1985).

The thermal mass of a direct gain system might be a concrete floor slab, a brick or stone wall, or both. Floors and walls used for thermal storage in direct gain systems need to be only four to six inches thick (Schepp and Hastie 1985) as heat does not generally penetrate deeper than that, especially in floors. Greater heat penetration is possible in the walls, but only when they are placed directly behind glass. In this case, it is no longer a direct gain system as the wall stands between the occupants and solar energy. Whenever the thermal mass serves as an exterior wall, heat flow from it is controlled by placing insulation outside. In this system, moveable insulation prevents the heat from flowing out through the glass at night.

The main advantage of direct solar gain is its efficiency. The performance of this system is not easy to predict with accuracy, but some reports (Hopman and Bachman 1984; Bhandari and Bansal 1992) indicate that the system is superior to other passive options in delivering heat to the living space. The exposed living space of a direct gain home is bathed in light, and the resident may feel uncomfortable due to too much light. This can also cause the colours of furniture and fabrics to fade. The system also places limitations on the use of wall hangings and floor carpets for decoration, as more thermal mass is required to store heat; if heat is not properly stored, overheating and a rapid drop in temperature may occur within the living space.

The extra cost required for a direct solar gain system is small compared to **the cost of** conventional homes (Erat 1985). The use of movable insulation to be operated during the night is crucial because the glass area is large in this system In the absence of such a covering over the glass the applicability of the direct gain design is restricted to moderate climates only.

Thermal Storage Walls

The thermal storage wall is an option to avoid many of the limitations of direct gain passive solar systems. The thermal storage wall is placed about four inches behind a glass area that is about the same size as the wall (Schepp and Hastie 1985). The space between the two is sealed as tightly as possible to prevent air leakage. The sunlight passes through the glass and strikes on to the dark-coloured mass, which begins to heat. After a while, the heat penetrates through to the living space on the other side. The inner surface of the wall then releases heat to the room in much the same way as a radiator does, although at a lower temperature. The wall acts as an intermediary between the sunlight and the living space. For this reason, such a system is also called an **indirect solar gain system**.

Indirect solar gain systems are of two types. Heavy masonry painted a dark colour, called a **Trombe Wall**, is used in one. Another method is to use water in a dark-coloured container made of metal or plastic; and this is called a **Water Wall.**

Trombe Walls

Trombe walls (Figure 2.5) are usually about one foot thick and can be either one or two stories high. They are named after Felix Trombe, who, with architect Jacques Michel, helped to popularise the design in France in the 1960s (Schepp and Hastie 1985). These systems can be made by different types of dark-coloured stones or bricks. Brick walls are reasonably efficient even if not painted black, whereas cement blocks need to be painted black. The inside surface of the wall can have a finished surface applied to it without it losing too much of its heat-transferring property.

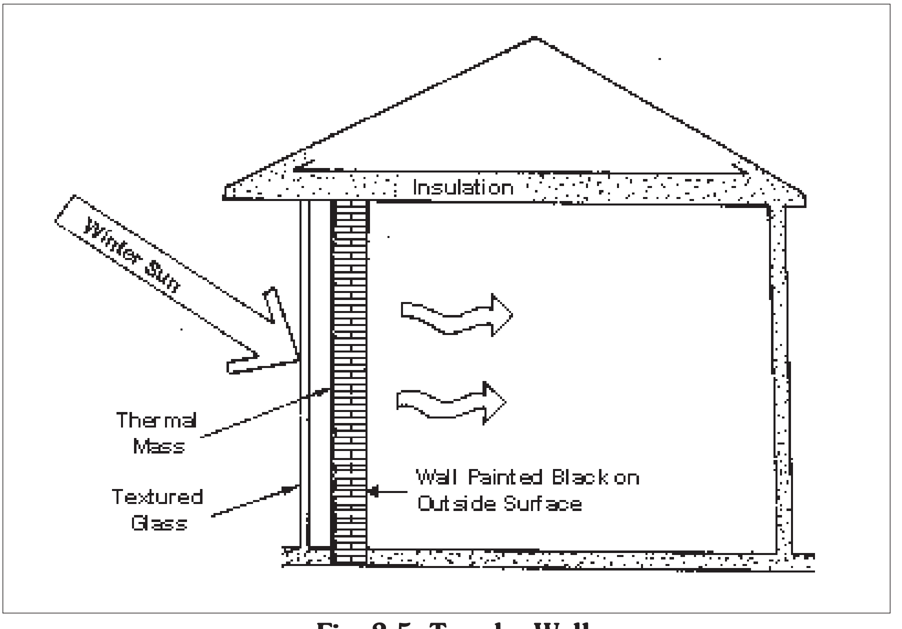


Fig. 2.5: Trombe Wall

Vented Trombe Walls are appropriate if the living space needs to be heated in the early afternoons. The vents are small, rectangular holes in the wall (about 1-3 m^2 for every 100 m^2 of wall area). The holes are spaced along the bottom and top of the wall with about 2.5 m separating the upper ones from the lower ones (Schepp and Hastie 1985). How the Vented Trombe Wall works is shown in Figure 2.6. When the outside surface of the wall is exposed to the sunlight, it heats it. The air in the space between the wall and the glass also heats up and begins to rise. As hot air reaches the top, it is naturally forced through the vent opening at the top of the wall and into the room. The space left by the rising air creates a suction effect at the bottom of the wall, and this draws in the cooler air in the room through the bottom vent openings. A thermosiphoning loop is thus created. Flexible dampers are used to prevent a reverse

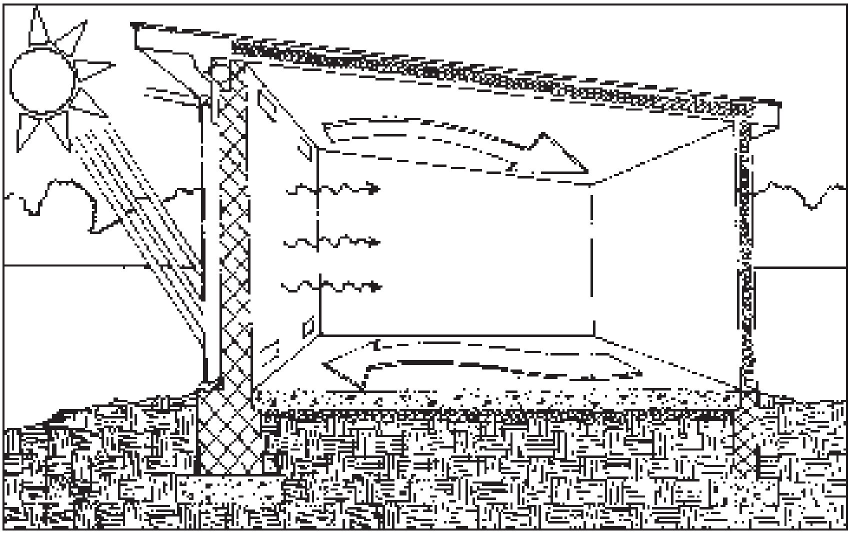


Figure 2.6: Vented Trombe Wall

thermosiphon loop at night. The damper only permits air to travel in one direction. In order to use solar heating in the early morning, one can place a window in the wall. Sunlight can penetrate into the space, and a view is also provided. The wall also looks more conventional from the outside. The system is preferred in colder regions (less than 0° for more than a month) because in milder climates (<0° temperature occurs once or twice in a year) overheating may result.

Since sunlight strikes the wall and not the room itself, fading of furniture and fabrics is not a problem and hence there are fewer limitations on the interior design of the home than in the case of direct solar gain system. A major disadvantage of the 'Trombe Wall' however is the slowness of the wall's heat transfer process which causes the outside surface to become very hot compared to the rest of the wall. The temperature can reach as high as 65°C, creating a wide temperature difference from the outside and thus sucking heat outside through the glass. The temperature difference between the wall and the air of the living space might be 5-10°C, and this is enough to induce the wall to release its heat, but hardly comparable to the sucking effect on the other side. Therefore, double glazing and moveable insulation are necessary to improve the overall efficiency of this system.

Water Walls

Thermal storage walls can also be made of water. In most cases such walls are not a structural component of the building but are often portable. Metal or plastic containers house the heat-absorbing water. The containers are usually painted with dark-coloured paint, preferably black. Sometimes water is dyed black or the whole wall is made translucent or even transparent for aesthetic reasons. Water walls (Figure 2.7) perform in a different way from from Trombe masonry walls (Erat 1985). Water has a greater heat capacity, is more efficient, and, because it is a better conductor, distributes heat

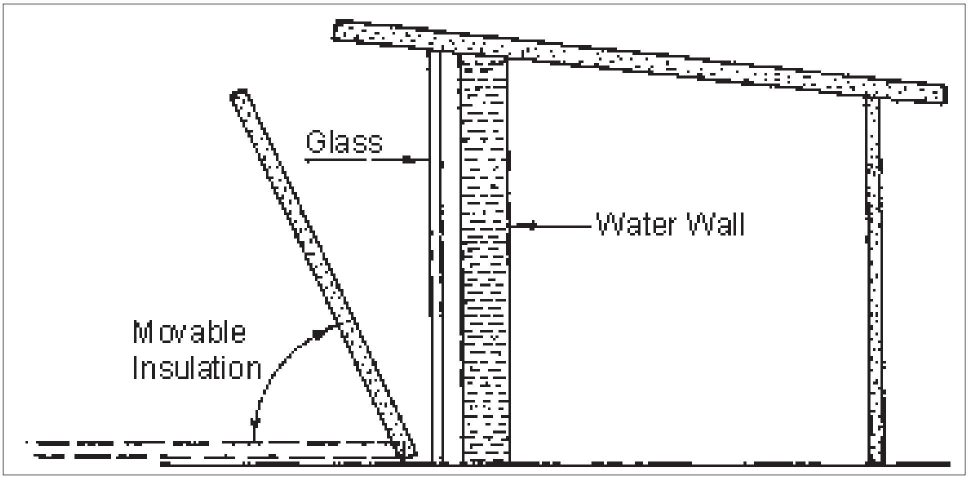


Figure 2.7: Water Wall

more quickly to the living space in the early hours of the day. It also means that the wall does not stay warm for long. Another result of the conduction properties of water is a lower temperature on the outside surface of the wall. Heat moves quickly from the outside surface of the wall to the inside, because it not only moves through the wall by conduction, but causes the water to move within its containers in the same way hot, convecting air moves within a room. This renders the outside surface of the wall cooler, consequently minimising the loss of heat through the glazing to the outside air. The 'Water Wall' is a little more efficient at transferring the sun's heat to the inside than the Trombe Wall.

Phase Change Walls

A slightly different concept of absorbing sunlight is that used to apply phase change materials. These substances change phase – usually from solid to liquid - when they are heated. Only after all of the materials have changed phase does the temperature start to rise significantly and vice versa. Most importantly, such materials store more heat than stone, brick, and water, and they are available in tubes or as floor tiles and are also lighter than the aforementioned materials. Phase Change Materials (PCMs) used in passive solar heating systems usually change phase between 25 and 40°C (Schepp and Hastie 1985). This is warm enough for the heat released to be warmer than the air in the room and cool enough so that heat loss through glass is minimal.

Tubes of phase change materials sometimes are placed together to form a sort of thermal wall (Figure 2.8). Usually the tubes absorb sunlight and radiate it to the other side like a Trombe or Water Wall. Individual tubes can be spaced far enough apart to allow air to circulate around them, providing connective heating as Vent Trombe Walls do. No thermosiphoning circulation occurs, although the air rises as it warps around each tube somewhat randomly.

The advantage the Phase Change Wall has over Trombe or Water Walls is the constant lower temperature, so less heat is lost through the glass than with the latter two

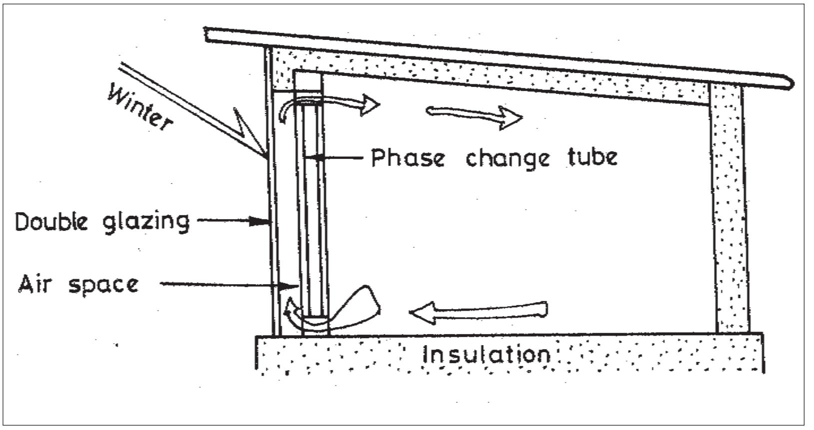


Figure 2.8: Phase Change Wall

devices. One of the disadvantages of the PCW is that, over time, it loses its ability to change phase back and forth. Because of this uncertainty, its durability and longevity is questioned. Research is currently underway to find a way to mix phase change substances with concrete or to fill the voids in cement blocks with them.

Sun Spaces

Sun spaces, solar greenhouses, solariums, and sun rooms - all are names for a room with a lot of south-facing glass that is in some way separated from the rest of the house (Figure 2.9), and it is called an isolated solar gain system. It is an isolated room that is heated and heat is transferred to the main living space. The reason sun spaces are popular is because of their versatility in terms of design. In theory, a glass roof tilted to the optimum angle (angle of latitude plus 15) can provide more energy in winter than vertical glass, although in summer shading is difficult in this type of construction.
In winter, sunlight passes through the windows and warms the darkened surface of

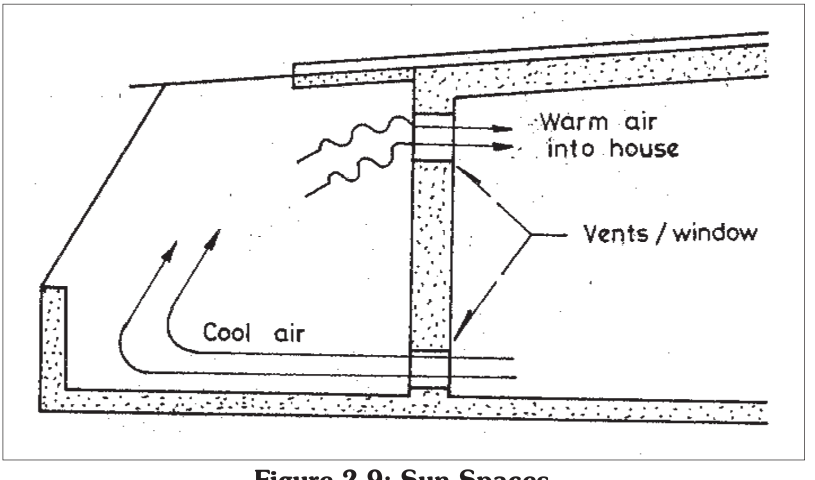


Figure 2.9: Sun Spaces

the floor, wall, and water-filled drums or other storage elements. Some of the heat is absorbed and remains until after the sun has set and the sun space temperature begins to cool. The heat not absorbed by the storage can raise the air temperature inside the sun space during a winter day to between 30-40°C. If the north wall of the sun space is part of the storage system, it heats up and transfers heat to the living space on the other side of it, in much the same way as an unvented 'Trombe wall'.

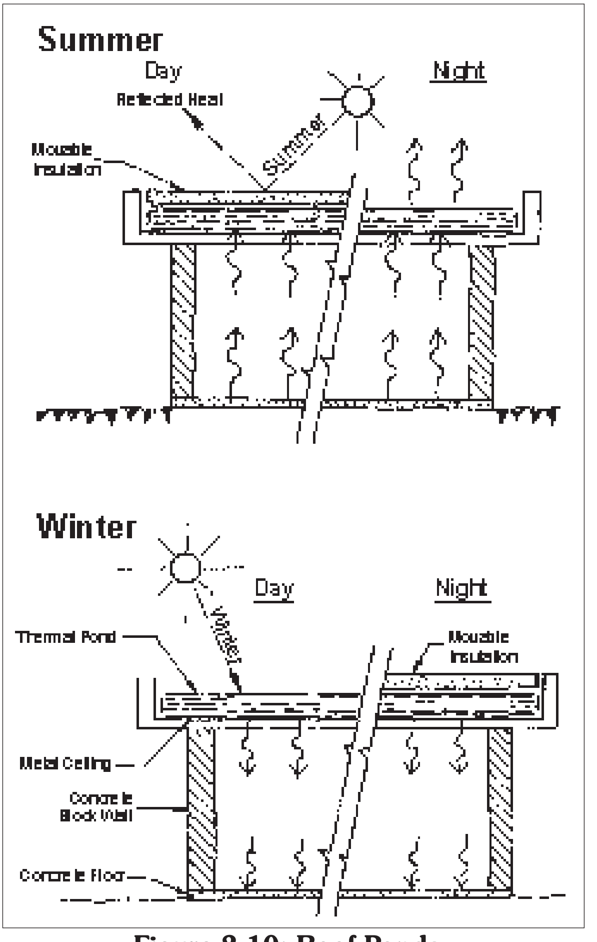


Figure 2.10: Roof Ponds

Roof Ponds

The basic concept of a roof pond is that of a horizontal water storage area (pond) placed on the flat roof of a building. The water is either kept in small bags or in one large container (Figure 2.10). During winter, in the daytime the water on the roof is exposed to the sun and becomes heated. When the sun goes down, an insulated roof covering slides over the water and the heat radiates downwards into the living space. Thus, the system is basically a horizontal, thermal storage wall. In the summer, the system works in reverse. During the day heat inside the house rises and is absorbed by the insulated roof pond. At night the roof insulation is put in place and the heat radiates to the cool night sky naturally. The system thus cools the building during both day and night. At present, the roof pond may be theoretically sound but has not become a very popular passive solar design option because occupants hesitate to put such an enormous amount of water on their rooves and also because the roof has to be metallic.

Issues in Solar Passive Building Technologies

In today's context and n the context of the generations to come, the mountain development issue is not only one of economic prosperity but also one of the sound health of the environment in which we live. Given the increasing constraints in supplies of natural resources and growing environmental concerns in the mountains, issues related to improving energy efficiency and the use of environmentally sound materials and techniques for the construction of buildings are a prerequisite to the creation of better living conditions.

Technological Choice, Accessibility and Cost

The technologies employed to create heat primarily depends on the climatic conditions as well as on easy access to particular types of energy. For example, in moderate climates in the rural areas of the HKH region, energy for cooking and heating the house is being provided by rudimentary fuelwood-burning stoves, whereas in the extremely cold climatic zone supplemental heating devices burning biomass fuels are common. With increased access to materials(primarily plastic because of low transportation and handling costs) in isolated mountain areas, and by creating awareness about orientation, for example, placing the fuelwood stove in the wall between the kitchen and living room, and so on, the interior spaces can be made comfortable with less fuelwood and other forms of biomass.

It is not that the mountain people are not aware of the health hazards of smoke pollution, but lack of options (whether due to high costs or lack of scientific knowledge or lack of an integrated programme to cater to their felt needs) means that they are making do with things as they come on a day - to - day basis. Economy is another restricting factor affecting the perception of comfort limits and, in addition, the ability or readiness to invest in the building structure. Here it is important to view the building in a life-cycle perspective. Pay-back periods are different for different components - the building envelope itself being the most durable.

Housing as an Energy Saving Option

Currently, a traditional cooking stove serves multiple functions by meeting the cooking, heating, and drying needs of the household. The introduction of the concept of passive solar building technologies to meet the need for heating will not only help to reduce the amount of biomass fuels used for heating but also the amount of biomass fuels used for cooking, as there will be a decrease in the temperature difference between heat source and heat sink through minimising the heat loss to the surroundings. Reduction in the quantity of fuelwood required for the domestic sector would lessen the time required for fuelwood collection, thereby alleviating the work-loads of women and children. In addition, if less heat is required then improved cooking stoves could also be used.

Housing as a Health Improvement Option

With a proliferation of passive solar building technologies, there would be less need to use an open fire, and this in turn would decrease the exposure to unburned carbon particles within the building envelope. The need for proper ventilation and air movement to facilitate the functioning of the passive system would help to create better living conditions with a subsequent improvement in indoor air quality. All these factors would reduce health hazards significantly, particularly those to which women and children are most exposed. In the long term, this would also help to reduce the rate of deforestation in the mountains as well as the volume of emission of greenhouse gases into the atmosphere.

Legislative Framework, Building Norms and Codes

The modern construction sector appears to be concerned with the active climatisation of buildings without any serious concern about the increasing pattern of energy consumption and its impact on the surrounding environment. It is only concerned with saving construction costs without considering the social costs. Under such circumstances, the intervention of the government becomes necessary for formulating building codes through a legislative framework and for monitoring the same.

The introduction of norms, regulations, and bye-laws will apply only to construction within what is called the formal sector of the economy. Many of the houses in mountain areas are, however, built outside this legal framework. Therefore, other means must be sought to complement the legal instrument and influence informal construction activities. In this respect, financial incentives, combined with educational programmes for consumers and builders, would be one way of encouraging energy-efficient building construction.

Further constraints to energy-saving architectural design are lack of norms, information, documentation, and skills and the fact that market values exceed the value of energy and comfort. In this respect, low-cost housing manuals and training would be appropriate. Academic institutions and technical vocational training institutions could play a catalytic role.

Concluding Remarks

The present task is to improve knowledge about the prevailing conditions of indoor climates, thermal performance, and energy consumption in today's buildings and to suggest improvements in the form of up-to-date building norms and design parameters suitable for different climatic zones in the HKH region. In addition, different designs are needed for different types of buildings, climates, and economic levels. It is also necessary to develop handbooks encouraging the use of local environmentally-benign building designs and materials that can improve the indoor environment in the mountains.

Further, an intellectual discourse among the policy planners, practising engineers and builders, and researchers from the region is needed to carry out an inventory of climatic zones and to determine the suitability of building types and materials in addition to developing methods, tools, and regulations for energy saving within the passive solar building sector.

The building industry, universities, and research bodies should be involved in the development of energy-efficient building designs. Materials and construction techniques - within both the formal and informal sectors of the economy-should give due consideration to the traditional practices and knowledge base. At the same time, the knowledge and methods evolved should be fed into the education systems and adequate information should be made available to the market and to entrepreneurs.

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