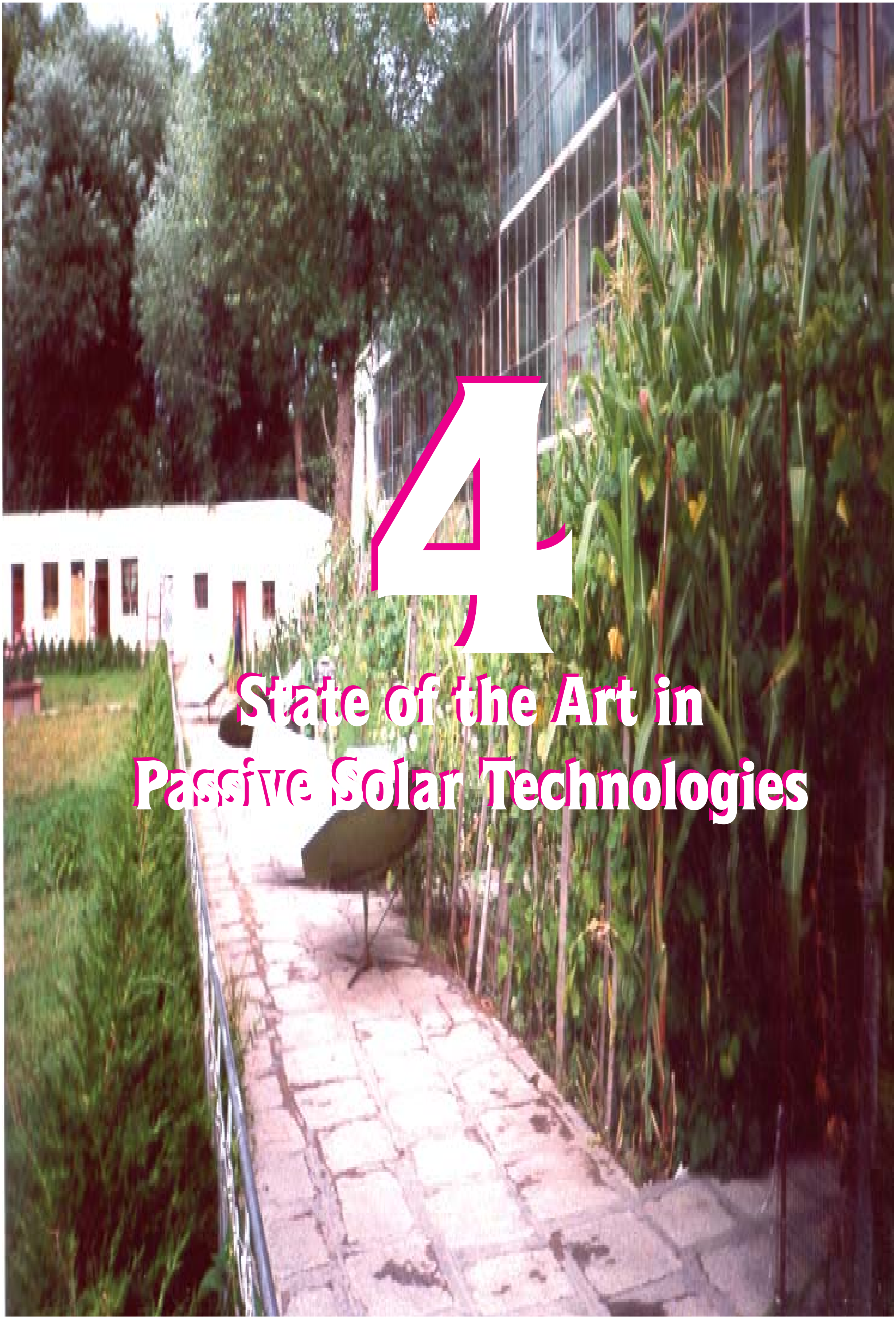
4

State of the Art in Passive Solar Technologies



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

M.Chandra

Introduction

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

Advanced Materials for Passive Buildings

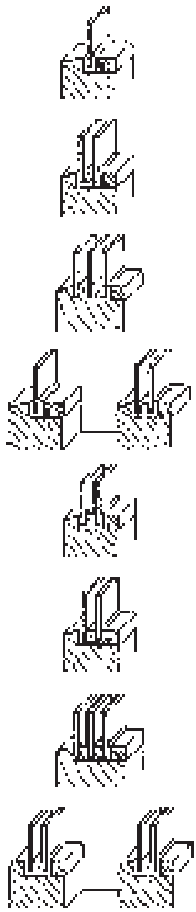
New and improved materials are often crucial to technological or cost breakthrough and solar energy is no exception. For this reason, special attention has been given to the investigation of a variety of innovative materials that promise to bring about dramatic improvements in the performance and reliability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

Insulating Window Glass

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

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

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



U-value $[W/m^2K]$	g-value [-]	τ-value [-]
5.8	0.82	0.90
3.0	0.75	0.82
2.1	0.68	0.74
2.0	0.68	0.74
1.8	0.61	0.70
1.3	0.62	0.70
0.73	0.46	0.55
0.65	0.41	0.50

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

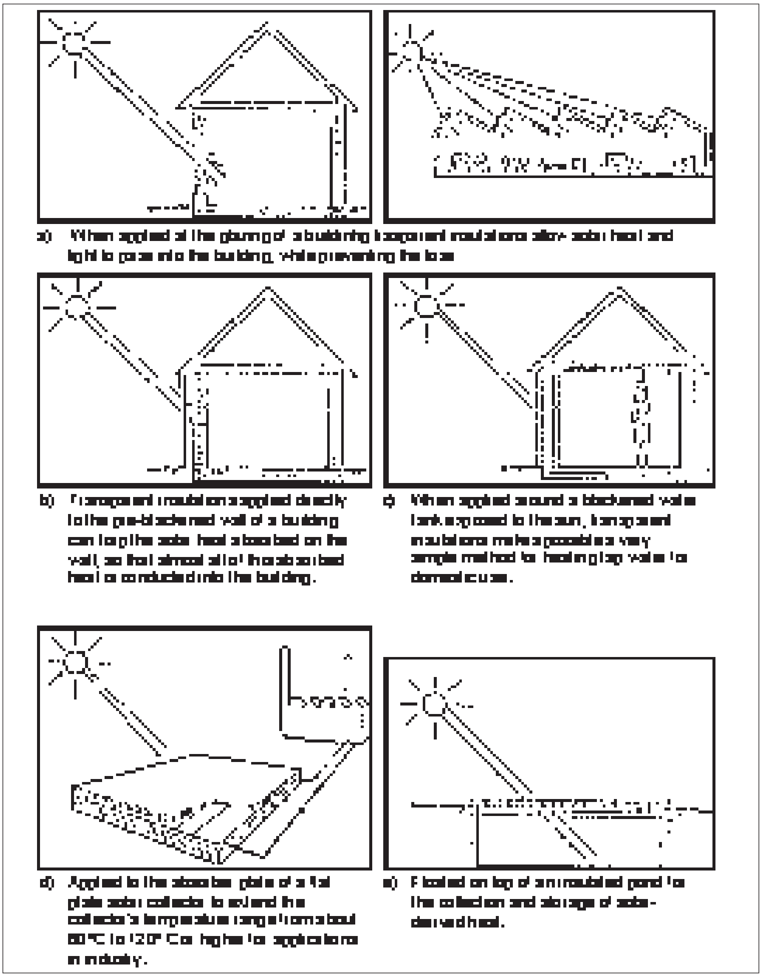


Figure 4.2: Examples of the Uses of Advanced Transparent Insulation Materials

Weather Panel/Prefabricated Roof Panel

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

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

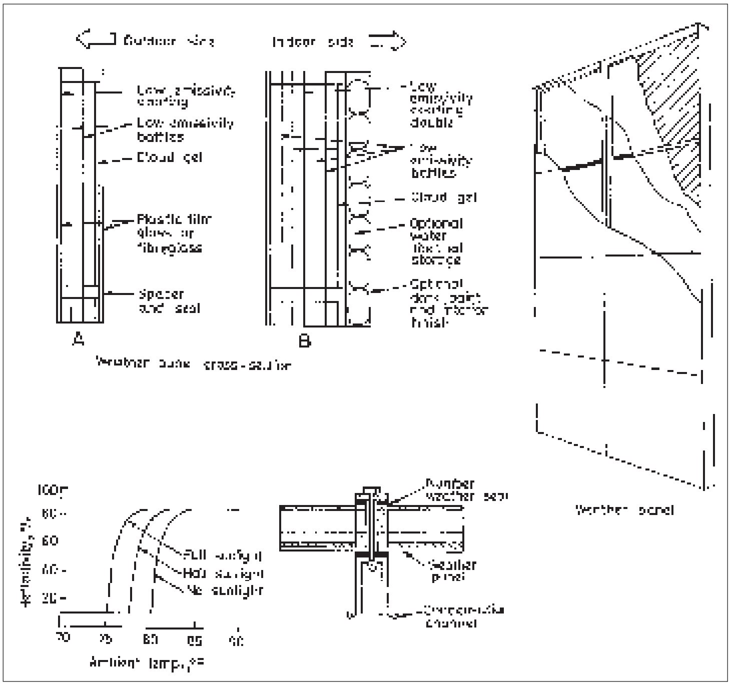


Figure 4.3: Weather Panel Details

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

New Passive Heating Approaches/Concepts

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

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

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

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

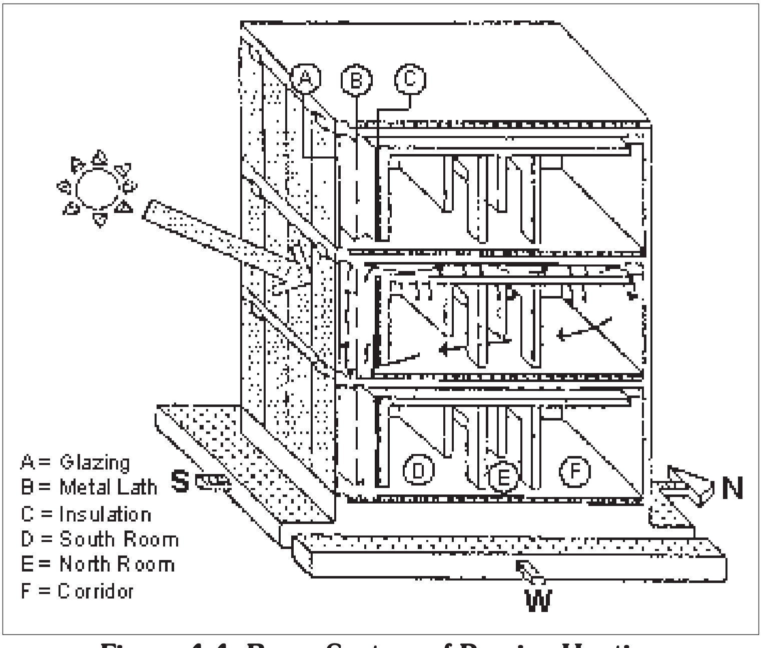


Figure 4.4: Barra System of Passive Heating

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

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

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

Opposite Sun Space Passive Solar Air Heating System

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

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

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

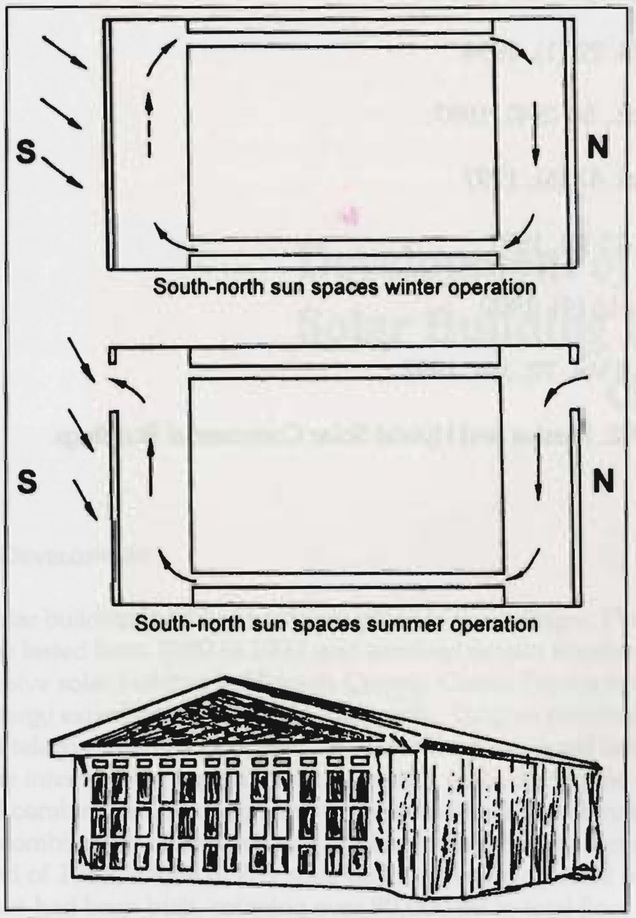


Figure 4.5: Opposite Sun Space Passive Solar Air Heating System

Further Reading

Bansal, N. K.; Hanser, G.; and Minke. G., 1994. *Passive Building Design: A Handbook of Natural Climatic Control*. Holland: Elsevier.

Energy and Buildings Vol. 21, 1994

Solar Energy, Vol. 22 (1), 1994

Solar Energy, Vol., 50 (3/4), 1997.

Solar Energy, Vol. 47 (6), 1997.

Sun World, Vol. 15 (2), 1991.

Sun World, Vol., 16 (4), 1992

IE(I) Journal - AR Vol. 72, Jan. 1992.

IEA Task 11, 1992. Passive and Hybrid Solar Commercial Buildings.

4.2 Development of Passive Solar Building in China

Chen Xiaofu

Research and Development

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

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

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

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

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

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

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

Introduction and Application of Solar Buildings in Different Areas

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

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

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

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

Economic Benefits

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

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

Problems and their Causes

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

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

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

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

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

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

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

Strategies and Suggestions for Future Development

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

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

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

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

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

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

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

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

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

4.3
Solar Building in Tibet

Ci Zhen

Introduction

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

Solar Building with Extension

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

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

Solar Building with a Heat- collecting Wall

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

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

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

4.4
Passive Solar Building Construction at High Latitudes

Du Xiabin

Introduction

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

Passive Solar Building Design

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

Material Composing the Wall

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

Table 4.2: Thermal Performances of Common Wall Materials

Material	Thermal Conductivity (W/m°C)	Heat Transmission Rate (W/m² °C)
Common Brick Wall	0.76	9.86
Clay Wall	0.70	9.19
Cement Wall	1.50	15.26

Convective Hole

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

Sunlight Adjustment

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

Passive Solar Building Construction

Direct Beneficial Type

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

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

Heat Concentrating Type

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

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

Concluding Remarks

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

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

Irshad Ahmad

Introduction

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

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

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

Analysis of the Climate in Gilgit (Northern Areas)

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

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

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

Table 4.3: Summary of Weather Data for Gilgit

Month	Mean DB	Max. DB	Min DB	RH	Wet bulb	Wind speed	Wind Dir.	Calm %
Jan	2.2	9.2	-2.7	56	-4	1.2	W	76
Feb	6.1	12.0	0.2	50	-2.4	2.1	W	66
Mar	11.6	17.9	5.4	41	2.0	2.3	W	52
Apr	16.6	22.9	9.4	29	4.5	2.5	W	62
May	20.1	28.4	11.7	27	8.2	2.5	SE	69
Jun	24.8	34.2	15.2	27	10.1	2.4	SE	72
Jul	27.4	26.1	18.8	21	11.5	2.5	SE	72
Aug	26.7	25.1	18.1	26	12.2	2.1	SE	76
Sep	26.2	21.6	12.2	27	10.2	1.9	W	79
Oct	16.0	25.2	6.6	21	6.0	1.4	W	82
Nov	9.2	17.8	0.6	40	1.0	1.0	W	86
Dec	4.2	11.0	-2.4	54	-2.6	1.0	W	86
YEAR	15.7	22.6	7.8	28	5.5	2.0		74

Bio-climatic Chart for Gilgit

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

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

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

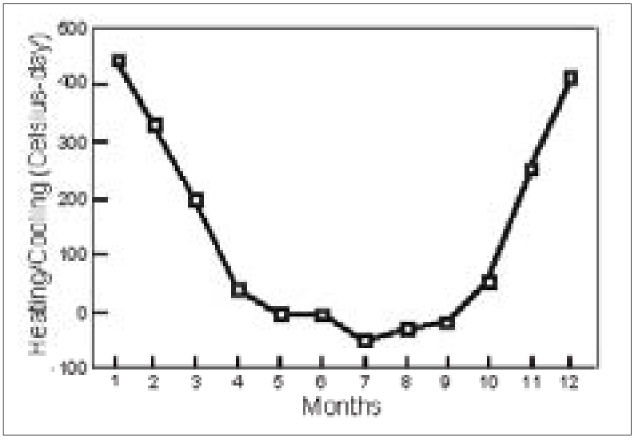


Figure 4.8: Heating/Cooling Degree Days in Gilgit

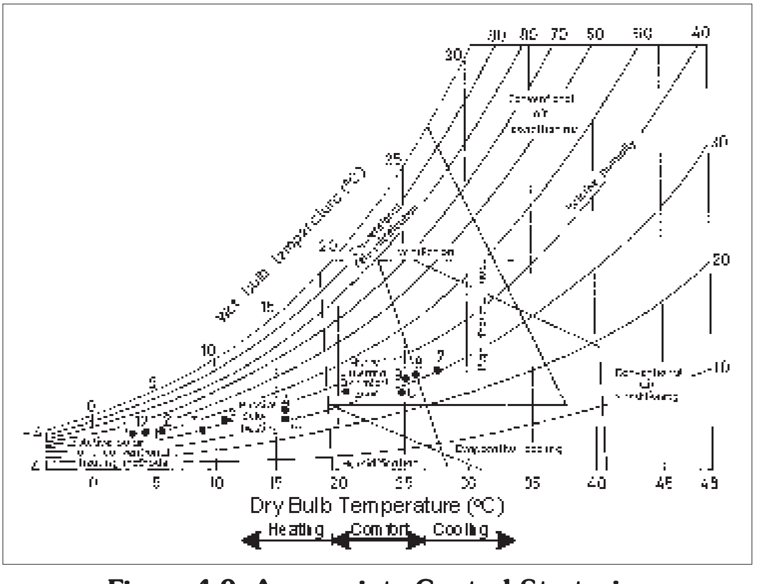


Figure 4.9: Appropriate Control Strategies

Identification of Passive Strategies for Gilgit

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

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

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

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

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

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

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

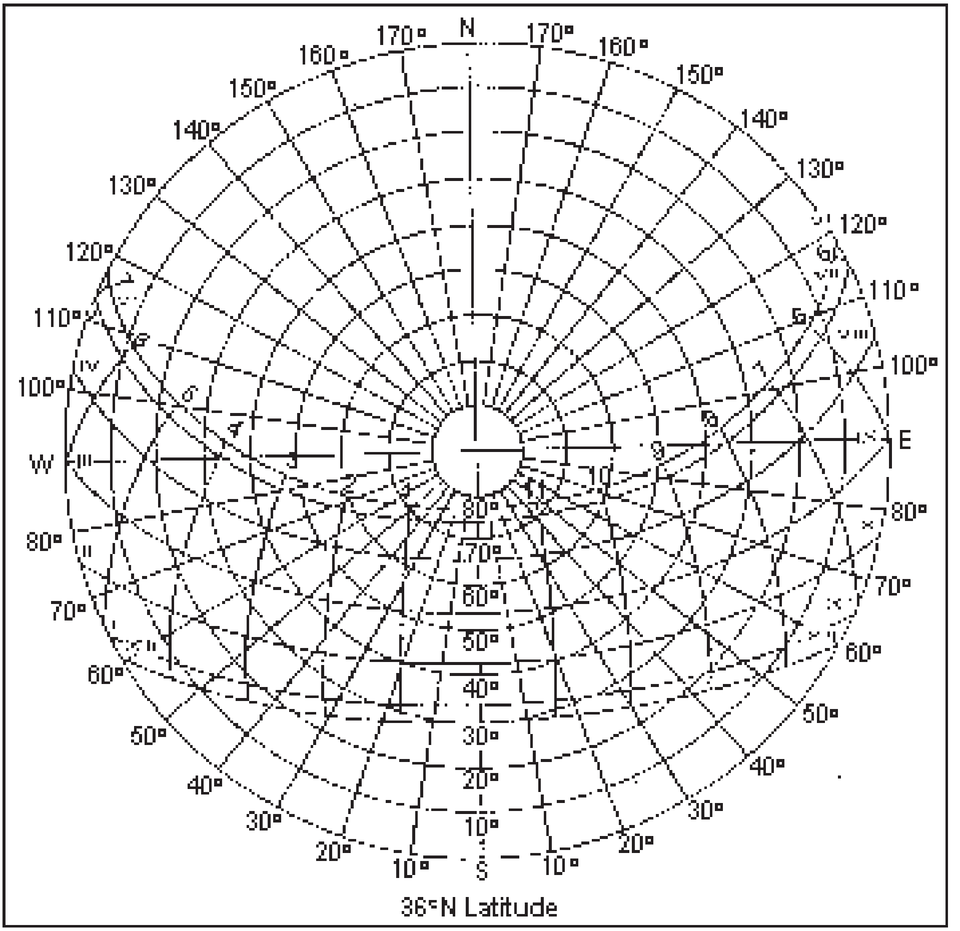


Figure 4.10: Sunpath Diagram for Gilgit

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

Domestic Hot Water and Cooking Systems

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

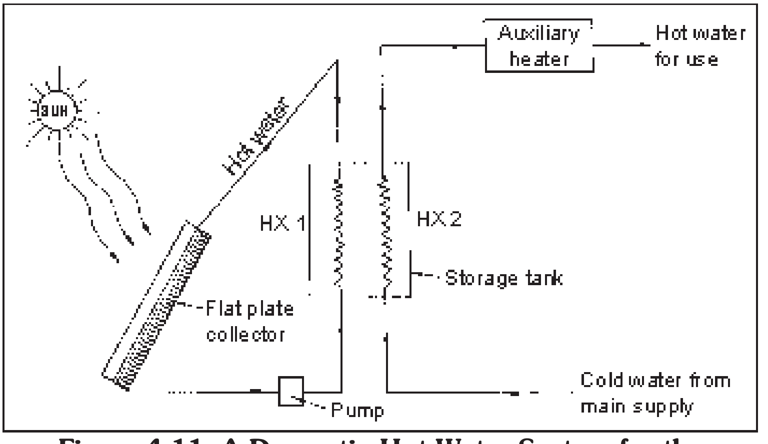


Figure 4.11: A Domestic Hot Water System for the Northern areas

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

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

Conclusions and Recommendations

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

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

* There are 52 Pakistani rupees to one US dollar.

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

Further Reading

Ministry of Petroleum and Natural Resources, 1995. *Energy Year Book 1995*. Islamabad: Government of Pakistan.

Syed, Anis Ali,(n.d.). *Atlas of Pakistan and Survey of Pakistan*. Rawalpindi: Director Map Publication.

Meteorological Division,(n.d.) *Meteorological Data Handbook*. Karachi: Government of Pakistan.

Olgyay, Victor, 1963. *Design with Climate-Bioclimatic Approach to Architectural Regionalism*. Princeton, NJ: Princeton University Press.

Irshad A.; Abro, R.; and Akhter, P., 1997. *Solar Thermal Activities at National Institute of Silicon Technology, Proc*. Lahore: Pakistan Institute of Physics, Conf.

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

S.P. Jain

Water Proofing for Rooves : Heat Reflection and Low Heat Conduction

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

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

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

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

New Approach

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

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

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

Table 4.4: Specifications for Heat Insulating Treatment

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

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

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

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

Table 4.5: Roof Specification

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

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

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

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

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

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

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

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

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

Improved Wall Material Treatment

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

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

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

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

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

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

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

1.2 metres (above floor centre)

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

Table 4.7: Approximate Density, Thermal Conductivity and Reflection Coefficient

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

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

Further Reading

Jain, S.P., 1987. 'White Washing Roof Tops of Residential Buildings'. New Delhi: *The Indian Architect*, 9 (1): 1.

Gangopadhy, P.K. and Jain, S.P., 1985. 'Development of Alternative Heat Insulating and Water Proofing Materiel for Roofs in Tropics'. In *Indian Concrete Journal*, Vol 59 pp 77-85.

Council of Building Research (CBRI), 1990. 'Development of Alternate Heat Insulating Materials and Treatments of in Tropics'. In *CBRI Annual Report, 1990*.

CSIR, 1991. *Alternate Heat Insulating Treatment of Roofs*. CSIR New Vol. 41, No. 3-15.

CSIR, 1990. 'CBRI R&D High Light 1990'. In *CSIR New Vol. 41 No. 203*, p250.

Jain, S.P., 1991. 'Development of New Passive Cooling Design for Alternative Heat Insulation of Roofs Tropics'. In *Journal of Solar-Energy Society of India*, Vol. No. pp 2121-131.

Jain, S.P., 1997. 'Simple Low Cost Practical Procedures for Minimal Maintenance of Exposed Building Surfaces under Tropical Climates'. In *Builders and Developers World*, Vol. 2. April, 1997 pp5 to 12.

4.7
Automated Controls and Photovoltaics in Solar Passive Building

N.K. Bansal & V. Garg

Introduction

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

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

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

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

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

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

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

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

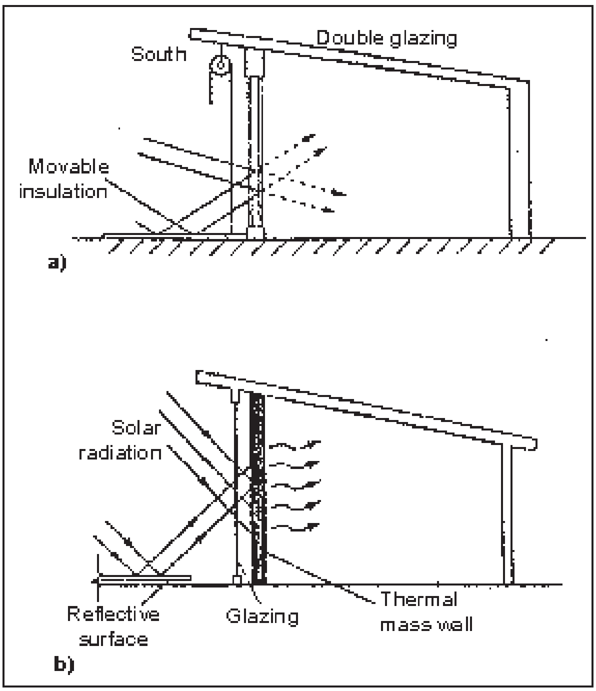


Figure 4.12a: a) Configuration of Direct Gain b) Configuration of Mass Wall

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

Autumn/Spring: Excess heat from the south-facing wall is extracted by fan to the top of the atrium. Air from the atrium is heated further if necessary before being distributed to the production area. The blinds on the south-facing wall are set automatically at an angle to admit or reflect solar radiation. Automatic louvers at the top of the atrium admit fresh air to be mixed with the warm air going to the production area. Fans circulate air within the production area to prevent stratification. Glass louvers between the offices and production area are opened to allow air to return to the atrium via the offices. Radiators operate independently according to the temperature in each zone.

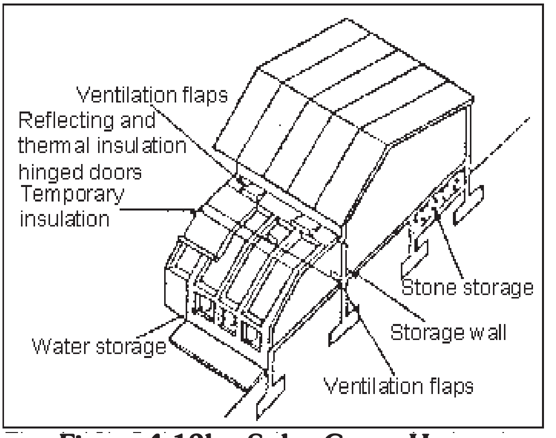


Figure 4.12b: Solar Green House Attached to the Building

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

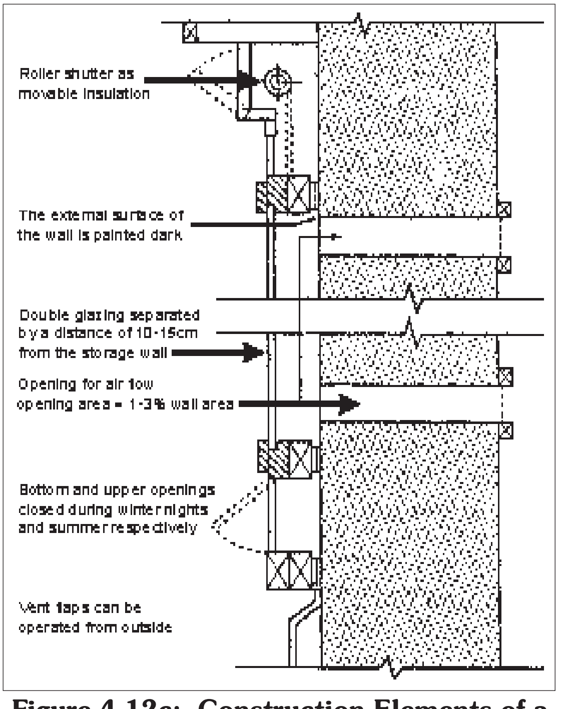


Figure 4.12c: Construction Elements of a Trombe Wall

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

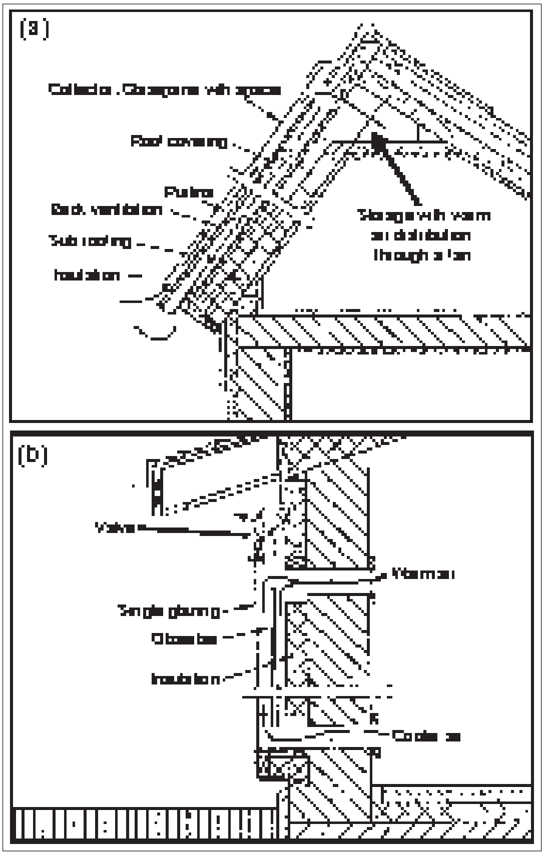


Figure 4.12d: a) Thermosiphon Air Panel Installed on the Roof b) Thermosiphon Air Panel Installed on the Wall

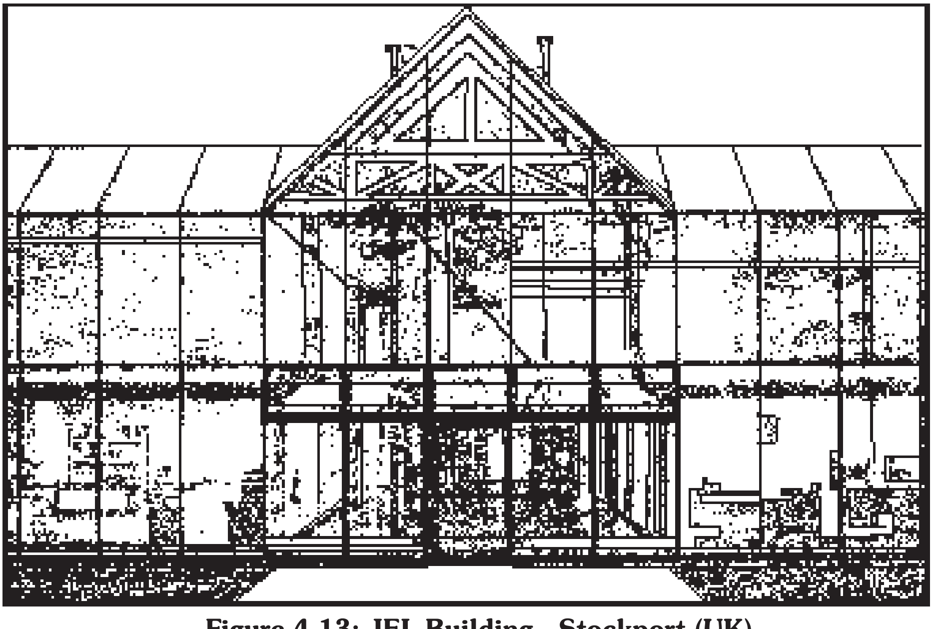


Figure 4.13: JEL Building - Stockport (UK)

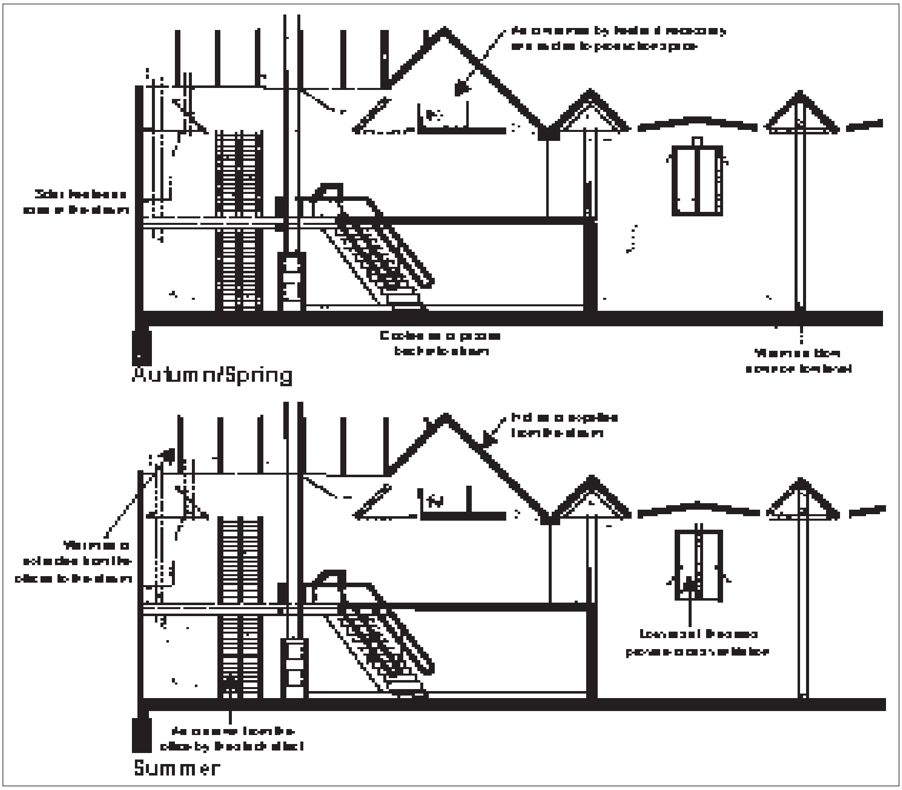


Figure 4.14: Functioning of Different Solar Passive Concepts in a Building

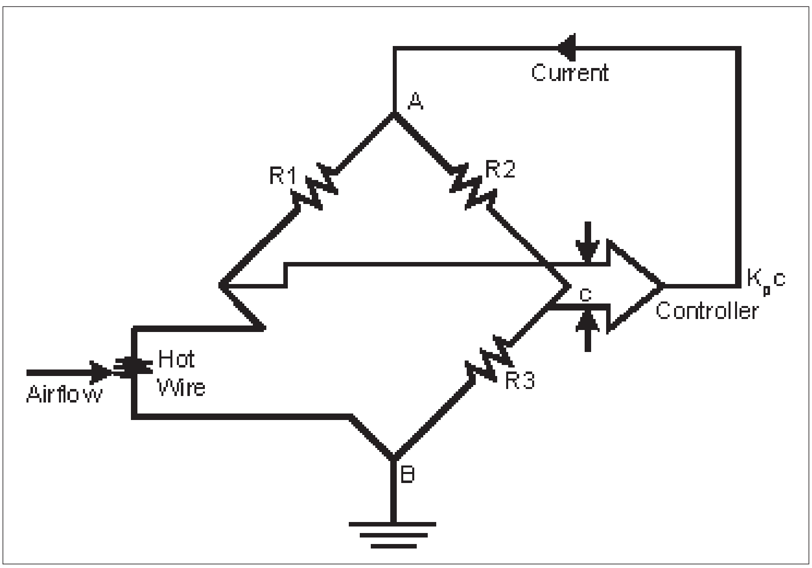


Figure 4.15: Hotwire Anemometer Analog Controller

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

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

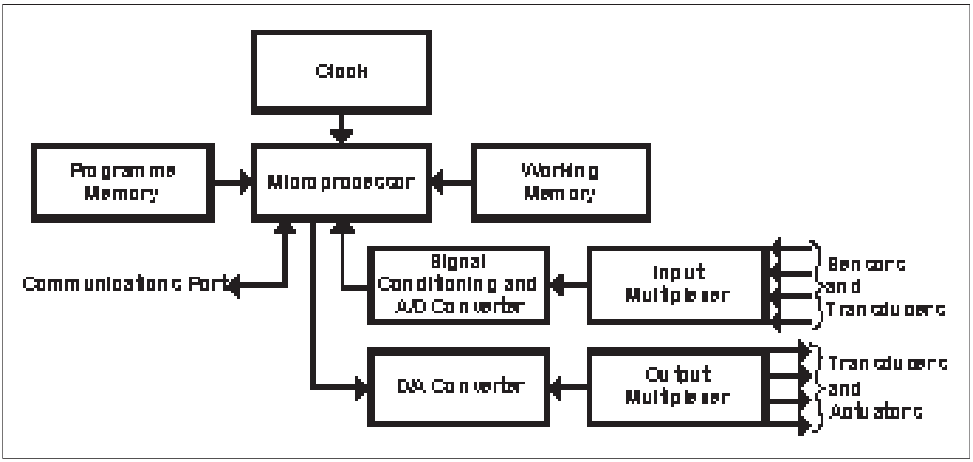


Figure 4.16: Block Diagram of a Direct Digital Controller

Electronic Controls

Basic Control Actions; ON-OFF Control

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

Proportional Control (P)

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

Integral Action (I)

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

Derivative Action (D)

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

Fuzzy Logic Controller (FLC)

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

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

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

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

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

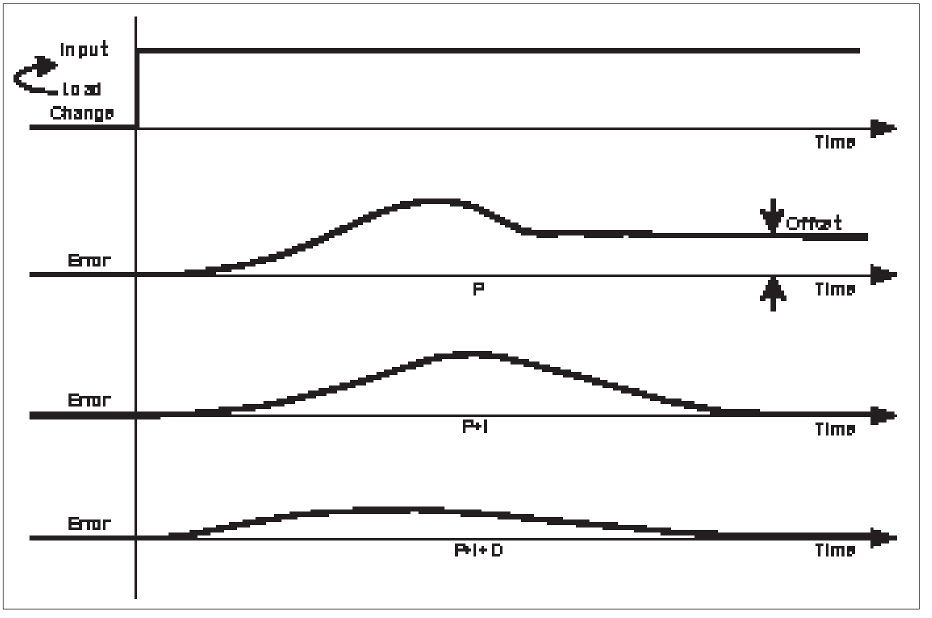


Figure 4.17: Performance Comparison of P,PI,PID Controllers when Subjected to Uniform Step Change

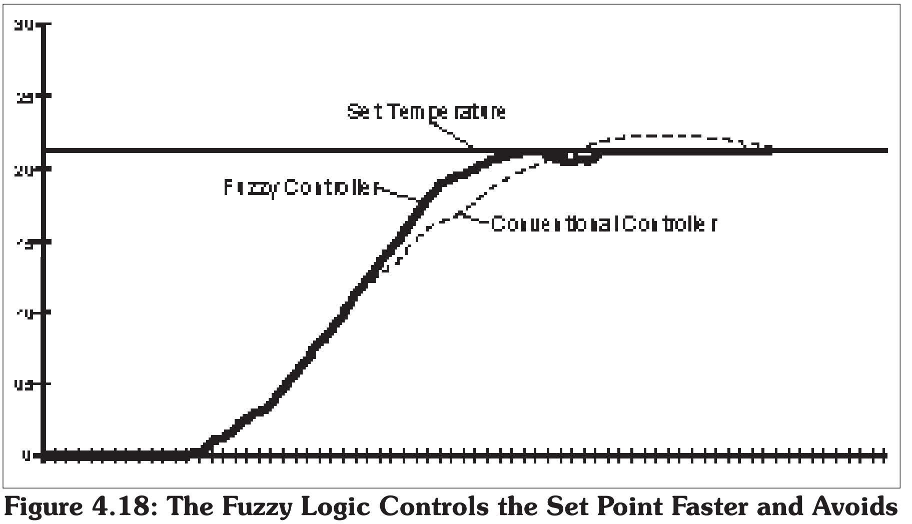


Figure 4.18: The Fuzzy Logic Controls the Set Point Faster and Avoids Overshoot

Photovoltaic (PV) Systems in Buildings

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

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

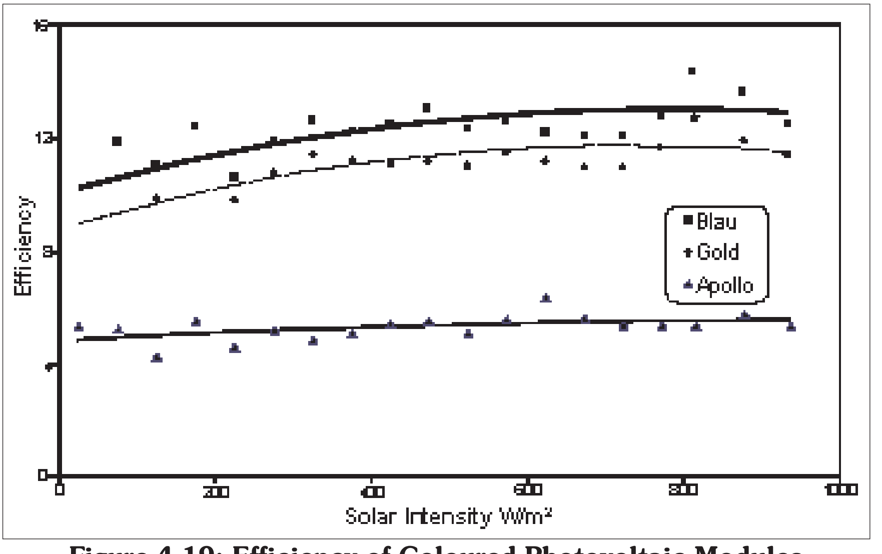


Figure 4.19: Efficiency of Coloured Photovoltaic Modules

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

Planning Dimensioning of Small PV Systems

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

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

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

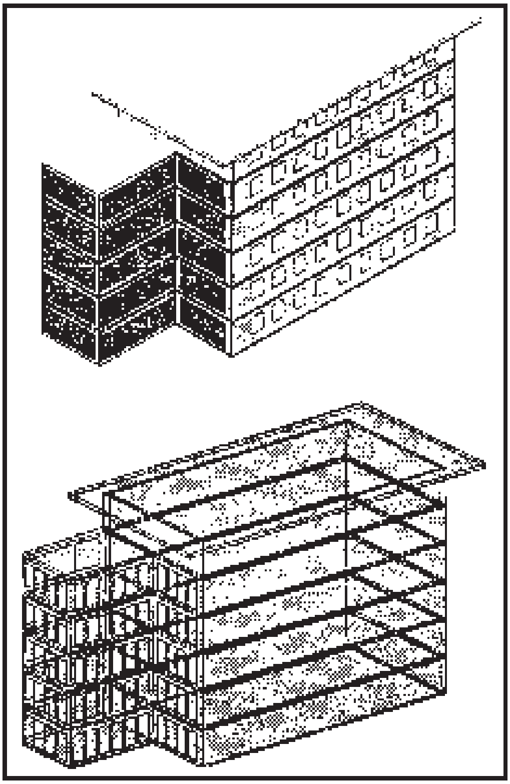


Figure 4.20: Photovoltaic Building Facade

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

Examples of System Dimensioning

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

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

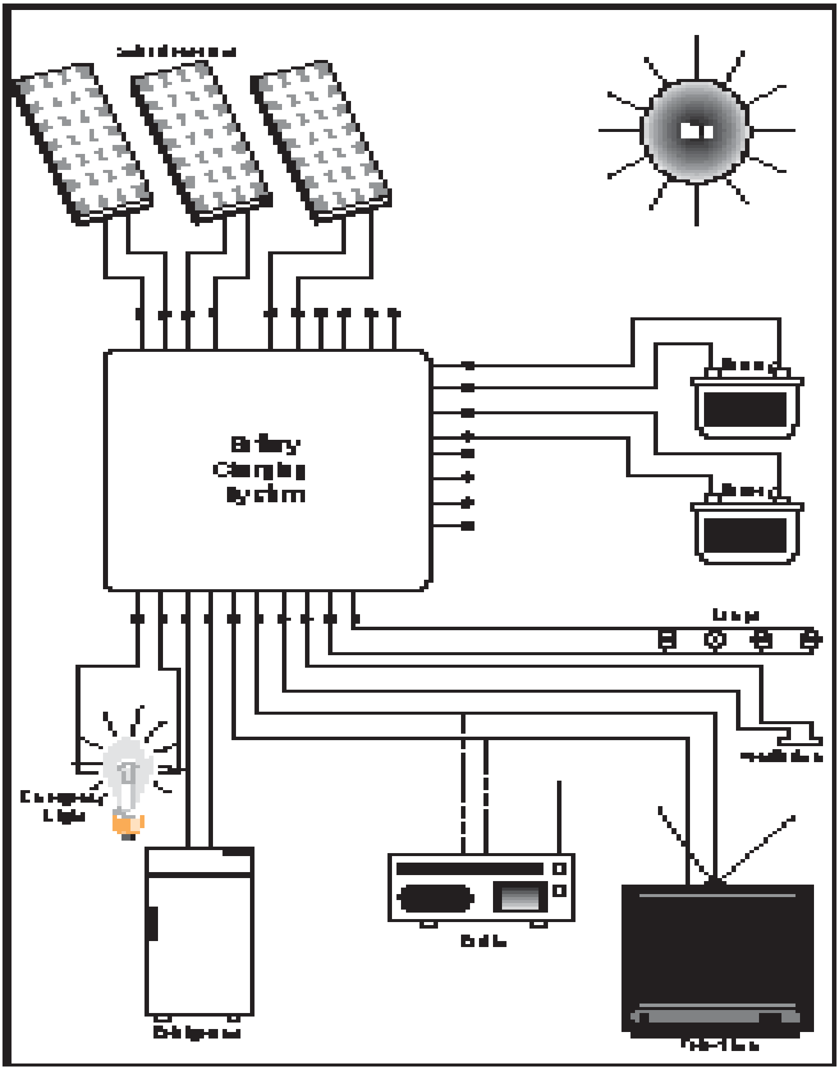


Figure 4.21: Photovoltaic System Supplying Autonomous Electricity to a House

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

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

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

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

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

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

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

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

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

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

Conclusion

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

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

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

Further Reading

Bhandari, M.S. and Bansal, N.K., 1994. 'Solar Heat Gain Factor and Heat loss Coefficients for Passive Heating Concepts'. In *Solar Energy*, 53 (2), 199-208.

Kreider, J.F. and Rabl, A., 1994. *Heating and Cooling of Buildings Design for Efficiency*. Singapore: McGraw Hill Inc.