ICIMOD

Profiting from Sunshine

Passive Solar Building in the Mountains

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International Centre for Integrated Mountain Development
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Profiting from Sunshine - Passive Solar Building in the Mountains

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Collection of Papers on National Workshops in China, India, Nepal and Pakistan

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Foreword

High altitude areas of the Hindu Kush-Himalayans are characterised by low ambient temperatures for most parts of the year. The inhabitants in this region rely on wood, agricultural residue, and animal waste to keep their houses warm, in particular during the winter season. The use of biomass has resulted in deforestation and ecological imbalances. Additionally the use of biomass for space heating without proper heating stoves severely affects the health of the occupants, especially women and children. There is therefore an urgent need to develop alternative options for space heating in the mountain areas of China, India, Nepal, and Pakistan.

ICIMOD, as an international institution committed to the development of mountain regions, recognised the need for appropriate design of buildings to help either to eliminate the use of fuels for space heating or reduce energy consumption. In order to have an overview of the available knowhow, technologies, and house building practices, ICIMOD supported the organization of national workshops on Passive Solar Building Technologies (PSBTs) in China, India, Nepal, and Pakistan. Prior to these workshops very little had been published on PSBT in the HKH, and ICIMOD was requested to present the papers of all these workshops in a comprehensive and concise manner useful to the professionals engaged in promoting PSBTs. The present volume is an outcome of this effort. This document is the first of its kind to provide an overview on (i) Fundamentals of Solar Energy and Solar Radiation, (ii) State of the Art in Solar Passive Technologies, (iii) Solar Passive Building Design in the Mountains, (iv) Building Materials for Hilly and Mountain Areas, (v) Application and Design of Passive Solar Systems for Buildings, and (vi) Issues and Future Directions required for the promotion of PSBTs in the context of mountain areas of the HKH Region. I am confident that this document in its present form will be useful to those who are involved in the application and dissemination of passive solar building technologies. It also provides a good introduction to the subject for those energy specialists who are looking for new options for space heating in the HKH.

I would like to extend my sincere appreciation to the programme coordinators from China, Mr. Wang Gehua, Director, Centre for Energy, Environmental Protection and Technology Development, Ministry of Agriculture, Beijing; to Dr. S.S. Chandel, Principal Scientific Officer, State Council for Science, Technology, and Environment, Shimla, India; to the Centre for Applied Research and Development and Department of Architecture, Institute of Engineering, Kathmandu; and to Aga Khan Housing Board for Pakistan, Karachi, for organizing the national workshops on Passive Solar Building Technologies in their respective countries and establishing a network of institutions on the subject in the HKH Region.

I would like to thank Professor N.K. Bansal, Centre for Energy Studies, Indian Institute of Technology, New Delhi, for consenting to review the papers presented in the national workshops and to be one of the editors of this document.

Finally, I would like to thank Dr. Kamal Rijal, Renewable Energy Specialist, ICIMOD, who, as the Coordinator of the Programme, has been responsible for bringing out this document in its present form.

Mr. Egbert Pelinck
Director General

February 2000

Editorial Preface

Although passive solar technology has been used by builders for three millennia and more (if one considers the techniques used in ancient Egypt and Mesopotamia), its applications in mountain regions are not as well documented as applications in other areas. For this reason we have not followed as strictly as is the norm the custom of listing only references cited. Whenever our authors have been able to give full particulars of a publication that can be used for buildings in mountain areas, it has been listed.

Readers will understand that passive solar technology in mountain areas has two dimensions;viz., the new applications that are being promoted on the market and the hidden part of the 'iceberg' as far as passive solar technology is concerned—the measures used traditionally to capture sunlight and profit from it. It is hoped that this document will enthuse researchers and builders to pursue this topic and search for all the applications possible that will make living and working in the mountains more comfortable in future than it has been in the past.

Abstract

In the Hindu Kush-Himalyan (HKH) Region it is difficult to keep houses warm during winter. Usually biomass fuels are burned for cooking and space heating. Using biomass fuels has resulted in large-scale deforestation and ill effects on the health of mountain people, especially women and children, from the smoke produced. Solar radiation is available in most parts, and it is sensible to take solar energy consciously into consideration in designing buildings in order to reduce the use of biomass fuels for space heating.

The International Centre for Integrated Mountain Development (ICIMOD) is committed to improving the living standards of people living in the HKH Region. In the light of this objective, the Centre organized workshops on Passive Solar Building Technologies in China, India, Nepal, and Pakistan to establish a network of institutions involved in promoting Passive Solar Building Technology (PSBT) in mountain areas. The state-of-the art reviews clearly indicated that concrete efforts had been made in China and India to promote a solar passive heating programme, whereas there have been individual efforts in Nepal and Pakistan to build passive solar homes. The compilation of these papers in a comprehensive and concise manner should help to share knowledge about new developments in the respective countries as a means of promoting PSBTs in mountain areas.

This book, the first of its kind, provides an overview of the (i) National Workshops; (ii) Potentials for Application of PSBTs in Mountain Areas; (iii) Fundamentals of Solar Energy and Solar Radiation; (iv) State of the Art in Solar Passive Technologies; (v) Solar Passive Building Designs in the Mountains; (vi) Building Materials for Hilly and Mountain Areas; (vii) Application and Design of Passive Solar Systems for Buildings; and (viii) Issues and Future Directions required for the promotion of PSBTs in mountain areas of the Hindu Kush-Himalayan Region.

Overall, concrete solutions are needed to introduce solar passive building concepts in the HKH Region. Understanding climate, traditional architecture, construction materials, and construction techniques is important for optimum passive building designs, and this book attempts to provide some insights.

The following activities are recommended: (i) analysis and classification of climatic conditions in the HKH Region; (ii) study of vernacular architecture and identification of passive building elements; (iii) study of urban architecture; (iv) selection of an appropriate thermal simulation programme; (v) creation of a database and thermophysical properties of building materials and traditional building components; (vi) quantification of individual design patterns, for example, direct gain, indirect gain, thermal storage, solarium, cavity insulation, building form, roof shape, and underground structure; and (vii) preparation of manuals on design guidelines, design context, and construction issues. The information and knowledge thus prepared should then be disseminated to architects, users, and the construction industry, in both the formal and informal sectors. Design guidelines have not been provided for rural mountain areas anywhere in the world. Any initiative in this respect would help improve the health, efficiency, and lifestyles of rural people residing in mountain areas.

Acknowledgements

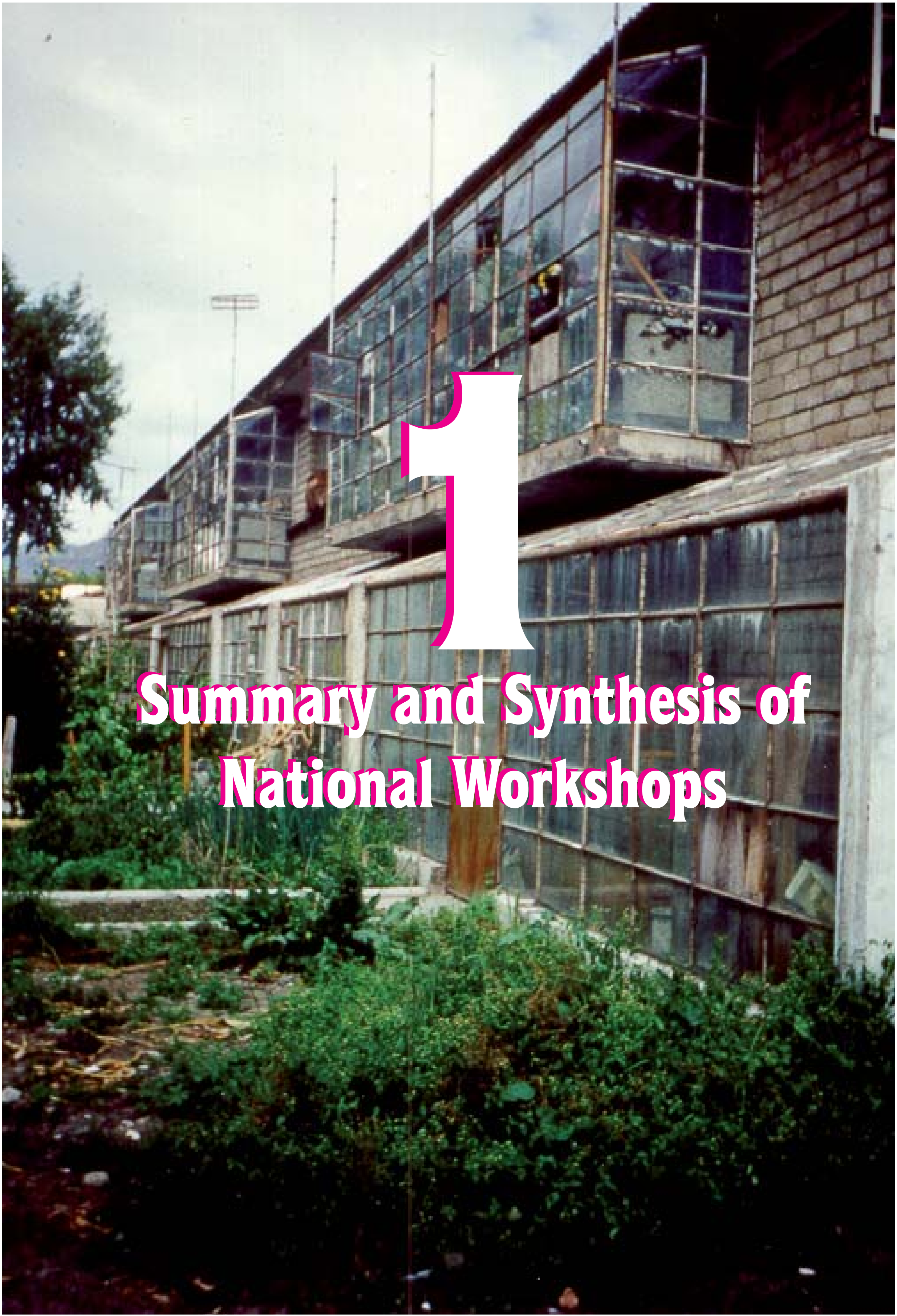
The International Centre for Integrated Mountain Development (ICIMOD) recognised the need to review the status of passive solar building technologies (PSBT) in the HKH region and has made a conscious effort to disseminate knowledge of passive building science to these regions. The editors are grateful to the ICIMOD authorities for this initiative and for giving them the responsibility of editing the proceedings of four workshops. One of the editors (N.K. Bansal) is personally grateful to Dr Kamal Rijal, the joint editor, for asking him to co-edit the work. Editing was not simple and the help of Dr. M. S. Bhandari of IIT Delhi is acknowledged for his help in collating the written texts.

Acronyms

Ah	Ampere hour
ASHRAE	Association of Heating, Refrigeration and Air-Conditioning Engineers
BTU	British Thermal Unit
CBRI	Central Building Research Institute
COP	Coefficient of Performance
CPWD	Central Public Works Department
CSIR	Council of Scientific and Industrial Research
DD	Degree Day
DDC	Direct Digital Control
EJ	Eta Joule
EMSs	Energy Management Systems
FET	Fluorinate Ethylene Teraphithlate
FLC	Fuzzy Logic Controller
GI	Galvanised Iron
HKH	Hindu Kush-Himalayas
HP	Himachal Pradesh
HVAC	Heating, Ventillation and Air-Conditioning
ICIMOD	International Centre for Integrated Mountain Development
ICS	Improved Cooking Stove
IFA	International Energy Agency
IIT	Indian Institute of Technology
IR	Infrared
ITBP	Indian Tibet Border Post
J	Joule
KJ	Kilo Joule
°k	degree kelvin
kWh	kilowatt hour
masl	metres above sea level
MIT	Massachussets' Institute of Technology
MJ	Million Joule
mm	milimetre

NBRI	National Building Research Institute
NGO	Non-Governmental Organization
NIST	National Institute of Silicon Technology
PCM	Polycrystalline membrane
PMA	Polymethylacrylate
PSBT(s)	Passive Solar Building Technology
Pv	Photovoltaic
R&D	Research and Development
RBC	Reinforced Brick Concrete
RC	Reinforced Concrete
RCC	Reinforced Cement Concrete
SHS	Solar Home System
SIER	Shanghai Institute of Energy Research
TAP	Thermosiphonic Air Panel
tce	tonnnes of coal equivalent
TI	Transparent Insulation
TIM(s)	Transparent Insulation Material(s)
UNDP	United Nations Development Programme
UP	Uttar Pradesh
UV	Ultra-violet
U-Value	thermal insulation
V	Volt

Contents



1 Summary and Synthesis of National Workshops

1 Summary and Synthesis of National Workshops

N.K. Bansal

Introduction

The International Centre for Integrated Mountain Development (ICIMOD) is committed to improving the living standards of mountain people, especially of those living in rural areas of the Hindu Kush-Himalayas (HKH). In light of this objective, the Centre took the initiative of organizing four national workshops on Passive Solar Building Technologies in China, India, Nepal, and Pakistan. In these countries, solar passive programmes have been in progress for some time, and most of the HKH region lies in their mountain areas. The basic objectives of these workshops were to review the status of passive solar technologies, identify gaps in technology that need further development, and create a network of experts and policy-makers in this field to use appropriate technologies. The proceedings of each workshop contained a great deal of information which forms the basis of this book.

Synthesis

The general problem in the HKH region is heating buildings during winter. This is usually done by using fuelwood or dung for the dual purpose of cooking and space heating. Using fuelwood has resulted in large-scale deforestation and the ill effects of smoke on the health of mountain people, especially women and children. These problems are common to almost all areas of the HKH.

Solar radiation is available in most parts, and it is sensible to use solar energy consciously in designing buildings in order to reduce the use of fuelwood and dung for space heating purposes. Concrete efforts have been made in China and India to promote a solar passive heating programme, whereas there have been individual efforts in Nepal and Pakistan to build passive solar homes.

The Chinese Programme

Information about the availability of solar radiation in various provinces of China is very good. According to the solar map of China, solar energy of about 1,160-1,140 kwh/m^2 per annum is available in most of the North-East, with 2,600 hours of annual sunshine. The normal practice is for people to take advantage of solar energy by installing windows in the south. As a result of research efforts, information has been provided about the advantage of orienting buildings towards the south and installing collector-cum-storage walls with material and surface characteristics, thermosyphoning effects, and heat concentrating devices.

The Chinese government has formulated national standard "Technology Requirements for Passive Solar Houses and Methods for Heat Performance Tests". The standard specifies the division of districts, technological conditions, methods for heat performance tests, methods of economic analysis, and rules for examining solar houses. The standard was accepted in 1994 and implemented in 1998.

Under programmes supported by the UNDP and the Federal Republic of Germany, two projects; namely, (i) Experimental Demonstration Centre for Solar Heating and Cooling and (ii) Renewable Energy Village in Daxin (Beijing) were carried out. About 231 solar passive houses were built, covering a floor space of 80,000 square metres, were simulated, and measured. These buildings clearly demonstrated that solar passive building technologies can save 60 to 70 per cent of conventional energy. Some form of conventional energy is, however, absolutely necessary for thermal comfort. The additional investments to incorporate pasive solar building technologies (PSBTs), which amount to about 12-20 per cent of the cost, are payable over a five- to eight-year time period. The 7th and 8th five-year plan periods represented a stage of comprehensive research and demonstration, as well as sizeable introduction and application of solar buildings. The buildings were constructed with different heat collection modes, namely, direct heating, heat collection, and storage walls and an attached greenhouse.

The Indian Programme

The solar passive programme in India is nearly two decades old. It commenced with the construction of three solar passive houses in locations in Delhi, Jodhpur, and Srinagar, representative of three different climatic conditions in the country. The performance of these houses was evaluated to gain experience and to help in designing the future programme. A comprehensive review of climatic conditions, definition of climatic zones, and study of vernacular architecture was undertaken to identify the various methods used in traditional architecture to keep houses warm in winter and cool in summer. A handbook of basic guidelines was prepared and simultaneously awareness and training programmes were organized all over the country. Himachal Pradesh took the lead in formulating a Solar House Action Plan. Under this programme, many buildings have been constructed with a conscious effort to use solar passive concepts and optimise them. The Solar House Action Plan of Himachal Pradesh aims to develop simple design guidelines for solar passive building and to monitor solar passive building in Himachal Pradesh.

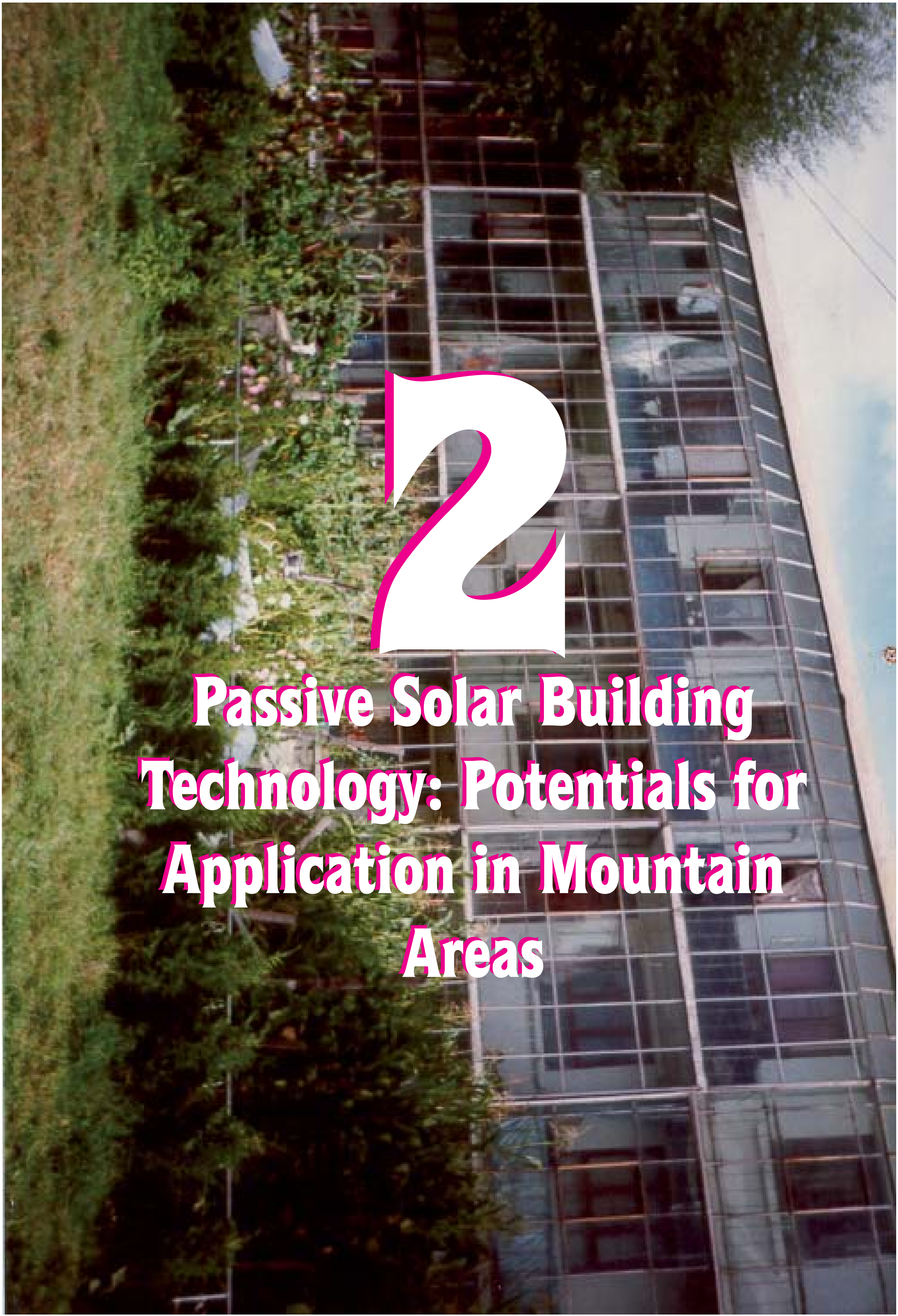
Unlike in China, however, no standards have been drafted and therefore the implementation of the programme is not definitive. A directed approach would help to apply the existing knowledge in an effective manner.

The Nepalese Programme

In Nepal, buildings are normally designed to use solar energy to keep the interiors warm. In Solukhumbu and Manang, houses have been oriented to the south-east, keeping the large glazed windows towards the south with few or no openings on the north and west. Sometimes, the interior walls have wooden boards fixed to them to act as insulation. In Nepal, however, passive solar building development and implementation are in the initial stages and a comprehensive programme is needed to provide the knowhow required. Nepal needs support to adopt and formulate an appropriate passive solar building technology suitable to the physical, socioeconomic, and cultural context of the country.

The Pakistan Programme

In Pakistan, there is an appreciable awareness about the use of solar energy for buildings and for day to day use. Climatic analysis of the mountain areas of Pakistan has been undertaken. This analysis tells us that Gilgit and other areas in the Hindu Kush-Himalayan region have mean dry-bulb temperatures varying between -2.7°C in January and 36.1°C in July; such climates have substantial heating requirements. Various techniques used for solar passive heating have been reviewed: direct gain, indirect gain, isolated, and hybrid systems. It is, nevertheless, clear that the use of such systems is rather rare because of the lack of a directed programme. In a few institutions, educational programmes covering passive solar building technology are being introduced. A couple of architects have used the principles of passive heating and cooling. Academically, researchers have been working on thermal simulation models such as '**CHEETAH**' and '**ARCHIPAK**', underground structural models, computer simulation of transparent insulation covered buildings, and so on. Nevertheless, the impetus to use these technologies was lacking from the workshop proceedings. One architect/planner designed and constructed a passive solar house with a roof garden and an earth air tunnel to keep the building comfortable throughout the year.



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.

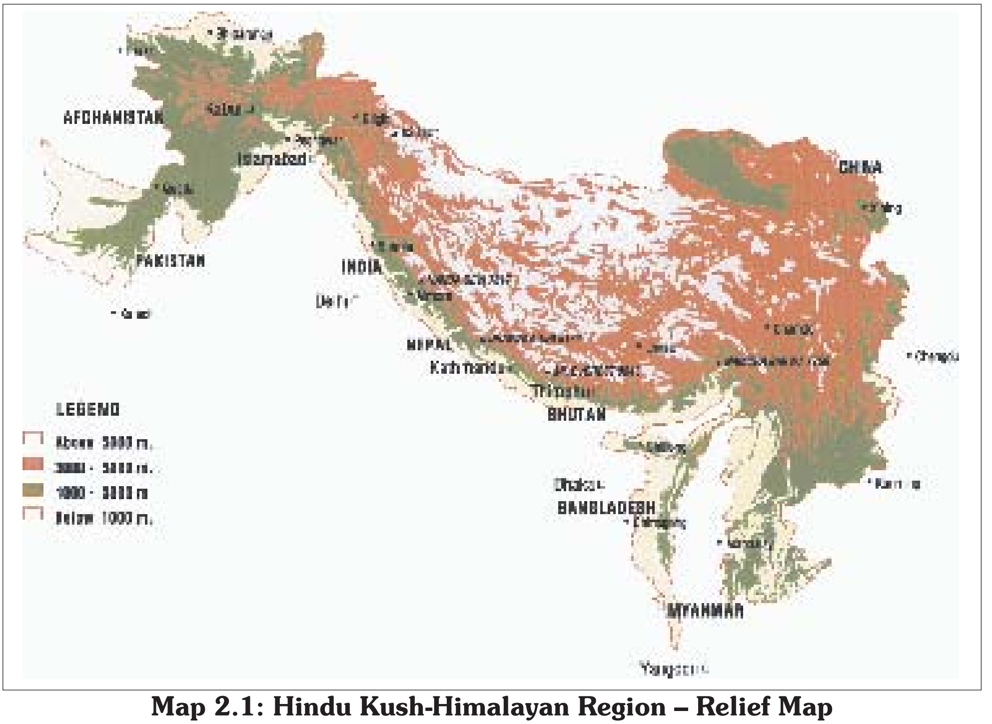
Availability of Solar energy in the HKH Region

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 x 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.

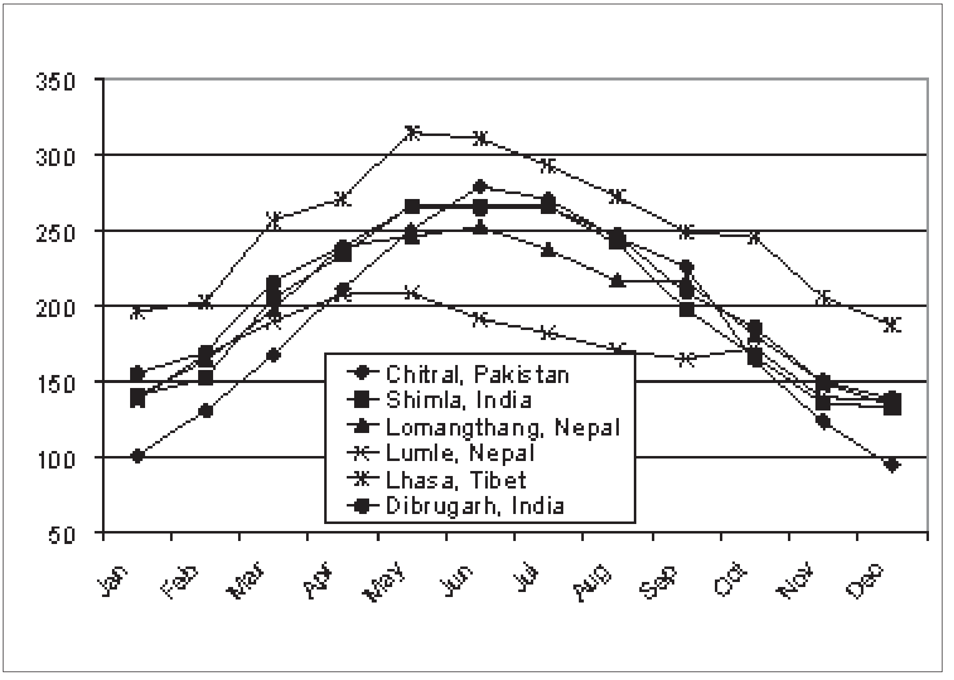
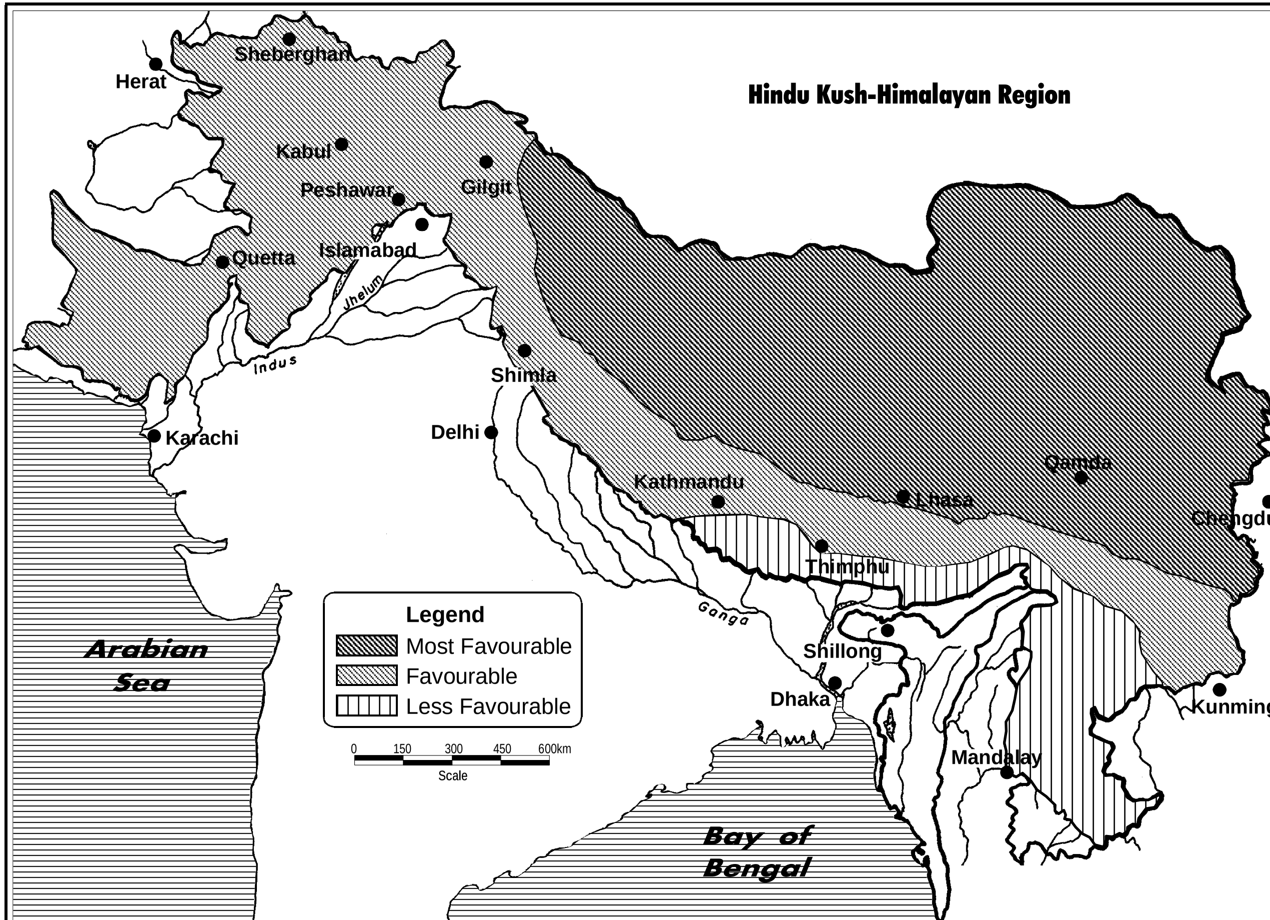


Figure 2.1: Monthly Average of Daily Global Solar Radiation in Selected Areas of the HKH

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

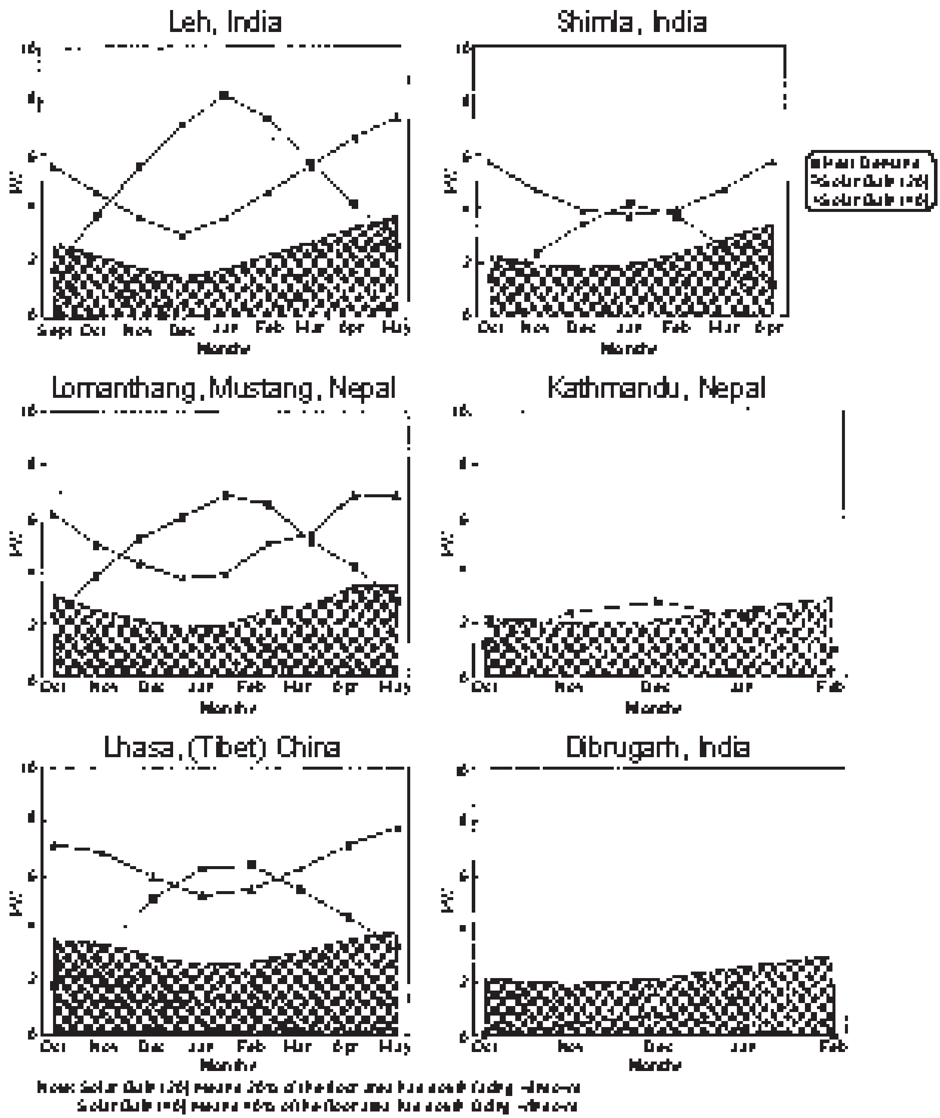


Figure 2.2: Heating Energy Demand and Solar Gain in Selected Places of the HKH

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

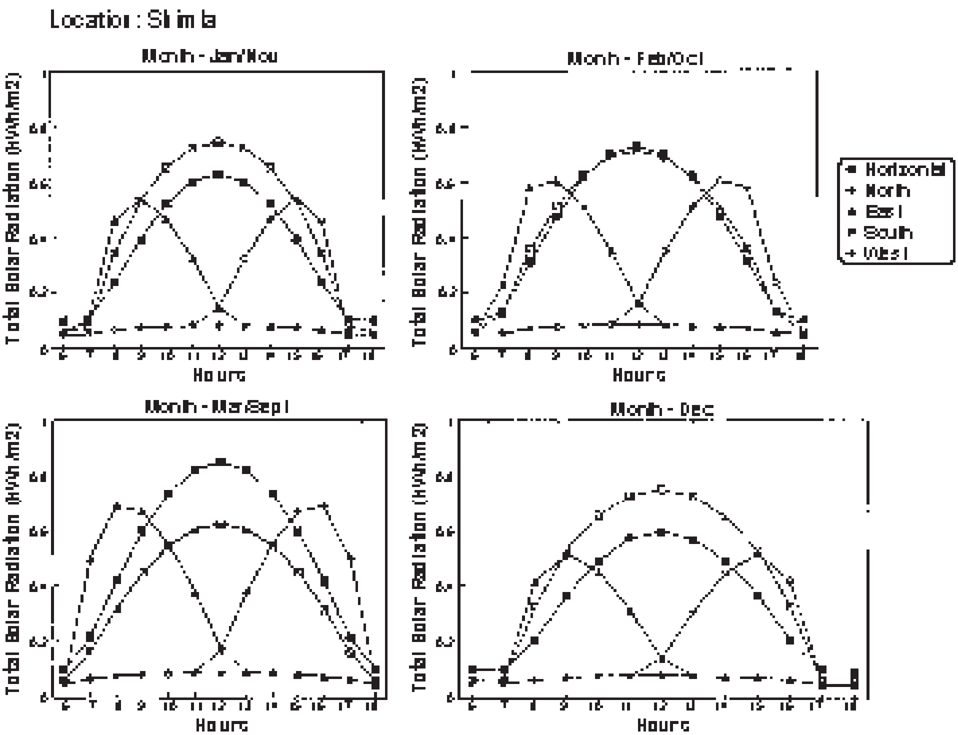


Figure 2.3: Total Solar Radiation of Surfaces of Different Orientation

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, low-density 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.

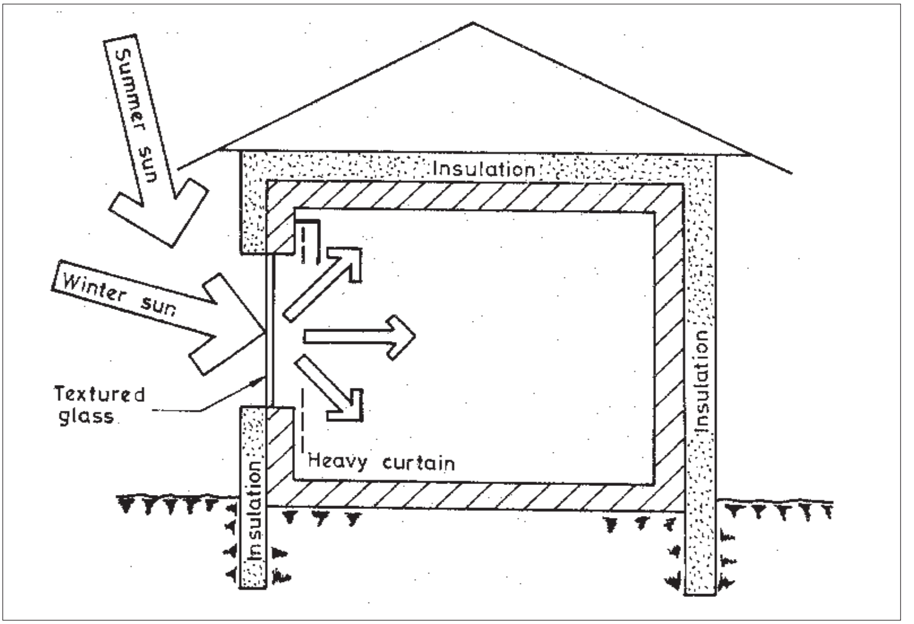


Figure 2.4: Direct Solar Gain

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.

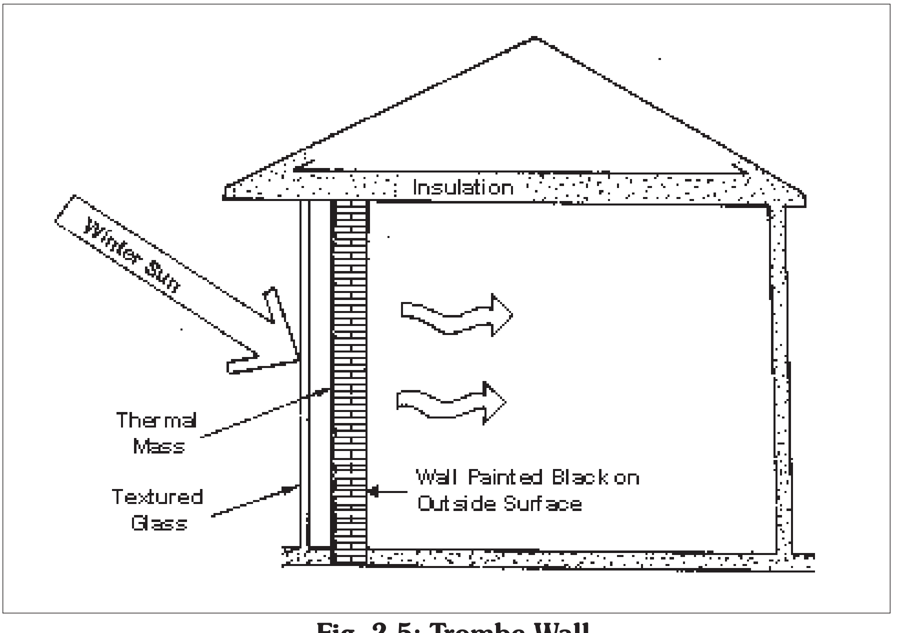


Fig. 2.5: Trombe Wall

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

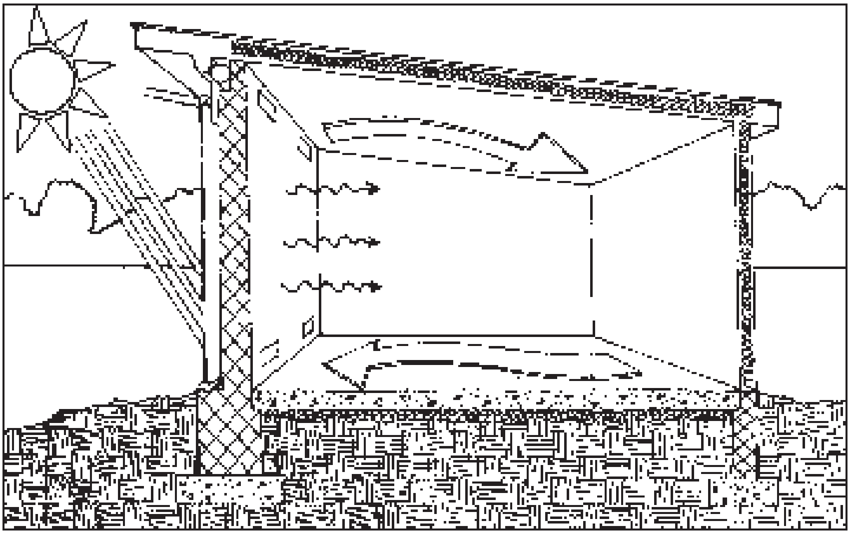


Figure 2.6: Vented Trombe Wall

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

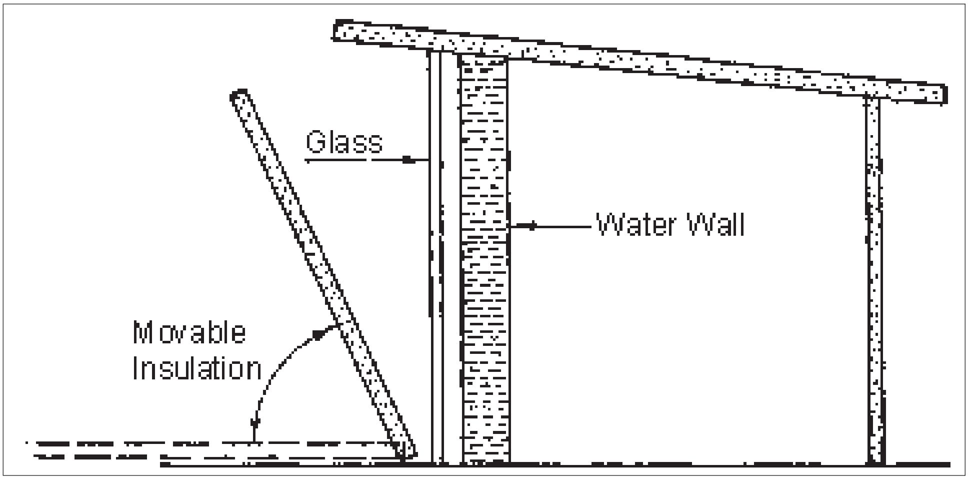


Figure 2.7: Water Wall

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

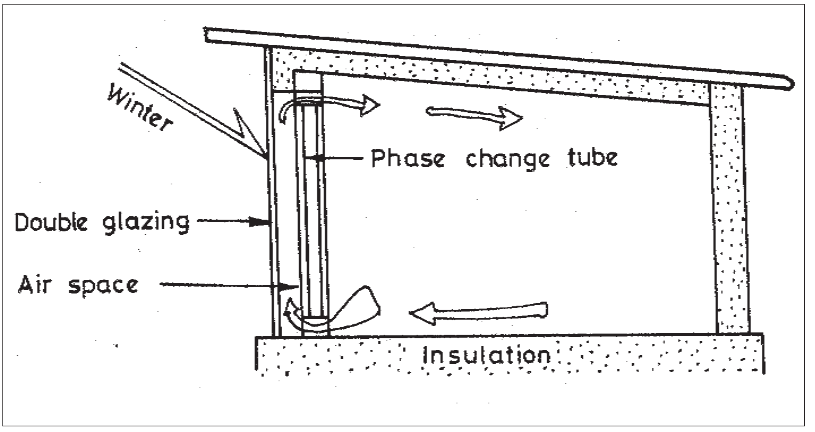


Figure 2.8: Phase Change Wall

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

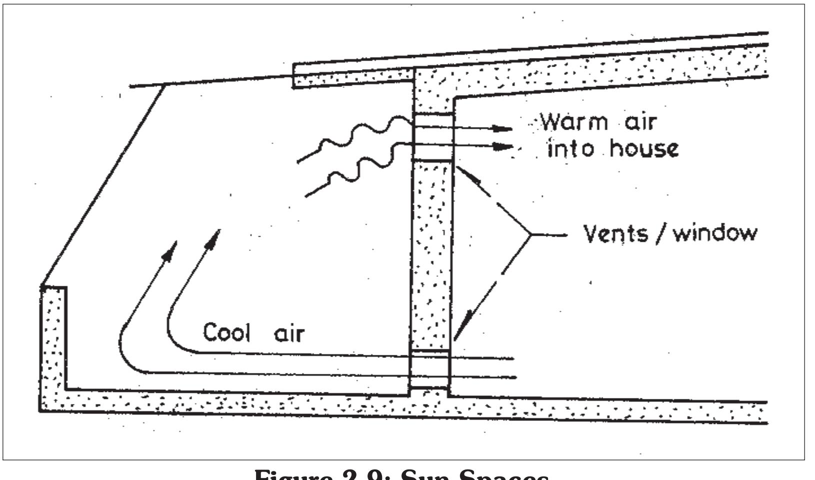


Figure 2.9: Sun Spaces

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'.

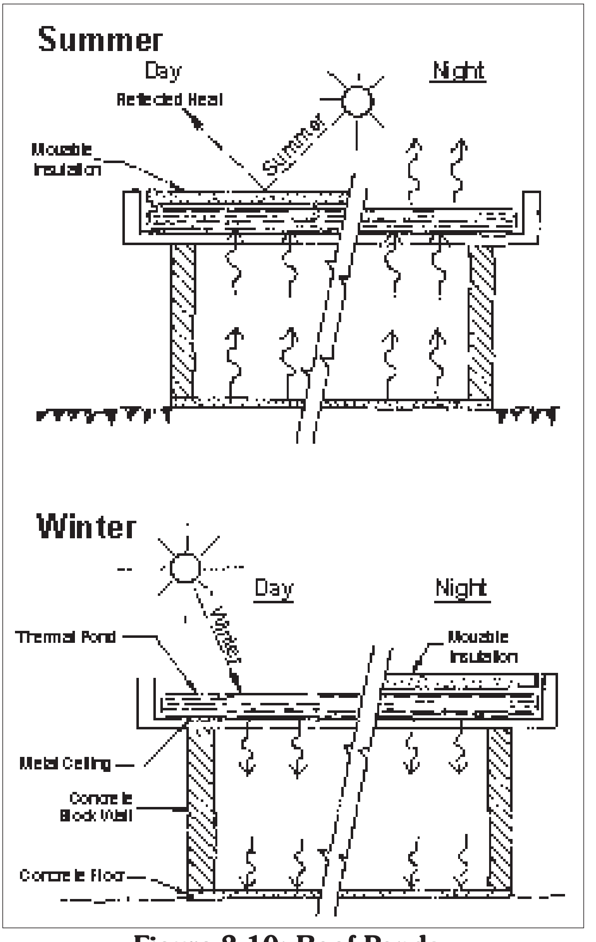


Figure 2.10: Roof Ponds

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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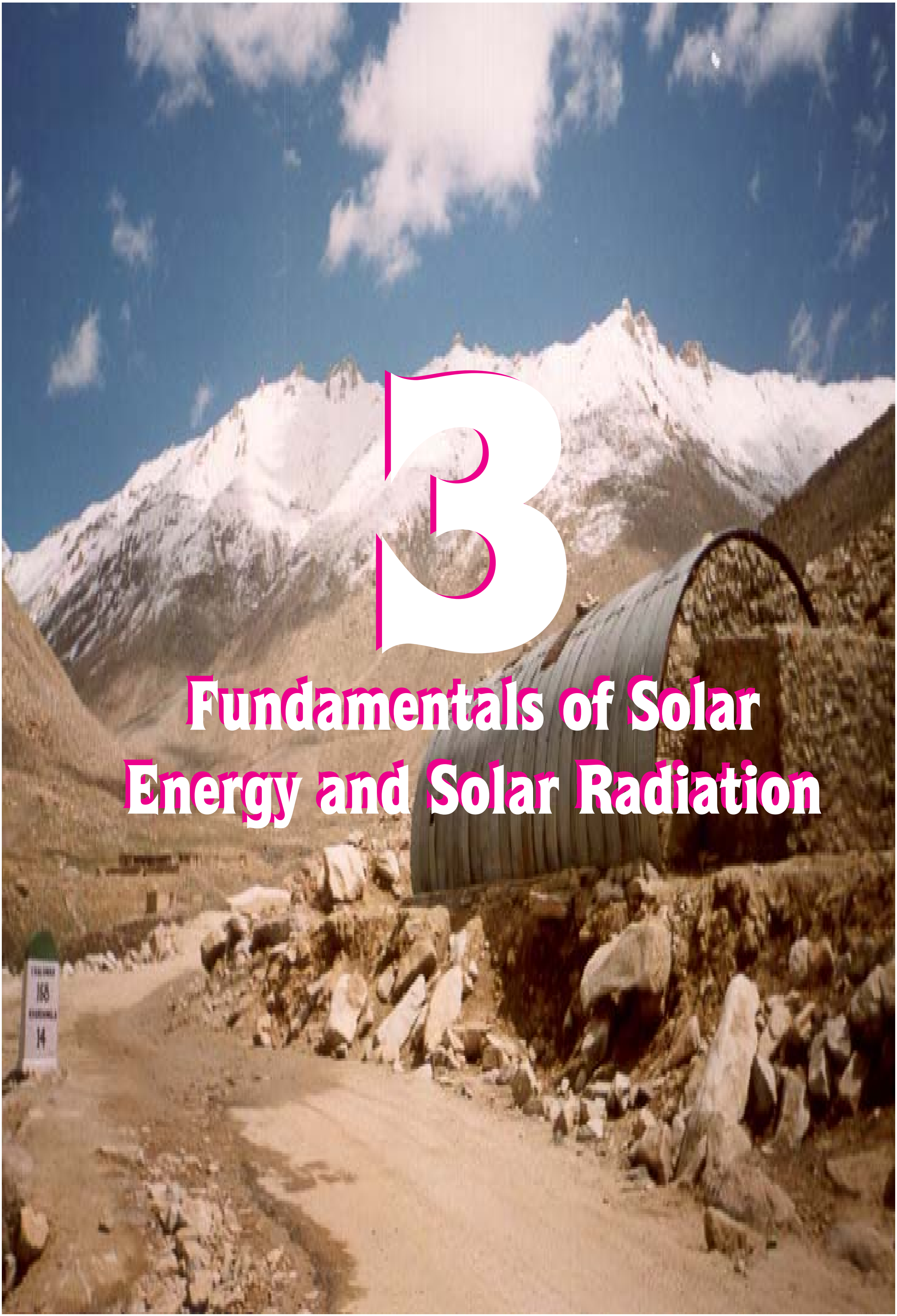

3

Fundamentals of Solar Energy and Solar Radiation

3.1

Fundamentals of Solar Energy

Ahmand Aga

Introduction

Earth receives radiant energy from the sun at the rate of 5.6 x 10^6 EJ/a (1 EJ = 10^{18} J). which is more than ten times the energy that is theoretically available from fossil fuels. The total energy available from fossil fuels that can be harnessed economically is only 0.5 per cent of the sun's energy (1.9 X 10^{14} tce). The world's currently available primary energy sources amount to about 9 x 10^9 tce, which is just 0.005 per cent of the annual solar radiation.

Solar radiation Quality

The emission spectrum of black body radiators is determined by their temperature. The spectrum of solar radiation outside the earth's atmosphere varies in relation to the emission of a black body at 6000° K; it is an almost continuous spectrum from about 200nm (nano-meter=10^{-9}m) of ultra-violet to 300nm of infra-red, with a strong peak around 500nm. Atmospheric absorption is to some extent selective, changing not only the quantity but also the spectral composition of the radiation received.

The shorter wave lengths represent a higher grade energy and all of the solar radiation can be considered for conversion to heat. But only the short wave, high energy component will be able to produce a photoelectric effect.

Quantity of Solar radiation

The intensity of radiation reaching the upper limits of our atmosphere, its mean value, 1395 W/m^2, is taken as the 'Solar Constant', and there is a variation of plus or minus

3.5 per cent due to the variation in the distance between the earth and the sun (152 x 10^4 km at the aphelion and 147 x 10^4 km at the perihelion).

Atmospheric absorption reduces this intensity to some extent, partly depending on the air mass through the atmosphere and partly on the state of the atmosphere (cloudiness. suspended particles). When the sun is at a low altitude angle, the intensity decreases. With a zenith position the intensity measured on a horizontal plane may approach one kW/m^2 (at sea level).

The annual total amount of radiation received at a given location depends on its geographical latitude and on local climatic factors. Solar radiation maps of the earth (as shown in Figure 3.1) give a rough indication of what can be expected at various locations.

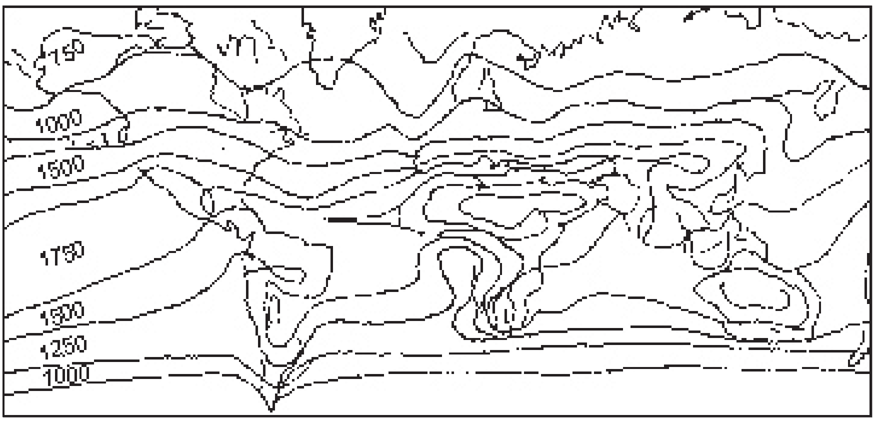

Figure 3.1: Solar Radiation Map of the Earth

Incident Radiation

If the radiation intensity on a tilted plane is to be calculated, the total radiation as measured on a horizontal plane must be divided into direct and diffuse components. The direct component will then be handled vectorially. The diffuse radiation incident on the tilted plane will be proportionate to the fraction of the sky's hemisphere to which the plane is exposed.

The relationship between the sun and any building can be examined from two points of view.

1. Exclusion of solar radiation as it would cause overheating. An extra load on air conditioning. glare problems, or deterioration of materials.
2. Ensuring adequate sunlight to obtain heat when it is in short supply or purely for its psychological effect.

There is no doubt that, in tropical climates, the first point will dominate, whereas in cold winter regions the latter will prevail. It has been shown, however, that, even in moderate climates, severe overheating can occur. All glass walls have been proved to be thermally inferior to solid walls with small windows, as glass walls result in large heat gains in summer. The use of extensive glazing on south-facing walls has been advocated. Such buildings are described as solar housing. The apparent contradiction can be resolved in terms of time. Both statements may be true at different times of the year. For example, for a particular solar house, 33 per cent of the heat required is gained through the windows, 49 per cent by the collector system, and 18 per cent by an auxiliary heat source. Another type of building can be designed to be heated exclusively by solar heat gain through the windows. Solar heat gain through the windows is common even in winter, and its magnitude can be verified by means of the following simple calculation.

If indoor temperature, $t_i = 20°C$
Outdoor temperature, $t_o = 0°C$
Thermal transmittance is taken as, $U = 5\ W/m^{2}°C$
Radiation Intensity I, $= 400\ W.m^2$
Solar gain factor, $g = 0.8$
For 1 m^2, we have Q loss $= 5 \times 20 = 10\ W/m^2$, Q gain $= 400 \times 0.8 = 320\ W/m^2$

The gain is more than three times the loss. However, the above is true only for the period of sunshine. Even if we take a sunny day in winter, for the 24-hour period the total loss may be greater than the total gain.

At the very best, in December and January. a south-facing wall may get over 200 $W.h/m^2$ of radiation a day. The heat loss during the same 24 hours may be $2400 W.h/m^2$ and most days will have much less radiation than cited. Double glazing would improve the situation, but, clearly, what is needed is some form of control of solar gain and coordinated control of all the thermal factors of the building.

The position of the sun at any point in time is defined in terms of two angles: altitude (a) and azimuth (g) (Figure 3.2 shows the Solar Geometry).

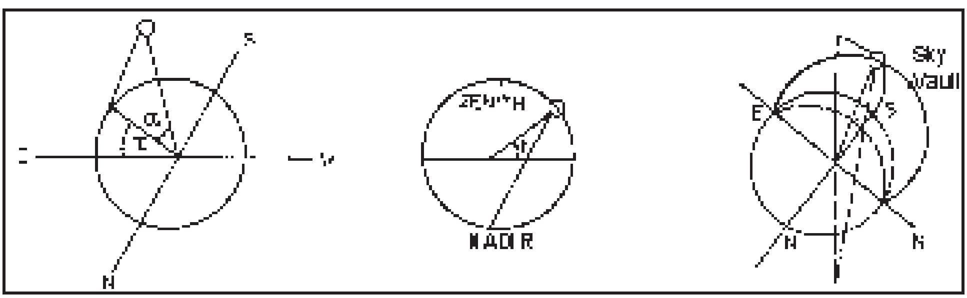

Figure 3.2: Solar Geometry

These angles can be found for any hour of the year from almanacs or from sun-path diagrams of various kinds. By far the best known of these are the stenographic solar charts (Figure 3.3). The two angles can be read directly (as shown in Figure 3.3):

γ. or the azimuth angle by projecting the time point from the Centre to the Perimeter scale.
α. or the altitude angle

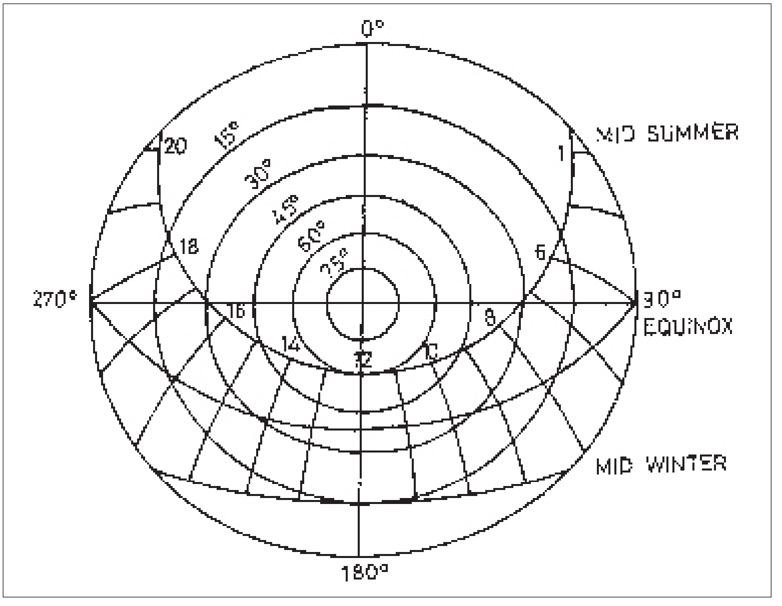

Figure 3.3: Solar Charts Giving Altitude and Azimuth Analysis

If the sun's position is to be related to the building or rather to a particular vertical wall of the building, shadow angle protractors (Figure 3.4) have to be used. This will give readings of two additional angles (Figure 3.5):

d, or the horizontal shadow angle, the azimuth difference (if any orientation, i.e., the wall a azimuth is w, then d = w -γ) and

e, or the vertical shadow angle, i.e., the altitude angle of the sun, projected parallel to the wall on to a vertical plane which is perpendicular or the wall. This will normally be the plane of assertion of the building when d is zero, i.e., the sun is directly opposite the wall, e = in all other cases e-a, the relationship can be expressed as

tan e=sec d/tan α.

On the basis of plans and sections, the shading mask of any device can be constructed by using the protractor when this shading mask is laid immediately along the date and hour lines.

The size and physical make-up of devices do not matter from the point of view of geometry; many different devices can give the same performance. Thus, early on in the process, the designer may decide what the required shading performance is, i.e., the shading mask, still preserving his freedom to select the actual device.

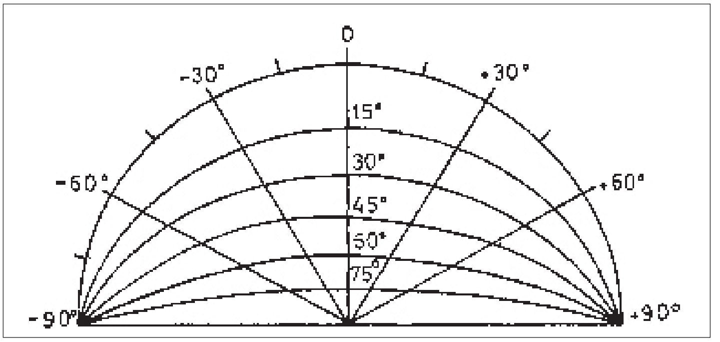

Figure 3.4: The Shadow Angle Protractor

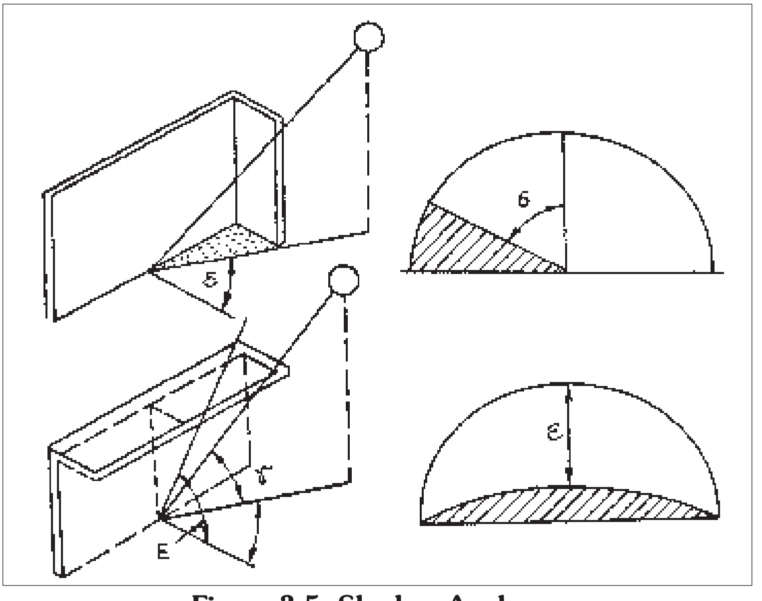

Figure 3.5: Shadow Angles

Fixed shading devices are purely negative controls, i.e., they exclude the sunshine. Adjustable shading devices (louvers) can be used, but they are rather expensive. However, even fixed devices can be designed to give selective performance, i.e., to admit the sun when it is desirable and exclude it when it would cause overheating. The period of overheating can be outlined on the sun path diagram and a shading mask constructed to match the shape of the overheated period as closely as practicable.

Shades over a south-facing window would exclude the high altitude summer sun but admit the radiation in winter when the sun is at a low angle. It is also shown how this is reflected by the shading mask and sun-path diagram. There is a close match between the shape of the overheated period and the shading mask.

Special glass can also be used for solar control. Heat-absorbing glass has selective absorption properties, whilst heat-rejecting glass has selective reflectance (Figure 3.6)

A. Glass with Fe_20_3 content, 6 mm
B. Polymethyl methacrylate sheet, 6 mm
C. PVC film 0.035 mm

Figure 3.6 gives the spectral transmission characteristics of certain types of glass and diagra mmatic representation of the reflection/transmission/absorption/re-emission processes. These special types of glass will reduce the radiant heat transmission, but, once installed, they will act as controls all the time, and there is no differentiation between summer and winter conditions.

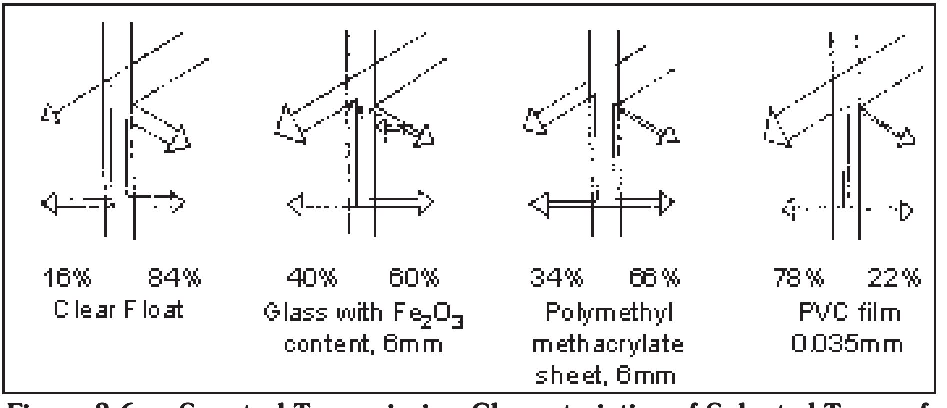

Figure 3.6: Spectral Transmission Characteristics of Selected Types of Glass

The concept of the building as a 'Climate Filter' is a reality and further it should be a selective filter, admitting environmental influences that are desirable and excluding the undesirable ones. Solar controls, both shading device and special types of glass, may be considered as selective filters. Their performance, however, cannot be considered in isolation. They will thermally interact with the whole building and its functions. The thermal behaviour of the building will be determined by factors such as:

1. window size and orientation,
2. type of glazing and any shading device,
3. surface qualities, size, and exposure of solid elements; and also by

1. thermal insulation of enclosing elements,
2. thermal capacity of the building fabric,
3. the relative position of insulation and its capacity, and
4. ventilation and its variability.

All these factors must be considered in relation to the use of the building and heat output of the lighting and of persons and processes in the building and the periodicity of these. The designer must be a conductor, coordinating the orchestration—the performance of a multitude of instruments.

In some situations. the means listed above, i.e., the passive thermal controls, may achieve satisfactory indoor conditions. Yet, even if comfort cannot be ensured by such means alone, a good design will reduce the task of active controls greatly, i.e., of installations using some form of energy input such as heating and air-conditioning.

3.2
Climatology and Passive Solar Building

H.B. Karki

Introduction

The climate of a particular place is closely related to the daily and monthly variation in solar radiation over the entire year. For passive solar building design, an understanding of solar energy in terms of sunbath, location, and intercepted solar energy is essential. The factors that affect the availability of solar energy are (1) geographic location; (2) site of the building; (3) orientation; (4) time of the day; (5) season of the year; (6) atmospheric conditions. i.e., clouds, water vapour, dust particles, and pollutants; and (7) building design. Some of these aspects are discussed below.

Basic Solar Geometry

There are two major motions of the earth: the revolution of the earth around the sun and the spinning of the earth on its own axis. Both motions play an important role in solar energy applications.

The earth's positions, tilted in relation to its orbital plane around the sun, provide the geometric basis for the annual variation of solar energy received on the earth's surface (Figure 3.7). The earth's polar axis is tilted 23° 27' (~ 23.5°) in relation to the plane of the earth's orbit around the sun. This plane is geometrically described by the sun-earth line, also called the solar elliptic plane. It is useful to visualise the sun- earth line as a cluster of parallel light beams. On two days in the year, March 21 and September 21 (The Spring and Autumn equinox), the sun's beams are parallel to the earth's equatorial plane. From the earth's point of view, on these two dates the sun rises and sets in the east and west, respectively. From the sun's position, an observer would see the east tilt at 23.5 in relation to the elliptic plane.

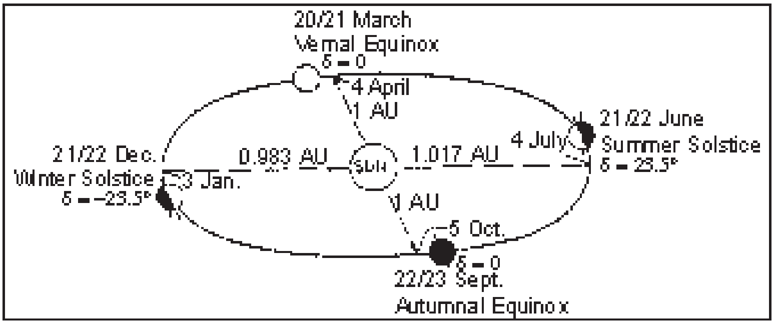

Figure 3.7: Motion of the Earth around the Sun

The angle measured by any point on the earth's surface between the sun-earth line and the plane defined by the earth's equator is the solar declination (Kreider and Kreith 1981), which is given as

$$\delta = 0.398 \cos [0.986 (N\text{-}10)] \qquad (3.1)$$

where, N is the number of days counted from January 1st.

The earth revolves in an elliptical orbit with the sun at one focus of the ellipse. The magnitudes of the semi-major axes and semi-minor axes are 1.4968 x 10^8km and 1.4966 x 10^8km respectively. The period of the earth's revolution about the sun defines one year. The perihelion (the position of the earth nearest to the sun) occurs on approximately the second of January and the aphelion (the position at the maximum distance) occurs on July 2. The declination provides a measure of the variation of positions on a seasonal basis.

To understand sun angles for the purpose of building design, the earth's orbit can be considered circular with the sun at its centre. In fact, the orbit is an ellipse; with the sun being off-centre. Orbital speed slows down as the earth moves closer to the sun and accelerates as it moves away. The eccentricity and obliquity of the earth's orbit result in a difference between solar time, measured by the sun's position in the sky, and standard time, measured by ordinary clocks running at constant speed. The equation used to correct discrepancies between solar time and standard time is given as:

$$t_{sol} = ts + E + 4 (\beta - \phi) \qquad (3.2)$$

where, E represents the equation of time

$$E = 12 + (0.1236 \sin x - 0.0043\cos x + 0.1538\sin 2 x + 0.0608\cos 2 x)$$

and where t_s is local standard time and the angle is x

$$x = \frac{360(N - 1}{365.242} \qquad (3.3)$$

To an observer on earth, the sun appears to revolve around the earth once a day. If this path could be observed for 24 hours, the sun's rays (the sun-earth line) would describe a solar ray cone drawn between the sun and earth. The shape of the cone varies each day according to the sun's declination (Figure 3.7). Coincidence with the ecliptic, the solar ray cone would in fact be a flat plane on the equinox dates.

The sun's path can be traced in various ways, by making a dome overhead with the observer on earth at the centre, the sun's apparent path would be traced on the dome as it intersects the solar ray cones or by a vertical cylindrical graph as shown in Figure 3.8.

The sun's position on the celestial sphere is usually given in terms of solar azimuth angle, α, and the solar altitude, a. These are shown in Figure 3.9. The altitude angle measures the sun's angular distance from the horizon and the azimuth angle, α, measures the angular distance from the south. The solar zenith angle, z, is the sun's distance from the zenith, which is the point directly overhead on the celestial sphere. Thus, a and z are complementary angles.

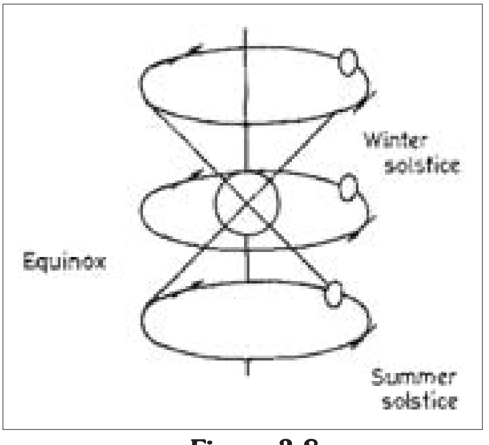

Figure 3.8

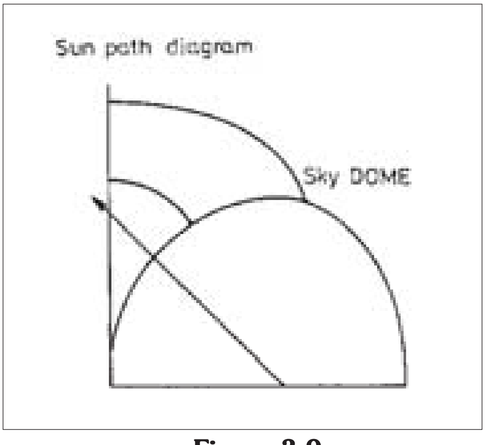

Figure 3.9

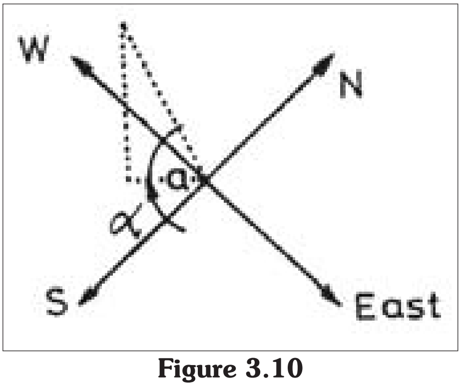

Figure 3.10

$a + z = 90°$
(3.4)

The solar altitude and azimuth angles are computed for any time date and location by using the following formula (Dickson and Cheremisinoff 1980):

$a = \sin\phi \sin\delta + \cos\phi \cos\delta \cos h_s$ (3.5)

where f is the latitude taken at positive north of the equator.

$$\sin\alpha = \frac{\cos\delta \sinh_s}{\cos\beta} \qquad (3.6)$$

and h_s is the solar hour angle and equal to 15 (12- t_s).

Sunset and sunrise occur when the solar altitude angle is zero. Then from equation (3.5) we have

$$\cos h_{sr} = \tan\delta \times \tan\phi \qquad (3.7)$$

where,

h_{sr} (sunrise) = - h_{ss} (sunset)

The intensity of solar radiation on a surface depends upon the angle at which the sun's

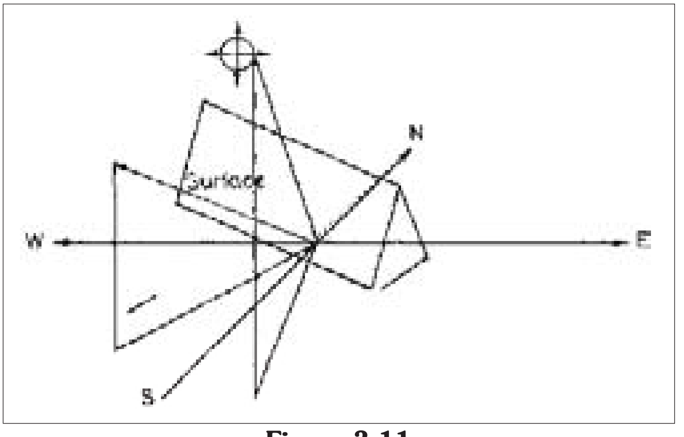

Figure 3.11

rays strike the surface. For a fixed surface:

$$\cos i = \cos\delta \cos(\phi-\tau) \cos h_s + \sin\delta \sin\tau \qquad (3.8)$$

where, τ is the angle of tilt.

At a particular hour of the day or day of the year, the environment casts a shadow on the surface. To calculate quantitative shading, the shading profile angle is required and from Fig 3.12 we have

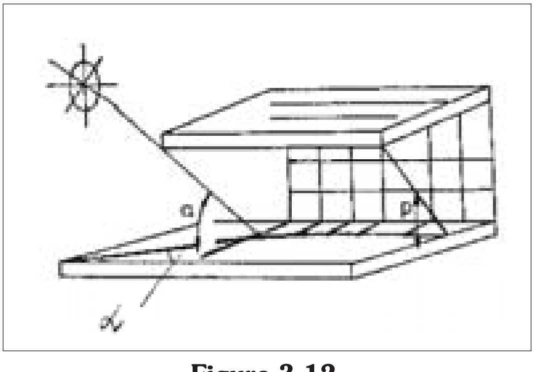

Figure 3.12

$$\tan p = \frac{\tan a}{\tan \alpha} \qquad (3.9)$$

$$d = \frac{\sin \tau + p}{\sin p}$$

Radiant Energy

Radiant energy is usually described as a stream of particles called photons, travelling in a transverse wave at the speed of light, c. Each photon possesses a wavelength and an amount of energy, E. These are related by the equation

$$E = \frac{hc}{\lambda} \qquad (3.11)$$

where h is Plank's constant, $h = 6.6 \times 10^{-34}$ Js. and $c = 3 \times 10^{8}$ m/s, the velocity of light, it may be expressed as:

$$E = h\nu \qquad (3.12)$$

since, $\nu = \frac{c}{\lambda}$

Solar radiation covers a fairly wide range of wave lengths. The approximate distribution of solar radiation in relation to wavelength has been shown in Figure 3.13.

Solar radiation is considerably altered in its passage through the earth's atmosphere. The two important mechanisms causing these atmospheric changes are absorption and scattering. There are several atmospheric constituents that absorb part of the incoming radiation. The first one is ozone, and it absorbs all the ultraviolet solar radiation.

The other absorbers are water vapour, carbon dioxide, oxygen, and other gases and particles. The water vapour absorbs specific wavelength bands in the infrared region. consequently the spectral distribution of radiation contains several pronounced dips and peaks in the infrared region.

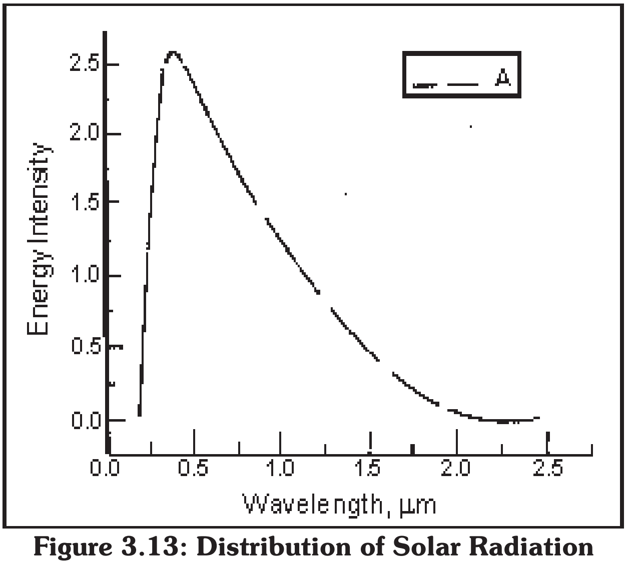

Figure 3.13: Distribution of Solar Radiation

The amount of water vapour in the atmosphere depends upon the local altitude, climate, and season. Since warm air can hold more water vapour without precipitation than cold air, the variation in atmospheric water vapour is generally higher in summer than in winter. The effect of this is a variation in solar intensity of from 5 to 20 per cent. In addition to this, scattering also produces considerable effects. Clouds' scattering reduces the incoming radiation intensity by 80 to 90 per cent through single multiple scattering, because it returns the incoming radiation to space. The solar radiation that travels through the atmospheric path, defined in terms of air mass (m), is calculated as:

$$m = \sec z. \tag{3.13}$$

However. for the spherical earth, eq 3.13 is valid only for zenith angles of less than 70°. The adjustment in air mass for local altitude is made in terms of the local atmospheric pressure (P). The adjustment is:

$$m = m_o \frac{P}{P_o} \tag{3.14}$$

where, P is the mean pressure and m_o and P_o are corresponding air mass and pressure at sea level.

In addition to this. spectral mass also has a considerable effect.

There are various types of instrument to measure solar radiation, both direct and diffused radiation. Among them are a) normal incidence pyrheliometers and b) pyranometers.

3.2.3 Figures of Merit of Passive Systems

From the first principle of thermodynamics, efficiency is the ratio of net useful heat energy to the total solar energy incident on the collecting surface. The corresponding efficiency for natural cooling is the ratio of net energy removed from the building to the total energy lost from the radiative cooling element of the building. Over an extended time period, the efficiency of a natural cooling system must be unity. This is also commonly known as figures of Merit of passive systems (Kreider and Kreith 1982)

Solar heating contribution: This is perhaps the most useful and least ambiguous figure of merit. it is simply the net energy contributed to the building by the passive solar element. The figure of merit is needed to compute the cost effectiveness of the system.

Solar heating fraction: The solar heating fraction (f) is the ratio of net energy provided to the building by the passive solar elements to the total heat required (Kreider and Kreith 1982; Yannas [ed.] 1983). Thus

$$f = 1 - \frac{Q_a}{L} \tag{3.15}$$

where Q_a is the auxiliary heating required. L is the total load of the building.

Historical Perspective : Passive Building Systems

The majority of passive systems for space heating can be placed within one of five generic system types (Kreider and Kreith 1982; Yannas [ed.] 1983; Mazaria 1987).

Types of passive system
1. Direct Gain
2. Thermal Storage-Wall
    •Masonry Walls
    •Water Walls
3. Solar Green House
4. Convection Loop
5. Thermal Storage Roof

Basic design elements are:
- thermal insulation of the buildings,
- solar energy collection,
- thermal storage,
- solar gains,
- sun angle considerations, and
- solar penetration through glass.

A direct gain system admits sunlight into the space to be heated. The system aperture is usually double pane glass, always located on the south faces of buildings (Figure 3.13). The interior material of the building is capable of absorbing sufficient energy through radiation and convection, shutters, reflectors, and roof overhangs are methods for increasing or decreasing gain at varying times of the day and year.

Convective Loops

Convective loops use an absorber surface to absorb incident radiation and then convect warm air into the building space (Figure 3.14).

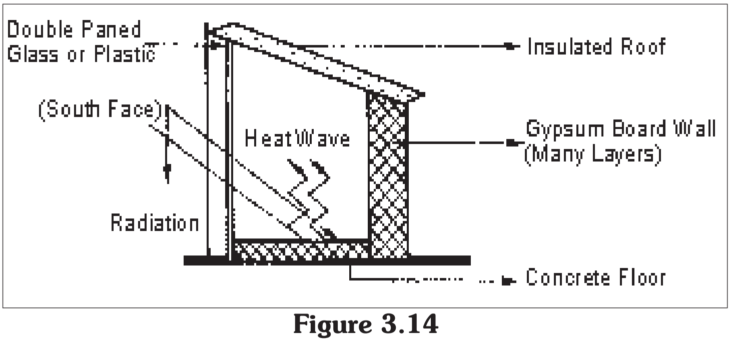

Figure 3.14

There are three types of storage system, short-term storage-lasting for a few hours only; diurnal heat storage-consisting of heat stored during the day that is returned at night; and long-term storage which refers to storage lasting longer than one day. Of these. diurnal storage is the most significant for passive solar designs.

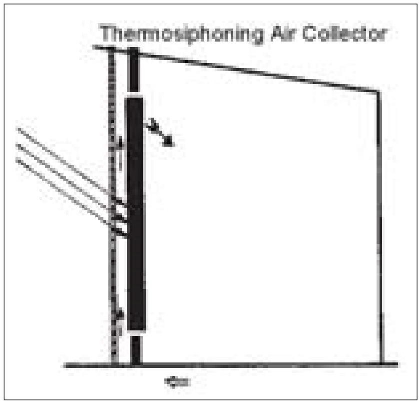

Figure 3.15

Diurnal storage is the capacity to store heat according to each degree of temperature swing ($Q_d = \Delta Q/\Delta T$). Heat capacities for various types of material are given in Table 3.1.

The diurnal heat capacity of a whole room is given as:

Table 3.1: Heat Capacities of Different Materials

Material	Density kg/m^2	Specific Heat Kcal/° C kg	Thermal Conductivity W/m C
Granite	2675	0.20	1.8
Concrete	2290	0.21	1.73
Concrete Masonry	2242	0.12	1.43
Limestone	2452	0.22	0.93
Builder's Bricks	1922	0.22	0.73
Adobe	1922	0.20	0.56
Hardwood	720	0.2	0.16
Softwood	512	0.22	0.12

$$Q_D = \Sigma_i A_i Q_i \qquad (3.16)$$

where A_i is the area of the first surface, and

Q_i is the diurnal heat capacity of i^{th} surface.

The main use of diurnal heat capacity is for estimating room temperature swing. From this, heat balance is calculated over a 12-hour period in the day, accounting for solar gain plus internal heat losses. The heat losses are calculated based on the heat loss coefficient of the building and the difference between the average inside temperature and the outside ambient temperature. The energy balance yields the following mathematical expression:

$$\Delta T = \frac{Q_s A - (T_r - T_a)H/2 = Q_i/2}{Q_D} \qquad (3.17)$$

where,
ΔT = room temperature swing
T_r = daily average room temperature
T_a = daily average ambient temperature
Q_s = daily solar gain per unit area of direct gain glazing
Q_i = daily internal heat
H = heat loss coefficient of the building
A = direct gain glazing area.

If one wishes, one can account for the detailed structure of the inside and outside hourly temperature profile to determine Q_s and T_r.

Convection through doorways can be estimated from the following relationship:

$$Q_c = 63.5\, W_d\, (H_d\, \Delta T)^{3/2} \tag{3.18}$$

where,
Q_c = heat flow
W_d = doorway width
H_d = doorway height
ΔT = room to room temperature difference

The main disadvantages of passive designs is that they usually require integration of the solar collection and storage function into the architecture of the building. Thus the solar energy system is an integral part of the building. This integration of function is not the contemporary approach to architectural design. If passive techniques are integrated

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3.3
The Spectral Characteristics of Global Radiation and Surface Albedo on the Northern Tibetan Plateau

Zou Jiling and Ji Guoliang

Introduction

In order to understand the spectral characteristics of total solar radiation and global surface albedo on the Qinghai and Tibetan Plateau while studying absorbed energy and output energy affected by global surface nature, total solar radiation and global surface albedo were observed in Wudaoliang. This is useful information for developing plant photosynthesis in the region.

Wudaoliang (35^o 17' N & 93^o 06' E) is located in the northern part of Qinghai and the Tibetan Plateau, between Kulun and Tanggual mountains. Its altitude is 4,612 m, and it has a sub-freezing, partially dry climate and the vegetation type is that of a sparse plain (Zhenyao and Xiangding 1981). The observation area is quite wide. The soil is sandy and supports sparse grass in summer. This paper reports on information collected for the period between August 1993 and July 1994 during 25 sunny days.

The paper analyses radiation flux of four bands, upward and downward: the total solar radiation band (0.3 to 2.8 mm), the ultraviolet radiation band (0.3-0.4 μm), the blue-purple radiation band (0.4-0.5- mm), and the near infrared radiation band (0.7-2.8 mm). A total spectral radiation apparatus (TBQ-4-1 model) produced in China was used in order to observe all bands. Two pieces of equipment were used to observe upward and downward components. The apparatus parameters are given in the references (Hao 1993). The apparatus was used to observe solar radiation along the Heihe River, and it demonstrated that the calibration is stable and the information reliable.

Total Spectral Radiation

Daily Variation in Spectral Radiation

The daily average variation in radiation showed that visible light energy is high at noon and low in the early morning and late afternoon; near-infrared radiation energy is high in the early morning and late afternoon and low at noon. The reason for this is that solar altitude is low in the early morning and late afternoon. Atmospheric thickness is broad and short waves are easily affected and weakened by all kinds of gases in the atmosphere, so that the long wave fraction is comparatively big. When solar altitude is higher, the atmospheric thickness is smaller, and short waves are less weak, infrared radiation energy is attenuated, and thereafter the visible light energy increases. The results are in agreement with the results observed in the Hexi region.

Seasonal Variation of Spectral Radiation

Table 3.2 gives the ratio of spectral band energy to total band radiation energy during four seasons of the year. The table shows that: (a) the energy of each band has different variations in different seasons. Ultraviolet is low in winter and high in summer, which is different from the seasonal variations in the plains; blue-purple radiation and near-infrared radiation are high in winter and low in summer. This is because the wind velocity is intense near the global surface, and there is a lot of dust in the atmosphere in winter and spring; the aerosol content increases in the air, so that short-wave energy is weakened; and visible-light is intense and infrared radiation low in summer. The table also shows that (b) the year's average radiation energy of ultraviolet is 4.8 per cent of the total radiation. The blue-purple content is 14.8 per cent; visible-light is 50.3 per cent, and near-infrared light is 49.8 per cent. The ultraviolet and blue-purple radiation intensities in Wudaoliang are higher than in the plains. The infrared radiation in Wudaoliang is lower than in the plains. The results are in accordance with earlier studies. The greater the blue-purple radiation ratio the better it is for formation of plant proteins and fat.

Table 3.2: Spectral Energy Ratio Distribution to Total Radiation (%)

Season	0.2-0.4 µm	0.4-0.5 µm	0.2-0.7µm	λ <0.7 µm	0.4-0.7 µm
Spring	4.7	14.5	50.0	50.0	45.2
Summer	5.1	12.0	51.8	48.2	46.7
Autumn	4.9	15.4	50.5	50.0	45.6
Winter	4.4	16.2	49.0	51.0	44.6
Average	4.8	14.8	50.2	49.8	45.5

Radiation energy for λ ≥ 0.7 mm and l < 0.7 mm was calculated. Table 3.3 gives the average solar radiation for λ ≤ 0.7 mm. In Wudaoliang, the intensity for λ < 0.7 mm in summer is more than in other parts of the country (Hexi Luzhoce) and than in Europe. This is because of the clear atmosphere due to high altitude.

Table 3.3 shows efficient radiation associated with plant photosynthesis (0.4-0.7 mm). It has the following characteristics: (a) the efficient radiation energy associated with photosynthesis is greater in Wudaoliang compared to Hexi Luzhou and (b) the efficient radiation changes with season, its energy ratio is higher in summer and lower in winter, and this conforms to results observed in the Hexi region.

Table 3.3: Comparison of the Energy Ratio of Two Bands to Total Radiation

Season	Spring		Summer		Winter	
	$\lambda > 0.7$ µm	$\lambda < 0.7$ µm	$\lambda > 0.7$ µm	$\lambda < 0.7$ µm	$\lambda > 0.7$ µm	$\lambda < 0.7$ µm
Hexi Luzhou	56	44	53	47	56	44
China	52	48	50	50		
European	51	49	48	52		
Wudaoliang	50	50	48	52	51	49

Solar Spectral Albedo

Using total spectral solar radiation and global albedo radiation. the solar spectral albedo in Wudaoliang was determined. Daily variation and seasonal variation in spectral albedo are discussed below.

Daily Variation in Spectral Albedo

Daily variation in visible-light albedo and near infrared radiation albedo for $\lambda > 0.7$ mm and $\lambda < 0.7$ mm is calculated, respectively. It was found that:

(a) A_v (visible-light albedo), A_N (global surface albedo), and A_k (total band albedo) are similar in daily variation, high in the early morning and late afternoon and low from 9.00 - 15.00 (this is due to the low sun angle in the early morning and late afternoon, which is weakened by the atmosphere)

(b) the albedo is different for different bands. The near infrared band, albedo A_N, is high and the visible-light albedo, $A_{V,}$ is low—this is in accordance with results in Hexi Luzhou; and

(c) the ratio of the visible-light band albedo to the near infrared band albedo (A_V/A_N) equals 0.48.9

In conclusion. for all bands the albedo increases when solar altitude is low and the near infrared albedo is high. This conforms with the results observed in Hexi Luzhou. It should be noted that ground conditions influence the albedo considerably.

Seasonal Variation in Spectral Albedo

The seasonal variation in spectral albedo is shown in Table 3.4, from which the following conclusions are drawn.

Table 3.4: Spectral Distribution of Albedo

Season	0.2-0.4 µm	0.4-0.5 µm	0.4-0.7 µm	λ > 0.7 µm	0.2-2.8 µm
Spring	0.251	0.0-68	0.182	0.248	0.267
Summer	0.229	0.66	0.122	0.201	0.195
Autumn	2.297	0.049	0.167	0.249	0.270
Winter	0.207	0.052	0.165	0.242	0.245

1) Ultraviolet and near infrared band albedos are high in winter, low in summer, and are the same as the global albedos of all bands. Ground conditions, such as a damp surface with plants in summer, give rise to low ultraviolet and infrared albedos. The snow on the ground makes the albedo greater in winter.

2) The blue-purple band albedo gives opposite results to those described in the previous passage: low in winter and high in summer. The reason for this is that the earth's surface is covered by green plants, making the blue-purple band albedo high in summer because it mostly reflects the wavelength l = 0.55 mm,

3) The near-infrared band albedo is highest (about 34%), the ultraviolet band albedo is about 31 per cent, and the blue-purple albedo is lower than the annual average in Hexi region.

Conclusions

1) In solar spectrum energy distribution, visible-light energy is high and near-infrared energy is comparatively low in Wudaoliang region. There is a difference between the plateau and the plains.
2) Ultraviolet radiation is high in summer and low in winter and blue-purple radiation and near-infrared radiation are low in summer and high in winter.
3) Visible-light energy is high at noon and low in the early morning and late afternoon.
4) Daily variation in the global spectral albedos, A_v, A_N and A_k, is the same, but the variation in A_N is twice as large as that of A_v when the ground is covered with snow. The difference between the value of A_N and A_v is not so great and the variation in A_v is more than in A_N.
5) The ultraviolet band and near infrared albedos are the same as the all-band albedo, i.e., low in summer and high in winter. The blue-purple albedo is high in summer and low in winter.

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3.4
Direct and Global Solar Radiation in the Region of Mt. Qomolangma During the Summer of 1992

Lu Longhua. Zhou Guoxian and Zhang Zhengqiu

Introduction

The solar radiation in the Mt. Qomolangma Region has always drawn the attention of Chinese and Foreign scholars. Since the 50s, mountaineering expeditions to Mt. Qomolangma have been organized, primarily to study the solar radiation. In summer 1992, an expedition to the Mt. Qomolangma Region took place. Observation sites were established in the Rongbu Temple area (28° 13'N. 86° 49'E. Altitude 4. 950m) and near Mt. Qomolangma. The environmental conditions are similar to those described by Yonguan et al. (1985). From June 30 to August 16, 1992, every fraction of radiation balance was observed by multi-channel remote wire-sensor radiation and the fraction of radiation sequentially observed for 24 hours. The characteristics of direct and global solar radiation in the Mt. Qomolangma Region are presented in the following passages.

Direct Solar radiation

Direct solar radiation was measured by home-made DFY-3 direct radiation meter with a measurement wave band of 0.3-4 mm. The solar radiation outside the atmosphere is 97.85 per cent of the solar constant (1337.6 W/m^2). On August 8, 1992, sunrise took place on Mt. Qomolangma at 7.32 hr (real sun time) local time and the sun set was at 17.02hr. The actual sunrise and sunset were two hours and 12 minutes and one hour and 37 minutes later than astronomical sunrise and sunset,

Figure 3.16 shows the average daily change in direct solar radiation and global solar radiation. When the sky is clear, direct solar radiation in the Mt. Qomolangma region is 890 W/m^2 shortly after sunrise, about 1. 050 W/m^2 around noon, and 839 W/m^2 before sunset. The daily average value is 976.2 W/m^2. The variation in values measured in a day is under 10 per cent (quadratic mean deviation: 73.9 W/m^2). Furthermore, estimation of direct solar radiation is made by means of global solar radiation (0.2-4 mm) and scattering radiation data obtained from the expedition. If relative deviation and quadratic mean deviation of the measured value (Si) and estimated value (S'i) are given. the values of (a) and (b) can be calculated as follow.

$$a = \frac{\frac{1}{N}\sum S_i \quad \frac{1}{N}\sum S'_i}{\frac{1}{N}\sum S_i} \tag{3.19}$$

$$b = \sqrt{\frac{\frac{1}{N}\sum (S_i - S'_i)^2}{\frac{1}{N}\sum S_i}} \tag{3.20}$$

where N is the number of observations.

When it is clear, the relative deviation of measured value and estimated value at different times (0.3-4.0 mm) is only 1.5 per cent, and the relative quadratic mean deviation is 5 per cent. This shows that the results of the observation are reliable.

Table 3.5 provides the atmospheric transparency during the expedition. The correction of average distance from the sun to the earth and the effect of wave band on the equipment's measurement of solar radiation outside the atmosphere was considered in the course of estimation.

$$P_m = m\sqrt{\frac{S.r}{S_o}} \tag{3.21}$$

P_m Atmospheric transparency coefficient
S Direct solar radiation of vertical ray surface when it is clear
r Correction coefficient of average distance from the sun to the earth, r is 1.03
S_o Solar constant (1367 Wm^{-2}), the wave band of S is 0.3-4.0 mm. solar radiation in the wave band arrived atmosphere outside is 97.85% of the solar constant, thus S is 1337.6 W/m^2.
m Atmospheric optic quality

Table 3.5 also shows that the average atmospheric transparency coefficient in the Mt. Qomolangma region is 0.687. Although the transparency at noon is lower than in the morning and the evening, the relative deviation in the atmospheric transparency coefficient in a day is only 2.4 per cent (quadratic mean deviation: 0.0165).

Table 3.5: Atmospheric Transparency Coefficient in the Mt. Qomolangma Region

Local time	7:41	8:41	9:41	10:41	11:41	12:41	13:41	14:41	15:41	16:41	Ave-rage	QMD
S	890.3	947.1	1010.0	1035.0	1046.0	1054.0	1015	1011.5	914.0	839.0	876.2	73.9
m	1.099	0.800	0.675	0.586	0.560	0.565	0.607	0.700	0.887	1.305		
Pm	0.709	0.674	0.682	0.679	0.680	0.691	0.666	0.700	0.673	0.716	0.687	0.0165

Based on data provided in Yonguan et al.1985, the same methodology was adopted to calculate the atmospheric transparency coefficient in the Rongbu Temple region in the 50s. The result showed that, when it is clear, the atmospheric transparency coefficients at 12:30hr in the region were 0.668 and 0.7116 in June and August 1992 respectively. The result measured by this expedition is close to 0.691. This shows that there is no distinct difference between the state of atmospheric transparency in 1992 and 1959.

Global Solar radiation

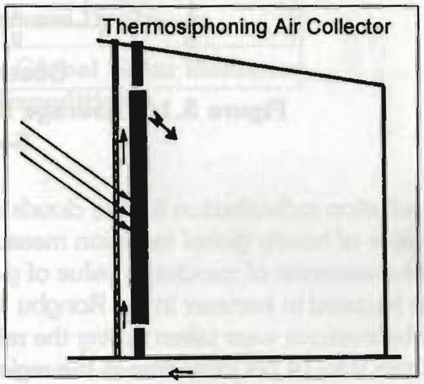

Figure 3.15:

All-wave global solar radiation (0.2-4 mm), ultraviolet global radiation (0.295- 0.385 mm), and infrared global radiation (0.7-4.0 mm) were observed by the expedition. Model PSP. Model TUVR, and Model PIRP, products of EPLAB, USA, were used. Daily changes in all-wave band global radiation, ultraviolet global radiation, and infrared global radiation are shown in Table 3.6. From Figure 3.15, it can seen that daily changes from of Q. IR, and UR are coincident on the whole. From Table 3.6, it is observed that ultraviolet radiation accounts for 3.74 per cent of global radiation and infrared global radiation accounts for 63.2 per cent of global radiation. The percentage changes of ultraviolet and infrared are small in one day (the quadratic mean deviations are 0.07 and 1.15 per cent respectively and account for 1.9 per cent of the average value). The maximum value of ultraviolet radiation was 62 W/m^2, corresponding to the maximum value of ultraviolet radiation in the west pacific equatorial region.

It is not unusual for the maximum value of global radiation to be greater than the solar constant in the Qinghai-Xizang Plateau area. This phenomenon is the result of solar

Table 3.6: Global Radiation. Ultraviolet Radiation and Infrared Radiation in the Mt Qomolangma Region

Local time	7:41	8:41	9:41	10:41	11:41	12:41	13:41	14:41	15:41	16:41	Average	AMD
Q	517.0	776.5	1002.8	11.97	1439.3	1458.0	12162	975.0	729.4	424.0	823.0	489.0
UR	19.3	29.1	38.0	44.8	53.0	53.0	48.0	37.3	26.7	16.0	33.6	16.1
IR	324.0	490.7	636.8	754.8	893.7	899.0	808.7	627	452.2	277.0	520	302.8
UV/ Q(%	3.7	3.8	3.8	3.7	3.7	3.6	3.8	3.8	3.7	3.8	3.7	0.07
IR /Q (%)	62.7	63.2	63.5	63.0	62.1	61.7	64.1	64.4	62.0	65.3	63.2	1.15

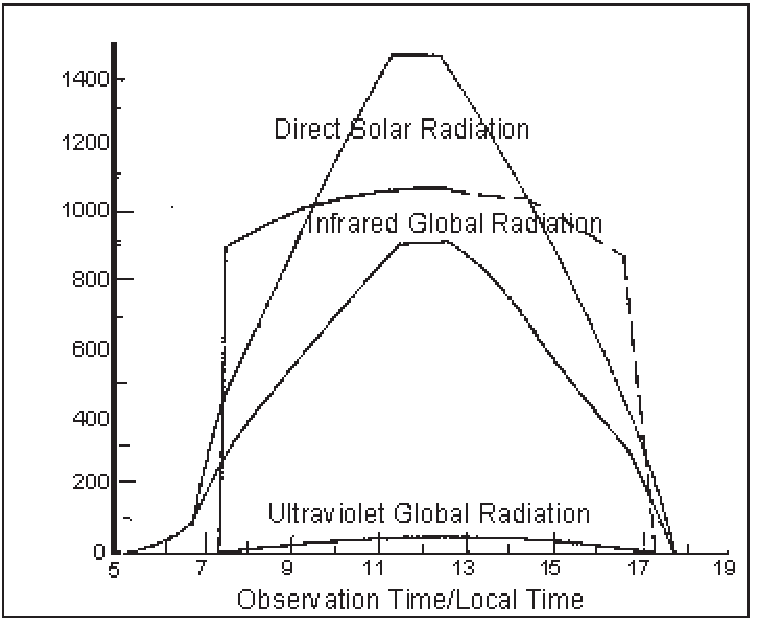

Figure 3.16: Average Daily Change in Direct and Global Solar Radiation

of solar radiation redistribution for the clouds in alpine areas. Figure 3.16 gives the maximum value of hourly global radiation measured. From the figure, we can see that the phenomenon of maximum value of global radiation being greater than solar constant is frequent in summer in the Rongbu Temple region of Mt. Qomolangama. The observations were taken during the rainy season. The phenomenon could be observed from 9 to 14 hrs local time in the region of Rongbu Temple. Mt. Qomolangma; it sometimes occurred as much as five times sequentially. The maximum value of instantaneous global radiation was 1688 W/m^2 (15:07, 5, August), which is 23 per cent greater than the solar constant. During the expedition, the maximum value of hourly amounts of global radiation recorded reached 4.71 MJ/m^2 (10:41-11:41, 4, August); the average intensity was 1308 W/m^2, i.e., 95.7 per cent of the solar constant.

Figure 3.17 gives the maximum value of instantaneous global radiation at different altitudes. Above 500m, the relationship between the maximum value of instantaneous global solar radiation and altitude can be expressed by:

$$Qmax = 157.346 \log_e(Z) + 274.548 \qquad (3.22)$$

On the northern summit of Mt. Qomolangma, the value of instantaneous global radiation measured was 1382 W/m^2. According to Equation 3.5.4, the maximum value of global radiation in the region is 1700 W/m^2. It can be observed that instantaneous global solar radiation is greater than solar constant at low altitudes. These sites are usually islands, and the radiation reflected from the clouds can be substantial. In low altitude areas, the reflection of the clouds plays an important role in the occurrence of this phenomenon—which is only for a short duration. In the Alpine region on the

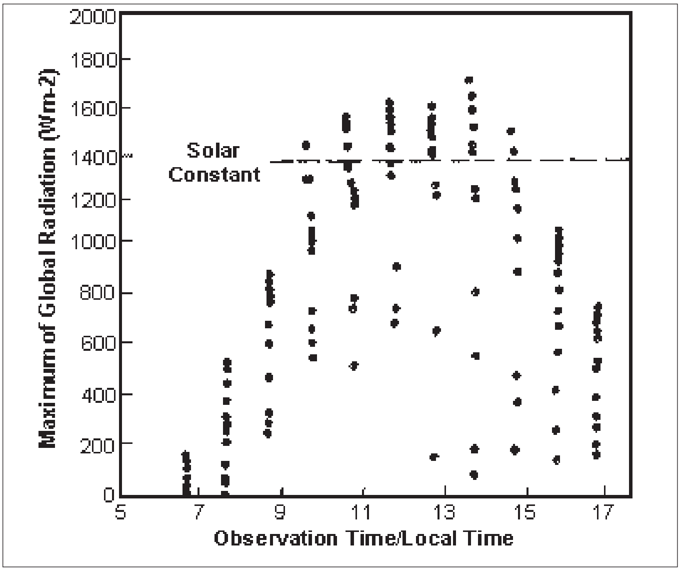

Figure 3.17: Maximum Hourly Global Solar Radiation Recorded by the Expedition

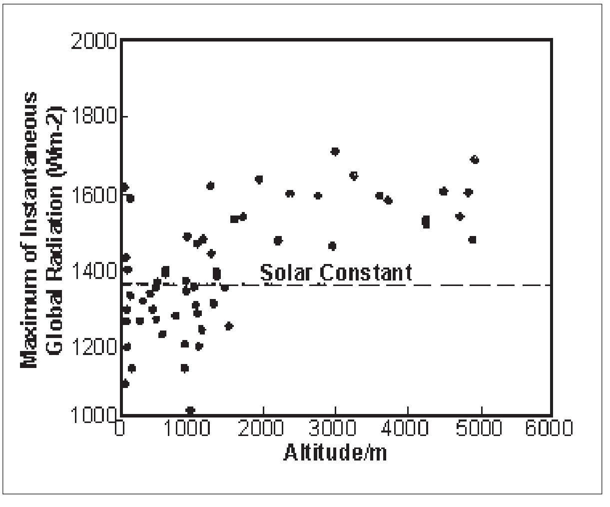

Figure 3.18: Relationship between the Maximum Value of Instantaneous Global Radiation and Altitude

other hand, one can have very strong direct radiation quite often. The phenomenon of instantaneous solar global radiation being greater than the solar constant in the plateau region of Quinghai-Xizang needs further study.

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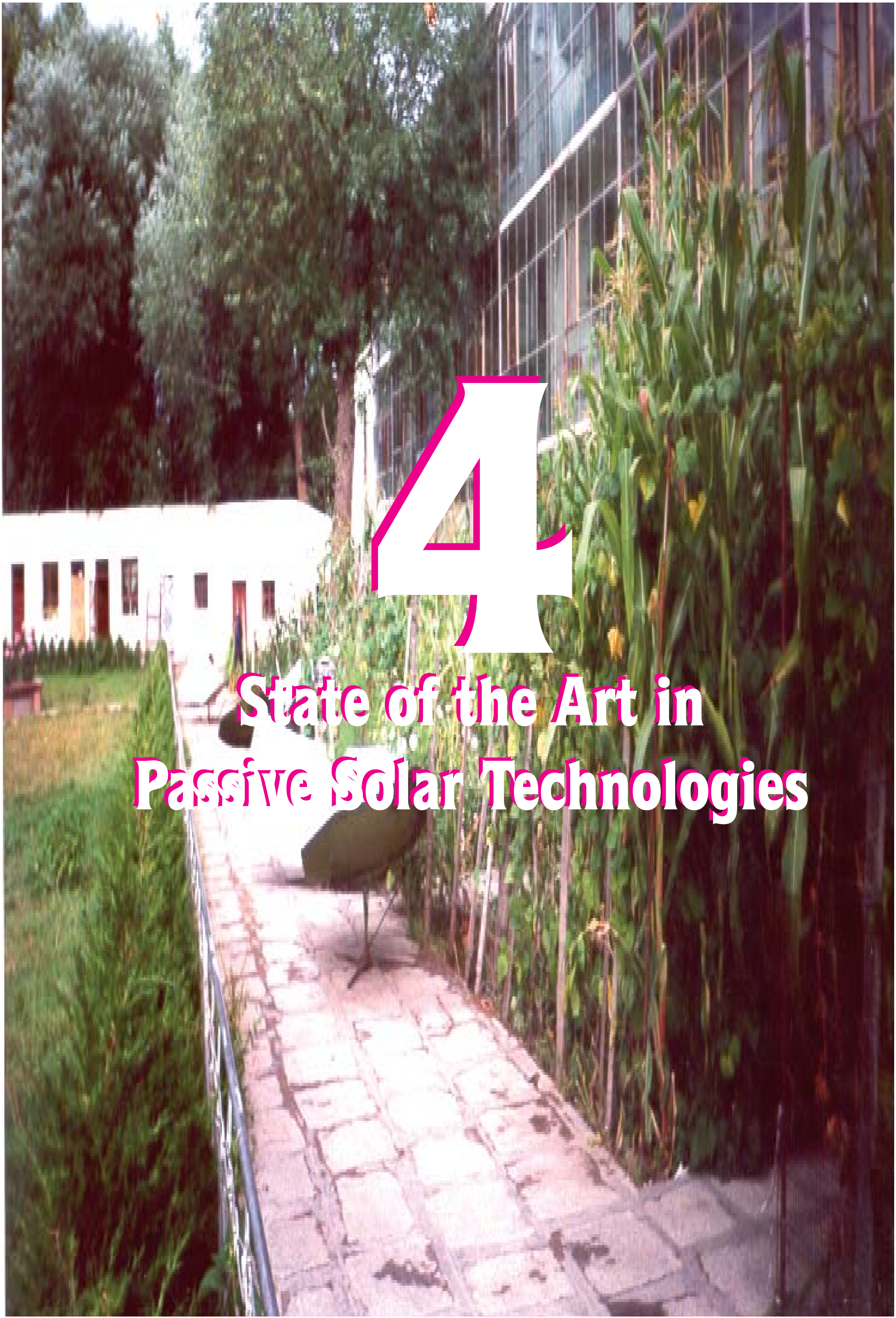
4

State of the Art in Passive Solar Technologies



4.1 International Status of Solar Passive and Low Energy Building Technologies for Cold Climates

M.Chandra

Introduction

The first conscious application of solar energy for passive heating of buildings in recent years was attempted by Trombe who built a series of houses in the Pyrenees, France, and made a successful engineering application of the idea originally proposed by Prof. E.O. Morse in 1881. The turning point in passive solar research was provided by the first passive conference held in Albuquerque in 1976. This was the result of an energy crisis that generated renewed interest in those aspects of solar energy which contributed to thermal comfort in buildings without or with little conventional energy inputs. As a consequence, solar passive and low-energy building technologies are today recognised as a distinct discipline. There are many solar passive and low-energy buildings all around the world today. Many new buildings that are presently being planned/constructed throughout the globe bear ample testimony to the success of solar passive and low-energy building technologies in cold climates.

Advanced Materials for Passive Buildings

New and improved materials are often crucial to technological or cost breakthrough and solar energy is no exception. For this reason, special attention has been given to the investigation of a variety of innovative materials that promise to bring about dramatic improvements in the performance and reliability of solar passive and low-energy buildings. Many of these new materials increase the insulation capability of the building envelope through special window glazing or building facade covers that reduce thermal losses or minimise unwanted solar gains, offering the possibility of acting as translucent systems to admit sunlight but reduce heat losses. Transparent insulating materials are particularly exciting. One of the transparent insulation materials is aerogel, a glass-like substance. Special coatings which enhance window performance as well as gas-filled window designs are also of great interest. Other materials studied facilitate the use of day lighting for natural illumination, improved thermal storage capacity through phase-change materials, and increased solar collector efficiency with special absorber coatings and plastic honeycomb collector covers.

Insulating Window Glass

One ideal solar energy device is the transparent insulator - the surface admits solar energy but blocks heat loss. Ordinary window glass has the quality required- it transmits most of the solar energy spectrum but effectively retards heat loss. The common double glass window unit - two panes of glass separated by a sealed air space - approaches what we would call a transparent insulator: it has about twice the thermal resistance of a single sheet of glass but still loses a major fraction of incident solar radiation. Although the heat insulation provided by double glazed windows is only about one-tenth that of 50 mm thick fibre glass, researchers have made great improvements in transparent insulation materials during the past 30 years. Such materials now have nearly the same insulation value as 50 mm fibre glass, while still allowing solar radiation to the same degree as a typical double glazed unit.

The variety of techniques, materials, and approaches is fascinating. Optical coatings, semi-conductors, vacuums, honeycombs, inert gases, and aerogels have been combined by physicists, engineers, and chemists, each through a particular process, because no single approach has emerged as the final solution. Transparent insulation materials can have many different features such as low emission coatings, multiple layers, honeycombs, aerogels, gas fills, combined approaches, and vacuum approaches.

Different types of glazing with their thermophysical properties are given in Figure 4.1, whereas Figure 4.2 illustrates the uses of advanced transparent insulation materials to reduce energy consumption while heating houses.

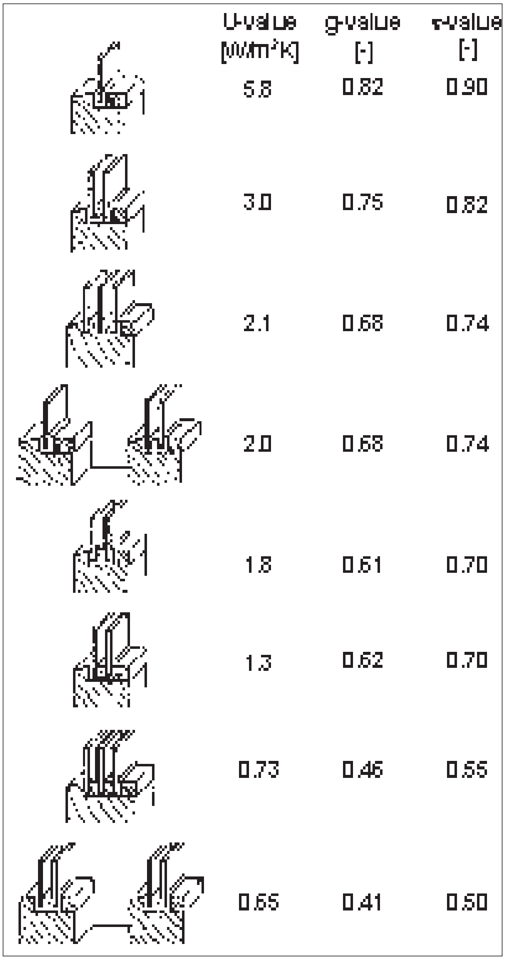


Figure 4.1: Thermo-physical Properties (U-1 g- and values) of Different Glazing Systems (Bansal *et al.* 1994)

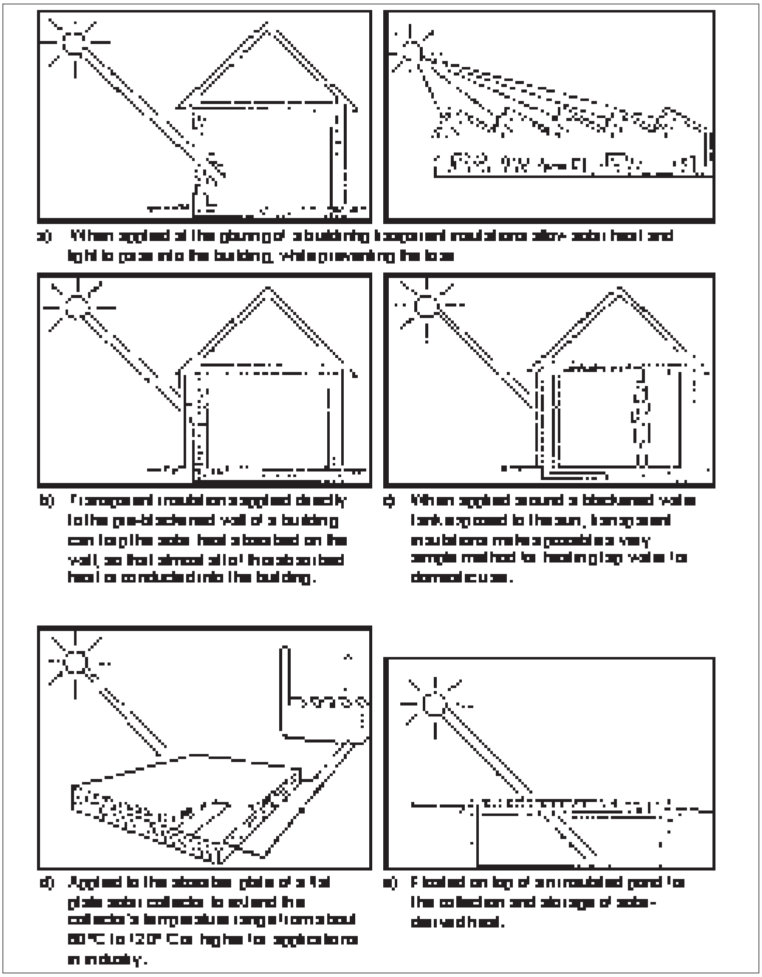


Figure 4.2: Examples of the Uses of Advanced Transparent Insulation Materials

Weather Panel/Prefabricated Roof Panel

A transparent insulation made from low-e and low-e baffles and an optical shutter called cloud gel have been combined into a prefabricated roof panel called the Weather Panel as shown in Figure 4.3.

The solar transmission of this panel varies depending on the building's need for heat and light. Optional overnight heat storage can be provided by a 2 cm thick layer of water with a lifetime of 30 to 40 years. As a result of their low thermal conductivity, high maximum solar transmission, and automatic rejection of solar heat and light, weather panels make a simple design strategy in passive solar architecture possible. This system collects heat and light during cloudy weather also. It has many advantages, for example, the entire collector/storage is on the roof and its shape and orientation have no specific requirements, resulting in complete freedom of aesthetics

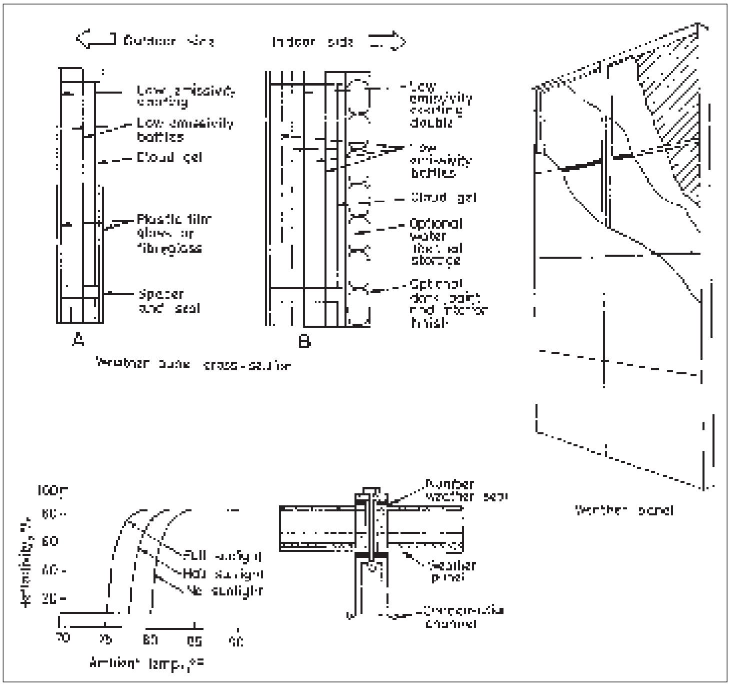


Figure 4.3: Weather Panel Details

and building site, shape, and use. It is claimed that average roof construction can be replaced at equal cost. This works well in cloudy winters when most heating is needed. Table 4.1 shows what percentage of a building's space heat can be provided by the sun during cold and cloudy winters.

New Passive Heating Approaches/Concepts

The transfer of heat from southern sun spaces into northern rooms/parts of the building can be facilitated by means of air fans, and for light, clerestories or skylights should be designed. However, these methods are limited to single storey buildings. In multistorey buildings, the northern spaces are defined as cooler zones and additional capacities are usually designed to provide thermal comfort in these spaces. However, the following systems facilitate the solar passive heating of northern spaces.

Table 4.1: Fraction of Solar Heat Needed for Space Heating in Passive Buildings	
Building Figue	4.4 and 4.5
Weather Panel Figue	2.8
So lar Tansmission	5-50%
Thermal Conductivity	
W/m² °C	.57
BTU/FT² °C	.10
Boston	80%
Seattle	76%
Munich	77%
Berlin	62%
Super insulated	79%

The Barra System : Insulated Glazed Solar Wall and Storage in Concrete Ceilings

This system (Figure 4.4) was developed by O.A. Barra in Italy. In this system the southern wall is insulated and it works as a thermosiphonic air heating, solar collector. The hot air emerging from the insulated collecting wall flows horizontally within channels embedded inside a concrete ceiling, serving also as thermal storage space. Part of the heat is stored inside a concrete ceiling, while the still warm air exits from the channels in distant parts of the building that are not facing the sun. The air thus warms the distant rooms first before flowing back through the building space to the inlets in the lower part of the collecting wall facing the sun. This assures even temperature distribution throughout the whole house and is an improvement on the temperature distribution with other passive solar systems.

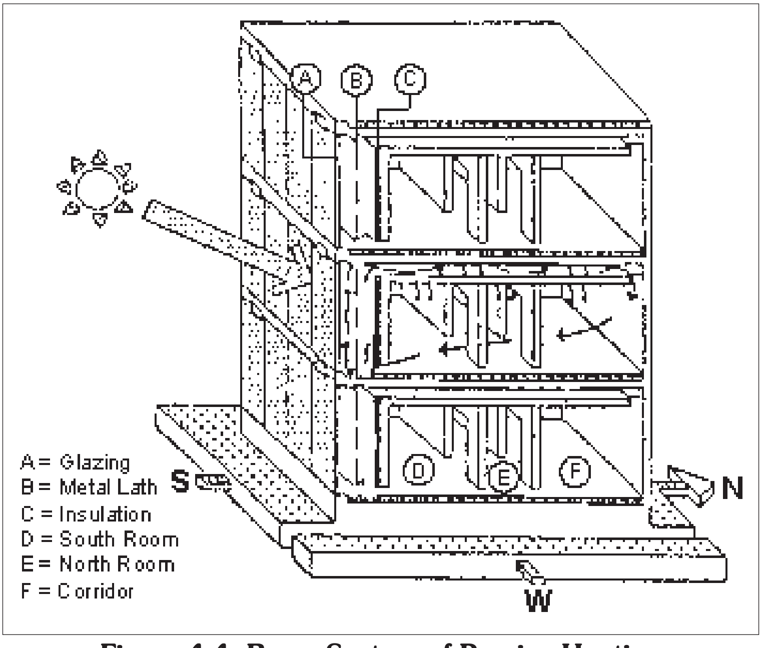


Figure 4.4: Barra System of Passive Heating

Because the air flow in the solar wall is Thermosiphonic, the flow rate is approximately proportional to the square root of the temperature elevation of the air in the collector above the indoor level, which in turn depends on the intensity of the impinging solar radiation. As a result, the air temperature is relatively high even with low radiation (and low flow) conditions. The high temperature of the air flowing within the channels of the concrete ceiling and the large surface area of the channels help to maintain a high degree of heat transfer from the air to the concrete. The fact that the storage elements are completely interior within the envelope of the insulated walls ensures a high degree of storage efficiency by the concrete ceiling. With insulated walls surrounding the living space, unwanted heat loss in winter (especially during extended cloudy periods) and heat gains in summer are minimised in comparison to a thermal storage wall.

The Barra system can be applied to multistorey buildings and even to buildings in which the main rooms face the sun. When the front facade of a building is not facing the sun, it is possible to use the rear or side southern facades as collecting walls because a major part of the solar heat is transferred first by convection to the northern side of the building. The thermal performance of this system depends to a great extent on the delicate natural convection currents. The moving air must come into contact with as much surface area of the collecting wall and of the mass in the ceiling as possible, without being slowed down too much. These considerations should affect the detailing of the channels.

Because of its relatively high temperatures (higher than in other passive systems), the collector wall is subject to large thermal stresses. Polystyrene insulation should not be used because collector temperatures may well exceed its melting point. Infiltration losses should be minimised. Good sealing, automatic back draft dampers, consisting of a light flap plastic film acting as a one-way valve, should be fitted to both inlet and outlet vents to prevent reverse convection during the night.

Opposite Sun Space Passive Solar Air Heating System

In this system proposed by Melih Tan of Turkey, the solar energy gained in the southern sun space of an apartment in a multistorey building is transferred passively to the northern glazed space of the apartment through air ducts placed in the ceiling and the floor (see Figure 4.5). As all other sides of the apartment, except the south and the north, are common with those of the neighbouring apartments, a kind of double envelope composed of a southern sun space, a northern glazed space, and air ducts in between is formed for each apartment. The principle aim of this passive concept is not to heat the internal spaces by solar energy, but to increase the temperature of the spaces between the double envelope by solar energy and thus reduce the heat loss from the internal spaces. Because of this feature, the system makes use of low intensity solar radiation also.

One can also use this concept between east and west sun spaces. In this, solar energy gained in the eastern sun space will be transferred to the western sun space before noon and vice versa in the afternoon. Therefore, the system is applicable to south-north or east-west facades and thus removes the constraint of having to orient the building to the sun. The system was first applied in Ankara Solar House (Figure 4.5). The system was applied between the southern sun space and the northern glazed space. Here it was found that natural air circulation overcomes a distance of 10m between the opposite sun spaces and the velocity of air flow increases with the increase of the temperature difference between the opposite sun spaces. In another solar building, known as the Belko Solar Building, the system was applied between the eastern and the western sun spaces. The natural air circulation overcomes a distance of 13 m in this case. In both the applications it was also shown that the system provides cooling during summer when the system is operated in the cooling phase. The overall percentage of energy saved during the cold season in both cases is reported to be around 73-74 per cent. Thus with the new configuration of the opposite sun space passive solar heating system, horizontally or vertical elongated buildings are recommended and their orientation towards the sun need not be taken into account.

Several programmes for solar passive buildings (IEA 1992) have been undertaken by the Department of Energy (USA), European commission, International Energy Agency (IEA) etc to demonstrate the low energy consumption for well-designed solar passive houses.

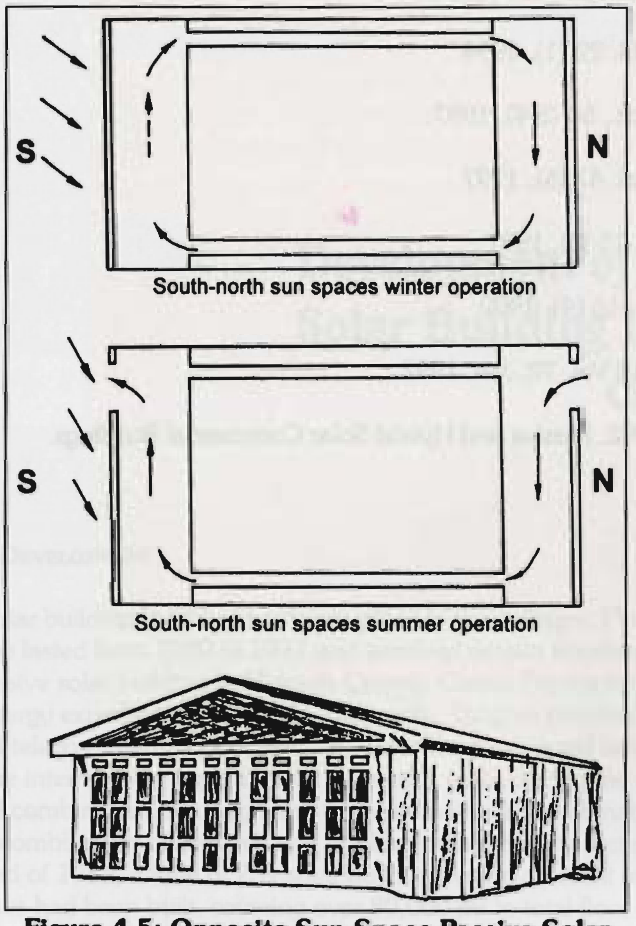


Figure 4.5: Opposite Sun Space Passive Solar Air Heating System

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4.2 Development of Passive Solar Building in China

Chen Xiaofu

Research and Development

Research into solar building in China has taken place in three stages. The research and exploration stage lasted from 1980 to 1997 and involved certain important projects, e.g., the first passive solar building in Minquin County, Gansu Province; the comprehensive solar-energy experiment building in Xining city, Qinghai province; and the Quanji post and teleco mmunication's office, and the Yangcum guest house in Tianjin municipality. The intermediate experimental stage took place during the 6th five-year plan period and combination of foreign and Chinese methods, combination of sites and areas, and combination of research and application are the characteristics of this stage. By the end of 1985, a total of 231 solar buildings using different methods and with different uses had been built, covering over 80,000 m^2 in total floor space—mainly in Beijing, Gansu, and Tibet. The heat collecting systems included direct heating, heat collecting and accumulating walls, and sun annexes. During the heat collecting period, the temperature in the main rooms was on average about 10°C with supplementary investments of above 25 per cent. The recovery on investments may take four to 20 years, depending on the different conditions of the areas. The 7th 5-year plan and 8th 5-year plan periods were periods of comprehensive research and demonstration, as well as considerable establishment and application of solar buildings. With support from relevant government authorities, a dozen scientific research institutions, universities, and colleges and extension management departments joined hands and built different types of solar buildings for demonstration purposes in a dozen provinces and cities. The temperature in the main rooms,as a major index was over 12°C on average during the heat collecting period. For room temperatures no lower than 8°C, the collecting period for solar energy could be guaranteed to an extent of 80 per cent with a supplementary investment below 20 per cent. The results of these endeavours are as follow.

1. Solar buildings for research and demonstration purposes were built in the north, northeast, west,and intermediate regions of China. In addition many kinds of solar housing technologies are being promoted, e.g., the direct heating mode, heat collecting and heat accumulating walls, and sun annexes, which can be used proficiently and flexibly. Certain new heat collecting modes are also being introduced such as lattice walls, fast heat collecting walls, and air heat collecting devices. An innovative solution for dealing with severe fluctuation of room temperature in solar houses is being introduced through use of building designs with heavy-duty structures.

2. Advanced mathematical models and models for performance prediction and optimised design have been adopted widely. The integration of research results, test methods, computer application technology, construction technology, and certain effective energy-saving technologies into the design of solar buildings has guaranteed design standards.

3. An interesting study was carried out on solar energy building materials such as phase-change materials. Heat-conserving curtains made of aluminised textile fabrics, enhanced transparency membranes for glass and sealing bars for windows and doors, and selective absorption coatings for heat-collecting walls. They are being used in the construction of solar buildings and the results have been good.

4. A systematic complete design manual and structure atlas, the first of its kind, was compiled and published. It summed-up theoretical results and engineering practices, including advanced design methods with Chinese features that suit national conditions.

5. National standards entitled 'Technological Requirements for Passive Solar Houses and Methods for Heat Performance Tests' were formulated to specify the division of districts, technological conditions, methods for heat performance tests, methods of economic analysis, and examination rules for solar houses. These standards were accepted in 1994 and implemented in 1995.

6. Auxiliary sources of heat are an indispensable facility of solar buildings in the northern region. They not only solve the problem of solar energy shortage during cloudy days and cold winter periods, but also make use of the residual heat from cooking, thus raising energy-saving efficiency. Good progress was made in research on this subject during the 7th 5-year plan period, and this resulted in the development of a number of cooking-heating stoves.

Introduction and Application of Solar Buildings in Different Areas

Two thirds of the total area of China falls above the latitude 35°N and temperatures are below 5°C for over 50 days a year. There is a significant difference in the development of solar buildings in different regions of China. This is mainly due to differences in geographical location, climate, and sunshine. Solar buildings are mainly concentrated in the North, North West,and North East regions of China, as well as in certain places in the intermediate region and Tibet. By the end of 1994 the total area of solar buildings was 270 million m^2. Almost all civil structures adopted solar technology, including single-story and multistorey houses.

In the west, it is cold and dry, and the possibility for heat collection lasts for five to nine months, with few exceptions. Energy consumption in these areas is 1.5 to 5 times the national average. The extreme natural conditions hamper the supply of sufficient energy. For example, Gansu Province is short of energy resources. The energy available locally is only sufficient to meet the fuel requirements for three months a year. Since the construction of the first solar building in Minqin county,Gansu Province,in 1977, a Gansu Natural Source of Energy Institute was established and a Northwest China Municipal Designing Institute. In Yuzhong a solar energy base and certain extension sites in South Gansu, Dunhuang, and Ali have been established. They have designed and introduced over 350,000m^2 of solar buildings. In certain areas, large groups of solar houses have been built,e.g.,those in the Gannan Cooperative,The Nationality Normal College, and those in Cuoqin and Geer counties in Tibet.

The North East area is severely cold; the coldest area of the country Heating is needed for five to six months a year. The average room temperature in the winter is around -20°C. The dissemination of passive solar building technology started fairly late in these areas. Experimental research into solar building has been carried out since 1988. Since then, there have been obvious achievements as a result of the hard work of the government and authorities at different levels. By the end of 1994, various solar buildings have been built in three provinces with a total area of 17.5 million square metres. Among them, the most beneficial and influential ones are the schools. Here massive publicity and good demonstration have occurred, in Lioning Province for example. This has given people an opportunity to experience the advantage of solar buildings. The government of Liaoning also formulated policies related to the combination of solar building technologies with village and township planning. At present, there are different kinds of solar building for residential purposes: they cover more than 9.7 million square metres. There are also a few hundred primary and high schools using PSBT concepts due to the the provincial government's promotion of solar school rooms in 1990.

The dissemination of solar building concepts in the North started quite early, and the related research has been carried out in more depth. In 1981, Beijing Solar energy Research Institute, Qinghua University, Tianjing University, and Germany implemented a joint project on solar building in Yihe village, Daxing county, a suburb of Beijing. From that time, five million square metres of different solar buildings have been constructed These are mainly in Daxing, Pinggu, Changing in Beijing, Yangcun, Ninghe,and the southern suburb of Tianjing, Tang County,Anguo Chengde city as well as the suburb of Shijiazhuang. In some areas,such as Pinggu and Ninghe, massive residential buildings equipped with solar energy have been built. The spread of these solar buildings in Hebei province is extensive in every area and city within the province. Up to the end of 1994, solar buildings covered an area of over three million square metres.

Economic Benefits

The economic benefits of solar buildings are different in different areas, for different standards of construction, and varying room temperatures. In remote districts, the economic benefits of PSBT are high. This is due to the shortage and high prices of conventional energy in these areas. It normally takes three to four years for repayment of the capital investment; it can take 10 years or even more than 15 years in areas where the availability and price of conventional fuels are cheap. Generally speaking, in terms of comfortable room temperatures for residential buildings, solar energy guarantees a solar heating fraction (SHF) of 50 per cent in the North East ; 24-30 kg of coal per square metre can be saved during the cold weather. In the North, the SHF is 70-80 per cent ; 16-20 kg coal can be saved. Given an SHF of around 70 –80 per cent in the West, 20-40 kg coal can be saved.

The use of solar energy in schools and universities not only saves energy and reduces environmental pollution but also saves investment since schools have classes during the day and no one stays there at night, thus matching the cycle of the sun. In 1990, there were more than 130 primary and high schools in 14 cities in Liaoning that had different standards and types of solar buildings covering more than 1.2 million square metres. In total this can save about 6,000 tonnes of standard coal and 12 million *yuan* in heating costs every year during the cold season.

Problems and their Causes

Problems with the Administration — The spread of solar building relates to multi-profession and multi-sector. Despite the rural energy system, it is also closely related to construction, land, planning, and other sectors. Both national and local construction administration departments have not adopted the design and spread of the solar building into their normal scope of business. It is worth studying seriously how to integrate, coordinate, and share out the work suitably within various sectors.

Lack of Unified Design Norm and Evaluation Standard — Some building designers and builders build houses without fully understanding the passive concept. Some just copy or imitate indiscriminately experiences in other parts of the country. Therefore, they do not reach the targetted population and designs are also not suitable for specific locations. Hence this affects the reputation of solar building technology.

Insufficient Publicity and Demonstration — Farmers in many areas do not really know what solar building technology is or about its benefits.

Future R&D — There is a need for further research and development, for example, for heat preservation and moisture protection problems, the selection principle of heat gathering and light penetrating wall materials, and the gap between double glazing.

Commercialisation — There is no specific industry for solar energy construction materials and no professional construction team. This has resulted in sub-standards with regard to heat preservation materials, light penetrating materials, and coating.

Misuse and Mismanagement — Some users block the vents of the heat gathering wall. The heat-gathering wall may be full of dust or it may have broken windows. These things seriously affect the performance of passive solar technology.

Incentives — Since solar building can not be treated as a commodity. At present, the economic benefits for those institutions and people who are carrying out solar building research, design, and extension are poor. Thus, they are not highly motivated to carry out further work in this area.

Strategies and Suggestions for Future Development

Coordinate, regulate, and encourage the development of PSBT by improving leadership. Rural energy departments at all levels should play a leading role in coordinating different industries and government organizations engaged in village and township planning and construction and land management. Based on survey and investigation, laws and special policies ought to be formulated in terms of village and township construction investment, township planning, land distribution, and supply of materials.

Promote, guide, and expand the experimentation. Rural house construction grows by 600 -700 million sq.m. per year in China, more than half of this area is located where heating is needed. Thus, it is necessary to extend solar building technology with support from local leaders and the understanding of the public. There should be further experimentation in order to reach more areas and more people and attract potential users by demonstrating the cost-effectiveness and efficiency of passive solar heating.

Reduce subsidies and encourage users to construct all forms of sun glass-houses. In addition to policy encouragement, governments should provide financial assistance according to the development levels and financial abilities of different regions. In poor areas where the annual per capita income is below 400 *yuan*[*], households are not able to construct new houses or construct solar annexes. Poverty alleviation funds can be used to subsidise construction,and technical assistance can be provided free of cost.

In areas with an annual per capita income of around 600 *yuan* (such as West China), it is the right time to construct new houses. Technical services, consultants,and training are priorities for extension activities. Favourable policies need to be formulated. Middle and low quality sun-glass houses need to be upgraded and good quality sun-glass houses constructed for exhibition.

In areas with an annual per capita income above 800 *yuan*, households should be encouraged to build their own sun-glass houses. For areas that already have sun-glass houses, technical assistance should be provided. For areas that have no experience in constructing sun-glass houses, demonstration are needed. In areas with favourable sunshine, sun-glass houses can be extended to small and medium-scale towns and cities. Measures such as enhancing the heat retention ability of the walls, subsidising

[*] There are 8.28 *yuan* to one US dollar.

costs based on savings accrued from heating expenditure, appropriately designing the styles of buildings, and optimising heat collection ought to be taken immediately.

Strengthen training and improve management. With development of sun- glass houses, management and technical skills may be insufficient. All levels of government should focus on human resource development so that the quality of technicians and managers will be improved.

Pay attention to relevant research and keep a large group of researchers by increasing research grants. Although research on sun-glass houses has made a lot of progress in China, there are still gaps between China and other advanced countries in terms of inputs and technical skills. Researchers and designers often face financial problems. The government should provide funds for research on passive solar building technologies.

4.3 Solar Building in Tibet

Ci Zhen

Introduction

Tibet is located in the middle of the Qingzang Plateau, north of the Himalayas. The average altitude is about 4,200 masl. The people of Tibet have to endure an extremely cold climate, often with rudimentary heating methods. Tibet is rich in solar energy. Scientists have designed many kinds of office buildings and dwellings equipped with good heating facilities by using solar energy. So far around 200,000 square metres of solar housing have been constructed in Tibet. The following passages describe two kinds of passive solar building used in Tibet.

Solar Building with Extension

This type of solar house is designed as an extension of an existing house by building a 0.8-1.0 metre wide sun-house covered with glass on the south side. This type is simple and looks beautiful. The cost is only 15-20 per cent more than that of a traditional house.

According to the measurements, the room temperature can be maintained at up to 8°C with a southern exposure, 5°C with a northern exposure at two o'clock in the morning in winter in Lhasa, Shane, and Rikaze (3,700-4,000 masl). In Naqu, Ali prefecture, the temperature reaches 5.5°C on the south of a building and 2.5°C on the north (4,000-4,500 masl). The disadvantage of this kind of solar house is that heat losses occur quickly. The temperature is relatively lower in rooms on the north side of the building.

Solar Building with a Heat- collecting Wall

Heat-collecting walls are built on the southern side of the main house and sealed with glass. The distance between the glass and the wall is 19 cm; the surface of the wall is uneven and painted black to absorb sunlight and reduce reflecting light. Ventilation holes are kept in the upper and lower parts of the wall. The principle is that the cooler room air comes into the collecting wall through the lower holes, heats up, and then the warm air flows into the room by the upper holes. All holes are closed in the evening to reduce heat loss. The cost of this type of solar house is 15-20 per cent higher than a traditional one. The indoor temperature is 2°C -2.5°C higher with this system than in a normal building. An auxiliary heat source is necessary in winter as the room temperature on the southern side can only reach 11.5°C-12.5°C in Lhasa, Shannan, Rikaze, and 7.5°C- 8.5°C in Ali and Naqu.

In order to improve heat efficiency, certain heat accumulating materials are mixed into the wall, e.g., $Na_2 SO_4 10H_2 O$. The fusion point for $Na_2 SO_4 10H_2 O$ is 11°C-115°C, heat of fusion is 1,628.35 kJ/ kg. This material is good for heat accumulation and there is no corrosion or toxicity. Fifteen to thirty per cent of such materials can be added to the wall. In daylight, cool air is heated and enters the room, at the same time heat-accumulating materials absorb the heat. In the evening, when the temperature of the collecting wall is lower than the temperature of the accumulating materials, the heat accumulating materials begin to release heat and crystallise. Cool air becomes warmer and flows into the room as compensatory heat, therefore, the room temperature on the southern side stabilises. According to tests carried out, if a proportion of 30 per cent of $Na_2 SO_4 10H_2 O$ is added to the collecting wall, the indoor temperature can reach 15°C in winter in Lhasa.

At present, a solar energy central heating system is in the experimental stages. The water is heated by a solar energy collector, warm water then flows into each room through taps, and then the room temperature increases through radiation. If this system is successful, the disadvantages of the above two types of solar house will be eliminated.

4.4 Passive Solar Building Construction at High Latitudes

Du Xiabin

Introduction

According to the solar resource map of China, the solar radiation available in the North East ranges between 1,100 to 1,140 kWh/m^2 per annum, with 2,600 annual total sunshine hours. Historically, people have used solar energy for heating by installing south-facing windows in thatched cottages and tents. This is the simplest form of solar heating. By integrating solar heating technology into building construction, money can be saved. Passive solar building is divided into the following categories : a) direct beneficial type, b) heat concentration wall type, c) additional green building typed, and d) roof concentration type. This paper focusses on the design and construction technology for two types of solar building, the direct beneficial type and the heat concentration wall type.

Passive Solar Building Design

The main elements of passive solar building design are heating, heat preservation, and energy conservation. Passive solar building must face south (in the northern hemisphere) because in winter this provides the best solar heating effect. If the direction is towards the east or west, the azimuth angle should be less than 15°.

Material Composing the Wall

The function of the wall is heat concentration, heat preservation, and heat transmission. From Table 4.2, it is clear that the material with the best heat concentration and preservation properties will have the worst heat transmission properties. Therefore, the selection of wall material depends on the needs of the building. Normally, a wall is used for heat preservation, therefore, material with low thermal conductivity is used. Because the wall absorbs heat, a special dope or stone should be built outside it. Normally the colour black has the best effect, but bottle green and brown are also acceptable. These colours are five per cent less efficient than black.

Table 4.2: Thermal Performances of Common Wall Materials

Material	Thermal Conductivity (W/m°C)	Heat Transmission Rate (W/m^2 °C)
Common Brick Wall	0.76	9.86
Clay Wall	0.70	9.19
Cement Wall	1.50	15.26

Convective Hole

The construction of a heat preservation wall means that glass windows have to be added outside the wall. commonly, there is an 80-120 mm gap between the wall and the glass windows.

Sunlight Adjustment

Sunlight adjustment is used to prevent sunlight from falling directly into the room, at the same time ensuring that it heats it in winter. One simple way is to use eaves as shade; and these can be designed and integrated into the building. The size of the eaves are determined by the size of the window and the sun tracking position.

Passive Solar Building Construction

Direct Beneficial Type

In order to increase the lighting surface, this type of solar building is commonly designed with large windows and a small overhang on the south side. More sunlight enters directly into the rooms, air and floor temperatures inside the room rise, and it becomes warmer. According to this practice, in the North of China, especially in Suihua region which is at high latitude, the best proportion between the solar lighting surface and wall surface is about 45 per cent.

The sill level is kept at 600 mm. Wall materiala are of standard brick and grout (multiple materials) with a thickness of 500 mm (it can be 370 mm on the southern side). The proportion between the windows and wall on the south side should be 48 per cent. For example, in a building with three rooms, 10m long, 8m wide, and 2.8m high, the doors face north and the overhang on the south is 750 mm wide. there are three windows of 2,500 mm width and 1,560 mm height. From floor to window sill the distance is 750 mm, from window top to eaves 360 mm (including the cycle girder), and the window has double glazing. Perlite is spread as a heat preservation layer on the roof top. The floor is hollow with a 500 mm x 500 mm cavity filled with slag, covered with oil paper or plastic cloth. In order to increase heat preservation efficiency at night, some kind of heat preservation curtain can be installed for the floors and windows.

Heat Concentrating Type

An additional glass window (80-120 mm) is installed outside the south-facing wall. Convective holes are opened in the wall. The sunshine heats the air between the glass window and the wall. The air is drawn through the holes by convection and increases room temperature inside.

The wall is made of normal standard brick and mud. The rest of the building is the same as that of the direct beneficial type. The convective holes should be air proof, otherwise cold air will enter.

Concluding Remarks

In high latitude areas, traditional heating systems cannot be replaced by solar heating systems completely. Solar energy is a kind of low density energy,especially in winter as irradiation angles are low and sunlight hours short, so solar energy is limited and temperatures are low (about-28°C). This means traditional heating systems are necessary as well as efforts to conserve energy. It is unwise to enlarge the surface of a lighting window and heat concentrating wall blindly. We plan only for six to eight hours of solar radiation but also 16-18 hours of heat dissipation (especially on winter nights). So the proportion between lighting surface and wall surface should be no more than needed. Heat concentrating windows should be air proof and clean, convective holes should be closed and air proof at night. Otherwise, an additional heat preservation window curtain can be installed in order to improve the effect.

4.5
Passive Solar Building Technologies for the Hindu Kush and the Himalayan Region (HKH)

Irshad Ahmad

Introduction

Fossil fuel resources are limited and prices are escalating rapidly. Moreover, use of these energy resources is associated with adverse effects, and it is advisable to avoid their use whenever possible. Use of alternative fuels such as renewable energy from the sun, wind, and biomass should be encouraged. Renewable energy sources have an unlimited lifespan and have minimal adverse effects on the environment.

The most rapid growth rate in energy consumption in Pakistan is observed in the domestic sector. This is because standards of living are improving and more comfortable indoor conditions are required, leading to an increase in the use of energy for heating and cooling buildings. Houses are being constructed with little regard for local climates.

This paper presents climatic analyses from Gilgit in the Hindu Kush-Himalayan (HKH) Region with a view to identifying passive strategies to keep buildings comfortable without the use of conventional fuels. Finally, it suggests a means to reduce the energy requirements for heating, cooling, and lighting of houses in Gilgit by using natural means. The provision of solar devices to cater for cooking and domestic hot water is also discussed.

Analysis of the Climate in Gilgit (Northern Areas)

The Northern Areas are located between 35° and 37° North latitude and between 73.5° and 75° East longitude at an altitude of 4,500 masl. The climate falls within the very cold, sub-humid and arid range (Syed n.d.).

A summary of weather data for Gilgit, based on 30 years' (1961-90) meteorological observations (Meteorological Hand Book n.d.), is given in Table 4.3. The daily dry-bulb temperature varies from -2.7°C in January to a maximum of 36.1°C in July. The average wet-bulb temperature varies from –4°C in January to 13.3°C in August. The wind velocity varies from 1.0 knot in December to 2.5 knots in July. The dominant wind direction in winter is from West to East, while in summer it is from south-east to north-west. The direction of winter winds from West to East indicates that windows should not be placed in the western facades of buildings, as this would exacerbate the extremely cold conditions.

Heating and cooling degree days for Gilgit were calculated using dry-bulb temperature data from Table 4.3. The base temperature for calculating heating degree days was taken as 18°C, while the temperature base for estimating cooling degree days was 26°C. Heating and cooling degree days for all months of the year in Gilgit (Figure 4.8) show that there are substantial heating requirements for seven months of the year and negligible cooling requirements for three months in summer.

Table 4.3: Summary of Weather Data for Gilgit

Month	Mean DB	Max. DB	Min DB	RH	Wet bulb	Wind speed	Wind Dir.	Calm %
Jan	2.2	9.2	-2.7	56	-4	1.2	W	76
Feb	6.1	12.0	0.2	50	-2.4	2.1	W	66
Mar	11.6	17.9	5.4	41	2.0	2.8	W	58
Apr	16.6	22.9	9.4	29	4.5	2.5	W	62
May	20.1	28.4	11.7	27	8.2	2.5	SE	69
Jun	24.8	24.2	15.2	27	10.1	2.4	SE	72
Jul	27.4	26.1	18.8	21	11.5	2.5	SE	72
Aug	26.7	25.1	18.1	26	12.2	2.1	SE	76
Sep	26.2	21.6	12.2	27	10.2	1.9	W	79
Oct	16.0	25.2	6.6	21	6.0	1.4	W	82
Nov	9.2	17.8	0.6	40	1.0	1.0	W	86
Dec	4.2	11.0	-2.4	54	-2.6	1.0	W	86
YEAR	15.7	22.6	7.8	28	5.5	2.0		74

Bio-climatic Chart for Gilgit

A bio-climatic chart is an ordinary psychometric chart showing dry-bulb and wet-bulb temperatures and relative humidity (Victor 1963). Bio-climatic charts also indicate different techniques for rendering indoor air temperature thermally comfortable.

These techniques include high thermal mass, passive heating, humidification, de-humidification, and evaporative cooling.

To identify appropriate climate control strategies for Gilgit, mean daily dry-bulb temperatures and the relative humidity of each month were drawn on a bio-climatic chart (Figure 4.9). In the chart January, February, and December are in the extreme left-hand corner, indicating that active solar and conventional heating techniques are needed to make indoor temperatures comfortable. The chart also shows that passive solar heating is needed in March, April, October, and November. May, June, August,and September are in the comfort zone and require no remedial measures, while the month of July would require high thermal mass and evaporative cooling to bring it into the comfort zone. This month falls very close to the comfort zone and, therefore, a minimum of evaporative cooling might be needed. Use of high thermal mass is not desirable as high thermal mass might not be compatible with passive heating in winter.

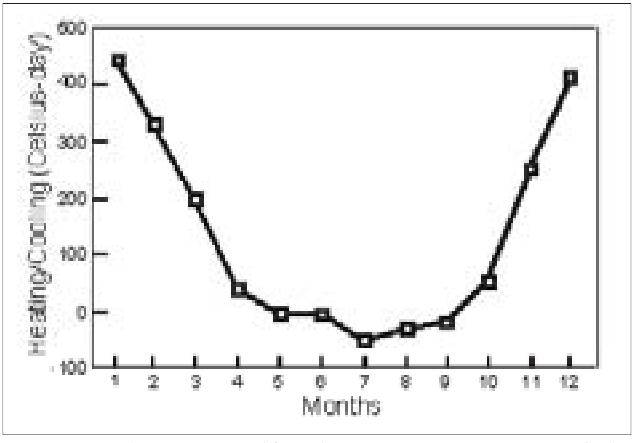

Figure 4.8: Heating/Cooling Degree Days in Gilgit

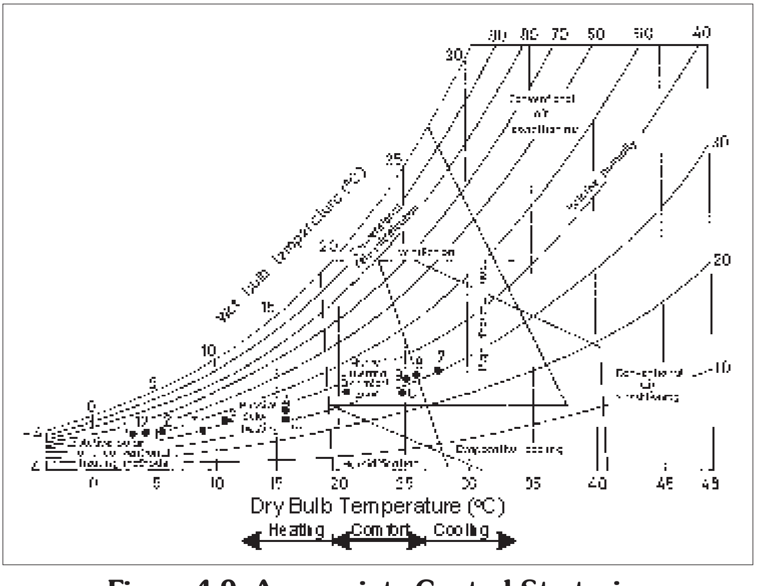

Figure 4.9: Appropriate Control Strategies

Identification of Passive Strategies for Gilgit

The bio-climatic chart and heating/cooling degree days show that severe cold weather persists in Gilgit for seven months of the year, and only one month is mildly warm. This means that buildings should be designed for severe winter conditions. To achieve this, the following strategies are suggested.

1. Restrict conductive heat flow from the building envelope by installing good insulation into the walls and roof and under the floor slab. An overall heat transfer coefficient of 1 $W/m^2.°C$ is desirable. Wooden doors and windows should be painted. Paint protects wood from moisture, making it more resistant to heat flow. The insulation in the walls and roof should be installed as close to inside surfaces as possible to prevent inside heat loss to the outside environment. The floor slab should have insulation on the bottom as well as on the sides.

2. Restrict infiltration through doors and windows to prevent cold outside air from entering and the warm inside air from exiting. Suitably-sized south-facing windows are needed to take advantage of direct solar gain in winter. A typical size would be 15 per cent of the floor area. South-facing windows with overhanging shades are recommended to maximise solar radiation in winter; and this is absorbed by the floor slab for night time re-radiation. The thermal mass of the floor should be carefully matched with heating requirements and window size to prevent over/under heating.

3. Promote solar heat gain in winter as suggested by using south-facing windows of suitable size and shades. Shades should be of a size that will prevent solar heat in summer when it is undesirable. The Sun-Path diagram (Figure 4.10) is useful for estimating shading of the site by surrounding buildings, trees, and other obstructions.

4. The Trombe Wall concept can be used for winter heating and thermal storage. In this case thermal storage will be located in the south-facing wall itself. A separate estimation of the amount of optimum thermal storage and whether this storage should be located in the Trombe Wall or in the floor slab will be needed.

5. Promote natural ventilation when desirable. As the prevailing winter winds in Gilgit are from West to East, windows on the western facade should be avoided. Luckily, winter wind velocities are low. Winds are more frequent in summer and are from SE to NW and south-facing windows have already been suggested for winter solar gain. These south-facing windows will encourage natural ventilation, especially during summer nights when outdoor temperatures are low. The low outdoor temperature will cool the thermal mass of the floor slab during the night and keep the indoors cool during the day, provided the daytime infiltration is kept to a minimum.

   A detailed estimation of the cooling contribution from nocturnal ventilation and the thermal mass needed to store this cooling is required.

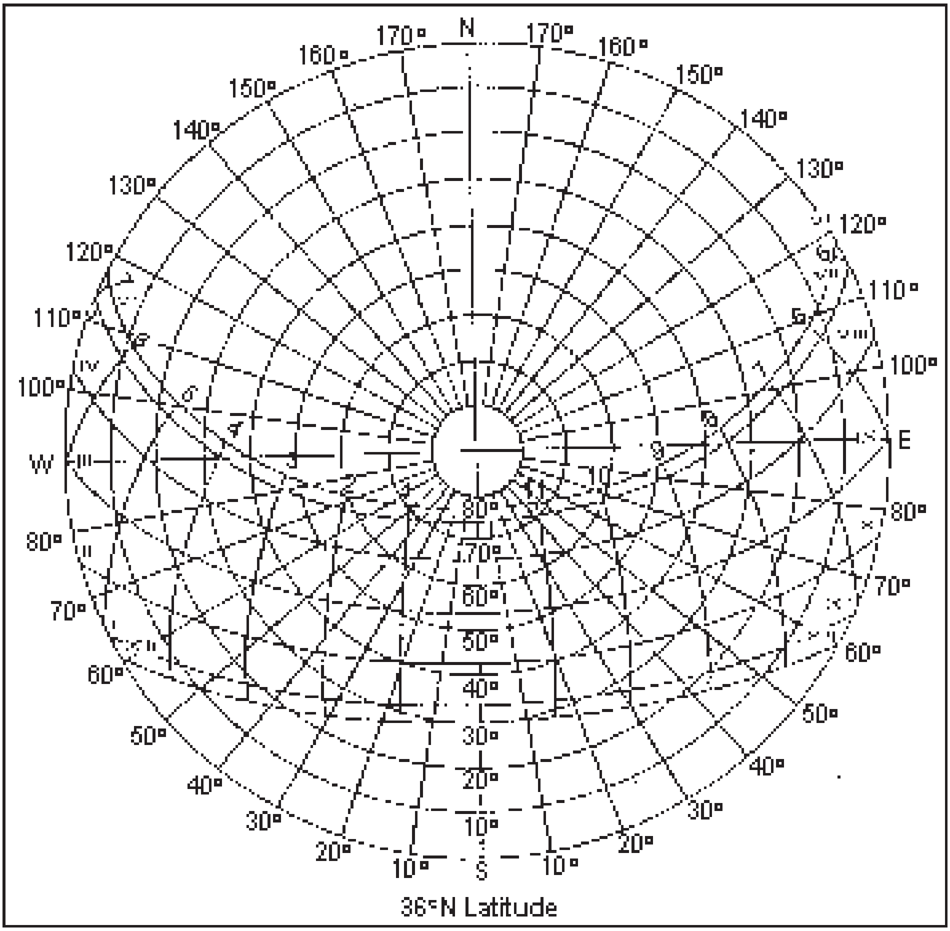

Figure 4.10: Sunpath Diagram for Gilgit

6. Promote daylight saving by using south-facing windows and roof shutters to encourage natural lighting during the daytime. As far as architecturally feasible, rooms used during the day should be located along the southern side of the house to take advantage of direct solar heating and natural daylight. East/West running partition walls should be minimised as they might impede transference of heat and daylight from the southern side of the building to the northern side.

Domestic Hot Water and Cooking Systems

A lot of energy is consumed for heating water and cooking meals. A family-sized solar water heater has been developed at the National Institute of Silicon Technology (NIST). The NIST design has three flat plate collectors of one square metre each and a double-walled storage tank with a capacity of 200 litres. This design had to be modified to suit the Northern Region because of the freezing winter conditions in the area. The modified design has four flat plate collectors, a storage tank with two heat exchangers, and an auxiliary heater (Figure 4.11). An anti-freeze solution flows through the collector with the help of a circulating pump. The anti- freeze solution flows through the flat plate collectors,heats up, and flows to the storage tank through a heat exchanger coil, HX1,where some of the heat is transferred to the fluid in the storage tank. The outgoing,relatively cool antifreeze solution is again pumped to the collector, and this cycle continues as long as enough solar energy is available.

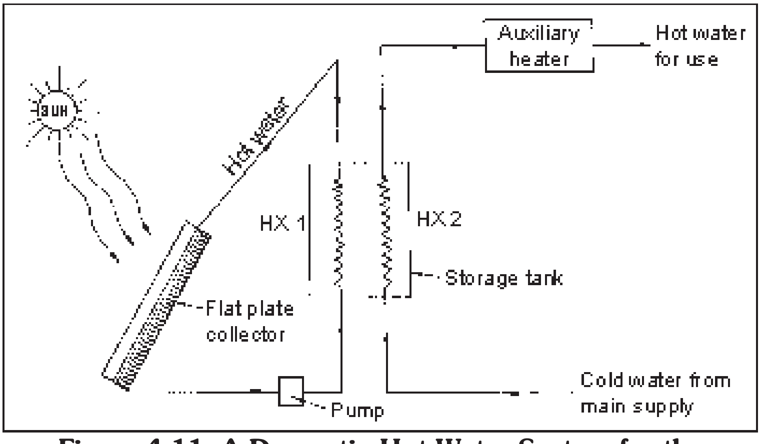

Figure 4.11: A Domestic Hot Water System for the Northern areas

The cold water from the main water supply system is heated for use while passing through another heat exchanger (HX2) located in the storage tank. When the water stored is not hot enough because of cloudy weather/over use of hot water, an auxiliary heater is used. This auxiliary heater uses oil, gas, or wood. This modified system costs a little more than the NIST design because of the additional cost of a heat exchanger and circulating pump. This same system can be used for active winter heating.

Box- type solar cookers with in-built thermal storage to take care of sun interruptions are being developed. This cooker can cook lentils, boil rice, and bake cakes in 1-1/2 to 2-1/2 hours depending upon the season. The cooker costs about PRs 1,000-1,500*. Another parabolic concentrating-type solar cooker has been designed at NIST: it cooks like an ordinary gas stove. It costs from PRs 6,000 to 8,000 a unit.

Conclusions and Recommendations

Gilgit weather data have been plotted on the bio-climatic chart and the following passive strategies have been identified.

- Use high insulation on the inside surfaces of walls and rooves.
- The floor slab should be insulated from the underneath and sides. Use of wooden doors and window frames is advisable.

* There are 52 Pakistani rupees to one US dollar.

- Infiltration through doors, windows,and other openings should be minimised.
- South-facing windows are not suitable for direct solar gain in winter and natural ventilation in summer. Windows should not be placed on the west.
- High thermal mass is not advisable as it is detrimental to winter heating which is the predominant need in Gilgit.
- Roof shutters and windows should be used for light during the day.
- Domestic solar water heaters and solar cookers should be used to save energy.
- Further studies are required to estimate the optimum amount of thermal mass to store heat from direct solar gain in winter and to store cooling from nocturnal ventilation in summer.

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4.6 Natural Cooling, Heat Insulation and Improved Wall Materials for Solar Buildings

S.P. Jain

Water Proofing for Rooves : Heat Reflection and Low Heat Conduction

The objective is to eliminate the use of lime-concrete and mud *phuska* cum brick tiling and white washing of RCC/RBC rooves and construct low-cost, comfortable houses with durable, water proof, and maintenance free rooves.

The problems of conventional heat insulation cum water proofing materials and treatments are well-known, e.g.,deterioration of traditional roof surfaces, leakage through cracks in the joints of brick tiles over mud *phuska*-treated rooves, and rain piercing the proofing membrane over compressible lime concrete-treated rooves. Sometimes rooves collapse completely. These defects are caused by extreme climatic variations, i.e., by constant heating and cooling, expansion and contraction of rooves/ thermal movement, U.V. radiation, and rains, etc. Considerable dead-loads on buildings which require additional concrete (15 to 25%) and steel (25 to 35%) because of heavy heat insulation–cum-water-proofing treatment.

White-washing has been the common practice for reflecting incident heat, yet field experience has indicated only marginal improvements in indoor thermal comfort in addition to the many practical difficulties of maintaining the white-wash. Existing rooves are extremely absorptive of incident heat due to their reddish/greyish or algae-blackish surface colour. Such rooves cause discomfort as a result of additional heat gain, reducing human efficiency and productivity. They also add to the (i) cooling loads on conditioned buildings affecting the overall cost of air-conditioning and (ii) maintenance costs and inconvenience to the occupants.

Because rooves receive the greatest proportion of incident heat during the day and lose the greatest amount of stored heat at night, the current shortage in energy and materials,and the above problems and circumstances, a new passive natural cooling technology was designed and developed by the author. Based on the thermophysical properties and availability of suitable materials, this design has been drawn to use the waste and cheaper products available to derive the optimum benefits by meeting the functional needs of rooves in the tropics.

New Approach

In place of heavy lime-concrete and mud *phuska* with clay tile and white-wash, a lightweight concrete (600 to 800 kg/m^3) of cement and a low-cost product such as sintered fly-ash, cinder, or bloated day aggregate could be employed in a ratio of 1:5 and with a thickness of 2.5 cm (average), together with a surface treatment of white glossy/glazed china tile pieces (5.0 cm thick average). Lime concrete can be used instead of the above aggregates. The thinner, light-weight medium types of inorganic insulating materials are used for low-heat conduction and to reduce appreciable dead loads on rooves and heat-flow through rooves.

The other problems are taken care of by using white -glazed China tile pieces. An inorganic water-proofing solution is also mixed with the mortar to make the broken tile pieces water proof.

Table 4.4 shows the relative difference in dead loads, cost, and life expectancy. Now,in principle, the new technology could provide a glossy/glazed white, thin smooth and

Table 4.4: Specifications for Heat Insulating Treatment

S. No	Specifications for heat insulating treatment over 10cm RCC	Total thickness (cm)	Bulk density kg/m^3	Dead loads on buildings kg/m^2	Estimated cost (Rs./m^{2}) at Roorkee in 1997	Life expectancy (years)
1.	10.0 cm lime concrete	20.0	2400	240	162.0	5 to 10
2	10.0 cm mud *Phuska*, 5.0cm brick tile	25.0	1900	285	180.0	5 to 10
3.	0.4 cm glazed white china ceramic tile pieces embedded in 0.4 cm thick cement: sand mortar (1:3)	10.8	2200	18.0	91.0	50 or more
4.	0.4 cm white glazed tile pieces embedded in 1.0 cm thick cement: sand mortar 1:3 over 2.5 thick light weight concrete of density 600 to 800 kg/m^3	13.3	1150	38	142.0	50 or more

weather resistant, durable rock-type surface to the roof, and it has been found to work as the first line of defence against adverse effects of the sun's radiation and rain.

The lightweight concrete should be laid on rooves with a minimum thickness of 2.5 cm.However, the actual thickness is determined by the slope as per the size of the roof for a proper runoff gradient according to Indian standards. This treatment has been used for many buildings.

Table 4.5 compares the performance of conventional panels and the new heat-reflecting panels with thermal chambers (60x60 cm). A comparison of the effects of these panels was made under controlled conditions (uniformity, mixture of materials, degree of supervision, and workmanship) and during different periods of heat flow on a hot, clear sunny and calm day in the actual field.

Table 4.5: Roof Specification

S.No.	Roof Specifications	Measured max surface temp. °C under actual field conditions for representative exposure on a hot summer day (13.6.89) Outdoor maxima (42.4°C) and minima (16.0°C)	
		Exposed roof	Ceiling
1.	10.0 cm RCC	58.0	52.7
2.	10.0 cm lime-concrete 10 cm RCC	53.0	38.8
3.	0.4cm glazed ceramic white china tile pieces on 10.00 cm RCC	41.5	40.2
4.	0.4 cm glazed white china tile in 2.5 cm lightweight concrete over 10.0 cm RCC	43.6	38.4

Apparently, the rooves and ceiling surface temperatures can be reduced by 16.5°C and 12.5°C respectively with the new treatment on a10.0 cm R.C.C. panel and with these new materials. Surface treatment competes well with conventional treatments in thermal performance. When rooms in buildings with rooves of identical size were tested (11.4 cm R.C.C. and a 22.9 cm solid brick wall) by treating one and not the other, the difference in roof, ceiling, and indoor air temperatures were 18°C, 13°C, and 4°C, respectively in the same hot-weather periods. The difference is due to the enclosure effect.

Moreover, in sunny hot, dry and clear weather conditions, when the treated surface could be maintained highly reflective, the temperature of the treated roof terrace was reduced to 20°C compared to the ordinary roof surface. Therefore the thermal performance of alternative heat insulating materials and treatment is remarkable.

Tile pieces should be used with extreme caution. A skilled person is needed to make this application an integral part of roof construction. A judicious combination and application of civil, thermal, and chemical engineering principles is required.

Treated rooves can easily be converted into additional living space. Heat absorption through them is reduced considerably, whereas heat dissipation during the night is quite rapid because of the reduced thickness and reduced heat capacity.

Retention of the Natural Finish of Lime-Surkhi (mixed lime and brick dust) Plaster for Long Periods without Annual Maintenance

A very useful feature of lime-*surkhi* plaster treatment can be seen in the exposed walls of test rooms plastered with lime (July 1997). Probably the reason why algae does not grow on lime- *surkhi* plaster is the high pH value of 12.5 when it is wet. Algae cannot grow under such circumstances and the mixture retains its natural surface for quite a long time. This saves annual maintenance costs as white-washing is not needed every year after the rainy season. Plastering with 2.0 cm thick lime-*surkhi* (1:1.5) is therefore recommended.

Savings of 45 per cent on the use of bricks can be realised by constructing an 11.5 cm thick solid brick wall instead of a 23 cm solid brick wall. However, the initial cost of 2.0 cm of lime-*surkhi* plaster is nearly 1.5 times the cost of 2.0 cm of cement sand plaster (1:6), although the savings in annual maintenance costs are enormous.

To plan and design for minimal maintenance of exposed wall surfaces, a simple low-cost, practical procedure can be adopted for in the tropics.

Improved Wall Material Treatment

Table 4.6 gives a comparison between integrated discomfort degree hours under hot-dry conditions, showing the overall effect of lime-*surkhi* plaster over exposed surfaces of 11.5 cm of solid brick wall and 23.0 cm of solid brick wall in cement sand (1:6) plaster on both sides.

To improve the overall performance of an 11.5 cm solid brick wall, a very simple mixture of lime-*surkhi* (1:15) plaster can be used on exposed wall surfaces. The overall performance is enhanced by its natural high reflection coefficient and low value of thermal conductivity (see Table 4.7.)

Full-scale field testing was carried out with isolated panels of 90 x 60 cm in specified thicknesses in actual rooms to test the results.

The integrated discomfort degree hour (Table 4.6) rating was used to compare the overall behaviour of 2.0 cm thick lime-*surkhi* plaster over an exposed surface of an 11.5 cm thick solid brick wall. In addition, observation of the performance of the water proofing was carried out after the new treatment. It was observed that the differences in integrated discomfort degree hours in per cent (66, 79, and 98) for untreated cases for the two walls (11.5 and 23.0 cm thicknesses) in three (east, south, and west) directions

directions fell considerably to 16, 19, and 23 per cent respectively, due to the lime-*surkhi* plaster treatment. Similarly, the difference in the Tropical Summer Index at 1.2 metres above the floor fell from 37 to 7 per cent with lime-*surkhi* plaster treatment. The minor differences between 16, 19, and 23 per cent can be reduced further.

Table 4.6: Comparison in the Performance of Walls Plastered with Different Materials

	Date (1.6.77)			Date (24.5.79)		
Elements	23.0 cm solid brick wall- cement sand plaster both sides	11.5 cm solid brick wall cement sand plaster both sides	Inferiority % of 11.5 cm thick brick wall w.r.t 23.0 cm thick brick wall plaster both sides	23.0 cm solid brick wall cement sand plaster both sides	11.5 cm solid brick wall 2.0 cm lime- *surkhi* plaster outside	Inferiority % of treated 11.5 cm brick wall
East wall insides surface	71.6	118.6	66	61.7	71.6	16
South wall	44.6	79.7	79	49.0	58.3	19
Inside surface West wall Inside urface	50.3	99.6	98	53.7	67.1	25
T.S.I.	61.3	83.8	37	68	73.2	7

1.2 metres (above floor centre)

Note: -1.2.0 cement plaster was applied on all the inside surfaces of the two test rooms, Cement mortars (1:4) and (1:6) were used in 11.5 and 23.0 cm thick walls respectively.

Table 4.7: Approximate Density, Thermal Conductivity and Reflection Coefficient

Physical Constants	Cement Sand Plaster (1:6)	Lime-*surkhi* Plaster (1:15)
Density (kg/m^3)	1800	1000
Thermal conductivity (K. cal/hr °C m)	0.64	0.38
Reflection coefficient	32.8	65.3

Note: Per cent of cement – sand and lime – *surkhi* plasters and their surfaces

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4.7
Automated Controls and Photovoltaics in Solar Passive Building

N.K. Bansal & V. Garg

INTRODUCTION

Various passive heating concepts such as the (i) Direct Gain, (ii) Glazed Mass Wall, (iii) Trombe Wall, (iv) Solarium, and (v) Thermosiphonic Air Panel (TAP) concepts are schematically shown in Figure 4.12. Bhandari and Bansal (1994) have studied the performance of these systems by determining the two parameters, namely, the solar heat gain factor (g) and the overall heat loss coefficient (U). As soon as losses predominate over gains, these building elements should be provided with an insulating shutter, roller, or other form of insulating system between the passive element and the ambient. Table 4.8 contains U values without and with night insulation as well. It is obvious that failure to install shutter, insulation, or venetian blinds over any of these passive concepts will result in high energy losses. For the climate of Shimla and Leh, approximate energy losses are given in Table 4.8.

Table 4.8: Overall Heat Loss Coefficient, U ($W/m^2\,°K$), and Solar Heat Gain Factor, g, of Passive Heating Concepts

Passive concept glazing	Direct gain			Trombe wall			Thermosiphon air panel			Mass wall			Solarium		
	g	U_I^a	U_{II}^b	g	U_I	U_{II}	g	U_I	U_{II}	g	U_I	U_{II}	g	U_I	U_{II}
Single-glazed	0.92	5.80	3.35	0.37	0.98	0.50	0.43	2.21	1.74	0.29	1.32	0.84	0.17	1.39	1.27
Double-glazed	0.82	2.66	1.63	0.65	0.72	0.37	0.52	1.45	1.17	0.42	1.04	0.69	0.21	1.06	0.98

U_I [a], U value of passive heating element without night insulation
U_{II} [b], U value of passive heating element with 0.05-m thick night insulation

For air conditioning, lighting, etc, the energy losses can be much more than estimated in Table 4.9.

Table 4.9: Estimated Energy Losses in the Failure of Controls or Mechanically Putting Down the Shutters (kWh/m²a)

	Estimated Energy Losses			
	Leh		Shimla	
Concept	SG	DG	SG	DG
Direct gain	294	50	76	22
Trombe wall	57	42	15	11
Thermosiphon air panel	56	33	15	8
Mass wall	57	42	15	11
Solarium	14	10	4	2

Electronic controls in a real building employing passive concepts can be much more demanding as shown in the following example.

In the building given in Figure 4.13, one has mainly direct gain and sunshine. The central atrium acts as a plenum for collecting solar heated air before it is ducted to the production area in winter or vented out in summer.

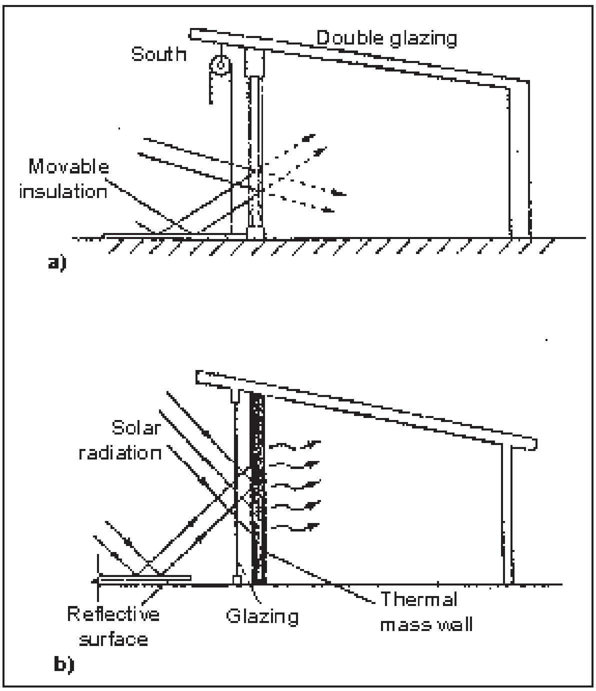

Figure 4.12a: a) Configuration of Direct Gain
b) Configuration of Mass Wall

<u>Autumn/Spring</u>: Excess heat from the south-facing wall is extracted by fan to the top of the atrium. Air from the atrium is heated further if necessary before being distributed to the production area. The blinds on the south-facing wall are set automatically at an angle to admit or reflect solar radiation. Automatic louvers at the top of the atrium admit fresh air to be mixed with the warm air going to the production area. Fans circulate air within the production area to prevent stratification. Glass louvers between the offices

and production area are opened to allow air to return to the atrium via the offices. Radiators operate independently according to the temperature in each zone.

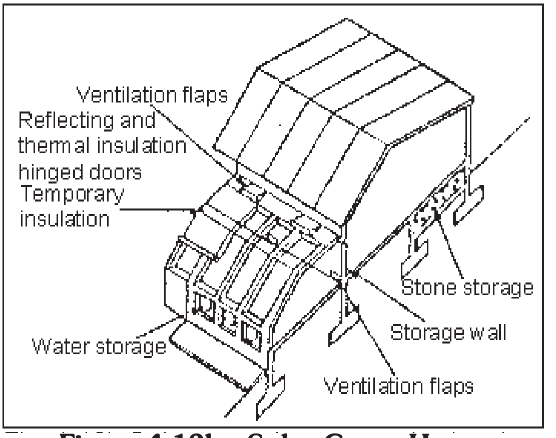

Figure 4.12b: Solar Green House Attached to the Building

Winter: Blinds are set to 10° to allow maximum solar gain. Air at the top of the atrium is ducted to the heater first, then to the production area. Anti-stratification fans are on in the production area. Glass louvers between the atrium and production area are open to allow air to return. Radiators operate independently. In summer, hot air is drawn out of the office into the atrium where it is discharged to the outside. External blinds prevent excessive gains. Opening the windows on the east and west elevations allows cooler air into the offices. All these operations demand precision electronic controls and cannot be achieved manually.

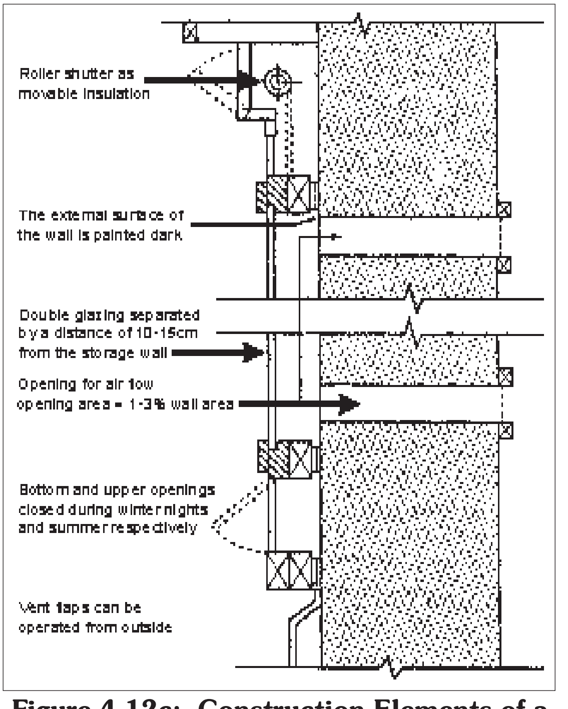

Figure 4.12c: Construction Elements of a Trombe Wall

Electronic controls are used in heating, ventilation, and air-conditioning (HVAC) systems, and their use is on the increase in day-to-day appliances such as venetian blinds, lamps, electrical gadgets, and so on. Figure 4.15 shows a simple analog electronic control system used to control the temperature of a hot wire anemometer for air-flow measurements. Since the heat loss from the heated wire is a function of velocity, one measures the term, I^2R, which can be calibrated to the velocity. The controller produces a current output proportional to the difference in voltage, 'e',between two branches of a wheatstone bridge. An increase in current results from an increase in air flow over and heat transfer from the heated wire. After calibration, the voltage drop across the hot wire is a direct and accurate indication of air flow over the wire.

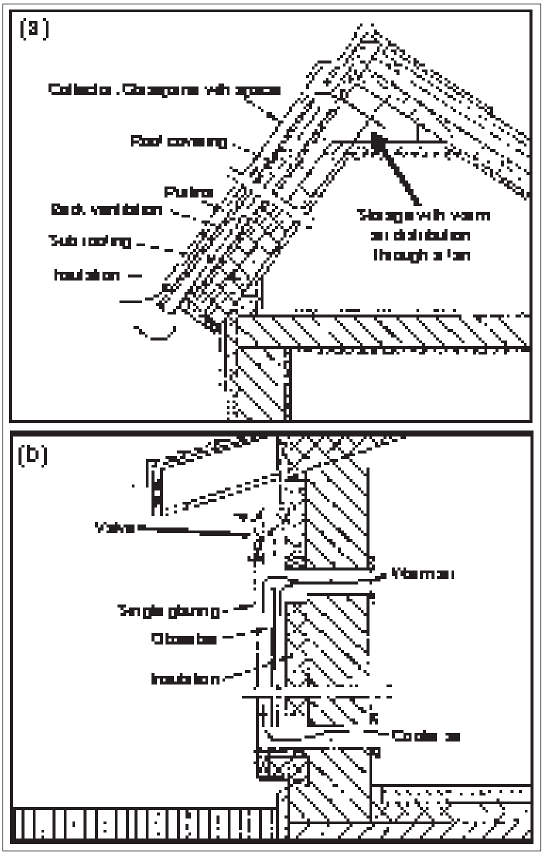

Figure 4.12d: a) Thermosiphon Air Panel Installed on the Roof b) Thermosiphon Air Panel Installed on the Wall

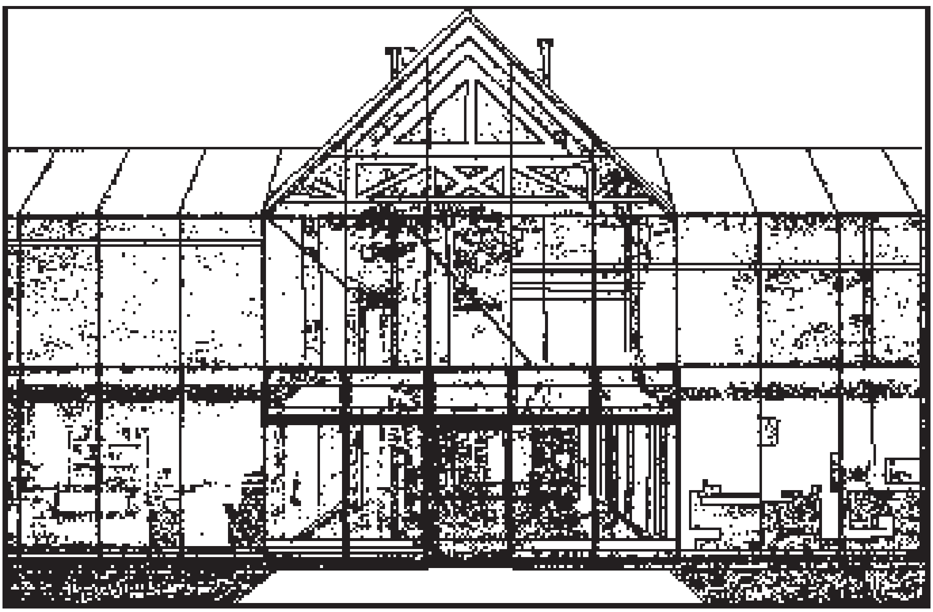

Figure 4.13: JEL Building - Stockport (UK)

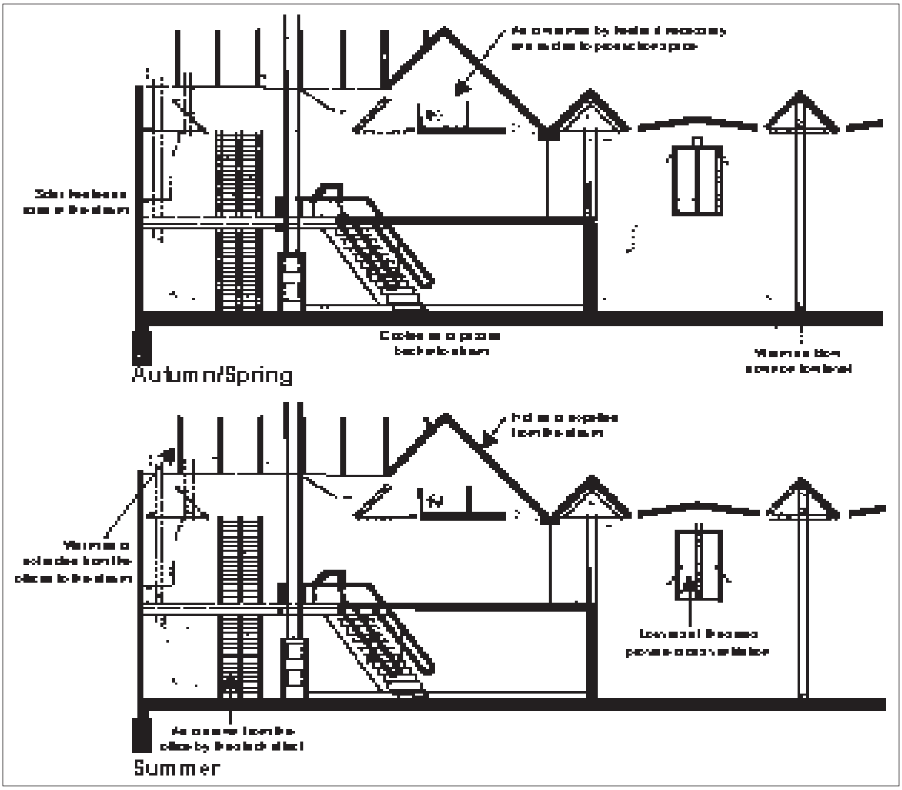

Figure 4.14: Functioning of Different Solar Passive Concepts in a Building

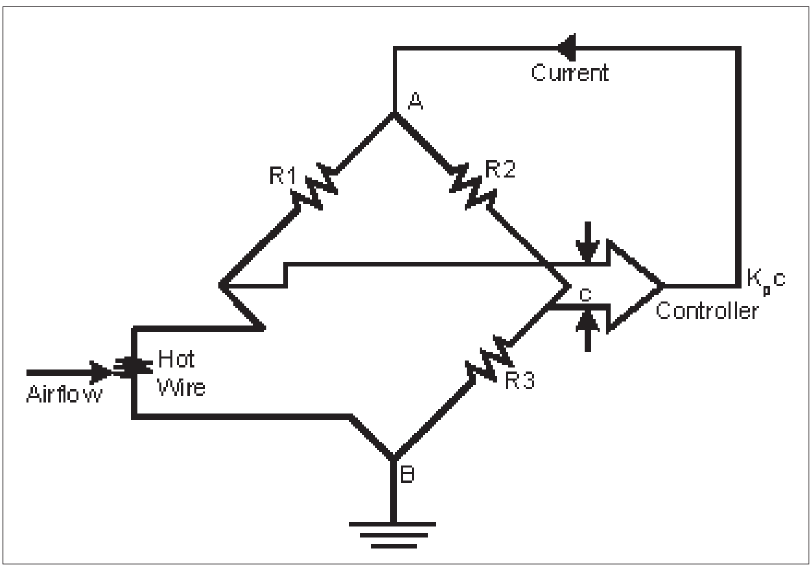

Figure 4.15: Hotwire Anemometer Analog Controller

The hot-wire system embodies all features of an electronic control system. The sensor component is the differential voltage measurement, 'e', across the bridge. The proportional controller and actuator is the wire resistance that indirectly accomplishes the desired control goal - a constant - temperature hot-wire anemometer.

Direct digital control (DDC) — enhances the previous analog-only electronic system with digital computer features. The term 'digital' refers to the use of digital computers in these systems. Modern DDC systems use analog sensors (converted to digital signals within a computer) along with digital computer programmes to control HVAC systems. The output of this micro-processor based system can be used to control electronic, electric, or pneumatic actuators or a combination of them. DDC systems have the advantages of reliability and flexibility that others do not. For example, it is easier to set control constants accurately in computer software than to make adjustments on a controller panel with a screw-driver. DDC systems offer the option of operating *energy management systems* (EMSs) and HVAC diagnostic knowledge-based systems,since the sensor data used for control are very similar to those used in EMSs. Pneumatic systems do not offer this capability. Figure 4.16 shows a schematic diagram of a direct digital controller. The entire control system must include sensors and actuators not shown in the drawing.

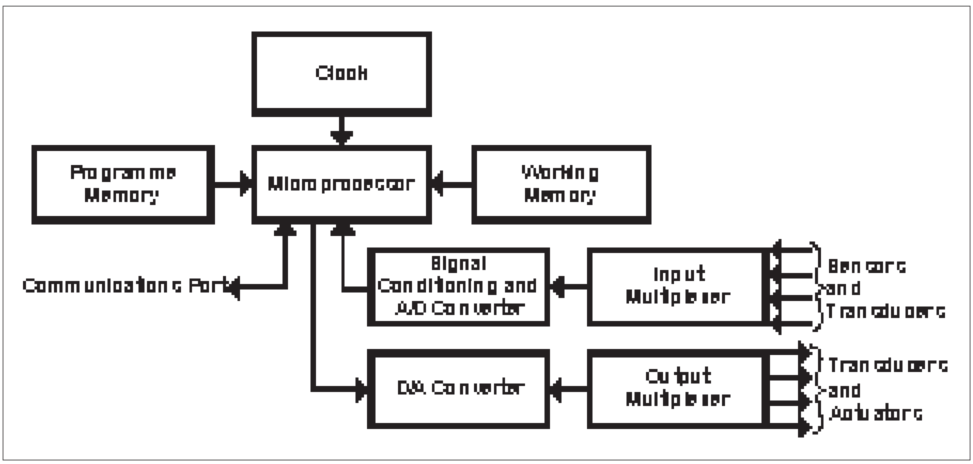

Figure 4.16: Block Diagram of a Direct Digital Controller

Electronic Controls

Basic Control Actions; ON-OFF Control

The on-off controller is the cheapest and most widely-used type. It is the kind that is used in domestic heating systems, refrigerators, and water tanks. When the measured variable is below the set point, the controller is on and the output signal is the maximum value. When the measured variable is above the set point, the controller is off and the output is zero. This process actually shows overshoot and undershoot, which may be as great as or greater then the differential gap of the controller.

Proportional Control (P)

The cycling inherent with on-off control would be objectionable for most processes. For steady operation when disturbances are absent, the controller variable must be a continuous function of the error. With the proportional control, the most widely used type, the controller output is a linear function of the error signal. The controller gain is the fractional change in output divided by the fractional change in input.

Integral Action (I)

With integral control, the controller output is proportional to the integral of the error. There is no offset with integral control, since the output keeps changing as long as any error persists. However, the initial response to an error is slow, and proportional control is ordinarily used with the integral control. The integral action corrects for the offset that usually occurs with proportional control only, and the effect is similar to manual adjustment or resetting of the set point after each load change.

Derivative Action (D)

Derivative action is often added to proportional control to improve the response of slow systems. By increasing the output when the error is changing rapidly, derivative action anticipates the effect of large load changes and reduces the maximum error.

Fuzzy Logic Controller (FLC)

Fuzzy logic reduces complex systems to easy-to-understand rule sets. Whereas a PID loop with automatic tuning requires highly complex mathematics, the mathematics for fuzzy logic controls are considerably simpler.

Classical set theory places definitions into discrete sets, for example, below 23°C the temperature is cool, above 23°C it is normal. Because there is an instant change at the boundary, classical theory does not handle boundary conditions well.

Fuzzy logic takes set theory one step further, allowing partial membership of different sets. For example, 23°C can be described as 60 per cent, belonging to the warm set; 40 per cent belonging to the normal set. Fuzzy logic mathematically reproduces the same ‘intuitive’ control concept used by a human operator.

The operation of controls needs some power, though very small. For a perfect passive house, this power can be provided by a photovoltaic system producing the power required from solar energy. A performance comparison of P,PI,PID controllers is give in Figure 4.17.

Figure 4.18 gives a comparison of a conventional controller with a fuzzy logic controller. The figure clearly shows that the fuzzy logic controller reaches the set point temperature faster then the conventional controller and shows no oscillations.

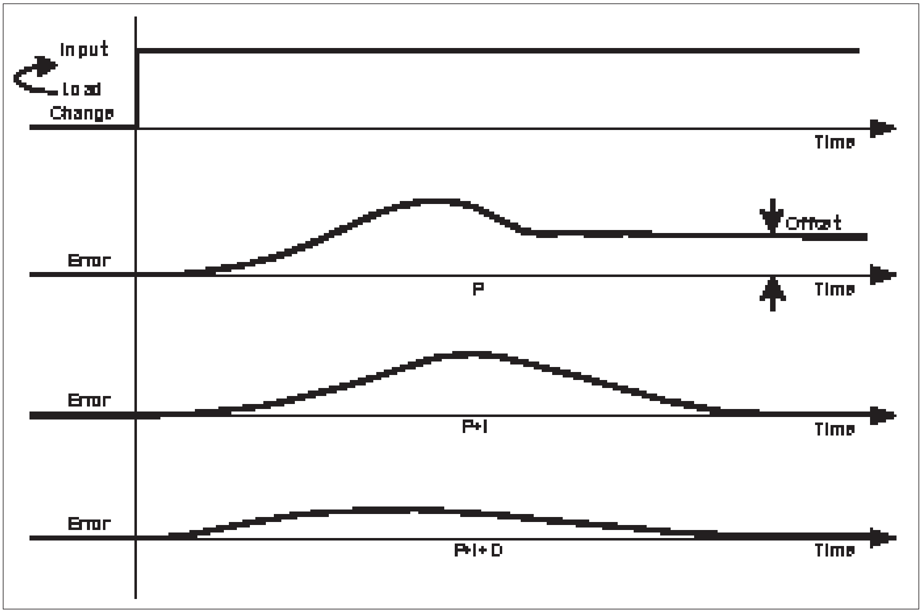

Figure 4.17: Performance Comparison of P,PI,PID Controllers when Subjected to Uniform Step Change

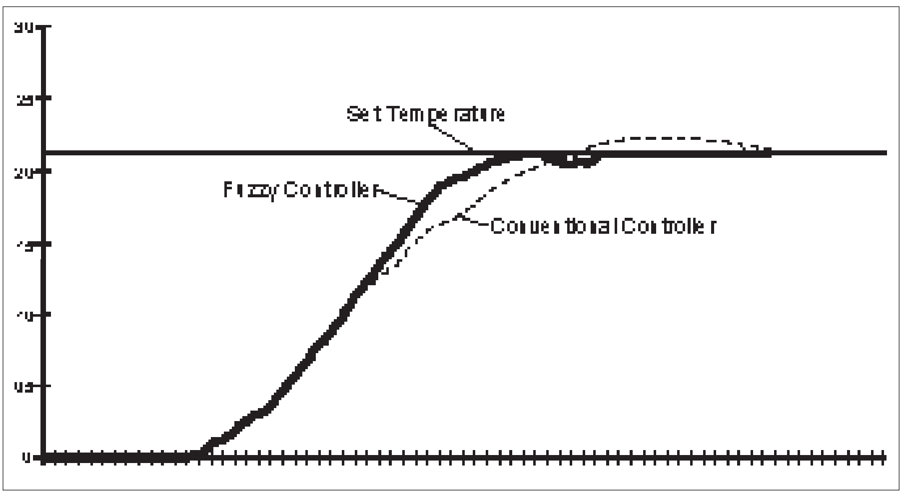

Figure 4.18: The Fuzzy Logic Controls the Set Point Faster and Avoids Overshoot

Photovoltaic (PV) Systems in Buildings

A number of projects based on the centralized system shows that,besides power electronics, which does offer some economical advantage for such a system, a decentralized system providing power to individual houses is better from the point of view of system technique, control, and monitoring. It has also been proved in Europe and America that the integration of photovoltaic modules in the building facades is a sensible possibility for production of electricity that can be used in the building. The use of photovoltaic facades provides protection from weathering, is useful as heat insulation, provides noise protection,and could even be used for air heating. Nowadays photovoltaic modules are available in different colours, allowing the client to choose a surface appearance for the building envelope. The efficiency of photovoltaic modules with different colours is given in Figure 4.19

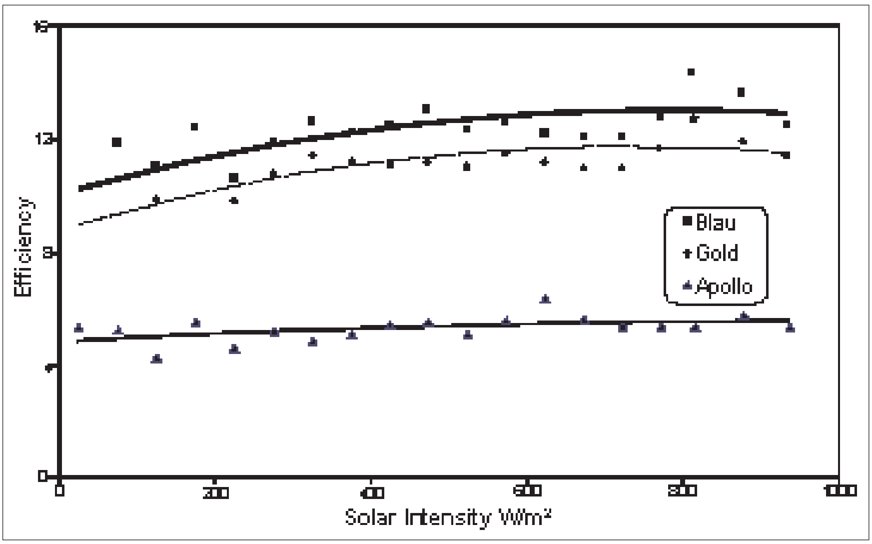

Figure 4.19: Efficiency of Coloured Photovoltaic Modules

It is seen that the average efficiency is about 12.1 per cent for blue-coloured modules and 11.0 per cent for the magnetic colour (Kreider and Robl 1994). The apollo colour efficiency is as low as 5.3 per cent.

Roof integrated solar modules are a common sight in Europe now (Figure 4.20). Roof integrated SPV modules can be properly designed to work as shading devices also. A planner of a photovoltaic integrated building facade or roof in any case needs information about the available energy from the SPV system in relation to the available solar energy and the temperature of the modules. Computer programmes enable visualisation of photovoltaics before actually finalising the building drawings.

Planning Dimensioning of Small PV Systems

An example of the sizing of a photovoltaic system is given in the following passages.

At first it looks simple to design a PV system with the help of different components. However, it is not simple, particularly to design an optimum system that is simultaneously cost effective.

In designing a PV system, one has to first of all know the demand, and this is usually known in average terms. The availability of solar energy is also known in average terms only. Short-time peak demand can be supplied by batteries. It is, however, useful to know the demand profile, and this can be determined from the following information.

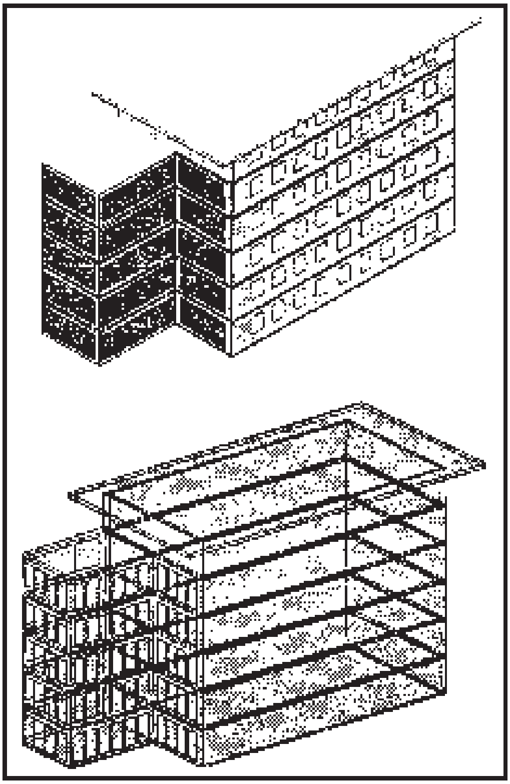

Figure 4.20: Photovoltaic Building Facade

- When should this system work? round the year, only in phases, only during the day or also at night?
- How much energy consumption is there in a given time period (day, week, month); energy consumption with various uses, connecting cycles?
- Which voltage supply is needed or desired,e.g., 6, 12,or 24 V?
- What are the additional considerations, e.g., how long should the system work when the sun is not shining?
- Are there limitations on optimal orientation or inclination of solar modules during installation?

Examples of System Dimensioning

Our example is of a Solar Home System which is used to supply electricity to a house not connected to the grid. The concept of this photovoltaic system is given in Figure 4.21. This house is used only at weekends throughout the year, from Friday afternoon to Monday morning, i.e., three days.

The electricity requirements for all three days can be derived from the following Table 4.10.

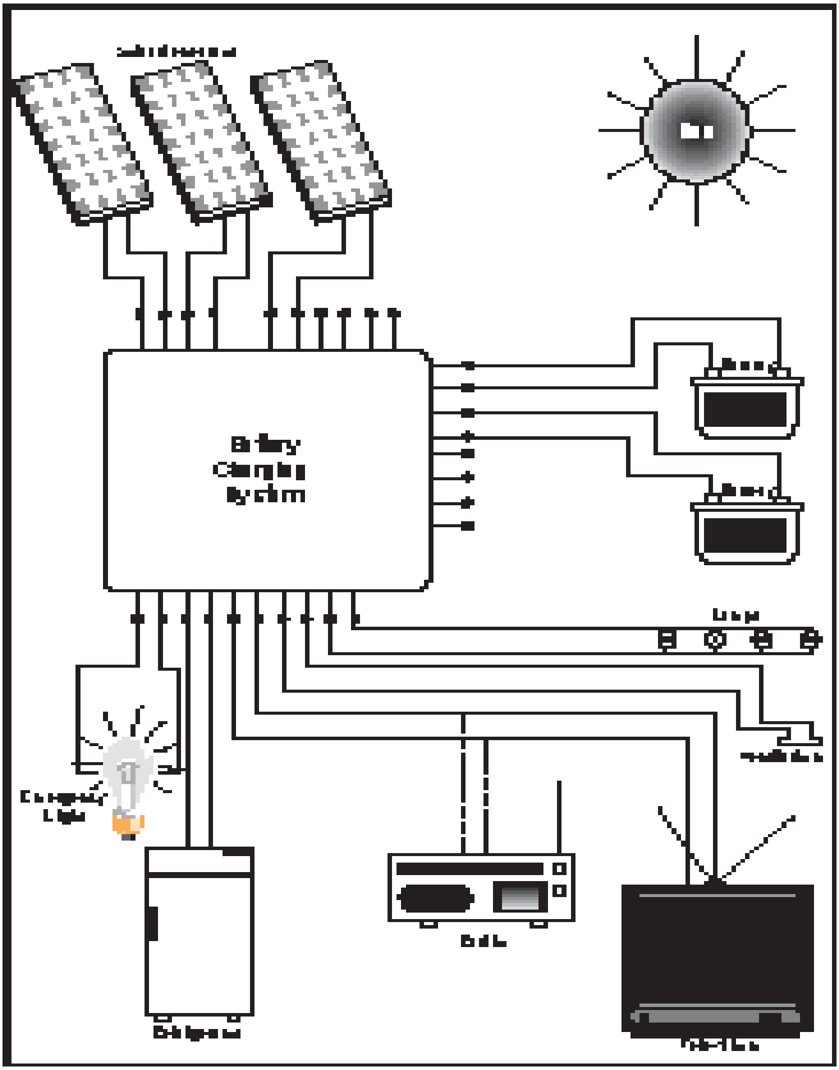

Figure 4.21: Photovoltaic System Supplying Autonomous Electricity to a House

Table 4.10: Energy Demand Calculations (Battery Voltage = 12 V)		
- 5 Lamps (16W) for 3 to 6 h/d	5 x 1.33 x 6 x 3	= 120 Ah
- 2 Radios for 3 h/d	2 x 0.25 x 3 x 3	= 4.5 Ah
- 1 Colour TV for 4 h/d	5.8 x 4 x 3	= 70 Ah
- 1 B&W TV for 2 h/d	1.25 x 2 x 3	= 7.5 Ah
- 1 Refrigerator for 10 h/d	5.8 x 10 x 3	= 174 Ah
- 1 Water pump (60W) for 2 h/d	5 x 2 x 3	= 30 Ah
- Other equipment (drill machine etc.)	5 x 3	= 15 Ah
1 h/d		
Total		421 Ah

Water pumps and other equipment (vacuum cleaner, hand equipment, etc) should be used in the forenoon so that batteries are not loaded unnecessarily. Eventually one can run the refrigerator also with a time control so that when the TV is running the refrigerator is not. These measures do not save energy but reduce the power taken in from the batteries.

The system losses can be taken care of by multiplying the equipment energy requirement of 421 Ah by a factor of 1.2.

In order to determine the size of the battery, there are two important considerations; first of all the safety factor taken fully into account, i.e., the permissible discharge. If one wishes to discharge the batteries up to 40 per cent of capacity, the total capacity has to be increased by 70 per cent, i.e., a multiplication factor of 1.7. One should also take into account a self-discharging rate of two per cent,i.e., a multiplication factor of 1.02.

In total therefore, the following correction factors should be considered.

System losses	= 1.2
Low discharge factor	= 1.7
Self-discharge factor	= 1.02
Total 1.2 x 1.7 x 1.02	= 2.1

The battery capacity therefore should be double the capacity required to run the equipment.

In the present example, therefore, the accumulator capacity is 421 x 2.1 = 884.1 Ah. This can be achieved by having six batteries with 2V individual cells connected in a series and equivalent to 900 Ah. If all the other equipment, except the water pump and hobby equipment, is used simultaneously, it will draw a current of 21 A from the storage battery.

Dimensioning for the energy gain side, i.e., the solar generator, is much more critical because it depends on the available solar energy. In principle, one can divide the calculated accumulator capacity (900 Ah) by the number of days available for collecting solar radiation. This, however, depends greatly on the period of the year. In winter, one has to use winter solar radiation, resulting in a large PV area.

Let us take the solar radiation from Table 4.11. For a 35 Wp monocrystalline module, the output is 14.5 Ah/d i.e. about 72 Ah/week and module. For horizontal installation the number of modules is 900/72 = 12.49, i.e., 13 modules. The number of modules will decrease for an inclined position.

Conclusion

1. It is seen that most passive systems need controlled operation to achieve the best performance.
2. It is difficult to control various operations manually, e.g., closing and opening vents, venetian blinds, air distribution, etc.

Table 4.11: Energy Output from a Monocrystalline 35 Wp Solar Module			
Month	**Average Solar Radiation (Wh/m^2 d)**	**Electrical Output (Wh/d)**	**From PV module (Ah/d [12V])**
January	4806	162	13.5
February	5857	197	16.4
March	6967	234	19.5
April	7900	265	22.1
May	8580	288	24.1
June	8833	288	24.0
July	7903	266	22.2
August	6900	232	19.3
September	5806	195	16.3
October	4800	161	13.4
November	4620	155	13.0
December	4225	142	12.0
Annual Average	6433	216	18.0

2. It is difficult to control various operations manually, e.g., closing and opening vents, venetian blinds, air distribution, etc.
3. Based on simple electrical principles it is possible to develop electronic controls to exercise these options. This needs a suitable choice of sensors and electronic circuit, backed up by adequate software.
4. Out of various types of controls, namely, on/off, P, PI, PID, and fuzzy logic, fuzzy logic is best from the point of view of energy efficiency.
5. The power required to exercise these controls and for other requirements in the building can be provided by solar photovoltaic systems which need to be integrated into building designs. Use of such PV systems can help save on the finishing of external surfaces, simultaneously providing heat insulation, noise insulation, and protection from weathering.

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5

Passive Solar Design of Buildings in the Mountains

5.1
A Review of Various Techniques for Passive Solar Building

M. Hussain

Introduction

In order to be successful, passive solar buildings must interact with the climate in a positive manner. This requires an understanding of climatic factors on the following three levels.

1. The macro-climatic level or an understanding of large-scale regional climatic conditions
2. The micro-climatic level or local-scale environment on the site
3. Internal climate or human-scale conditions within the building

The macro-climate is the general climate of the region determined by the latitude, elevation, and general terrain. Climates in various regions of the country vary from cold composite to normal composite to hot and dry to maritime desert climates. As a result of this climatic variation, architecture also varies from place to place.

Micro-climate, on the other hand, deals with modifications made to the natural landscape and the degree to which this intrusion will influence the environment when a building or a complex of buildings is built. A thorough micro-climatic analysis will suggest to the designer the ideas that go hand in hand with nature, so that man's influence is complementary to the elements that already exist.

The last level is dealt with in the building itself. The interior thermal environment of buildings can be regulated in several ways. Since the ultimate goal of architecture is to provide shelter and comfort, it is necessary to know how we experience comfort in different circumstances.

In order to maintain an average internal metabolic temperature of 37°C, the human body must function well throughout a wide range of climatic and physical activities. Room temperatures between 18°C -25°C (cooler than body temperature) are the temperatures at which the body operates efficiently.

Techniques for Passive Solar Architecture

If a building is designed properly, it will function as a solar collector, collecting heat when the sun is shining and storing it for later use. It will cease to operate when there is not enough heat in storage and when the sun is not shining. To use the sun's energy, the building must satisfy three basic requirements.

Orientation

The building should be oriented in such a way as to allow the sun's rays to penetrate in winter, simultaneously avoiding the summer sun with adequate shading. This helps to keep the building warm during winter without problems of overheating during summer.

Storage

Buildings must store heat for periods when the sun is not shining, and they must store coolness for warm and hot periods when the sun is shining. Probably the most efficient storage container is the material of which the building is made. All materials absorb and store heat as they are warmed. When temperatures around become cooler, the stored heat is released to cooler surroundings. During summer the opposite conditions are in force. If the building is shaded so that little direct solar energy penetrates, heat gains will be limited. At night when the outside air is cooler then it is during the day, ventilation of air into the building will cool the air.

Trapping the Warmth/Coolness

Good use must be made of the heat /coolness, letting it escape only very slowly. An energy conscious building in a cold climate, for example, should have a thermally tight weather skin, incorporating adequate insulation along with double glazing and good quality weather stripping. The building configuration or shape should take the surface to volume ratio into account. The smaller the ratio, the lower the potential for heat loss and gain. Adequate and proper insulation is a primary energy conservation measure, along with its appropriate location or placement. Windows are prime elements affecting the control of heat loss or gain, and these should be designed to accept or reject solar radiation.

Passive solar cooling is simply the tempering of interior spaces by optimising the use of natural thermal phenomena. A structure designed for natural cooling ideally incorporates features that minimise heat gains. Wherever possible, the external heat gains should be controlled before they reach or penetrate the weather skin. Also internal heat gains through lights, people, and equipment should be reduced by both design and management. Many passive cooling methods include cross ventilation, radiation to the sky, day to night cooling and opening of walls or rooves, induction of pre-cooled air, night cooling of interior air and building masses, earth tempering, and water evaporation. This science integrates traditional architectural solutions, modern materials, refined knowledge of thermodynamics, and the use of all nature's helpful patterns.

Direct System

Direct systems are the most commonly used in passive solar buildings and are generally the most efficient way to use the sun's heat. In this system, the heat is collected through windows (collectors) directly facing the sun which admit winter radiation. The interior space contains adequate thermal storage material in the building structure and furnishing that absorbs solar energy (Figure 5.1). During the summer, the windows, walls, and rooves are opened during the night for natural/induced ventilation, cooling the thermal mass and the interior space (Figure 5.2).

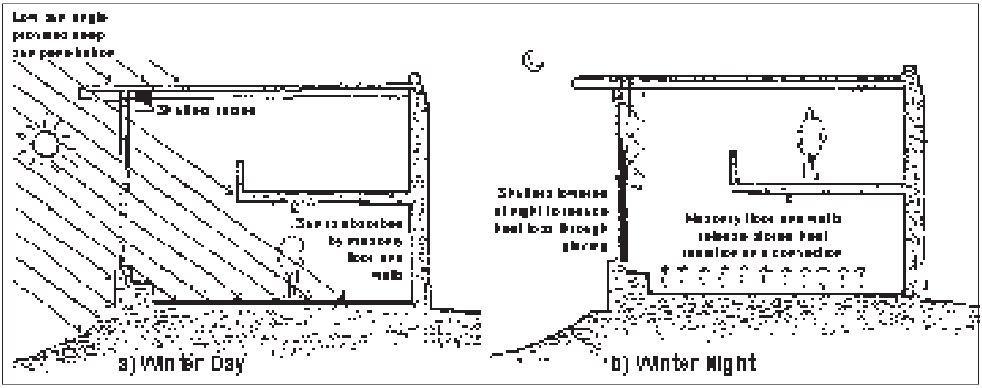

Figure 5.1: Direct Passive Solar Heating

Various building elements should be provided with adequate shading to minimise

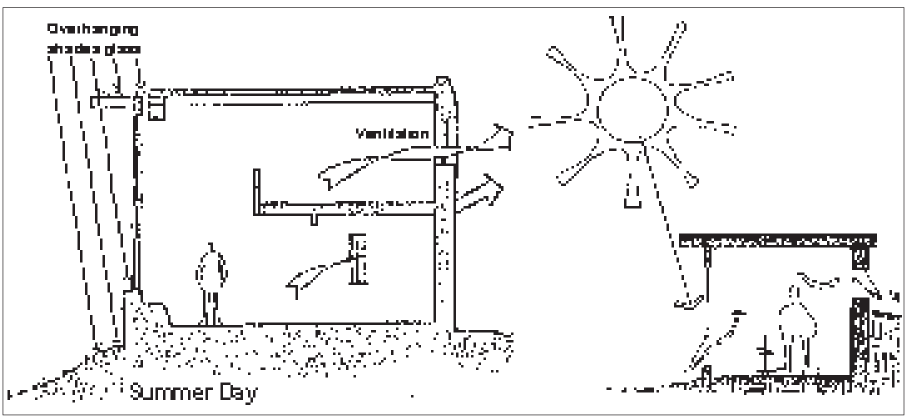

Figure 5.2: Direct Passive Solar Cooling

the amount of radiation absorbed by the outside surfaces during summer. The roof requires maximum attention in this respect since it receives maximum radiation in summer. Surface shading can be provided as an integral part of the building or it can be provided by a separate additional cover.

Shading provided by external means should be such that it does not interfere with night-time cooling. This is particularly important for roof surfaces that are exposed to the cool night sky. A cover over the roof provided by the solid concrete or galvanised iron sheets provides protection from direct radiation, but it does not permit radiation to the night sky. An alternative method is to provide a cover of deciduous plants or creepers. Because of the evaporation from the surface of the leaves, the temperature of such a cover will be lower than the day-time air temperature and at night it may be even lower than the sky temperature (Figures 5.3 and 5.4).

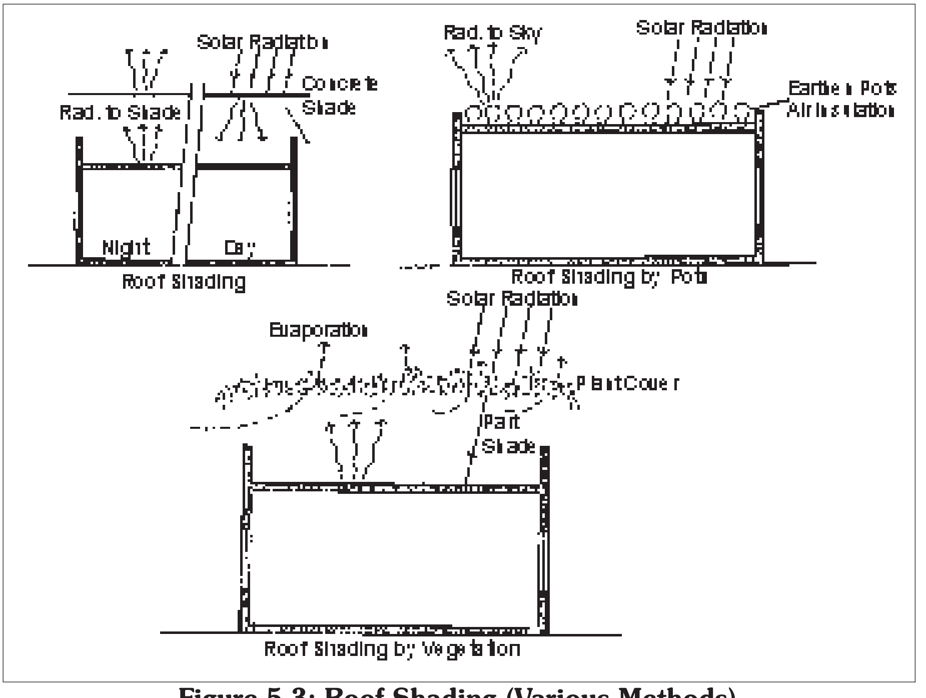

Figure 5.3: Roof Shading (Various Methods)

Indirect System

In the indirect passive system, a thermal storage mass is introduced between the direct solar radiation and the living space (Figures 5.5 and 5.6).

The heat is transferred through the thermal storage mass by conduction, then to the space by radiation and convection. The heat between the mass wall and the glazing can be conveyed to the interior if the mass wall is vented. Such a mass wall is commonly known as a ‘Trombe Wall’. The thermal storage mass is generally of a thick and

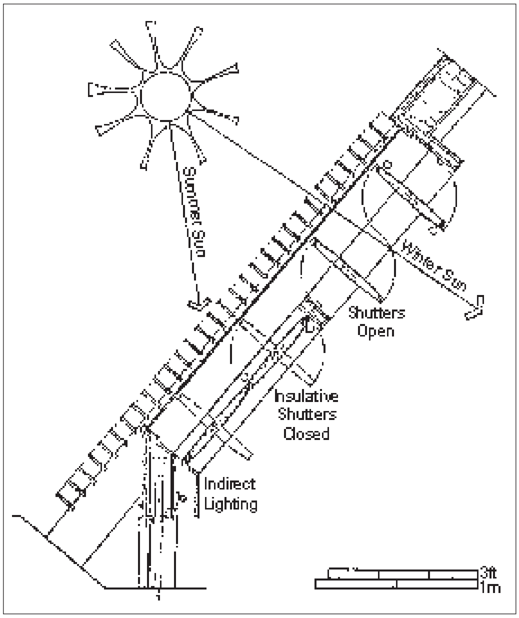

Figure 5.4: Detail of Insulated Louver and Summer Sunshade

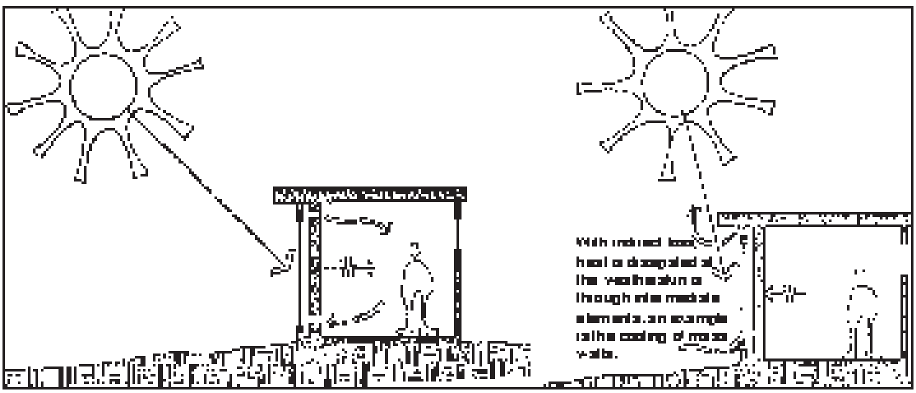

Figure 5.5: Indirect Passive System

heavier material and is placed directly behind the south glazing. The mass wall should be shaded and vented to the exterior during summer months, particularly at night to facilitate additional cooling.

Roof pond (suggested by Hay and Yellot [1969]) storage is another indirect system that places the liquid storage mass on the roof top. It is fitted with operable insulation panels. In the cold season, these panels are moved during the day to expose the storage mass to the sun so that it can absorb energy. At night the panels are replaced over the storage, allowing the stored energy to radiate to the interior of the building. During summer, this process is reversed. The roof pond is covered by insulation panels

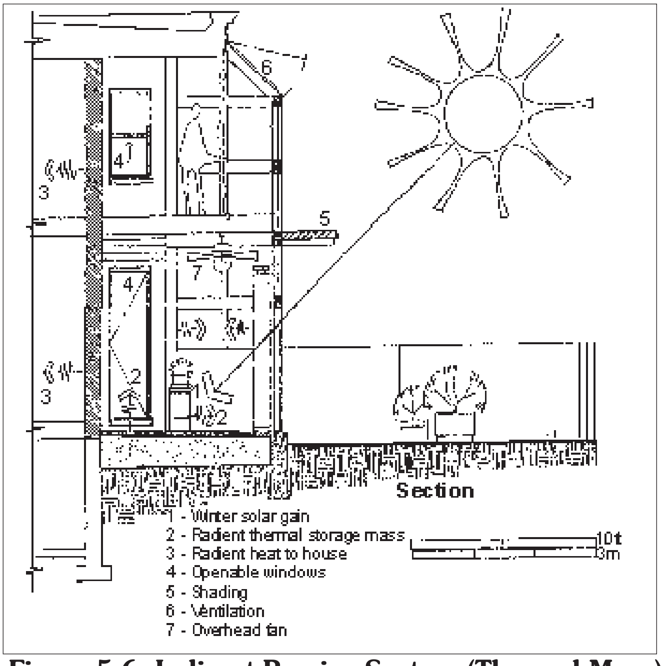

Figure 5.6: Indirect Passive System (Thermal Mass)

during the day, so that internal heat is absorbed by the roof pond, thereby cooling the space. At night the panels are opened allowing the storage mass to radiate heat to the environment by evaporation, convection, and radiation, thus the water attains its capacity to cool the living space (Figure 5.7).

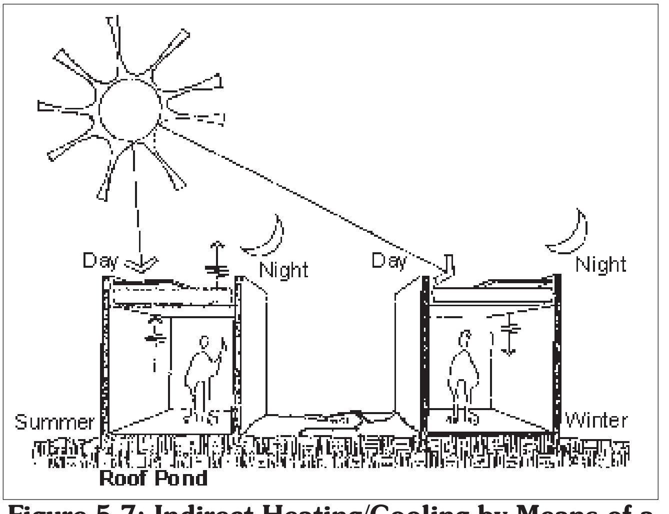

Figure 5.7: Indirect Heating/Cooling by Means of a Roof Pond

Isolated System

In this system, the collection/dissipation of heat is adjacent to or away from the weather skin and remote from the living space. Heat is drawn directly from the thermal storage mass as needed. Greater flexibility in design and operation can be attained by isolating the building from the solar energy collector and the storage (Figure 5.8).

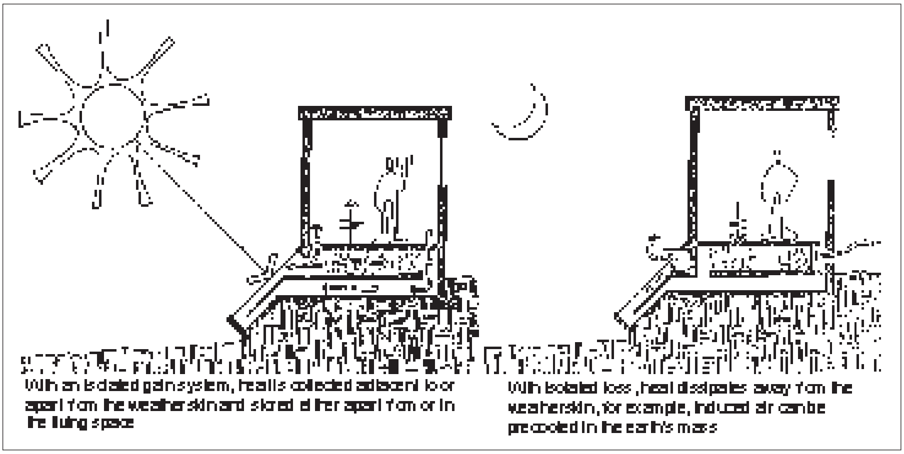

Figure 5.8: Isolated Passive System

The concept of an attached solarium or greenhouse proposed by Balcomb (1978) represents a marriage of the concepts of direct and indirect gain. The living space has a thermal storage wall on the south and attached to this is a space enclosed by glass. The glass enclosure, called a sun space, receives the heat by direct gain while the living space receives it indirectly through the thermal storage wall in between (Figure 5.9).

The system works on the basis of thermosiphoning, whereby the air, as it is heated or cooled, induces a cycle of air flow. As the sun warms the collection surface, the air rises, pulling the cooler air from the storage, thus causing a natural convection loop.The

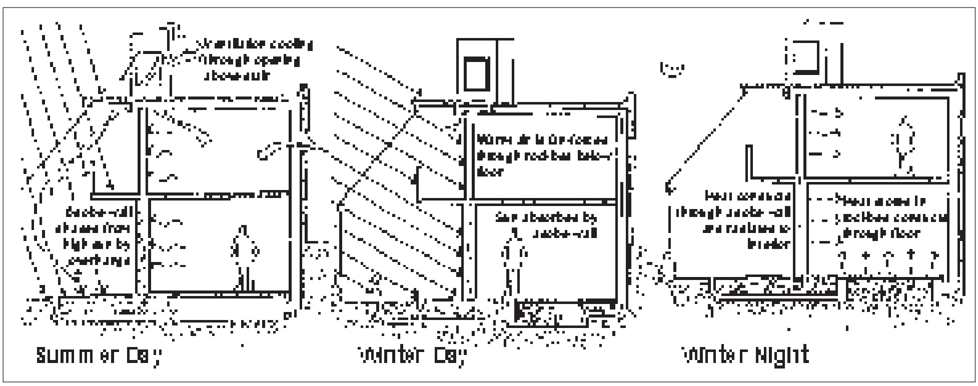

Figure 5.9:A Sun Space as Part of the Passive System

air thus circulated heats the interior spaces. Once the heat is conveyed to the interior space, the air falls and returns to the collection area, and this cycle continues. The highest point of the convection loop can be opened in summer to allow the heated air to escape, thus inducing the pre-cooled air through the interior spaces.

The double envelope is another effective approach in which the heated air flows around the building's interior core. The layer of tempered air insulates the building (Figure 5.10). Evaporative cooling methods have long been used successfully, particularly in dry climates. Double envelopes work on the principle that evaporation of water takes place by conversion of sensible heat into latent heat, a large amount of heat is, therefore, removed through this method. The evaporative cooling system most commonly employed is a window unit air cooler with evaporative pads, a fan, and a pump, but many innovative evaporative coolers have been developed in different countries.

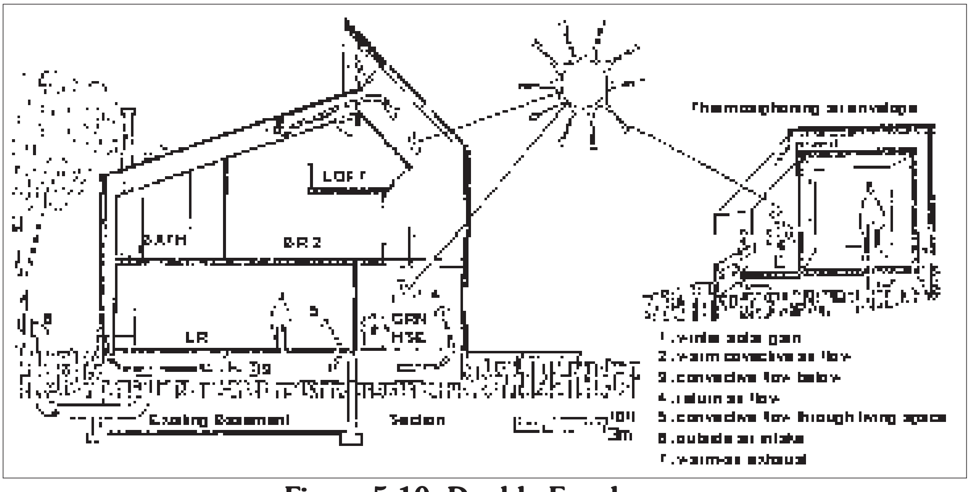

Figure 5.10: Double Envelope

Many passive solar buildings combine features of direct, indirect, and isolated systems. Each feature is incorporated according to varying degrees of design needs. For example, a mass wall may be used in living rooms to prevent the damage to furniture by direct sun, while direct gain may be desirable in a bedroom to catch the early sun (Figure 5.11).

Hybrid System

Although passive solar systems or their combinations can be designed to work well in most climates, certain mechanical features are sometimes added to enhance their performance.

When the operation of a passive system relies on mechanical means, e.g., a fan or a pump, it is classified as a Hybrid System (Figure 5.12). This system offers improved collection of solar energy and efficient removal of excessive solar heat. It facilitates a

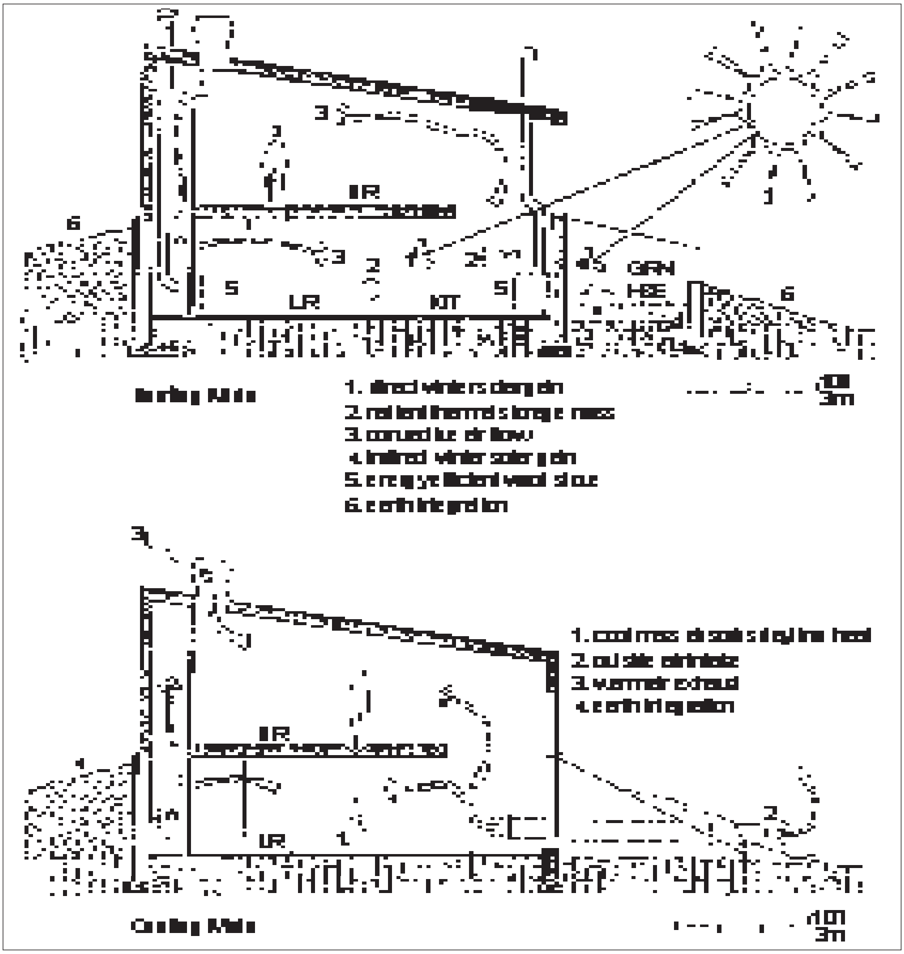

Figure 5.11: Combination of Systems

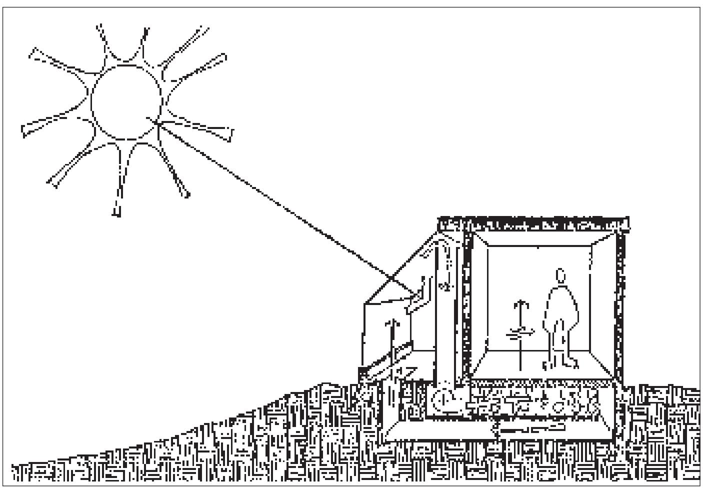

Figure 5.12: Hybrid System

balanced distribution of solar energy and eliminates hot or cold areas. Automation of the system reduces the need for manual participation.

An example of a hybrid design is a passive solar greenhouse which collects large amounts of solar energy, yet contains no thermal mass. A thermostatically controlled fan draws off the heated air to well within the building. The stored heat may slowly be conducted through a floor slab, then radiate to warm a room on the northern orientation. Thermal storage is mechanically charged while the distribution is passive (Figures 5.13 and 5.14). Establishing an intermittent spray of water on the roof, thermostatically controlled, is another effective method of cooling in the summer months. This system requires a pump along with a thermostat and is successful in areas where abundant water is available.

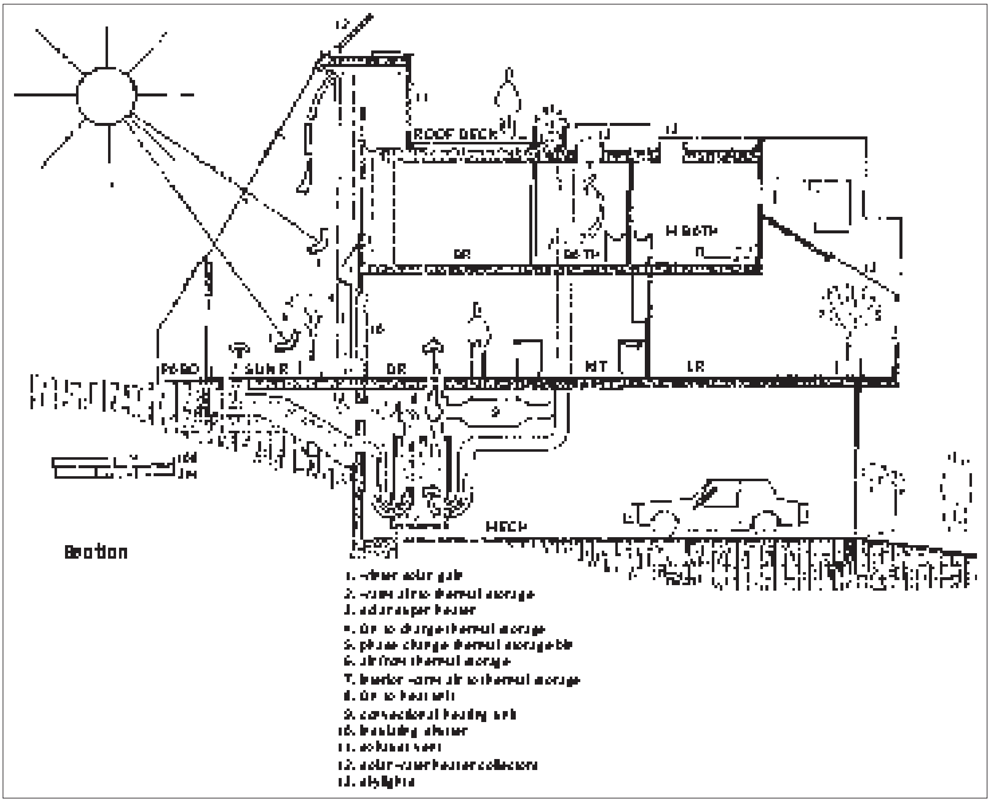

Figure 5.13: Hybrid System

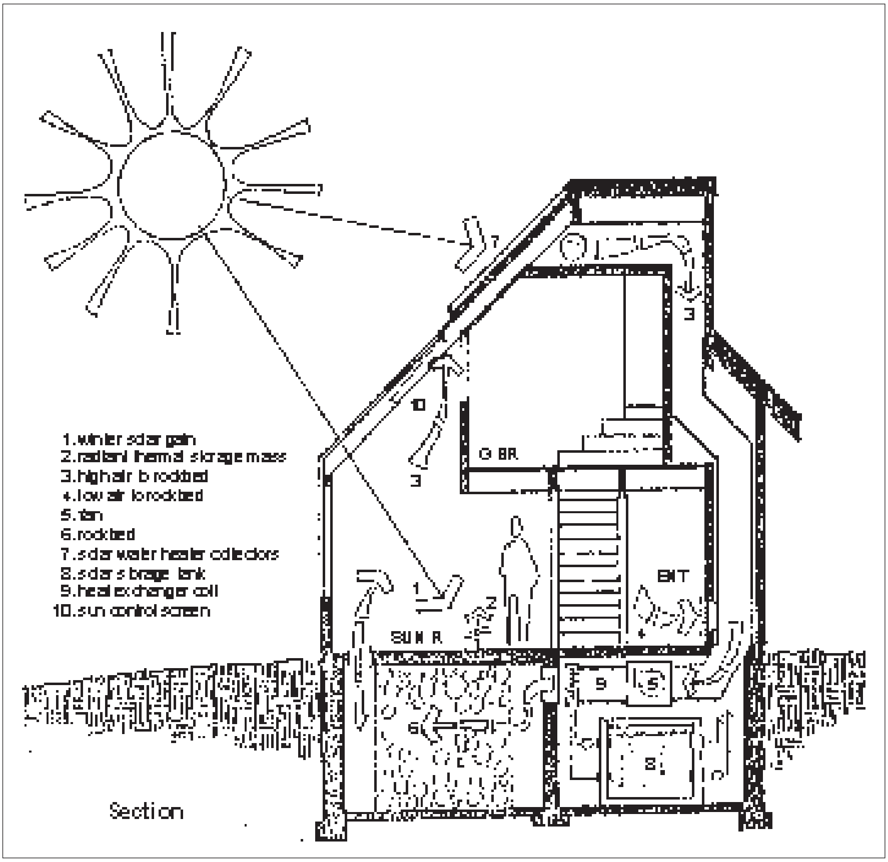

Figure 5.14: Hybrid System

Conclusion

As long as the energy was abundant and cheap, the excesses of international style were of little concern. Dependence on mechanical means for heating and cooling was largely accepted by architects and clients alike. Now, with the depletion in non-renewable energy sources, ecological implications, and the exponentially increasing energy bills, architects are forced to design and construct buildings with passive solar concepts that are able to maintain acceptable internal temperatures even in extreme climatic conditions. Significant research in climatic design has continued since 1950. Still there is a need in the developing countries to investigate, more particularly, passive concepts of cooling and heating.

It is estimated that more than 80 per cent of all the residential buildings that will exist in the year 2000 A.D. are already built without or with little regard to passive concepts. For passive solar architecture and energy-conscious design principles to have an impact on the residential sector, renovating and weathering of existing housing stock must be given priority.

These renovations should aim at the following.

a) Design and installation of simple passive systems with typical components that can be used in a majority of projects
b) Interface with the existing passive systems, if any
c) Improving the function and appearance of existing residences
d) Improving cross ventilation for summer cooling
e) Optimising the use of passive solar gains
f) Investigating new passive concepts of cooling and heating the buildings

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5.2
Thermal Simulation for Energy Conservation: Case Studies of CPWD Buildings in High Altitude Regions

N.K. Bansal & S. Yadav

Introduction

A detailed analysis of **three** case studies is presented. These buildings cover two major climates in high altitude regions; **cold and cloudy** and **cold and sunny**. They also represent thermal analysis through computer simulation for various energy conserving options. The representative locations are **Shimla** (HP), **Gauchar** (UP), and **Leh** (Jammu and Kashmir).

Generalisations concerning building performance are difficult and sometimes impossible due to the diversity of building types and climates (design, construction, hours of use, etc). However, the case studies presented confirm that it is possible to design passive solar energy-efficient buildings within conventional constraints that are well accepted by clients, owners, and occupants. Energy savings, with a combination of various passive features, for the case studies range from 10-70 per cent. These savings can be attributed to the use of double glazing, insulation, cavity construction, orientation, micro-climate, and sun space.

Climatic Conditions

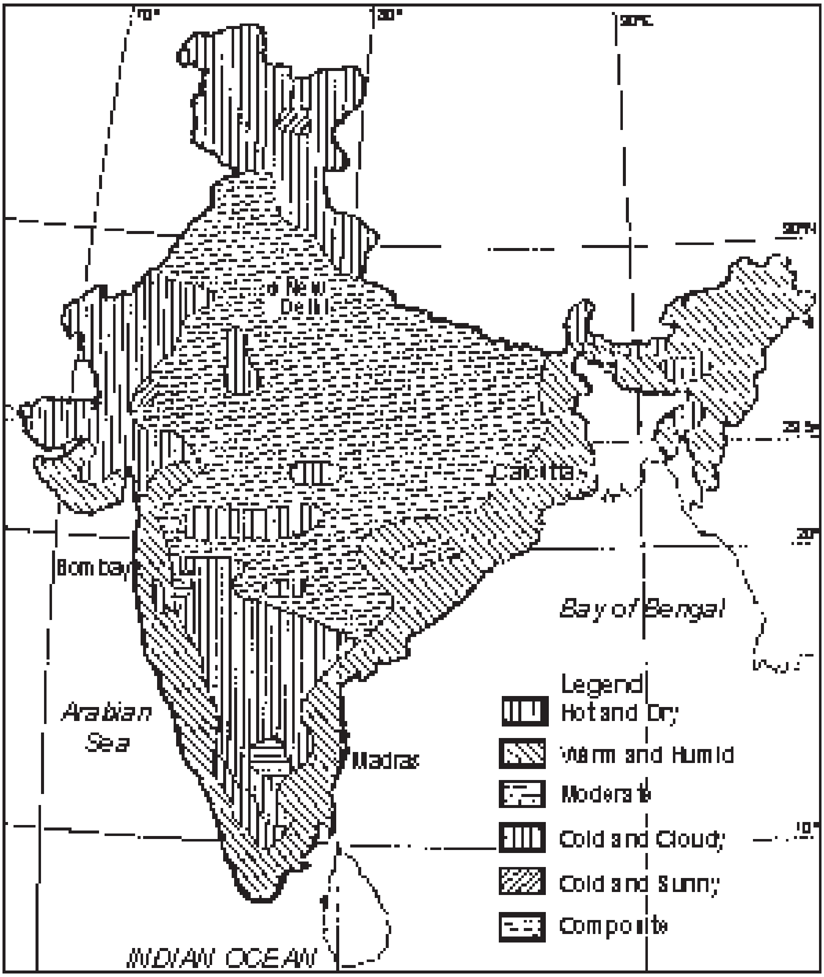
India has a wide variety of climates, ranging from extremely hot desert regions to high altitude locations with severely cold conditions. On the basis of monthly mean data recorded in 233 stations located in all parts or India, the country has been divided into the following six climatic zones (Bansal and Minke 1995).

1. Hot and Humid (HD)

2. Warm and Humid (WH)
3. Moderate (MO)
4. Cold and Cloudy (CC)
5. Cold and Sunny (CS)
6. Composite (CO)

As can be observed from the map (Map 5.1) the hilly region is dominated by either a cold and cloudy or cold and sunny climate.

The detailed climatic data for two representative locations (cold and cloudy and cold and sunny) are given in Tables 5.1 and 5.2.



Map 5.1: Climatic Zones of India

Table 5.1: Climatic Data for Shimla

Location Shimla	**Climate Type (Cold and Cloudy)**
Latitude: 31°06'N	Annual mean maximum temperature: 17.1°C
Longitude: 77°10'E	Annual mean minimum temperature: 10.1°C
Altitude: 2,202m above mean sea level	Annual mean temperature: 13.6°C
	Annual range of mean temperature 7.0°C
	Annual global solar radiation: 2,412 kW/hm^2

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature (°C)												
Maximum	8.5	10.3	14.4	19.2	23.4	24.3	21.0	20.1	20.0	17.9	15.0	11.3
Average	5.2	6.7	10.6	15.2	19.2	20.2	18.3	17.6	16.9	14.3	11.1	7.7
Minimum	1.9	3.1	6.8	11.2	15.0	16.2	15.6	15.2	13.8	10.8	7.3	4.2
Relative Humidity (I)												
Morning	48	45	37	32	34	53	86	89	75	47	31	36
Evening	62	59	48	37	35	53	88	92	82	59	48	55
Rainfall (mm)	65.2	47.6	58.1	37.6	53.7	147.5	414.5	385.4	195.2	45.4	6.7	23.7
Wind Speed (m/s)	1.1	1.2	1.3	1.3	1.2	1.0	0.8	0.7	0.8	0.9	0.9	1.0
Wind Direction												
Morning	SE	S	S	S	NE	NE	NE	NE	NE	NE	NE	SE
Evening	S	S	S	S	SW	SW	S	S	SW	SW	S	S
No. of Clear..												
Mornings	15	15	17	19	22	16	3	3	13	25	25	19
Evenings	11	10	13	14	17	11	2	1	7	22	23	15
Solar Radiation (kWh/m^2)	55	52	60	61	65	63	65	63	58	57	53	54

Table 5.2: Climatic Data for Leh

Location LEH
Latitude: 34°09'N
Longitude: 77°34'E
Altitude: 3,514m above mean sea level

Climate Type (Cold and Shiny)
Annual mean maximum temperature: 12.4°C
Annual mean minimum temperature: -1.4°C
Annual mean temperature: 5.5°C
Annual range of mean temperature 13.8°C
Annual global solar radiation: 2,315 kW/hm^2

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature (°C)												
Maximum	-2.8	0.8	6.4	12.4	17.1	21.1	24.7	24.2	20.9	14.2	7.8	1.6
Average	-8.4	-5.5	0.0	5.6	9.9	13.9	17.4	16.9	13.1	6.6	0.6	-4.7
Minimum	-14.0	-11.8	-6.3	-1.2	2.8	6.7	10.2	9.6	5.4	-0.9	-6.6	-11.1
Relative Humidity (I)												
Morning	61	59	55	50	39	39	49	54	47	45	45	54
Evening	51	46	43	32	27	24	34	36	32	28	34	42
Rainfall (mm)	11.8	8.6	11.9	6.5	6.5	4.3	15.7	19.5	12.2	7.1	2.9	8.0
Wind Speed (m/s)	0.9	1.0	1.5	1.9	1.9	1.8	1.4	1.3	1.3	1.4	1.4	1.0
Wind Direction												
Morning	NE	NE	S	S	S	S	S	SW	S	S	NE	NE
Evening	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
No. of Clear..												
Mornings	23	21	25	27	26	27	25	26	26	29	28	24
Evenings	23	23	24	24	24	26	25	25	26	28	27	25
Solar Radiation (kWh/m^2)												
Global	131	**150**	201	230	265	267	265	238	195	165	127	109
Diffuse	47	47	54	61	65	64	65	63	52	51	45	40

Case Study 1 ITBP Barracks at Leh (Jammu and Kashmir): Cold and Sunny Climate	
Location	Leh is located at an altitude of 3,514 masl mean, at a latitude of 34° 09' N, and 77° 34' E longitude.
Project	The premises are generally meant for residences for army personnel.
Site Micro-climate	The site for ITBP covers an area of approximately 80 acres, essentially drawn up for a housing scheme. The site gently slopes towards the west, with no ground cover, facing the prevalent S-W winds. It also receives very intense solar radiation throughout the year with clear sunshine days as high as 25 days a month.
Building Form	The individual building block is designed as a residential block of built up area approximately 34 sq. m. The typical floor plan for each unit consists of habitable rooms, i.e., drawing room, bedroom, and lounge facing due South and utilities (kitchen, toilet) located in the North (Figure 5.15).
Construction	Walls are designed as load-bearing walls of 375 mm thick stone. The exposed roof is RCC slab with insulation on the outside with terracing. The plinth walls are lined with 2" thick insulation internally to cater to the condensation and thereby seepage problems. Openings are in the form of double glazed windows and Trombe Walls. The inner layer of the Trombe Wall is made of 200 mm thick hollow concrete blocks (Figure 5.16).
Thermal Performance Analysis	The typical floor plan has been divided into 4 zones for the simulation programme. There is a substantial temperature differential between the zone temperatures and the ambient, yet the temperatures within the zone are below 0°C. The reasons for the same are as follow. 1. Heat loss through the windows and the building envelope 2. Shading of Trombe Wall due to the staggered building design 3. Infiltration of prevalent cool winds from the South-West

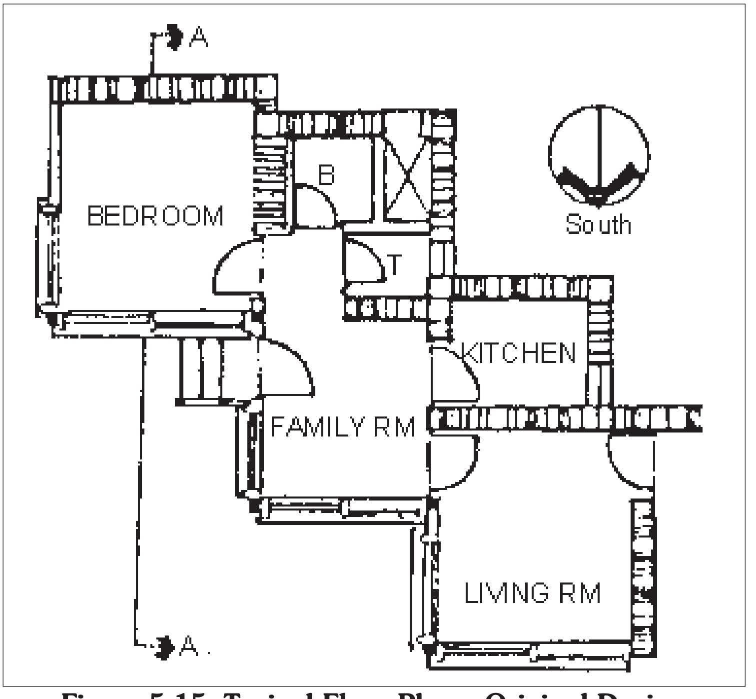


Figure 5.15: Typical Floor Plan – Original Design

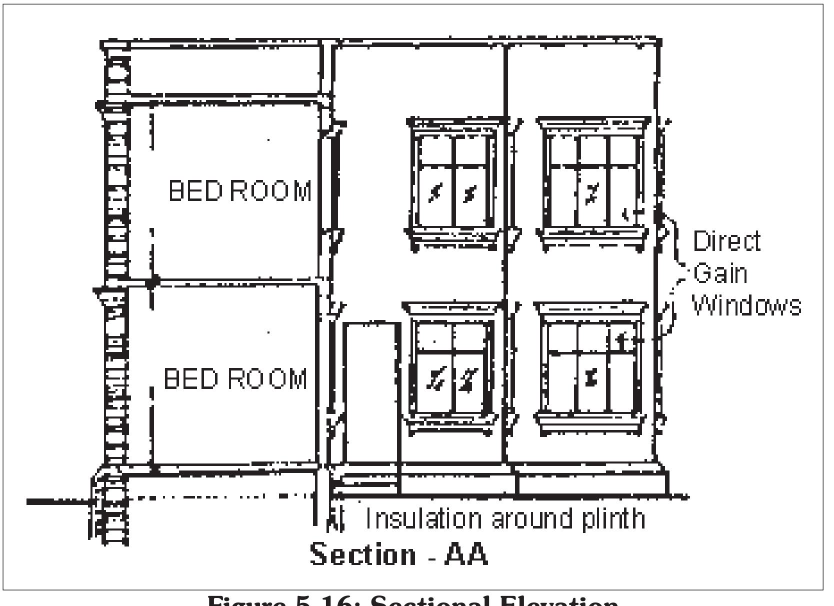


Figure 5.16: Sectional Elevation

Various Options Analysed

1. Orientation
2. Effectiveness of Trombe Wall/Interchanging the position of the Trombe Wall with Direct Glazed Windows
3. Addition of Sun Space
4. Insulation

Design Recommendations

Based on analytical study of the simulation results and the corresponding study of the recommended design changes; the following are the design recommendations (See Thermal Analysis Figure 5.17 and Recommended Design Figure 5.18).

1. Addition of a single height/double height glass house facing south adjoining at least two rooms on the ground floor and two rooms on the first floor
2. 10 cm. thick insulation on the East, West, and North walls, except in the toilet, kitchen, and store (to act as buffer against the cold winds)
3. A 15 cm. thick roof insulation, partly above and partly below the roof slab
4. Interchanging the position of Trombe Walls and direct gain windows to avoid shading of Trombe Walls by adjoining staggered walls
5. Replacement of hollow concrete blocks in the Trombe Wall by solid concrete blocks

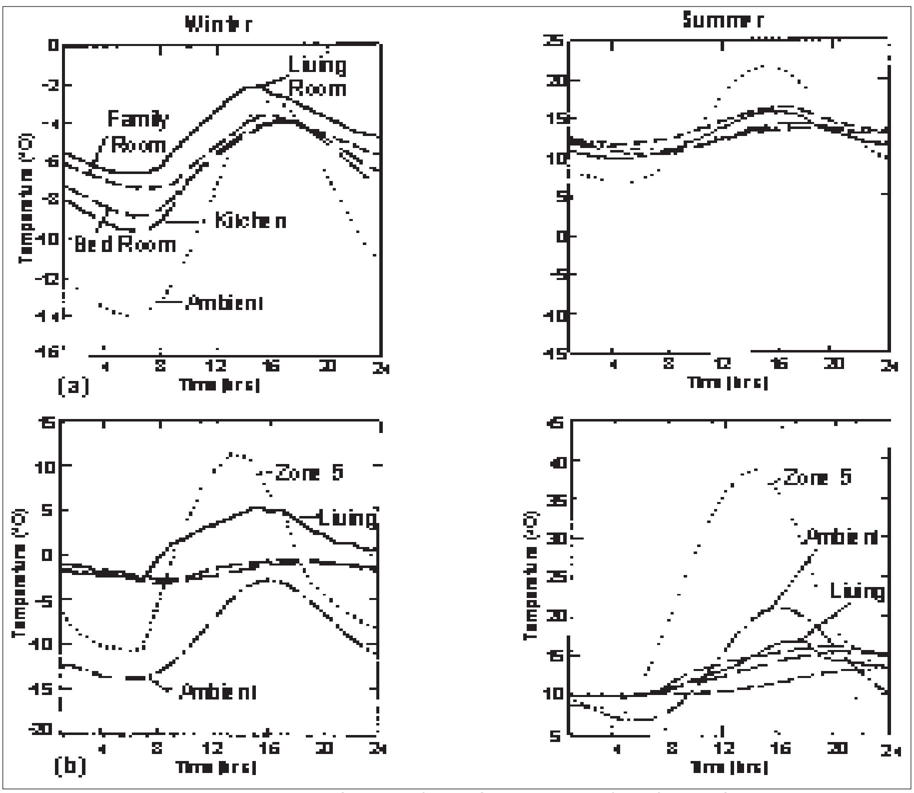


Figure 5.17: Thermal Performance Analysis for (a) Original Design and (b) Recommended Design

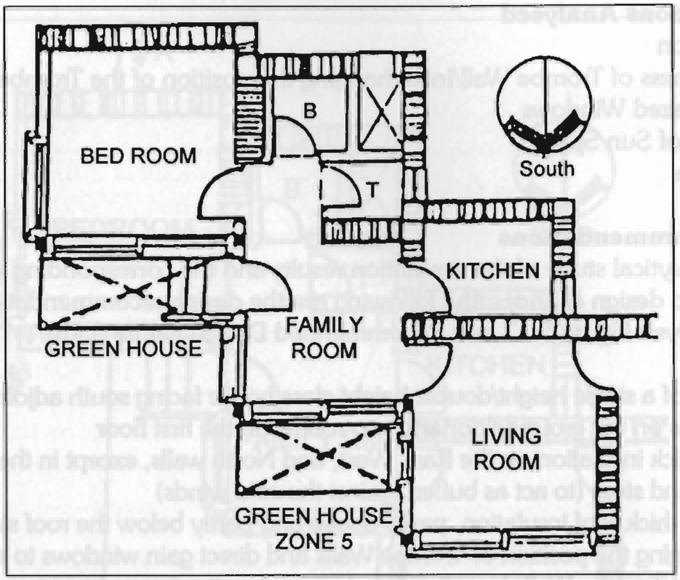


Figure 5.18: Typical Floor Plan - Recommended Design

Case Study 2 **ITBP Barracks at Gauchar, Uttar Pradesh. Cold and Cloudy**	
Location	Gauchar is located in the Garhwal region of Uttar Pradesh, at an altitude of 780 masl, a latitude of 30.4° North, and a longitude of 79.2° East.
Project Site	The building by CPWD is meant for residential purposes for ITBP, army personnel.
Site Micro-climate	The building is designed as a residential barracks for ITBP, with a total built up area of 1,754 sq.m. Each residential block comprises of a dormitory of 20 beds (140 sq.m. area in each zone), and there are 60 beds in each of the blocks. Toilet blocks are separated from the dormitory by a lobby. The longer axis is oriented towards North-East and South-West. Both the major walls on the North and South have cupboards serving as cavities.
Building Construction and Area	The structure is of framed RCC. The walls are normal single brick. The floor area is 746 sq.m. on the ground floor, the total area of three floors being 1, 754 sq.m.-- comprising of the ground and two other floors.
Energy Performance of Original Design	The original design is of normal brick wall and single glazed windows The energy consumption of this design was found to be 1, 7961 kWh/a.

Simulations were performed for a number of cases and the results in terms of energy consumption are presented in Table 5.3.

Table 5.3: Energy Consumption for Different Options Considered

	Option	Energy Consumption (kWh/a)	% Reduction in Energy Consumption
1.	Original design with normal brick wall and single glazed windows	17961	
2.	Original design (with normal brick wall and single glazed windows) and with North-South orientation	15214	15
3.	Original design with normal brick wall and double glazed windows	15785	12
4.	Original design with cavity roof and double glazed windows	13394	25
5.	Original design (normal brick wall and single glazed windows) with insulated walls and roof	9961	44
6.	Original design with glass house corridor and roof cavity	8247	54
7.	Original design with glass house corridor towards the south facade and cavity roof and double glazed windows	6919	61
8.	Original design with glass house corridor towards the south facade and cavity roof and double glazed windows with north-south orientation	5185	71
9.	Proposed design with roof cavity, single glazed windows, and individual glass balconies on the North and South	11780	34

Recommendations

Based on analytical study of the thermal simulation exercise, the following are the design recommendations (Figure 5.19).

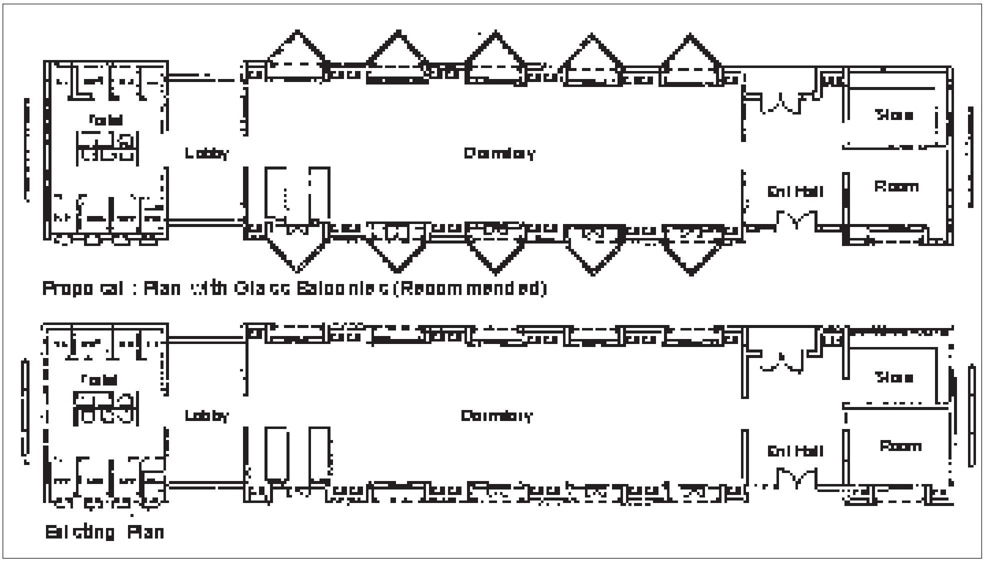


Figure 5.19: Originally Conceived Plan and the Recommended Plan of ITBP Barracks at Gaucher

1. The front block facing South-East should be shifted further 2 m (S-E) to allow sun radiation on the block behind it.
2. All windows must be double glazed.
3. The south face should be provided with a glass corridor as on all the floors. In this case the windows may be single glazed as well.
4. True orientation of the original design towards North-South will reduce energy consumption by 15 per cent.
5. The external finish should be of a light colour instead of the proposed grit wash in grey stone aggregate.

For cold and cloudy climates, the following are the passive features identified.

- Increase in solar heat gain
  - ⇨ by orienting the larger walls towards the South, and
  - ⇨ by providing an open glass corridor on the sides of the house protected from the cold wind.

- Increase in internal heat gain
  - ⇨ by providing a false ceiling under the roof,
  - ⇨ by avoiding openings on the windward side (exclusion of infiltration), and
  - ⇨ by locating the house on the leeward side of a hill for protection from cold winds.

- Balance of temperature fluctuations
  - ⇨ by constructing thick stone/mud walls.

- Humidity control
  - ⇨ by absorption/desorption of back-filled earth between the house and hill (earth berm).

Alternative Design for Nirman Bhawan, Shimla

An alternative energy efficient design for Nirman Bhawan was prepared, incorporating various energy advanced de-lighting and hypocaust systems for greater energy efficiency.

By computer simulation, it was found that comfort conditions can be maintained inside the building without using any of the conventional fuels during the day. The annual heating energy demand during working hours can be reduced to nil by using insulated cavity walls, a 30-40 per cent glazing area on the south facade inclined at 60° to the horizontal. The south facade of the building at an inclination of 60° to the horizontal has solar photovoltaic cells to meet basic lighting needs. The proposed design has an approximate cell area of 1,050 sq.m. An advanced de-lighting system, namely, light shades, has been used to increase illuminance levels at a distance of 9.1 m from the edge of the window and to improve the luminance gradient across the room under variable sun and sky conditions throughout the year (Figure 5.20).

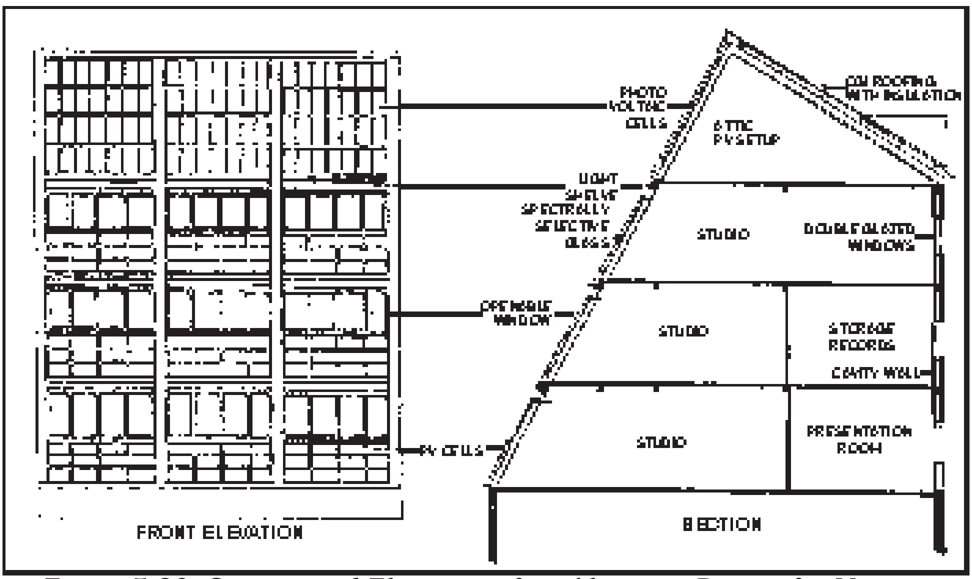


Figure 5.20: Section and Elevation of an Alternate Design for Nirman Bhawan at Shimla

Case study 3 Nirman Bhawan Shimla (Himachal Pradesh): Cold and Cloudy	
Location	Shimla is located at an altitude of 2,202 masl at a latitude of 31.6 North and Longitude 77.10 East
Project	Nirman Bhavan, is an office building for the Public Works' Department
Site Microclate	• The building premises cover a built up area of approximately 6,500 sq.m. It is an eight-storeyed centrally heated building around a central atrium of 300 sq. m. floor area. • The building lies on a south-facing slope on Cart Road in Chotta Shimla, in the cold and cloudy climatic zone of India, characterised by low solar radiation in winter with a high percentage of diffuse radiation. The diurnal range varies from 5°C-20°C. Precipitation, in the form of rain and snow, is distributed throughout the year with maximum rainfall during the months of July and August. The total precipitation is around 1,400 mm.
Building Form	The building plan is trapezoidal and evolves around a central atrium space which acts as a greenhouse. Office spaces are separated from the atrium by full height partitions. Guest suites are provided on the lower floor.
Construction	The building is an RCC framed structure with 230 mm thick external walls clad with slate tiles and plastered on the inside. The internal walls are 115 mm thick brick walls. The structure has RCC roofing, except for the central atrium which has perpex sheet roofing.
Thermal Performance Analysis	The building was simulated for thermal performance and to enhance its energy efficiency various solar passive features have been incorporated.
Various Energy Reduction Options Analysed	Orientations-increase of south facade; insulation in North and West walls; addition of sun space; and reduction of window area on north elevation.
Thermal Simulation Results and Analysis	• By insulating all external walls and rooves the energy demand fell by 49%. • By Insulating only North side walls and roof, there is a reduction of 38%. • By reducing the window area on the North side by 50% and insulating the entire building a 55% saving in energy consumption was achieved.

Conclusions

In the hilly regions of North India, there are essentially two major climatic regimes: 1) Cold and Cloudy and 2) Cold and Sunny. Case studies of army residential housing and PWD (Nirman Bhawan) have been presented for Leh, Gauchar, and Shimla.

In general, the passive features that will enhance the energy performance of buildings in these climatic regions are as follow.

Features Identified	% Energy Reduction (Approx.)
Orientation	(10-15)
Double Glazing	(10-20)
Insulation (Walls and Roof)	(30-40)
Sun space/Solarium	(30-40)
Cavity Construction (roof)	(10-15)

Additionally, renewable energy systems can be incorporated as demonstrated in the case of Nirman Bhawan, Shimla.

Further Reading

Bansal, N. K. and Minke, C., 1995. *Climatic Zones and Rural Housing in India*. Germany: KFA, Juelich.

CPWD, 1994. 'Computer Simulation for Energy Efficiency in Buildings'. Reports Prepared by CES, IIT. New Delhi: CPWD.

5.3
Survey and Design Studies on Residential and Dispensary Buildings in Hilly Regions

P. Chandra

Introduction

Basic elements of the climate effect human comfort and building design. Among these elements air temperatures, humidity, wind movement, and solar radiation. A balance in all these elements can bring comfort in any type of climate. In a cold climate air temperatures between 12-15°C and relative humidity around 50 per cent would be considered comfortable. Estimates have shown that up to 35-40 per cent of energy used to make buildings comfortable can be saved by using the passive solar concept. Additional measures, such as roof and floor insulation, airtight doors and windows, multi-layered glass, heat absorbing films, rock bed and solar heating, control of wind movement, the restricted exposure of walls to cold winds, use of '*garma/kangri*' (traditional heating device) for heating, maximisation of absorption of solar radiation, skylight rooves, moisture penetration, optimum building design, improved heating appliance and lighting design, and swing in indoor temperatures, can be applied to save energy.

In addition to climatic factors, building design and architecture are influenced by other parameters :

- socioeconomic status,
- type of work performed,
- energy requirements,
- existing environmental quality,
- site conditions,
- local construction materials,

- location of utilities,
- ways and means used to create comfort, and
- users' acceptance of the solution to the problem.

Many of these factors are interlinked to each other and affect the building design considerably.

A survey was carried out in Shimla to study the above-mentioned aspects. A total of ten buildings was surveyed in and around Shimla in order to collect data on various aspects of design, construction, and climate. Selection of the office and residential buildings was carried out with the help of the local unit of Himachal Pradesh Public Works' Department.

Study of Selected Buildings

Shimla and Mussoorie Railway Board Office Buildings

This building is a five-storey building with a carpet area of 15, 915 sq. m. A verandha all around the building protects the building from direct cold winds. The sloping roof was of G.I. sheeting with a wooden ceiling. The intermediate floors were constructed with 10 cm RCC and cement plaster. The walls were 23 or 11.5 cm brick walls. There were no curtains over the glazed windows. The temperatures inside the rooms were varying from 10 to 15°C and the relative humidity was from 30 to 38 per cent. A few heaters (equivalent coal consumption was around 10 kg per day per room) were used by senior officers. From four to eight fluorescent tubes were used in each room throughout the day. There was very little daylight in the building.

Accountant General's Office (Gordon Castle)

This is a four-storey building situated on Mall Road. The building faces North-West. The roof construction is of G.I. sheet with a slope of 60° to horizontal. The wood ceiling was provided to check the flow of heat. The intermediate floors were constructed in 10 cm stone with 2.5 cm wood chip board layer over it. The walls are made from 45 to 70 cm thick stone with 2.5 cm. wooden inside layers. The glass area was around 60 per cent of the wall area. The North-West of the building was uncomfortable during winter and heating was needed. Usually 7.5 to 10 kg of coal was consumed daily to heat a room. The occupants in the South-East reported that the building was comfortable up to one p.m. and '*garma*' was used only in the afternoons. Generally the light was poor and four to eight fluorescent tubes were used by staff. The room temperatures measured varied from 8-12°C and relative humidity prevalent during the period was 35 to 45 per cent.

Central Secretariat Building

This building is oriented towards the North-West and is situated on Circular Road. It has three floors and a basement. The inside air temperatures were high, varying from 10 to 21°C with 40-45 per cent relative humidity. The roof was of G.I. sheeting and had a slope of 30° to horizontal. The intermediate floors were constructed in 10 cm RCC and

2.5 cm cement plaster on both sides. The walls were of 35 cm stone with plywood as inside lining. The heating was prevalent only during the period of snowfall.

State Bank of India Building

This is a four-storey building with a flat roof of RCC supported on columns. The walls were made of 11.5 cm brick used as filler walls. The inside air temperatures reported were similar to those of the Central Secretariat. In some places, discomfort in winter was reported and people used *'garma'* to heat the rooms. Four fluorescent tubes per room were used throughout the building.

Residential Buildings - Shimla

The residences covered in the survey consisted of one- or two-roomed units in two- to four-storeyed constructions. These were situated in the area near H.P. Bhawan and Park area, Khalini. The floor area varied from 20 to 40 sq. m. The residents were either from low or middle income groups. The indoor temperatures varied from 8 to 14°C and relative humidity from 42 to 68 per cent. Radiators were used for heating in three houses and from 8 to 20 litres of kerosene per month were consumed.

Analysis of the data collected from these buildings revealed that the following specifications for construction had been used.

Roofs
i) Gable roof of G.I. sheet, the slope varying from 15 to 60° from horizontal
ii) 10 cm mud *phuska* over 12 cm RCC slab and cement plaster
iii) 4 cm brick-tile and 5 cm mud *phuska* over 12 cm RCC and cement plaster

Walls
i) 23 cm brick with cement plaster
ii) 11.5 cm brick with cement plaster as partition walls
iii) 35 to 70 cm stone masonry with inside plaster
iv) 45 cm mud and stone wall with mud plaster on both sides
v) 2.5 cm wooden planks as partition walls
vi) An inside wooden lining was provided in some buildings.

Intermediate Floors
i) 10 cm RCC with plaster on both sides
ii) 2.5 cm wood plank over 10 cm RCC floor
iii) 4 cm brick blast over 10 cm RCC floor and cement plaster on both sides
iv) 2.5 cm chip mortar over 10 cm RCC floor
v) 15 cm RCC with cement plaster, used over the basement

Ceiling
i) Curved G.I. sheet
ii) Wooden ceiling
iii) Plywood ceiling in a frame

The doors and windows were generally made of wood with a 40 to 50 per cent glass area. The overall glazed area varied from 10 to 15 per cent of the floor area. The outdoor and indoor dry- and wet-bulb temperatures, relative humidity, and wind velocity ranges are shown in Table 5.4.

Table 5.4: Ranges of Temperature and Humidity Obtained in Buildings in Shimla

	Temperatures		Relative Hhumidity %	Wind Velocity m. sec
	Dry Bulb C	Wet Bulb C		
Outside	2.0-18.0	1.0-11.7	20-60	0.2-1.5
Inside	5.6-18.4	4.5-12.8	20-42	---

Buildings in Mussoorie

The U.P. Mines and Metals' Corporation Ltd proposed a housing complex for its staff at its site in Labihdar, Mussoorie. The complex was designed by a team of senior architects from the Central Building Research Institute, Roorkee, using solar passive heating concepts optimised by using computer simulations, and it was ensured that better comfort conditions could be obtained in these buildings.

Design of Residences

The residences were in seven blocks of five residences each. Three residences were grouped as a multistorey building, while the other two were designed as duplex houses and were attached to the multistorey building. All the residences were designed to possess similar facilities: two bedrooms, a living room, a study and a dining room, kitchen, toilet, W.C. (dressing room), and a bathroom. In addition, a garage was provided on the ground floor below the duplex. The carpet area was 92 sq. m. The front face was oriented towards the South to receive solar radiation. The wind direction in winter was S-SE, therefore operable windows were avoided on this side. The plan of the residence is shown in Figure 5.21. The passive concepts used in the buildings were orientation to achieve clear southern exposure, Trombe Walls, attached greenhouses, and protected entrances on the ground floor.

The construction materials used for rooves, walls, windows, and doors are as follow.

Roof:	10 cm RCC slab, inclined at 22.5 deg to horizontal
Walls:	20 cm stone masonry with cement plaster on the inner side
I floor:	10 cm RCC with floor finish
Windows:	5 cm wooden airtight frame with 20 per cent glass area
Doors:	4 cm teakwood
Louvers:	Inclined at 22.5 deg to horizontal

Table 5.5 gives the detailed climatic data of Mussoorie used in computer simulation.

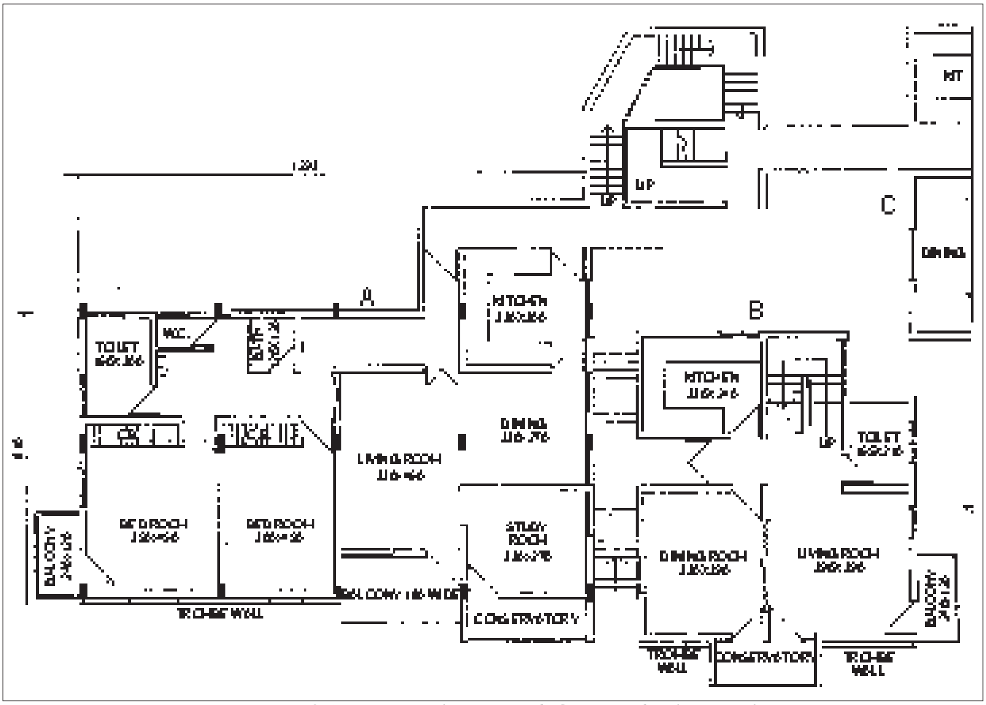


Figure 5.21: First Floor and Second Floor Plan

Table 5.5: The Mean Monthly Values of Climatic Data for Mussoorie						
Months	Temperatures		Relative Humidity %	Vapour Pressure mb	Wind Speed Kmph	Rainfall mm
	Dry Bulb Deg.C	Wet Bulb deg.C				
Jan	6.0	3.0	65	5.8	6.7	66.4
Feb	7.5	4.6	62	6.5	7.4	66.9
Mar	11.9	7.4	54	7.2	7.9	62.5
Apr	17.7	11.0	45	8.2	7.9	29.5
May	20.7	12.4	44	11.1	8.4	45.1
Jun	20.6	16.5	67	15.6	7.2	188.5
July	18.5	17.7	94	19.8	5.6	736.5
Aug	18.0	17.7	96	19.5	4.7	754.7
Sep	17.2	16.6	90	17.2	5.4	222.2
Oct	14.4	11.0	70	11.4	6.1	64.8
Nov	11.0	7.1	58	7.5	6.2	7.7
Dec	7.9	4.5	59	6.0	6.8	21.2

The solar radiation data obtained from the meteorological department provide figures for horizontal surfaces in the case of Mussoorie, therefore the data for vertical surfaces were obtained by using computer software (SOLRAD) developed at CBRI, Roorkee. The indoor temperatures were computed using this data. The mean values obtained as a result of passive solar design are given in Table 5.6 for Block A.

Table 5.6: Mean Values of Temperatures (def C) Obtained on Simulation

Floor/Room	Ground	Ist Floor	2nd Floor
Bed –I	11.8	12.5	12.2
Bed II	12.2	12.9	12.8
Living + Dining	7.2	8.5	8.6
Study	8.7	10.8	10.9
Kitchen	9.9	9.8	9.5

Conclusions

1. Moisture can be prevented from penetrating through walls, roof, and floor by (i) raising the floor level above the ground and (ii) by avoiding water stagnation in the vicinity of the building.
2. A sloped roof should be provided to ensure quick disposal of rain water and facilitating snow clearance from the roof.
3. Glass areas can be reduced depending on lighting requirements.
4. Double glass windows reduce heat loss.
5. Infiltration of air through openings in windows and doors should be avoided to prevent heat loss.
6. Considerable quantities of coal and wood are needed to keep the environment warm.
7. '*Garma*' used inside generates huge amounts of dust and smoke.
8. The *'Garma'* design needs improving, since it consumes too much fuel for the amount of useful heat generated.
9. The inlets and outlets of central air heating should be designed carefully and placed in opposite walls.
10. The temperature range in old buildings where heavy stone is used is higher than in other buildings. However, in buildings where there is more glass the air temperatures were are still higher, but nowhere do they reach the comfortable range.
11. In new buildings where brick construction is used and rooves are thin, residents mostly have to use radiators.
12. In residential buildings, private owners carpet the drawing and bedooms. A single heater is used for warmth.
13. In government buildings glass covers about 50 per cent of the area and curtains are not provided to prevent heat loss.

Acknowledgement

The author wishes to thank the Head of the Efficiency of Building Division for constant encouragement and for the interest shown in this study.

5.4 Research on the Regional Advantages of Passive Solar Buildings in High and Cold Areas in Yunnan Province

Shi Feng, Xie Jian, Xia Chaofeng, Lu Enrong, Zhao Zhenghong

Geographic and Climatic Characteristics of Yunnan Province

Yunnan province lies between 97.5°-106° longitude east and 21°-29° latitude north. The total area of the province is 394,000 sq.km. In the west is the West Yunnan Valley and in the east the main body of Yungui Plateau. The topography extends to high altitudes in the north and is low-lying in the south. North of the regions of Lijiang and Diqing lies the Tibetan Plateau, with an average altitude of 4,000-5,000 masl. The average altitude is less than 500 m around the lower reaches of the Yuan and Lancang rivers. Horizontal and vertical variations in climate in Yunnan Province are extreme. From south to north the climate zone changes from tropical, semi-tropical to warm in low-lying areas to high altitude areas;hence climates change from valley, mountain, to high and cold mountains, giving a special 'tri-dimensional' aspect to the climate.

The features of climate in Yunnan Province are as follow.

1. The difference between seasons is not apparent. There is no summer in the North-east and north-west, in the central area it is neither cold in winter nor hot in summer; and in river valley areas in the south there is no winter and it is always summer.
2. The difference between humid and dry seasons is apparent. The humid season falls between May and October and the dry season between November and April.

In most parts of Yunnan, heating is not necessary in winter. However, in the north- east and north-west, people have to heat their houses to survive the cold winters.

WINTER CONSUMPTION OF ENERGY IN HIGH AND COLD AREAS

North-west Yunnan is close to Tibet. There are two counties with altitudes between 3,000 and 4,000 masl, namely, Deqin and Zhongdian. In these counties average temperatures for six months of the year are less than 5°C, out of which three months have an average temperature of less than 0°C. The average temperature in the coldest month is -3.8°C. There are three counties with altitudes between 2,000 and 3,000 masl, namely, Niglang, Weixi, and Langping, where average temperatures during three months of the year are less than 5°C. The average temperature in the coldest month is 1.2°C. Because of a complex topography and poor transportation in these remote counties, except in a few towns, people use fuelwood for heating. In recent years, rapid development of rural and urban construction and improvement in living standards have led to a rapid increase in fuelwood consumption. This has had a negative impact on the environment. In the past, extensive areas of forest were decimated and good quality timber burned to ash, reducing forest areas substantially and causing serious soil erosion.

POSSIBILITIES FOR DEVELOPING PASSIVE SOLAR BUILDINGS IN HIGH AND COLD AREAS OF YUNNAN

Solar heating has a strategic significance. It will not only save large amounts of conventional energy resources and protect the environment, but will also improve living standards. Passive solar building is simple and economically feasible. Chinese researchers began working on PSBT in the 1970s, and after twenty years' of effort, passive solar building has been used widely in Tibet and north-west and north-east China.

Passive solar building concepts can be applied in high and cold areas in Yunnan Province. Passive solar concepts can be used to heat buildings in winter. Solar resources and climatic conditions in the area in the cold season are shown in Table 5.7. Compared to Lanzhou, where passive solar concepts are widely used, Yunnan has more solar resources as the radiation values and sunshine rates are higher than those in Lanzhou. Also, there is a marked difference between the dry and humid seasons: there are fewer cloudy days in the cold season than in other seasons and Yunnan has more sunshine days than Lanzhou. Furthermore, although altitudes in the area are high, the wind speed is low and the temperature is not too low. Therefore, passive solar building presents good prospects.

EFFECTIVENESS OF PASSIVE SOLAR BUILDINGS IN HIGH AND COLD AREAS OF YUNNAN PROVINCE

Diqing is located in the north-west of the province at an altitude of 3,276 masl. The cold season lasts for about nine months.There is neither coal nor electricity, and fuelwood and charcoal are used for cooking and heating. Heating an average sized office room takes four to five cubic metres of fuelwood annually. The population of Diqing is 280,000. Annually 620,000 cubic metres of fuelwood are used and at least 400,000 cubic metres are for heating. Because of over-harvesting, the economic value of the forests decreases and the environment is destroyed. To overcome the energy supply shortage, the Science and Technology commission of Diqing established a passive solar building in Zhongdian County in 1986.

Table 5.7: Climatic Data for Yunnan Province

		Deqin	Zhongdian	Ninglang	Weixi	Lanping	Zhaotong	Zhenxiiong	Weixin	Ludian	Lanzhou
Latitude		28°39'	27°50'	27°18'	27°13'	26°41'	27°20'	27°25'	27°50'	27°10'	36°03'
Longitude		99°10'	99°42'	101°51'	99°31'	99°32'	103°45'	104°51	105°03'	103°33'	103o54'
Altitude		3592.9	3276.1	2240.5	2325.6	2344.9	1949.5	1666.7	1172.5	1950.0	1517.5
Average Temperature (°C)	November	1.5	7.5	8.2	7.5	7.2	7.5	7.3	9.1	7.8	
	December	-1.3	4.6	4.8	4.6	4.0	3.6	3.2	5.1	4.1	
	January	-.30	-3.8	4.1	3.6	3.2	2.0	1.2	3.1	2.6	
	February	-2.4	-1.6	6.6	4.7	5.0	3.8	2.8	4.7	4.9	
	March	0.4	1.7	10.3	7.6	8.2	9.1	8.0	9.5	10.9	
	April	3.8	5.2	14.2	10.9	11.6	13.1	12.5	14.1	13.9	
Average Radiation Amount (Mj. m2-month)	November	367	426	445	404	417	371	282	231	379	280
	December	430	427	448	444	402	469	416	385	459	228
	January	322	402	378	377	351	257	204	168	296	249
	February	313	406	392	359	365	344	241	193	345	321
	March	410	513	531	460	534	516	392	291	532	458
	April	457	504	634	466	541	571	463	380	571	547
Average Monthly Sunshine Rate (%)	November	62	68	63	64	62	42	21	12	40	
	December	68	79	72	72	69	42	21	12	40	
	January	60	74	76	65	69	43	21	12	43	
	February	49	63	71	53	60	46	23	14	46	
	March	47	58	67	51	58	57	33	21	59	
	April	43	48	61	44	46	56	38	28	57	
Average Wind Speed (m/s)	November	1.9	2.1	1.8	1.0	1.1	2.3	2.1	0.9	1.8	
	December	2.0	2.0	1.6	1.1	1.3	2.4	2.0	1.0	1.9	
	January	2.2	2.4	2.2	1.3	1.5	2.8	2.0	1.0	2.3	
	February	2.3	2.9	3.0	1.4	1.7	3.4	2.2	1.1	3.0	
	March	2.3	2.9	3.1	1.6	1.8	3.7	2.4	1.2	3.3	
	April	2.1	2.8	3.2	1.5	1.6	3.4	2.4	1.3	3.0	

The effectiveness in terms of saving energy was remarkable in the first year after establishment. The building is a brick-concrete structure. The area of the plinth is 402 sq. m. and it has 15 rooms, 14 of which need heating. The building is heated by a mixed method of direct heating and a heat collection and storage wall. The test results during December, January, February (90 days) are as follow.

Indoor temperature	< 8°C	8 days	9%
Indoor temperature	> 12°C	82 days	91%
Average temperature	14.2°C		1.7°C in normal building

Five years after establishment of the building, no additional sources were needed for heating in winter. Because of the unique climate and geography, thermal insulation is not necessary for passive solar building, hence the incremental cost is much less than the average in other areas. Generally, the incremental cost can be recovered in two years. Dissemination and use of passive solar technology in this area will result in substantial economic and social benefits.

After establishment of this passive solar building, dissemination and use of passive solar technology developed rapidly. In the last 10 years, various types of solar building have been constructed and experimented upon, and all of them had good results. To date, 124 public buildings and four private buildings in Zhongdian, with total plinth areas of 238,480 square metres have been built with solar technology. Since 1990, all new buildings have used this technology. Dissemination and use of solar technology in Diqing Region has achieved great economic, social, and biological benefits. An expenditure of 2,756,000 RMB *yuan* for 260,000 cubic metres of fuelwood was saved (equal to 14,310,000 kWh of electricity).

However, the dissemination and use of solar technology is limited to the towns. If solar buildings can be introduced to rural areas, the benefits will increase.

Conclusions

- Demand for heating is very high in north-west and north-east Yunnan.
- There is sufficient solar energy in Yunnan's high and cold areas..
- Climatic differences between dry and humid seasons favour the use of passive solar building technology.
- The successful application of solar technology in Zhongdian Region demonstrates that passive solar buildings have good prospects.
- Dissemination and use of passive solar technology in rural areas should be strengthened.

Further Reading

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5.5
Energy Efficient Building Design: Passive Solar Energy Approach

I.A. Chaudhry

Introduction

Increased electricity bills and heavy taxes on fuel imports mean that new and renewable resources of energy which are affordable are needed. In Pakistan, twenty-five per cent of energy use is in the domestic sector, out of which thirty-three per cent comes from electricity for illumination, cooling, and other domestic purposes. Due to the prolonged summer season, most of this energy is used for cooling buildings. This amount can be reduced appreciably by incorporating inexpensive passive solar energy principles into the basic designs of new buildings and improvements of old ones. The following features should be taken into consideration.

- Orientation of building
- Cross ventilation
- Building materials for roof and walls
- Use of evaporation from water for cooling

The field of solar architecture is vast, and many interesting approaches and technologies are being developed. In short, advances in this field should result in buildings obtaining most energy requirements from the sun.

Orientation and Position of the Building

The appropriate orientation of buildings in the landscape and in relation to the sun and wind is the first main step in the planning process (Table 5.8). The orientation and

Table 5.8: Site Orientation Chart

	Hot Humid Regions	Hot Arid Regions
Objectives	Maximize shade Maximize wind	▪ Maximize shade late in the morning and all afternoon ▪ Maximize humidity. ▪ Maximize air movement in summer
Adaptations		
Position on Slope	High for wind	Low for cool air flow
Orientation on Slope	South	East-south-east for afternoon shade
Relation to Water	Near any water	On the lee side of water.
Preferred Winds	Sheltered from the north	Exposed to the prevailing winds
Clustering	Open to wind	Along E-W axis for shade and wind
Building Orientation	South, towards prevailing winds	South
Tree Forms	Trees with dense canopies. Use deciduous trees near the building	Trees hanging over the roof

position of a building are most important for the room temperature and the interior climate of every building (Figure 5.22). Proper orientation provides more comfort without costing more and is mainly a design problem. There are often constraints to the optimal selection of a building site and orientation of a building; and these are caused by adjacent buildings, roads, and land.

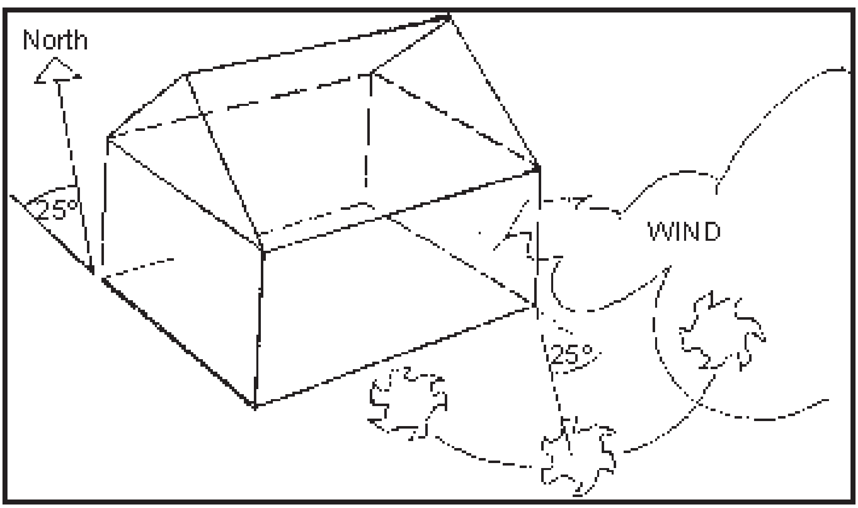

Figure 5.22

General Rules for Hot Arid Regions

Wind Orientation

Main walls and windows should be oriented towards the prevailing wind direction in order to allow maximum cross ventilation (Figure 5.23).

Slope Orientation

Lower hillsides benefit from cooler natural air movement during the early evening and warm air movement during early morning (Figure 5.24).

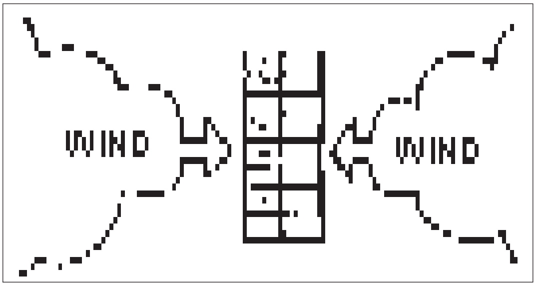

Figure 5.23

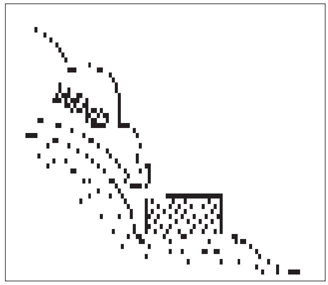

Figure 5.24

South Orientation

Exterior wall openings should face south but should be shaded either by roof over- hangs or by deciduous trees in order to limit the access of excessive solar radiation into the dwelling. The size of the windows on the east and west should be minimised in order to reduce heat gains in the early morning and late afternoons (Figure 5.25).

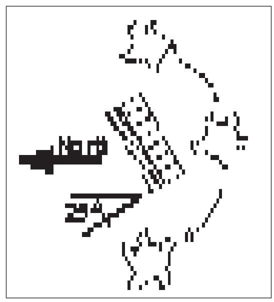

Figure 5.25

Trees

Natural shading by trees gives effective natural cooling (Figure 5.26).

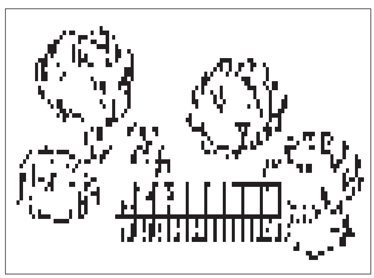

Figure 5.26

Relation to Water

Indoor and outdoor activities should take maximum advantage of cooling breezes by increasing the local humidity level and lowering the temperature. This can be achieved by locating the dwelling on the leeward side of a stream or lake (Figure 5.27).

Clusters

Multiple buildings are best arranged in clusters to facilitate heat absorption, shading opportunities, and protection from east and west exposure (Figure 5.28).

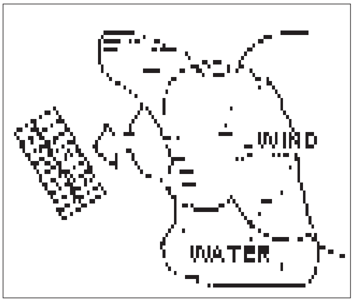

Figure 5.27

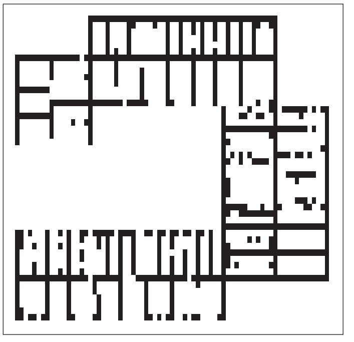

Figure 5.28:

Insulation, Absorption and Heat Storage

Insulation

Reduction in heat flow from outside into a room and vice versa can be achieved by insulating a roof or wall. The insulation should be mounted on the 'Cold Side' of the wall (Figure 5.29). Efficient insulation can principally be obtained by using porous materials, e.g., polyurethane foam, porous concrete, bricks, and panels made of glass fibre or natural fibres (coconut, wood, glass, wool)(Table 5.9).

Absorption/Reflection

The radiation of heat and light are absorbed or reflected by building materials to a certain degree. In hot areas, it is desirable to reflect the solar heat radiation during the day as much as possible (Table 5.10). This can be done by using a bright outside wall or roof coatings (Figure 5.30).

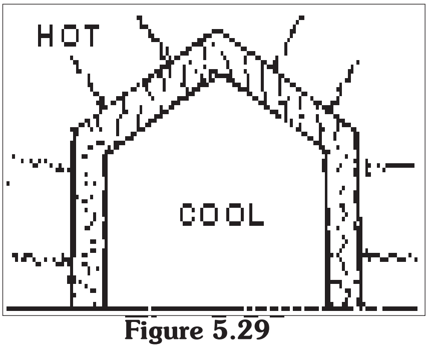

Figure 5.29

Heat Storage

Roof wall materials store a certain degree of the incident solar radiation that is transmitted by warm air through the walls and rooves. The stored heat radiates into the cool room air after a characteristic storage time (Figure 5.31). Heat

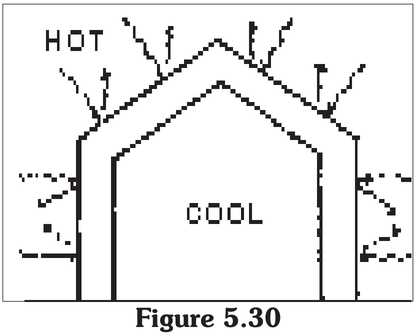

Figure 5.30

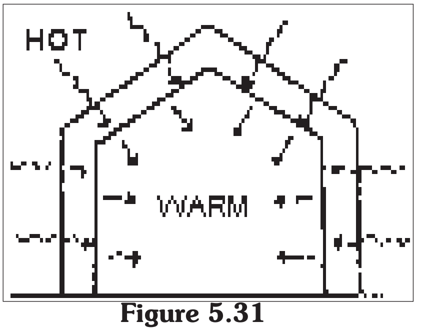

Figure 5.31

Table 5.9: Heat Insulation Values	
Materials	Conductivity (w/m. °K)
Adobe bricks	0.5
Burnt bricks	0.2-0.7
Cement mortar	1.5
Concrete	1.8
Earth (humid)	2.1
Stones, rocks (dense)	2.5
Sand (dry)	0.6
Asbestos	0.25
Plywood panel	0.24
Granulated cork	0.04
Wood (dry)	0.1-0.2
Sawdust	0.06
Insulated panels of expanded polyurethane	0.03
Wood-shredded cement in metal slabs	0.12
Glass	0.8

Table 5.10: Reflection Coefficient of Various Paints/Colours		
Rooves	White asbestos cement	50
	Copper sheeting	64
	Red roofing tiles	70
	Aluminium foil, unpolished	29
	Aluminium foil, polished	15
	Galvanized iron, dirty	89
	Galvanized iron, clean	77
	Bituminous felt	89
	Asphalt	95
Walls	Concrete	70
	Fire clay	70
	Bricks (red)	-
Paint	Whitewash	21
	Black	97
	Yellow	48
	Bright aluminium	20
	Dark aluminium	62
	Bright red	65
	Light red	72
Surroundings	Grass	80
	Rock	84
	Sand/grey	82

storage capacity differs from material to material. It is high for rocks, water, concrete, and so on (see Table 5.11 for storage capacities).

Table 5.11: Heat Storage Capacities

Material	Specific Heat (BTU/ft^3°F)	Capacity (wh/m^3•k)
Adobe bricks	25.4	472.6
Asbestos cement board	28	523.1
Burnt bricks	24	447.5
Cast iron	54	1006.9
Cement mortar	19.2	358
Concrete	28	523.1
Expanded polyurethane (insulating panel)	0.57	10.6
Limestone	22.4	417.7
Plywood or wood panel	9.9	184.6
Sand	18	335.6
Stone, rocks	19	354.4
Water	62	1162

Room Climate

A comfortable climate is established in a house with an optimum combination of air temperature from walls, ceiling, and floor. Therefore, the ideal roof reflects and insulates well and ideal walls reflect solar radiation, insulating against the heat peaks during the day and storing a certain amount of heat which then radiates into the room during the night in hot and arid regions (Figure 5.32). Wall openings allow cool air to flow inside the building.

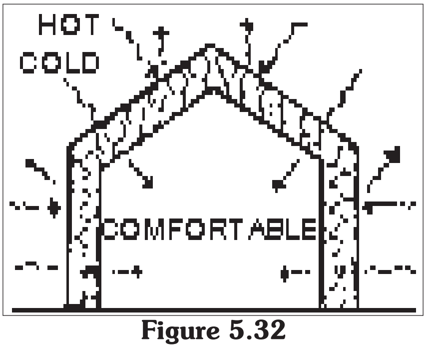

Figure 5.32

By taking the above factors into consideration a substantial amount of energy can be saved and better living conditions can be provided at no extra cost. The Mughals used these passive solar systems in their gardens and forts.

FURTHER READING

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5.6
Retrofitting Traditional Buildings by Passive Solar Concepts in Jumla and Solukhumbu

M.R. Pokharel & B.K. Parajuli

Introduction

People build houses to escape from the bitter cold during winter. Additional measures can bring more solar energy into these houses and reduce heat losses, providing more comfort to the occupants. Examples of two houses in Solukhumbhu and Jumla are given here. Different housing forms have not been dealt with in this paper.

Houses in Solukhumbu and Jumla

In this context, two houses were a point of departure—one in Jumla and the other in Solukhumbu. In Jumla the house had a flat roof whereas in Solukhumbu the house had a sloping roof. The problem was to make these houses warmer than they were by means of passive solar building technology.

Design Approach

The houses in these areas have evolved over many years. Due to the mountainous terrain, movement of people and materials over long distances is rather difficult, and hence local materials and skills have been used to a great extent. As a result, the buildings have acquired distinct characteristics and identities. So, the basic approach was to introduce passive solar building concepts in such a way as to maintain the original characteristics of the houses. The approach was to improve the houses marginally rather than to create a foolproof situation. The concept was used taking local materials and skills into consideration.

Houses in Jumla

Jumla is cold, since it is situated between two Himalayan ranges at an altitude of about 2,400 masl. One has to cross the Annapurna range to reach Jumla from Kathmandu. Houses are built facing the south-east to receive the early morning sun and to continue receiving it until late in the afternoon. The ground floor is preceded by open courts and is used for cattle with special provisions for horses.

Access to the upper floor is by an outside timber stem ladder. Houses like these with cattle on the ground floor and access to the upper floor by an outside stone stairway were built on the borders of England and Scotland and were known as bastle houses. The house described here is 73 sq. m. on the ground floor and 200 sq. m. in total.

The upper floor consists of a terrace at the front called an '*atlo*' leading to the living room, known as the '*ubra*'. This room is used for social gatherings. The kitchen is the next in line with the living room. Adjoining the living room is the store. The living room is in the front while the bedroom is on the side of the open terrace.

The space at the front over the first floor is open, and this open space is used for drying crops. There is a storeroom on the second floor towards the rear of the house which is used for storing grain if it rains while drying it in the sun. Only rich people have this kind of a storeroom, known as '*panda*', and it also serves as a status symbol. There are no stairs inside and both floors are approached from the outside by a wooden ladder. Perhaps people in this region did not have the technique for making an opening in the floor. It forms a striking feature of the house, despite being such an appendage.

The structure of the house is very interesting. Both load-bearing walls are used as framed structures for support. Joists are used and on the top of these are placed wood shavings which are then finished with mud and made into a levelled floor. The joists rest on the beam spanning the timber posts, two of which are placed at each of the four corners of the room, usually over a stone base rather than being driven straight into the ground as one would ordinarily expect; there are eight in all. One of the twin posts ends in the ground floor ceiling, while the other one continues to the first floor and ends in the second floor ceiling in the spanning cross-beams which receive the joists. These joists extend further into the rest of the wall.

The cantilever of the roof is about 50 cm all around. On the top of the roof, mud plaster is used as a finish. On the wall, timber ties are used, two of which, one on the exterior face and the other on the interior face, are tied to each other by transverse timber pieces by simply nailing over the horizontal ties. These ties occur on two levels, one at sill level and the other at lintel level. The practice of providing such ties can be seen only at Chainpur in Bajhang in the west of Nepal.

The houses in Jumla are distinct in terms of their structure. While there are timber posts at the centre of the interiors in other houses in the country, these are conspicuous by their absence in the houses in Jumla. The timber posts are in the corner instead. The provision of the ties is another striking structural difference. Such ties are also found in the houses in Afghanistan.

From a distance, the houses of Jumla give the impression of modern architecture because of their flat rooves. What is particularly prominent is the red and white paint, the white covering a smaller area and being applied above the level of the red paint. This practice of painting the lower-level red and the higher level white can be seen in houses in other parts of the country. Houses built in Jericho in 6,000 BC were painted in this fashion.

The projected cantilever of the roof is the next to be seen because of the repetitive effect created by it being present on the first, second, and third floors. The third notable feature is wooden ladders placed outside the house. The windows are also notable but they attract less attention as they are few in number and small in size. The roof is identical in construction to the floors, except that there are two layers of planking and only one layer on the floors

Houses in Solukhumbu

Sherpa houses are built facing south-east in order to be able to catch the winter sun, since this place is severely cold in winter because of the altitude. The villages are at quite a high altitude. Therefore, many windows are placed in the south-facing wall while windows are kept to a minimum in the east- and west-facing walls. On the northern side, there are virtually no windows because the houses are built over south-facing slopes. This particular house is, however, built facing south. There are windows in the south and the west.

Invariably, of two storeys, the cattle and storage occupy the ground floor while the upper floor is used for living. This is also a place for meditation. The attic is used for cooking and storage. In certain cases, the cooking is done in the room adjoining the living room which is otherwise used as a bedroom. The house is entered through the short side from a door which leads to the ground floor and the stairs. The stairs go up to the first floor and the attic. Access to the toilet can be had from this stairway which is on the first floor.

The building consists of load-bearing walls on the periphery with a row of wooden posts in the centre. The binders span between the posts and the joists span over the binders which in turn receive the floor boards or wood shavings. The posts are not driven into the ground, but rest on flat stones instead. When wood shavings are used, it is plastered with mud to produce a level floor. In essence, the building consists of a load-bearing-cum-framed structure with a joisted floor. It has a coupled roof with an overhang on either side.

The windows are the most visible elements due to their large size. The construction of the windows is also different from others in the country. The various parts: lintels, jambs, and sill, are joined without any nails. After the windows, the roof, which uses shingles, appears most clearly. The windows and the roof could be called the primary and secondary elements comprising Sherpa architecture.

On a sunny day, the court in front of the house acts as a place for social gatherings, but as it is mostly cloudy in winter, the living room usually serves such a purpose. The cloth banner (prayer flag)placed on a bamboo pole erected in the front court identifies the house of a Sherpa, as it is invariably present at the front of all their houses.

Retrofitting Measures

In introducing passive solar technology, use should be made of local materials, technology, and manpower. Bamboo matting can be made and applied to the timber framework laid over the wall which is plastered**.** A gap of 50 mm has to be maintained between the mat and the wall so it can act as a proper insulation mechanism.

Passive Solar Building in Jumla

In the houses in Jumla, windows can be added in the south-facing and east–facing walls. This means more solar radiation will be received in the day time. The ceiling can be provided with a false ceiling of bamboo matting. Protruding pointed bamboo pieces have to be used in the matting, otherwise it will act as a breeding ground for rats. Similarly, the outside of the walls are provided with bamboo matting fixed to the timber frame adjoined to the ties provided in the walls.

An air gap of 50 mm has to be maintained to provide proper insulation. It is expected that the heat will be stored inside the rooms for longer periods than previously, making the interior warmer.

Passive Solar Building Technology in Solukhumbu

In Solukhumbu, the openings are already wide. So sizes need not be enlarged. Similar insulation as that used in Jumla should be used. At a later stage, it will be determined whether the area of the window should be increased or decreased. (Figures 5.33 to 5.46 illustrate details of these houses.)

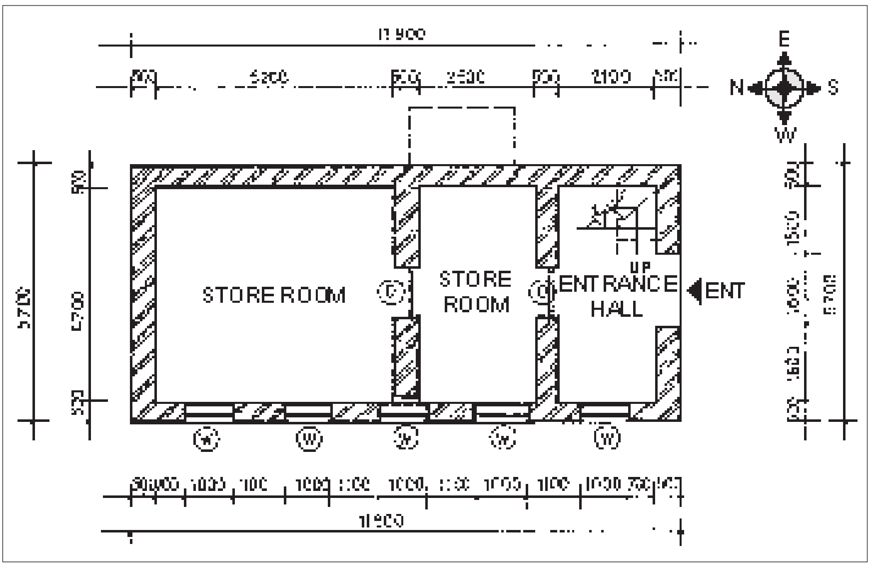


Figure 5.33: Ground Floor Plan (Solukhumbu)

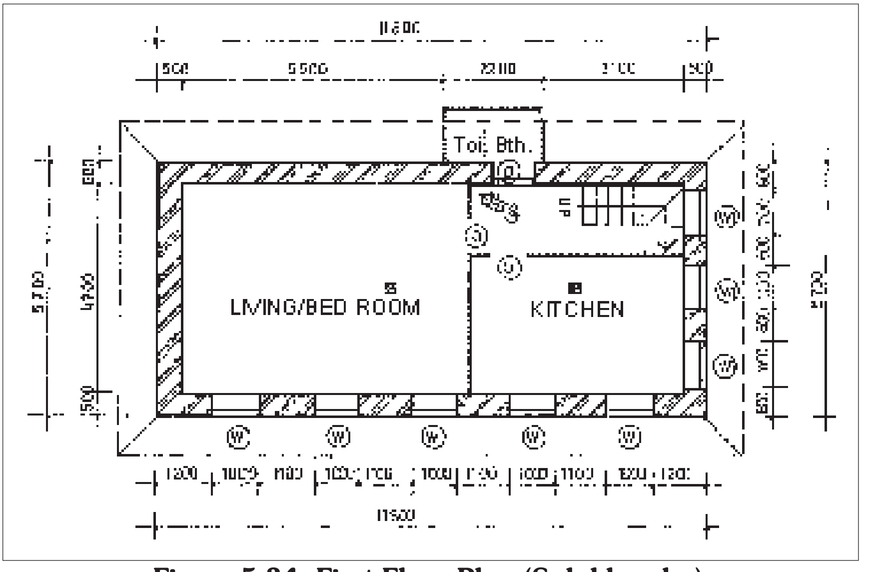


Figure 5.34: First Floor Plan (Solukhumbu)

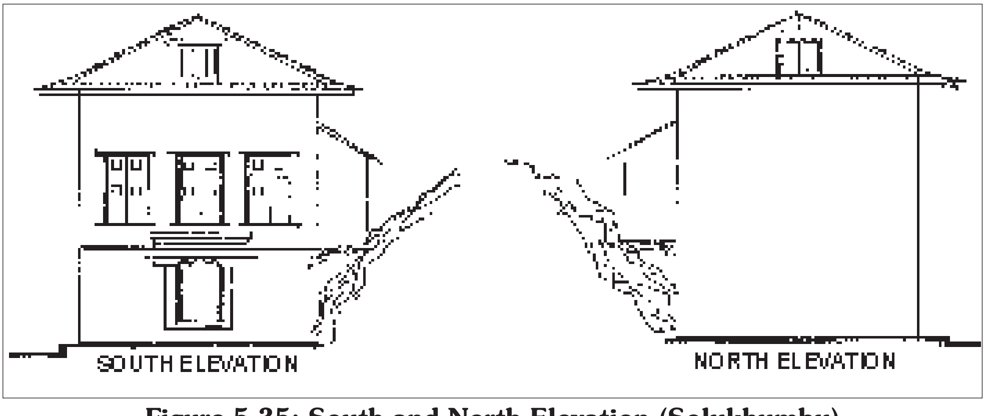


Figure 5.35: South and North Elevation (Solukhumbu)

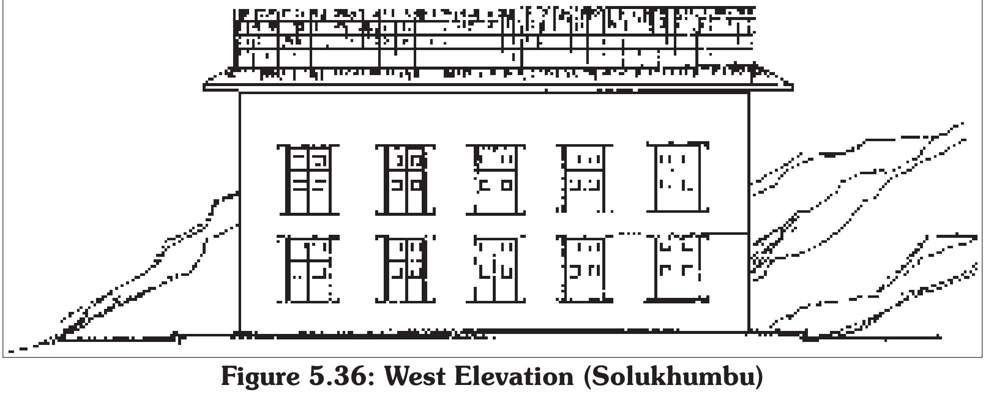


Figure 5.36: West Elevation (Solukhumbu)

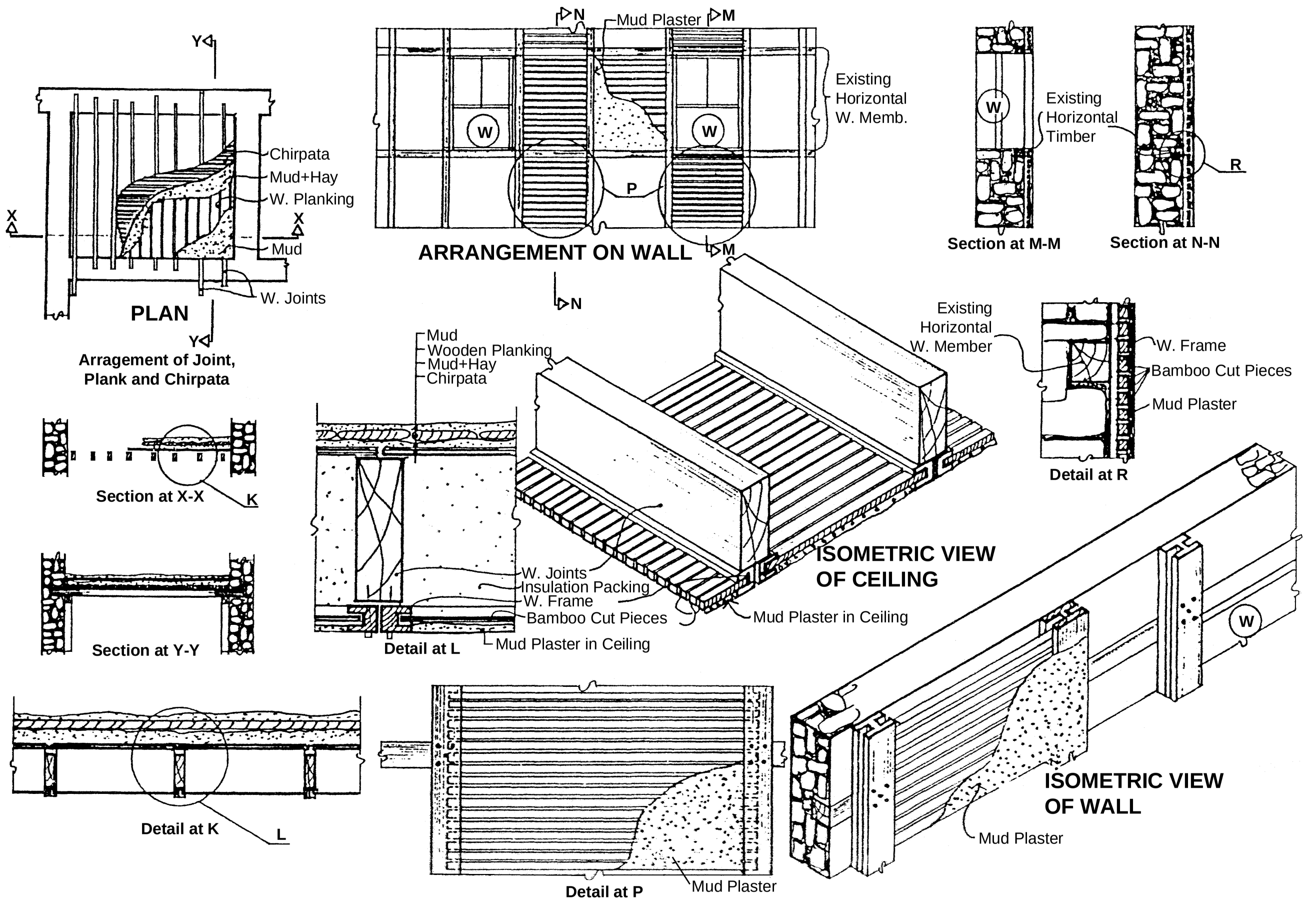


Figure 5.37: Details of Houses in Jumla and Solukhumbu

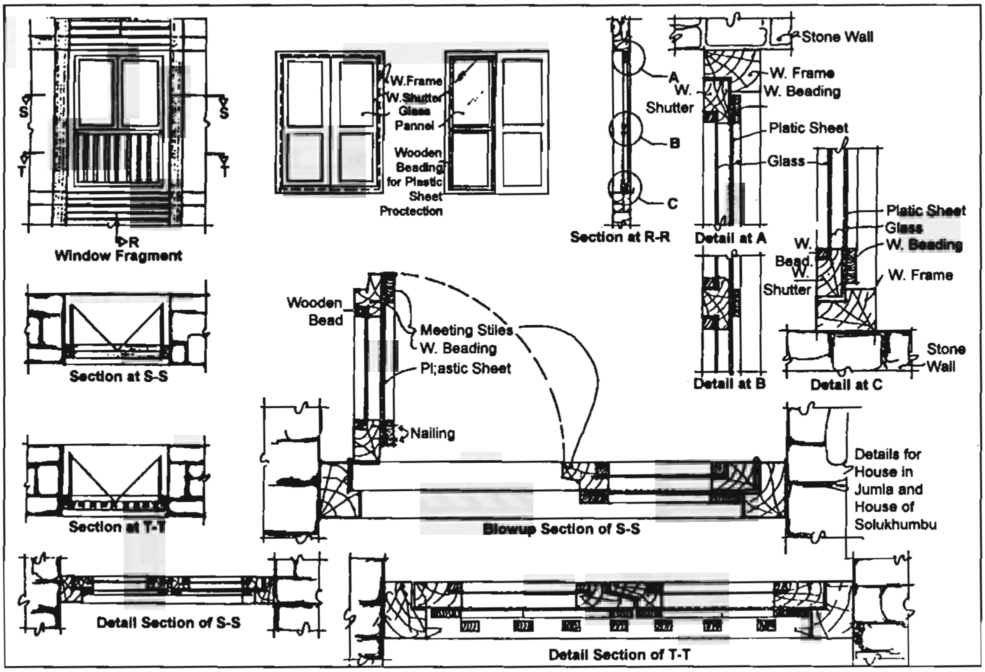


Figure 5.38: Details of Houses in Jumla and Solukhumbu

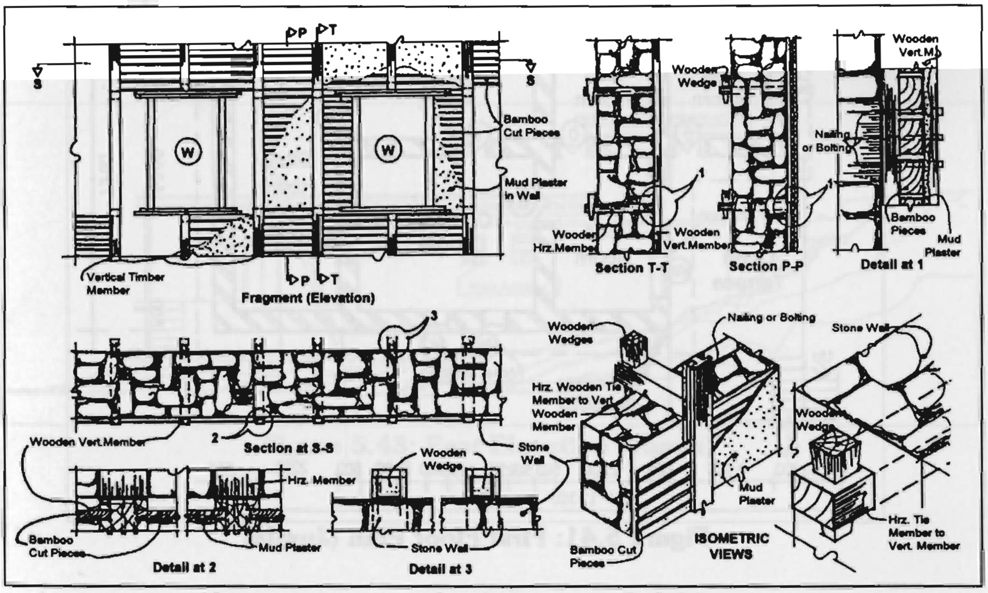


Figure 5.39: Details of House in Solukhumbu

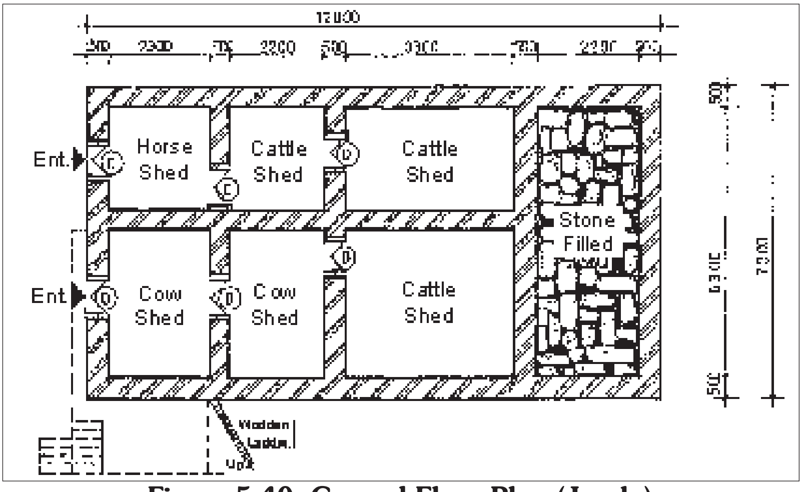


Figure 5.40: Ground Floor Plan (Jumla)

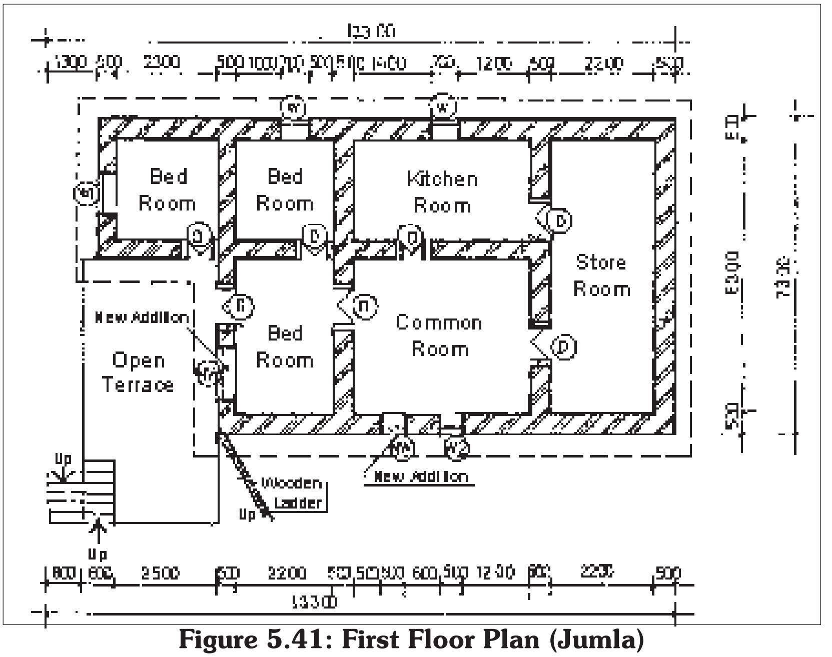


Figure 5.41: First Floor Plan (Jumla)

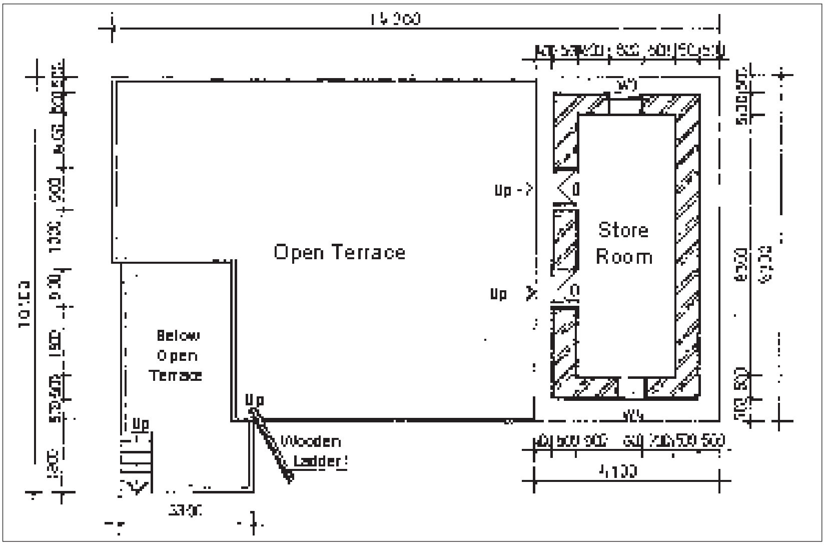


Figure 5.42: Second Floor Plan (Jumla)

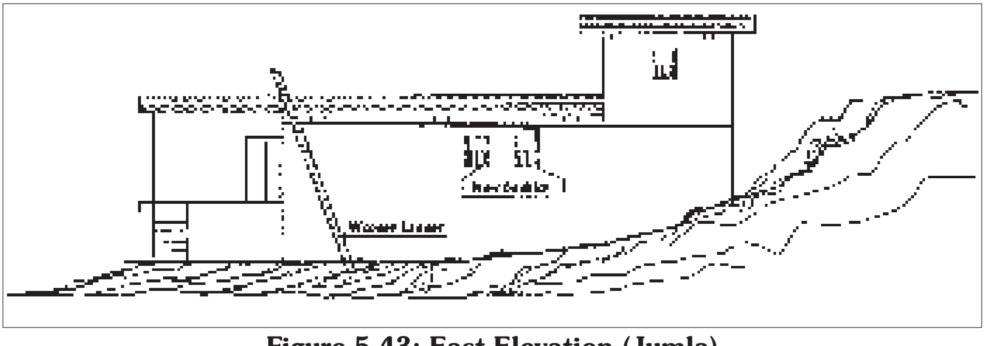
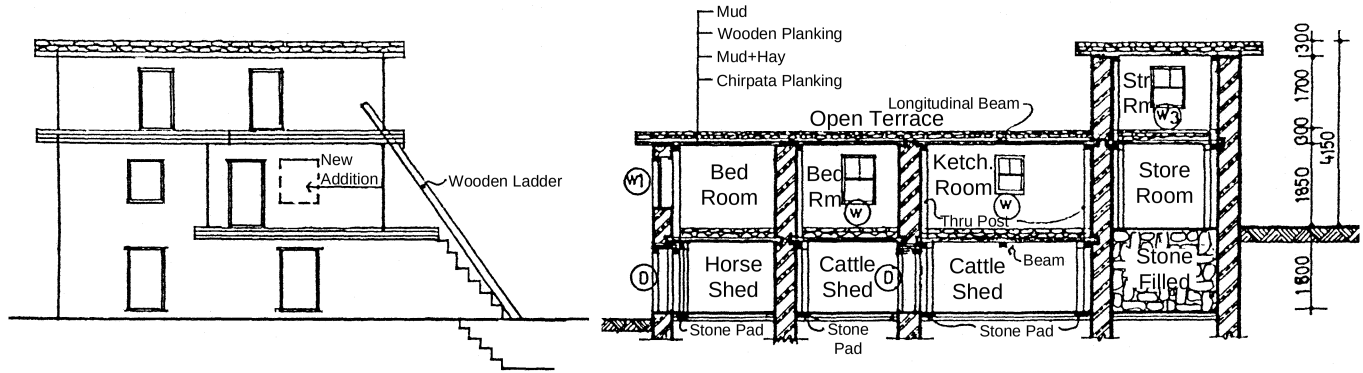


Figure 5.43: East Elevation (Jumla)



South Elevation (Jumla)

Longitudinal Section (Jumla)

Figure 5.44: South Elevation and Longitudinal Section (Julma)

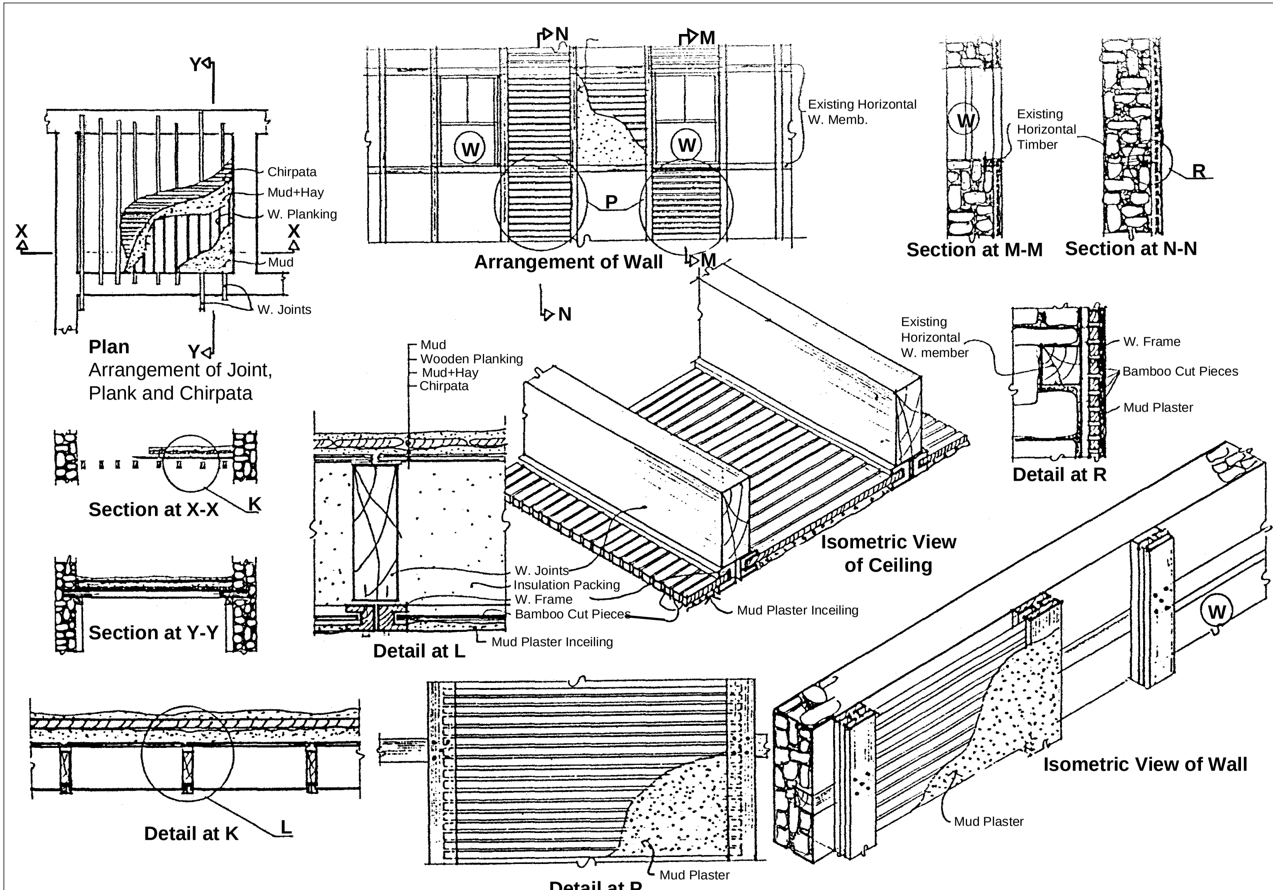


Figure 5.45: Details of Houses in Jumla and Solukhumbu

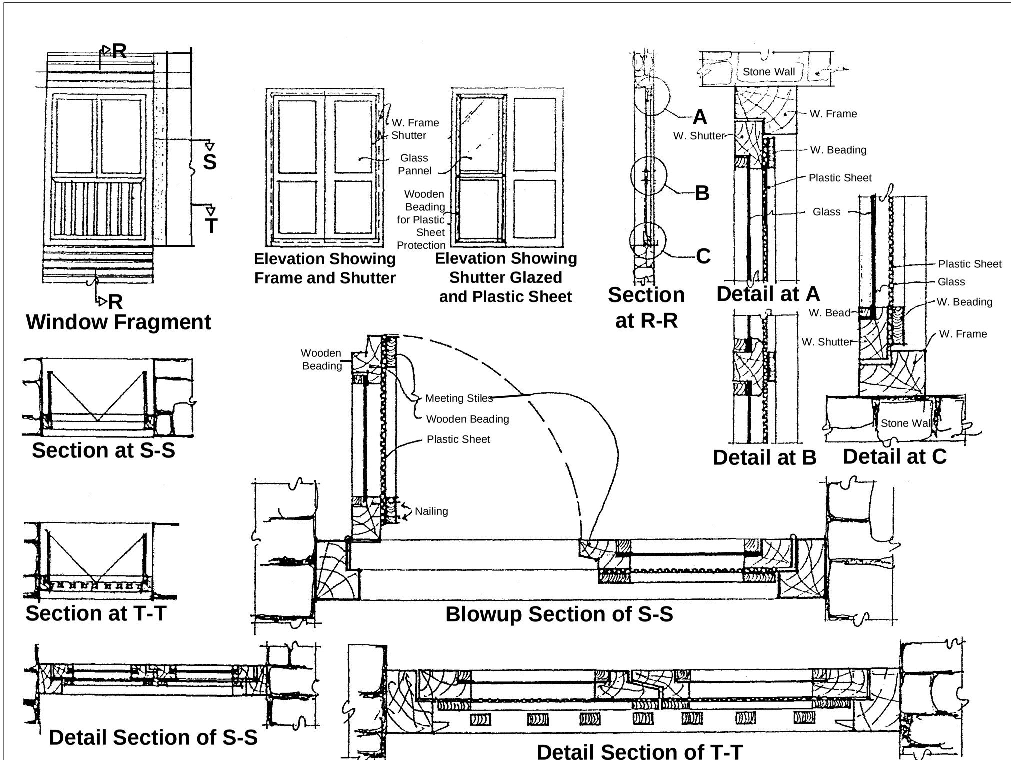


Figure 5.46: Details of Houses in Jumla and Solukhumbu

5.7
Analysis Before and After Incorporation of Passive Solar Building Technology in Buildings in the Himalayan Region

Y.R. Dahal & T.R. Bajracharya

Introduction

This paper mainly concentrates on case studies carried out in the districts of Solukhumbu and Jumla to assess how successful use of passive heating systems in traditional buildings can be. For the case study we took one building from the west (Jumla) and another from the east (Solukhumbu) of Nepal. These two districts are located at high altitudes where the climate is very cold. The availability of solar energy in these places is substantial and almost 300 days are sunshine days. People from the Himalayan region have different cultures and architectural traditions. For example, in Jumla all houses have flat rooves with fuelwood stacked on top. The windows are also very small. In Solukhumbu, the rooves are inclined and they have sufficiently large windows.

Case Studies

Jumla

Jumla lies within the Far-Western Region of Nepal at a latitude of 29°17' N and a longitude of 82°10' E and at an elevation of 2,300 masl. The minimum temperature is -13.4°C and the maximum 33°C.

For our thermal calculation, we have taken the average temperature for the whole year. The maximum relative humidity is 85 per cent in the morning in August and the minimum is 23 per cent in the evening in January.

Outdoor maximum temp = 25°C
Outdoor minimum temp = -9.575°C
Outdoor daily range = $(t_o)_{max}$ - $(t_o)_{min}$ = 25 -(-9.575) = 34.575 > 11.1
Let the inside room temperature = t_i
Outside and inside temp diff. = (ti + 9.575) > 8.3
Correction of equivalent temp diff. = ((ti + 9.575) - 8.3) - (34.575 - 11.1) x 0.25)
= (ti -4.6)
Mass of wall = r D X A = 1500 X 0.5x1
= 750 kg/m^2 area
Mass of roof = 1000 x 0.25 x 1
= 250 kg /m^2

Analysis of Existing Building

The total amount of heat gain through the windows and doors is given in Table 5.12. This amount of heat can be used effectively for space heating, if it can be retained within the building envelope.

Radiation heat gain Q_R = 1273.32 W (5.1)

Table 5.12: Direct Solar Gain through Windows and Doors

WALL	Windows & Door Area (m^2)	Average Radiation Intensity (W/m^2)	Total (W)
East	1.34	178.25	238.85
West	1.34	177.29	237.56
South	1.96	406.56	796.91
		Total	1273.32

The total heat loss from the building is given by:

Total heat loss from building Q_T = (435.68 ti + 2913.55) (5.2)

The thermal calculation for the building is given in Table 5.13.

Table 5.13: Thermal Calculation of Building

Item	Time	$(\Delta t_E)_{table}$	$(\Delta t_E)_{corr.}$	U	A	Q
East Wall	3 p.m.	10.6	(ti + 6)	1.561	21.97	34.29 (ti + 6)
South Wall	8 p.m.	8.9	(ti + 4.3)	1.561	11.54	18.02 (ti + 4.3)
West Wall	11 p.m.	12.8	(ti + 8.2)	1.561	21.97	34.29 (ti + 8.2)
North Wall	10 p.m.	4.4	(ti - 0.2)	1.561	13.50	21.07 (ti - 0.2)
Roof (Exposed	6 p.m.	21.7	(ti + 17.1)	0.964	66.94	64.58 (ti + 17.1)
Roof (Unexposed)	-	-	(ti +9.575)	0.964	15.84	15.28 (ti +9.575)
Doors & Windows	-	-	(ti + 9.575)	1.773	4.84	8.22 (ti + 9.575)
Floor	-	-	(ti + 9.575)	0.919	82.78	76.12 (ti + 9.575)
Infiltration	-	-	(ti + 9.575)	20.4	8.03	163.81 (ti + 9.575)

After Incorporation of Passive Solar Technology

Passive solar heating for this building is by the direct gain method. It is necessary to prevent heat transferring from inside to outside during the night. For this purpose we have modified the building in the following way.

- We created a 50 mm air gap outside the wall with bamboo net with a thickness of 15 mm.We plastered it with a homogeneous mixture of rice husk and mud which was 25 mm thick; these materials are available locally.
- Assuming 20 per cent of rice husk mixed with mud for plastering purposes.
- For simplicity, assuming a 5 mm thick rice husk layer outside the bamboo net and 20 mm of mud with a total thickness of 25 mm.
- Add one window on the south side and another window on the west side and increase the dimension of the existing window in the south to 100 mm x 1,500 mm to allow sufficient solar radiation into the room.

The total amount of heat gain through the windows and doors is given in Table 5.14, after incorporating the passive solar technologies mentioned above.

Table 5.14: Direct Solar Gain through the Windows and Doors

WALL	Windows & Door Area (m^2)	Average Radiation Intensity (W/m^2)	Total (W)
East	1.24	178.25	338.85
West	2.18	177.29	286.49
South	3.96	406.56	1610.09
		Total	2235.43

Radiation heat gain $Q_R = 2235.43$ W (5.3)

The total amount of heat loss from the building is given by:

Total heat loss from building $Q_T = (249.44\ ti + 203.77)$ (5.4)

The thermal calculation for the building after incorporation of Passive Solar Technology is given in Table 5.15.

Two equations (5.2 and 5.4) obtained for the existing conditions and after incorporation of passive technology are plotted in graphs with inside room temperature on the X - axis and total heat on the Y – axis. From the graph, (Figure 5.47) it is seen that the slope of the line after incorporation is less than with the existing condition.

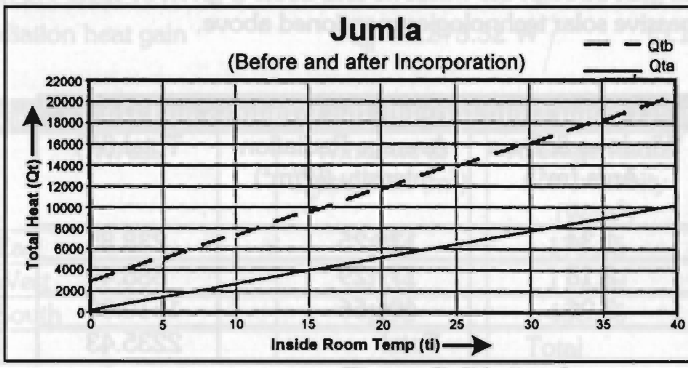
Another graph was plotted to show the difference in heat, before and after passive building technology on the Y-axis, and inside room temperature on the X- axis.

Table 5.15: Thermal Calculation of Building after Recommendations

Item	Time	$(\Delta t_E)_{table}$	$(\Delta t_E)_{corr.}$	U	A	Q
East Wall	3 p.m.	10.6	(ti + 6)	0.346	21.97	7.61(ti + 6)
South	8 p.m.	8.9	(ti + 4.3)	0.346	11.54	3.30(ti + 4.3)
West Wall	11 p.m.	12.8	(ti + 8.2)	0.346	21.97	6.85(ti + 8.2)
North wall	10 p.m.	4.4	(ti - 0.2)	0.346	13.50	4.67(ti - 0.2)
Roof (Exposed	6 p.m.	21.7	(ti + 17.1)	0.298	66.94	20(ti + 17.1)
Roof (Unexposed)	-	-	(ti +9.575)	0.298	15.84	4.73(ti +9.575)
Doors & Windows	-	-	(ti + 9.575)	0.330	7.84	2.47(ti + 9.575)
Floor	-	-	(ti + 9.575)	0.294	82.78	24.37(ti + 9.575)
Infiltration	-	-	(ti + 9.575)	20.4	8.03	175.44(ti + 9.575)

this graph (Figure 5.48) we can directly read the amount of heat saved inside the building at a particular temperature after the incorporation of passive building technology.

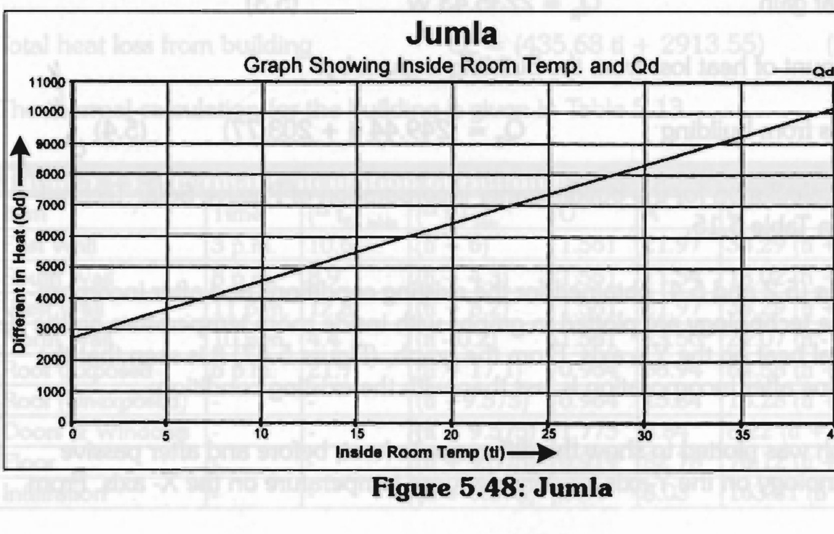
Solukhumbu



QTb = 435.68ti + 2914.55
Qta = 249.44ti + 203.77

ti	Qtb	Qta
0	2913.55	203.77
5	5091.95	1450.57
10	7270.35	2697.37
15	9448.75	3944.17
20	11627.15	5190.97
25	13805.55	6437.77
30	15983.95	7684.57
35	18162.35	8931.37
40	20340.75	10178.20

Figure 5.47: Jumla



ti	Qd
0	2709.78
5	3641.38
10	4572.98
15	5504.58
20	6436.18
25	7367.78
30	8299.38
35	9230.98
40	10162.58

Figure 5.48: Jumla

Solukhumbu

Solukhumbhu lies within the Eastern Region of Nepal at a latitude of 27° 31'N, a longitude of 86° 37'E, and an elevation of 2,770 masl. The minimum temperature of this district is - 5°C and the maximum temperature 23°C.

For thermal calculation we have taken the average annual temperature. The maximum relative humidity of the district is 96 per cent on a morning in July and the minimum is 54 per cent on a morning in April.

Outdoor maximum temp	= 15 °C
Outdoor minimum temp	= -4 °C
Inside temp.	= ti
Outdoor daily range	$= (t_o)_{max} - (t_o)_{min} = 15 - (-4) = 19°C > 11.1$
Outside and Inside temp diff	= (ti + 4) > 8.3
Correction of equivalent temp diff.	$= D\ t_g = ((ti + 4) - 8.3) - (19 - 11.1) \times 0.25))$
	= (ti -6.27)
Mass of wall	= r D X A = 1500 X.5 x 1 = 750 kg/m^2 area
Mass of roof	= 1000 x.26 x 1 = 260 kg /m^2

Analysis of the Existing Building

The total amount of heat gain through windows and doors is given in Table 5.16.

Table 5.16: Direct Solar Gain through Windows and Doors

WALL	Windows & Doors (m^2)	Average Radiation Intensity (W/m^2)	Total (W)
East	1.5	143.17	214.75
West	7.5	143.17	1073.77
South	4.5	410.86	1848.87
		Total	3137.4

Radiation heat gain, $Q_R =$ 31 37.4 W (5.5)

The total heat loss from the building is given by:

Total heat loss from building $Q_T = (585.49\ ti – 1177.9)$ (5.6)

The thermal calculation for the building is given in Table 5.17.

After Incorporation of Passive Solar Technology

Since passive solar heating for this building is by direct gain method, it is necessary to prevent heat transfer from inside to outside during the night, For this purpose we have modified the building as follows.

Table 5.17: Thermal Calculation for the Building						
Item	Time	$(\Delta t)_{max}$	$(\Delta t)_{mean}$	U	A	Q
East Wall	3 p.m.	10.6	$(t_i + 4.23)$	1.561	40.58	$63.56(t_i + 4.23)$
South Wall	3 p.m.	3.9	$(t_i + 2.63)$	1.561	19.62	$30.62(t_i + 2.63)$
West Wall	11 p.m.	12.3	$(t_i + 6.58)$	1.561	34.98	$54.60(t_i + 6.58)$
North wall	10 p.m.	4.4	$(t_i - 1.27)$	1.561	24.12	$37.65(t_i - 1.27)$
Roof (unexposed)	3 p.m.	5.5	$(t_i - 0.77)$	0.869	67.26	$58.44(t_i - 0.77)$
Doors & Windows	-	-	$(t_i + 4)$	1.578	13.5	$21.30(t_i + 4)$
Floor	-	-	$(t_i + 4)$	0.869	67.26	$58.44(t_i + 4)$
Infiltration	-	-	$(t_i + 4)$	20.4	12.76	$260.43(t_i + 4)$

Creating a 50 mm air gap outside the wall using a 15 mm thick bamboo net and plastering it with an even mixture of rice husk and mud (25 mm thick) (these materials are available locally.):

- assuming 20 per cent of rice-husk mixed with mud for plastering purposes, and
- for simplicity, assuming a 5 mm thick rice-husk layer outside the bamboo net and 20 mm of mud with a total thickness of 25 mm.

Direct Solar Gain through windows and doors is the same as before incorporation, because there is no change in door and window areas.

The total heat loss from the building is given by:

Total heat loss from building $Q_T = (344.17\ ti - 1875.88)$ (5.7)

The thermal calculation for the building after incorporation of Solar Passive Technology is given in Table 5.18.

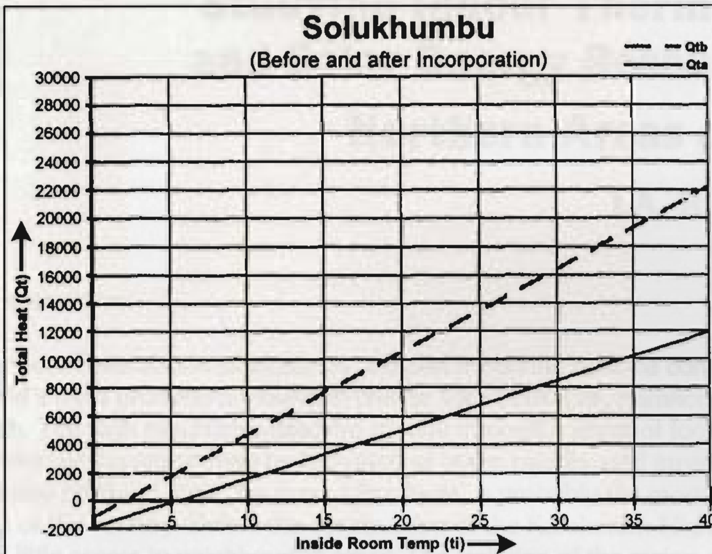
Two equations obtained for the pre-existing condition and after incorporation of passive technology are plotted on the graph, with the inside room temperature on the X axis and total heat on the Y-axis. From the graph (Figure 5.49), it can be seen that the slope of the line after incorporation is less than in the pre-existing condition.

Another graph has been plotted to show the difference in heat before and after application of passive building technology on the Y - axis and inside room temperature on the X -axis. From this graph, (Figure 5.50) we can directly read the amount of heat saved inside the building at a particular temperature after the incorporation of passive building technology.

Conclusion

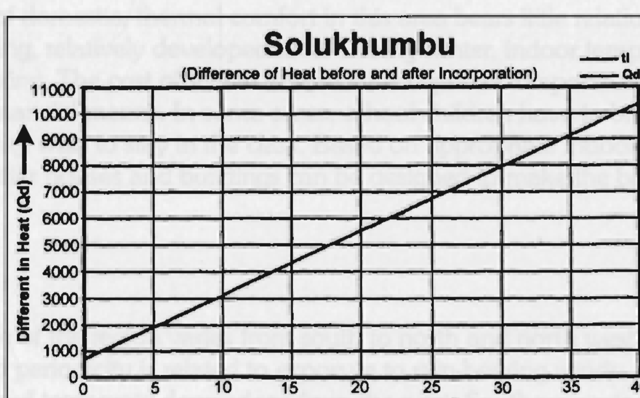
From the above two case studies, it is found that, at a particular inside temperature, a certain amount of heat is saved after the incorporation of solar passive technology. Although there are several other methods that can be applied, in this case existing walls were insolated by creating cavities and more heat was trapped inside the building by increasing the size of the windows.

Table 5.18: Thermal Calculation for the Building after Passive Heating Modifications						
Item	Time	$(\Delta t_E)_{table}$	$(\Delta t_E)_{corr.}$	U	A	Q
East Wall	3 p.m.	10.6	(ti + 4.33)	0.339	40.98	13.89 (ti + 4.33)
South Wall	8 p.m.	8.9	(ti + 2.63)	0.339	19.62	6.65 (ti + 2.63)
West Wall	11 p.m.	12.8	(ti + 6.53)	0.339	34.98	11.86 (ti + 6.53)
North wall	10 p.m.	4.4	(ti - 1.87)	0.339	24.12	8.17 (ti - 1.87)
Roof (Exposed	8 p.m.	5.5	(ti - 0.77)	0.289	67.26	19.43 (ti – 0.77)
Doors & Windows	-	-	(ti + 4)	0.316	13.5	4.26 (ti + 4)
Floor	-	-	(ti + 4)	0.289	67.26	19.43 (ti + 4)
Infiltration	-	-	(ti + 4)	20.4	12.76	260.48 (ti + 4)



ti	Qtb	Qta
0	-1177.90	-1875.88
5	1749.55	-155.03
10	4577.00	1565.82
15	7604.45	3266.67
20	10531.90	5007.52
25	13459.35	6728.37
30	16386.80	8449.22
35	19314.25	10170.10
40	22241.70	11890.90

Figure 5.49: Solukhumbu



ti	Qd
0	697.98
5	1904.58
10	3111.18
15	4317.78
20	5524.38
25	6730.98
30	7937.58
35	9144.18
40	10350.78

Figure 5.50: Solukhumbu

5.8
Studying Indoor Thermal Comfort and Solar Energy Resources in the Northern Areas of Pakistan

I.A. Rija & J.F. Nicol

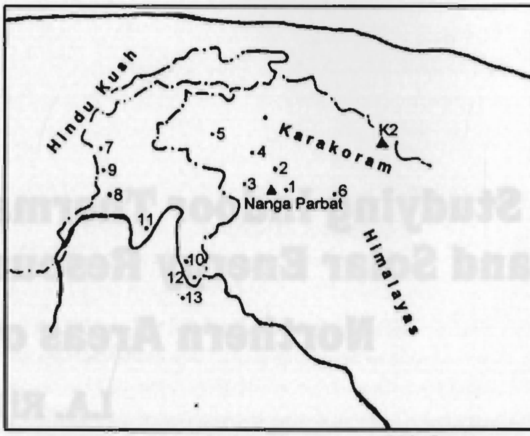
Introduction

Northern Pakistan stretches across complex mountain systems containing three of the world's most prominent mountain chains: the Himalayas, Karakoram, and Hindu Kush. The high mountains descend quickly through a series of foothills. The sub-division of the region may be identified as outer, middle, and inner Himalayas. The extreme northern zone, the inner Himalayas, is probably the most underdeveloped part of the country. Before the construction of the Karakoram Highway, the inhabitants had little access to neighbouring areas. The isolation of the region ended with the coming of the Karakoram Highway.

The level of domestic, thermal comfort in this area bears little relation to that of the neighbouring, relatively developed area. During winter, indoor temperatures are often below freezing. The cost of fuel to ensure an acceptable temperature is beyond people's financial means. In some cases, school children have to bring their own fuel to school if they wish to stay in the class. Based on appropriate indoor thermal comfort indices, better houses and buildings can be designed to make the best use of solar radiation.

Climate

The climate of the region varies from south to north and north west. The variation in rainfall and periodicity is related to exposure to rain-bearing winds: the monsoons from the south and temperate depressions from the west. Southern parts receive very heavy rain. The northern parts, Chitral, Gilgit, and Skardu, lie virtually outside the monsoon belt. The extreme northern areas are very dry. The region experiences very cold winters belt. The extreme northern areas are very dry. The region experiences very cold winters with frequent frosts and heavy snowfall but has mild summers. The region is equipped with an efficient meteorological network. There are twelve observatories, as listed in Table 5.19, recording various meteorological variables. These are marked on Map 5.2 by the corresponding numbers given in the table.



Map 5.2 Northern Region of Pakistan with Observatories

Table 5.19: Meteorological Observatories in Northern Pakistan					
Station	**Cate-gory**	**zone**	**Longi-tude**	**Latitude**	**Altitude (m)**
1. Astor	C	Inner Himalayas	74.90	35.37	2167
1. Bunji	C	Inner Himalayas	74.40	35.67	1372
2. Chilas	C	Inner Himalayas	74.10	35.42	1250
3. Gilgit	B	Inner Himalayas	74.33	35.92	1459
4. Gupis	C	Inner Himalayas	73.40	36.17	2155
5. Skardu	B	Inner Himalayas	75.68	35.30	2209
6. Chitral	B	Central Himalayas	71.83	35.85	1499
7. Dir	B	Central Himalayas	71.85	35.20	1369
8. Drosh	B	Central Himalayas	71.78	35.57	1464
9. Kakul	B	Outer Himalayas	73.25	34.18	1308
10. Saidu Sharif,	C	Outer Himalayas	73.35	34.73	961
11. Murree	C	Outer Himalayas	73.38	33.92	2167
12. Islamabad	A		73.10	33.62	507
13. Quctta	A		66.95	30.18	1672

Note:
A=solar radiation, sunshine duration, and meteorological elements
B = sunshine duration and meteorological elements
C= meteorological elements only

Mean minimum and mean maximum temperatures along with precipitation recorded at various stations are given in Figure 5.51. There are substantial variations in rainfall between humid and dry climates. To display precipitation, therefore, two scales have been used: 0-150 mm for dry and semi humid, and 0-350 for humid zones. From the figure it appears that the range of temperatures between the hottest and coldest months is considerable. In many places it exceeds 25°C, the average temperature. In summer the climate is pleasant.

Sub-Division of the Northern Region

Based on topographic and climatic variations (particularly precipitation) the region may be divided into three zones.

a. Outer Himalayas - Humid

This area includes the Murree Hills and adjacent part of Hazara. It is the most developed and relatively densely populated area in the region. Rainfall from monsoon and western disturbances is more than in any other part of the country and occurs throughout the year. The monsoon starts in June and remains active until the middle of September. Annual mean precipitation in Murree and Abbottabad (Kakul) is 1, 789 and 1, 366 mm respectively, of which more than 50 per cent falls from June to September. July and August are the rainiest months. Winter rain is relatively less frequent and accompanied by snow at the end of December. Snowfall continues until the end of February. The summers are mild and winters are cold. Due to severe cold weather, people in the higher hills generally leave their homes and move to the plains or valleys in the winter months. The hill slopes are forested.

b. Middle Himalayas - Sub-Humid and Semi-Arid

In the rain shadow of the outer Himalayas, flanked by the Hindu-Kush range in the north, the Middle Himalayan zone is a region of deep valleys and lofty ranges, snow-covered mountains, and pine forests of great beauty. The zone includes Swat, Dir, Malakand, and Chitral. The rainfall decreases towards the north-west, the annual mean of 1, 416 mm in Dir decreases to 1, 054 mm in Saidu Sharif, and 443 mm in Chitral. The area lies virtually outside the monsoon belt. The decrease in annual total rainfall is therefore due to light during summer. About two-thirds of the total precipitation occurs during December-April. The coldest month is January and the hottest July. Forests on the mountain slopes produce timber for export.

c. Inner Himalayas - Arid

Further to the north the mountain areas of Gilgit and Baltistan become very dry. Annual mean rainfall in Gilgit is 129 mm and in Skardu 204 mm. The area is marked by low precipitation in winter, hardly coming to double figures in many places. Up in the north is the most heavily glaciated area. Winters are cold and snowy and summers are cool. March-May are the rainiest months, April receiving the most rain. There is a secondary peak from July to September, August being the rainiest month. The climate is healthy and dry. The population is sparse. The principal towns and villages are Astor, Chilas,

Chilas, Gilgit, Hunza, Nagar, and Skardu. There are some extremely difficult and dangerous areas, particularly around Nanga Parbat and K2. Hunza Valley was once known as Shangri-La, partly because it was incredibly remote and used to be accessible only from the north. Most of its links were, therefore, with China and Tibet.

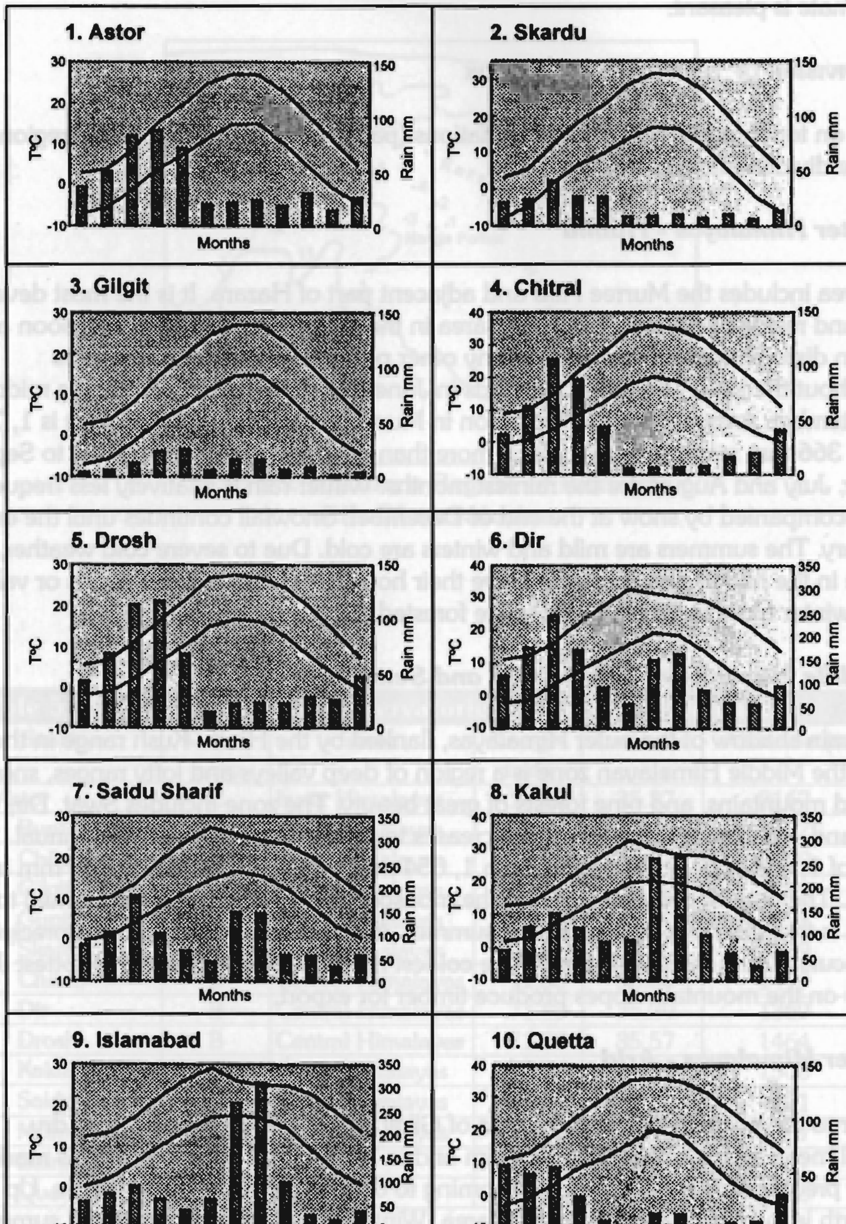


Figure 5.51: Variations in Temperature (Min. and Max.) and Rainfall in Different Locations

Foodstuff and other commodities were airlifted from Islamabad, Karachi, and Peshawar mainland. However, the construction of the Karakoram Highway (Sharah-e-Rashim) has ended the isolation of the region. Now the highway is playing a major role in the development of this remote area.

Building Technologies

Stone, soil, and timber are traditional building materials. Soil is used for blocks, mortar, plaster, and as roof-covering material. However, traditional wall construction is affected by the availability or unavailability of soil and timber. In areas with little soil, a timber/ stone sandwich type of construction is used. In valleys where timber is scarce, instead of timber reinforced walls, stone walls are used. Timber is used only for roof spans and internal columns. The rooves are usually supported by timber planks independently.

Materials such as cement and steel, nails and ironmongery, and lime and bricks are virtually unused in traditional buildings. This reflects the high cost involved in acquiring these materials. Use of such materials can only be seen in government buildings and along the Karakoram Highway.

Indoor Thermal Comfort

A basic function of the building is to ensure the thermal comfort of its occupants and to protect them from the heat or cold outdoors. Architectural solutions to the provision of pleasant indoor conditions are based on appropriate temperature standards. Current temperature standards are based on experiments in climate chambers (pre-fixed climatic conditions) and do not take the outdoor climate into account. The outdoor climate is extremely variable. These standards thus do not represent the real building. An alternative approach to determining comfort conditions is through field studies. Several field studies have been conducted worldwide and the results correlated (Humphreys 1976; Humphreys 1978). It was thus demonstrated that, in naturally ventilated buildings, the comfort temperature is related to the average outdoor temperature - in other words to climate and season.

The design indoor temperatures recommended by the Government of Pakistan for sizing the heating and cooling devices and plants in buildings are 21°C in the cold season and 26°C in the hot season, irrespective of local climatic conditions. These figures are based on standards developed by ASHRAE (ASHRAE n.d.). The upper limit is for summer comfort and the lower limit for winter comfort. In an air-conditioned building, a standard specifying a single temperature can be achieved; in naturally ventilated buildings, it is virtually impossible to do so. An indoor temperature standard which varies with outdoor conditions can be met by a naturally ventilated building. The existing standards thus cannot take into account the highly diversified climate of Pakistan.

Thermal Comfort Studies - Building Design Temperature

In order to determine comfort conditions applicable in different seasons and climatic regions of Pakistan, two field surveys were carried out (Nicol *et.al*. 1994; Nicol *et al.*

1997). The surveys were carried out in five cities, (Islamabad, Karachi, Multan, Quetta, and Saidu Sharif), one in each climatic zone. The details of the surveys and the results are given in Nicol *et al.* (1994) and Nicol et al. (1997). Detailed analysis of the data collected shows that the design indoor temperature for buildings in Pakistan can be determined according to the formula:

$$T_d = 0.36\,T_o + 18.5 \qquad (5.8)$$

However, there are large variations in climate from the coastal lowlands in the south to the high mountains in the north. These variations suggest that the design indoor temperature should be determined for each climatic region separately. During the thermal comfort studies, empirical relationships for indoor design temperature were developed for each of the above locations. For application in the northern areas, the equation is only for the Middle zone (for Saidu Sharif). However, due to climatic resemblance, Saidu Sharif may be taken as representative of the Outer zone. The climate of the Inner zone differs in terms of rainfall pattern and amount, but the temperature regimes are similar. Therefore, whilever a thermal comfort study of the area is not carried out, the equation for Saidu Sharif may be applied to the Inner zone too for evaluating the design indoor temperature. The equation for Saidu Sharif is:

$$T_d = 0.41\,T_o + 15.3 \qquad (5.9)$$

The indoor design temperatures for different locations in the region have been calculated using Formula 5.8. The results have been listed in Table 5.20.

Table 5.20: Design Indoor Temperatures for Buildings in Northern Areas

Month	Astor	Bunji	Chilas	Gilgit	Gupis	Skardu	Chitral	Dir	Drosh	Kakul	Muree	Saidu
Jan.	14.4	16.8	18.0	16.7	15.1	14.3	17.0	17.1	17.1	18.3	16.8	18.7
Feb.	15.0	17.7	19.0	17.8	16.1	15.5	17.5	17.5	17.7	18.7	16.9	19.2
Mar.	16.8	19.7	21.2	20.1	18.3	18.0	19.2	19.3	19.6	20.4	18.68	20.9
Apr.	19.1	21.7	23.5	22.1	20.7	20.5	21.5	21.5	22.1	22.4	20.7	23.3
May	20.8	23.3	25.5	23.5	22.4	21.9	23.6	23.3	24.4	24.3	22.4	25.4
June	22.7	25.2	28.0	25.5	24.5	24.0	26.0	23.3	26.9	26.0	23.7	27.0
July	23.9	26.7	29.0	26.6	25.8	25.2	26.8	25.7	27.6	25.5	23.1	27.1
Aug	23.9	26.0	28.7	26.2	25.3	25.1	26.3	25.3	27.2	25.1	22.8	26.5
Sep.	22.1	24.4	27.1	24.4	25.5	23.3	24.4	24.0	25.8	24.4	22.4	25.5
Oct	19.8	22.0	24.1	21.9	20.9	20.4	22.0	22.0	23.2	22.9	21.2	23.6
Nov	17.4	19.2	21.0	19.1	18.4	17.5	19.7	19.9	20.5	20.9	19.6	21.2
Dec.	15.4	17.2	18.5	17.1	15.9	15.3	17.6	18.0	18.0	19.1	17.9	19.4

Solar energy Resources

Energy supplies in the outer Himalayas are quite efficient compared to the Middle and Inner zones. All cities, major towns, and most villages are connected to the national grid. However, most areas of the Middle and Inner Himalayas are poorly endowed with conventional energy resources. Poor transportation infrastructure, the high costs involved, and severe weather conditions do not facilitate the maintenance of a proper energy supply system from the national grid. The energy requirements for cooking are met predominantly with wood, shrub, and agricultural and animal wastes and kerosene is used for lighting. Due to shortage of energy and lack of transportation facilities, there is no industrial base. The conventional forms of energy are not favoured because of the location. One possible solution would be to use renewable energy: solar, wind, and geothermal. Solar energy offers great potential, particularly for space and water heating.

Evaluating Solar energy Potentials

Although there are a dozen meteorological stations, none of these records solar radiation. However, research over the last couple of decades has proved that it can be estimated by means of other climatic parameters by applying a model developed for a nearby location where solar radiation is measured. The choice of the location and the model depends on climatic similarity and the measured climatic variables. Two types of climatic variable may be considered for estimation of solar radiation. The first types influence incoming radiation, e.g., cloud cover, humidity, and precipitation. The second types are indicative of incoming radiation such as temperature and sunshine duration. Among the different climatic elements, sunshine duration is significant. In the northern areas it is recorded in six locations: one in the Outer, two in the Inner, and three in the Middle Himalayan zone.

Solar radiation is measured in six locations in Pakistan: Islamabad, Karachi, Lahore, Multan, Peshawar, and Quetta. It appears that the climate of the Outer and Middle Himalayas resembles the climate of Islamabad and that of the Inner Himalayas resembles that of Quetta. Different models for predicting solar radiation have been developed for each of these six locations (Raja 1996). Among these models, the simple insolation-sunshine relationship with monthly coefficients produced the best results. Using the insulation-sunshine model for Quetta, global radiation over Gilgit, Skardu, Drosh, and Chitral were evaluated. The Islamabad model was used for calculating global radiation over Dir, Kakul (Abbottabad), and Murree. In each case locally recorded sunshine duration was used. A detailed methodology can be found in the earlier work of Raja (Raja 1996), the estimated values of global radiation at each location are given in Table 5.21.

Table 5.21: Global Solar Radiation MJ/m² over the Named Station

Month	Chitral	Dir	Drosh	Gilgit	Kakul	Skardu
Jan.	9.1	8.7	9.4	7.4	20.1	7.6
Feb.	11.7	9.9	12.0	9.2	11.4	9.5
Mar.	14.2	12.2	14.6	12.2	12.8	12.4
Apr.	19.2	18.7	20.1	19.1	20.2	19.6
May	22.9	21.1	22.9	20.8	21.6	20.9
June	26.7	22.2	27.8	22.2	22.1	22.9
July	24.1	20.4	24.8	21.4	19.0	21.2
Aug	21.1	18.1	21.7	18.9	17.9	19.4
Sep.	18.8	16.2	19.2	17.1	18.2	17.0
Oct	14.8	12.2	15.0	12.0	15.2	12.2
Nov	10.8	10.1	11.2	8.9	11.0	9.4
Dec.	8.4	7.2	8.5	6.0	8.2	60.

Discussions

The Northern Areas on the average experience about 2, 500 bright sunshine hours annually. The annual mean global radiation varies from 14.8 MJm^{-2} to17.8 MJm^{-2}, the Inner zone receiving the lowest and the Middle zone the highest. During the summer more than 20 MJm^{-2} are received at almost all stations; the highest at Drosh (27.7 MJm^{-2}). In winter (December to January) solar radiation falls below 10 MJm^{-2}.

Solar energy use requires accurate scientific assessment of the resource. For practical application of solar energy much more sophisticated data are required. Simple global radiation finds little direct use. The data required may spread from diurnal variation and time of day to detailed statistical analysis. Such data ensure the designing of an appropriate and efficient solar-heating system.

A building designed taking into consideration the outdoor climate and based on appropriate indoor temperature standards will provide better living conditions. However, there is a need to conduct detailed studies to evaluate the potentials of solar energy and indoor thermal conditions in public buildings and houses. Such a solar energy study will provide the basic data required for design of an appropriate system.

With modest funding these two areas, solar energy potentials and indoor thermal conditions, can be studied in detail. Appropriate knowledge of these will influence the building design and enhance the use of solar technology in the region.

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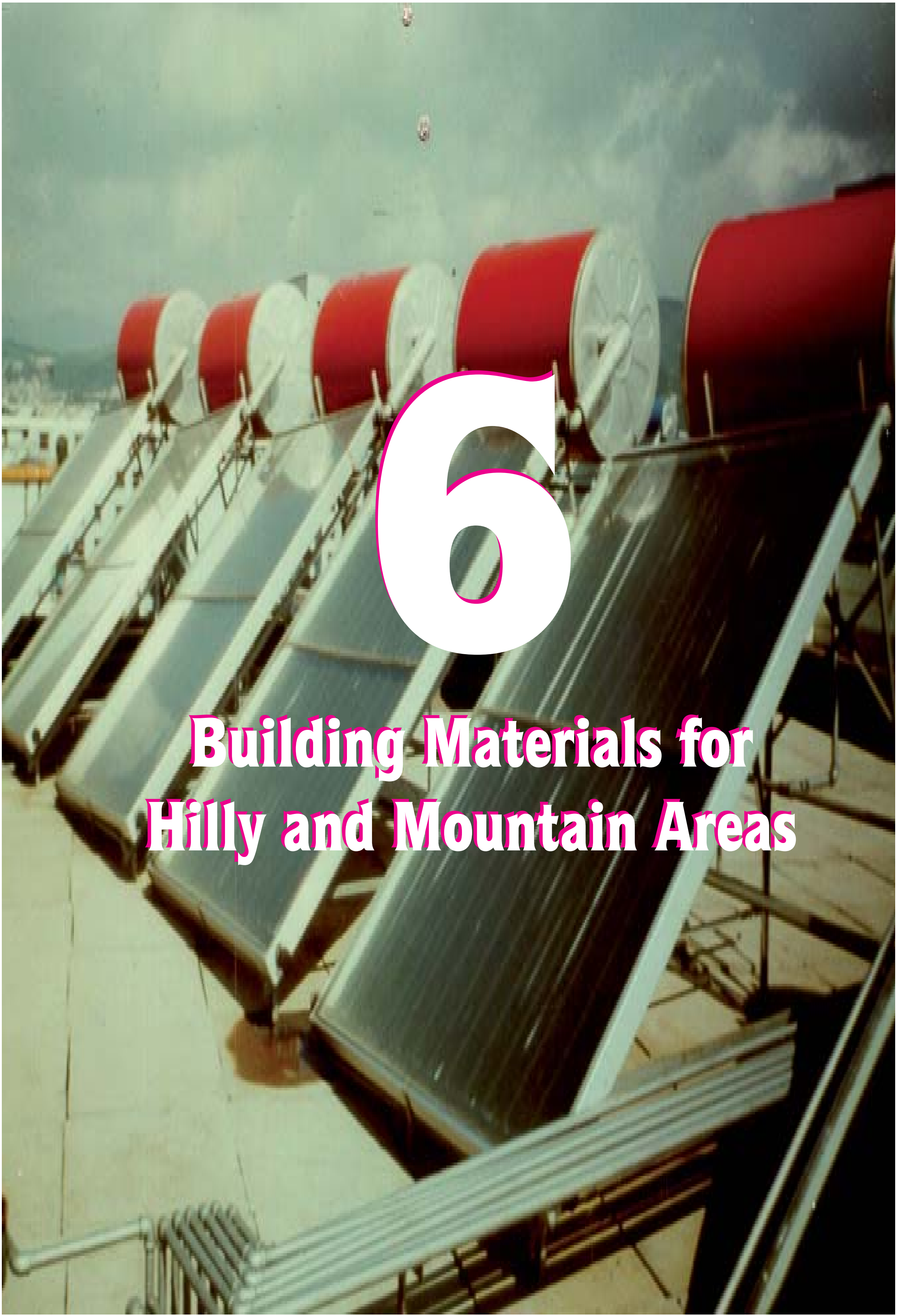
6

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.

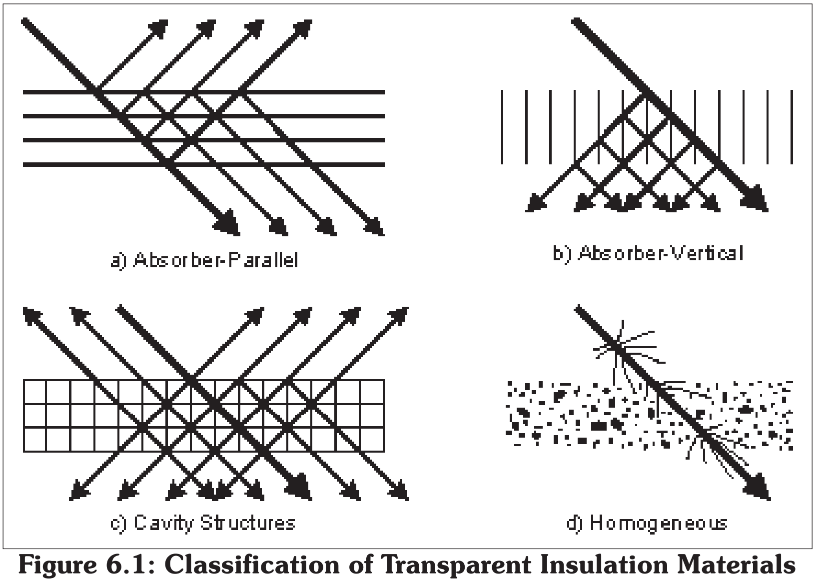


Figure 6.1: Classification of Transparent Insulation Materials

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 :

$$R_o = \frac{(a_o^2 + 2\ .9)^3}{(a_o^2 + 7.9\ )} \quad (6.1)$$

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

The Rayleigh number is given by:

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

so for convection suppression

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

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.

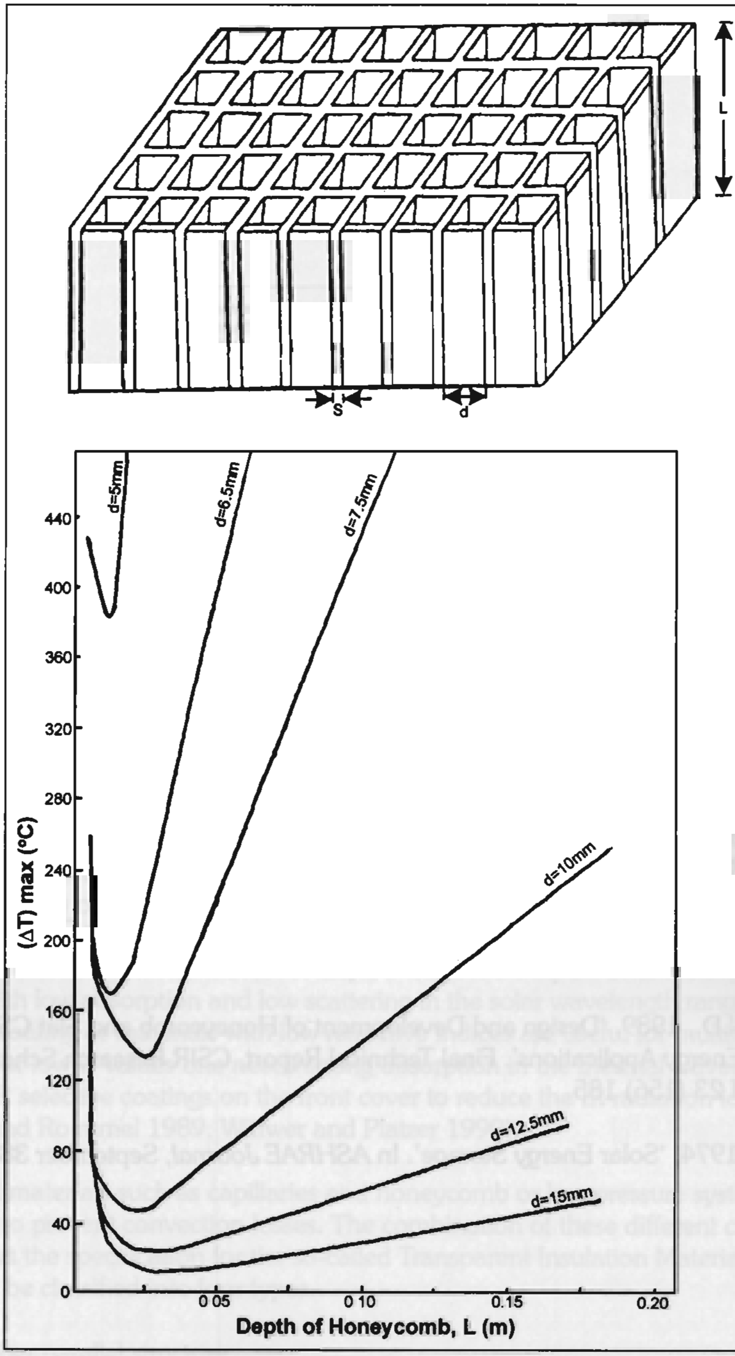


Figure 6.2: Variation of $(\Delta T)_{max}$ for Air Filled Honeycomb with Its Depth and Cell Size

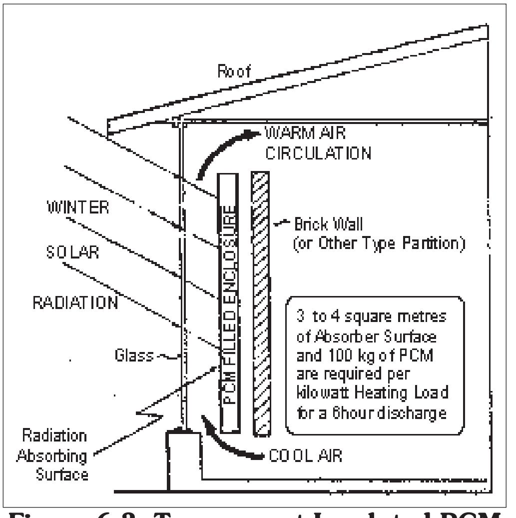


Figure 6.3: Transparent Insulated PCM Storage Wall

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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.

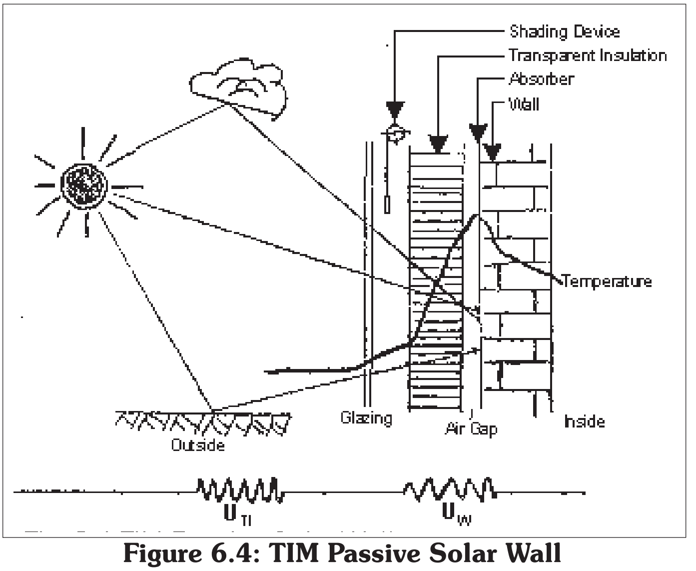

Figure 6.4: TIM Passive Solar Wall

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

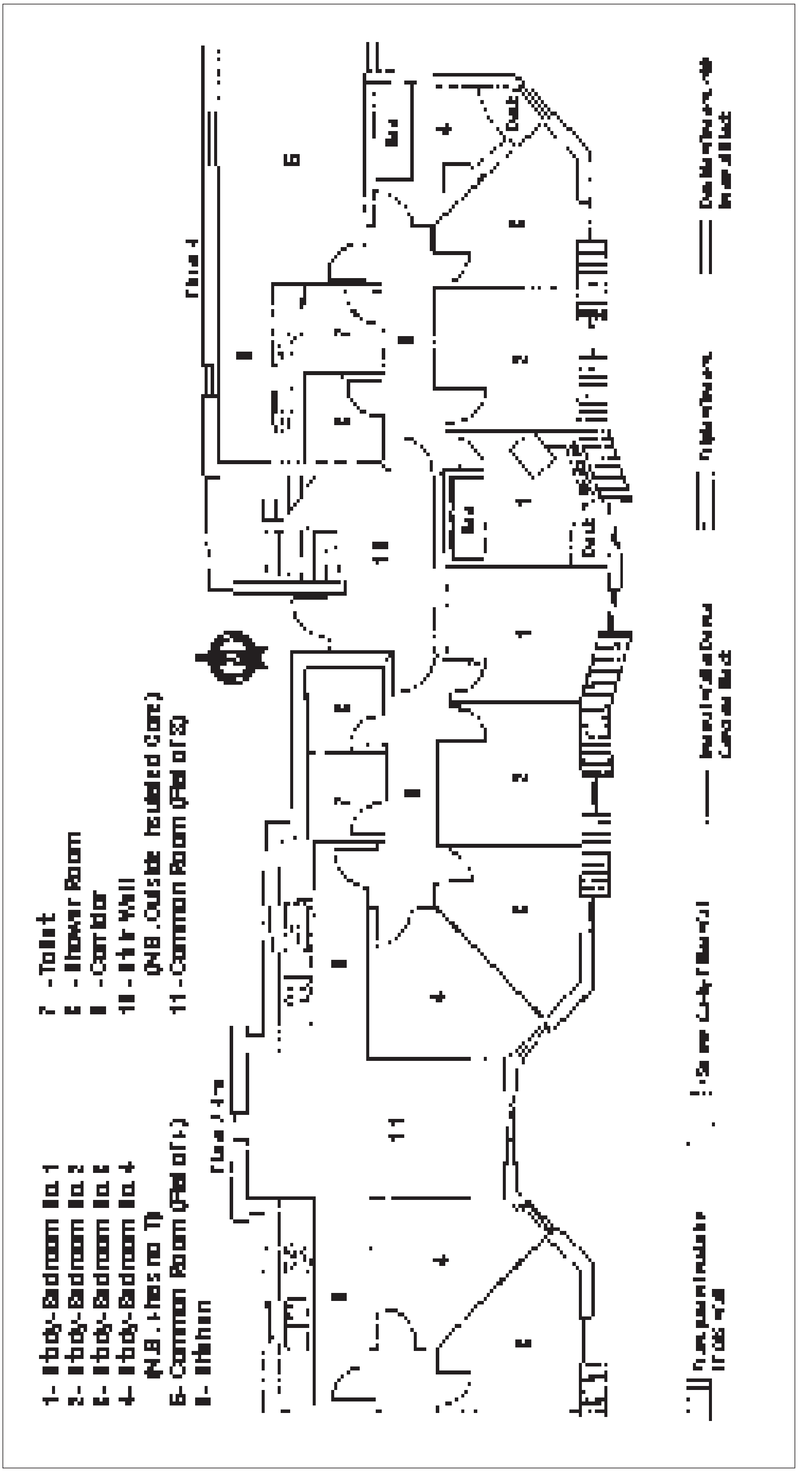

Figure 6.5: Plan of Strathclyde University's Residences in Glasgow

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

Rukhsana Rahooja, Syed Muzaffar Hasan, Tanveer Saleem, 1989. 'Assessment and Improvement of the Thermal Efficiency of a Standard Low Cost Urban House in Metroville-2, Karachi' XIth International Congress, CIB -89, Paris, France.

Syed Muzaffar Hasan, 1989. *Appropriate Opening Sizes for Natural Ventilation*. Karachi: National Building Research Institute.

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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.

7

Application and Design of Passive Solar Systems for Buildings

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

N.K.Bansal & M.S. Bhandari

INTRODUCTION

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

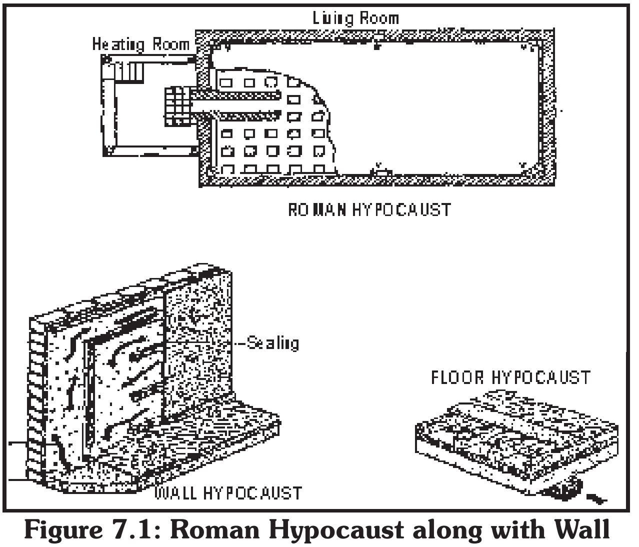

Figure 7.1: Roman Hypocaust along with Wall and Floor Hypocausts

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

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

Case Studies

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

THE SCHOOL AT TOURNAI, BELGIUM

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

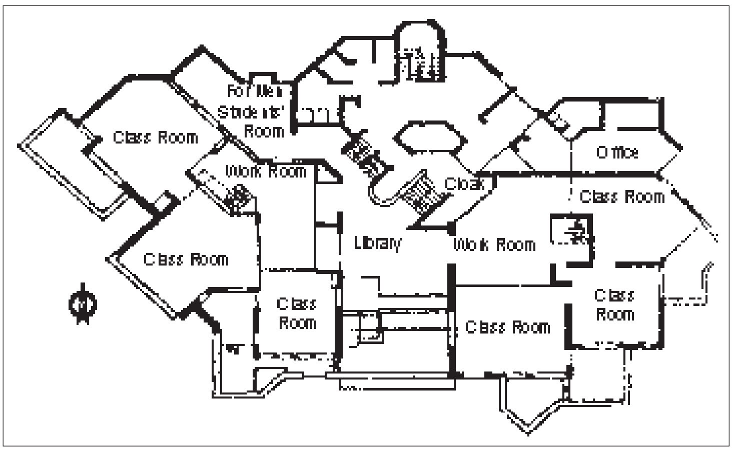

Figure 7.2: Building Plan

METEOLABOR LABORATORIES, SWITZERLAND

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

U-Values (W/m^{2}K)	Walls = 0.28, roof : 0.21, windows 1.98 and building 0.36
Site data	Lat. 47°20'N and altitude: 548m
Climatic data	Gh: 1425 MJ/m^2, sunshine hours: 643 annual degree days (base 20°C) 4,730

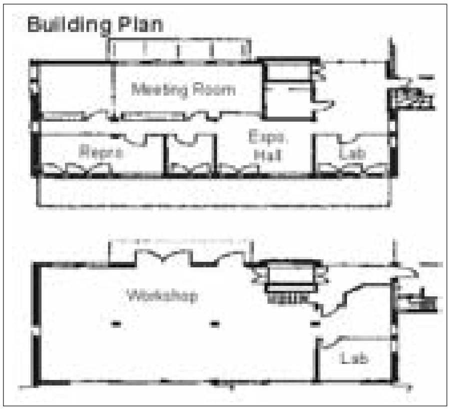

Figure 7.3

SOGECO OFFICE BUILDING ITALY

Floor area	Gross: 1,500 square metres Heated : 1380 square metres
Volume (m^3)	Gross : 4915 Heated : 4378
U-value (W/m^{2}K)	Roof : 0.58, wall: 0.518 window 2.0
Site Data	Latitude: 37°24'N and altitude : 50m
Climatic data	Gh: 6257 MJ/m^2, sunshine hrs: Degree days (20°base): 1493

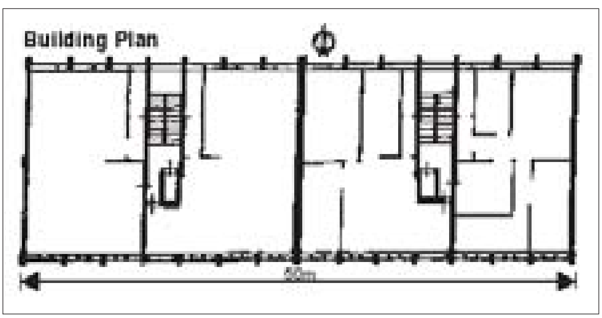

Figure 7.4

SHOPFLOCH KINDERGARTEN GERMANY

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

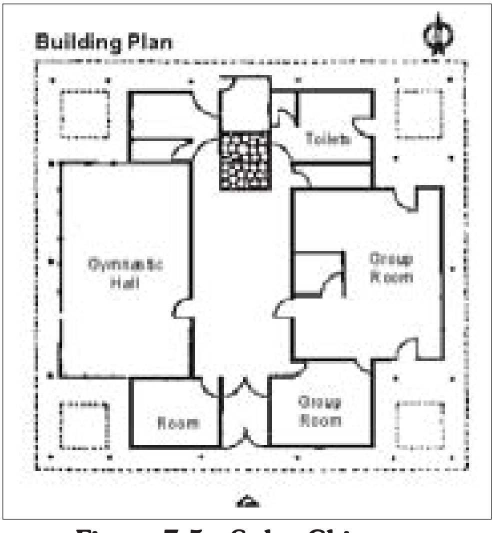

Figure 7.5: Solar Chimney

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

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

Solar Chimney

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

Table 7.1: Results of the Case Studies Analysed						
Building Type	Solar Features	Annual Degree Days (DD)	Floor Area (M^2)		Per M^2 DD Energy Requirement	U-Value ($WM^{-2} K^{-1}$)
			Gross	Heated		
The School of Tournai Belgium	Greenhouse Solar air collectors Warm air from solar collectors circulates through cavities in the internal double wall & in precast concrete slabs.	3754	2635	1720	65.3 kJ pa	0.57
Meteolabor Laboratories Switzerland	Greenhouse Solar air collectors Solar heated air from the greenhouse and collectors is made to flow through sheet metal tubes embedded in the concrete floor.	4730	640	420	22.6 kJ pa	0.36
Sogeco Office Building ITALY	Solar chimney integrated in the south facade with storage in the ceiling provides hot air.	1493	1500	1380	15.4 kJ pa	0.79
Schopfloch Kindergarten GERMANY	Solar air collectors Hot air from solar collectors circulates through the floor and parts of the inner wall.	3908	270	250	128.4 kJ pa	0.90

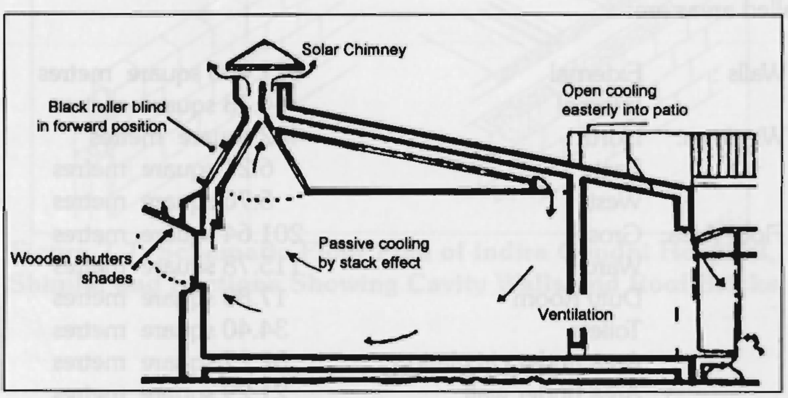

Figure 7.6: Building with a Solar Chimney

Building Blocks for Hypocaust Construction in India

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

Table 7.2: Material and Energy Characteristics of Cavity Blocks

(Bagley 1996)

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

Design of Indira Gandhi Hospital, Shimla

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

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

The detailed areas are:

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

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

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

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

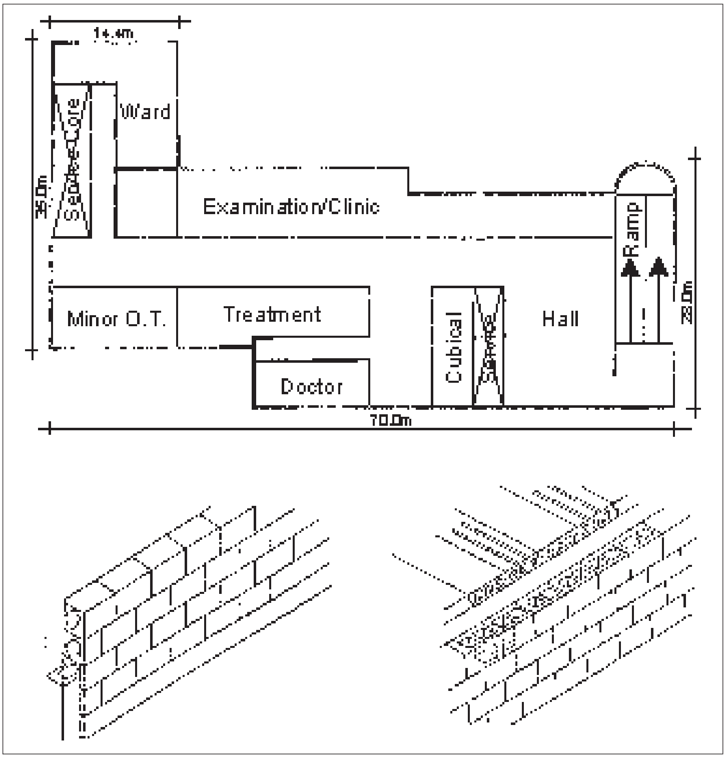

Figure 7.7: Schematic Floor Plan of Indira Gandhi Hospital, Shimla, and Sections Showing Cavity Walls and Roof Bricks

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

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

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

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

Table 7.3: Heating Requirements(kWh/month)

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

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

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

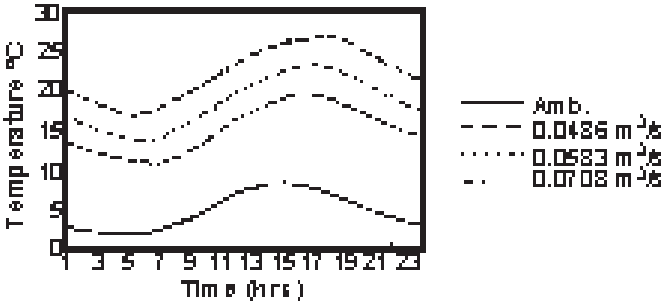

Figure 7.8: Room Temperatures Obtained from a D.G. Set Coupled Hypocaust at Different Mass Flow Rates (Continuous Flow)

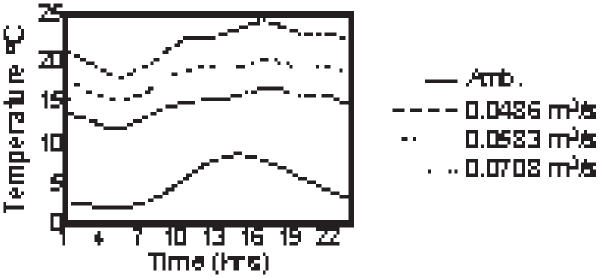

Figure 7.9: Room Temperatures Obtained from a D.G. Set Coupled Hypocaust at Different Mass Flow Rates (Intermittent Flow)

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

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

Conclusions

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

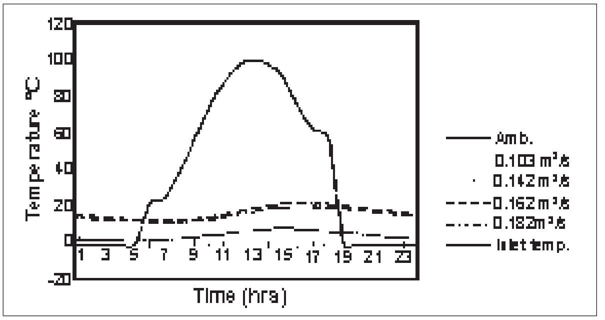

Figure 7.10: Room Temperatures Obtained from a Solar Air Heater Coupled Hypocaust at Different Mass Flow Rates

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

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

S. Alam

Introduction

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

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

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

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

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

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

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

Objectives

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

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

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

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

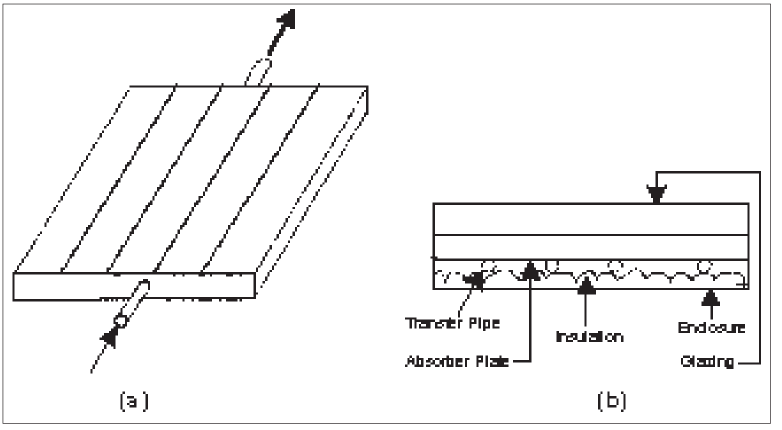

Figure 7.11: (a) A Typical Flat Plate Collector Showing Transfer Pipes (dashed lines) under the Absorber Plate, (b) A Cross-sectional View of the Same Flat Plate

Array Orientation

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

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

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

Where:

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

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

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

Season	Tilt (A) Degrees	Flux (Kw-hr/m^2-day) South, = 0	Flux (Kw-hr/m^2-day) (East West = 90)
Winter	0 (horizontal	1.4	1.4
Solstice	175	2.2	1.2
(D = 112.5)	41	2.2	1.2
	645	2.5	0.98
	90 (vertical	2.2	0.69
	0 (horizontal)	4.5	4.5
Equinox	175	5.5	4.2
(D = 90)	41	2.9	2.8
	645	7.6	2.0
	90 (vertical)	7.6	2.0
	0 horizontal	6.4	7.6
Summer	175	4.2	7.2
Solstice	41	1.5	6.2
(D = 66.5)	645		4.7
	90 (vertical		2.0

Source: Winder 1982

Array Size

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

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

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

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

Series and Parallel Arrays

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

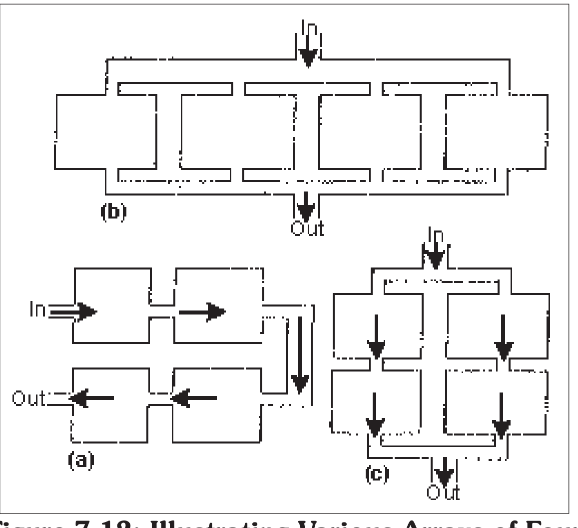

Figure 7.12: Illustrating Various Arrays of Four Panels (a) Series' Array, (b) Parallel Array, and (c) Combination Array

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

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

Heat Losses from Pipes

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

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

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

The heat loss from the pipe is given by:

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

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

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

Two Simple Applications of a Solar Heating System

A. *Solar Hot-Water Supply System*

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

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

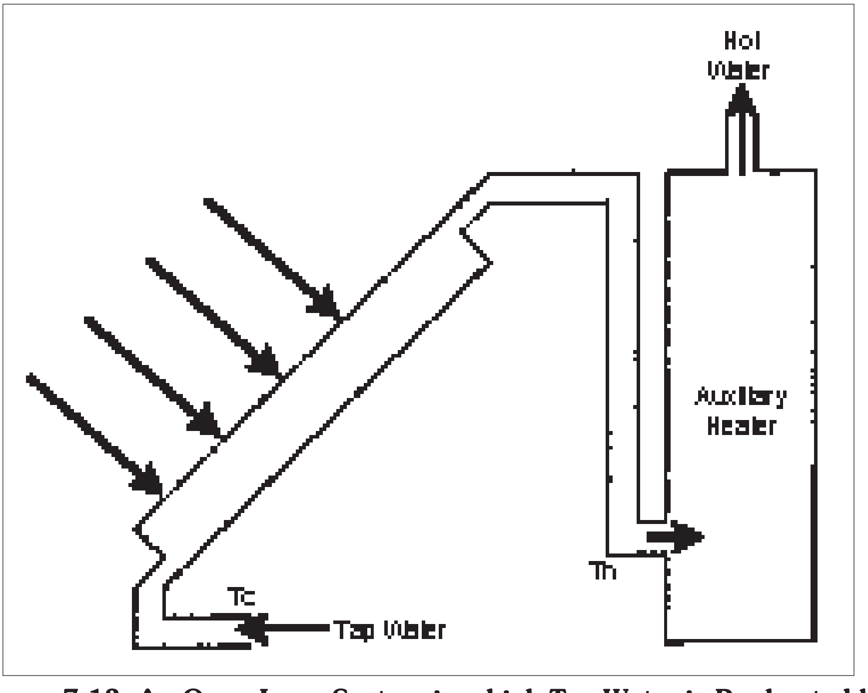

Figure 7.13: An Open Loop System in which Tap Water is Pre-heated by Solar Energy and then Heated by an Auxiliary Heater

B. *Solar-assisted Space heating System*

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

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

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

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

Environmental Indices	Gilgit	Yasin	Chitral
Mean monthly Temperature, F			
January	43.30	23.00	40.10
July	86.00	68.00	83.40
Mean daily temp(minimum of coldest month), F	10.30		13.30
Absolute minimum precipitation, mm			
January	10.00	05.00	35.00
July	08.00	08.00	08.00
Mean annual Precipitation, mm	123.00	136.	448.00

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

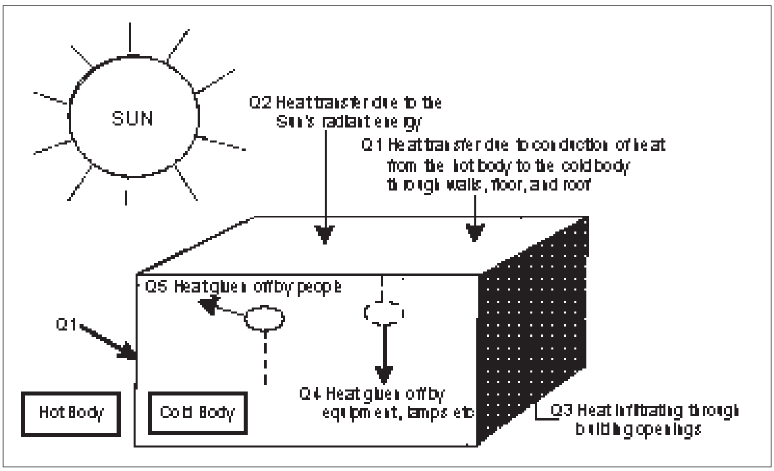

Figure 7.14: Heat Gain in a House in Gilgit

Calculations of Heat Load and Array Size

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

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

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

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

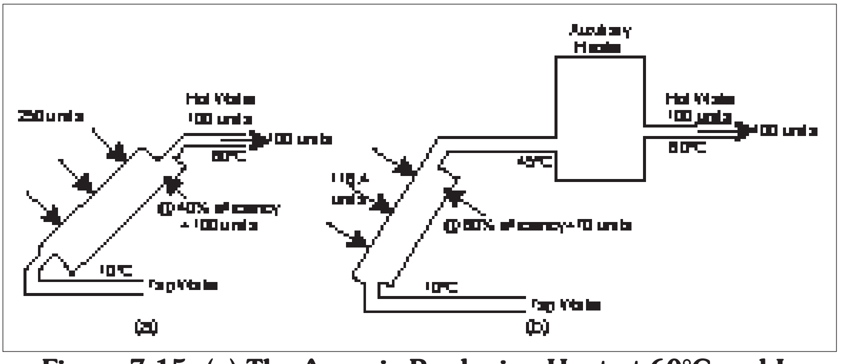

Figure 7.15: (a) The Array is Producing Heat at 60°C and Is Operating at 40% Efficiency (b) The Array is Producing Heat at 45°C and Is Operating at 60% Efficiency

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

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

An Auxiliary Heater Increases Array Efficiency

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

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

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

7.2.8 Computer Assisted Passive Solar Building Designs

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

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

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

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

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

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

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

Conclusion and Recommendations

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

Financial Assistance

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

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

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

S.Ahmed

Introduction

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

Methodology

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

1. The parameters for thermal evaluation are:

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

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

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

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

Evaluation Parameters

Climatic Analysis

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

Table 7.6: Climatic Data

Environmental Indices, Gilgit		Yasin	Chitral
Mean monthly temperature			
January	42.8° F	22° F	40.1° F
July	86° F	68° F	82.4° F
Mean daily minimum of coldest			
Month	32° F		29.2° F
Absolute minimum	10.8° F		12.2° F
Precipitation			
January	10 mm	5 mm	25 mm
July	8 mm	8 mm	8 mm
Mean annual precipitation	122 mm	126 mm	448 mm

The following observations are made based on the analysis.

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

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

Comfort Zone

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

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

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

Ventilation Requirements

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

Review of the Existing Buildings

Roof Systems

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

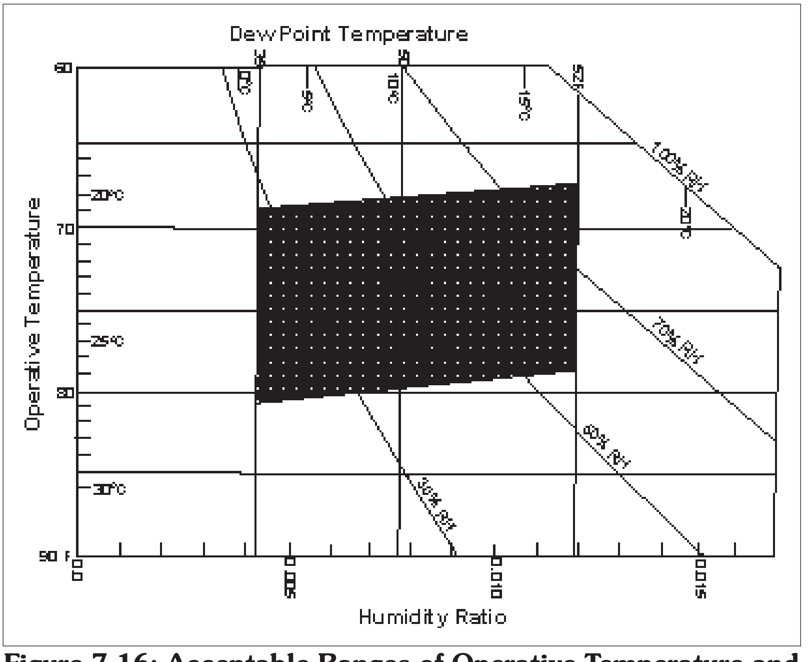


Figure 7.16: Acceptable Ranges of Operative Temperature and Humidity for Persons Clothed in Typical Summer and Winter Clothing at Light Mainly Sedentary, Activity (Adapted by Permission from ASHRAE Standard 55-81, 1981)

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

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

Wall Systems

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

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

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

Ventilation

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

Shading Devices

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

Effects of Different Building Systems on the Environment

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

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

Recommendations in the Existing System

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

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

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

Recommendations for New Designs

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

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

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

8-inch Thick Wall Orientation	Time	Window Shaded Area	Window Unshaded Area	Ventilator Shaded	Ventilator Unshaded Area
East	8 am	6%	94%	62%	38%
East	10 a.m.	47%	53%	100%	0%
South	12 noon	2%	23%	100%	0%
West	2 p.m.	7%	53%	100%	0%
West	4 p.m.	6%	94%	62%	38%
15-inch Thick Wall					
East	8 am	13%	32%	81%	19%
East	10 am	77%	23%	100%	0%
South	12 noon	100%	0%	100%	0%
West	2 pm	77%	23%	100%	0%
West	4 pm	13%	32%	81%	0%

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

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

Appendix 7A: Minimum Ventilation Requirements

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

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

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

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

Appendix 7B: Calculation of Air flow through Windows

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

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

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

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

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

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

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

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

Table 7B.1: Area of Walls and Roof

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

Table 7B.2: Area of Windows

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

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

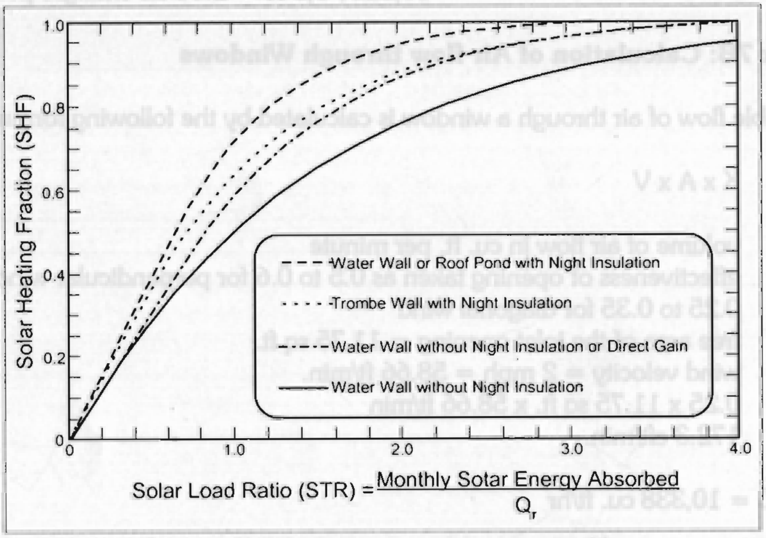


Figure 7.B1: Solar Load Ratio (SLR)

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

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

Detailed calculations are provided in Appendix C

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

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

Detailed calculations are provided in Appendix C

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

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

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

Source:Ashrae Handbook of Fundamenatals 1977.

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

Table 7B.7: Clear Day Solar Heat Gain

January 21th Latitude = 36./0 deg. North. Ground Reflectivity Assumed = 0.2

Time a.m.	N	NE	E	SE	S	SW	W	NE	HOR	TIME a.m
8	8	23	139	164	92	8	8	8	42	4
9	15	15	167	235	167	15	15	15	101	3
10	19	19	130	246	215	49	19	19	147	2
11	22	22	65	224	243	116	22	22	177	1
12	23	23	23	178	252	178	23	23	187	12
Half-day	76	91	512	958	844	276	76	76	560	
Total										

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

Corresponding Values

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

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

APPENDIX 7C

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

1) 12-inch Thick Terracrete

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

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

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

3) 8-inch thick hollow blocks

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Introduction

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

Basic Shelter

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

Objectives

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

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

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

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

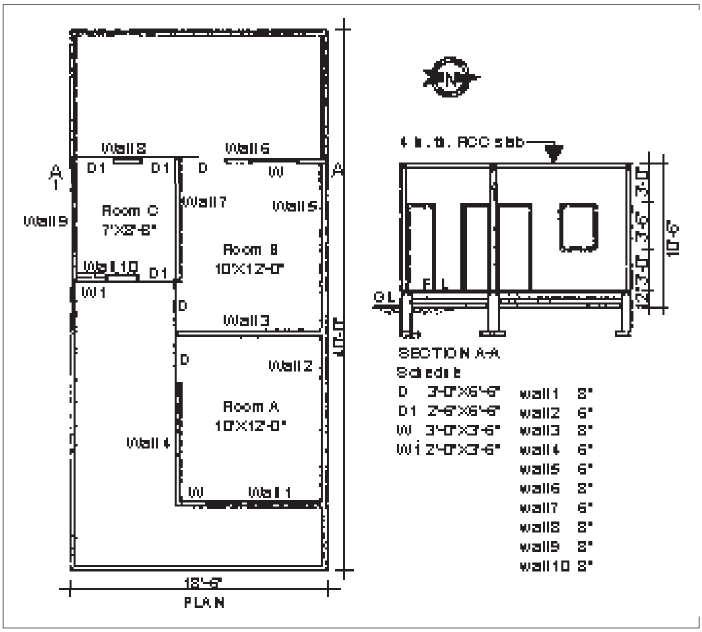


Figure 7.17: Test Model House: A Standard Low-Cost Urban House in Metroville, Karachi

Theoretical Considerations

Thermal Model Equation

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

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

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

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

Thermal Analysis of the Test Model House

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

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

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

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

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

Table 7.10: Efficiency of Standard Low-Cost Urban Housing

Room No	Conduction Q_c		Convection Q_v	Radiation ($Q_c\phi$)		Radiation (Q_u)	Total heat ΣQ-
	Walls	Roof		Walls	Roof	Glass	$Q_c + Q_v$ $Q_c\phi + Q_g$
A	622.26	426.5	122.5	742.14	1062.2	87.69	2086.29
B	498.65	522.91	159.02	607.25	1276.2	87.69	2152.72
C	460.10	274.9	82.46	578.44	669.6	58.50	2125.00
Σq	1582.01	1225.21	274.98	1928.22	2009.1	222.8	8264.11
P	18.9	14.00	4.48	22.06	26.0	2.8	100

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

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

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

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

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

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

Improvement of the Roof

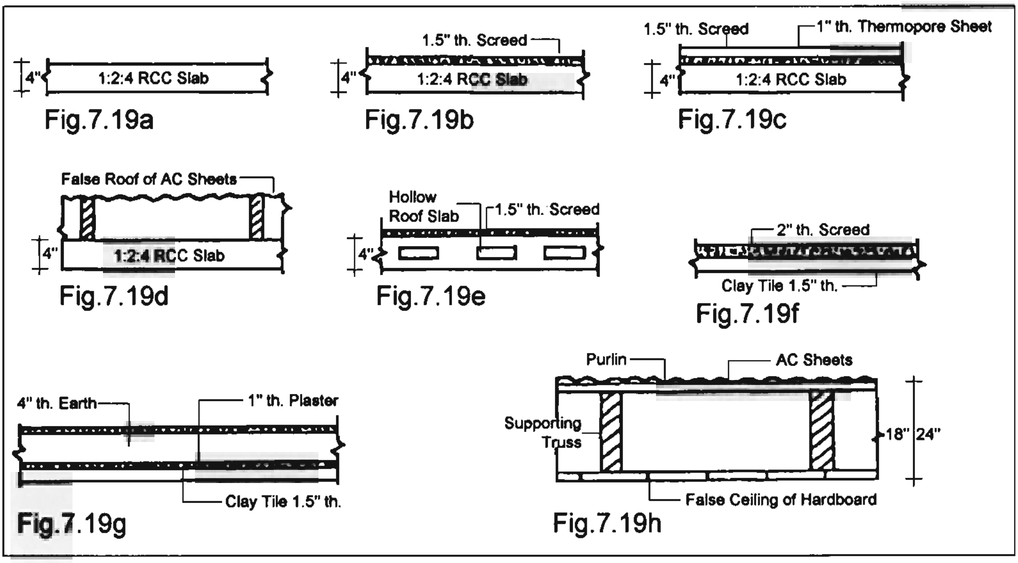
The roof of the test model house is constructed with a four-inch reinforced concrete (1:2:4) mix. As shown in Table 7.12, the heat gained by the roof alone is 50.8 per cent of the total heat gain by the model house. To reduce this, the thermal response of the roof has been studied by considering the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

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

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

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

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



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

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

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

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

Improvement of the Wall

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

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

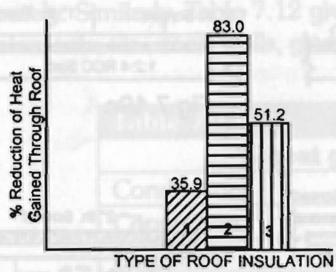


Fig. 7.20

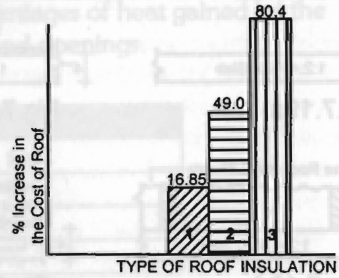


Fig. 7.21

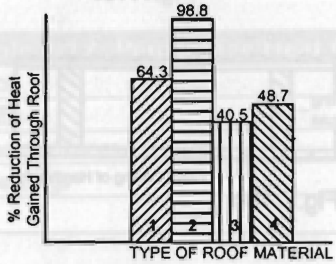


Fig. 7.22

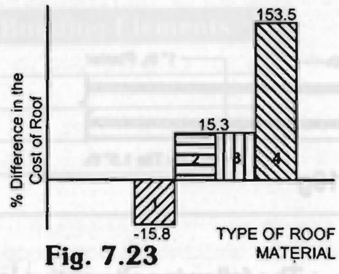


Fig. 7.23

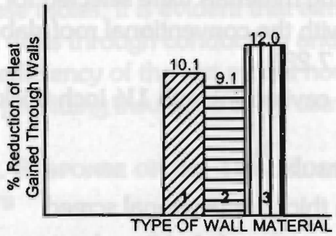


Fig. 7.24

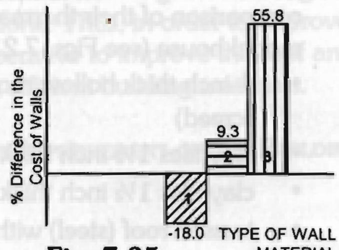


Fig. 7.25

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Conclusion and Summary of Results

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

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

Further Reading

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8

Issues and Future Directions

8
Issues and Future Directions

N.K.Bansal

Introduction

Passive solar design is an interdisciplinary subject involving researchers, construction agencies, material and component development, and finally the architect who translates all the information into a product. The architectural design process involves several steps, from the schematic drawing phase to construction development through detailed design. In this process, the definition of the building evolves from general to specific. Each phase, therefore, requires adequate thermal design tools ranging from rough simple rules of thumb to detailed estimates.

From a detailed survey of literature and information available in the proceedings of workshops in China, India, Nepal, and Pakistan, it seems that the thumb rules do not exist at all, particularly for the climatic region of the Hindu Kush-Himalayas. Even climatic information needed for solar passive design is hardly available. Information about materials, components, and scientific tools is diffused and needs to be made available in an organized and concise manner. There are a number of issues that need to be considered for solar passive buildings.

Climatic analysis

Foremost in considering solar passive designs is the analysis of climatic data, identification of climatic zones, and the need for heating and cooling and duration of need. The management of environmental influences requires adequate evaluation of bioclimatic impacts. Identification of climatic zones and analysis of climatic data not only establish the severity of the climate but also help to identify possible passive concepts, their potential, and their limitations.

The climatic parameters essential for passive design are temperature, cloudiness, humidity, rainfall, wind direction, and solar radiation. One then needs to plot these parameters to assess the range of variation and the prevailing generalised climatic conditions.

Climatic conditions help to visualise the general features of a place and climatic requirements of building design. For building design level, however, more information is necessary to evaluate how climate is affected by the geography and topography of a certain site and surroundings, and how this could be influenced by building location and landscape features. Heated air and pollution of urban areas produce a haze which leads to lower irradiation levels and poor air quality. Reduced nocturnal heat emission and inversion weather conditions support increasing fog and the frequency of rain through condensation on polluted air.

Though generalised information about climatic parameters in the Hindu Kush-Himalayas is available, organized documentation and its correlation with building design are yet to be made available and useful for architects.

Building Organization

Building design and appropriate selection and sizing and organization of materials can considerably influence the energy requirements of a building. The important points that need to be considered in this respect are building shape, building-sun relationship, building-wind relationship, building vegetation relationship, and building-special organization or thermal zoning. It is also necessary to make an inventory of common building materials and their uses in construction.

Solar access is a requirement for passive solar heating systems. The amount of solar radiation in any location on a site depends on diurnal and seasonal solar availability. Data of monthly mean values and daily and/or hourly values are required for quantitative calculation methods to estimate the efficiency of passive solar systems. For individual design of passive systems, orientation of the sun collecting areas, their construction, and physical properties must be carefully considered.

Orientation of a building with respect to wind direction can influence loss of heat from a building considerably. Building of surfaces exposed to prevailing winds in winter should be minimised, especially with respect to glazed areas. The effect of wind on heat losses can be reduced by landscaping, a phenomenon that needs to be understood in more detail.

Relation of the building location to topography, vegetation, and organization of building space are some of the concepts that need to be studied and documented in detail.

Building System Options

The term building system refers to the structure, exterior envelope, and interior partitions. The manner in which these building elements are configured determines the heat loss or gain characteristics and the type of passive solar system needed. It is essential to make a detailed inventory of the range of options and factors to be considered in the building structure, insulation, glazing, shading, and passive solar system.

The various options that need detailed description are building structure, building components, and strategies that determine thermal storage capacity, structural capacity, durability/reliability, and ultimately the thermal performance of a building. The choice of building materials, orientation, glazing material, and glazing structure along with passive solar strategies such as solar collection, heat storage, heat distribution, natural ventilation, and de-lighting determine the energy performance of a building.

One should distinguish between passive and active solar energy use. Active solar systems require a solar collector outside the living space to be heated, transferring it to a separate storage element by pump or fan. Many times, simple natural means will not be able to create sufficient fluid flow and therefore some knowledge about the type of fan, pump, and power requirements becomes absolutely essential.

Users' Influence

Occupant behaviour and needs directly influence and determine energy demand, consumption, and waste. The way owners operate passive systems in a house will have a major impact on internal climatic conditions. Solar passive design of a house should therefore study occupant behaviour and existing practices and adopt those concepts that match local practices. An example of this aspect is the use of a kitchen's waste heat for space heating either through a hypocaust construction or other design aspects.

Urban Versus Rural

Very often there is a vast difference between rural and urban architecture. Usually rural houses are designed and constructed to match the prevailing climatic conditions. An example of such a house is a farmer's house in Shimla (Figure 8.1)

The house is located on a slope towards the windward side and there is a relatively large verandah to reduce the effect of wind in a climate in which the sun is available only sometimes during the winter. In general, the openings of these houses are small and are well insulated by means of a cavity roof and thick mud walls. The resulting temperatures during typical May and December days are given in Figure 8.2.

A typical urban house (Figure 8.3) on the other hand is made of an RCC frame structure with only 15 cm brick walls resulting in large temperature fluctuations as seen from Figure 8.4.

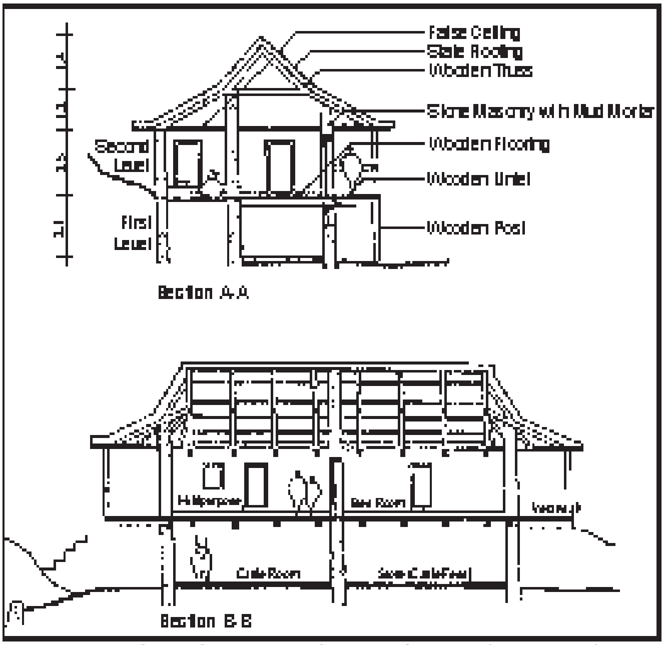


Figure 8.1: Section of a Traditional Farmer's House in Shimla (North India)

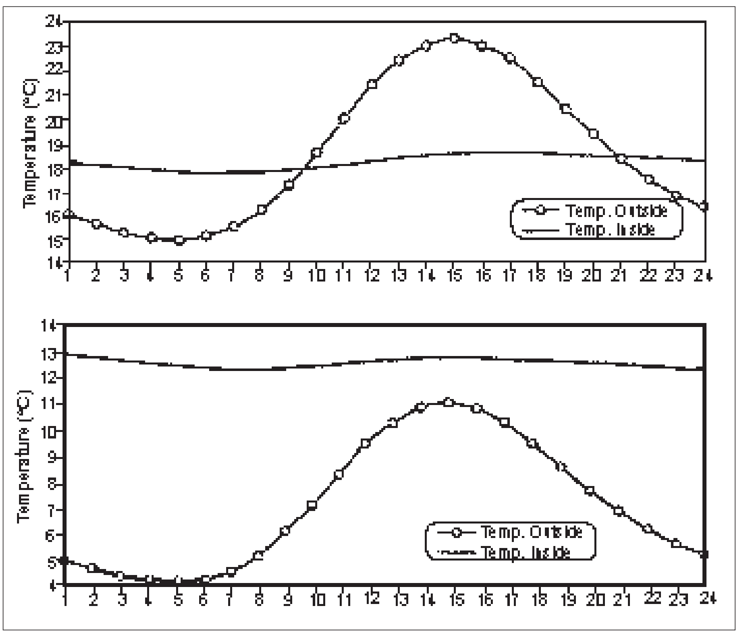


Figure 8.2: Daily Temperature Variations on Typical Summer and Winter Days in the Farmer's House

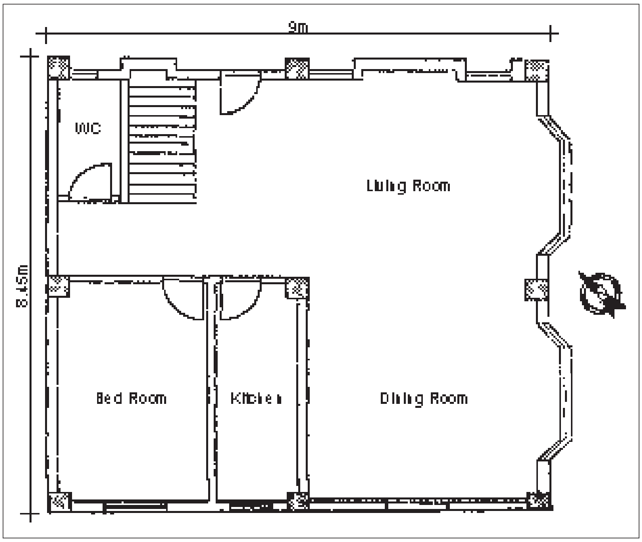


Figure 8.3: A Typical Urban House in Shimla

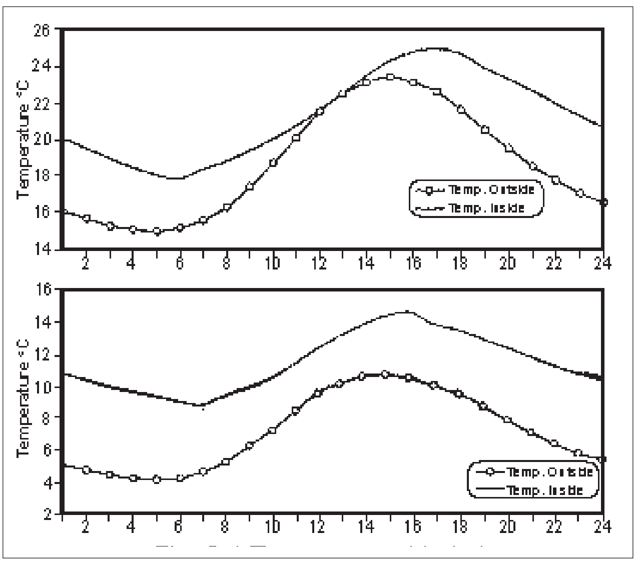


Figure 8.4: Temperature Variation

It is therefore necessary to study vernacular architecture in the Hindu Kush-Himalayas in detail and to try to understand the concepts of solar passive heating /cooling and modify them suitably for urban applications. Solar passive building design in rural areas may require only minor variations in design for improvement in the thermal performance of a building.

The above results clearly show that urban architecture has to be radically modified to use solar passive design concepts. Comprehensive guidelines incorporating available building components are necessary for effective results.

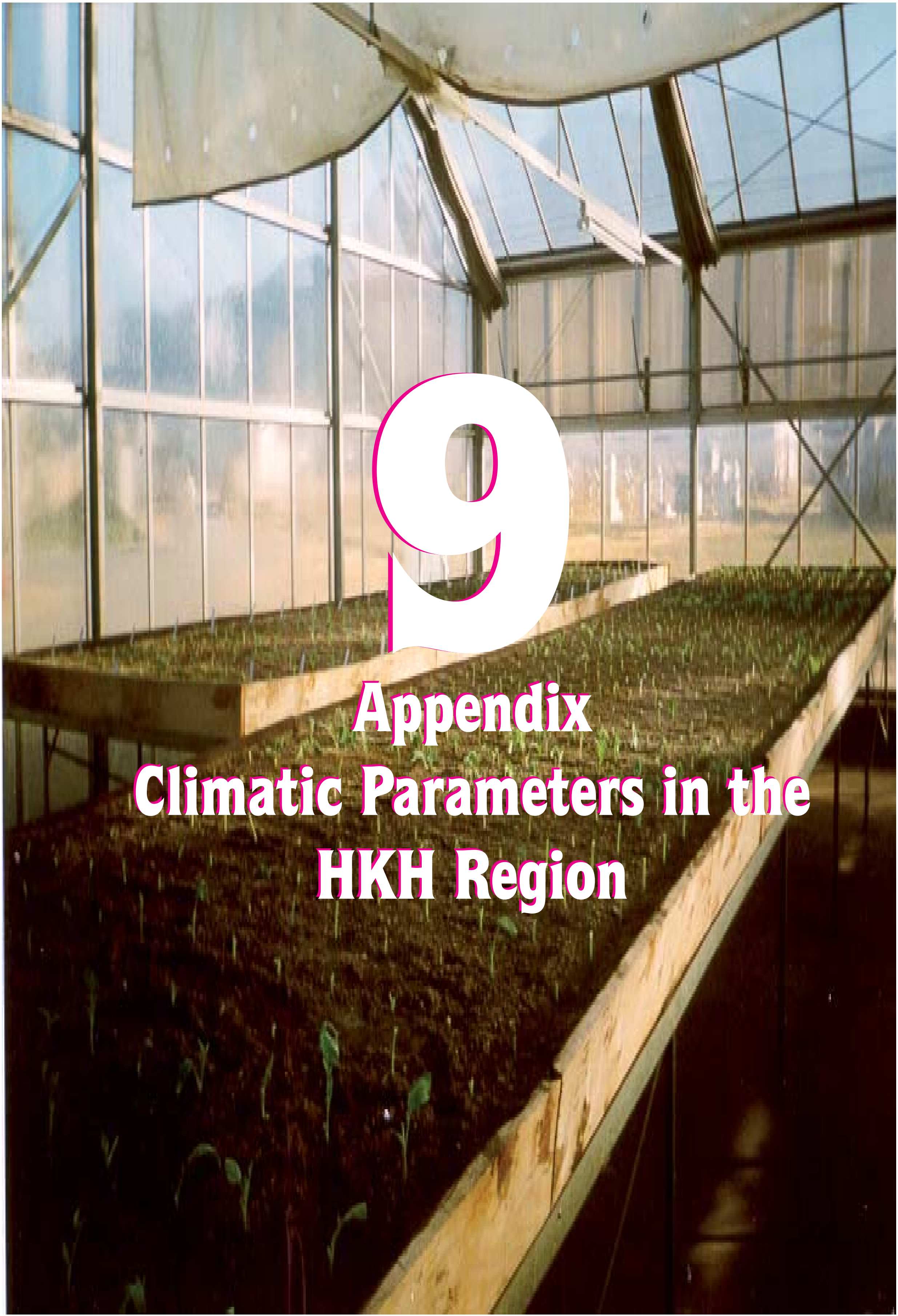
Future Directions

Awareness about solar passive concepts and their utility in achieving either thermal comfort or reducing energy demands in a building is well spread throughout the Hindu Kush-Himalayan region, as evident from the contributions presented in the ICIMOD-sponsored workshops in China, India, Nepal, and Pakistan. There have been concrete programmes for solar passive buildings, especially in China and India. The overall impression from the proceedings is that concrete solutions are needed to introduce solar passive building concepts. The understanding of climatic elements, traditional architecture, construction material, and construction techniques is important for optimum passive building design.

In order to promote the techniques of solar passive design, the following work needs to be undertaken and documented systematically.

1. Analysis and classification of climatic conditions in the Hindu Kush-Himalayan region
2. Study of vernacular architecture and identification of passive building elements
3. Study of urban architecture
4. Selection of an appropriate thermal simulation programme
5. Creation of a data base and thermophysical properties of building materials and traditional building components
6. Quantification of individual design patterns, for example, direct gain, indirect gain, thermal storage, solarium, cavity, insulation, building form, roof shape, and underground structure
7. Preparation of manuals on design guidelines, design context, construction issues, and design tool selection and use

The comprehensive information thus prepared needs to be disseminated to architects, users, and the construction industry. One should be careful in distinguish among users even construction industry. One should differentiate between rural and urban architecture. Design guidelines have not been attempted for the rural context so far anywhere in the world. Any initiative in this direction can i mmensely improve the health, efficiency, and lifestyle of rural people in the Hindu Kush-Himalayan Region.



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Appendix
Climatic Parameters in the HKH Region

Appendix I: Climatic Parameters in the HKH Region

Table 1: Monthly Rainfall Normals, mm (1901-1950)

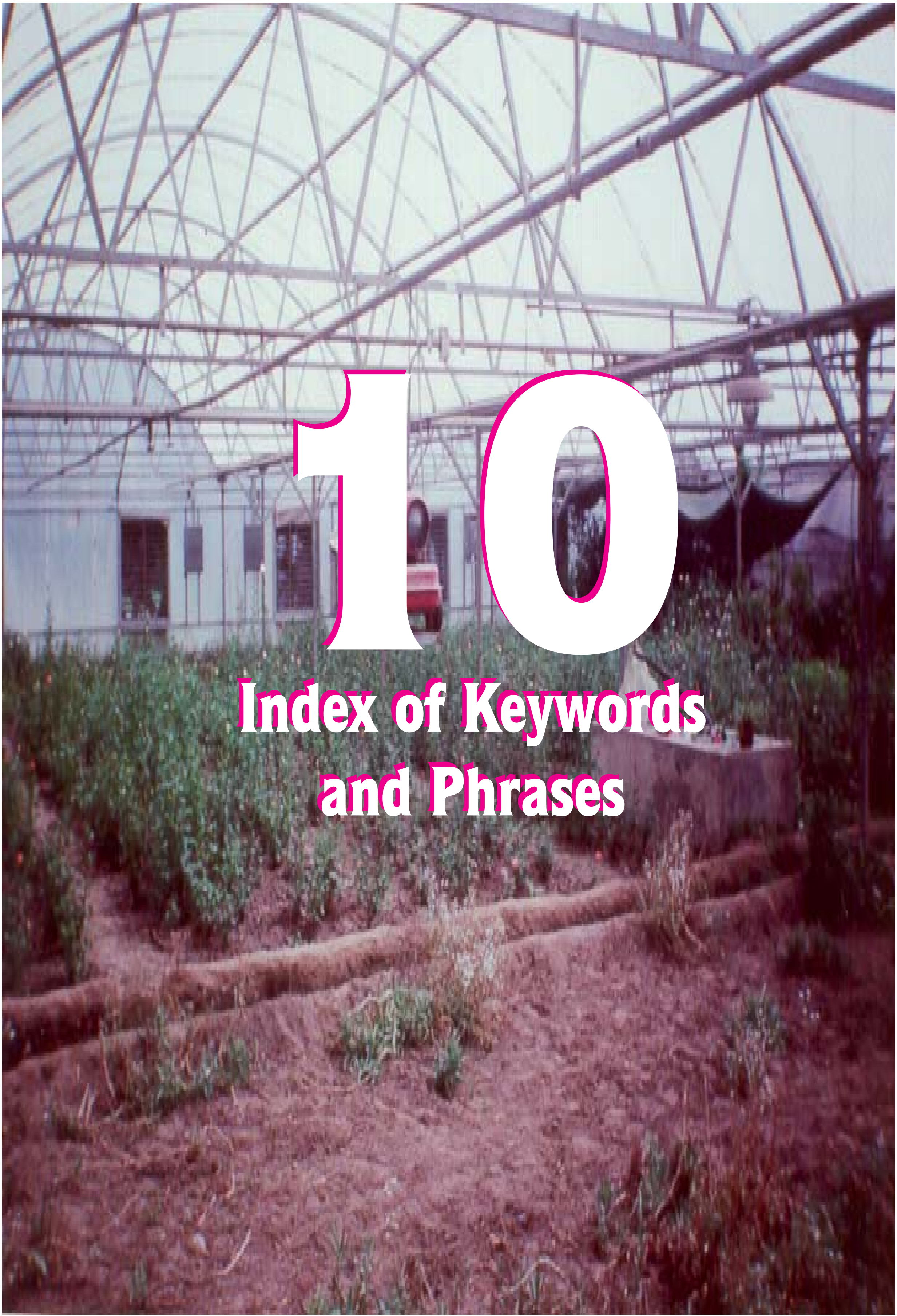
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	YEAR
Kathmandu Nepal 1,324 m	10	42	15	26	129	246	373	347	182	36	2	8	1416
Shimla, Kumaon Himalaya 2,200 m	65	70	64	46	60	149	416	419	182	33	10	2	1516
Nainital Kumaon 1,953 m	70	73	53	38	84	391	769	750	363	61	13	2	2667
Pithoragarh Kumaon	44	56	40	28	73	183	300	287	149	33	7	22	1222
Pasighat/Tirap Frontier Tract, NE Assam	55	97	138	273	466	967	975	622	585	261	33	24	4466
Darjeeling 2,265 m	11	32	54	113	231	597	792	643	446	142	25	6	3092
Kyelong, N. Punjab Himalayas	59	64	102	79	56	23	33	33	52	21	7	26	555
Srinagar, Kashmir Himalayas	70	74	94	90	60	34	56	63	40	28	13	37	659
Kargil, Ladakh 2,658 m	37	38	60	42	25	7	7	10	10	6	3	21	266
Lhasa, Tibet 3,658	0.2	0.1	2	4	21	73	142	149	57	5	0.8	0.3	454
Chamdo, Tibet 3,241	2	3	7	13	45	98	113	107	73	28	3	2	494
Xigaze, Tibet 3,836 m	0.6	0	0.9	2	9	66	144	154	58	4	0.2	0	439

Source: Domroes (1979, p53) and Domroes (1988, p149)

Table 2: Temperatures (°C) in the Western and Eastern Himalayas at Altitudes above 3,500masl

Station	Altitude (m)	Latitude N.	Longitude E.	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Leh	3,514	34°09'	77°34'	-1	1	7	13	17	22	25	24	215	15	8	2	Max
				-3	-12	-6	-1	3	7	10	10		-1	-6	11	Min
Xigaze	3836	29°13'	88°55'	-4.1	-0.5	2.9	7.7	11.9	14.7	4.2	13.0	11.8	6.5	0.4	-3.5	Ave
Lhasa	3658	29°42'	91°8'	-2.3	0.8	4.3	8.3	12.6	15.5	14.9	14.1	12.8	8.1	1.9	-1.9	Ave
Gangton	3750	27°15'	88°-9	3	3	5	10	11	13	13	13	13.4	10	6	3	Max
				-9	-9	-6	-2	2	4	6	5		-1	-6	-8	mix
Medium Altitude (2,200-3500 MASL																
Skardu	2,288	35°18'	75°37'	1	3	10	17	23	27	31	31	26	19	12	5	Max
				-9	-9	0	6	10	13	22	16	16	5	2	-6	Min
Chamdo	3241	31°11'	96°59'	-2.5	0.3	4.3	8.5	12.4	14.9	16.3	15.2	13.1	8.2	2.1	-2.7	Ave
Darjeeling	2,265	27°03'	88°16'	8	9	13	16	17	18	18	19	18	17	13	10	Max
				2	3	6	9	11	14	14	14	13	10	6	3	Min
Low Altitude (below 2,200 MASAL31																
Srinagar	1,587	34°05'	74°50'	5	7	14	19	25	29	31	30	29	23	17	9	Max
				-4	-1	3	7	11	14	18	17	12	5	-1	-3	Min
Shillong	1,500	25°34'	91°53'	16	17	32	23	23	24	24	24	23	22	19	16	Max
				4	6	20	14	15	17	18	18	16	13	8	4	Min
Source: A. 1981; 10 and Domroes (1988, p100); 100																

Table 3: Physical Properties of Common Building Materials				
Descriptions	Specific Heat Jkg °C	Density kg/m³	Heat Capacity Wh/m³ °C	Conductivity W/m °C
Water	4186	1000	1163	0.55
Steel	502	7850	1093	45.30
Marble	879	2240	633	1.43
Concrete	840	2300	537	.65
Glass	840	2600	607	1.15
Brick	920	1800	460	0.66
Limestone	908	1650	417	1.80
Gypsum	1100	600	183	0.16
Sand	840	1600	373	0.77
Pine	2700	600	450	0.13
Fir	2700	600	437	0.13
Adobe	1006	1110	280	0.48
Air	1000	1.25	0.347	0.14
Source: Erat (1985); Brad and Hastie (1985)				



10 Index of Keywords and Phrases

Index of Keywords and Phrases

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Participating Countries of the Hindu Kush-Himalayan Region

Afghanistan	Bangladesh
Bhutan	China
India	Myanmar
Nepal	Pakistan

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