5

Passive Solar Design of Buildings in the Mountains

5.1
A Review of Various Techniques for Passive Solar Building

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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).

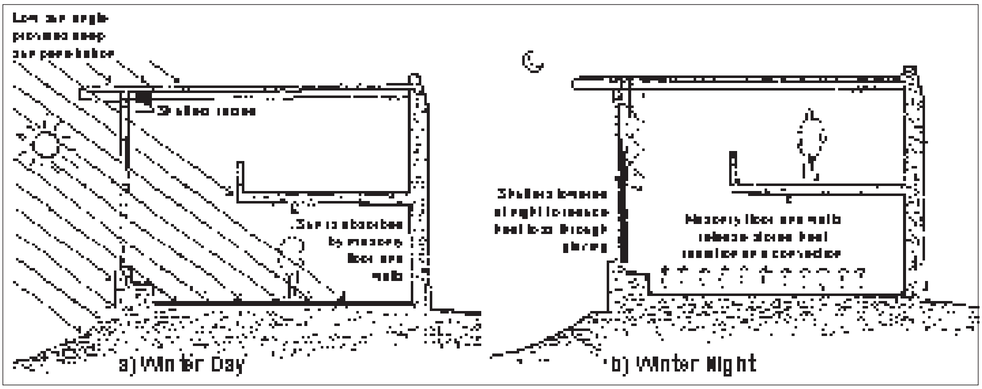


Figure 5.1: Direct Passive Solar Heating

Various building elements should be provided with adequate shading to minimise

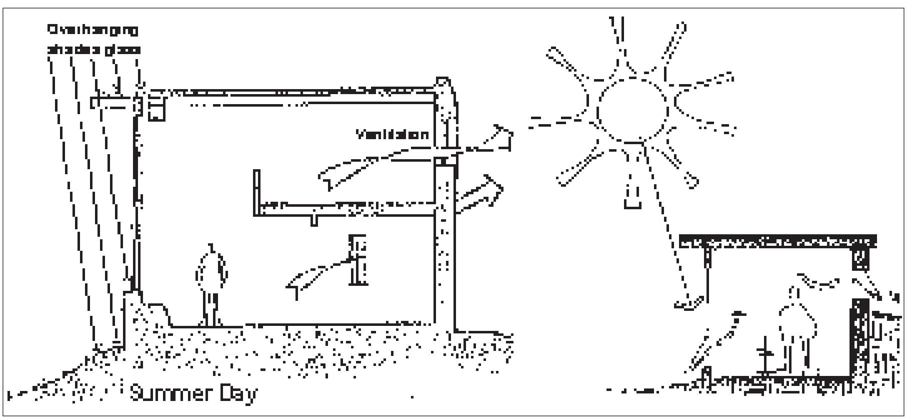


Figure 5.2: Direct Passive Solar Cooling

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).

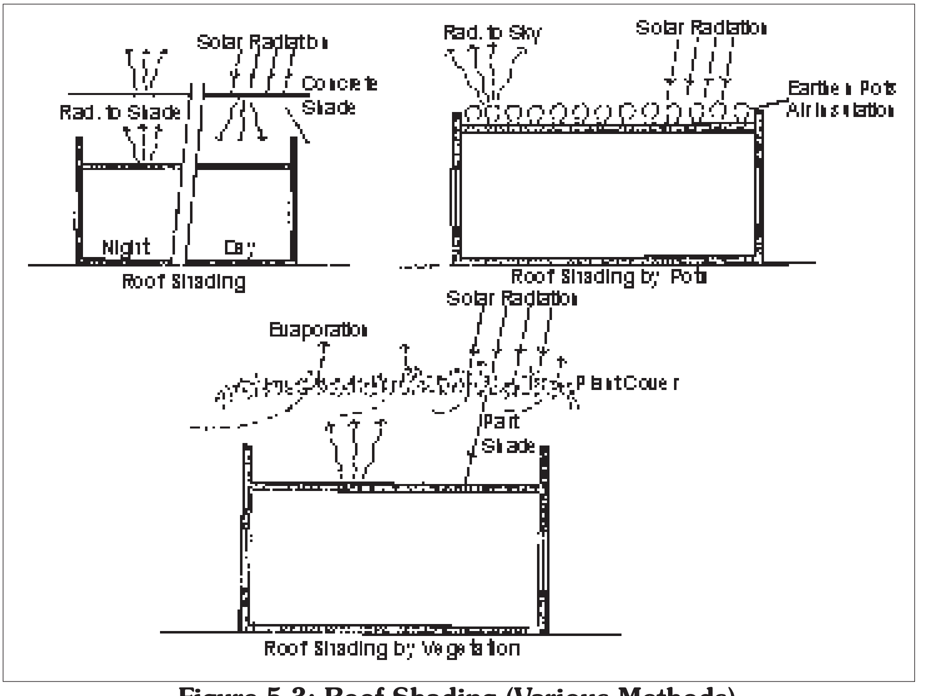


Figure 5.3: Roof Shading (Various Methods)

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

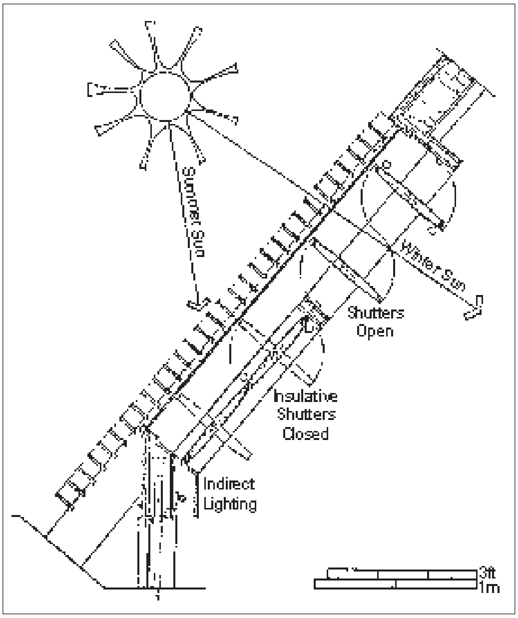


Figure 5.4: Detail of Insulated Louver and Summer Sunshade

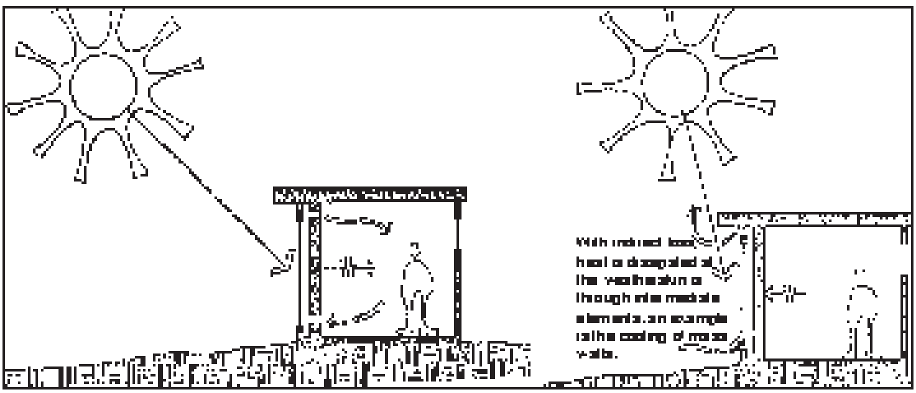


Figure 5.5: Indirect Passive System

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

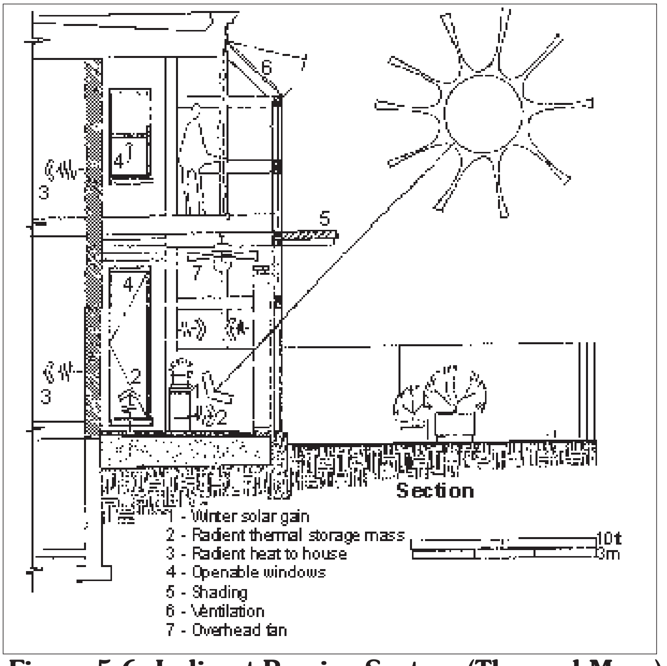


Figure 5.6: Indirect Passive System (Thermal Mass)

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).

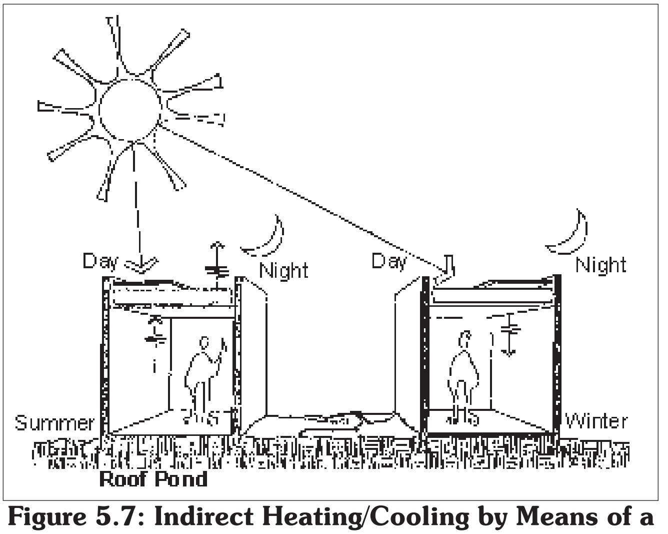


Figure 5.7: Indirect Heating/Cooling by Means of a Roof Pond

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).

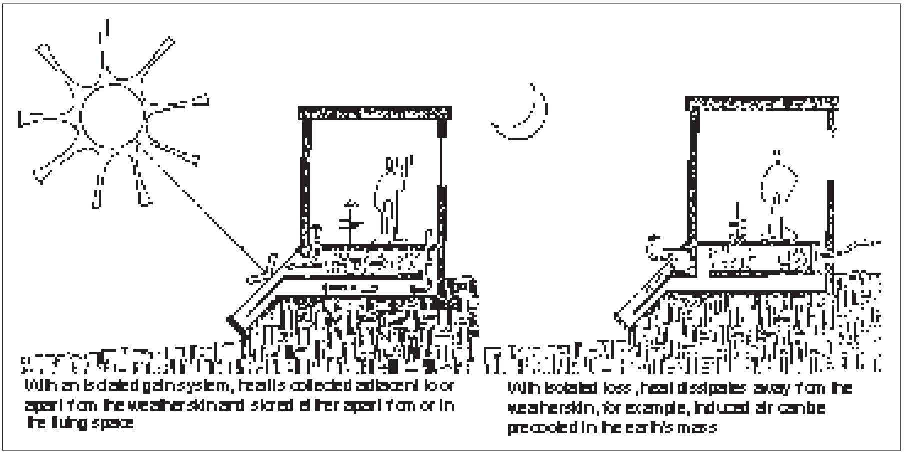


Figure 5.8: Isolated Passive System

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

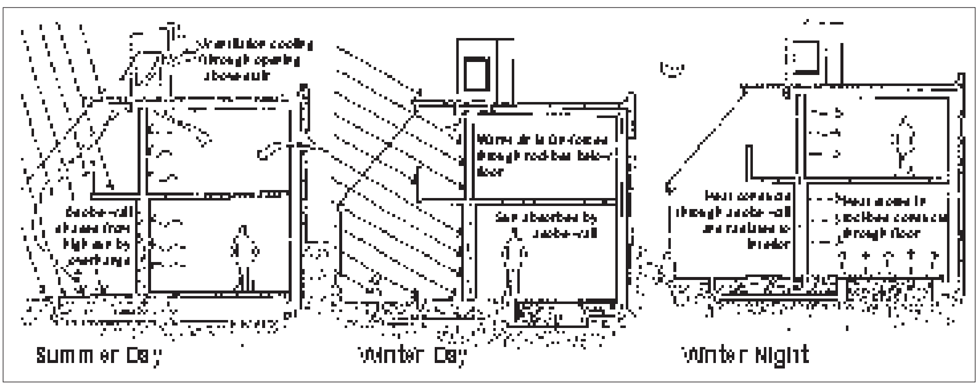


Figure 5.9:A Sun Space as Part of the Passive System

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.

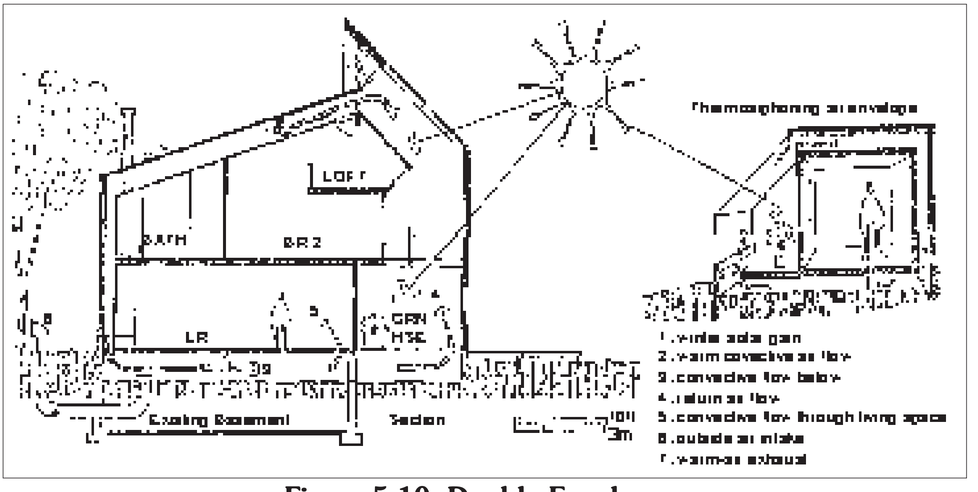


Figure 5.10: Double Envelope

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

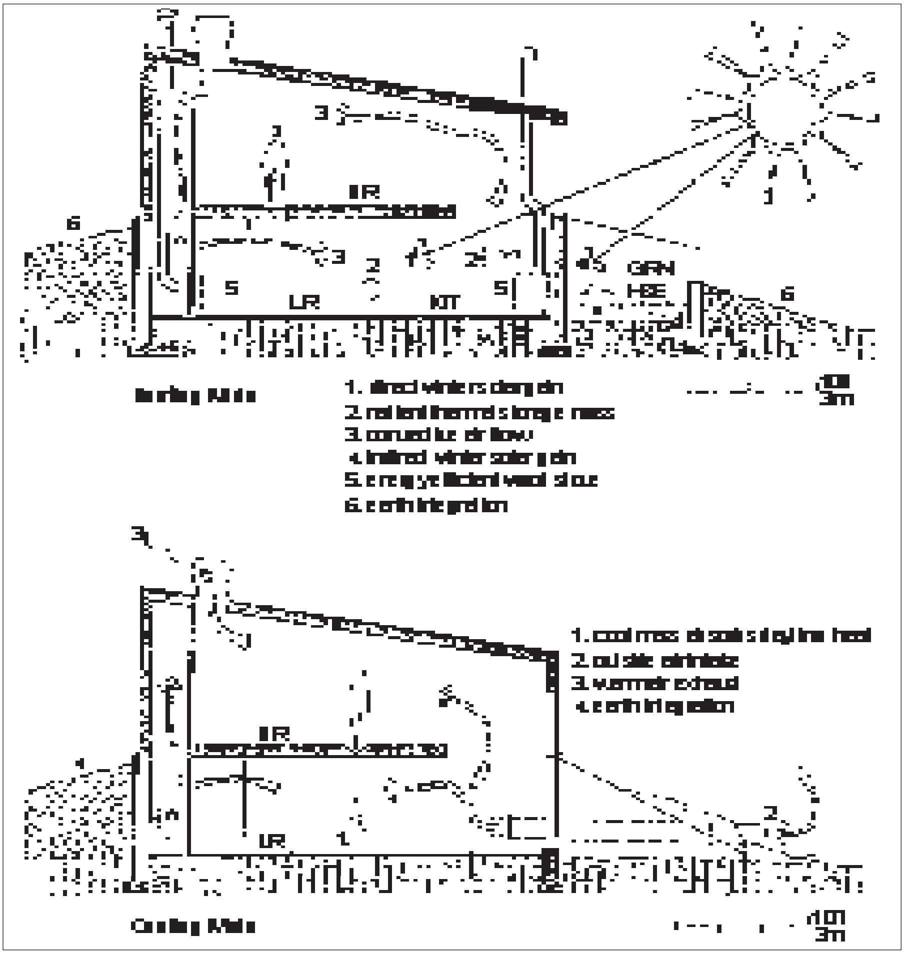


Figure 5.11: Combination of Systems

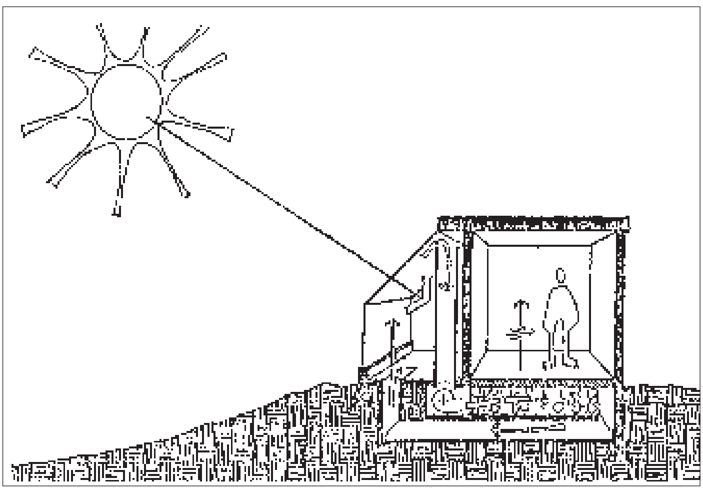


Figure 5.12: Hybrid System

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.

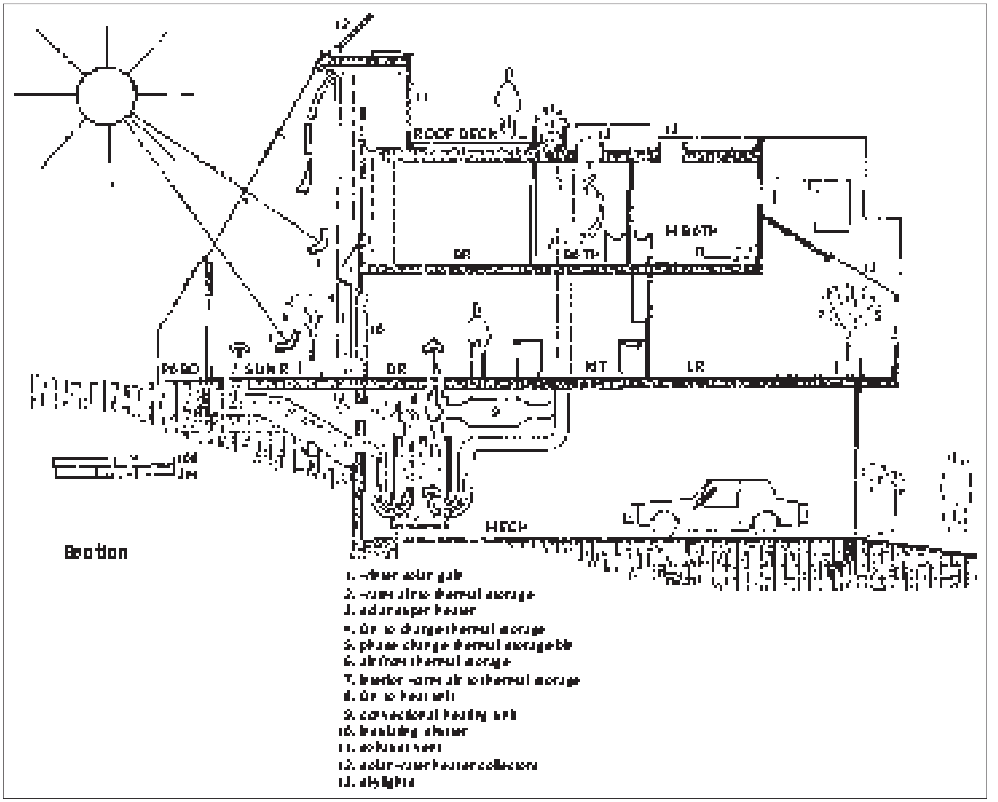


Figure 5.13: Hybrid System

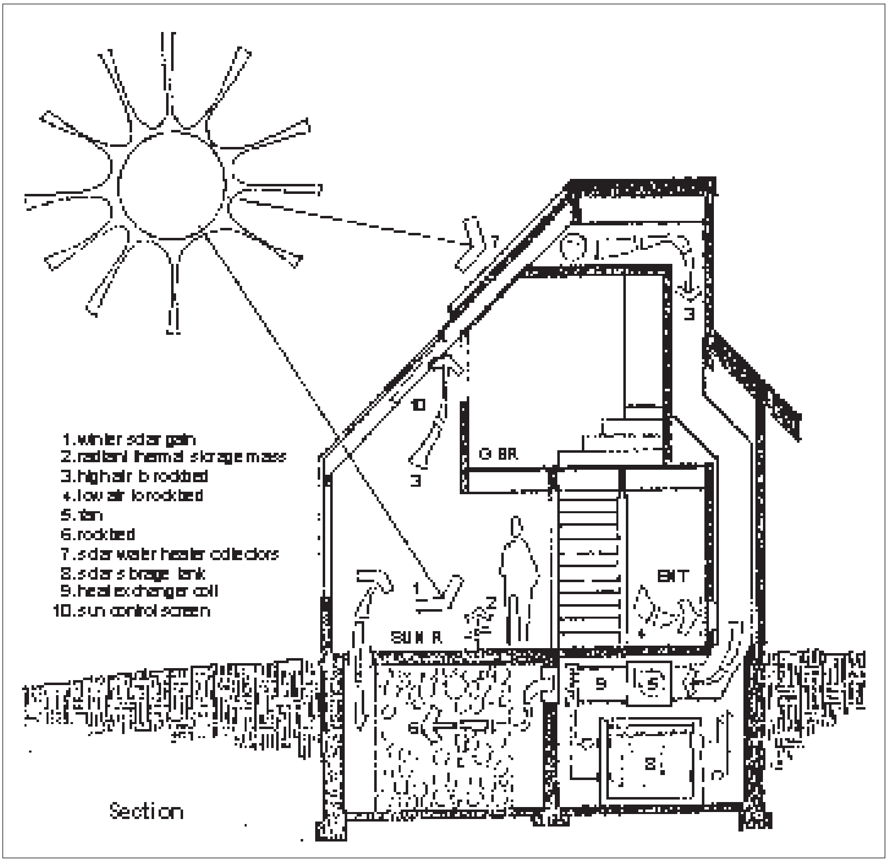


Figure 5.14: Hybrid System

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

Further Reading

Akhtar, N., 1996. 'Energy Efficient Housing at Lahore'. B. Arch. Thesis, Department of Architecture. Lahore: University of Engineering and Technology.

Anderson, B., 1977. *Solar Energy Fundamentals in Building Design*. New York: McGraw Hill Book Company.

Balcomb, J.D., 1978. 'State of Art in Passive Solar Heating and Cooling'. Paper presented at the 2nd National Passive Solar Conference, Philadelphia, USA.

ENERCON, 1990. *Design Manual: Energy Efficient Buildings in Pakistan*. Islamabad: National Energy Conservation Centre.

Hay, H.R. and Yellot, J.I., 1978. 'Natural Air-conditioning with Roof Pond and Movable Insulation'. In *ASHRAE Transc 75*.

Kreider, J.F. and F. Kreith, 1975. *Solar Heating and Cooling: Engineering, Practical Design and Economics*. McGraw Hill Book Company

Moore, F., 1993. *Environmental Control Systems Heating Cooling Lighting*. New York: McGraw Hill, Inc.

Morseel, 1881. 'Warming and Ventilating Apartments by Sunrays'. U.S. Patent 246 Trombe F. [1972] U.S. patent 3.

Sodha, M.S.; Bansal, N.K. Bansal; P.K. Kumar A. and M.A.S. Malik, 1985. *Passive Solar Building. Science and Design.* Pergamon Press.

Wright, D. and Andrejko, D.A., 1982. *Passive Solar Architecture: Logic and Beauty*. New York: Van Nostrand Reinhold Company.

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

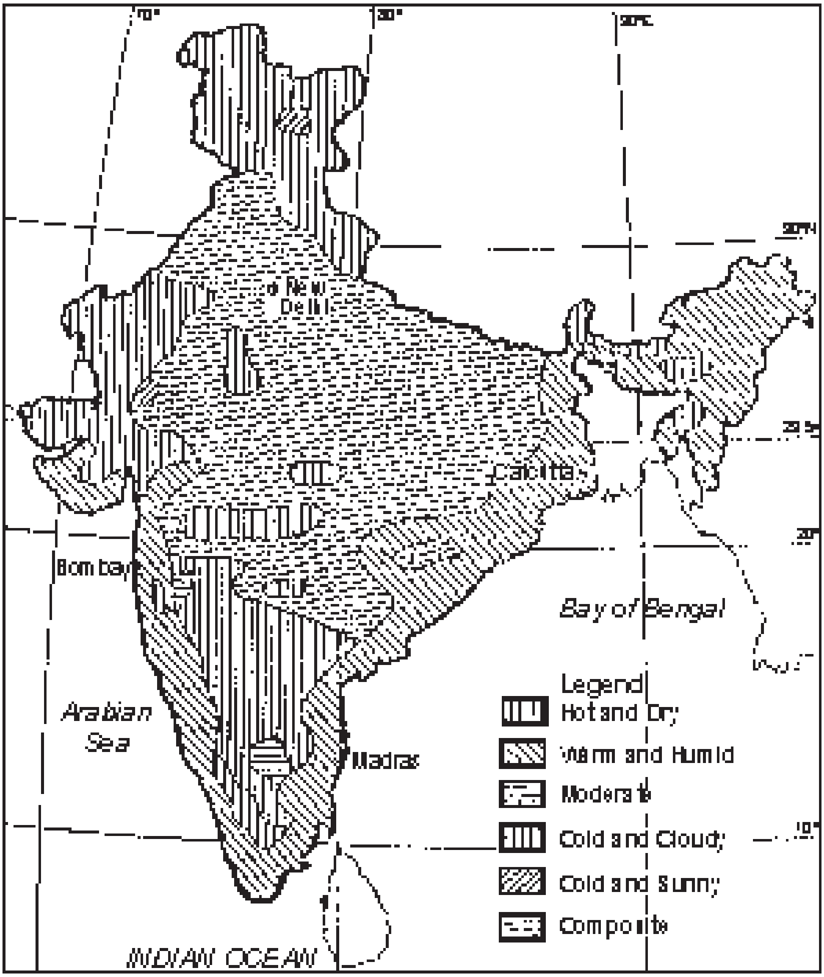
India has a wide variety of climates, ranging from extremely hot desert regions to high altitude locations with severely cold conditions. On the basis of monthly mean data recorded in 233 stations located in all parts or India, the country has been divided into the following six climatic zones (Bansal 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
Latitude: 31°06'N
Longitude: 77°10'E
Altitude: 2,202m above mean sea level

Climate Type (Cold and Cloudy)
Annual mean maximum temperature: 17.1°C
Annual mean minimum temperature: 10.1°C
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

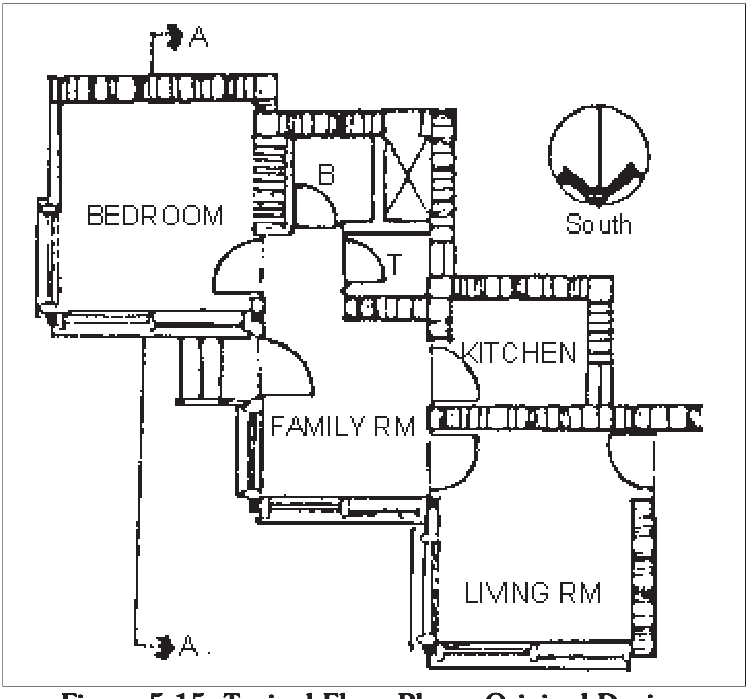


Figure 5.15: Typical Floor Plan – Original Design

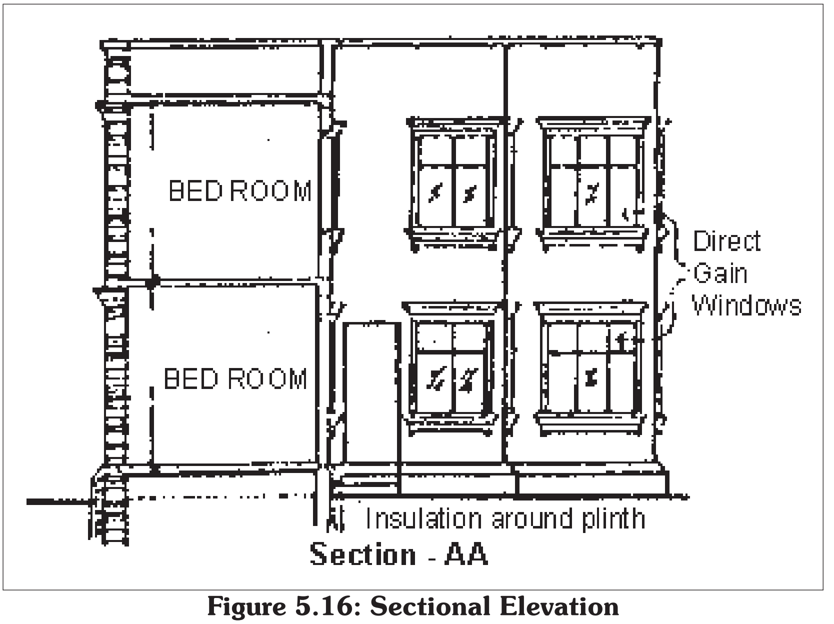


Figure 5.16: Sectional Elevation

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

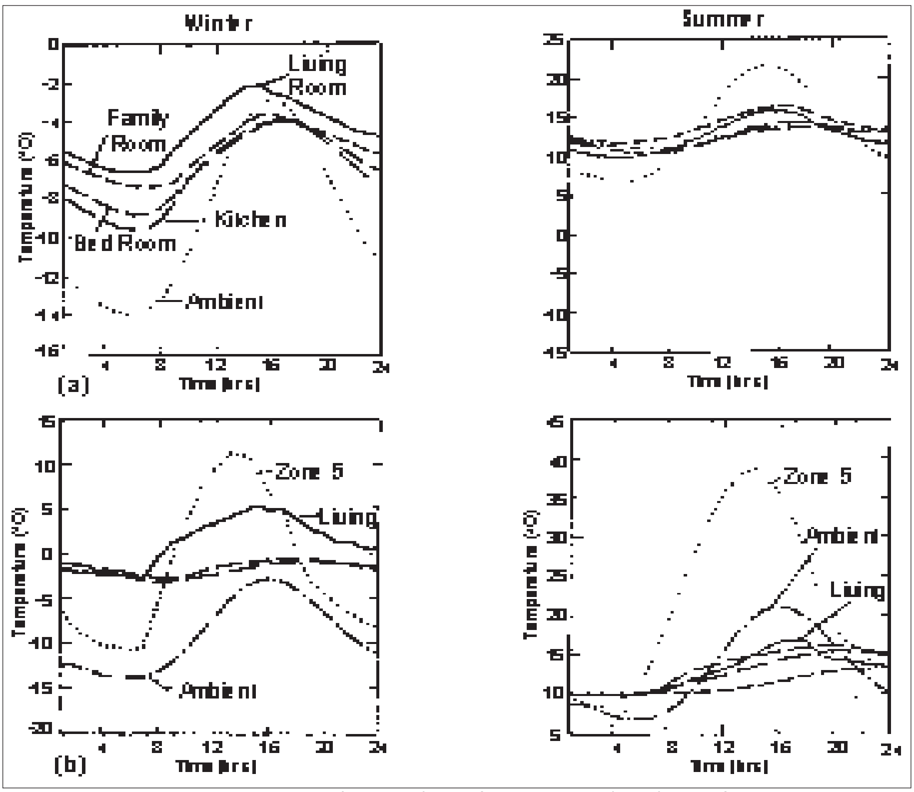


Figure 5.17: Thermal Performance Analysis for (a) Original Design and (b) Recommended Design

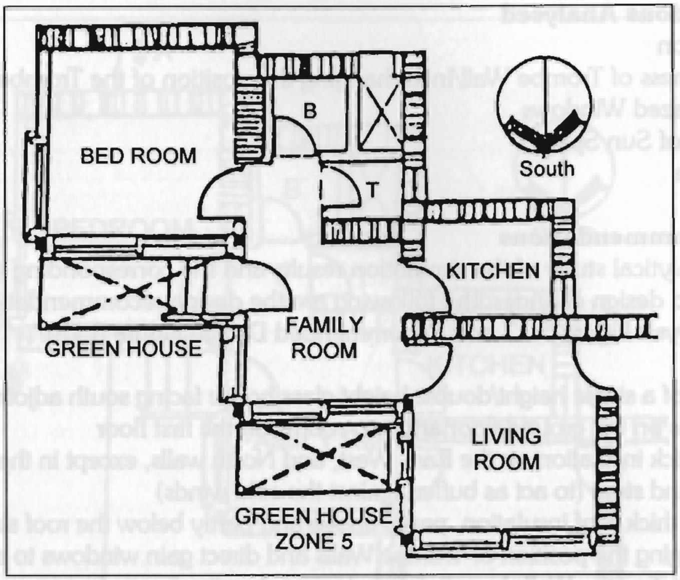


Figure 5.18: Typical Floor Plan - Recommended Design

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).

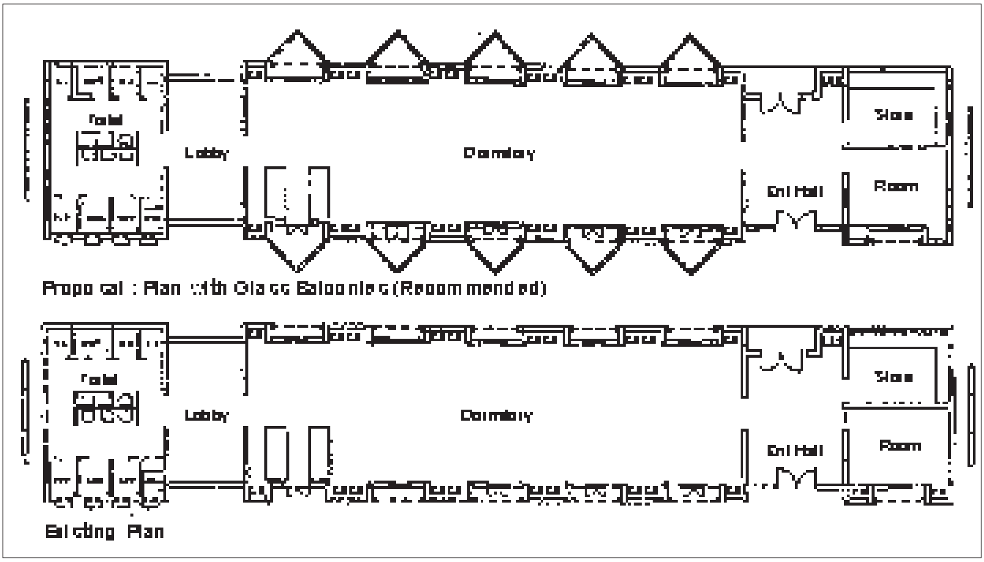


Figure 5.19: Originally Conceived Plan and the Recommended Plan of ITBP Barracks at Gaucher

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).

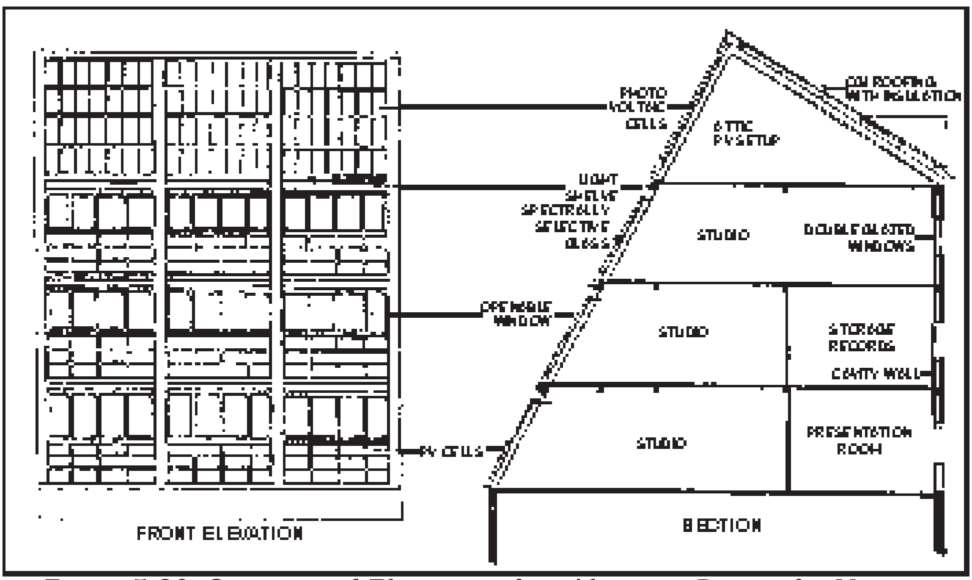


Figure 5.20: Section and Elevation of an Alternate Design for Nirman Bhawan at Shimla

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.

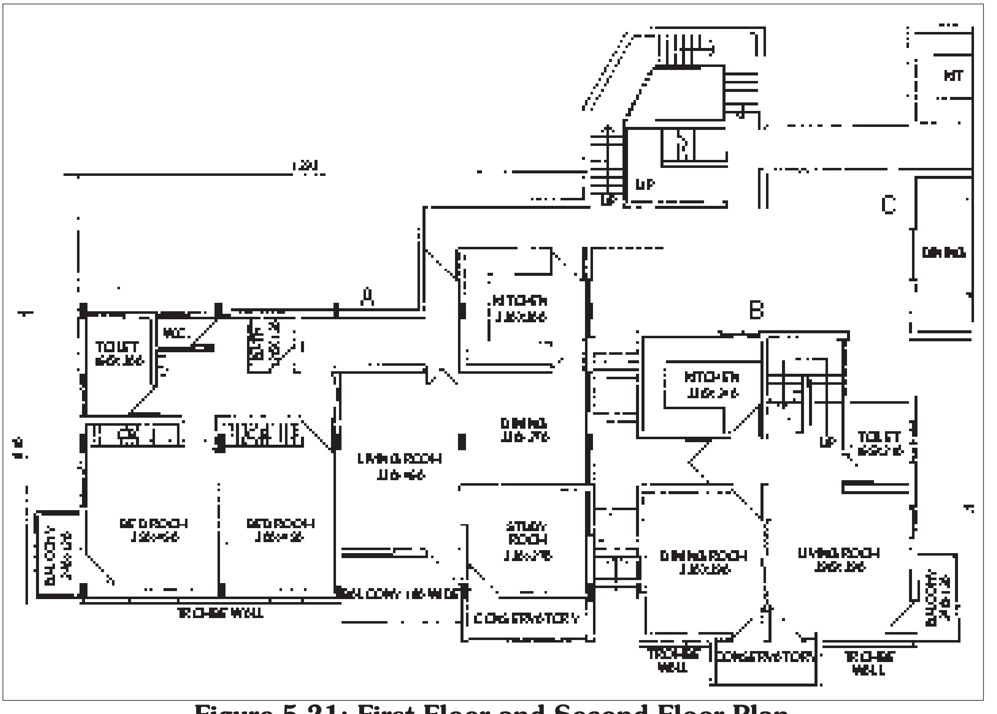


Figure 5.21: First Floor and Second Floor Plan

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

Zhao Xiguang and Zhang Shuangxiang, 1988. 'Experiment on Passive Solar Building in Diqing Region'. In *Energy Resources in Yunnan*, Vol. 2. Yunnan: Publisher not given.

Zhang Xinfan; Bai Jijian, and Wang Shouwu, 1991. Discussion on Feasibility of Passive Solar Nuilding in Northeast China at the 1991 Meeting of China Society of Solar Energy, October.

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.

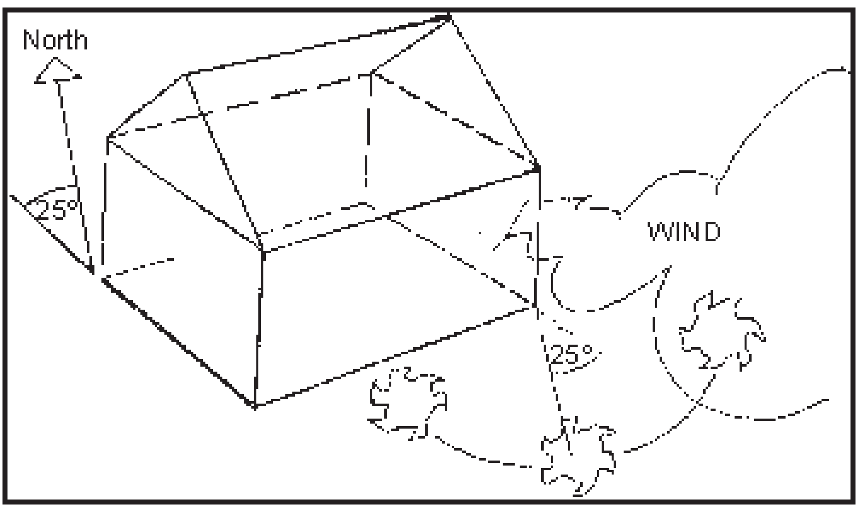


Figure 5.22

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).

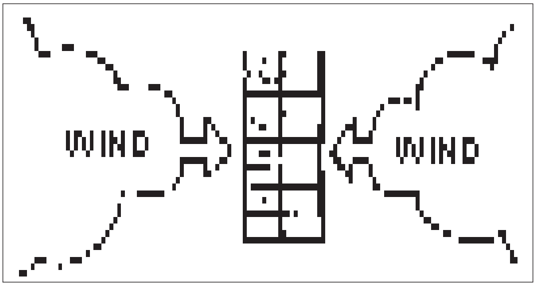


Figure 5.23

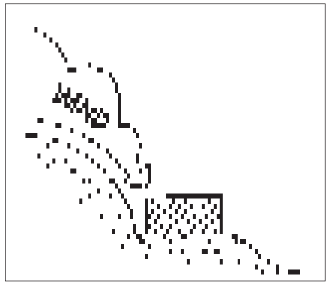


Figure 5.24

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).

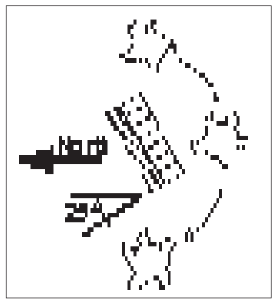


Figure 5.25

Trees

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

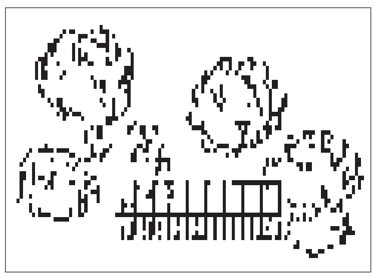


Figure 5.26

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).

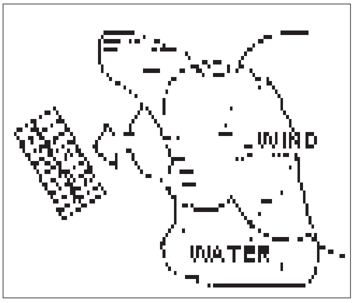


Figure 5.27

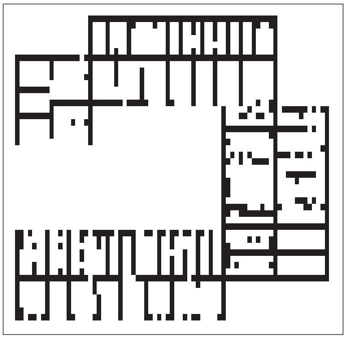


Figure 5.28:

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).

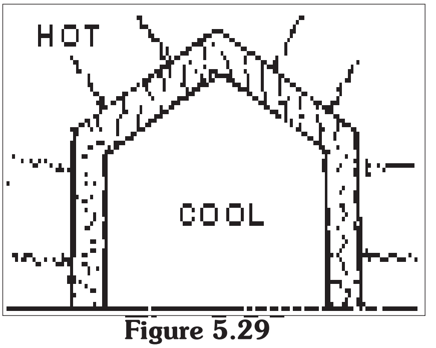


Figure 5.29

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

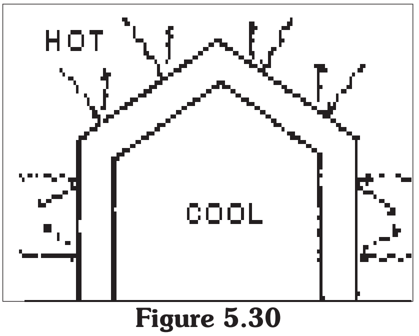


Figure 5.30

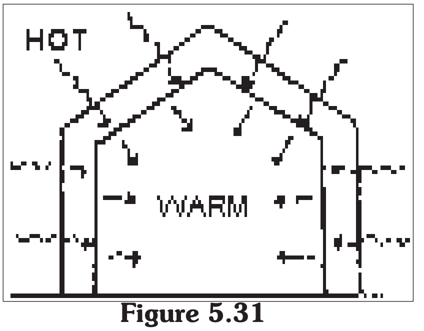


Figure 5.31

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
	Galvanised iron, dirty	89
	Galvanised 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^2•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.

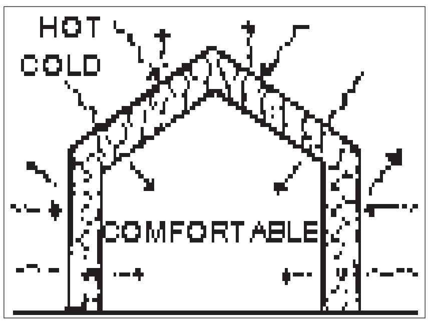


Figure 5.32

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

U.S. Department of Housing and Urban Development, 1976. *Solar Dwelling Design Concepts*. Washington D.C. 20402: US Government.

Lippsmier G., 1969. *Building in the Tropics*. Munich: Springer Verlag.

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.)

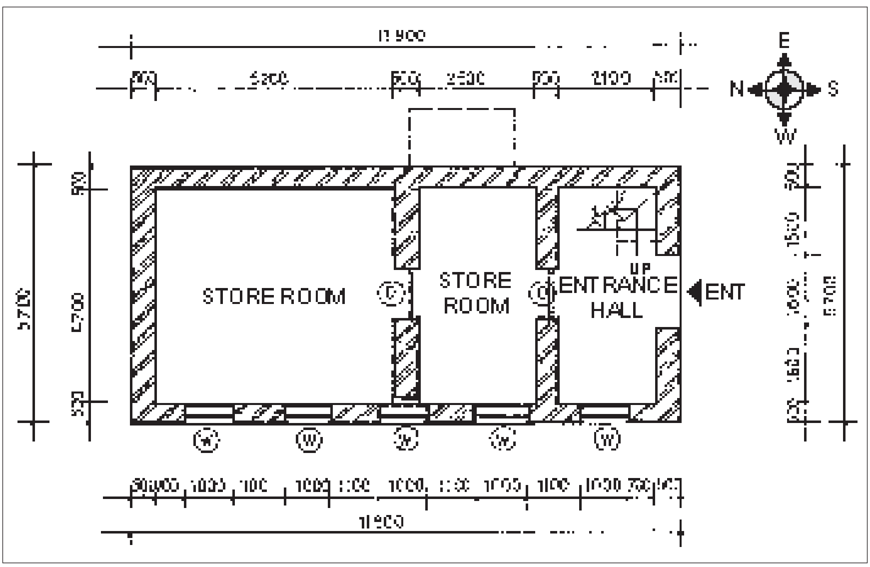


Figure 5.33: Ground Floor Plan (Solukhumbu)

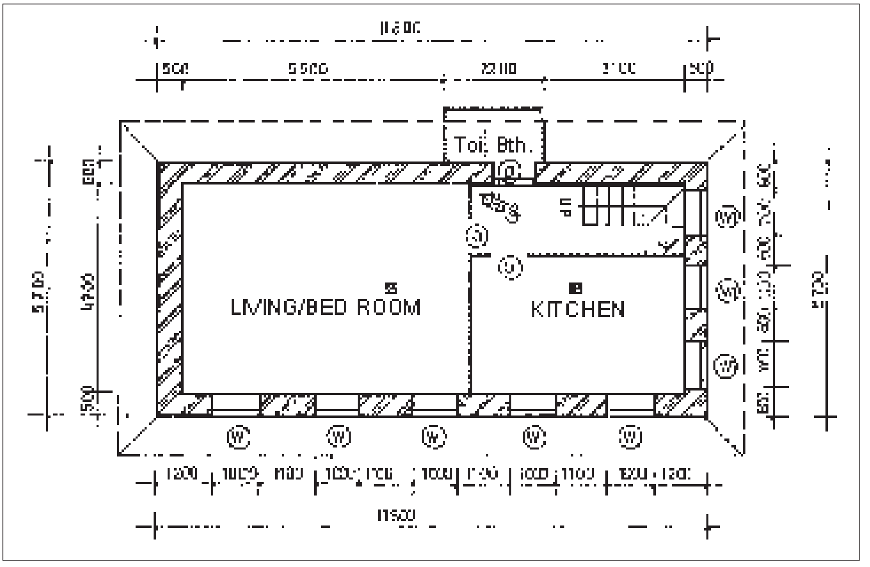


Figure 5.34: First Floor Plan (Solukhumbu)

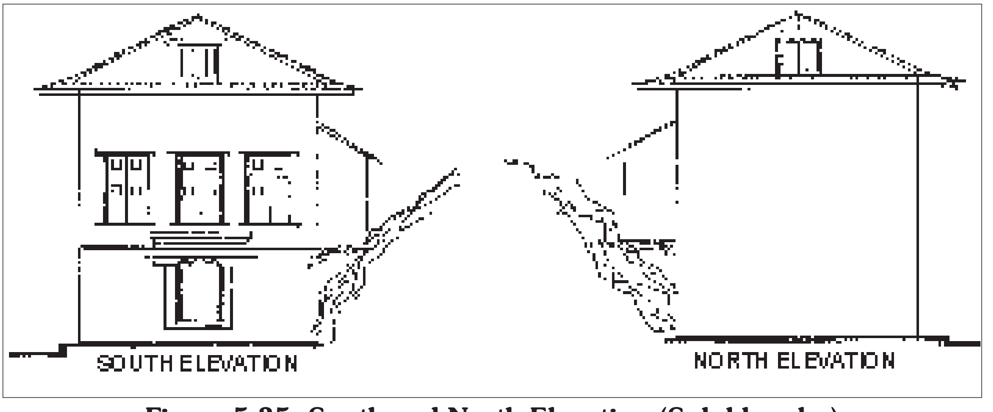


Figure 5.35: South and North Elevation (Solukhumbu)

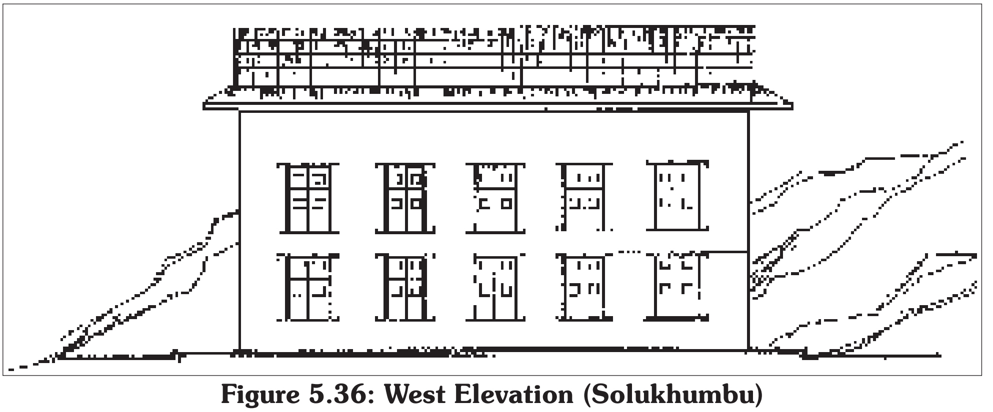


Figure 5.36: West Elevation (Solukhumbu)

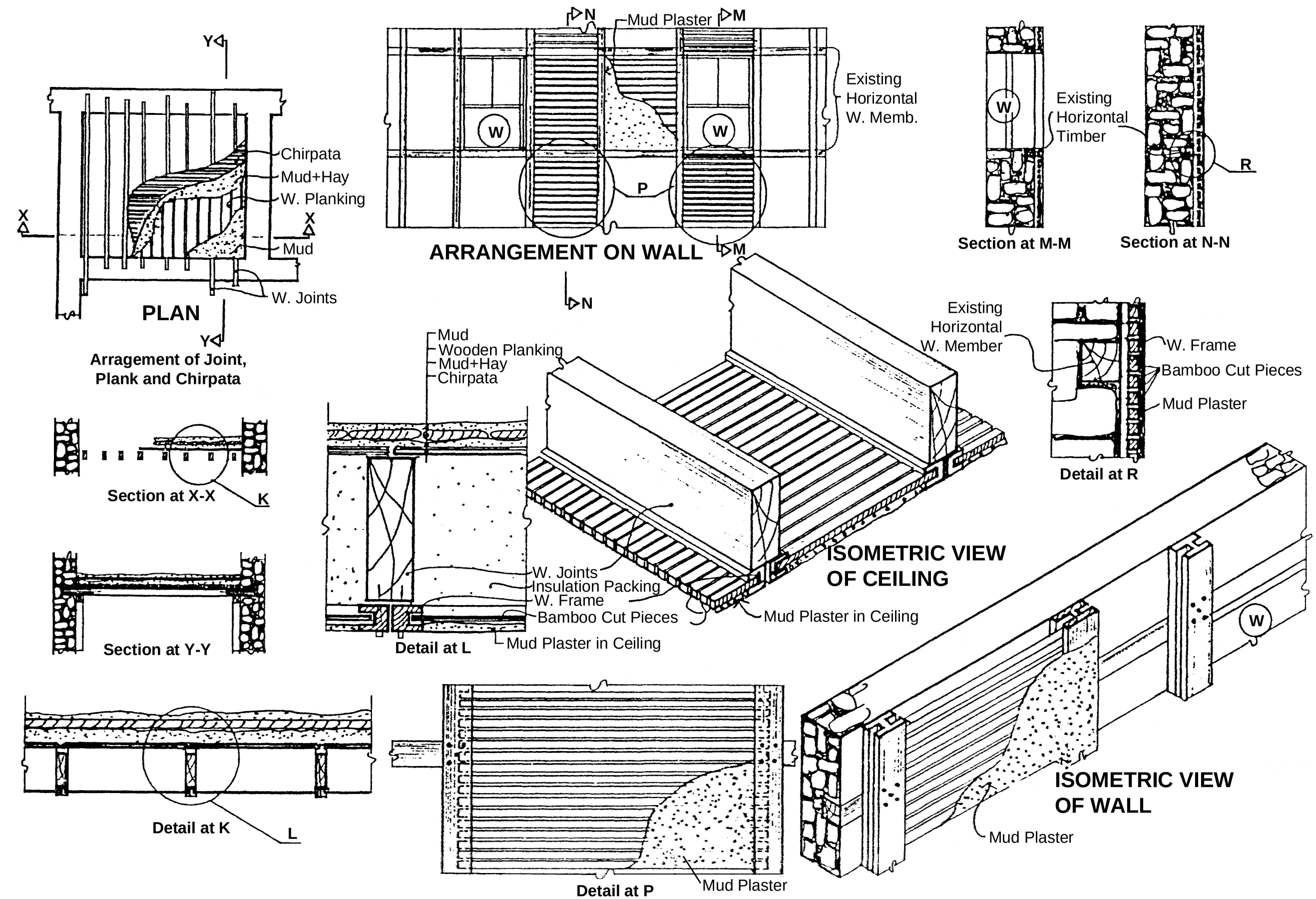


Figure 5.37: Details of Houses in Jumla and Solukhumbu

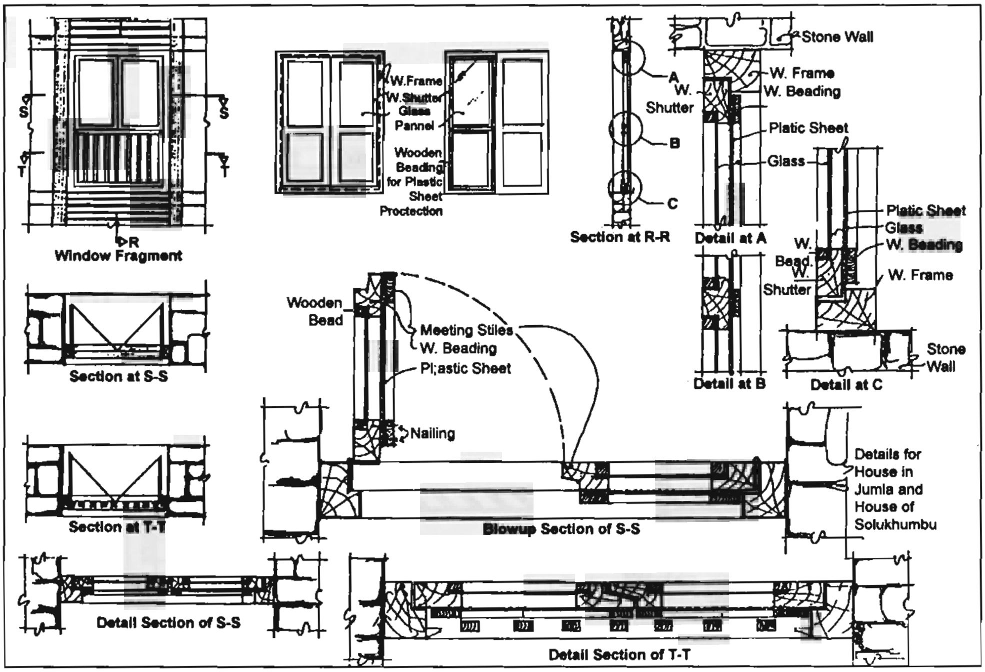


Figure 5.38: Details of Houses in Jumla and Solukhumbu

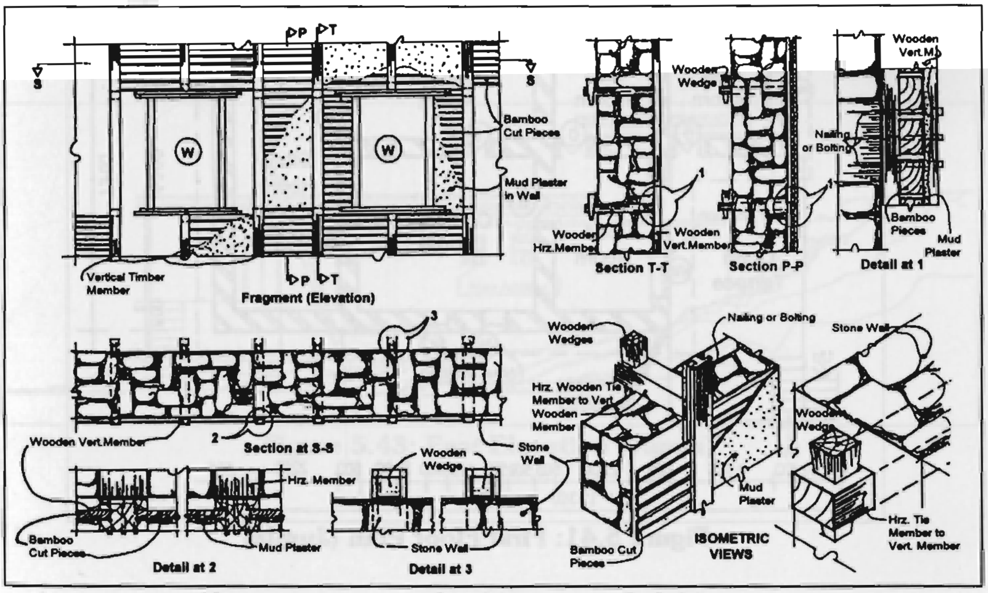


Figure 5.39: Details of House in Solukhumbu

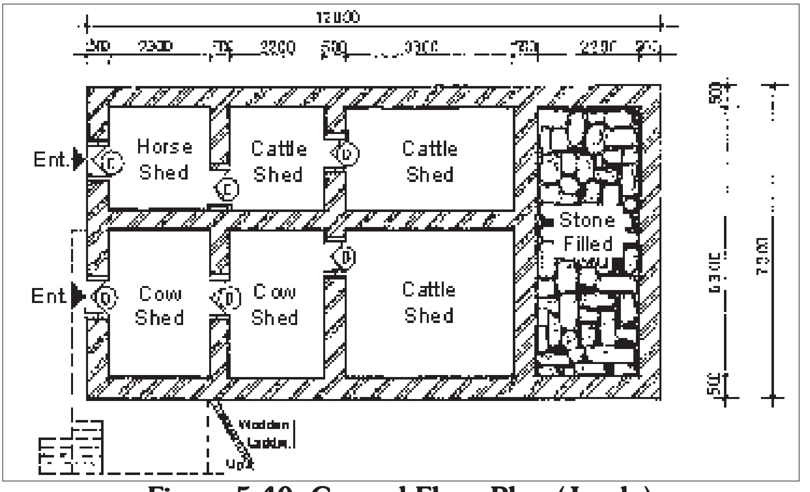


Figure 5.40: Ground Floor Plan (Jumla)

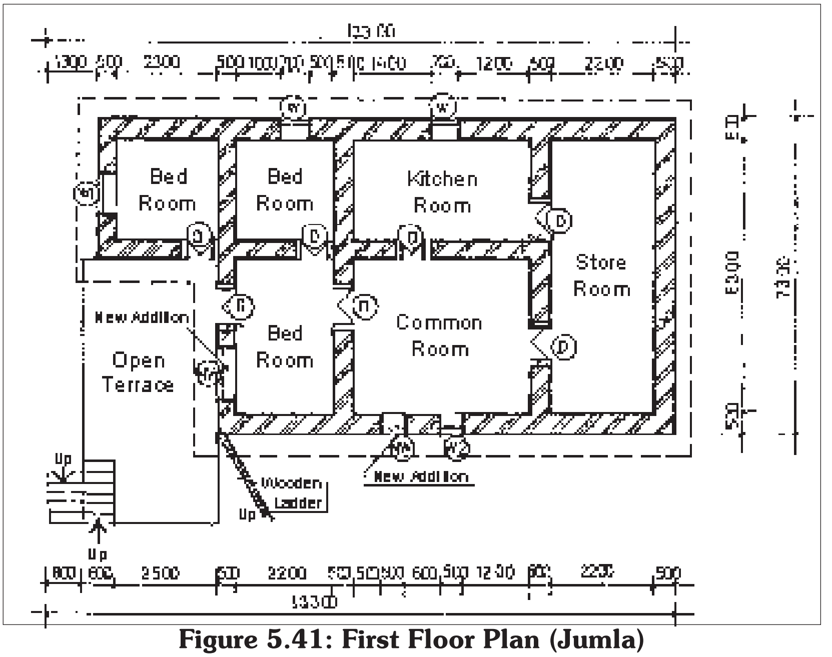


Figure 5.41: First Floor Plan (Jumla)

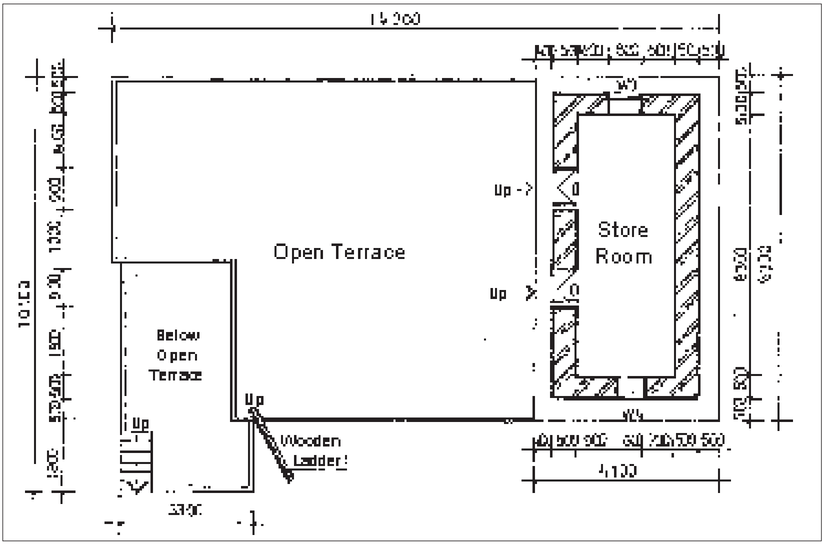


Figure 5.42: Second Floor Plan (Jumla)

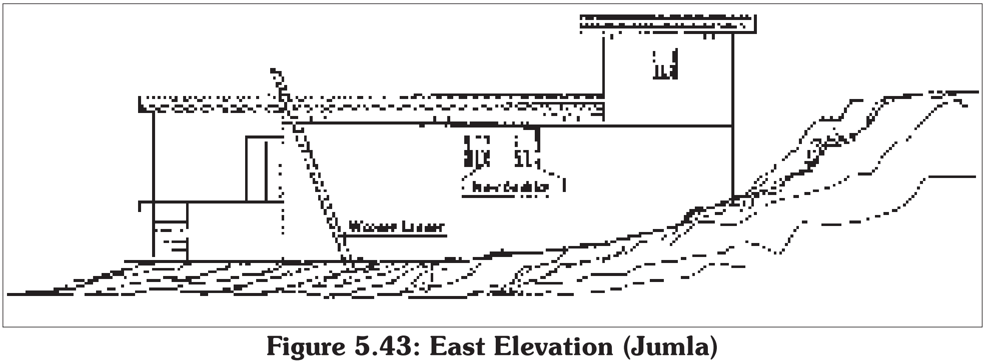


Figure 5.43: East Elevation (Jumla)

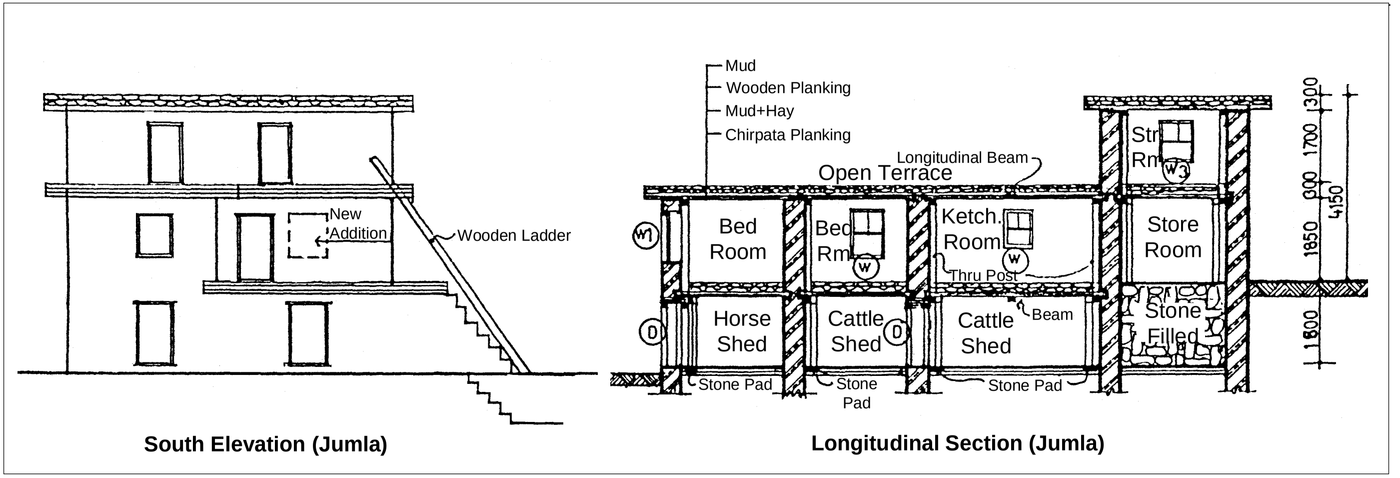


Figure 5.44: South Elevation and Longitudinal Section (Julma)

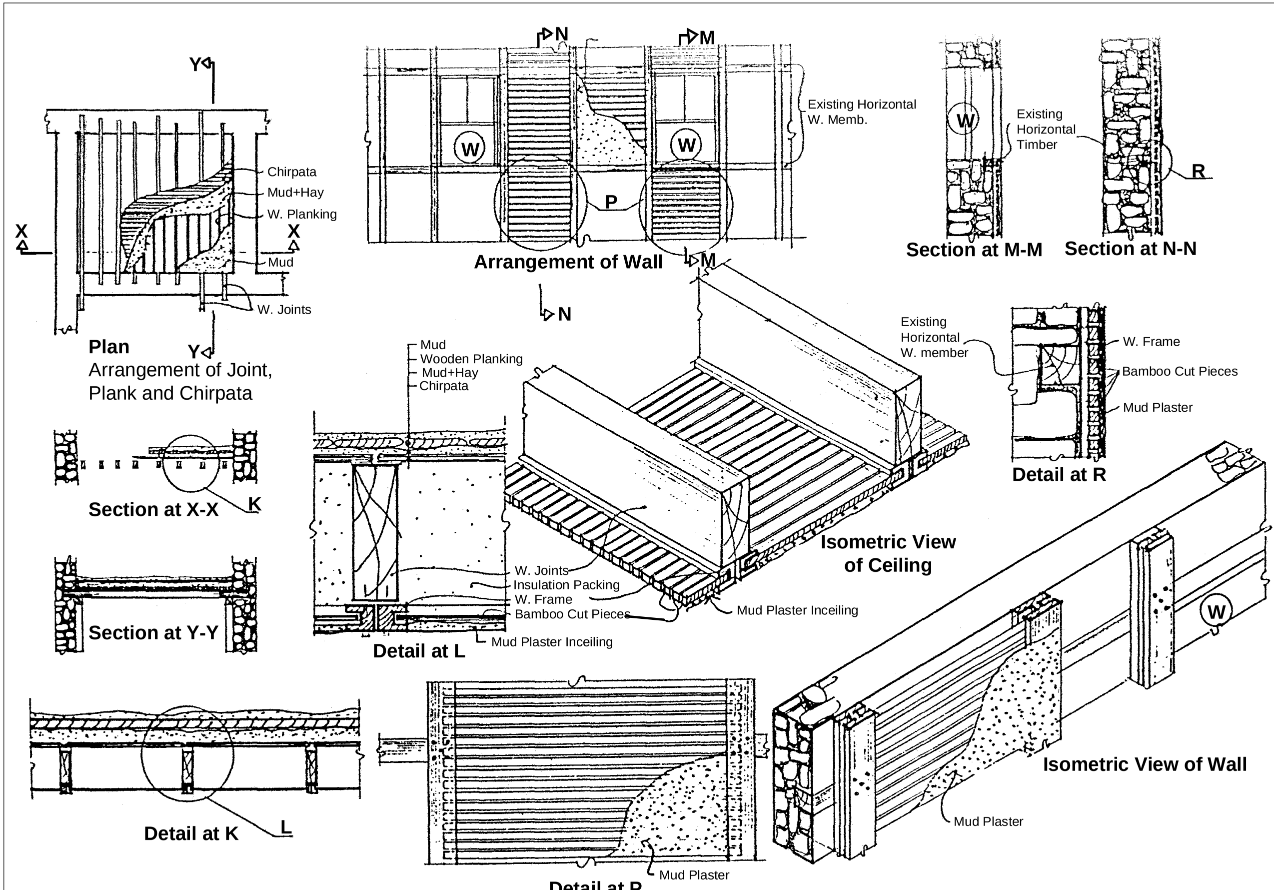


Figure 5.45: Details of Houses in Jumla and Solukhumbu

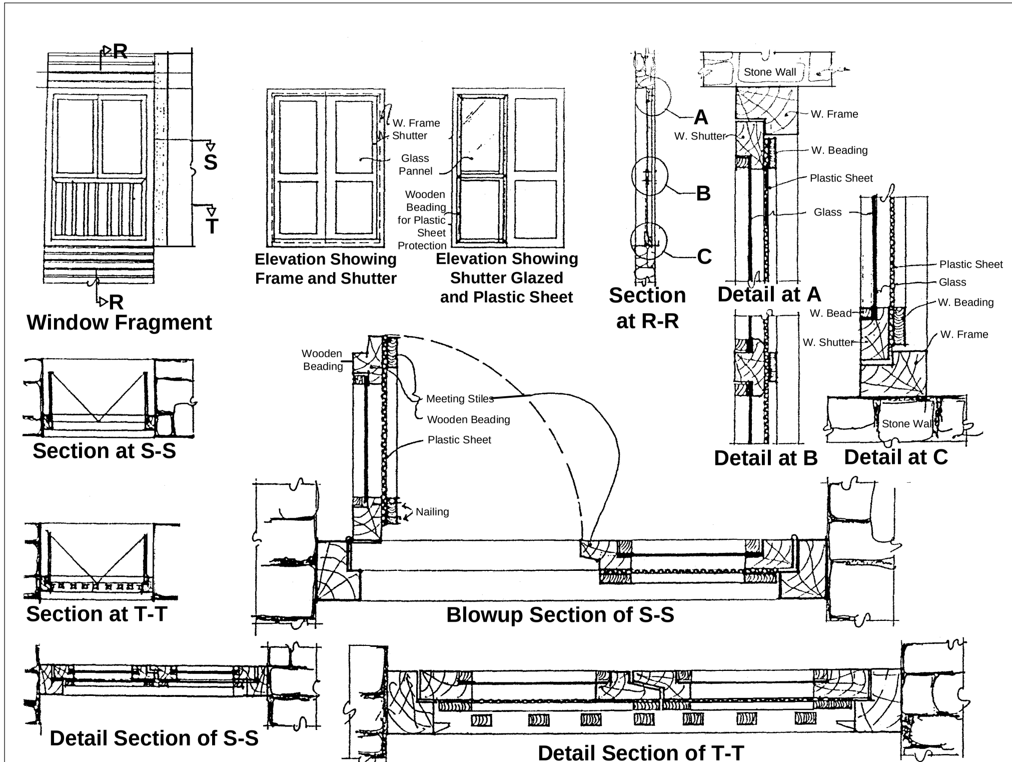


Figure 5.46: Details of Houses in Jumla and Solukhumbu

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/m² area
Mass of roof	= 1000 x 0.25 x 1
	= 250 kg /m²

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 (m²)	Average Radiation Intensity (W/m²)	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	228.85
West	2.18	177.29	286.49
South	2.96	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.

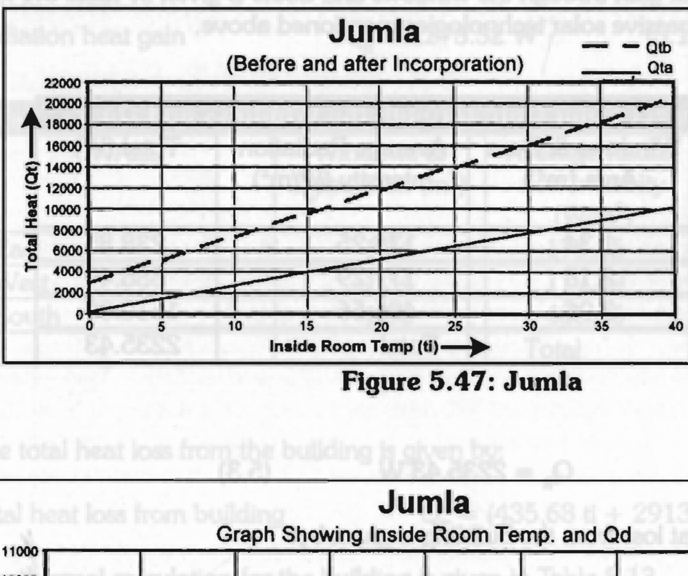
Another graph was plotted to show the difference in heat, before and after passive building technology on the Y-axis, and inside room temperature on the X- axis.

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.

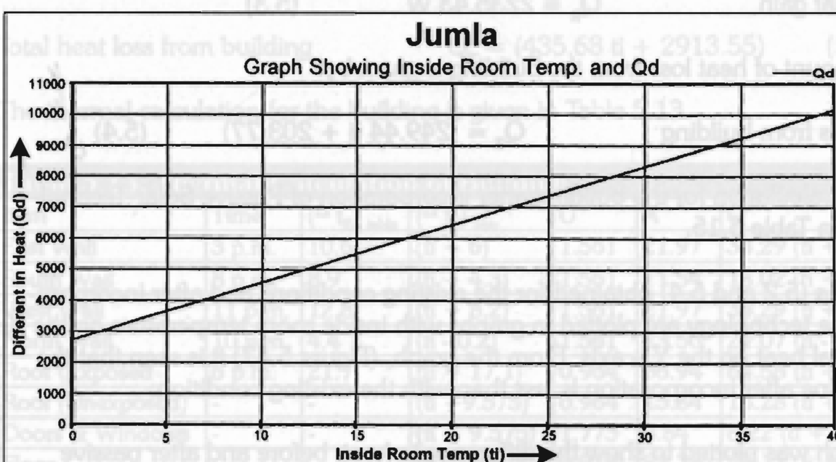
Solukhumbu



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/m² area
Mass of roof	= 1000 x.26 x 1 = 260 kg /m²

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 (m²)	Average Radiation Intensity (W/m²)	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	$(\Delta t)_{max}$	$(\Delta t)_{min}$	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	$(t_i + 6.53)$	1.561	34.98	$54.60(t_i + 6.53)$
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.

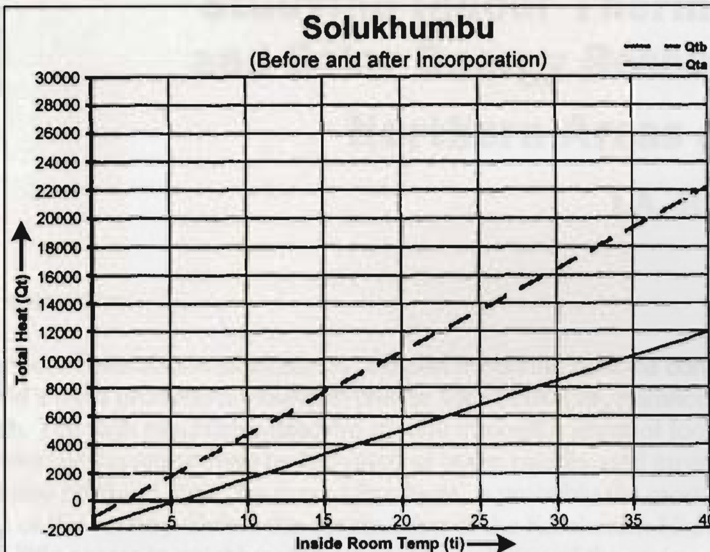
Two equations obtained for the pre-existing condition and after incorporation of passive technology are plotted on the graph, with the inside room temperature on the X axis and total heat on the Y-axis. From the graph (Figure 5.49), it can be seen that the slope of the line after incorporation is less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

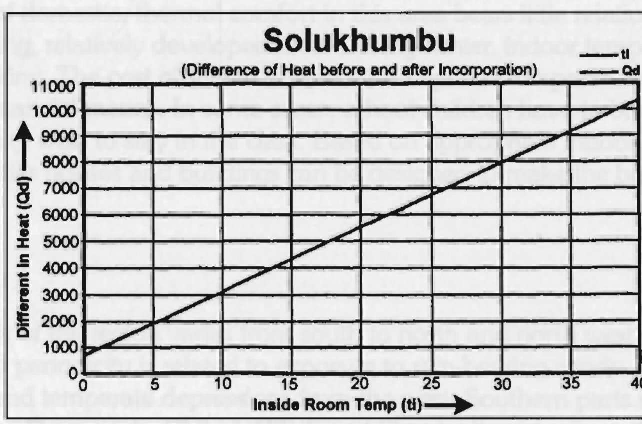
Table 5.18: Thermal Calculation for the Building after Passive Heating Modifications						
Item	Time	$(\Delta t_E)_{table}$	$(\Delta t_E)_{corr.}$	U	A	Q
East Wall	3 p.m.	10.6	(ti + 4.33)	0.339	40.98	13.89 (ti + 4.33)
South Wall	8 p.m.	8.9	(ti + 2.63)	0.339	19.62	6.65 (ti + 2.63)
West Wall	11 p.m.	12.8	(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)



QTb = 585,49tl - 1177,9
Qta = 344,17tl - 1875,88

ti	Qtb	Qta
0	-1177.90	-1875.88
5	1749.55	-155.03
10	4577.00	1565.82
15	7604.45	3286.67
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

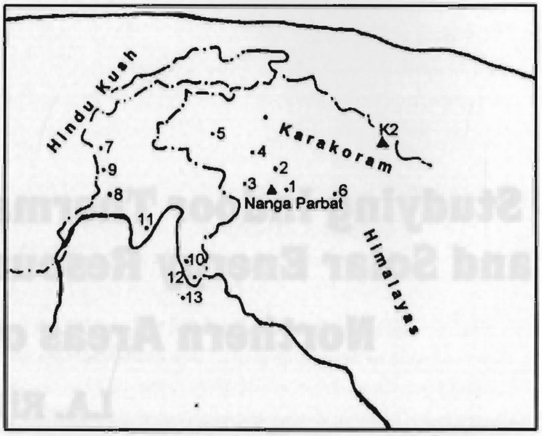
Introduction

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	Category	zone	Longitude	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.

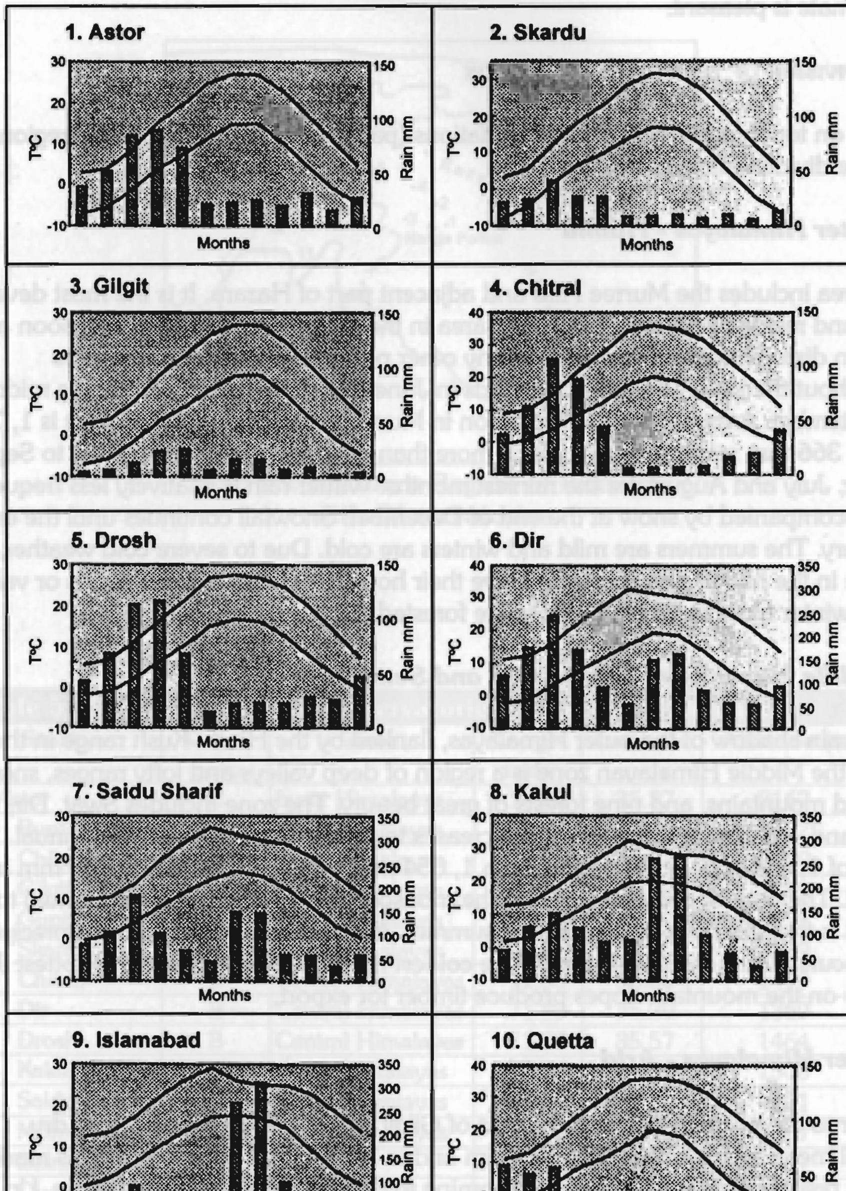


Figure 5.51: Variations in Temperature (Min. and Max.) and Rainfall in Different Locations

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/m^2 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.

Further Reading

ASHRAE, Standards 55-198, (not dated). *Thermal Environment for Human Comfort*. Atlanta USA: ASHRAE.

Humphreys, M. A., 1976. 'Field Studies of Thermal Comfort Compared and Applied'. In *Building Research Engineering Vol. 44*.

Humphreys, M. A., 1978. 'Outdoor Temperatures and Comfort Indoors'. In *Building Research and Practice, Vol. 6 (2).*

Nicol, F.; Jamy, G.N.; Sykes, O.; Humphreys, M.; Roaf, S.; and Hancock, M., 1994. *A Survey of Thermal Comfort in Pakistan*. School of Architecture, Oxford: Oxford Brookes University.

Nicol, F.; Raja, I.; and Alaudin, A., 1997. *Thermal Comfort in Pakistan 2.* School of Architecture, Oxford: Oxford Brookes University.

Raja, I. A., 1996. *Solar Energy Resources of Pakistan*. Oxford: Oxford Brookes University, U.K.