SOLAR ARCHITECTURE FOR HOT DRY CLIMATE WITH SPECIAL REFERENCE TO CITY OF AJMER (RAJASTHAN)

A DISSERTATION

Submitted in partial fulfillment of the
Requirements for the award of the degree
Of

MASTER OF ARCHITECTURE

BY

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" This erring race of human beings dreams always of perfecting their environment by the machinery of government and society; but it is only by the perfection of the soul within, that the outer environment can be perfected."

Sri Aurobindo (1872-1950)

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled " **SOLAR ARCHITECTURE FOR HOT DRY CLIMATE WITH SPECIAL REFERENCE TO CITY OF AJMER (RAJASTHAN)"**, in partial fulfillment of the requirement for the award of the degree of **MASTER OF ARCHITECTURE,** submitted in the Department of Architecture and Planning, Indian Institute Of Technology, Roorkee is an authentic record of my own work carried out during a period of August 2002 to February 2003 under the guidance of **Prof. P.K. Patel.**

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Dated
24th February, 2003

(Vikram Joshi)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

From the dawn of civilization, the pattern of human settlements has been an expression of man's relation with nature. Traversing from a hunter-gatherer way of life to the early agricultural, advanced agricultural, industrial and modern age, impacts of settlements have increasingly become matter of environmental concern. Upto the medieval times settlements were planned taking into consideration the constraints and potentials of resources such as climate, water, land and vegetation.

The fall out due to the life styles and development strategies of the last 100 years in terms of inequity, growing population and depletion of natural resources, has made us all aware within the global community that the basic needs of the growing population will not be met through the conventional development methods, materials and technologies. The mounting costs and impacts of air, water and solid waste pollution are adversely affecting local economies, natural environments and public health.

This dissertation adopts a practical focus to develop sustainable building approaches for hot-dry climatic regions in India. The environment of hot dry lands presents many difficulties to those who live and work in them. Temperatures are usually high by day, and often at night, with low humidity and dry and dust laden winds. Vegetation is sparse and local resources of many areas are limited. Buildings can do much to provide a means of creating the best possible environment for physical, mental, and spiritual comfort. Apart from building, the main area of responsibility of an architect, builder, or planner lies in satisfying the needs of the people, for whom the development is to be carried out. In hot dry lands the needs assume special significance. The fledging solar industry is no longer a backyard operation and has many enthusiasts will shape the future way of living for the better: better use of our Earth resources, for cleaner air, healthier life. The project investigates availability of natural energies as a design resource and employs the findings to find out the appropriate means for designing a building in hot dry climate.

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CHAPTER-1
INTRODUCTION

1.1 INTRODUCTION

Housing forms by far the most common building type throughout the world. On average over half of all investment is made in construction and over one third of this investment in construction is devoted to housing. Put another way, over 15% of all savings in both developed and developing countries is invested in dwelling construction. Since new housing represents a significant proportion of national investment in most countries, it should be clear that housing can play an important role in economic development plans, not merely as a non productive investment diverting funds from other more productive sectors, but as a valuable investment to provide shelter, security and comfortable living conditions for the occupants; and to produce more than " housing"- to produce homes. These homes will play an important role in social development, providing the environment is which the family can develop. [1]

The fall out due to the life styles and development strategies of the last 100 years in terms of inequity, growing population and depletion of natural resources, has made us all aware within the global community that the basic needs of the growing population will not be met through the conventional developmental methods, materials and technologies. Communities and local governments are experiencing increasing demands for basic services at levels that exceed their dwindling budgets. Concurrently, the mounting costs and impacts of air, water, and solid waste pollution are adversely affecting local economies, natural environments and public health.

The term 'appropriate architecture' is used for the integration into construction of all the separate technologies and disciplines involved in the research and promotion of sustainable solutions. 'Green Architecture' is another name used for this approach. Resource Efficiency is a new approach to these widespread problems of air, water and solid waste pollution. Utilizing innovative management practices and new technologies, Resource Efficiency aims to reduce the demand and the costs for energy, water, and materials within communities. The results are monetary savings, which benefit the local economy, reduced environmental impact, and conservation of resources. The terms efficiency and conservation are often used interchangeably, but in fact they have different meanings. Efficiency means getting the same or better service while using less resource. Conservation means simply using less and reducing waste; without efficiency, conservation generally implies a reduction in the level of service. [2]

Practicing resource efficiency makes it possible to reduce the pressure that construction places on natural resources. At this time, constructing and operating buildings consumes more materials and energy than any other single activity in the country. Increasing consumer demand, combined with the growth of human population, is reducing our worldwide natural resource base even as technological innovation creates new possibilities.

Sustainable architecture aims at creating environment friendly and energy efficient buildings. This entails active harnessing solar energy and using materials, which do the least possible damage to the so-called 'free resources'-water, ground and air. An increase in the housing activity has already put an immense pressure on our dwindling energy sources and other vital resources like water, which has led to increasing environmental degradation. However, it is only as late as the Ninth Plan that some thought has been given to development and improvement of urban areas as economically efficient, socially equitable and environmentally sustainable entities. Some concern is now shown to stop the growing deterioration in the urban environment, which is reflected in key urban indicators like housing conditions, pollution levels and traffic congestion. Thus, development of sustainable habitats becomes a key solution to resolve growing guzzlers. [3]

The idea is to first reduce light and energy demands through architecture and space designing and then meet those demands by using energy efficient devices, which are environmentally friendly. For example, efficient lamps and luminaries like compact fluorescent lamps, high efficiency tube lights with electronic chokes, mirror optic luminaries and such devices integrated with daylight can reduce power consumption significantly, at the same time providing adequate lighting.

The word "arid", according to the dictionary, refers to an area that is without moisture- a barren region wanting in interest of life. A "shelter" is a refuge something that recovers or defends. The design problem then is to create a refuge in a barren place. There are many factors, which must be considered in defining and executing the concept of shelter in an arid environment. While some basic factors apply to any climate or condition, in an extreme climate such elements may provide not only for comfort but also for survival itself. [1]

Housing programmes for hot dry lands are closely related to the present and the likely future pattern of their economic and physical development. It is therefore necessary to form some broad assessment of the resources of these regions, resources that include the physical, technical, financial and human, and upon the exploitation of which depend the nature and form of settlement.

The environment of hot dry lands presents many difficulties to those who live and work in them. Temperatures are usually high by day, and often at night, with low humidity and dry and dust-laden winds. Vegetation is sparse, the socio-economic conditions are poor, and the local resources of many areas are limited.

In designing and planning for hot dry desert regions, it is necessary not only to understand the needs of the people but also to study the climate and the ways it affects materials and structures. The hot dry land pose many problems in relation to building materials, techniques, costs, and labor, which require special attention from construction industry. The present and future development of hot dry lands demands not only efficient management of resources but also the need for adequate consideration of any actions that may result in the alteration of the environment.

1.2 PRESENT SCENARIO

"The cancer of industrialization and excessive consumption of resources began gradually and did not reach catastrophic levels until the last two decades. So, it could be hypnotized that the reversal of those trends could take some time. I am convinced that nothing will change until the earth is seen again as the primary focus of philosophical discourse and source of all survival decisions."

Architect James Wines

The design, construction, and maintenance of buildings have a tremendous impact on our environment and our natural resources. The buildings together use one-third of all the energy consumed in India and two-thirds of all electricity. By the year 2010, another 38 million buildings are expected to be constructed. The challenge will be to build them smart, so they use a minimum of nonrenewable energy, produce a minimum of pollution, and cost a minimum of energy, while increasing the comfort, health, and safety of the people who live and work in them. [4]

Further, buildings are a major source of the pollution that causes urban air quality problems, and the pollutants that cause climate change. They account for 49 percent of sulfur dioxide emissions, 25 percent of nitrous oxide emissions, and 10 percent of particulate emissions, all of which damage urban air quality. Buildings produce 35 percent of our carbon dioxide emissions, the chief pollutant blamed for climate change. [4]

Traditional building practices often overlook the interrelationships between a building, its components, its surroundings, and its occupants. "Typical" buildings consume more of our resources than necessary, negatively impact the environment, and generate a large amount of waste. Often, these buildings are costly to operate in terms of energy and water consumption. And they can result in poor indoor air quality, which can lead to health problems.

There are many opportunities to make buildings cleaner. For example, if only 10 percent of homes used solar systems, we would avoid 8.4 million metric tons of carbon emissions each year. [4]

Green building practices offer an opportunity to create environmentally sound and resource-efficient buildings by using an integrated approach to design. Green buildings promote resource conservation, including energy efficiency, renewable energy, and water conservation features; consider environmental impacts and waste minimization; create a healthy and comfortable environment; reduce operation and maintenance costs; and address issues such as historical preservation, access to public transportation and other community infrastructure systems. The entire life cycle of the building and its components is considered, as well as the economic and environmental impact and performance. [3]

In today's scenario, architecture and the urban environment have a very deep relationship. It starts and ends with the word "**SUSTAINABILITY**".

India is blessed with abundant sunshine and wind, and though the government is implementing one of the world's largest programmes in renewable energy it will hardly reduce the anticipated shortfalls generated under conventional energy sources. Budgetary allocations for promotion of renewable energy are still too low (0.8% of total funds allocated to the energy sector in the eighth Five Year Plan from '92 to '97) compared to conventional energy sources that operate with huge subsidies from the government. Investment from industries in research and development of renewable energy is insufficient to make a difference both in quality and quantity. Financing and end-user acceptability are still considered major barriers. Considering all these points it is normal that the promotion and the development of renewable energy sources is still considered as a frontier adventure. [4]

1.2.1 WIND

The wind, one of nature's most abundant resources, is a form of solar energy. It is renewable, nonpolluting, universally available, and when used as fuel, free.

"The Rajasthan government is trying to tap the potential of the desert and harness wind energy to tackle the state's power problems. Last year, REDA (Rajasthan Energy Development Agency), a wholly owned unit of the state government, installed a 2 MW demonstration project at Amarsagar in Jaisalmer district. The project has so far produced seven lakh units of electricity. In the next three years, the state government expects to attract investment of Rs 500 crore in the private sector for the generation of 100 MW of electricity from wind energy. It has already received 10 proposals for producing 236 MW of power. High-speed wind is available in the desert for most part of the year and with the success of the Amarsagar project, the government is planning capacity addition with participation from the private sector. Asian Wind Turbine of Chennai is expected to set up 2.25 MW capacity wind energy units at Devgarh in Chittorgharh district. It will have three Denmark made generators of 750 KW each" (***The Times of India, 7 July 2000***)

1.2.2 RENEWABLE ENERGY POTENTIAL AND ACHIEVEMENTS IN INDIA

TABLE: 1

SOURCES/TECHNOLOGIES	UNITS	APPROXIMATE POTENTIAL	ACHIEVEMENTS (TILL DECEMBER 2000)
WIND POWER	MW	45,000	1,267
SMALL HYDRO POWER (UPTO 25 MW)	MW	15,000	1,341
BIOMASS POWER	MW	19,500	308
BIOMASS GASIFIER	-	16,000	35
BIOMASS COGENERATION	-	3,500	273
URBAN AND INDUSTRIAL WASTE BASED POWER	MW	1,700	15.20
SOLAR PHOTOVOLTAIC	MW/KM^2	20	47
SOLAR WATER HEATING	MILLION M^2 COLLECTOR AREA	140	.55
BIOGAS PLANTS	MILLION	12	3.10
IMPROVED	MILLION	120	33.00

Source: MNES. 2001. *Renewable Energy in India Business Opportunities.* New Delhi: Ministry of Non-conventional Energy Sources.

1.2.3 WATER, WATER EVERYWHERE, NOR ANY DROP TO DRINK ...

The present water crisis is a result of factors that have been operating for a long time, with the patronage and encouragement of successive governments. The drought is only an aggravating factor, or an immediate cause. Rajasthan has historically been a water-deficient state, but the dehydration of Gujarat should make us sit up

Water is life. Otherwise how else would one explain water riots breaking in Saurashtra, or the large-scale migration that is currently taking place in desiccated Rajasthan? This colourless, odourless, and tasteless liquid is essential for all forms of growth and development – humans, animals and plants. And if this basic need is not met, then all hell can break loose.

"Helpless, drought-hit districts of Gujarat have little choice other than to pray for the success of the administration's desperate attempts to strike new sources of drinking water... The drought is causing social concern, as there have been reports of water riots in the Saurashtra region. The situation in Kutch and northern Gujarat is reported to be equally grim. Almost all dams supplying water to the urban areas have gone dry and district administrations are desperately looking for alternative sources "***(The Observer of Business and Politics, 15 April 2000)***.

1.3 IDENTIFICATION OF THE PROBLEM

Sustainable Development of Human Settlements has always been a prerequisite for Environmental Conservation.

So far, there has been limited research on the development of traditional and unique houses and urban systems to meet the stressed climate of arid zones. The use of solar and wind energy is technologically possible and economically feasible for daily application in a household unit or a small neighborhood. It is alarming to realize that much of the current housing design for arid zones has occurred by the simple applications of non-arid zone patterns. Unfortunately, this has become a common phenomenon supported by the urgency of providing housing for a growing population

From the dawn of Civilization, the pattern of human settlements has been an expression of mans relation with nature. Traversing from a hunter-gatherer way of life to the early agricultural, advanced agricultural, industrial and modern age, impacts of settlements have increasingly become matter of environmental concern. Upto the medieval times settlements were planned taking into consideration the constraints and potentials of resources such as climate, water, land, and vegetation.

Water conservation and recycling was part of settlement development and management.

The water system of Jodhpur, Rajasthan, India perhaps one of best examples of sustainable water use in an arid settlement. Dictates of topography provide the clues for planning land uses - public areas, commercial areas, residential areas, etc. Orientation of buildings, drainage, placement of open spaces, water bodies were carefully thought of and thus problems of pollution, resource depletion were rarely matters of concern.

With the advent of industrialization, population of settlements rose due to concentration of non-agricultural uses in large settlements. Land uses such as industries, commerce-wholesale, retail and high densities in residential areas started becoming proliferating in town and cities. The pattern of urbanization had taken root, which also resulted into an unsustainable pattern of growth. Scarcity of resources such as water, pollution of air, water, increasing demand for energy, unsanitary conditions, deteriorating health indicated the quality of life in human settlements. These conditions are likely to be further aggravated, as a result of

- Inequitable economic growth;
- social, economic, ecological and environmental deterioration;
- uncontrolled urbanization and consequent conditions of overcrowding;
- pollution and deterioration of available infrastructure, etc.

Thus these problems pose a formidable challenge to human understanding, imagination, ingenuity and resolve and that the priorities to promote the qualitative dimensions to economic development

1.4 STATEMENT OF SIGNIFICANCE OF ISSUE

The last two decades have brought significant changes to the design practice in industrialized countries and in India. Much of it can be attributed to the traumatic escalations in energy prices, material shortages, trade embargoes and wars. The heightened concerns over pollution, environmental degradation and resource depletion have also impacted the social and economic nature of design practice. India, a nation of -- -- people, is at the cusp of modernity. Against the backdrop of traditional cultures and age-old traditions, it has attained self-sufficiency in food production, industrial production ...etc. The enormous population, while it has benefited from industrial growth, has also created tremendous pressure on the availability of land and energy resources. When compared to the US, India has one-third land mass and over four times population. This adequately describes its very high density living in urban areas and an acute shortage of resources. Due to the high population, low land mass and scarce natural resources, the need for sustainable housing in India is both real and urgent. The future of mass housing lies in employing sustainable and cost-effective technologies, and developing appropriate design approaches for these technologies. It is my interest to study an array of sustainable technologies and their usefulness in the Indian context.

1.5 AIM

- THE DISSERTATION AIMS TO UNDERSTAND THE SPECIFIC NEEDS OF THE PEOPLE IN INDIAN CONTEXT TO DERIVE THE GUIDELINES AND CRITERIA, WHICH EXAMINES HOW TO EVALUATE AND ARRIVE AT APPROPRIATE SOLUTIONS FOR DEVELOPMENT IN TERMS OF SHELTER IN A HOT DRY DESERT CLIMATE REGION IN INDIA.

1.6 OBJECTIVES

As the need for land, food and housing increases rapidly, we are faced with the pressure of supply. Appropriate architecture. The concept of development then needs to be re-examined to be able to meet the demand. We need to create and promote new approaches for a more accountable and sustainable future, where "solutions grow from place". Where there is ' ecological accounting' and 'equity in resource accessibility'.

Taking these criteria into account we need to examine how to evaluate and arrive at appropriate solutions for development in terms of shelter. The following objectives are an attempt towards that.

- *TO STUDY THE INFLUENCE OF HOT DRY DESERT CLIMATE ON HUMAN BEINGS*
- *TO STUDY THE INFLUENCE OF HOT DRY DESERT CLIMATE ON BUILDINGS*
- *TO STUDY THE CRITERIA USED TO IDENTIFY THE MOST APPROPRIATE BUILDING MATERIALS AND TECHNOLOGY*
- *TO STUDY ACCOUNTABLE AND SUSTAINABLE PRACTICES OF DEVELOPMENT IN VIEW OF THE INDIAN CRISIS OF HIGH POPULATION GROWTH AND NATURAL RESOURCE CRUNCH*

1.7 SCOPE OF WORK

This investigation and project will adopt a practical focus and develop suitable building approaches for hot dry desert region in India. The project will first investigate availability of natural energies as a design resource, and how sustainable materials and technologies can be applied to construct buildings. It will then employ the findings of the investigation to find out the appropriate means for designing a building in hot dry desert region in India.

1.8 METHODOLOGY

- In designing and planning for these areas it is necessary not only to understand the needs of people but also to study the climate and the way it affects materials and structures. In fact, a rational ultimate solution to living and working in arid regions will involve a completely new approach to settlement planning.
- To investigate the technology available for tapping the renewable sources of energy and which can be directly applied to the building industry.
- To study the traditional and vernacular architecture of the region as the traditional house often represents the result of many years. The reason that we must take care in interpreting the lessons of the traditional house is that the conditions in which and for which it developed.
- Apart from investigating inexpensive partial methods of mechanical environment control, it should point to the need for careful attention to ways in which indoor climate can be regulated by suitable planning, orientation and design of buildings.
- Considerable degree of attention will be paid to the aspect of how to reduce the impact of solar heat, particularly during the summer.
- Observation through case studies.

1.9 LIMITATIONS

- Rational use and conservation of resources must be based upon scientific data, but unfortunately much of this is not available, particularly data is related to specific regions.
- The multi-disciplinary approach for the solution of conservation problems require simultaneous attention where solutions must balance and accommodate a number of diverse factor as architecture, planning, public health, economics, finance, all these are so intertwined that it is often difficult to isolate a single element for study, analysis and application.
- It is technically possible to harness solar energy for cooling a building, but under present conditions of limited market the cost of equipment required to achieve this objective is too high.
- The building costs of projects in remote locations are likely to remain high, whilst the markets remain unstable.
- Under present circumstances, it is impossible to measure and anticipate building demands.
- The problems of building and planning in hot dry lands are very closely related to the form, size and pattern of settlements, and these in turn are determined by the development programmes for these regions.
- The pattern of existing settlements and their future growth depends on the manner in which the industries are exploited, but this is governed by the availability of water, power and efficient transport.

There are two important considerations in resource development. It must be physically feasible and economically efficient. If physical circumstances limit what can be done, economic considerations further limit what can be done profitably. In many parts it may be possible to exploit a number of local resources but, before this is done, the proposals will have to show that production costs can be kept sufficient to maintain a reasonable standard of living for those engaged in the enterprise. Resources therefore need to be viewed, against the general background of the distinctive way of life, technology and economics of the region.

LITERATURE SURVEY

"There must be new contact between men and the earth; the earth just be newly seen and heard and felt and smelled and tasted; there must be a renewal of the wisdom that comes with knowing clearly the pain and the pleasure and the risk and the responsibility of being alive in this world."

Wendell Berry

The Inter-governmental Meeting on Human Settlements and Sustainable Development, called for by the **United Nations Commission on Human Settlements (UNCHS), at The Hague in November 1990,** identifies **four sustainable development criteria for judging a settlement.**

1. The quality of life it offers to its inhabitants

2. The scale of non-renewable resource use (including the extent to which secondary Resources are drawn from settlements, by- products for reuse)

3. The scale and nature of renewable resources use and the implications for sustaining Production levels of renewable resources

4. The scale and nature of non-reusable wastes generated by production and consumption activities and the means by which these are disposed off, including the extent to which wastes, impact on human health, natural systems and amenity. [3]

2.1 SUSTAINABILITY AND ARCHITECTURE

Sustainability emerges as one of today's most meaningful ideas in architecture and planning. It is based on the understanding that our resources are limited and their reckless usage may lead to environmental and human catastrophe. This recklessness, painful as it is, stimulates research and invention and helps us to shape our understanding of architecture and its role for the future. [5]

The energy crisis of the 70's reshaped building form. Building design became consciousness of orientation, size of windows; shading; ventilation; insulation and important building technology. New materials, such as steel, glass and cement reshaped the volume and mass of out contemporary buildings; indeed this energy crisis reshaped our attitude to modernity. Design elements as pilotis, glass facades, and flat roofs were critically compared with important objectives of the time. Energy consumption, comfort and adaptation to regional affinities. [3]

The great and renewed interest in the history of architecture, particularly in connection with passive and low energy architecture, redefined our attitude towards the past and also gave new meaning to the future. If modernity is sometimes criticized as a one-dimensional movement towards a so-called ' better future', the energy crisis, the growing understanding of our limited resources and some major technological failures required a fresh look at our ' culture of buildings', because we indeed need broader concepts. We are dealing merely with the art or technology of making buildings; we are also involved in the totality of the ' human nature' relationship. This is needed at all scales.

In the 80's the human environment dialogue occurred in all levels of design, regional, urban and building design scale. Three dominant understandings emerged.

1. Our resources are limited.
2. The impact of our deeds on nature may be irreversible
3. We have a obligation for future generation

These three understandings had an important impact on the ' culture of the buildings' in the 80's. Environment and ecology became important factor in national and international activities. The 'green politics' in Europe, the 'environmental consciousness' in the U.S. and Asia, the 'Rio Declaration', with even the Church addressing the issues. All became pressing strategies of the decade.

Scarcity of resources became a global issue. In different parts of the world, scarcity takes on a different form as witnessed by the lack of food, water, fresh air, land and time. The deep sense of scarcity becomes ' all prevailing'. The fear of scarcity moved from the academy, the laboratory and the research institute, to the decision-making centers of the nation, the region and the urban centers. The sense of scarcity redefines the architectural profession. The concept of 'sustainability' emerged as the most relevant design issue of recent years and probably the most important for out profession this decade. Century... millennium.

Sustainability embraces all scale of design, simultaneously. In a large region for instance a certain detail may be of crucial importance, i.e. the insulation code which affects the energy basis of a region or the run-off water management in a city, that affects the drainage system of a region. Sustainability uses the lessons from the past as vital factors to shape the future.

As we approach the end of the century, our profession is benefiting more from the past than it did in previous decades. It is neither a denial nor mimicry of the past, but an adaptation lessons to contemporary conditions. We should hope that with careful design and thoughtful research and application, sustainability can furnish the sound 'platform' of history as a meaningful guideline for the future.

Sustainability creates an important bridge between disciplinary and inter disciplinary activities. The complexity of problems that lie ahead of us can only be dealt with by the synergetic effect of inter disciplinary collaboration. Another aspect concerning sustainability is the 'permanence of change', if we analyze the foci of interests and chain of events of the last decades, we can surely state that permanent change has dominated our profession. Changes as seen in the shifting of the profession in such design issues as: the solar collectors of the 60's, the zero energy building of the 70's, the research for bio climatic cities, and the sense of region and the spirit of place of the 80's.

One of the most interesting features of the architecture in this century is the balance between the two opposing trends, 'unity' and 'diversity'. We are continuously in search of the universal principals and the uniting factors that direct the essential elements of our profession. At the same time, our profession is constantly searching for response and resonance. The search is for organic diversity, certainly not the idiosyncrasies of fashion or the dangers of artificial originality. Rather we search for diversity, which responds to the local conditions and regional affinities. Within this context, sustainability can serve as conceptual 'Archimedes lever'. Sustainability can mobilize real needs, it can utilize scarcity to create new forms of creativity that can apply to the rich and the not so rich countries as countries becomes global. [3]

Sustainable design requires a fundamental change in mind-set and a change in values toward less consumption and environmental stewardship

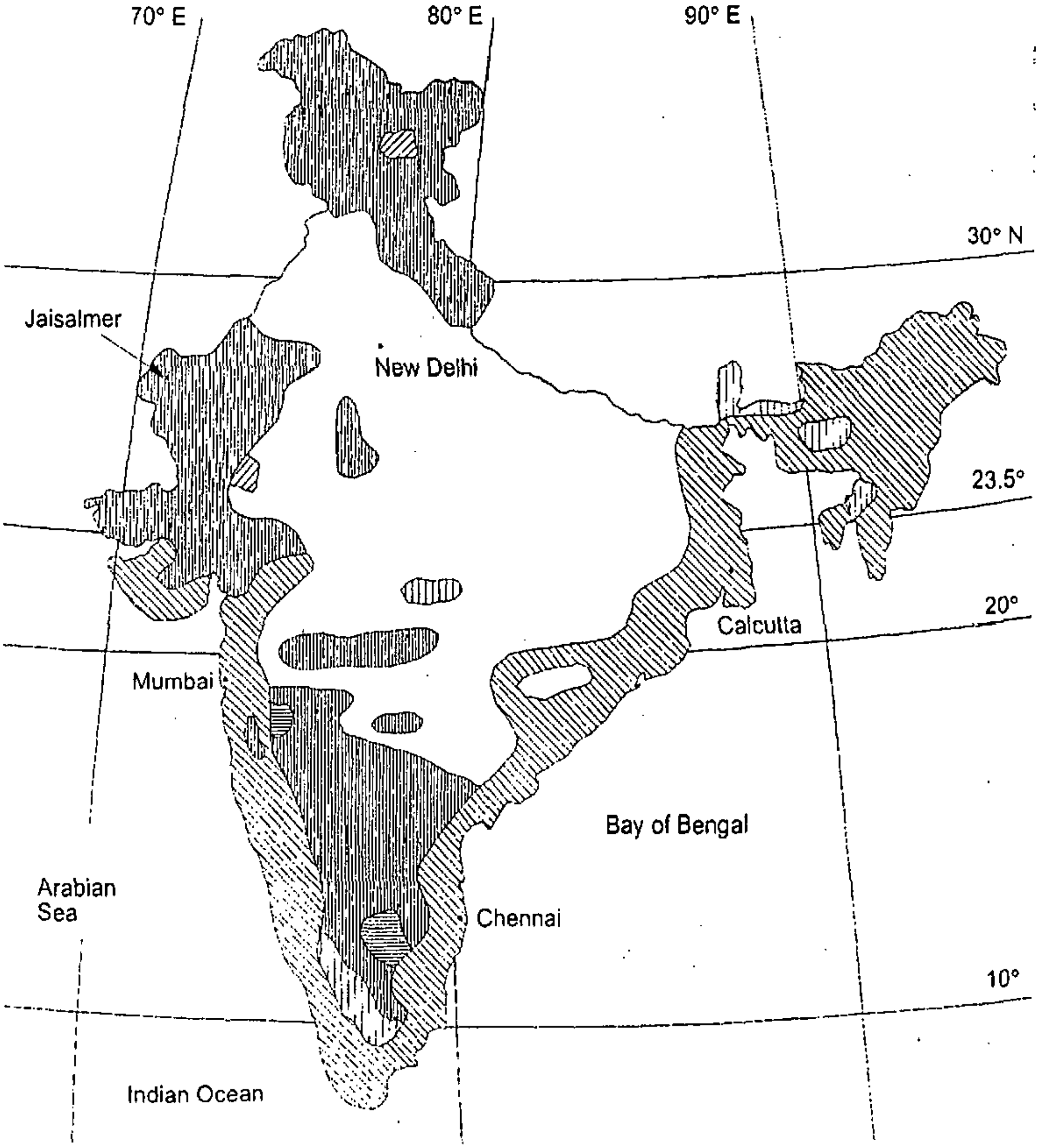
2.2 CONCEPTS OF SUSTAINABILITY

- The first concept of sustainability is to exemplify principles of conservation, that is, to survive.
- The second concept of sustainability is bioregionalism, or the concept that all life is on a community basis-that future technology must function within bioregional patterns and scales. [3]

2.3 NATURE OF HOT DRY DESERT CLIMATE

Hot dry desert climates normally occur between latitudes 15° and 35° north and south of the equator. The sun will be almost overhead at noon in the hottest months, but in the cooler months it will have an altitude of approximately 45° at noon. In hot dry climates, wind is a liability not an asset. Hot dry winds will increase discomfort and carry dust and sand. Many hot dry climates also experience a cool or cold season, and protection against cold winds is also desirable. Reduced wind speeds will also reduce the influence of drifting sand.

In hot dry conditions 'dust devils' may also be experienced. These are small whirlwinds, which raise sand and dust, and are caused by the rising of very hot air from just above the sunlit ground surface. They are sometimes initiated by some movement, such as a person moving across an open space or an animal moving across the desert. They may also occur at street corners where local thermal air movement is triggered off by an eddy in the large-scale wind patterns. Little can be done to avoid dust devils, except



MAP-1 VARIOUS CLIMATIC ZONES OF INDIA

Source: CLIMATE RESPONSIVE ARCHITECTURE: A DESIGN HANDBOOK FOR ENERGY EFFICIENT BUILDINGS, TMH PUBLISHING COMPANY LTD, 2001

to avoid building forms such as high towers or slabs which create eddies at low levels, and to avoid sources of dust in built up areas.

Another climatic feature, which often occurs in hot dry climates, is the temperature inversion. The result is a drop in wind speed, and the lack of air movement can result in a steady increase in pollution source such as industry or heavy traffic. When inversions continue during the day, the effect of solar radiation on pollutants can cause a photochemical smog.

Air temperature: DBT, in the shade rises quickly after sunrise to a day-time mean maximum of 43 to 49 °C. during the cool season the mean maximum temperature ranges from 27 to 32°C, night-time mean minima are between 24 and 30°C in the hot season and between 10 and 18°C in the cool season. The diurnal range is very great: 17 to 22°C.

Humidity: RH varies from 10 to 55%, as the wet-bulb depression is large. The vapor pressure is normally between 750 and 1500 N/m2

Precipitation: it is slight and variable throughout the year, from 50 to 155 mm per annum. Flash-storms may occur over limited areas with as much as 50 mm rain in a few hours, but some regions may not have any rain for several years.

Sky conditions: sky conditions are normally clear. Clouds are few due to the low humidity of the air. The sky is usually dark blue, with a luminance of 1700 to 2500 cd/m2, and further darkened during dust or sandstorms to 850 cd/m2 or even less. Towards the end of the hot period, dust suspended in the air may create a white haze, with a luminance of 3500 to 10 000 cd/m2, which produces a diffuse light and a painful glare.

Solar radiation: it is direct and strong during the day, but the absence of cloud permits easy release of the heat stored during the day-time in the form of long-wave radiation towards the cold night sky. Diffuse radiation is only present during dust haze period.

Wind: winds are usually local. The heating of air over the hot ground causes a temperature inversion, and as the lower warm air mass breaks through the higher cooler air, local whirlwinds are often created. Winds are hot, carrying dust and sand-and often develops into dust storm.

Vegetation: vegetation is sparse and difficult to maintain because of the lack of rain and low humidity. The soil is usually dusty and very dry. Strong sunlight, illuminating a highly reflective light colored and dry ground can create a luminance of 20 000 to 25 000 cd/m2. Soils dry quickly after rain and would generally be fertile if irrigated. The sub soil water table is very low.

Special characteristics: during certain months dust and sand storms may be frequent. The high daytime temperature and rapid cooling at night may cause materials to crack and break up. [6]

2.4 NEEDS

Buildings can do much to provide a means of creating the best possible environment for physical, mental, and spiritual comfort. Some of the needs of people in hot dry environments, to help arrive at a valid basis for planning, design, and construction.

Apart from building, the main area of responsibility of an architect, builder, or planner lies in satisfying the needs physiological, psychological and sociological- of the people, for whom the development is to be carried out. In hot dry lands the needs assume special significance, and without clear definition of their particular requirements it is impossible to design, build and plan for them.

2.4.1 PHYSIOLOGICAL COMFORT

Physiological uncomfortable conditions in arid climates are mainly caused by the extreme heat and dryness and, to a lesser extent, by the nuisance of flies, sand, and dust storms.

Human thermal comfort is usually found when the mean skin temperature is maintained by various means below 33.9 °C and above 31.1°C. in hot dry conditions a person is comfortable when his body is able to dissipate to the surroundings all the heat it receives, including heat lost by evaporation from the skin and from the respiratory system. In a building the heat loss from the body to the surroundings is mainly related to the air temperature, mean radiant temperature, humidity and air movement, and to a person's clothing, physical activity, and state of health. If some or all of these factors are combined in such a way as to make it difficult for the body to dissipate its heat, then the equilibrium necessary for physical comfort is upset, and there is a gradual increase in the tissue temperature until a state of discomfort is reached, which affects work output and efficiency and in extreme cases causes heat stroke or intense fatigue. The interrelationship of the various factors is complex, and to a degree each affects the other. Movement of air, for instance, reduces the effects of humidity, and radiation may increase the air temperature.

The human body is able to lose heat to its surroundings by convection by evaporation, and by radiation. Loss of heat by convection and radiation can take place only when the air and surroundings are at less than body temperature. Loss by evaporation depends upon the relative humidity of the surrounding air and the rate of air movement. Air movement will assist in cooling the body only when the air temperature is less than that of the skin and the relative humidity of the atmosphere is not very high. Consequently, up to a point beyond which heat alone becomes a factor of discomfort, hot dry air tends to be more comfortable than hot humid air. The onset of thermal discomfort coincides with the onset of perceptible sweating.

Apart from the problems of physiological comfort generated by adverse climate, by far the most significant irritant in arid lands is air pollution by dust and sand. There is little scientific evidence to suggest that the presence of dust and sand particles in the atmosphere is a hazard to human health, but they possess a considerable nuisance value, which is most obvious to the people who live in these regions. Apart from the dust storms, which periodically limit visibility, particle-polluted air causes discomfort and irritation to the eyes, nose, and throat, and it also has a demoralizing effect on people, particularly on the housewife. Extra cleaning and washing considerably increase her domestic work, and household equipment and mechanical fixtures require more frequent and often costly repairs. In exposed locations constant bombardment by wind blown sand causes damage to glazing, metal, wood and asbestos, and strips galvanizing and paintwork off buildings, making them unsightly and causing early deterioration.

2.4.2 PHYCHOLOGICAL COMFORT

Considerable information is available to enable physiological comfort requirements to be assessed with reasonable accuracy, but it is important to remember that a comfortable body is no guarantee of a comfortable mind. The design and construction industry should therefore take equally careful account of the factors affecting psychological comfort. Knowledge in this field is fairly scanty at present, but enough basic data is available to help in the development of the right approach.

Factors such as the size, proportion, character and surroundings of rooms, the color scheme, and even the views from windows have a great psychological effect. There is the combined effect of the sun, fresh air, and greenery, which impinge on man's higher nervous activity, providing favorable sense impressions during periods of physical activity and rest.

The psychological effect of color is well known, and various color standards have been established which are based on ability to soothe, stimulate, cause visual fatigue, and/or promote increased physical activity. White and various shades of colors commonly found in nature, such as yellow and green, exert a soothing the strength of chromatic and achromatic vision. The importance of this fact in the dreary environment of hot dry lands is obvious.

The proportions of habitable areas such as rooms and courtyards also possess psychological significance. Courtyard walls must be proportionate in width and height to the area of the ground they enclose, and the height of a ceiling needs to be related to the floor area of the room. A room with a low ceiling appears to be larger than one of the same size with a higher ceiling, but the cramped space of the former can take away the feeling of relaxation and rest and could well exert an unfavorable psychological influence.

In arid lands, particularly in settlements, which are remote and isolated and possess a monotonous environment, boredom causes considerable mental stress. There have been a number of experiments on the effects of monotony on human behavior. One of the most interesting studies, on sensory deprivation, found that human beings subjected to complete monotony showed definite signs of impairment of thinking. Under extreme conditions of isolation in a completely monotonous environment. [6]

2.5 DESIGN AND CLIMATE

It is obvious that a building in the tropics should differ from one situated in other zone, but it is less obvious that even in the same area-city, town, village or rural area-there are microclimatic differences which should be recognized in the design and construction of buildings. As a result of various influences the air temperature in an urban area, for example, can be as much as 8°C higher than in the surrounding countryside, while the relative humidity can be 5-10% lower.

Climatic design is based on typical or normal weather conditions and it is usually relatively easy for the designer to obtain the necessary meteorological data for any given region from a variety of published material. Unlike regional climate data, however, site climate information is not readily available and will have to be acquired through personal observation and local experience. Some of the more important factors which may cause local variations and which the designer must consider are:

2.5.1 TOPOGRAPHY:

The shape, orientation, exposure, elevation, and hills or valleys at or near the site must be investigated as they can have an effect on not only temperature but also the distribution of solar radiation, wind and precipitation. The influence of small hills on rainfall patterns can be quite pronounced, for instance, particularly when moisture-bearing winds blow regularly from the same direction. The windward slope in this case can be expected to receive a rainfall of more than the regional average and the leeward slope correspondingly less. The higher or steeper the hill, the greater will be the effect.

2.5.2 WATER:

The proximity of bodies of water can moderate extreme temperature variations; land on the lee side of water will be warmer in winter and cooler in summer. Humidity may also be affected, depending on the general temperature pattern. The larger the body of water, the greater its impact on the microclimate.

2.5.3 GROUND SURFACE:

The portion of solar radiation, which reaches the earth, raises the temperature of the ground. The amount depends on latitude, the season, the slope of the ground, the hour of the day and the nature of the terrain-and during the daytime the highest temperature is always found at the boundary between the ground and the air. The temperature, in other words, increases considerably as one approach the ground. At night, as a result of the loss of heat by evaporation and the effective outgoing radiation, the reverse is true and the temperature decreases as one approaches the ground.

2.5.4 VEGETATION:

In all hot dry zones the beneficial effect of even the lightest plant cover is quite considerable and the designer should take all existing plants into account. Vegetation also provides protection against glare, dust and erosion. It can, on the other hand, have disadvantages when it is too close to a building, as roots can damage foundations and drain pipes, leaves can block gutters, and desirable air movement can be drastically reduced or directed away over the building.

2.5.5 WINDBREAKS:

Physical features such as neighboring buildings, walls, trees etc, which may influence air movement or cast shadows, must be taken into account. There is a difference between the shelter offered by windbreaks composed of plants and that offered by solid screens or buildings, as the extent of shelter depends not only on height but also on the degree of permeability. Plant material, which permits a certain amount of air to pass through, causes less turbulence than solid screens and, as a result, a greater total area of shelter.

2.5.6 ORIENTATION:

The orientation of a building is determined by the climatic factors of wind and solar radiation as well as by the view, noise and requirements of privacy, which may, at times, override the climatic considerations. The orientation of a building is affected by the quantities of solar radiation falling on different sides at different times. It has, however, been recognized that both radiation and temperature act together to produce the heat experienced by a body or surface. This is expressed as the sol-air temperature, which includes three component temperatures: firstly that of the outdoor air; secondly, the solar radiation absorbed by the body or surface and, lastly, the long wave radiant heat exchange with the environment.

2.5.7 FORM:

It can be taken as a rule that the optimum shape is that which has the minimum heat gain in summer and the minimum heat loss in winter. From radiation calculations in different environmental situations, a square building is not the optimal shape anywhere, although it is more efficient in both summer and winter than shapes elongated in a north-south direction. In every case, the most satisfactory shape is one in which the building is elongated in some general east-west direction.

2.5.8 STRUCTURE:

There is a continuous exchange of heat between a building and its outdoor environment. The factors affecting this transmission are convection, radiation through windows, evaporation-all which will be discussed under the following headings-and conduction which may occur through the walls and roof inwards or outwards: this includes the effect of solar radiation on these surfaces.

The amount of heat penetrating a building depends largely on the nature of the walls and roof. In the hot period of the day heat flows through these elements into the building where some of it is stored; at night, during the cool period, the flow is reversed. When appropriate properties are chosen, it is possible to achieve and maintain comfortable internal temperatures over a wide range of external conditions. The materials and type of construction to be used must be assessed in terms of the following.

- Absorptivity/emissivity
- Insulation value
- Thermal capacity

2.5.9 COURTYARD CONCEPT

Courtyards and large irrigated gardens go a long way to break the monotony and harshness of arid landscape. Many basic requirements are expressed in layouts in the Middle East and North Africa where traditional houses tend to congregate together in mass protection against stress of environment. Many of these mud and brick huts are arranged around simple private, communal courtyards acting as cooling wells. Each dwelling is characterized by outer walls directly on the streets with most rooms opening onto an inner court which is not only a private garden but is also an extension of the living areas of the house. In summer a pleasant continuous circulation of cool moist air is kept up through the use of grass, trees and vines.

2.5.10 SUN CONTROL AND BUILDING DESIGN

Building design in hot, dry regions presents problems where sun is far more serious factor to deal with than breeze. A hot bright sun overheats practically everything- the roof, walls, exposed terraces and surrounding ground. These surfaces either reflect light, or therefore heat, into the building or they transmit heat directly through the roof and walls into the interior. So the problem reduces itself to ways and means by which the building could be protected from the impact of solar heat.

2.5.11 LOUVRES

The brise-soleils or sun-breakers seem to have become the hallmark of contemporary tropical architecture. Though increasingly designed on a functional basis, they are still used too often to provide façade patterns only. In hot dry climates, where day temperatures regularly exceed 100°F, their use has several limitations, particularly those made up of heavy materials. Experiences of office workers in recent buildings in Chandigarh have been far from happy. The outer glazed walls of many of these buildings are enveloped in a fixed screen of precast concrete louvers, which store up heat during the day, and after sunset they steadily warm the cooler night air on its way into the building. In conditions where buildings rely chiefly on night cooling. The answer seems to be either in using sun louvers that are made up of light thin materials or preferably employ smaller windows, which could be kept shut during the afternoon, only opened at night.

2.5.12 ROOF SHADING

Owing to its orientation and comparatively large area, the roof can be one of the main sources of heat gain in a building. The first objective should be to reduce the proportion of radiation absorbed by the outer surface of the roof. Here the color of roof finish is of some importance. If the rooms below are used during the daytime, the under-side of top layer could well be shiny metal, roof space well ventilated and the ceiling well insulted. Generally in high day temperature areas, thick flat roofs with considerable heat storage capacity are ideal.

Traditionally the practice of building walls in heavy weight materials is quite common where thick walls of high heat storage capacity provide excellent protection from the heat of the day. Such construction takes a considerable time to warm up. It also cools down slowly. In many areas, a building with 18inch masonry walls and well-insulated roof has been known to possess a time lag of about 12 hours. In winter, when the outside temperature is in the 50°s, this is a considerable advantage. But in summer when the temperature may never fall below 80°F it remains too warm for comfort. To get over this, people sometimes sleep on the roof, possibly protected by a light canopy sleeping case or a verandah. But this does not solve problems of privacy or sudden rain or dust storms. The suggestion that bedrooms and other areas reserved for night use only should be built up in light structure is a good one. The idea could lead to some exciting architectural solutions where both heavy and lightweight construction could be incorporated within a single structure.

The process of cooling a structure at night can be accelerated still further by mechanical ventilation system. Of these a simple exhaust fan is by far the most economical. Installed near the ceiling in a central position is effective. It is possible to cool off the entire house at night by the proper location of such a fan so that it can expel hot air from inside and draw through the house cooler air from outside, thus ensuring a cool interior for a long period of the following day. By this method the house will not get a chance to accumulate heat during the summer months as to make it practically unlivable.

2.5.13 EVAPORATIVE COOLERS

In many middle-eastern countries, the usual practice is to cover all openings with large thick mat of Hessian or lily pad roots continuously soaked in water from a perforated tub or pipe from which water trickles down at a steady rate. Hot dry outside air is made cool and moist before it reaches the interior. This principle has been applied to unit coolers where an electric fan not only accelerates this flow, but its motor can also be used for recirculating some of the water that may collect at the bottom of the soaked felt. Its capital and running cost is much lower compared to the refrigeration type of air conditioners. The components, motor, pump and fan can be easily assembled and maintained by an average handymen.

2.5.14 UNDERGROUND TUNNELS

Underground tunnels with moist walls are efficient evaporative systems. If these tunnels are as deep as 16 feet below ground their walls remain at a constant temperature the year round. A considerable amount of heat absorption is produced during summer, in addition to that produced by the evaporation of moisture from the walls. In Bareilly, India, such a tunnel has been found to cool hot dusty air from 105°F down to 80°F and to produce an agreeable amount of humidity as well as removing most of the dust. During winter the walls of the tunnel produce a warming effect. The tunnel excavated in the Bareilly experiment is 3 ft. wide, 6 ft. high and about 50 ft. long and its floor 16 ft. below ground level, running from a wall pit to the basement. A medium-sized suction fan running at slow speed circulates the air. The system is no doubt an economical one where the major cost of refrigeration is cut down considerably.

The obvious conclusion to draw is that buildings being designed now will, in most cases, still is functioning when the screws on fossil fuels are really tightening. What is certain is that energy prices will rise steeply since there is no evidence of any real will to stave off this crisis by the ambitious deployment of renewable energy technologies. The pressure to incorporate the external costs like damage to health, buildings and above all the biosphere into the price of fossil fuel will intensify as the effects of global warming become increasingly threatening. All this emphasizes to take the plunge into renewable technologies as a matter of urgency. [7]

CHAPTER-3
RENEWALBE TECHNOLOGIES

"For a country like India, it is particularly necessary to develop an energy technology vision on the basis of which technology development and dissemination can be managed and promoted to provide economic benefits to society to the maximum possible extent."

Dr R K Pachauri
Director-General, TERI

A fast-growing economy, India is targeting ambitious growth rates of seven to eight percent over the next two decades. Economic growth coupled with a growing population necessitates an increase in energy consumption. Alongside, the imperative to reduce poverty by meeting the basic needs of the poor renders energy a crucial input for India's development process. The need of the hour, therefore, is to meet the energy needs of all segments of India's population in the most efficient and cost-effective manner while ensuring long-term sustainability. [8]

3.1 OVERVIEW

India accounted for 12.5% of total primary energy consumption in the Asia-Pacific region and 3% of world primary energy consumption in 2000/01 (BP Statistical Review of World Energy. British Petroleum. 2001). Per capita energy consumption remains low at 486 KGOE (kilograms of oil equivalent) compared with a world average of 1659 KGOE in 1998. Increasing oil and coal imports in recent years is an area of concern for the Indian energy sector, with net energy imports increasing from 8% in 1980 to 13% in 1998. [8]

There is no room for doubt that the greatest single threat to the expanding use of fossil fuels for energy. There are the technological means available to counter this threat, which fall into two main categories of the energy regime: supply and demand. Supply side targets in curbing *demand* are buildings and transport. As a prelude to considering buildings in detail there is some advantage in looking at the prospects for renewable energy, not only as offering a snap shot of the energy future which will have an impact on all our lives but also because it will directly have an impact on buildings in the future. Many of the technologies are appropriate as so-called 'embedded' systems, that is, systems that may be independent of the grid and can be incorporated as standalone generators within buildings.

The four main natural resources, which offer a wide range of generation possibilities, are Sun, wind, biomass and water.

3.1.1 SOLAR RADIATION

Solar radiation is the primary source of renewable energy. Besides offering a direct source of energy, it derives the earth's climate creating opportunities to draw energy from wind, waves, tides (together with the moon) and a host of biological sources. It is particularly appropriate as an energy source for buildings. Following paragraphs are by way of information.

3.1.1.1 PASSIVE SOLAR ENERGY

Advocates of passive solar design have been around for many decades and the prize-winning schemes for passive solar housing mounted in 1980 show that the technology has not advanced significantly since that time. However, the intensification of the global warming debate has led to increasing pressure to design buildings which make maximum use of free solar gains for heating, cooling and lighting.

3.1.1.2 ACTIVE SOLAR

This term refers to the conversion of solar energy into some form of usable heat. In temperate climates the most practical application of solar radiation is to exploit the heat of the sun to supplement a conventional heating system.

3.1.2 WIND POWER

Wind energy is one of the clean, renewable energy sources that hold out the promise of meeting a significant portion of energy demand in the direct, grid-connected modes as well as stand-alone and remote 'niche' applications (water pumping, desalination, and telecommunications) in developing countries like India.

Wind is a by-product of solar power and, as with the tides, wind power has been exploited as an energy source for over 2000 years. Whilst it is an intermittent source of power, in certain countries, wind is a major source.

- Whilst the technology is well developed and robust, there are drawbacks to this form of power. The most frequently cited are:

- Often the most advantageous sites are also places of particular natural beauty.

- Such sites are often some distance from the grid and centers of population

- At full revolutions the noise they create can be intrusive.

- They have been implicated in interfering with television reception.

- They can be a hazard to birds.

- The output is unpredictable. **[8]**

3.1.3 PHOTOVOLTAICS

The amount of energy supplied to the Earth by the sun is five orders of magnitude larger than the electricity needed to sustain modern civilization. One of the most promising systems for converting this solar radiation into usable energy is the photovoltaic (PV) cell. PV materials generate direct electrical current when exposed to light. The uniqueness of PV generation is that it is based on the 'photo-electric quantum effect in semi-conductors', which means it has no moving parts and requires minimum maintenance. Silicon is, at present, the dominant PV material, which is deposited on a suitable substrate such as glass. Its disadvantages are that it is expensive; it is; as yet, capable of only a relatively low output per unit of area, and, of course, only operates during day-light hours and is therefore subject to fluctuation in output due to climate and seasonal variation. As it produces direct current (DC), for most purposes this has to be changed to alternating current (AC) by means of an inverter.

Perhaps the greatest immediate opportunity afforded by PVs is its potential radically to improve the quality of life in the rural regions of developing countries. This is certainly one area on which the industrialized countries should focus capital and technology transfer to less and least developed countries. [5]

3.1.4 BIOMASS AND WASTE UTILIZATION

Electricity is the key to economic development for any country. During the last five decades, the demand for electricity has increased manifold in India, primarily due to the rapid rate of urbanization and industrialization. The conventional fossil fuel resources for power generation are fast depleting and there is a growing concern over the environmental degradation caused by conventional power plants. Against such implications, power generation from non-conventional resources assumes greater significance. Among the various renewable energy sources, biomass conversion technologies appear to be one of the best suited for conversion to shaft power/electricity.

ADVANTAGES

- Biomass is available all round the year. It is cheap, widely available, easy to transport.
- It can be obtained from plantation of land having no competitive use. Store, and has Biomass-based power generation systems, linked to plantations on wasteland, simultaneously address the vital issues of wastelands development, environmental restoration, rural employment generation, and generation of power with no distribution losses, environmental hazards
- It can be combined with production of other useful products, making it an attractive byproduct.
- The term 'biomass' refers to organic matter, which can be converted to energy. Some of the most common biomass fuels are wood, agricultural residues, and crops grown specifically for energy. In addition, it is possible to convert municipal waste, manure or agricultural products into valuable fuels for transportation, industry, and even residential use.

As a renewable fuel, biomass is used in nearly every corner of the developing world as a source of heat, particularly in the domestic sector. Unlike other renewable, biomass is a versatile source of energy, which can be converted to 'modern' forms such as liquid and gaseous fuels, electricity, and process heat. Bioenergy also permits operation at varying scales. For example, small-scale (5–10 kW), medium-scale (1–10 MW) and large-sale (about 50 MW) electricity generation systems or biogas plants of a few cubic meters (Indian and Chinese family plants for cooking) to several thousand cubic meters (Danish systems for heat and electricity). This variety of scales is useful for power generation for decentralized applications at the village level as well as for supply to the national grids. Bioenergy is particularly attractive for decentralized applications for producing gaseous fuels or electricity. Unlike wind, solar or micro-hydroelectric systems, modern biomass energy systems could be set up in virtually any location where plants can be grown or domestic animals reared. Renewables such as solar, wind, and micro-hydroelectric require 'spare' or additional capacity to produce adequate energy when the conditions are right, such as water flow or wind speed. This intermittent feature of such renewable energy sources necessitates electricity storage facilities, especially with small and local systems. Bioenergy sources such as producer gas systems do not require electricity storage. In short, biomass energy systems offer an opportunity for sustainable and equitable development.

It is estimated that the amount of fixed carbon in land plants to roughly equivalent to that which is contained in recoverable fossil fuels. While the economics of converting biomass and waste to energy are still some what uncompetitive compared with fossil fuels, the pressure to reduce CO_2 emissions combined with 'polluter pays' principles and landfill taxes for waste will change the economic balance in the medium term. Increasing environmental pressures are stimulating the growth of waste to energy schemes. An ever increasing body of regulators are limiting the scope to dispose of waste in traditional ways. Sorted municipal solid waste (MSW) represents the greatest untapped energy resource for which conversion technology already exists.

There are three ways in which biomass and waste can be converted into energy:

- Direct combustion
- Conversion to biogas
- Conversion to liquid fuel.

CHAPTER-4
SOLAR ARCHITECTURE

4.1 SOLAR ENERGY

4.1.1 INTRODUCTION

Sun, the centre of our solar system delivers 17,000 million MW of energy every year to the Earth, an amount 15,000 to 20,000 greater than is currently utilised on the planet. The Sun, a continuously renewing source of energy is the living source of heat and light for the Earth. Since humankind first created shelter, builders and architects of ancient civilizations have sited and designed their buildings to take advantage of the sun's heat and light, what we now call solar architecture. Solar energy systems contribute to the health and well being of the occupants of the building as well as the surroundings. In addition, they reduce the dependence on conventional energy systems, which are scarce and more importantly damaging to the environment. Like a living organism, the solar building continuously seeks the path of the Sun. The building becomes a skin that orients the occupants to the universal calendar. The object of the building should be to synchronize the beauty and comfort of the natural world with the internal environment. [9]

The solar radiation data available gives the values of energy per unit area at select locations. Accurate information of the available solar radiation at a given place is essential for the design of efficient solar energy systems. One has to ascertain the maximum and minimum levels of radiation at a place and adopt a suitable value for the design of the system.

Considering the radiation available in different parts, India is divided into five zones. The global radiation varies from 3.5 to 6.3 kWh per day per sq.m. more than 80% of the country receives an average solar energy radiation level of above 5.2 kWh per sq.m. on horizontal surface. Thus, there is great scope for the use of solar energy for various applications in our country.

A number of systems utilising solar energy have been developed over the years mainly for the purpose of heating space as well as water, and other associated applications such as solar dryers, water distillation plants as well as photovoltaic cells.

which converts solar energy into electricity. Solar energy utilization techniques can be classified as passive, active and hybrid systems.

The sun's energy arrives on earth in the primary form of heat and light. Other aspects of solar radiation are less easily perceived and their detection often requires sophisticated equipment. All solar radiation travels through space in waves, and it is the length of these waves (the shortest is less than a millionth of an inch, the longest more than a thousand yards) by which all solar radiation is classified. The aggregate of all radiation aspects of the sun is called the solar spectrum.

There are two important facets about the solar spectrum.

1. While the sun emits radiation in all wavelengths, it is the short wavelength radiation that accounts for the majority of energy in the solar spectrum. For example, the portion of the spectrum perceived, as the visible light is a relatively small segment compared to the variety of spectrum wavelengths, yet accounts for 46 percent of the energy radiating from the sun. Another 49 percent, that which is perceived as heat, is derived from the infrared band of the spectrum.

2. The proportion of different wavelengths in the solar spectrum does not change and therefore the energy output of the sun remains constant. A measurement of this phenomena is known as the Solar Constant, defined as the amount of heat energy delivered by solar radiation to a square foot of material set perpendicular to the sun's rays for one hour at the outer edge of the earth's atmosphere. The Solar Constant measurement is about 429.2 BTU's with minimal changes over the year. The energy measured as the Solar Constant is not a measure of the amount of solar energy that actually reaches the earth's surface, since as much as 35 percent of all the solar radiation intercepted by the earth and its surrounding atmosphere is reflected back into space. Additionally, water vapor and atmospheric gases absorb another 15 percent. As a global average only about 35-40 percent of the solar radiation entering the atmosphere actually reaches the earth's surface. [9]

As a practical matter, global averages are of little interest. The essential point is that the atmosphere impacts on the amount of solar energy that actually reaches the earth's surface - the more atmosphere solar radiation has to move through, the more is lost on the way. In this regard, two celestial events – the daily rotation of the earth and its seasonal tilt of the earth's axis – are important in determining the length of atmosphere through which the sun's rays must pass before striking any particular location on the globe. These events set the upper limit amount of solar energy that can reach the surface of the earth at any location on any day of the year.

4.1.2 ENERGY DENSITY

One of the conditions for accurately measuring the Solar Constant requires the intercepting surface to be perpendicular to the sun's rays. Since solar radiation travels in parallel rays, the perpendicular position identifies the maximum density of rays striking a surface. Any deviation from perpendicular reduces the radiation density and the amount of energy intercepted. The angle created by incoming radiation and a line perpendicular to an intercepting surface is called the angle of incidence.

4.1.3 RADIATION AND SURFACES

When sunlight strikes a surface it is reflected, transmitted or absorbed, in any combination depending on the texture, color and clarity of the surface. All completely opaque surfaces both reflect and absorb radiation but do so in different ways. For example, a rough surface such as stucco reflects sunlight in a scattered fashion while a smooth, glossy surface reflects uniformly and at an angle equal to the angle of incidence. The wavelengths of solar radiation that are reflected are determined by the color of the surface material. A red stucco surface, for example, will scatter (diffuse) wavelengths in the red band of the spectrum and absorb all others, while a white glossy surface will reflect all wavelengths in the visible spectrum at an angle equal and opposite to the angle of incidence. Conversely, a rough black surface absorbs all wavelengths in the visible spectrum, while the transparent surface of window glass allows nearly all radiation to pass through it with comparatively little reflection or absorption, and without deflecting it from its parallel lines of travel. Translucent materials also transmit radiation but scatter the rays as they pass. It should be noted that relatively few materials are excellent reflectors, transmitters, or absorbers of the sun's rays.

4.2 HEAT BEHAVIOUR

4.2.1 HEAT ABSORPTION

Sunlight, in the form of short wave solar radiation, exhibits a transformation from solar energy to heat energy when impacting a material (absorption). The temperatures of a white surface and a black surface exposed the same direct sunlight is a simple demonstration of this conversion. The temperature of the black surface is higher because it is absorbing more solar energy. As solar energy is absorbed at the surface of a material it stimulates movement of the molecules in the material. Molecular movement is measured in terms of heat – the greater the movement, the greater the heat. Since the color black absorbs more of the spectrum than the color white, it will in turn be hotter (more molecular excitement) than white.

4.2.2 CONDUCTION

As a material absorbs radiation and molecular movement continues to accelerate, the heat energy is redistributed through the material due to the natural phenomenon of maintaining equilibrium. This occurs when stimulated molecules, vibrating at a faster rate, impact adjacent molecules vibrating at a slower rate, thereby dissipating and "spreading the wealth". In this way, heat is conducted away from the source of energy as the material seeks to distribute the energy evenly throughout its mass. The rate at which energy flows or is conducted though a material depends on the density of the material and conduction, the rate at which molecules are capable of receiving and passing on energy. Gases are poor conductors; metals are comparatively good conductors; and less dense materials containing tiny air pockets and voids conduct heat at a much slower rate.

4.2.3 HEAT TRANSFER

Heat transfer from a solid material to a fluid medium (liquid or air) occurs by radiation (infrared). It is a continuation distributed molecular "bumping" between a solid material and a transfer medium (air or liquid). The added dimension of using fluids is they can move across a hot solid surface, allowing molecules of the fluid to become agitated (heat), then move away from the heat source, and t be replaced by new, unheated molecules. This process of fluid movement is called natural convection when the movement is unaided by machinery (i.e. hot air rises), and forced convection if the process is aided by a pump or fan.

The process occurs naturally as the molecules of a fluid begin to vibrate when heat is applied, and then becomes less dense (lighter) than the surrounding unheated fluid. The lighter heated molecules rise at a rate determined by the amount of heat applied. Boiling water is a good example of heated molecules near the burner rising quickly to the surface to the point of surface disruption (boiling) Steam generated by the process is simply water molecules whose vibration rate is violent enough to allow them to break from of the water surface.

Birds that seem to hang in the air without beating their wings are evidence of the power of natural convection. On clear sunny mornings, air at the surface of the ground (especially dark surfaces) is heated rapidly and rises in columns with enough force to suspend the bird overhead and even push it upward. The reverse of this process occurs as convected molecules get further from the heat source of heat, give up their energy (slower molecular excitement), and fall. Conduction and convection can be thought of as processes by which solar energy can be both transported and stored.

4.2.4 EMISSIVITY

The principle of solar energy absorption was discussed in terms of two surfaces exposed to the sun. Conduction was then discussed to show how absorbed solar energy moves through a material, always in a direction away from the source of heat to attain equilibrium. NOTE: Any molecular movement is continually generating heat in the form of radiant energy. Unlike solar energy, radiant energy is limited to infrared radiation emitted from a material at low temperatures. The extent to which a material emits thermal energy depends both on the temperature of the material and nature of its surface. Polished metal surfaces are poor emitters and poor absorbers of thermal energy. Again, as with solar radiation, the amount of thermal energy a surface will intercept depends on the angle of the incoming radiation. **[10]**

Glass has the special characteristic of transmitting nearly all solar radiation that it intercepts (which moves through it) and is less transparent to most thermal radiation. The temperature build-up in a closed car on a sunny but cold day is evidence of this characteristic. Solar energy passes through the windows is absorbed by interior materials, and reradiated into the interior space in the form of thermal energy (heat) which is unable to pass back through the glass to the outside. This has become known as the greenhouse effect.

4.2.5 *HEAT STORAGE*

All materials can store heat to some degree. The ability of a material to do so is called its specific heat – the amount of heat, measured in BTU's for a given mass, a material can hold when its temperature is raised one degree Fahrenheit. As an indicator of a material's value as a heat storage medium in solar heating of spaces, the specific heat of a material is not very useful. The usefulness of a material in such an application is determined by its heat capacity, a measurement of the specific heat of a material multiplied by its density. The higher the heat capacity, the more effective the material is for heating and cooling. Finally, a good storage medium material must absorb heat when it is available, and give I t up when it is needed, and it must be a relatively good heat conductor. [9]

4.3 PASSIVE SOLAR ARCHITECTURE

It relies upon the design or architecture of the building itself to ensure climate control by way of natural thermal conduction, convection and radiation. The rudiments of solar passive design were developed and used through the centuries by many civilisations across the globe; in fact, many of these early civilisations built dwellings that were better suited to their climatic surroundings than those built today in most developed and developing countries. This has been largely due to the advent of cheap fossil fuels that allowed for artificial temperature and light control at the cost of natural light and cooling. A substantial share of world energy resources is therefore being spent in heating, cooling and lighting of such buildings. The use of solar passive measures such as natural cross ventilation, sufficient day-lighting, proper insulation, use of adequate shading devices coupled with auxiliary energy systems that are renewable and environment friendly can considerably bring down the costs as well as the energy needs of the building.

4.3.1 PASSIVE SOLAR SYSTEMS

The term passive solar refers to systems that absorb, store and distribute the sun's energy without relying on mechanical devices like pumps and fans, which require additional energy. Passive solar design reduces the energy requirements of the building by meeting either part or all of its daily cooling, heating and lighting needs through the use of solar energy.

4.3.1.1 HEATING

Heating the building through the use of solar energy involves the absorption and storage of incoming solar radiation, which is then used to meet the heating requirements of the space. Incoming solar radiation is typically stored in thermal mass such as concrete, brick, rock, water or a material that changes phase according to temperature. Incoming sunlight is regulated by the use of overhangs; awnings and shades while insulating materials can help to reduce heat loss during the night or in the cold season. Vents and dampers are typically used to distribute warm or cool air from the system to the areas where it is needed. The three most common solar passive systems are direct gain, indirect gain and isolated gain. A direct gain system allows sunlight to windows into on occupied space where it is absorbed by the floor and walls. In the indirect gain system, a medium of heat storage such as wall, in one part of the building absorbs and stores heat, which is then transferred to the rest of the building by conduction, convection or radiation. In an isolated gain system, solar energy is absorbed in a separate area such as greenhouse or solarium, and distributed to the living space by ducts. The incorporation of insulation in passive systems can be effective in conserving additional energy.

Passive Solar Heating presents the most cost effective means of providing heat to buildings. Generally, the amount of solar energy that falls on the roof of a house is more than the total energy consumed within the house. Passive solar applications, when included in initial building design, adds little or nothing to the cost of a building, yet has the effect of realizing a reduction in operational costs and reduced equipment demand. It is reliable, mechanically simple, and is a viable asset to a home. The following are rules of thumb and an explanation of the essentials of passive solar design.

The mechanism of heating and cooling equipment is usually referred to as a system. A building is designed (home, apartment house, etc.) and a heating/cooling system using forced air equipment with air ducts; radiant floors using hot water; etc., is specifically designed for it. In passive building designs the system is integrated into the building elements and materials - the windows, walls, floors, and roof are used as the heat collecting, storing, releasing, and distributing system. These very same elements are also a major element in passive cooling design but in a very different manner. It should be understood that passive solar design does not necessarily mean the elimination of standard mechanical systems, although recent designs coupled high efficiency back-up heating systems greatly reduce the size of the traditional heating systems and reduce the amount of non-renewable fuels needed to maintain comfortable indoor temperatures, even in the coldest climates.

The preceding explanations show that two elements must be present in all passive solar heating designs: a south facing exposure of transparent material (glass, plastic) to allow solar energy to enter; and a material to absorb and store the heat (or cool) for later use. With these two basic elements in mind a number of approaches to designing a passive solar heated structure are available. Passive cooling is discussed elsewhere in this tutorial.

4.3.2 PASSIVE SOLAR DESIGN

The following section contains a brief description of basic passive solar design approaches. Subsequent sections contain more detailed information regarding each design and some advantages and limitations of each. Do not assume that because a particular design is more effective for a particular purpose (i.e. water walls respond more quickly in the absorption and release of heat) that it will serve in all climates and in all designs as the most effective approach to passive solar heating or cooling. Conversely, identified limitations do not mean that the approach is ineffective, only that it is more appropriate and effective under specific conditions. In choosing a particular design approach, site and climate conditions must be evaluated carefully so that the best approach or combination of approaches is incorporated. No one passive design approach is most advantageous in all climates or on all sites and situations. In the building design industry there are certain ways of doing things that have been developed over years of experience. These are sometimes called rules of thumb (RT). The same is true of passive solar building design. In the following sections, rules of thumb are identified for emphasis. Keep in mind that these are simply guidelines that will, if observed, produce favorable passive solar heating performance. In some cases tables that give detailed information based on climate and site variations supplement the rules of thumb.

4.3.2.1 DIRECT GAIN

The simplest of approaches is a direct gain design. Sunlight is admitted to the space (by south facing glass) and virtually all of it is converted to thermal energy. The walls and floor are used for solar collection and thermal storage by intercepting radiation directly, and/or by absorbing reflected or reradiated energy. As long as the room temperature remains high in the interior space storage mass (walls, floors) will conduct heat to their cores. At night, when outside temperatures drop and the interior space cools, the heat flow into the storage masses is reversed and heat is given up to the interior space in order to reach equilibrium. This re-radiation of collected daytime heat can maintain a comfortable temperature during cool/cold nights and can extend through several cloudy days without "recharging".

Direct gain design is simple in concept and can employ a wide variety of materials and combinations of ideas that will depend greatly upon the site and topography; building location and orientation; building shape (depth, length, and volume); and space use.

A direct gain design requires about one-half to two-thirds of the total interior surface area (RT) to be constructed of thermal storage materials. These can include floor, ceiling and wall elements, and the materials can range from masonry (concrete, adobe, brick, etc.) to water. Water contained within plastic or metal containment and placed in the direct path of the sun's rays has the advantage of heating more quickly and more evenly than masonry walls during the convection process. The convection process also prevents surface temperatures from becoming too extreme as they sometimes do when dark colored masonry surfaces receive direct sunlight. The masonry-heating problem can be alleviated by using a glazing material that scatters sunlight so that it is more evenly distributed over walls, ceiling, and floor storage masses. This decreases the intensity of rays reaching any single surface but does not reduce the amount of solar energy entering the space.

4.3.2.2 INDIRECT GAIN

This passive solar design approach uses the basic elements of collection and storage of heat in combination with the convection process. In this approach, thermal storage materials are placed between the interior habitable space and the sun so there is no direct heating. Instead a dark colored thermal storage wall is placed just behind a south facing glazing (windows). Sunlight enters through the glass and is immediately absorbed at the surface of the storage wall where it is either stored or eventually conducted through the material mass to the inside space. In most cases the masonry thermal storage mass cannot absorb solar energy as fast as it enters the space between the mass and the window area. Temperatures in this space can easily exceed 100°F. This build up of heat can be utilized to warm a space by providing heat-distributing vents the top of the wall (where the heated air, rising upward due to less density, can flow into the interior space. Vents at the bottom of the wall allow cool air to be drawn into the heating space thereby replacing the out flowing hot air, and picking up heat itself. The top and bottom vents continue to circulate air as long as the air entering the bottom vent is cooler than the air leaving the top vent. This is known as a natural convective loop. At night the vents can be closed to keep cold air out and the interior space is then heated by the storage mass, which gives up its heat by radiation as the room cools. A variation of the vented masonry wall design is one that employs a water wall between the sun and the interior space. Water walls used in this way need not be vented at top and bottom and can be constructed in many ways - even 55-gallon drums filled with water, or specially constructed plastic or sealed concrete containers. Again, as the water is heated, the convection process quickly distributes the heat throughout the mass and the interior space is warmed by heat radiated from the wall. **[10]**

Another design approach takes advantage of the greenhouse effect as well as the direct gain storage wall. A south facing "greenhouse space" is constructed in front of a thermal storage wall exposed to the direct rays of the sun. This wall would be at the rear of the greenhouse and the front of the primary structure. The thermal wall absorbs heat at the same time the interior space of the greenhouse is being heated. If a vented masonry wall is used as storage, heat can also be released into the living space by convection. This combination also works with an unvented water wall. The greenhouse, then, is heated by direct gain while the living space is heated by indirect gain. The advantage is that a tempered greenhouse condition can be maintained through days of no sun, with heating from both sides of the thermal storage wall.

An indirect gain design which provides is the thermal pond approach, which uses water encased in ultraviolet ray inhibiting plastic beds underlined with a dark color, that are placed on a roof. In warm and temperate climates with low precipitation, the flat roof structure also serves directly as a ceiling for the living spaces below thereby facilitating direct transfer of heating and cooling for the spaces below. In colder climes, where heating is more desirable, attic ponds under pitched roof glazing are effective. Winter heating occurs when sunlight heats the water, which then radiates energy into the living space as well as absorbs heat within the water thermal mass for nighttime distribution. During the summer, a reverse process, described later, occurs. For best effect, roof ponds must be insulated (movable) so that heat will not radiate and be lost to the outside. One of the major advantages of this approach is that it allows all rooms to have their own radiant energy source with little concern about the orientation of the structure or optimal building form.

4.3.2.3 ISOLATED GAIN

Finally, the isolated gain design approach uses a fluid (liquid or air) to collect heat in a flat plate solar collector attached to the structure. Heat is transferred through ducts or pipes by natural convection to a storage area - comprised of a bin (for air) or a tank (for liquid), where the collected cooler air or water is displaced and forced back to the collector. If air is used as the transfer medium in a convection loop, heated air coming from the collector is usually directed into a rock (or other masonry mass material) bin where heat is absorbed by the rocks from the air. As the air passes its heat to the rocks it cools, falls to the bottom of the bin and is returned to the collector completing the cycle. At night the interior space of the structure is heated by convection of the collected radiant energy from the rock bin. If water is the transfer medium, the process works in much the same way except that heat is stored in a tank, and as hot water is introduced, cooler water is circulated to the collector. In naturally occurring convection systems (non-mechanically assisted) collectors must be lower than storage units, which must be lower than the spaces to be heated (RT). Of course, the addition of distribution assisting equipment can allow for placement of system elements anywhere, but that would then be an Active Solar System.

4.4 PASSIVE SOLAR HEATING DESIGN CONSIDERATIONS

4.4.1 SITE CONSIDERATIONS

The performance of any solar energy building, especially one of a passive design, is strongly impacted by the site and the siting of the building in relation to its surroundings. During the winter, the north side of a building receives little direct solar impact due to shading from the winter sun, which is low in the sky, while the south side is exposed to the benefits of winter sun exposure. If site conditions are restricted, the passive solar heated building location will be the area that receives the most sunlight between the hours of 9:00 a.m. and 3:00 p.m. during the winter months. The building location should be near at northern extremity of the sunny area so that future development on properties to the south will not block access to winter sunlight. This location also allows open space for winter activities or gardens to be exposed to as much winter sun as possible. [9]

4.4.2 BUILDING SHAPE AND ORIENTATION

Generally, buildings oriented along an east-west axis are more efficient for both winter heating and summer cooling (RT). This orientation allows for maximum solar glazing (windows) to the south for solar capture for heating. This orientation is also advantageous for summer cooling conditions since it minimizes east-west exposure to morning and afternoon summer sunlight. This does not mean that all buildings must be rigidly shaped oriented. Different building shapes and orientations can be designed to perform efficiently by combining effective glazing, solar exposure, and shading into the building form. This efficiency can be enhanced by variations in the placement of interior spaces and by the use of such options as clerestories and skylights. Depending upon the site, topography, and shape of the available space, orientations other than east and west may be desirable. However, for most climates, an east-west axis is the most efficient for both heating and cooling.

4.4.2.1 NORTH WALLS

In an east-west oriented building, a north facing exterior wall will receive little sunlight during the winter and this will be a major source of heat loss since heat always moves toward cold. Additionally, building shading of north side open space usually renders it unusable for outdoor use. To alleviate these situations the building should be shaped so that the roof slopes downward from the south to the north wall. This reduces the height of the north face of the building and therefore the area through which heat is lost. This also allows sunlight to reach more area of north side outdoor spaces. Variations of reducing heat loss conditions manifest in north walls include backing the building into a sloped hillside or providing a berm, both of which reduce the exposed north area. Both of these measures accomplish the purpose of a south to north downward sloping wall.

4.4.2.2 INDOOR SPACE PLANNING

With location, orientation and shape of the building is the consideration of interior space distribution. Habitable spaces that are most occupied and have the greatest heating and lighting requirement should be arrayed along the south face of the building. Rooms that are least used (closets, storage areas, garages) should be placed along the north wall where they can act as a buffer between high use living space and the cold north side.

4.4.2.3 ENTRYWAYS

Entries account for great deal of heat loss especially in small structures. Heat is lost during opening and closing of doors (or windows). Heat can also be lost by seeping between the doorframe and the door, and at windows. This kind of window, door or other wall penetration heat loss (or heat gain in the summer) is called infiltration. To reduce both direct and infiltration losses, entryways should be recessed or protected against the direct force of prevailing winds. Additional loss reduction can be accomplished by providing an enclosed interior "air lock" space between an entrance door and the main building. This double entry, or vestibule, creates a tempered zone between the outside elements and the interior living space thereby reducing the amount of warm air lost (and summer heat gained). It also reduces the amount of cold or warm air entering the living space when the interior door is opened.

4.4.2.4 WINDOWS

The major expanse of windows in a passive solar energy structure will be south facing solar windows. Whole design planning should include considerations re: the impact of heat gain in the summer; views; natural lighting; and privacy requirements in determining the placement and size of windows in the structure.

For the most part, window areas on east, west and north facing walls should be kept as small and as minimal as is consistent with interior requirements and should be recessed and all should be double-glazed. Windows are the least effective heat flow inhibitors of a building's shell, both in terms of letting heat out in the winter, and letting heat in the summer. When the outside temperature is 30°F and the inside temperature is 68°F, a square foot of single pane glass will lose 20 times as much heat (about 43 BTU's per hour) as a square foot of standard wood frame wall with 3'/z inches of insulation. [10]

4.5 DIRECT GAIN DESIGN

4.5.1 SOLAR WINDOWS

For Direct Gain heating the area of the glazed collecting surface is determined in response to the duration and severity of winter temperatures; the building size; and the amount of interior thermal storage mass. A correct balance between these factors must be found in order to avoid large daily temperature fluctuations that could result in overheating, even in the winter. As a rule (assuming the correct amount of thermal storage mass), 0.19 to 0.38 square feet of south facing glass for each square foot of interior floor area will provide enough sunlight to maintain an average temperature between 65°F and 70°F during the winter months in cold climates (average winter temperatures between 20°F and 30°F). In more moderate climes the same temperatures can be achieved with 0.11 to 0.25 square feet of south facing glass (average winter temperatures between 35°F and 40°F). Location and sizing of glazing is also dependent upon the building layout and types of spaces i.e., frequently used spaces vs. infrequently used spaces. Adjustments in glazing size and location of solar windows can occur by the use of reflectors, or when other passive solar design elements are used in combination with a direct gain system such as heat loss reduction by the use of movable insulation, double glazing, and by using wooden sash and frames. The lower heat conductivity of wood can reduce the heat loss around windows by as much as 20 percent.

4.5.2 CLERESTORIES AND SKYLIGHTS

Earlier it was mentioned that there might be considerations that override the need for a large expanse of south facing windows in passive heating designs. One is that interior room layout may affect the distance between the collecting windows and the interior thermal storage mass wall. Thermal storage masses in direct gain designs must receive direct sunlight impact, and the farther away from the collecting surface they are, the taller the collecting surface (glazing) must be in order to have sufficient surface solar contact because of the sun's angle. This situation may produce intolerable glare and overheating. Usually, storage walls should not be set back more than 1.25 to 1.5 times the height of the collecting surface - i.e. an interior thermal storage wall should be no more than 12' from the 8' tall solar collecting glazing wall. Also, direct sunlight may impact materials - i.e. dry out wood furniture; discolor certain fabrics; etc. so care should be taken re: interior decorating and maintenance. Finally, and most important, adjacent structures and/or vegetation may reduce the amount of direct sunlight to the point that a south facing collecting surface at ground level becomes infeasible or seriously reduced.

Any one, or combination of these conditions make south wall heat collection for direct gain problematic, but can be easily mitigated by the use of clerestories or skylights. Both of these features admit sunlight at the roof structure of a building and can be used to direct sunlight to a specific interior surface. They can also be used in combination with or as a supplement to a south facing glazed wall. Additionally, they provide for natural light applications, which can reduce the need and cost of artificial lighting.

Clerestories are vertical south facing windows located at roof level. Their advantages are that they allow diffuse lighting into a room; they provide privacy; and they can be placed almost anywhere on a roof. In a compartmentalized building layout, each room can have its own source of heat and light. They should be located at a distance from a thermal storage wall that allows direct sunlight to hit the wall throughout the winter. This distance is roughly 1.5 times the height of the wall. Ceilings in rooms containing clerestories should be light in color to reflect or diffuse sunlight into the living space. Large interior spaces may have multiple clerestories arranged to allow maximum admission of sunlight. Care must be taken that they do not shade each other, so the clerestorey roof angle (from horizontal) of each clerestorey should be roughly the same angle of the sun at its lowest winter point (noon on December 21). Skylights are simply openings in a roof, which admit sunlight -they is either horizontal (a flat roof) or pitched at the same angle as the roof slope. In most cases. Horizontal skylights are used with reflectors to increase the intensity of solar radiation (remember the angle of incidence). Large skylights should be provided with shading devices to prevent heat loss at night and heat gain during the summer months. [9]

4.6 PASSIVE COOLING

Passive solar technology can also be used for cooling purposes. These systems function by either shielding buildings from direct heat gain or by transferring excess heat outside. Carefully designed elements such as overhangs, awnings and eaves shade from high angle summer sun while allowing winter sun to enter the building. Excess heat transfer can be achieved through ventilation or conduction, where heat is lost to the floor and walls. A radiant heat barrier, such as aluminium foil, installed under a roof is able to block upto 95% of radiant heat transfer through the roof.

Water evaporation is also an effective method of cooling buildings, since water absorbs a large quantity of heat as it evaporates. Fountains, sprays and ponds provide substantial cooling to the surrounding areas. The use of sprinkler systems to continually wet the roof during the hot season can reduce the cooling requirements by 25%. Trees can induce cooling by transpiration, reducing the surrounding temperature by 4 to 14 degrees F.

Active cooling systems of solar cooling such as evaporative cooling through roof spray and roof pond and desiccant cooling systems have been developed along with experimental strategies like earth-cooling tubes and earth-sheltered buildings. Desiccant cooling systems are designed to dehumidify and cool air. These are particularly suited to hot humid climates where air-conditioning accounts for a major portion of the energy costs. Desiccant materials such as silica gels and certain salt compounds naturally absorb moisture from humid air and release the moisture when heated, a feature that makes them re-useable. In a solar desiccant system, the sun provides the energy to recharge the desiccants. Once the air has been dehumidified, it can be chilled by evaporative cooling or other methods to provide relatively cool, dry air. This can greatly reduce cooling requirements

4.6.1 EVAPORATIVE COOLING

When water evaporates it absorbs a large amount of heat from its surroundings (about 1000 BTU per pound of water evaporated). The most familiar example of this is the cooling effect of evaporating perspiration on the human skin. In arid, hot climates body temperature is partially controlled by the rapid evaporation of perspiration from the surface of the skin. In hot climates with high atmospheric moisture the cooling effect is less because the high moisture content of the surrounding air. In both situations, however, the evaporation rate is raised as air movement is increased. Both of these facts can be applied to natural cooling of structures.

Evaporative methods can be used to enhance the cooling rates in convective cooling systems. The familiar evaporative cooler, precursor to the air conditioner, is a mechanical system which uses these principles with a motor to force air movement and distribution. Passive cooling strategies with earth tubes and/or cool towers use the same principles but utilize natural systems for air drivers and distribution. If underground intake pipes are made from a porous material, and ground above them is well cool and watered, some evaporation will occur at the inner surface of the pipe.

Cool towers utilize wet cooling pads, and the force of gravity. Heavier, cooled air "falls", via gravity, into the building and its momentum floods the habitable area. This cool tower action, as well as that of the earth cooling tubes, can be enhanced and distribution extended, by the placement of thermal chimney "drivers" which can pull the cooled air through the building with an increase in both air quantity and velocity. In either case, the cooler air now has a higher relative humidity, but this is not usually a problem and can even be a benefit in arid climates.

In some areas, there may be a time of higher humidity (desert monsoon season). While sensible heat continues to be mitigated by passive cooling techniques, the latent heat contained in the humid air is more difficult to dissipate, which renders evaporative cooling less effective. The integration of a air dehumidification system easily corrects this short term problematic condition.

Evaporative cooling strategies are well suited to those areas of the southwest with the most severe cooling requirements. In the desert areas of the South, the warm night air (80 degrees+) may impede natural convection heat dissipation from a roof pond cooling system. That is one of the reasons why the cooling rate falls to about 25 BTU/hr/ft^2 in the extreme southeast corner of the state. Simple introduction of a thin water layer over the water containment surface can increase the overall cooling rate of the roof by 50-100 percent due to the resulting evaporation.

In the most severe climates where nighttime air temperatures often remain above 90°F in summer, sprays can be used to achieve maximum natural cooling, at standard roofs and roof cooling systems like the roof pond strategy. In the summer, sprays can be used to achieve optimum natural cooling. Water is pumped to sprinklers along the peak of a house and allowed to trickle down a sloping roof. The rate of evaporation is greatly enhanced in such a system because a much larger surface area is exposed to the night air. Roof sprays rely on a little external power to get the water to the roof and hence do not qualify as completely passive systems. But the total amount of energy consumed for pumping is very minimal compared to the energy saved by the added cooling rate attained. Excess water can be captured and reused or used elsewhere on the site.

An open pool of water located above the living spaces on the north side of a house is shaded from the summer sun but exposed to the cool north sky both day and night. Evaporation from the pool surface, aided by radiation and natural convection, keeps the water in this pool 30°F below the outside air temperature on a hot summer day, without the use of movable insulating panels. Natural convection brings this cool water into the house and draws heat back up to the pool as shown.

With all evaporative cooling methods, it is important to maximize airflow across the exposed water. Fresh air must be continually available to replace the humid air being built up near or over the water. Failing this, air will be quickly saturated with water vapor, and the evaporation and cooling rates will decline abruptly. Lips, edges and other structures or buildings that could block or deflect prevailing winds away from the water surfaces should be studiously avoided. Sometimes, a small fan to disturb the air over a pond will greatly aid the evaporation rate on a hot, sultry day or night.

Even with direct, active evaporative cooler systems, provision of interior thermal mass combined with direct evaporative cooling is a combination that works effectively. During the day, the structure can utilize the stored coolth in the walls and floors, and maintain an improved level of comfort while reducing power requirements of direct evaporative cooler system. In many areas of the southwest which are considered hot, arid zones, periods of higher humidity renders mechanical evaporative cooling unsatisfactory even when optimized techniques are used. A solution to this is the two-stage evaporative cooling system, which has been shown to be an effective alternative to direct evaporative cooling or refrigerated air-conditioning.

While not a passive system, two-stage evaporative cooling is an important element to be considered as part of passive cooling strategies. Cooling is accomplished by pre-cooling ambient air without humidification before further cooling by evaporation. The cool air entering the structure is then exhausted, typically through areas of heat gain such as windows or the attic. The pre-cooling may be accomplished by a combined cooling tower, heat exchanger unit, or by nocturnally cooled rock bed through which air is drawn. The second stage, evaporative cooling, is accomplished by a standard commercial evaporative cooling device, or by passive cooling elements of earth tubes or cool towers. Rock bed mechanical cooling has been used extensively in Australia with high degrees of effectiveness.

Two-stage evaporative system can also be combined with active and hybrid solar heating systems using the same storage (rock bed) system for both seasons. Working systems have been developed and demonstrated. This type of system is necessarily suited for new construction because of the requirement for the rock bed, which is most effectively located beneath the structure. It works well during hot, humid periods in the southwest using only slightly more power than direct evaporative cooling and the comfort attained is similar to that of refrigerated air-conditioning.

At night, one evaporative cooler cools the rock bed while the other cools the house using a one-stage evaporative cooler. During the day, hot outside air is drawn through the night-cooled rock bed where it is pre-cooled before entering the main house evaporative cooler. Since no moisture has been deposited in the rock bed, the pre-cooled air has not had moisture introduced into the house. An attractive feature of this type of system is the combining of heating and cooling systems in order to make the best possible use of components during the entire year. An air heater may be used to provide hot air during the heating season to the rock bed where the rock bed, fans, ducts and many of the control systems are used both during the heating and cooling season.

Recuperative and regenerative evaporative cooling options are other methods to produce greater comfort using evaporative cooling. These techniques use the relatively cool air exhausted from the structure to improve the performance of the evaporative cooling device. Evaporative cooled water reduces in temperature the ambient air in the heat exchanger without humidification as it enters the structure. The cool, dry air warms a few degrees as it passes through the structure and exits through the evaporative cooling device or a cooling structure. Since the exiting air is cool and dry, the wet bulb temperature is lower and the water produced by the evaporative cooling device is cooler than if ambient air were used. The rock bed heat exchanger and the evaporative cooling device could be combined into a single unit. If the rock bed is used to store heat in the winter, the cost effectiveness of the system is improved.

NOTE: The psychometric chart should be used at all times to analyze the effect of changing air conditions in these systems. As a rule of thumb, pre-cooling the air ten degrees will cause a three degree decrease in the output temperatures of an evaporative air cooler. The improper use of this rule can lead to errors of judgment when analyzing the results of changing conditions. [10]

Because of the large volumes of air that are moved in an effective evaporative system, the ducts must be large and appropriately sized. Typically, evaporative cooler ducts are at least three times the cross-section area of ducts refrigeration; ducts should be laid out using the shortest route possible and a minimum of turns. Evaporative cooling has been shown to be an effective alternative to refrigerated air-conditioning throughout the desert regions of the southwest. The selection of the particular evaporative cooling techniques must be made carefully through analyzing the local climatic conditions. These cooling systems should be integrated into the design of the home and where possible, with the design of the solar heating system. By integrating these systems at the design stage, greater efficiencies and more attractive economics can be obtained.

Evaporation occurs whenever the vapour pressure of water is lesser than the water vapour in the surrounding atmosphere. The phase change of water from liquid to the vapour state is accompanied by the release of a large quantity of sensible heat from the air that lowers the temperature of air while its moisture content increases. The provision of shading and the supply of cool, dry air will enhance the process of evaporative cooling. Evaporative cooling techniques can be broadly classified as *passive* and *hybrid.* Passive direct systems include the use of vegetation for evapotranspiration, as well as the use of fountains, pools and ponds where the evaporation of water results in lower temperature in the room. An important technique known as 'Volume cooler' is used in traditional architecture. The system is based on the use of a tower where water contained in a jar or spray is precipitated. External air introduced into the tower is cooled by evaporation and then transferred into the building. A contemporary version of this technique uses a wet cellulose pad installed at the top of a downdraft tower, which cools the incoming air.

Passive indirect evaporative cooling techniques include roof spray and roof pond systems.

4.6.1.1 ROOF SPRAY

The exterior surface of the roof is kept wet using sprayers. The sensible heat of the roof surface is converted into latent heat of vaporisation as the water evaporates. This cools the roof surface and a temperature gradient is created between the inside and outside surfaces causing cooling of the building. A reduction in cooling load of about 25% has been observed. A threshold condition for the system is that the temperature of the roof should be greater than that of air. There are, however, a number of problems associated with this system, not least of which is the adequate availability of water. Also it might not be cost effective, as a result of high maintenance costs and also problems due to inadequate water proofing of the roof.

4.6.1.2 ROOF POND

Roof ponds can be used both for heating during the winter months and for cooling during the summer months. In this section only the heating aspects of roof ponds will be discussed. It should be understood that this will vary depending on location, exposure and local conditions. The lower ratio given in the table should be adequate at lower latitudes while the higher ratio should be used at higher latitudes (colder climates). For latitudes higher that 36° north, roof ponds require greater solar gain exposure as well as greater protection from loss of gained heat.

The system is simple in concept. The roof pond approach brings the differing building aspects of a building - roof, ceiling, heating (and cooling) system, and heat distribution (does away with ducts) into one system. The roof ponds of contained water are the heating (and cooling) unit. The roof/ceilings of the building act as the structural support for the roof ponds; the "radiator" device for evenly distributed heating of the spaces below; and as a waterproof roof system providing protection from the elements. The movable insulation above the ponds is the weather protection, heating/cooling system "manager" and additional protection from the elements. Wintertime heating is comprised of daytime opening the insulating roof layer to allow solar radiation to heat the water beds; water bed warming heats the supporting structure which is also the ceiling for spaces below; heated support structure radiates heat to the space. At night the insulated roof panels close to contain heat gathered by the ponds to continue heating the spaces below. Cooling strategies, discussed later, are the opposite operation plus additional elements.

The sun in northern latitudes is at a lower angle with solar radiation traveling through a greater mass of atmosphere, which reduces its energy content by scattering and reflection. In this situation, increased area of exposure or use of solar reflection can be used to increase roof pond effectiveness. Additionally, in colder climates, the roof pond system benefits from insulating covers to prevent nighttime losses. The most beneficial insulation system is one that is multi-purpose and movable, operating only twice a day to 1) expose the ponds for heat collection, and 2) to cover the ponds to prevent heat loss at night. This insulation system is also beneficial in the summer when the roof ponds must be insulated to prevent summer heat gain. The movable insulation structure can operate in a number of ways - rolling, hinged, etc. In climates where snow is likely, ponds can be placed in a

Ceiling structural support for solar ponds (64#/cu. ft.) include structural metal decking (excellent for thermal transfer to spaces below) or thin reinforced concrete decks (more costly, less effective for direct transfer of heat).

In constructing the support structure for roof ponds, the clear span can be as much as 16 - 20 feet or more (for metal decking or reinforced concrete), requiring intermediate structural beams and supports depending on the layout of the interior space and the weight of the ponds and insulating devices. This can be a complicated matter and it is recommended that assistance be sought from a structural engineer prior to design.

It is important to provide a waterproof layer (membrane, etc.) at the pond support system surface to provide protections during draining of water for maintenance, and from waterbed material failure and/or weather impacts. The capability to drain the ponds in an easy and non-damaging manner is important. The water should be enclosed in ultra-violet light inhibiting (prevents degradation) plastic bags, waterproof structural metal or fiberglass tanks which form the ceiling below. The top of the water containment system must be transparent and the sides/bottom a dark color. Insulation panels should be constructed so that they can be tightly sealed when closed to prevent infiltration heat loss. In some applications insulating panels can also serve as reflectors when open in order to direct more solar to the ponds.

Heat is transferred from the roof ponds through the support deck to the interior space below. The edges of the deck should be carefully insulated to reduce heat loss. The underside of the support deck serves as an interior ceiling, and all surfaces (including galvanized metal decking) should be painted. Because the system provides a "radiant" ceiling it is important that no insulation is used between the root pond and the interior space. The one exception to this rule is at the bathroom, which generates high humidity from showers and tubs. Here, an uninsulated ceiling can result in condensation and drippage, so effective water barriers and insulation are critical.

Thermal ponds are typically water filled (6 to 12 inches deep) clear, ultraviolet inhibiting plastic bags. Care should be taken to choose materials which do not degrade when exposed to sunlight and water, nor are easily damaged from handing and local conditions. Temperature stratification in the ponds is avoided by using a clear top and dark bottom. With this configuration, sunlight will penetrate the water, be absorbed at the black surface and heat from the bottom will cause a continual convection cycle effect in the pond.

Finally, exposed pond tops should be sloped to drain. This avoids heat loss caused by evaporative cooling of the ponds during. While not a problem for waterbed "bags", this is a problem for more fixed types of installations.

Insulating panels can take many forms and configurations depending on local *conditions and design (flat roof with exposed ponds in temperate and desert settings;* pitched roof with glazing in snow country), and range from pivoting panels to horizontal, sliding panels constructed from standard metal building construction systems - insulation of polyurethane foam reinforced with fiberglass strands between aluminum skins placed within standard or easily formed metal frames. Panel tracks and supports must be designed so that the panel system (insulation and frames) fit as tightly as possible when closed in order to prevent compromise of the systems effectiveness. Without an effective seal system a great deal of heat stored can be lost at night due to infiltration.

The roof pond consists of a shaded water pond over an non-insulated concrete roof. Evaporation of water to the dry atmosphere occurs during day and nighttime. The temperature within the space falls as the ceiling acts as a radiant cooling panel for the space, without increasing indoor humidity levels. The limitation of this technique is that it is confined only to single storey structure with flat, concrete roof and also the capital cost is quite high. [9]

4.6.2 EARTH COOLING TUBES.

These are long pipes buried underground with one end connected to the house and the other end to the outside. Hot exterior air is drawn through these pipes where tit gives up some of its heat to the soil, which is at a much lower temperature at a depth of 3m to 4m below the surface. This cool air is then introduced into the house. Special problems associated with these systems are possible condensation of water within the pipes or evaporation of accumulated water and control of the system. The lack of detailed data about the performance of such systems hinders the large-scale use of such systems.

4.6.3 EARTH-SHELTERED BUILDINGS

During the summer, soil temperatures at certain depths are considerably lower than ambient air temperature, thus providing an important source for dissipation of a building's excess heat. Conduction or convection can achieve heat dissipation to the ground. Earth sheltering achieves cooling by conduction where part of the building envelope is in direct contact with the soil. Totally underground buildings offer many additional advantages including protection from noise, dust, radiation and storms, limited air infiltration and potentially safety from fires. They provide benefits under both cooling and heating conditions, however the potential for large-scale application of the technology are limited; high cost and poor day-lighting conditions being frequent problems.

On the other hand, building in partial contact with earth offer interesting cooling possibilities. Sod roofs can considerably reduce heat gain from the roof. Earth berming can considerably reduce solar heat gain and also increase heat loss to the surrounding soil, resulting in increase in comfort.

4.6.4 COMBINING SYSTEMS

Many times it is desirable, or even necessary, to use more than one passive heating design strategy. For instance, the use of a thermal storage wall may block a beautiful view while a direct gain design in the same south wall may create intolerable glare and have a tendency to overheat. In such cases the two designs can be used side by side or in any other configuration (a thermal storage wall on each side of a direct gain window). It is essential, however, to properly size this combination in order to maintain quality control and avoid undesirable temperature fluctuations. About 60 to 75% of the energy striking the collecting surface of a direct gain window can be used in space heating. On the other hand, only about 30 to 45% of the energy striking the collecting surface of a thermal storage wall is transferred to the interior space as heat. It can be seen that the approximate ratio in sizing this combination would be one square foot of direct gain window equals two square feet of thermal storage collecting surface. With these approximations in mind, it should be a relatively easy matter to size various combinations of passive solar designs.

Variation of roof pond designs make it impossible to present a simple rule of thumb for integrating with other design approaches. However, by reviewing the sizing techniques for the other systems and by knowing the specific design of the roof pond system, an approximate ratio can be calculated.

4.6.5 CLOUDY DAY STORAGE

Even on cloudy days passive solar heating designs continue to collect energy from diffused sunlight. However, this greatly reduced and diffuse solar radiation usually does not provide enough energy to keep interior temperatures at 70°F. Well designed thermal mass systems are sized to have carryover capacity and when combined with some auxiliary heating systems, provide for a comfortable environment for a number of cloudy days.

As a rule, direct gain systems can provide comfortable conditions for 1-2 cloudy days if the collecting area is increased by 10-20%, and the interior walls and floors are of solid masonry more than 8 inches thick. If water walls are used in place of masonry, increase the amount of water to two or three cubic feet for each square foot of south facing collecting area.

In climates where a number of consecutive sunny winter days are common there is a concern for overheating. For example, average temperatures with the above sizing may result in average interior temperatures of 74°F. However, on cloudy days, if the interior temperature drops an average of four degrees per day, comfortable conditions can be maintained for two days with no additional heating needed.

Over sizing in very cloudy or foggy climates is not recommended since thicker masonry takes a few days of sunshine to become fully charged. In climates such as these, overly thick storage masses are likely to result in under-heating problems. Glazed areas with minimum mass thickness should be used so that the system can respond quickly when sun is available.

Indirect gain systems differ slightly when designing for one or two cloudy days' storage. The collector area should be increased by 10 to 20%, and thermal storage walls of greater conductivity be used. If water walls are used, one or more cubic feet of water should be used for each square foot of collector area.

In indirect designs, if standard masonry wall material is used for cloudy day storage., the surface area of the wall should be increased instead of increasing masonry wall thickness. This may increase average daily temperatures, but overheating is easily mitigated by use of insulating panels or curtains drawn across the interior of the wall to provide temperature control. Built in ventilation systems can be used to control overheating for both indirect gain and direct gain systems.

4.6.6 MOVABLE INSULATION

In all structures, the greatest amount of heat gain is lost through glazing, either by conduction through the glass or by infiltration around the window frame. All heat loss during the winter reduces the efficiency of all heating systems including passive solar design, and where possible, movable, tightly sealed insulation should be used to cut losses to a minimum.

The use of movable insulation can simply involve manually operated panels that slide on a track across the glazed area, or be motor driven and temperature activated (more expense but more consistent control). Mechanical systems can be used to operate insulation difficult to reach manually. If the building is unattended when insulation should be moved, automatic timers connected to thermostats and/or light sensitive devices can operate, providing appropriate operation of the system. Some machinations can include automatically operated louvers, motor driven panels (roof ponds, etc.) and movable insulation. Whatever the method used, an effective insulation system will greatly increase the efficiency of passive solar designs.

4.6.7 REFLECTORS FOR PASSIVE SOLAR HEATING

If partial shading is problematic, collection of solar radiation can be greatly enhanced by the use of reflecting devices. Generally, horizontal reflector equal in width and one to two times. The height of the glazed opening in. length should be used for vertical (wall) glazing. South sloping skylights benefit from reflectors located above the skylight at a tilt angle of roughly 100° from the slope of the roof. The reflector should be roughly equal to the length and width of the skylight. Solar collection can be increased 30-40% when reflectors are used with vertical, horizontal, or sloping glazing. For greatest efficiency, the angle of a reflector in relation to the collecting surface must be carefully selected. In some instances, reflecting surfaces can be used to direct sunlight to an interior storage surface such as a water wall. Reflectors should also be constructed so that they can be used to block heat gain in the summer.

4.6.8 SHADING

South facing glass can be a source of overheating during summer months. The potential for overheating can be controlled by a roof overhang carefully designed to shade the glass during the summer (sun higher in the sky) but not block sunlight during the winter (lower in the sky), and by the use of movable outside shading devices.

Overhangs should be equal in length to roughly one fourth the height of the window opening in southern latitudes (36° NL) and one-half the height of the opening in northern latitudes (48° NL).

The projection of the overhang that will be adequate (provide 100% shading at noon on June 21) at particular latitudes can be quickly calculated by using the following formula:

Projection = window opening (height)/ F

A slightly longer overhang may be desirable at latitudes where this formula does not provide enough shade during August.

The usefulness of overhangs can be increased if they are constructed so that they are adjustable. Adjustable overhangs can be rolled back to admit sunlight on cold spring days. Trellised overhangs that support deciduous vines (vines that lose their leaves in the winter) are another way to block sunlight in the summer and admit sunlight in early spring. Retractable awnings and adjustable louvers can also be useful shading devices. [10]

4.6.9 OUTSIDE INSOLATION (OUT-SULATION)

Masonry wall exterior surfaces can lose large amounts of heat. For example - to achieve an insulation quality equal to 3.5 inches of fiberglass insulation, a concrete wall would have to be 12 feet thick. To avoid masonry wall heat loss to the exterior, it can be insulated on the outside. This "thermos bottle approach" includes the walls and the perimeter of foundation walls. Typical application is the addition of 1 to 2 feet of two-inch rigid waterproof insulation placed below grade to prevent stored heat in floors and walls from being lost to the outside.

In sunny temperate winter climates south facing, dark colored masonry walls need not be insulated, as heat gained during sunny days will offset nighttime heat loss.

4.6.10 NATURAL COOLING

Passive cooling techniques can be used to reduce, and in some cases eliminate, mechanical air conditioning requirements in areas where cooling is a dominant problem. The cost and energy effectiveness of these options are both worth considering by homeowner and builders. Contained within this section are rules of thumb and an explanation or the essentials of passive cooling systems.

In many parts of the southwest, summer cooling is as important as winter heating. In the arid part of the country, cooling is the primary design consideration.

Thermal comfort in summer means more than keeping the indoor air temperature below 75°. High temperatures, or high humidity (or both) can lead to excessive discomfort. Fortunately, the regions of high summer temperatures are quite arid (relative humidity is usually low). The only regions of fairly high humidity, the coastal regions, are also among the coolest parts of the region in summer.

There are three major sources of unwanted summer heat: direct solar impacts on a building and through windows and skylights; heat transfer and infiltration, of exterior high temperatures, through the materials and elements of the structure; and the internal heat produced by appliances, equipment, and inhabitants. Of the three, the first is potentially the greatest problem in the southwest, but it is usually the easiest to control. Table 14 lists approximate heat gains from each source for typical single-family detached homes in a climate where the temperature averages 75° F on a July day. The homes are built to local energy codes and are oriented east west, and have two-thirds of the total glazing facing south. The remaining glass is located on the east and west walls, and all glass is completely unshaded. Even assuming that sunlight could be excluded from the interior in summer (a difficult feat), these homes would experience excess heat loads of 250 to 450 thousand BTU per day in July. Worse yet, the houses would require about 4-8 tons of air conditioning each to handle peak heat gains and keep the rooms comfortable in the afternoon.

4.6.11 HEAT GAIN CONTROL

Many of the principles and techniques of passive solar heating are adaptable to natural cooling. Insulation and weather-stripping that prevent heat loss in the winter will also retard heat gain during summer. Movable insulating shutters for winter nighttime containment of heat gain can also be used to reduce summertime daytime heat gains. Inside the house, thermal mass such as masonry walls and floors, act as "heat sponges", absorbing heat and slowing internal temperature rise on hot days, and can be cooled down by nighttime ventilating (at the beginning and end of the summer season) and by use mechanical cooling during off-peak cost hours (nighttime). Suitably placed near a window, skylight, or vent, the same thermal mass can be exposed to cool night air to release the heat absorbed from the space earlier in the day. Finally, earth integrated buildings, embedded into the ground, benefit from the lower difference between interior and exterior surface temperature.

For optimum summer cooling, a building's surroundings should be designed to minimize summer sunlight striking external surfaces, and to prevent surrounding area heat re-radiation and reflection. Great temperature differentials between desert exterior conditions of 110+ degrees and 78 degrees required for interior comfort can be tempered using "thermal decompression" zones that become increasingly more effective as one nears the building. Mitigation of undesirable summer direct sun and thermal impacts is achieved through use of vegetation i.e. deciduous trees which interrupt the summer sun's direct path, and ground covers which prevent ground reflection as well as keep the earth's surface cooler thereby preventing re-radiation. One moves out of intense direct sun and heat through vegetation that filters sunlight and shades the ground; then through a more densely filtered zone with ground covers; then through a patio area with vegetation, trellises and water features; into a tempered building entry ("thermal lock"); and finally into the building proper. This movement, 110 degrees stepping down in stages to 78 degrees, allows the body to adjust properly, and provides the best means of arriving at a lesser differentiation between the building's perimeter wall interior and exterior surface temperatures. It is this difference, between interior and exterior surface temperature, that exacerbates the amount and rate of heat flow through the material

Glazing should be minimized on the roof and the east and west walls where summer sunlight is most intense.

Intense direct solar impacts from the sun rising in the east are equal to those of the setting west sun. The reason we feel the setting sun impact more is due to the added thermal impact of the earth reradiating the heat it has gained during the day. The summer sun is much higher in the sky and has a negative impact on skylights and roof windows and lead to enormous solar heat gains. They should not be used in hot climates unless they are insulated and/or shaded. Vertical south facing glass (windows, clerestories, etc.) with overhangs or shades, present fewer problems but are still adversely affected by exterior air temperature. A horizontal overhang or an awning above a south window is an inexpensive, effective solution. If it protrudes to half the window height, such an overhang will shade the window completely from early May to mid-August, yet allow for winter sun access. A trellis with deciduous vines can be used. Another good strategy is the use of deciduous trees that shade the south face and roof during the summer. All these shading methods work equally well with Trombe walls, water walls, greenhouses, and other south-wall passive solar collector strategies.

Mitigation for the roof and the east and west walls requires a different approach. Since the sun is low in the horizon during sunrise and sunset, overhangs are not effective for solar mitigation and vertical shading is in order. Vegetation is perhaps the most effective way of keeping the intense morning and afternoon sun off the east and west walls and windows, but care must be taken to avoid blockage of nighttime summer breezes that can be part of the diurnal cooling strategy. If vegetation is impractical, a combination of tinted or reflecting glass and exterior shades or shade screens that roll down over east and west windows are an effective strategy. Additionally, light-colored paints and materials on the roof and the walls are effective in reflecting away most of the sunlight that makes it past your shading.

4.6.12 CONVECTIVE COOLING MODELS

The heat gain control methods discussed above should suffice to keep room temperatures comfortable in houses built where mild summer temperatures are the rule. But there are many other regions of the southwest, particularly the desert areas, where additional cooling will usually be necessary. The next step in natural cooling is to take advantage of "convective" cooling methods - those that use the prevailing winds and natural, gravity-induced convection to ventilate a house at the appropriate times of the day.

The oldest, straightforward convective method admits cool night air to drive out the warm air. If breezes are predominant, high vents or open windows on the leeward side (away from prevailing breeze) will let the hottest air, located near the ceiling, escape. The cooler night air sweeping in through low open vents or windows on the windward side will replace this hot air and bring relief. To get the best cooling rates, leeward openings should have substantially larger total area (50% to 100% larger) than those on the windward side of the house.

If there are only light breezes at the site, natural convection can still be used to ventilate and cool a house as long as the outdoor air is cooler than the indoor air at the peak of the house. Since warm air rises, vents located at high points in the interior will allow warm air to escape while cooler outdoor air flows in through low vents to replace it. The coolest air around a house is usually found on the north side, especially if this area is well shaded by trees or shrubs and has water features. Cool air intake vents are best located as low as possible on the north side. The greater the height difference between the low and high vents, the faster the flow of natural convection and the more heat mitigation can occur.

There are two basic ways to enhance the convective cooling rate: 1) increase the volume of air escaping per minute, or 2) bring in cooler air. If Delta T is the temperature difference between exiting indoor air and incoming outdoor air, the overall cooling rate in BTU's per hour is given by the simple equation:

$$\text{Cooling rate} = 1.08 \times V \times DT$$

Where V is the volume of air escaping in cubic feet per minute. For example, an airflow velocity of 1-2 feet/sec. through a vent of 10 square feet will result in airflow rates between 500 and 1000 cubic feet per minute. If incoming air is 10 degrees cooler than the indoor air, the overall cooling rate will be about 5 to 10 thousand BTU's per hour. [10]

To a point, increasing the vent area will increase the airflow rate by natural convection. Turbine vents at the roof peak are one way to enhance airflow and improve the cooling rate. Even gentle breezes flowing up and over the roof peak create an upward suction that draws out warm interior air. An even better approach is to use solar radiation to induce a more rapid flow. One of the many possible approaches uses a Trombe wall vented to the outside. Sunlight striking the concrete wall will heat the air in the space between glass and wall to temperatures above 150°F. This very hot air rises quickly and escapes, drawing cool air into the house through low vents on the north wall. Additionally, specifically constructed "solar chimneys", composed of passive air heaters with seasonal dampers can be incorporated where solar heated air can be dumped into the building in the winter, and used as a "ventilator driver" in the summer to draw outdoor air through a house and ventilate it. Frequently, they can induce air velocities of 1-2 feet per second.

Another convective cooling strategy is the drawing of outdoor air is drawn through tubes buried in the ground and dumped into the house. Made of material that allows easy thermal transfer, these tubes are buried several feet deep to avoid the warmer daytime surface temperatures. Warm outdoor air entering the tube gives up its heat to the cooler earth, and cools substantially before entering the house. Thermal saturation of the surrounding earth must be addressed, by means of surface landscaping and watering, thereby removing the gained thermal energy from the tube/earth transfers. Though condensation is rarely a problem in dry climates, such tubes should be sloped slightly and have adequate drainage to insure that water build-up doesn't block the passage of air. The intake end should be screened and placed in a shady spot away from foot traffic. When properly built and sized, these underground tubes can supply cool air during the peak load daytime even in the hottest climates.

Other devices such as solar cookers, water distillation systems, solar dryers, etc. have been developed which can be used to reduce energy requirements in domestic households and in industrial applications.

4.7.1.2 ACTIVE COOLING

Absorption cooling systems transfer a heated liquid from the solar collector to run a generator or a boiler activating the refrigeration loop which cools a storage reservoir from which cool air is drawn into the space. Rankine steam turbine can also be powered by solar energy to run a compressed air-conditioner or water cooler.

Solar refrigeration is independent of electric supply and without any moving parts, for example, Zeolite refrigerator.

4.7.2 PHOTOVOLTAIC TECHNOLOGY

It involves the direct transformation of sunlight into electrical energy. Photovoltaic (PV) technology, an inherently clean source of energy, produces no noise, smoke, acid rain, water pollutants, carbon dioxide or nuclear waste because it relies on the power of the sun for its fuel. At the same time, Silicon, the raw material used for most PV cells is abundant and non-toxic. The large-scale production of PV systems has minimal impact on the environment, provided that the processes are properly controlled. Also, since PV systems use only sunlight for fuel, the environmental impact of activities such as mining, exploration, production and transportation, and the hazards of coal, oil and gas are eliminated. However, the drawbacks of such systems are their high initial cost and low efficiency, which results in high collector area requirement. Research efforts are therefore concentrated in reducing the cost and efficiency of PV systems and developing building integrated PV systems, which can be assimilated into the design of the building from the very beginning.

4.7.2.1 PHOTOVOLTAIC ENERGY CONVERSION

The primary component of the photovoltaic energy system is the photovoltaic cell array. These cells consist of semiconductor material such as Silicon (Si), cadmium sulphide (CaS), copper selenium arsenide (CuSeAs), gallium arsenide (GaAs), etc. Silicon is the most common element used in the production of the PV cell.

The creation of a 'p - n junction' is a pre-requisite for the occurrence of the photoelectric effect. The 'p - n junction' is created by *doping* a crystal of silicon with phosphorous and boron. This results in the formation of a junction with an excess of negatively charged electrons on one side ('n' type) and positively charged 'holes' on the other side ('p' type). The photoelectric effect is made possible by the existence of this electric field at the 'p - n junction'. When a light photon dislodges an electron from an atom either on the 'p' or 'n' side of the junction in the PV cell, it creates a free electron and a hole. The excess electrons flow from the 'n' side of the junction to the 'p' side producing an electric current in the process when the two sides of the PV cell are connected through an external circuit. Typically linked into modules, PV cells work by converting sunlight into electricity. The PV array can be if two types – flat plate systems and concentrator systems. [9]

4.7.2.2 FLAT PLATE SYSTEMS

a) SINGLE CRYSTAL CELLS

The photovoltaic cells most frequently used today are made of pure Silicon from a single crystal. The uniform crystalline structure assists the movement of electrons, making it relatively easy to attain high sunlight conversion efficiencies. These cells contain various different parts; an electrically conductive grid on the top surface of the cell to carry electric current generated, one or two layers of anti-reflective coating to increase the absorption of sunlight, a thin, doped layer of silicon called the collector and an electrode in contact with the base layer to complete the circuit.

Single crystal silicon cells are, however, expensive to produce, and several factors limit the extent to which the costs can be further reduced. Single-crystal silicon has very low capacity to absorb light, due to which the wafers have to be quite thick (100 microns) to achieve the required efficiency values. They are also extremely fragile and have to be handled very carefully during manufacture, packaging and transportation. In addition, almost 20% of the original ingot is wasted during manufacture. However, new techniques that produce long, thin sheets instead of ingots of silicon have reduced the costs associated with the slicing of ingots and polishing of wafers, at the same time reducing wastage. They are, however, very efficient up to 15% under working conditions. Gallium arsenide is also used for PV cells. It has the advantage of being more absorbent than silicon, and can operate efficiently over a wide range of temperature and is more resistant to radiation damage. Experimental PV cells made of single-crystal GaAs have achieved efficiencies as high as 26% as compared to 20% for single-crystal silicon cells.

b) SEMICRYSTALLINE AND POLYCRYSTALLINE CELLS

Semicrystalline cells are composed of a number of relatively large crystals called grains; with each covering an area of one square cm. Polycrystalline cells are composed of many much smaller grains. Manufacturing techniques for these cells are simpler and less expensive that those for producing perfect single-crystal cells. Semi and polycrystalline cells have lower efficiencies than single crystal silicon (upto 15%), because free electrons and holes tend to recombine at the boundaries between the different grains in the PV cell, thus reducing the amount of electricity that can be produced. Even so the low manufacturing costs of these types of silicon have made them popular for PV cells.

Amorphous silicon is most commonly used in commercial thin-film PV modules. The absorptivity of amorphous silicon is 40 times greater than single-crystal silicon. Consequently, an amorphous silicon cell of just 1-micron thick can absorb 90% of the visible light. The manufacturing process uses very little silicon and is much less expensive. Amorphous silicon modules are easy to make in a variety of shapes, which can accommodate various applications.

These solar cells are however considerably less efficient than crystalline silicon cells (8 - 10%), because it contains various structural and bonding defects where the free electrons and holes tend to combine. They are also less stable than crystalline silicon. However the low cost of these cells have made them popular in many consumer product applications.

c) DYE-BASED CELLS

This device is an electro chromic cell in which a liquid electrolyte is sandwiched between two layers of electrically conductive glass that serve as the cell's electrodes. The inside of the negative electrode is covered with a thin semiconductor layer of titanium dioxide coated with a ruthenium-based dye. The electrolyte contains negatively charged iodine ions in solution. When the molecules absorb light, they release electrons into the titanium dioxide. This transfers the electrons to the cells negative electrode, producing an electric current as the electrons flow from negative to positive electrode through the external circuit. The efficiency is about 7 - 12% comparable to that of amorphous silicon cells, providing a practical alternative, as these devices are inexpensive to manufacture and also quite durable.

These developments have however not reached the markets in India with research efforts being hindered by lack of funds, co-ordination and public awareness. Advanced photovoltaic systems when innovatively integrated into the architecture of the building can result in dramatic, elegant and cost-effective building, which is also environment friendly.

d) CONCENTRATOR SYSTEMS

When a series of PV cells are stacked on top of one another to create multi-junction cells, relatively high conversion efficiencies can be achieved. In such cells, each of the different PV cells absorbs a particular range of wavelengths converting it into electricity. Light that is not absorbed by the first layer is absorbed by the second layer and so on. Thus, multi-junction cells convert a broader range of wavelengths into electricity than single junction cells. They therefore have a potential for conversion efficiencies up to 40% (highest efficiency observed is 34.2% by *Boeing*). Copper indium selenide cells are specially used in concentrator systems. Inexpensive mirrors or lenses are used to intensify the incident sunlight by as much as 400 times, therefore to produce a given amount if energy the number of cells required is much less in concentrator systems. Concentrating PV cells reduce the cost of PV electricity by using inexpensive mirrors and lenses instead of additional PV cells to increase output.

The disadvantages of concentrator systems include the need to mount the system on a solar tracking support frame, which can substantially increase costs and their inability to perform on cloudy days. Also, the intense light produces heat that can reduce the durability of the system. Therefore such systems should include cooling measures either passive or active.

4.7.3 BUILDING INTEGRATED PHOTOVOLTAIC

Applications for building integrated photovoltaic (PV) are essentially unlimited. PV can be integrated with every conceivable structure - from bus shelters to high-rise office buildings, new structures and retrofits. Attractive variations in colour, texture, reflectance and transparency have been developed, as well as PV products that reflect traditional building materials such as roof tiles. However, such research is in its infancy in India and the development of PV products as replacements for traditional materials has not made enough progress for these to reach the market. The potential for such integration is, nonetheless, enormous.

Development of PV products for building integration is focused in three main areas - integral roof modules, roofing tiles and vertical facades. Roof integration has been the most popular application because PV modules have the greatest solar exposure in this location, and as a result, the highest power output. Vertical curtain walls and awnings are also practical as these can replace traditional cladding materials like glass.

Building integrated PV modules are typically produced on glass or metal substrates like traditional building materials. Modules produced in the same size as building materials like roof tiles or glass and other cladding panels can not only replace these materials efficiently but, being *multifunctional*, can also provide an added advantage by producing energy. The multifunctional nature of PV modules extends further than mere production of energy.

For example, a PV light shelf can shield direct sun while filtering comfortable diffused, indirect light into the interior. An opaque PV module used as awning can shade the interior from harsh direct sunlight and reduce cooling expenses. PV roof monitors can eliminate the need for daytime electric lighting by providing indirect daylight. Also, recently developed transparent thin-film modules can create energy-efficient PV modules with all the clarity and vision area of traditional glass.

Photovoltaic technology is in its infancy and more so in India, and its full potential is yet to be realized. Research and development in this field has to be intensified to produce user-friendly PV products that can be easily integrated into the building structure so that the costs involved can be reduced. This will definitely increase the popularity of PV products. A greater acceptance of such products along with advanced photovoltaic technology in the future may offer us the opportunity to design entirely new types of energy efficient buildings with a wholly unique aesthetic appeal. **[10]**

5.3.1 WIND POWER PROGRAMME

There is an estimated Gross Potential of 45,000 MW & Technical Potential of 13,000 MW. Considerable progress has been made in harnessing the large wind power potential available in the country. Supporting this effort is the world's largest wind resource assessment programme. New initiatives have been taken in re-assessment and expansion of the wind resource base. Center for Wind Energy Technology has been established. Large private sector corporations, public sector units and power utilities are being motivated to set up wind power projects.

Wind resource Map is given (w/m2 = Watt per square meter):

5.3.1.1 INSTALLATION

India now has the 5th largest wind power installed capacity in the world which has reached 1702 MW. 1639 MW of the total installed capacity has come through commercial projects. About 10.8 billion units of electricity have been fed to various state grids from wind power projects. [11]

The Ministry also deals with other emerging areas and New Technologies, such as, chemical sources of energy, fuel cells, alternative fuel for surface transportation and hydrogen energy etc. [11]

5.2 POWER

5.2.1 OVERVIEW

There is significant potential in India for generation of power from renewable energy sources, such as, Wind, Small Hydro, Biomass and Solar Energy. Special emphasis has, therefore, been given to the generation of grid quality power from renewable sources of energy. The Renewable Energy Power sector includes:

- Wind power programme
- Small hydropower programme
- Biomass power programme
- Biomass gasifiers programme
- Solar power programme

MNES had issued Guidelines to all the States on policies for power generation from renewable sources of energy with a view to encourage commercial developments in this sector.

- 15 potential States have announced policies.
- Cumulative Renewable Energy Power achievement: 3640MW.
- In addition, Biomass Gasifiers aggregating to 52 MW capacity are in operation in different part of the country. [11]

CHAPTER-5

ROLE OF GOVERNMENT IN RENEWABLE ENERGY SECTOR

5.1 SCENARIO

The importance of increasing use of renewable energy sources in the transition to a sustainable energy base was recognized in India in the early 1970s. During the past quarter century, a significant effort has gone into the development, trial and induction of a variety of renewable energy technologies for use in different sectors of the economy and sections of society in India.

5.1.1 STRONG INDUSTRIAL BASE

With a strong industrial base and successful commercialization of technologies in wind, solar photovoltaic, solar thermal, small hydel, biogas and improved biomass stoves, India is in a position today to offer 'state-of-the-art' technology to other developing countries and is poised to play a leading role in the global movement towards sustainable energy development.

5.1.2 LARGEST RENEWABLE ENERGY PROGRAMME

India has today among the world's largest programmes for renewable energy. Our activities cover all major renewable energy sources of interest to us, such as, biogas, biomass, solar energy, wind energy, small hydropower and the other emerging technologies. In each of these areas, we have programmes of resource assessment, R&D, technology development and demonstration. Several renewable energy systems and products are now not only commercially available, but are also economically viable in comparison to fossil fuels, particularly when the environmental costs of fossil fuels are taken into account.

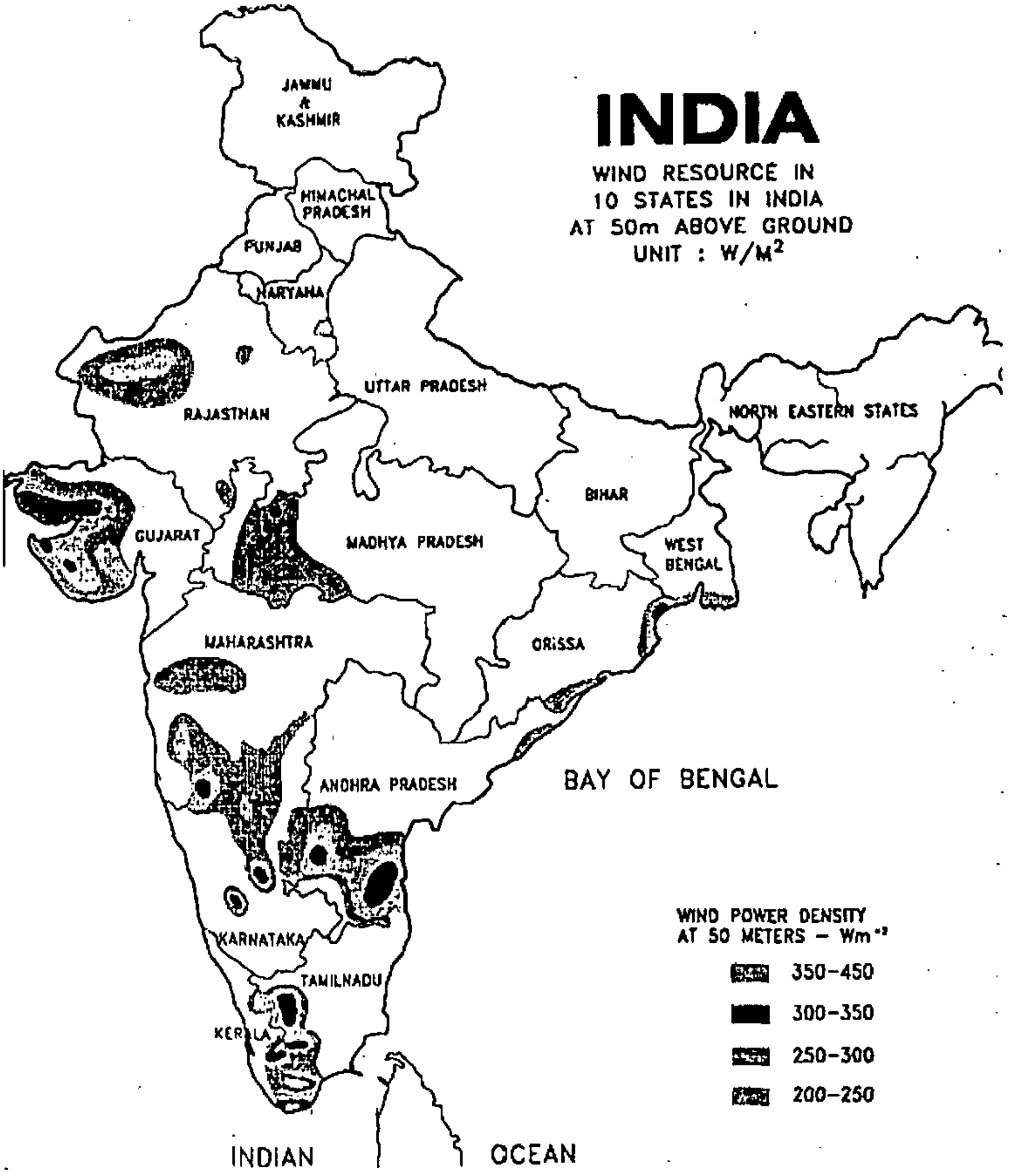
The Ministry is involved in the implementation of these programmes for development, demonstration and utilization of various renewable energy based technologies, such as, solar thermal; solar photovoltaic; wind power generation and water pumping; biomass combustion/co-generation; small, mini, & micro hydro power; solar power; utilization of biomass - gasifiers, briquetting, biogas, improved chulha (cook-stove); geothermal for heat applications and power generation/energy recovery from urban, municipal and industrial wastes; and tidal power generation.

5.3 RENEWABLE ENERGY PROGRAMMES

TABLE: 2

Group	Programme
Rural Energy	Biogas Improved Chulha (Cook-stove) Integrated Rural Energy Programme Special Area Demonstration Programme Animal Energy
Solar Energy	Solar Photovoltaics Solar Water Pumping Wind Pumping / Hybrid Systems Solar Thermal Solar Cookers Solar Energy Center
Power Generation	Small Hydro Power Wind Power Generation Biomass Combustion/ Cogeneration Power Biomass Gasifiers Solar Power
Energy from Urban & Industrial Wastes	Energy from Urban & Industrial Wastes
New Technologies	Chemical Sources of Energy Hydrogen Energy Geothermal Energy Alternative Fuel for Surface Transportation Tidal Energy
Planning, R&D, Technology Information Forecasting, Assessment and Databank	Non-Conventional Energy Technology Commercialization Fund NETCOF Technology Information Forecasting, Assessment and Databank Planning & Coordination International Co-operation Seminars and Symposia Research & Development Co-ordination
Information and Public Awareness	Information & Public Awareness

Source: MNES. 2001. *Renewable Energy in India Business Opportunities.* New Delhi: Ministry of Non-conventional Energy Sources.



MAP-2 WIND RESOURCE IN INDIA

Source: MNES. 2001. *Renewable Energy in India Business Opportunities*. New Delhi: Ministry of Non-conventional Energy Sources.

5.3.2 SOLAR ENERGY PROGRAMME

5.3.2.1 OVERVIEW

- Solar energy is the earliest source of energy known to mankind and is also the origin of other forms of energy used by man.
- Renewable sources of energy, such as, wind, hydropower, biomass and ocean energy are also indirect forms of solar energy.
- Energy from the sun has many salient features, which make it an attractive option. These include widespread distribution, lack of pollution and a virtually inexhaustible supply.
- India receives solar energy equivalent to over 5000 trillion KWhr/year, which is far more than the total energy consumption of the country. The daily average solar energy incident over India varies from 4 -7 KWhr/m^2 depending upon the location.

5.3.2.2 PROGRAMMES

India today has among the world's largest programmes in Solar Energy. The Ministry of Non-Conventional Energy Sources is implementing countrywide programmes on:

- Solar thermal programme
- Solar photovoltaic programme
- Major components of these programmes include R&D, Demonstration and Utilization, Testing & Standardization, Industrial and Promotional activities.

5.3.2.3 SOLAR POWER

- Under the solar power programme grid quality power generation based on solar thermal and solar photovoltaic technologies is being supported.
- A 140 MW Integrated Solar Combined Cycle (ISCC) Power Project is being given final shape for setting up at Mathania near Jodhpur in Rajasthan.
- Techno-economic clearance of CEA has been obtained and appraisal by World Bank/KfW, who would provide US $ 49 million grant assistance and US $ 150

million loan assistance respectively, has been completed.

- Government of India has accorded approval of the project as a Centrally-assisted project to be implemented by Rajasthan Renewable Energy Corporation Limited (RRECL), Jaipur.
- An Agreement has been signed on 29th October 2001 between KfW, Germany and Department of Economic Affairs, Ministry of Finance for composite loan amount of DM 250 million for the project.
- The Mathania ISCC Project will be the first of its kind, and among the largest such projects in the world.
- The Ministry is also providing support to grid interactive solar photovoltaic projects for voltage support at the tail ends of rural grids, for peak shaving / demand side management in urban centres and for diesel saving in islands/remote locations. [11]

5.3.2.4 SOLAR POWER PROGRAMME

POTENTIAL

- Solar Thermal Power Generation - 35 MW per Sq. Km

PROGRAMME

- It is proposed to set up a 140 MW Integrated Solar Combined Cycle Power Project with a solar thermal power capacity of 35 MW at village Mathania, Jodhpur district of Rajasthan.
- The solar thermal component will be based on the parabolic trough collector technology. The combined cycle power plant of 105 MW capacity will run on regasified-liquified natural gas (R-LNG).
- It would be a base load power plant of 140 MW capacity.
- The project will be implemented by Rajasthan Renewable Energy Corporation Limited (RRECL), Jaipur.

FINANCIAL ASSISTANCE

Ministry Grant - Rs.50 crore

Global Environment Facility Grant - US $49 million

(including Technical Assistance of US $ 4 million)

Loan from KfW, Germany - DM 250 million

Government of Rajasthan Equity - Rs.50 crore

REVIEW OF IMPLEMENTATION

A high power Steering Committee under the Chairmanship of Secretary, MNES with Chief Secretary, Government of Rajasthan as co-chairman.

PROGRESS

In October 1998, Rajasthan Renewable Energy Corporation Ltd. (RRECL), submitted Detailed Project Report of 140 MW ISCC Power Project at Mathania, Jodhpur, Rajasthan to Central Electricity Authority (CEA) for Techno-Economic clearance (TEC) of the Project. TEC has been accorded to the project by CEA on 27th August 1999 at completed cost of Rs.871.74 crore. Government of India accorded sanction of the project as a Centrally Assisted Project to RRECL in February 2000. RRECL have submitted supplementary project report to Central Electricity Authority for TEC owing to change of fuel from Naphtha to R-LNG. Heads of Agreement has been signed between GAIL and RRECL for supply of 0.46-0.5 MMSCMD R-LNG. Various preparatory activities towards finalization of EPC-O&M Contractor are underway. [11]

5.3.3 SOLAR THERMAL ENERGY PROGRAMME

The principal objective of the solar thermal energy programme being implemented by the Ministry is market development and commercialization of solar thermal systems, such as solar water heaters, solar cookers,

Solar air heaters/dryers etc. for meeting heat energy requirements for different applications in the domestic, commercial and industrial sectors of the country. Programme Components include:

- Promotion of solar thermal technologies through soft loan programme.
- Solar cooker programme for market development and commercialization of

solar cooking devices.

- Solar Buildings programme for training & education, awareness creation and also for providing assistance for design and construction of solar buildings.
- Regional Test Centres and Technical Back-up units for solar thermal devices and systems.
- Research & Development programme for development of new and emerging technologies and improvement of available technologies.
- Establishment of Aditya Solar Shops in major cities & towns of the country for on the spot sale of renewable energy products, servicing and information dissemination.

ACHIEVEMENT

- The total capacity of about 5,00,000 sq. m. solar thermal collector area.
- The total of about 4,85,000 nos. of solar cookers.

5.3.3.1 SOLAR THERMAL TECHNOLOGIES

Solar Water Heating

Solar water heating is an important application of solar energy. The areas of application include:

- Individual residential and apartment buildings;
- Restaurants and canteens;
- Guest houses, lodges, hotels and hostels;
- Hospitals and nursing homes
- Boiler feed water for commercial and industrial applications;
- Process feed water for paint industry, electroplating, galvanizing industry etc. involving direct feed to the various process baths at 70 to 80 C;
- Bottling plants and distilleries for syrup making, bottle cleanings etc.;
- Pharmaceutical, chemical and fertilizer industries;
- Textile industry;

- Food processing industry

Cost

Domestic 100 liters capacity: Rs.15000-20000

Larger systems: Rs.110-150 per installed litre

Soft loans are available to consumers from IREDA and from a few commercial banks for purchasing solar water heaters (Terms of Loan to Consumers)

Energy Savings

A solar water heater in a home, guesthouse, nursing home or restaurant usually replaces an electric geyser. Wider use of solar water heaters not only saves substantial amount of electricity but also contribute significantly to reduction in peak load demand. The installation of 1000 solar water heaters (of 100 litres capacity) can contribute to a peak load shaving of 1 MW. Large solar water heating systems which are usually used in hotels, hospitals, hostels, dairies and other industries result in substantial saving of either electricity or other commercial fuels like furnace oil, coal etc.

Environmental Benefits

Because of reduction of power generating capacity and saving of fossil fuels, large-scale utilization of solar water heaters also results in environmental benefits. A domestic solar water heater of 100 liters capacity can prevent emission of 1.5 tons of carbon dioxide every year.

Potential

The technical potential has been estimated as 140 million sq.m. of collector area.

Promotional Incentives

In order to promote large-scale utilization of solar water heaters and other solar thermal systems both financial incentives (in the form of soft loans) and fiscal incentive (in the form of tax benefits) are available. Soft loans are being provided to the users under an interest subsidy scheme of the Ministry through the Indian Renewable Energy Development Agency and a few commercial banks.

Manufacturing Base

The manufacturing base of solar water heating systems has since been improved substantially with a total number of 49. [11]

5.3.4 SOLAR BUILDINGS

An important role of buildings is to provide comfortable indoor conditions for the inhabitants. The energy requirement for maintaining the building interior cooler in summer and warmer in winter and also for lighting is quite significant. In India, the energy consumption in the building sector is progressively taking larger share of the total electricity generated. Solar efficient building design, popularly known as 'Solar Architecture' is essentially a climate responsive architectural concept. By incorporating various innovative features in building designs, the impact of climate both in summer and in winter can be minimized and as a result, the use of electricity or other conventional fuels can be reduced. The country has a large potential for energy conservation in buildings through appropriate use of solar energy. In order to promote solar efficient building designs, a Solar Buildings Programme is being implemented by the Ministry with the following components:

PROGRAMME COMPONENTS

(i) TRAINING & EDUCATION

Workshops and seminars are being organized throughout the country for creating awareness, generating public interest and providing inputs about the technology to engineers, academicians, scientists, planners, builders, students, consultants, housing financing organizations and potential house owners.

(ii) ORIENTATION COURSES

Orientation courses are being organized for architects and builders to motivate them for adopting solar efficient building design concept.

FINANCIAL PROVISION FOR THE ABOVE PROGRAMMES:

National/model workshop/Orientation course - Rs. 1 lakh each

Seminar/workshop of one-day duration - Rs. 30000 each

Refresher/Orientation course of 3 days duration- Rs. 60000 each

Workshop/Orientation course of 2 days duration or a session in international conference - Rs. 50000 each

(iii) AWARENESS PROGRAMME

The programme envisages creating awareness about the technology through publication of popular literature, books for architects and designers, publicity through various media etc.

(iv) DEMONSTRATION PROGRAMME

To demonstrate the concept of solar buildings, the Ministry accepts proposals for solar building projects for construction from government and semi government organizations generally through State Nodal Agencies. To encourage these organizations for constructing their new buildings on the basis of solar design principles, the Ministry provides the following partial financial assistance:

(a) PREPARATION OF DETAILED PROJECT REPORTS (DPRs)

50% of the cost of DPR of a building designed with the help of solar building design principles or 1.5% of the estimated cost of the building with a maximum of Rs.50, 000/- for each project.

(b) CONSTRUCTION OF SOLAR BUILDINGS:

Limited to 10% of the cost of the building with a maximum of Rs. 10.0 lakh for each project.

(v) OTHER ACTIVITIES

In addition to above, it is also proposed to take up other activities such as research and development, setting up data base, review of national building code, development of suitable curriculum for students of architecture etc. [11]

5.3.5 SOLAR PHOTOVOLTAIC PROGRAMME

5.3.5.1 OVERVIEW

The solar radiation falling over India is about 5,000 trillion kWh / year. There are about 300 clear sunny days in a year in most parts of the country. The average insolation incident over India is about 5.5 kWh / sq. meter over a horizontal surface.

5.3.5.2 PROGRAMME

In India there are about 300 clear sunny days in a year and solar energy is widely available in most parts of the country. Solar photovoltaic technologies offer a unique decentralized option for providing electricity locally.

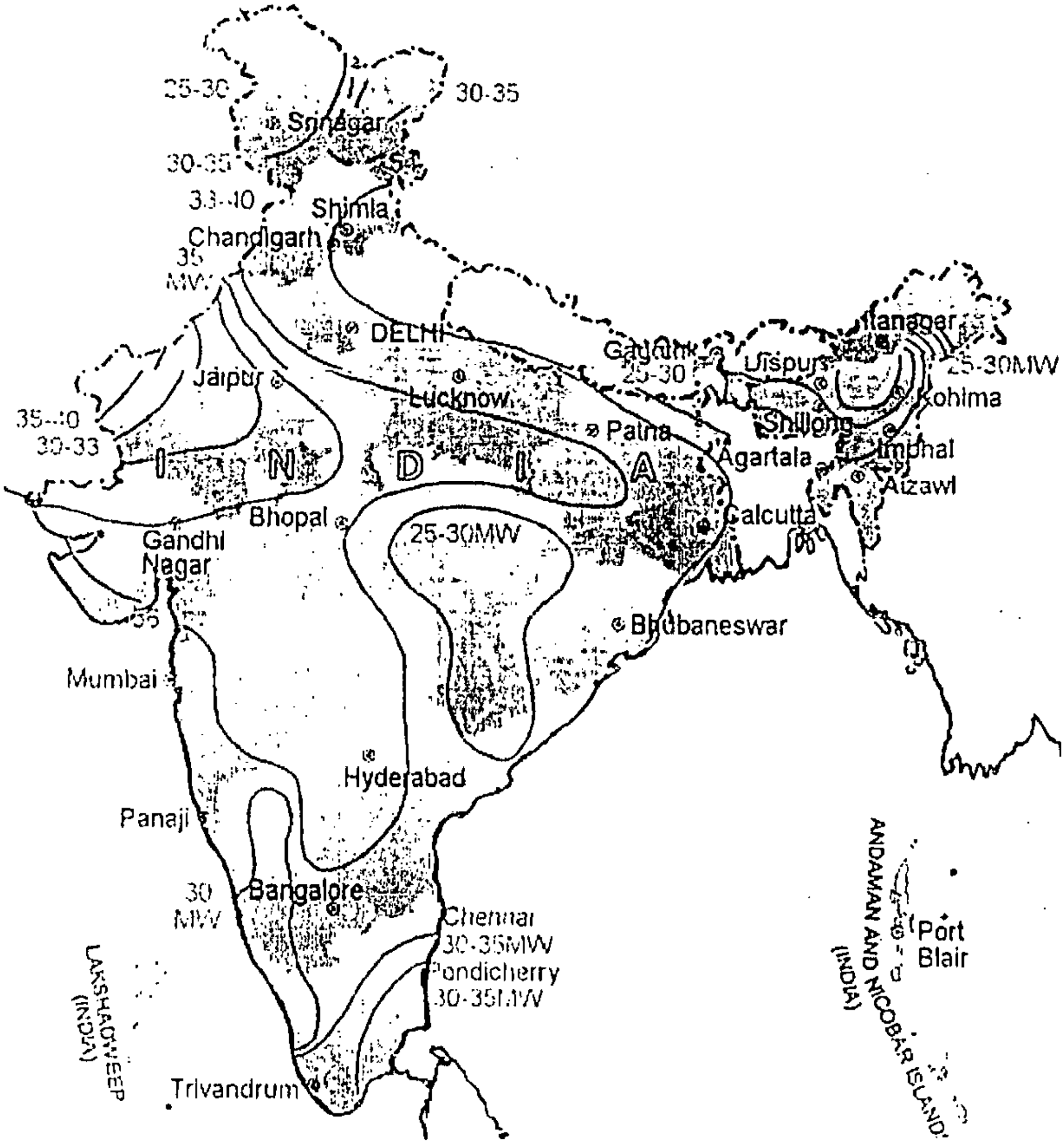
The Ministry for about last two decades is implementing a country wide solar photovoltaic programme. The Programme is aimed at developing the cost effective PV technology and its applications for large-scale diffusion in different sectors, especially in rural and remote areas. Major components of PV programme include R & D, Demonstration and Utilization, Testing & Standardization, Industrial and promotional activities.

The following PV systems are covered under the programmes of **MNES**:

- Home Lighting Systems
- Solar Home Systems Street Lighting Systems
- Stand Alone PV Power Plants
- Solar PV water pumping systems for agriculture and related uses
- Other applications of PV Technology including new applications

PROGRESS

Significant progress has been made in deployment of small capacity stand-alone PV systems in the country. By 31st December 2001 PV systems of about 83 MW aggregate capacity (about 9,20,000 systems), including export of about 29 MW have been in use for various applications. Under the PV program of MNES, over 6,10,000 systems aggregating to over 20 MW have been installed. This includes 3,85,000 solar lanterns; 1,80,000 home lighting systems; 41,000 street lighting systems, 4,204 water pumping systems and about 1.2 MWp aggregate capacity of stand alone power plants /packs.



MAP-3. ANNUAL MEAN DAILY GLOBAL SOLAR ELECTRIC CONVERSION POTENTIAL IN INDIA (MW)

Source: MNES. 2001. *Renewable Energy in India Business Opportunities*. New Delhi: Ministry of Non-conventional Energy Sources.

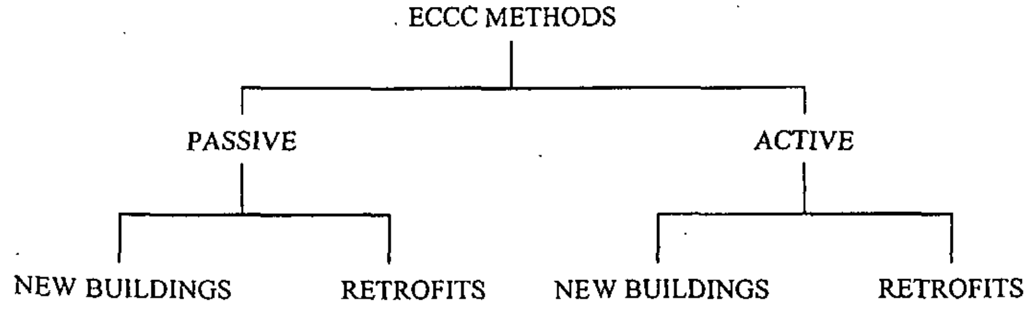
CHAPTER 6
METHODS OF CLIMATE CONTROL IN ARID REGIONS

6.1.INTRODUCTION

As we enter into the new millennium, the world is discovering again the old, forgotten virtue of thrift; it is discovering that our Earth, the source of all energy, is virtually infinite. Now comes the time for stocktaking: energy is needed for our civilization; without it our industry will halt, our transportation system will vanish, our medicine will go back a hundred years. The main source of energy now is oil. This is also the main source of our new materials, the plastics and man-made fibers. The amount of oil in the Earth's crust is finite. Should we burn this raw material, or should we save as much of it as possible to make materials for the development of expensive, energy-intensive metals?

People need homes, comfortable homes; industry needs buildings of the kind where it is possible to spend many long hours creatively. Moreover, some of the more sophisticated industries-for example, electronics-need buildings with well-controlled environments for their very existence. Thus, the energy expended on heating, cooling and control of humidity in buildings is considerable. If this energy, now produced from fossil fuels, could be saved and climate control could be achieved by some other means. India alone would save over 25 percent of its energy needs. [8]

It is impossible to convert all of the existing climate control (CC) systems to energy saving systems. However, one must make a start: to convert where possible, and to design new buildings with energy conservation in mind, energy conserving climate control (ECCC) methods can be divided into four categories, as indicated.



Passive ECCC is the use of the building itself to provide warmth in the winter and comfortable temperatures in the summer. This can be achieved with insulation, window shading, placement of the building to admit the breeze or keep it away as required, and other methods. The best use of passive climate control systems is in new buildings; but when one puts an extra layer of insulation on his roof or buys shades for his windows, he is converting the existing house into an ECCC.

Active ECCC usually starts with an energy distribution system very much like a conventional one to heat and cool the building. The energy needed to produce that heat or cold and to operate the required pumps and fans is taken, as much as possible, from sources other than fossil fuels. The most promising untapped source of energy for this purpose is solar energy. Since the active CC system does not require major changes in the nature of the building, it can be used in existing buildings as well as in new ones. Several passive ECCC methods are outlined below. **[12]**

6.2 DESIGN AND MATERIAL

The placement of the building in the environment is very important. When the more important area of the house is placed southeast with a picture window facing south, this area will receive direct solar heating on bright winter days, but will be shadowed in the summer because the Sun is higher in the sky. An overhang over the south windows designed to fit the latitude of the building can be very helpful. On the other hand, in a warm climate where heating is unnecessary, it may help to put the large picture window to the north for natural light without heat.

Shading the building, and particularly the windows, is a very helpful CC device. There are many forms of shading: shutters, blinds, heavy curtains, trees, other buildings. These can be used skillfully to keep the heat either inside the building, outside it or either of these two ways according to the season. A well-insulated building, which also has a minimum surface area, will exchange little heat with the environment and thus keep in the heat. Such a building is not suitable for hot climates; however, since one wants the cool air breeze to enter the house freely to compensate for such heat sources as lights, appliances and people.

Light colors tend to reduce building heat gain in summer. Accordingly light colored walls of heavy mass will have the lowest ETD (equivalent temperature differential) values. The table below lists typical building finishes and ground coverings in order of increasing heat reflectivity.

TABLE: 3 EFFECT OF COLOUR

SERIAL NO.	MATERIAL	%TOTAL INCIDENT HEAT REFLECTED
1	Tar & gravel, asphalt, etc.	7
2	Slate, dark soil, etc.	15
3	Grass, dry	30
4	Copper foil:	
	Tarnished	36
	New	75
5	Paint:	
	Light gray	25
	Red	26
	Aluminium	46
	Light green	50
	Light cream	65
	White	75
6	Whitewash, fresh snow cover, etc.	80
7	Aluminium foil*	95

Source: BUILDING RESEARCH NOTE, C.B.R.I, INTEGRATED ENVIRONMENT DESIGN (HOT AND DRY CLIMATES), UDC: 725-23, SFB: (92)

* Can be used within exterior constructions to prevent radiant heat flow and to prevent moisture migration. Heat gain through ceilings can be further reduced by insulating materials having a reflective top surface.

Note: summer air temperatures immediately above paved asphalt ground coverings can be 20 °F higher than nearby shaded areas of grass.

TABLE: 4 TIME LAG FOR HOMOGENOUS MATERIALS

MATERIAL		TIME LAG IN HOURS THICKNESS OF MATERIALS (mm)					
		25	50	100	150	200	300
Dense concrete	Min	-	1.1	2.5	3.8	4.9	7.9
	Max	-	1.5	3.0	4.4	6.1	9.2
Brick	Min	-	-	2.3	-	5.5	8.5
	Max	-	-	3.2	-	6.6	10
Wood	Min.	0.4	1.3	3.0	-	-	-
	Max.	0.5	1.7	3.5	-	-	-
Fiber insulating board	Average	0.27	0.77	2.7	5.0	-	-
Stone	Average	-	-	-	-	5.5	8.0
Stabilizing soil	Average	-	-	2.4	4.0	5.2	8.1

Source: BUILDING RESEARCH NOTE, C.B.R.I, THERMAL PERFORMANCE OF BUILDING SECTIONS IN DIFFERENT CLIMATIC ZONES, UDC: 699.38, SFB: ab-8

TABLE: 5 RECOMMENDED THERMAL PROPERTIES FOR WALLS AND ROOFS.

ELEMENT, CLIMATE AND CONDITION	U-VALUE	α	Q/1	TIME LAG
HEAVY ROOFS FOR HOT DRY CLIMATES				
Rooms for night use: diurnal range 10° C	.90	.4	-	8-14
12.5	.85	.4	-	8-14
15	.80	.4	-	8-14
17.5	.75	.4	-	8-14
20	.70	.4	-	8-14
Rooms for day use only	-	-	-	8-14
HEAVY WALLS FOR HOT DRY CLIMATES				
East wall	1.2 (.9)	-	-	10-16
West wall	1.2 (.9)	-	-	6-14
North and south wall	1.2 (.9)	-	-	8-14
Walls shaded from direct solar radiation	2.0 (1.6)	-	-	8-14
(Figures in the brackets show desirable improvement when the diurnal range exceeds 15° C)				

Source: BUILDING RESEARCH NOTE, C.B.R.I, THERMAL PERFORMANCE OF BUILDING SECTIONS IN DIFFERENT CLIMATIC ZONES, UDC: 699.38, SFB: ab- 8

TABLE: 6 WINDOW ELEMENTS AND THEIR FUNCTIONS.

Element	Function	Typical application
Thick curtain	Reduce heat loss (or gain) Provide privacy at night Reduce natural lighting	Night use rooms in cold seasons.
Lace curtain	Reduce glare Diffuse light Provide privacy by day	Day use rooms
Glass (closed)	Reduce heat loss Permit heat gain from solar radiation Prevent long wave radiation heat loss Allow a view out Allow daylight to enter Exclude dust, noise, pollution, insects, rain, wind, etc.	High % of fixed glass in cold season.
Glass (open)	Allow air movement (for body cooling) Allow ventilation (for hygiene) Allow ventilation (for structural cooling)	High proportion of operating glass in hot climates
Solid shutters or roller blinds.	Exclude solar radiation Provide security Exclude rain Protect opening from heavy winds Prevent glare Reduce rate of heat transfer.	Unshaded windows in hot sunny climates. Areas subjected to heavy storms or hurricanes.
Louvred shutters	Prevent glare Provide security Allow air movement and ventilation Provide privacy Exclude direct solar radiation Allow reflected sunlight to enter	Climates requiring night ventilation Climates with strong reflected sunlight.
Fixed screens (security bars)	Provide security Reduce light levels Reduce glare Reduce radiation Increase privacy	Climates requiring night ventilation.
Mosquito screen	Prevents insects entering Provide privacy by day Reduce light levels Reduce glare Reduce radiant heat gain (Reduce air movement)	Climates requiring night ventilation.
External shading devices.	Allow a view out Protect from rain Protect from direct solar radiation Protect from sky glare	Day use rooms facing the sun (simultaneous view, light and shade.)

TABLE: 7 REQUIREMENT FOR BUILDING FORM IN RELATION TO CLIMATE

CLIMATE	ELEMENT AND REQUIREMENT	PURPOSE
Hot dry climate	Minimize south and west walls	To reduce heat gain
	Minimize surface area	To reduce heat gain and loss
	Maximize building depth	To increase thermal capacity
	Minimize window wall	To control ventilation heat gain, and light

Source: BUILDING RESEARCH NOTE, C.B.R.I, THERMAL PERFORMANCE OF BUILDING SECTIONS IN DIFFERENT CLIMATIC ZONES, UDC: 699.38, SFB: ab- 8

TABLE: 8 U-AND TIME LAG VALUES

Materials with low *U*-values are those, which enclose, trap, or contain a film of air and generally are lightweight. On the other hand, materials with long thermal time-lags (i.e., building temperature lags behind outdoor temperature) are dense and heavyweight. Consequently, massive west walls, east walls, and roofs can greatly minimize solar heat impacts in summer); whereas, lightweight constructions are more sensitive to short-term solar impacts. Some data for homogenous materials are given below

Material	**Thickness (*Inch.*)**	**U-values**	**Time lag**
Brick (common)	4	.61	2-1/2 hours
	8	.41	5-1/2 hours
	12	.31	8-1/2 hours
Concrete (sand and gravel aggregate)*	4	.85	2-1/2 hours
	8	.67	5 hours
	12	.55	8 hours
Insulating fiberboard	2	.61	40 min.
	4	.09	3 hours
Wood (fir, yellow pine, etc.)	½	.68	10 min.
	1	.47	25 min.
	2	.30	1 hour

Source: BUILDING RESEARCH NOTE, C.B.R.I, THERMAL PERFORMANCE OF BUILDING SECTIONS IN DIFFERENT CLIMATIC ZONES, UDC: 699.38, SFB: ab- 8

- *The thermal inertia of concrete floor slabs prevents radiant panel systems from effectively responding to rapid changes in room temperature demand. The concept of ETD is used to account for heat transmission and thermal time lag properties of materials.*

Buildings with large thermal mass, such as thick-wall stone or brick structures, damp the diurnal and annual swings in temperature. They are suitable for climates, which require heating in winter and cooling in summer and can reduce the energy needed considerably. Another idea, which carries the thermal mass concept to extreme, is the underground building with an Earth roof. However, unless such a 'building' is well lighted and well ventilated, it is not acceptable to most people. In order to make many buildings energy conserving, the most important single factor is reduction of the glazed area where most heat is lost in winter through conduction and convection, and where most heat is gained in summer through direct solar heating and the 'greenhouse effect'. Modern technology can help by producing treated glass that will either absorb or reflect heat, and this, together with double glazing, can help in energy saving.

6.3 HEAT EXCHANGERS AND CONTROLLED VENTILATION

There are many factors that produce heat in a building: lights, refrigerators, cooking, washing and people. This heat can be put to use in various ways, such as cooling the light fixtures with air or water, etc. however, a large amount of heat (or cool air) is lost through ventilation. If the ventilation in the building is controlled through one or several outlets, it is possible to use heat exchangers to extract the heat from the rejected air stream and transfer it to the incoming stream.

6.4 PASSIVE COOLING DEVICES

Based on the type of cooling, passive-cooling devices can be divided into two categories: radiation cooling and cooling by evaporation. The latter concept can again be divided into two methods, cooling by water ponds and cooling by water sprays. These forms of cooling are most suitable for desert areas where the relative humidity is low.

Radiation cooling

At night when the air is still and the sky is clear, the main mode of energy transfer from the ground to the sky is radiation. Under such conditions the ground may cool considerably, sometimes producing frost with air temperatures much above freezing.

Especially in desert climates, the sky temperature is almost always lower than the ambient temperature. Therefore, a process is set up such that the surface cools down by radiation but immediately regains that heat through conduction and convection. When these terms are made much smaller than the radiation term, radiation cooling is attained.

Cooling by evaporation

Cooling by water ponds is a method which utilizes the high specific heat and high heat of vaporization of water to store heat in wintertime and produce comfortable temperatures the year round. On a sunny winter day the insulation is moved to expose the pond, which gets heated by the sun. at night, the insulation is moved to cover the pond and prevent heat loss so that the heat of the pond permeates into the building. On a summer day the pond is kept covered during the daytime and is opened at night so that some of the water evaporates and thus cools the pond. In the daytime this layer of cool water keeps the inside of the building comfortably cool. Fans are used to move the air where and when needed.

6.5 ACTIVE CLIMATE CONTROL USING SOLAR ENERGY

As stated earlier, active CC systems use a conventional distribution system and modified, but conventional, principles of air conditioning. Active CC systems have two principal advantages over the passive ones: first, they can be fitted in existing buildings without major modifications; second, the building techniques used for the installation of such systems are the conventional ones-in other words, one does not need new equipment, newly-trained builders, etc.

A solar room air conditioner does not exist and probably will not exist for a very long time. Large systems are always expensive; the periodic expenditure on fuel and electricity is replaced by an initial expenditure and can be translated into equivalent periodic payments of interest and depreciation. Thus, it is not difficult to establish a break-even collector cost for certain applications. Unfortunately, the permissible system cost derived from these considerations is rather low which means that the expense involved with the present solar systems is too high for total climate control; major changes in materials, design and manufacturing methods must be made before it becomes obvious that the best choice for active CC is solar energy. The following sections describe the principal parts of an active CC system using solar energy;

- The air conditioners
- The solar collector
- The heat storage devices

6.6 AIR CONDITIONERS POWERED BY SOLAR ENERGY

An absorption air conditioner is well suited for use with solar energy since it is a machine that produces cold from heat without the intermediate use of any other form of energy. Indeed, solar water-cooled absorption machines have been used to cool demonstration buildings; but there have been problems, which have stemmed from the basic difference between a machine whose source of heat is at 150°C (steam heated) and one, which has to operate with a source at 90°C. All heat exchangers involved must be much more efficient.

Present day development of solar air conditioners is much more advanced for the absorption type operated with lithium bromide-water system and water for the refrigerant. However, there is also activity in machines that use solar energy for the production of rotary motion where the rotating shaft is used to drive a compressor. Air-cooled machines are also a possibility but to date very little progress has been made in their development. All types of solar air conditioners are suitable for arid regions. The absorption water-cooled machine must be backed up by electricity for the operation of its pumps. The solar compressor type machine may be made independent of all utilities; but poor water quality or scarcity of water altogether in arid zones makes air cooled machines attractive. Thus, the exact type of machine must be determined for each and every situation. [12]

6.7 SOLAR COLLECTOR

In this section we shall consider thermal solar collectors, that is, those which transform the radiant energy of the sun into heat by heating a fluid. For every collector configuration, the amount of useful heat developed per m^2 per unit time equals the total solar energy absorbed minus the losses.

The collector plate is covered by a black deposit whose absorption is high. Some deposits may absorb up to 97 per cent of the solar radiation. However, this deposit must be a poor infrared emitter.

To reduce losses, one must minimize each of the heat loss terms. Choosing a suitable insulation material may minimize the conductance. Convection can be minimized by proper design of the cover plate, by using more than one cover plate or by using transparent honeycomb structures to create small air cells. Radiation is minimized by minimizing the collector plate surface emissivity. A deposit with a low emissivity and high absorptivity is called 'selective surface'; many collectors today feature a selective surface, often coupled with low-iron glass.

The essential parts of a solar collector are:

- The heat-collecting device, which are placed in the optical focus of the concentrator
- Any insulation or cover that is needed.

6.8 SOLAR ENERGY STORAGE

In solar energy systems, as in those powered by wind energy. We are confronted with the problem of the non-constant energy source, which must be balanced against the varying energy demand. Obviously, peak demand almost never coincides with peak availability. Therefore, there is an obvious need for an energy storage device. A thermal energy storage device will typically consist of:

- A heat exchanger (that introduces the hot fluid from the collector.
- The storage medium itself
- Heat exchanger (to remove energy from the storage)

Obviously, the problems associated with proper design of storage devices are the minimization or elimination of temperature drops between collector and load, and the minimization or elimination of heat loss from the storage. There are several ways by which energy may be stored

- Specific heat
- Heat of fusion
- Electrical storage batteries

So far the major components of a solar CC have been considered. Let us explore *how these components can be combined to form a complete system and what is needed to* control this system for maximum saving of conventional energy.

The first step in the design of a CC system is the calculation of the energy required for heating and cooling the building.

The designer must decide which fraction of the building's energy requirement has to be supplied by solar energy. Obviously this fraction would be larger in desert areas where the solar insolation is unobscured by clouds/or air pollution. However, it is very expensive to expect a building to derive all its CC energy needs from the sun.

Control of solar CC systems is complicated by the fact that one must balance the variable source against a variable consumer in addition to the usual controls needed for a conventional CC system. Thus, the regular controls of conventional air conditioning, heating and hot water systems will not be considered here. The purpose of the special controls of solar systems is to maximize the amount of energy saved by its most efficient use. The controls do this by measuring insolation values and temperatures at selected points in the system and by controlling the flow rates and the direction of flow of the various hot and cold fluids.

The control subsystem must decide among various options according to a predetermined programme; which source of energy to choose-solar, storage or auxiliary Which consumer to supply heating, air conditioning, hot water or storage.

In addition to the complex function of optimizing energy use, the control subsystems must also keep the solar system from damage. Damage to the system can occur from two conditions-extreme cold and extreme heat. **[12]**

CHAPTER-7

SOLAR HEATING AND COOLING SYSTEMS FOR ARID REGIONS

7.1 *INTRODUCTION*

The use of incident solar radiation to meet the energy requirements of a building is appropriate for arid zone locations. While arid regions are often thought of as dry areas with minimal humidity or rainfall, these characteristics can be used to advantage in solar energy applications. The lack of rainfall diminishes one particular disadvantage of solar applications, the intermittent nature of the energy source, and provides for an abundance of available energy. The low humidity allows for higher levels of intensity in the energy source and thus provides for greater flexibility in utilizing the solar radiation.

The integration of a solar heating and cooling system into an arid zone house must take into account the specific advantages and limitations of arid regions. The substantial differentiation between day and night temperatures, the low humidity, the relatively intense solar radiation, and the limited availability of water must influence any specific design of a solar heating and cooling system. In fact, these factors must be incorporated into the solar system design as assets and not as obstacles to be overcome. The most appropriate solution to the design of a solar heating and cooling system for an arid zone house is a combination of a active and passive components, each designed to take advantage of the particular characteristics of arid regions. Passive components, such as massive walls, can be utilized to damp out the daily fluctuations of ambient temperatures. Active solar systems can then be used to provide a more closely controlled comfort environment. [12]

While the advantages of utilizing passive solar system concepts are well recognized, the emphasis in this chapter is on the active solar system components. It is these active solar components, which will be considered in developing a final design alternative for an arid-zone house. Such a design will allow for a comfort environment comparable to modern conventional heating and cooling systems. In developing this design, we shall first consider some basic solar heating and cooling systems and components, evaluate their applicability to arid zones, and arrive at a final design schematic most appropriate for arid zone applications. It should be understood that architectural features and passive systems would complement this final active system design and be utilized whenever appropriate to reduce the heating or cooling loads or to damp the extremes of daily and seasonal excursions of house temperature, humidity, and the comfort environment in general.

7.2 SOLAR HEATING AND COOLING SYSTEMS

A solar heating and cooling system may be defined as any system which utilizes solar energy to heat and/or cool a building with a distinction being made between an active and a passive system.

A south facing window or a skylight would be considered a passive system since each admits solar radiation and reduces the normal heat loss. *A passive system* is a system, which has no mechanically moving parts, although it may involve a thermodynamically forced heat transfer fluid movement, such as thermo siphon action.

An active system is one, which provides mechanically controlled collection and distribution of solar heat and thus corresponds directly with (HVAC) systems in buildings. The key elements of an active solar heating and cooling system consist of a solar collector array, a heat storage unit, an auxiliary furnace, a heat transfer circuit (pumps, blowers, etc.) a method of delivering and extracting heat from the building, a cooling machine for space cooling, and facilities for providing solar heating of the domestic hot water.

Operationally, the solar collector intercepts solar radiation, converts it to heat, and utilizing some heat transfer fluid, transfers the collected energy to a thermal storage unit. The heat or thermal storage unit is an essential element because it provides for use of the solar generated heat available during periods of low solar radiation and at night. In general, the solar collector and thermal storage unit can operate independently of any heating or cooling requirement of the building and can be collecting and storing solar energy whenever there is sufficient incident solar radiation.

An auxiliary furnace is required as a backup to the heating/cooling system for those periods when the solar collector/thermal storage subsystem is unable to meet the heating/cooling demands. While the solar collector could be sized large enough to provide the full heating load through the year, this is not economical. It is preferable by far to have an auxiliary furnace or boiler capable of meeting the full heating/cooling demand (at design conditions) and use this auxiliary during periods of high heating/cooling load demands and low solar availability.

Heat delivery to the building can be accomplished in several ways. In an air system, the solar heated air can be taken directly from either the solar collector or the thermal storage unit and delivered to the building by utilizing a blower and duct distribution system. In a liquid system, a liquid-to-air heat exchanger can be used to provide heat to a central air distributing system, or the liquid can be piped directly to the heated space where separate fan coil units can be used to heat the building.

A number of different methods can be used for cooling. These include absorption cooling machines, Rankine cycle vapor compression, solar assisted desiccant dehumidification, radiative evaporative cooling, and others, both active and passive systems may be considered for the purposes of cooling the building. In addition, a heat pump may be utilized either as a conventional cooling unit powered by electricity or as the auxiliary furnace for the solar space heating system.

Finally, solar energy from a collector or a thermal storage unit can be used to preheat the domestic hot water available from a cold water supply main. As hot water is used in the building, the preheated water replaces the hot water taken out of a conventional hot water heater. Conventional fuels such as natural gas or electricity are used to boost the temperature of the solar preheated water to the desired temperature of the water remaining in the auxiliary hot water tank at the desired temperature. During the summer a solar pre-heat hot water unit, installed as part of the heating system, can normally meet 100 percent of the domestic hot water load. **[12]**

7.2.1 SOLAR COLLECTORS

A solar collector is a device to convert incident solar radiation to useful energy, usually in the form of heated air or a heated liquid. Each collector consists of an absorber plate (commonly a blackened metal surface), which absorbs the incident solar radiation and converts the solar energy to heat. The heat in the absorber plate is transferred to an appropriate heat transfer fluid, which passes through the absorber plate and delivers the heat to another part of the system. In the process of collecting energy, the heated absorber plate will tend to lose heat to the surroundings. The solar collector components other than the absorber plate are therefore designed to reduce these unwanted heat losses from the collector. Heat may be lost from the absorber plate by radiation, conduction, and/or convection. Insulation beneath the absorber and the transparent covers above reduce all three methods of heat loss. Glass covers, for example, are opaque to the thermal radiation emitted from the absorber plate and also reduce convection losses due to air movement across the absorber. The air space between the absorber plate and cover acts to reduce conduction losses between the two components.

Most commercially available solar collectors intended for use in solar heating and cooling systems are called *flat-plate collectors*, in order to distinguish them from *concentrating collectors,* which gather solar radiation over a large area and focus the radiation on to a smaller absorber area. The effect of a concentrating collector is to increase the fluid temperature delivered from the collector, even though the quantity of heat gained is effectively the same as for a flat plate collector with the same aperture area. A technical disadvantage of a concentrating solar collector is that only the direct solar radiation can be focused. Diffuse solar radiation, resulting from reflections from the Earth and sky, cannot be focused; this appreciable loss in the available solar energy greatly detracts from the effectiveness of a solar concentrator, in addition, the concentrating solar collector must track the sun throughout the day; the resulting expense of construction, operation, and maintenance of a rotating tracking collector is generally much too severe to allow for its use in residential applications of solar heating and/or cooling systems. [12]

In the area of flat plate collectors there are, at present, two principal but distinct designs: air heating and liquid heating collectors. This distinction is important since the two types of collectors represent essentially different types of solar systems (air and liquid). This is discussed in more detail below:

7.2.2 THERMAL STORAGE UNITS

Because of the variations in solar radiation and atmospheric temperature and the resulting non-correspondence between available solar heat and heating load demand, some form of energy storage is required. This energy storage requirement is most economically provided by some form of thermal storage, this is, the storage of cool (or heat) within the heating and cooling system. The types of thermal storage units, which might be utilized, are quite extensive. It is technically possible to store heat in scrap metal, eutectic salts (utilizing the latent heat between phase changes in addition to sensible heat storage), waxes, ceramic bricks, etc; but because of simplicity and economy, most commercial systems utilize either hot water storage for liquid systems or pebble-bed storage (storing heat in rocks) for air systems.

7.2.3 SOLAR HEATING SYSTEMS (AIR)

In the air-heating system, an air-heating collector absorbs solar radiation and converts it to heat for space heating. Circulation is from the solar system to the building in the same manner as most modern heating systems; air is the heat transfer medium. The building is heated directly from the collector whenever heating is needed during sunny periods. Air is circulated from one end of the collector to the other with the temperature typically being raised from 20° C to 60° C-70° C. cooler air from the building is returned directly to the collector for reheating. [12]

The thermal storage unit utilizes the heat exchange and heat storage characteristics of a dry pebble-bed, the most practical storage medium for use with air-heating collectors. Solar heated air is routed from the solar collector through the storage unit, thereby heating the pebbles; the cool air in the lower part of the storage unit returns to the collector for reheating. Temperature stratification in the storage unit assures maximum heat recovery from the solar air collector by allowing the collector to operate at the lowest possible temperature. The efficiency of a solar collector is inversely proportional to the temperature difference between the collector's absorber plate and the ambient. In the evening and during the periods of low solar availability, heat is delivered to the building from storage by circulating air through storage in the opposite direction. Because of the temperature stratification, this method provides heat to the room at the highest available temperature in the storage unit. The system automatically provides auxiliary heating from fuel or electricity when solar heat is not available from either the collector or storage. Domestic hot water can be made available by inserting a hot water heat exchanger in the hot air duct from the collectors. In this case, solar energy can provide preheated water whenever the collector is being heated by the sun.

7.2.4 SOLAR HEATING SYSTEMS (LIQUID)

Most liquid-heating collectors are water heating collectors, but if water is used as the solar collector fluid in a cold climate, some freeze protection must be needed. The most direct method is to allow the collector to drain into the storage tank whenever the pump shuts off. Then, when the solar heating of the collector is sufficient to allow for heat collection, the pump circulates water through the collector and routes the heat to the thermal storage unit, gradually increasing the overall temperature in a hot water thermal storage unit, gradually increasing the overall temperature in storage. Because there is virtually no temperature stratification in a hot water thermal storage unit, the temperature increase across the solar collector is usually 5° C to 10° C, and the inlet temperature to the collector is essentially the thermal storage water temperature varying from 35° to 100° C. [12]

An alternate method is to use ethylene glycol with the water in the collector loop. This also allows for a slightly higher boiling point of the collector liquid. To avoid the cost of a large quantity of glycol in the storage tank, a heat exchanger is inserted between the collector and storage unit; an additional pump to be used between storage and the exchanger may also be required. The advantage of this design is that there is no risk of freezing damage from improper collector draining or venting, nor from corrosion caused by the possibility of corrosion and freezing can then be weighed against the cost penalty of the heat exchanger, pump, and additional piping when using a water glycol mixture. Note also that the addition of glycol lowers the heat capacity of the water and thus reduces the collector efficiency slightly. Another important consideration is the effect of a power failure. A loss of pumping power would cause the water glycol collector fluid to boil since it no longer drains. These possibilities imply numerous problems, which must be addressed in the design of a liquid heating system.

7.3 INTEGRATED HEATING AND COOLING SYSTEMS

The addition of cooling to a liquid solar heating system is usually quite straightforward; hot water from the solar storage tank is piped to an air-conditioning unit where it provides energy to operate the cooling machine. The air-conditioning unit might typically be a lithium bromide absorption air conditioner, modified so as to use hot water instead of natural gas as the energy source. In a solar heating and cooling system, the auxiliary unit usually provides energy for both the heating and cooling function and operates as a 'replacement'. If solar heat is unavailable for heating or for operating the cooling machine, the auxiliary delivers heat for the entire load. In effect, heating and/or cooling is accomplished by using *either solar or auxiliary energy*. The alternative in a solar heating system is to utilize the auxiliary to 'boost' the air temperature to the desired level.

Because of the higher temperatures required to operate absorption chillers as well as other cooling machines, solar air-heating systems are not normally combined with cooling subsystems. The exception is the use of advanced, high performance solar air heating collectors to provide high temperature heat in order to run a cooling machine. An alternative to the use of more sophisticated solar collectors is to utilize passive solar cooling or conventionally powered air-conditioning methods.

7.4 APPLICATION TO ARID ZONES

With the basics of solar heating and cooling systems in mind. We now can integrate a specific solar system design with the arid-zone climatic conditions. To do this, we first consider the potential difficulties of various designs and then attempt to evolve a solar heating and cooling system design which best takes advantages of the characteristics of arid zones.

7.4.1 POTENTIAL DIFFICULTIES

a) SOLAR WATER HEATING AND COOLING SYSTEMS

A typical solar heating and cooling system consists of a liquid-heating solar collector (using a mixture of water and ethylene glycol), a thermal storage unit with a heat exchange mechanism between the collector fluid and the storage hot water, a circulating pump to deliver solar generated hot water to a set of heating coils, a lithium bromide absorption chiller, and a domestic hot water preheating subsystem. If we characterize arid zones as those regions with minimal precipitation and very low humidity, great differentiation between day and night temperatures, and relatively intense solar radiation, we can identify potential difficulties with the 'typical' solar heating and cooling system. Consider first the operation and maintenance of the solar collectors. Since the collectors utilize an aqueous solution as the collector heat transfer fluid, we must consider the potential problems of freezing, boiling, and corrosion of the collectors.

The freezing problem is effectively solved by using a liquid solution with a sufficiently low freezing point. This requires that we use sufficient ethylene glycol to permit flow under all conditions. It is possible to use lower concentrations of ethylene glycol than that specified by the manufacturer if our concern is to prevent bursting of pipes by the freezing of collector fluid. But under these conditions, flow will not be possible if the mixture turns to a slushy form; because of the intense solar radiation, it is possible to heat the solar collectors to the boiling point while the associated piping leading to and from the collectors may still be sufficiently frozen to prevent flow. The use of ethylene glycol or other non-freezing liquids may solve the freezing problem, but the potential for power failures over the expected life of the system virtually assures numerous opportunities for boil off of the collector liquid. In many cases the violent boiling conditions may damage or destroy the solar collector; if provisions are not made to capture the boiling liquid, then the water-glycol mixture must be periodically replaced. This reoccurring cost penalty can be an additional disadvantage of a liquid-heating solar collector.

Corrosion is also of considerable concern in aqueous solutions; it can be minimized when the dissolved oxygen concentration is zero. Perhaps more significantly, water circulated through a solar collector should not be permitted to become acidic since corrosion is considerably more rapid in acidic water solutions than in neutral or slightly basic solutions. Automotive grade ethylene glycol solutions do contain corrosion inhibitors. In general, a 30 percent concentration of antifreeze containing corrosion inhibitors is necessary to obtain sufficient protection against rust and corrosion. However, thermal decomposition of ethylene glycol occurs at temperatures in excess of 150° C, in the presence of air, the glycol degrades even more readily; a portion of the degradation product results in acidic solutions, which in turn promote corrosion.

An obvious conclusion to the foregoing discussion is the noting of advantages associated with using air as the collector fluid. Freezing, boiling, and corrosion difficulties are eliminated. In addition, maintenance costs of air-heating solar systems have been shown t be of the order of 1 percent per year of the initial installed cost. The annual maintenance costs of liquid type solar systems are expected to be higher due to corrosion, boil off, annual replacement of antifreeze, etc.

The use of typical flat-plate solar air heating collectors for the operation of cooling machines, however, is normally not technically feasible. The difficulty lies in the inability of the solar air-heating collectors to achieve high enough temperatures, typically 70° C to 80° C or 160 to 175 ° F for lithium bromide absorption cooling units and significantly higher for other cooling methods, while at the same time operating with realistic collector efficiencies. A possible alternative, however, is the use of solar air heating, evacuated tube solar collectors.

b) ABSORPTION COOLING SUBSYSTEMS.

A principal disadvantage of solar energy air systems is their inability to operate cooling units without resorting to highly sophisticated and unproven high performance solar air-heating collectors. And, at first glance, it would appear that cooling is absolutely essential for arid-zone houses. However, it is instructive to consider any potential difficulties that might arise from the use of cooling machines in arid-zone regions. Because of their performance in the field of solar cooling, we will consider the use of lithium bromide absorption chillers.

Critical to the performance of the lithium bromide chiller is the use of a water-cooled cooling tower. Such cooling towers in the past have been a source of maintenance and operational problems, particularly in areas of poor water quality. In the arid-zone regions, the difficulty of salt and mineral build up in the cooling tower because of the high mineral and salt content of the water can be a significant factor in the operation of the system. While flush down systems is readily available, this involves an unacceptable loss of water to the building and its environs. In addition, the evaporative losses of water make such operations infeasible in arid zone locations. Other cooling machines could be utilized in lieu of the lithium bromide units since these units do not require water cooling towers. While these air-cooled units eliminate the difficulties associated with water cooling towers, they require substantially higher solar input temperatures for operation. It is not clear whether or not air-heating, evacuated tube solar collectors could operate at such temperatures.

The use of cooling machines operated by highly sophisticated solar collectors in fact may represent technological over skill. In addition to potential operating problems with cooling towers and the cooling machines themselves, we are also requiring high temperature, high performance collectors which have their own particular disadvantages. Besides higher cost, an evacuated tube solar collector array could not act as the watertight typically have advanced problems and require considerably more sophistication in the design of the solar systems.

Inevitably, we are led toward simpler solar systems and, perhaps, more use of energy conservation and passive solar system techniques. With this in mind and in keeping with the previous discussions and conclusions, we may now consider some final design alternatives.

7.5 POSSIBLE SOLUTIONS, SOLAR AIR HEATING AND NOCTURNAL COOLING

The limited availability of water in an arid-zone region and the consequent low humidity and substantial differentiation between day and night temperatures makes the use of a solar air-heating collector a natural choice. The use of air as the heat transfer fluid eliminates problems of freezing, boiling, and corrosion, and provides for a simpler design. In addition, solar air-heating systems have a record of practicability, durability, and minimal maintenance and are a readily available, commercial reality.

Because of the substantial differentiation between day and night temperatures, it is possible to use nocturnal cooling by storing the cool night air in pebble-bed storage and then use the cool rocks to extract heat from the building during the day. An evaporative cooler can also be used to further cool the night air and increase the capacity of the 'cooling subsystem'. Note that in effect, this is no longer 'solar cooling' but merely a utilization of components of the solar heating system to take advantage of the climatic characteristics of the arid zone region.

The system provides solar space heating during the winter, solar domestic hot water heating on an annual basis, and converts to a nocturnal cooling/ cool storage system during the summer months. It is, of course, necessary that a changeover between the winter heating and summer cooling systems be made on a semi-annual basis. An alternate design could incorporate two heat storage units in order to provide heating and cooling in the spring and fall. During the winter heating season, the solar system would be sized large enough to provide 50 to 70 percent of the space and domestic hot water heating loads. During the spring, summer, and fall, the solar system would provide 100 percent of the domestic hot water heating load. Nocturnal cooling could be expected to maintain the interior building temperatures within 5° C of the normal set temperature.
Energy conservation features and passive solar subsystems could be utilized as well. Good insulation in exterior walls, double glazed windows, minimal infiltration, and massive interior walls would all contribute to reducing the space heating and cooling loads, south-facing windows could be utilized for winter heating if provided with detachable or adjustable shades to ensure against additional solar cooling loads during the summer. Note, however, that indiscriminate use of south-facing windows may provide heating during the winter, but will constitute an additional cooling load during the summer. And this possibility is not necessarily nullified by the use of overhangs to shade the windows in the summer since the sun is lower in the sky and adds radiation energy to the building during the mid morning and mid afternoon periods. [12]

7.6 PHOTOVOLTAICS

A brief mention should be made of the future possible use of photovoltaic, or solar cells, to convert solar radiation directly into direct current electricity. These solar energy collectors represent perhaps the most promising aspect of solar energy applications. However, present costs of the solar cells are quite high due to the difficulty of manufacturing solar cell arrays, so that solar photovoltaic energy systems are generally not economically feasible for building energy requirements. It is anticipated that economical, commercial photovoltaic systems will not be available within the next decade.

However, once the manufacturing processes can be improved to the point where photovoltaic become economically reasonable, they then could be incorporated into the solar air heating systems. This incorporation of two diverse solar energy devices would be necessary because solar cells have a maximum efficiency of about 20 percent. The remaining 80 percent of the incident solar energy is heat and can usefully be collected by a normal flat plate collector. With the availability of solar electricity, conventional cooling equipment could then be utilized. And, because of their high coefficient of performance for heating and cooling, heat pumps would be an obvious choice for cooling as the auxiliary heating unit. In this way, solar powered heat pumps could supplement the solar heating and nocturnal cooling system already described.

8.1 CASE STUDY I: TATA ENERGY RESEARCH INSTITUTE, GAUL PAHARI, GURGAON.

8.1.1 INTRODUCTION

A combination of technology and architecture, both traditional and modern, RETREAT makes ample use of an integrated design element, solar passive architecture, renewable sources of energy, conventional and non-conventional heating and cooling and energy saving features. RETREAT meets today's needs, at a time when we are paying heavy environmental costs. What makes the complex unique is its total independence of the city's electricity gird system, using solar panels and biomass gasifier to meet energy needs.

The self-contained energy efficient habitat built by Tata Energy Research institute is slated as the first of its kind in the country. Located on a 100-acre complex at Gaul Pahari in Gurgaon. Teri's new training institute generates its own electricity needs, uses an innovative technique for maintaining its indoor temperature, recycles its water and generates no waste. Built on what was once a swampy, degraded wasteland, the campus is called RETREAT (Resource Efficient Teri Retreat For Environmental Awareness And Training).

" A sustainable habitat design is an economically viable solution with minimum environmental foot print that can drastically reduce energy demands in buildings by 30 percent to 60 percent". This can be achieved through reduced demands on fossil fuels, reduced emissions, reduced pressure on natural resources like water, reduced waste generation and through recycling scarce resources, this 30 room training hostel boasts of conference facilities for 100 people, dining space and kitchen, recreational area and library, complete with computer facilities. The building design and engineering itself has led to a reduced peak load of 96 kW from a conventional 280 kW, showing a saving of 184 kW. RETREAT boasts of the country's first solar roof and its outdoor lights are also powered by solar panels. Space conditions and air-cooling is provided by an earth air tunnel, which consumes a fraction of the energy. In this system, air is forced through underground pipes and then circulated in the rooms and since the earth temperature is stable and at a depth of a mere four meters it is constant with a variation of plus or minus 1°C, the air thus flowing out is a comfortable 25.6° C.

To make a building like this, the thought of energy efficiency has to be there at the design stage. There is little you can do after the building has been constructed. Three important aspects are, functionality of the building, minimizing energy demands and space conditioning and lighting demands. For example it was kept in mind that the north block of the building would mainly be used in the daytime and thus the energy requirements here would be quite different from that of the south block, which is the residential area.

8.1.2 TRAINING HOSTEL

The first model building of this sustainable habitat, which is a 30-bed training hostel, is located at Gaul Pahari in Gurgaon. The building has been functionally divided into a north block comprising of the institutional facilities and a south block comprising of the residential facilities. An adjoining corridor connects the two blocks. The facility has 30 furnished rooms with attached toilets. There is indoor conference and seminar facility for 100 persons. Indoor and outdoor dining facilities and centralized laundry are provided in the training hostel. There is also a recreation room and a computer room with an attached library.

8.1.2.1 USE OF PASSIVE TECHNIQUES

The training center has been designed based on principles of solar architecture and would be fully based on renewable sources of energy.

- The building is insulated for reducing its space conditioning loads. Using vermiculite concrete and china mosaic white finish insulate the roof. Walls are insulated by using Styrofoam insulation.
- Part of the building is partially sunken into the ground in order to take advantage of ground storage and thus stabilize internal temperature.
- Shading devices and fenestration have been adequately designed to cut off summer sun and to let in winter sun.

- Glare free daylight has been adequately provided in the conference hall through use of specially designed skylights.
- Landscaping has been adequately designed so that wind directions are favorably altered. Deciduous trees are used in the south side of the building to shade during summer. During winter, the trees would shed their leaves thus letting in winter sun.

8.1.2.2 USE OF LOAD REDUCTION TECHNIQUES

Electrical demand was reduced to the load requirement of that of a conventional building of the same size. This has been achieved by the use of compact fluorescent lights, elimination of expensive heating and cooling use of appropriate control strategies to cut down wastage (master switching, toggle switching, day linking of lights, etc.) The space conditioning needs of the guest rooms (south block) are met by an underground network of tunnels at a certain depth below ground. The principle of the tunnel is to take advantage of constancy in temperature throughout the year at a certain depth below the ground. Two speed blowers are provided in the earth. Air tunnels for better regulation of airflow and for power savings. A solar chimney with a flat plate collector on top is provided with each south block room to create draft and for hot air exit.

The space conditioning needs of the north block, which comprises the conference and associated facilities, are met by ammonia based cooling system. The chiller heater combines the high operating efficiencies and the comfort of gas fired advanced absorption cooling and gas fired hot water heating. The total electrical requirement during cooling operations for a 5-ton chiller is 1.275kw and for heating operation is .415 kW. Liquid petroleum gas would be used as a source for driving the cooling/heating operation. The absorption system effectively blends two energy systems. Efficient LPG gas provides the primary energy for the absorption cooling cycle. Electricity in relatively small amounts transfers the work done by the gas cycle into the conditioned space by powering only motors and controls.

8.1.2.3 USE OF RENEWABLE SOURCES OF ENERGY AND THEIR INTEGRATION WITH THE BUILDING

After application of various load reduction techniques, the loads have been tried to be met by renewable sources of energy. The solar hot water system and solar photovoltaic system have been integrated with the building structure for enhanced aesthetics and cost reductions.

Larger photovoltaic systems, as currently installed in grid-connected applications, suffer from relatively high costs for substructure, mounting and land use. These costs may contribute to the total system's costs with more than 30% and are mainly related to expenses, which will probably not decrease, by technology or mass production. An opportunity to solve this issue, which is critical to the success of photovoltaic solar energy on a broader scale, is to hide these costs in applications where they would occur in any case. Apart from utilizing, for instance, highway sound barriers or rooftops, integration into building facades is a very promising solution. When compared to traditional glazing, the additional photovoltaic use of the façade may cost only some 20% more for modules, cabling and inverters. Moreover, when designed well in terms of aesthetics, photovoltaic façade elements provide an opportunity for architects to apply building components, which are well in line with environmental concerns and pleasing to the eye.

Cost savings through these combined functions can be substantial, e.g. in expensive façade systems where cladding costs may equal the costs of the PV modules. Additionally, no high-value land is required, and no separate support structure is necessary. Electricity is generated at the point of use. This avoids transmission and distribution losses and reduces the utility company's capital and maintenance costs.

It is important to realize the PV plants with a good quality in terms of aesthetics, technical safety and reliability, long service life and performance guarantee. The potential of PV in buildings is very high. The technology is ready and has even the potential for improvements and the material resources are available. Experience in several global projects revealed that there are several safety related issues, which need attention.

- Protection from electric shock for humans: protective measures

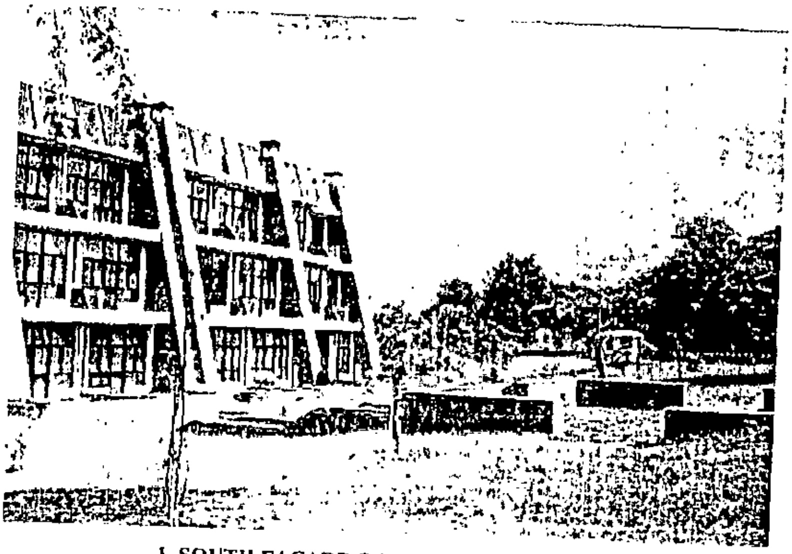
- Protection of equipment and surroundings from fire hazard due to overload and short circuit.
- Crystalline cells in black, dark blue, light blue, greenish violet, and bronze, amorphous modules mostly in brown shades.
- Various inter cell distances to allow transmission of light (crystalline modules), amorphous modules, can even be made semi-transparent, by incorporating many microscopic holes into the Si layer.
- Rear surface covers can be matched to the color of the cells; they can also be used to influence daylight. (E.g. diffusing)
- Cells can be selected for the same color.
- The front side grid can be matched in color.

8.1.2.4 PERFORMANCE MONITORING SYSTEM

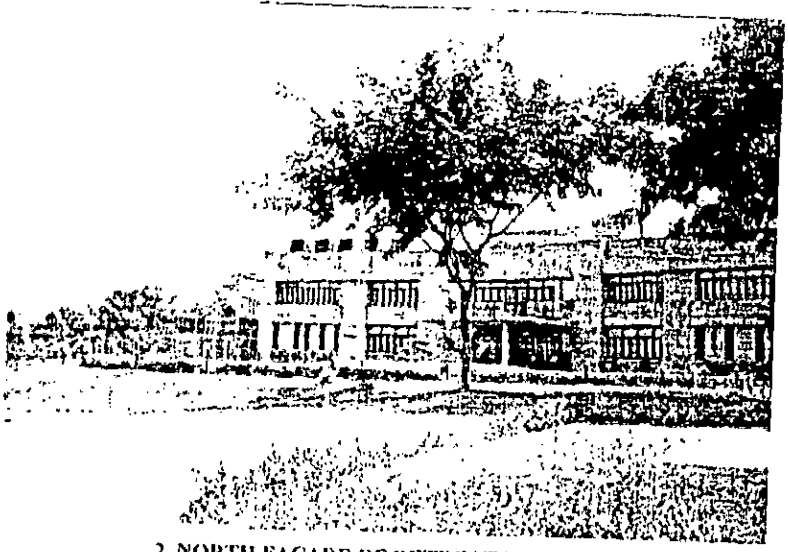
An expensive monitoring system consisting of several data loggers is connected to a centralized monitoring and control terminal. The parameters to be monitored are ambient temperature, humidity, solar insolation, room temperatures, and earth air tunnel inlet and outlet temperatures, hot and cold-water temperatures. Power consumption at different sections etc. the data collected will be utilized to improve the system performance in the new buildings, which are planned for the habitat.

8.1.2.5 CONCLUSION

The successful implementation of the project will lead to the demonstration of the concept of energy efficient and sustainable habitat for the 21st century. The data and experience from this project would lead to the evaluation of various designs, technologies and their cost effectiveness. The results will ultimately lead to design concepts for a cost effective habitat for the future. The integration of PV into architectural design offers more than cost benefits, it also allows the designer to create environmentally benign and energy efficient buildings without sacrificing comfort. Aesthetics or economy. The hostel will serve as a live demonstration for architects, town planners and others, who can stay there and experience an energy efficient house, based on renewable sources of energy.



1. SOUTH FAÇADE OF RETREAT BUILDING



2. NORTH FAÇADE OF RETREAT BUILDING

3. SOUTH FAÇADE DEPICTING THE USE OF SOLAR PANELS

PLATE-1: RETREAT BUILDING OF TERI AT GURGAON

8.2 CASE STUDY II:
BAREFOOT COLLEGE, TILONIA, RAJASTHAN.

8.2.1 INTRODUCTION

The "Barefoot" philosophy is based on the belief that village communities used to develop and maintain their own store of knowledge, which has been devalued in recent times and is slowly dying as people migrate to the cities to look for jobs. In 1972, this philosophy inspired the founding of the Social Work Research Center (SWRC), now known as the "Barefoot College", in Tilonia, a rural community in the Indian state of Rajasthan.

The founder and director of the college, Bunker Roy, wanted to break away from the Indian social-work tradition, which had an urban, middle-class and academic orientation, to create a programme that respected local skills, providing training and upgrading to help people help themselves. Over the years, the center has worked with local teachers, health-care providers, solar engineers and hand-pump mechanics in a comprehensive development plan, implemented with the rural poor for the rural poor. These programmes have led to a number of significant building projects realized by the "Barefoot Architects" - local members of the college staff. The largest of these projects is a campus for the college, which fuses local labor and materials throughout. The success of this approach is exemplified in the construction process of the campus. A young architect, Neehar Raina, prepared the architectural layout, and an illiterate farmer from Tilonia, along with twelve other Barefoot Architects, constructed the buildings. With the help of Neehar Raina's drawings, these Barefoot Architects, most of whom have no formal education, were able to build the complete campus and lay down its services. They were assisted by several village women who not only worked as laborers, but also participated actively in the day-to-day decisions about techniques used in the building process. Sometimes, the plans were drawn and redrawn on the spot to accommodate traditional building techniques that were not featured in the original design. The buildings are based principally on a traditional courtyard format with surrounding circulation verandas. Cubic in form with flat roofs, the buildings were constructed using local materials such as rubble stone with lime mortar for load-bearing walls, and large stone slabs for the roof. As is the custom in Indian vernacular architecture, the courtyards are highly decorated at ground level.

The architects also found numerous applications for Buck Minster Fuller's geodesic dome. Traditional housing in desert areas has sometimes used wood as a material, but this has become a scarce resource. Geodesic domes, however, are easily fabricated from scrap metal, which is readily available from discarded agricultural implements, bullock carts and pumps sections. The domes can be covered with a greater weight of thatch than traditional small-span structures, reducing the frequency and expense of re-thatching. The use of geodesic domes has also given rise to expertise in building emergency structures, including relief housing.

8.2.2 HOME FOR HOMELESS PROGRAMME

Through its Homes for the Homeless programme, the college has provided more than two hundred basic, low-cost dwellings in surrounding villages. Most of the buildings were constructed from earth-brick, but people with greater economic resources used other materials, including rubble stone and lime mortar. The houses have proved to be extremely functional and a great improvement on previous living conditions.

8.2.3 HARVESTING RAINWATER

Another of the college's projects is the development of structures to harvest rainwater, which have been installed at the campus and in schools throughout the region. In rural areas, large-scale efforts to provide water are typically made by tapping groundwater sources - an expensive, short-term process that often yields brackish water. Rainwater-harvesting structures, based on tried-and-tested rural technologies, gather water from flat rooftops and channel it to storage tanks, usually situated underground. The system is inexpensive, provides a year-round water supply and has led to wasteland reclamation. In several rural primary schools, the attendance of girls has improved because they do not have to spend hours walking several kilometers to collect drinking water.

8.2.4 PROJECT DATA

Client: Barefoot College-Bunker Roy, Director.

Sponsors: Social Work Research Center; Government of India; United Nations Development Programme; German Agro Action; HIVOS-Humanist Institute for Development Cooperation; Plan International.

Architects: Neehar Raina, campus design; Barefoot Architects of Tilonia - Bhanwar Jat and twelve Barefoot Architects, construction of the Barefoot College campus; Rafeek Mohammed and seven Barefoot Architects, geodesic domes; Laxman Singh assisted by Ram Karan, Kana Ram and Ratan Devi, rainwater-harvesting system; sixty Barefoot Architects, construction of 250 Homes for the Homeless.

- **Barefoot College**

Site area: 35,000m2

Built area: 2,800m2

Cost: INR 6,000,000

- **Rainwater Harvesting System (350 installations)**

Cost: INR 16,700,000 (USD 371,000)

- **Homes for the Homeless (250 units)**

Cost: INR 600 (USD 20) per m2

8.2.5 PROJECT HISTORY

- **Barefoot College**

  Design: February 1986

  Construction: April 1986-January 1989

  Site area: 35,000m2

  Built area: 2,800m2

- **Rainwater Harvesting System (350 installations)**

  Design: April 1987

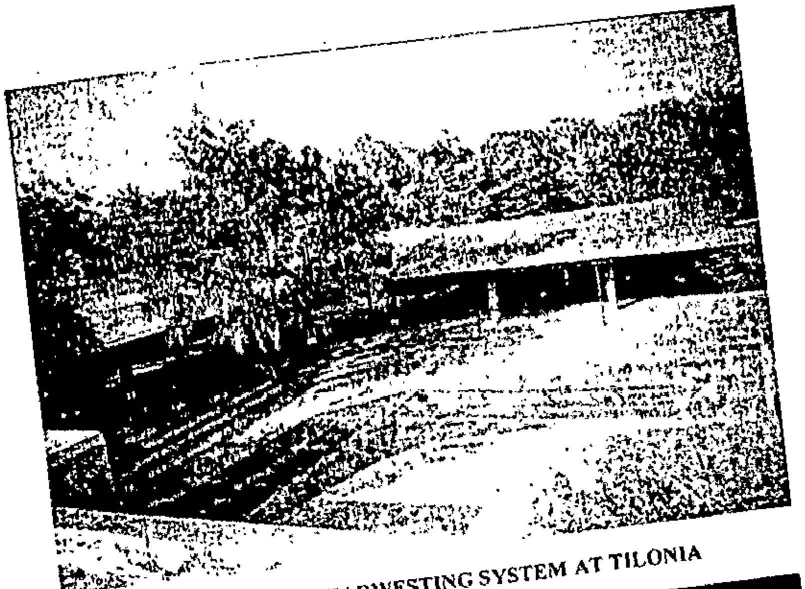
  Installation: 1988 and ongoing

- **Homes for the Homeless (250 units)**

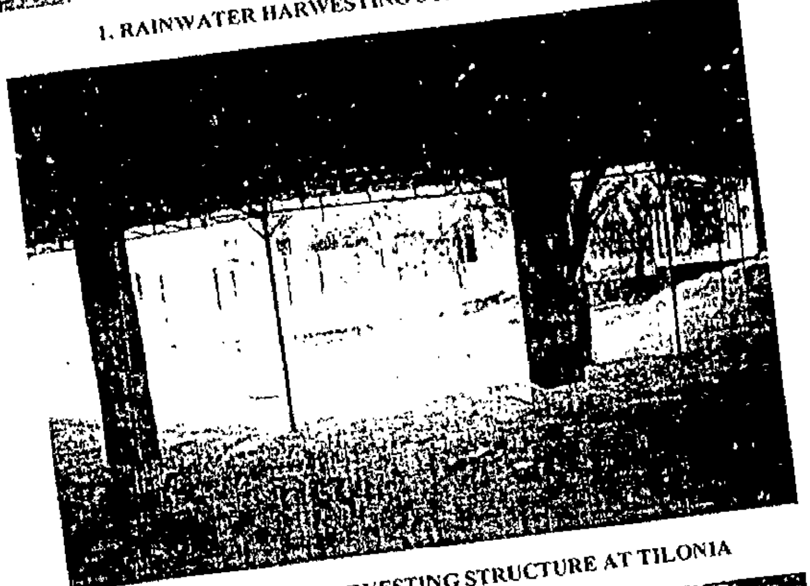
  Construction: 1986 and ongoing

8.2.6 CONCLUSION

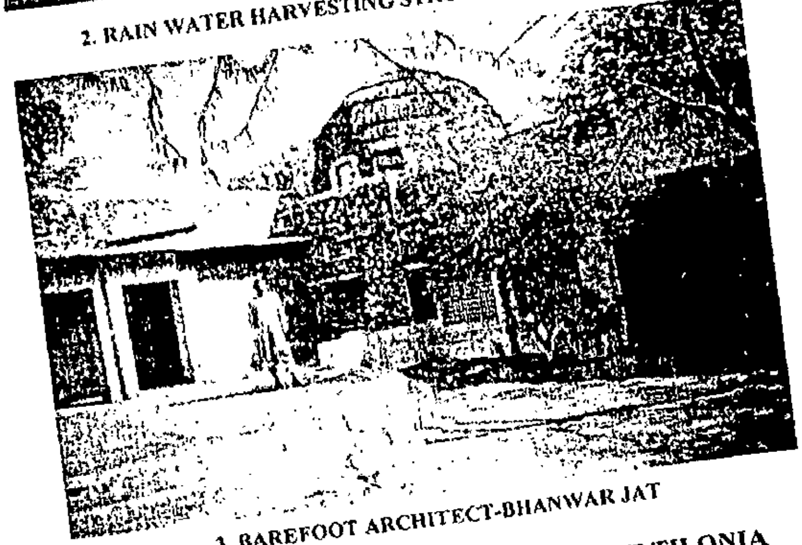
The Barefoot College has had a tremendous impact on Tilonia and other outlying rural settlements, influencing every aspect of people's lives. Lifting the surrounding population out of the vicious circle of poverty and helplessness, the college has facilitated a revival of traditional technologies and applied them on a wider scale to solve problems that have baffled scientists, engineers, environmentalists and politicians for years.



1. RAINWATER HARWESTING SYSTEM AT TILONIA

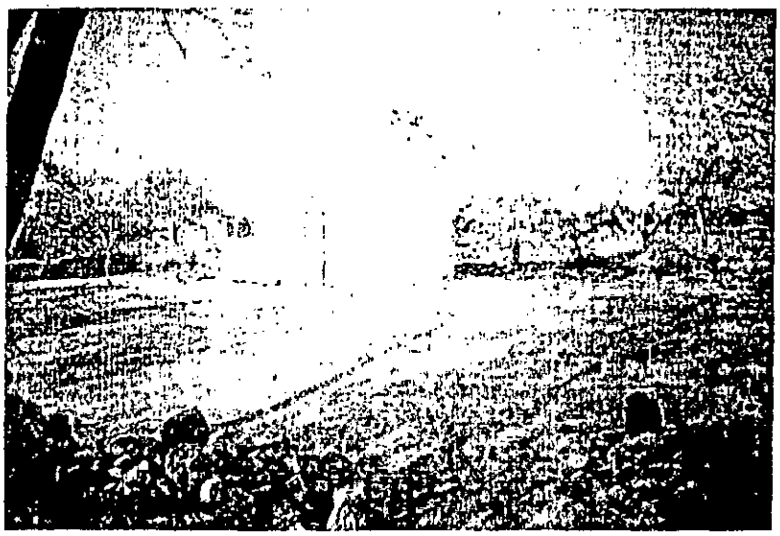


2. RAIN WATER HARVESTING STRUCTURE AT TILONIA



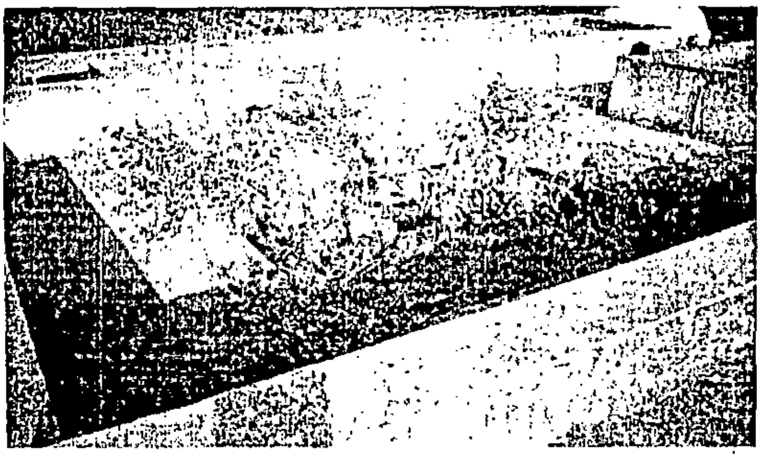
3. BAREFOOT ARCHITECT-BHANWAR JAT

PLATE 2. RAINWATER HARVESTING AT TILONIA



1. GEODESIC DOME STRUCTURE MADE INTO CLINIC LABORATORY

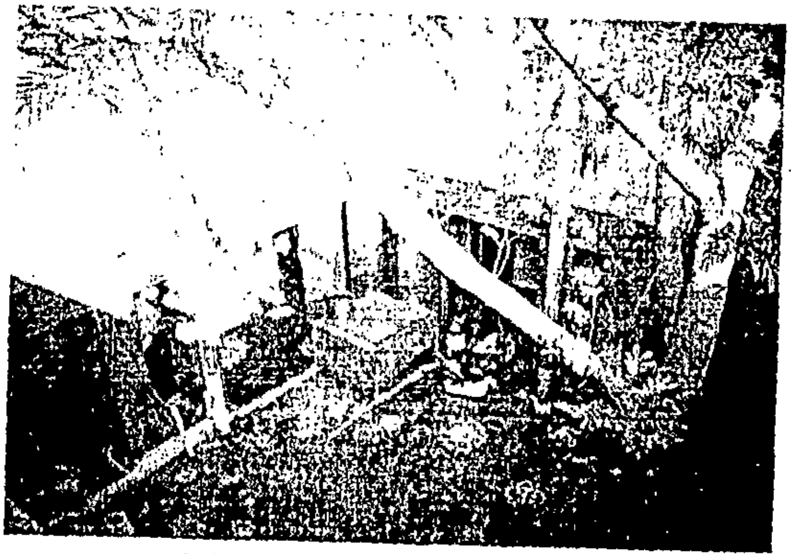
2. BAREFOOT ARCHITECT RAFIQ KHAN WITH GEODESIC DOME STRUCTURES



3. COURTYARD CONCEPT FOR THE HOSPITAL BUILDING

PLATE-3: GEODESIC DOME STRUCTURES AT TILONIA

1. COURTYARDS AS INTERNAL OPEN PLACE



2. COURTYARD PUT TO VARIOUS USES

3. VILLAGERS WORKING ON SOLAR LAMPS

PLATE-4: SOLAR TECHNOLOGY AT TILONIA

9.3 CLIMATIC CONDITIONS

Though located in Rajasthan, Ajmer experiences a moderate climate. As compared to other places of similar or even higher latitudes in Rajasthan Ajmer is milder and less hot. It's comparatively not that dry in summer and is cool during winters. The rainy season starts from July and ends sometime in the middle of August. During this time some flora does sprang out on the hills around, covering the barren and rugged relief with somewhat regular stretches of green. Often, the lakes of *Ana Sagar* and *Foy Sagar* do get saturated and overflow during this season. The average rainfall is 21.1 inches. This is also the time for picnic and hiking for the otherwise insert local masses of the city.

Summer: -

Mean maximum temperature: 43.7° C

Mean minimum temperature: 37.7° C

Winter: -

Mean maximum temperature: 23.3° C

Mean minimum temperature: 15.5° C

Other information: -

Altitude from mean sea level: 486 mt.

Clothing: summer- light tropical clothing.

Winter - light wollen clothing

Tourism seasons: - October to march

Languages: - Hindi, Rajasthani, Sindhi, and Urdu.

TABLE:11 CLIMATIC DATA FOR THE AJMER CITY

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT	NOV.	DEC.
MEAN MAX.	23.7	26.91	32.6	37.03	39.35	37.8	33.3	32.13	32.97	32.4	28.4	25.03
R.H.pm %	34.63	29	22.2	23.29	26.5	43.25	59.42	61.75	50.91	37.57	38.05	40.44
W.B.T: °C	14.5	15.8	17.8	21.2	23.5	26.5	24.5	25.2	26.3	21.3	18.8	16.4
24 HOURS WIND SPEED	.97	1.08	1.48	1.89	2.59	2.85	2.59	2.16	1.84	1.10	.94	.85
ET: MAX °C	18.9	21.9	23.8	26.3	27.8	28.5	26	26	27	24.8	22.8	20.2
MEAN MIN. DBT °C	6.97	9.93	16.6	22.07	26.25	26.48	25.17	24.24	22.41	17	11.15	8.25
R.H. am %	65	55	40	36.2	44.8	63.1	75.2	74.4	66.1	58.6	59.9	65.1
W.B.T: °C	4.3	6	9.3	13.2	18.2	21.5	21.8	20.7	18.2	12.5	7.2	5.2
ET: MIN °C	2.9	5.2	11.2	16.2	20	20.5	20	19.5	18	13.2	7.3	4.5

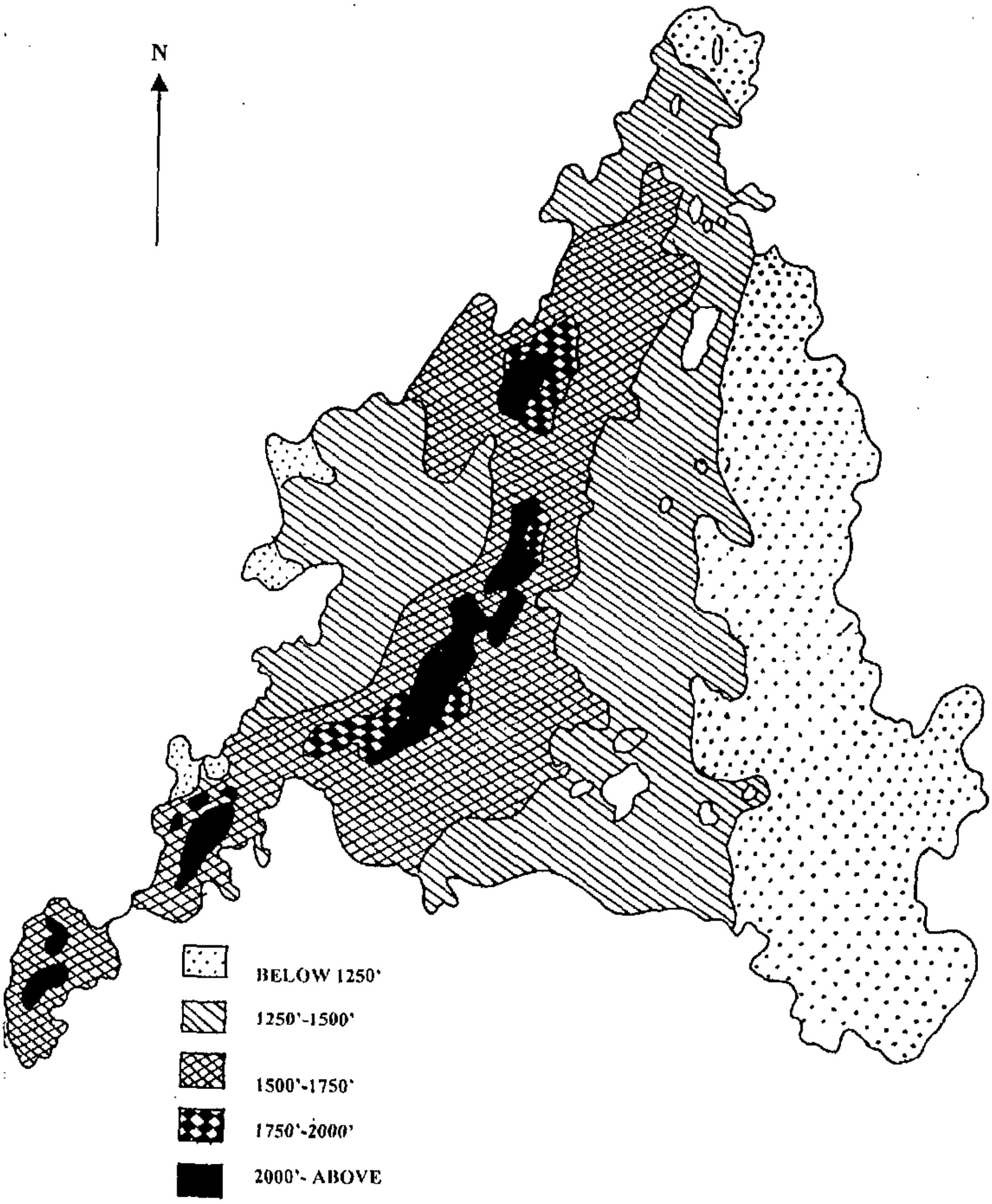
Source: AJAY SHARMA, " FOREST DEVELOPMENT IN AJMER DISTRICT," THESIS REPORT, DEPARTMENT OF GEOGRAPHY, GOVERNMENT COLLEGE, AJMER.

9.4 PHYSIOGRAPHY OF AJMER

Ajmer district is triangular in shape. It is generally a level plain inter-spread with low hills, which run from the northeast to the southwest in Ajmer district. Ajmer district is composed of 4 subdivisions namely Ajmer, Beawar, Kekri, and Kishangarh and 5 Tehsils namely Ajmer, Beawar, Kekri, Kishangarh and Sarwar.

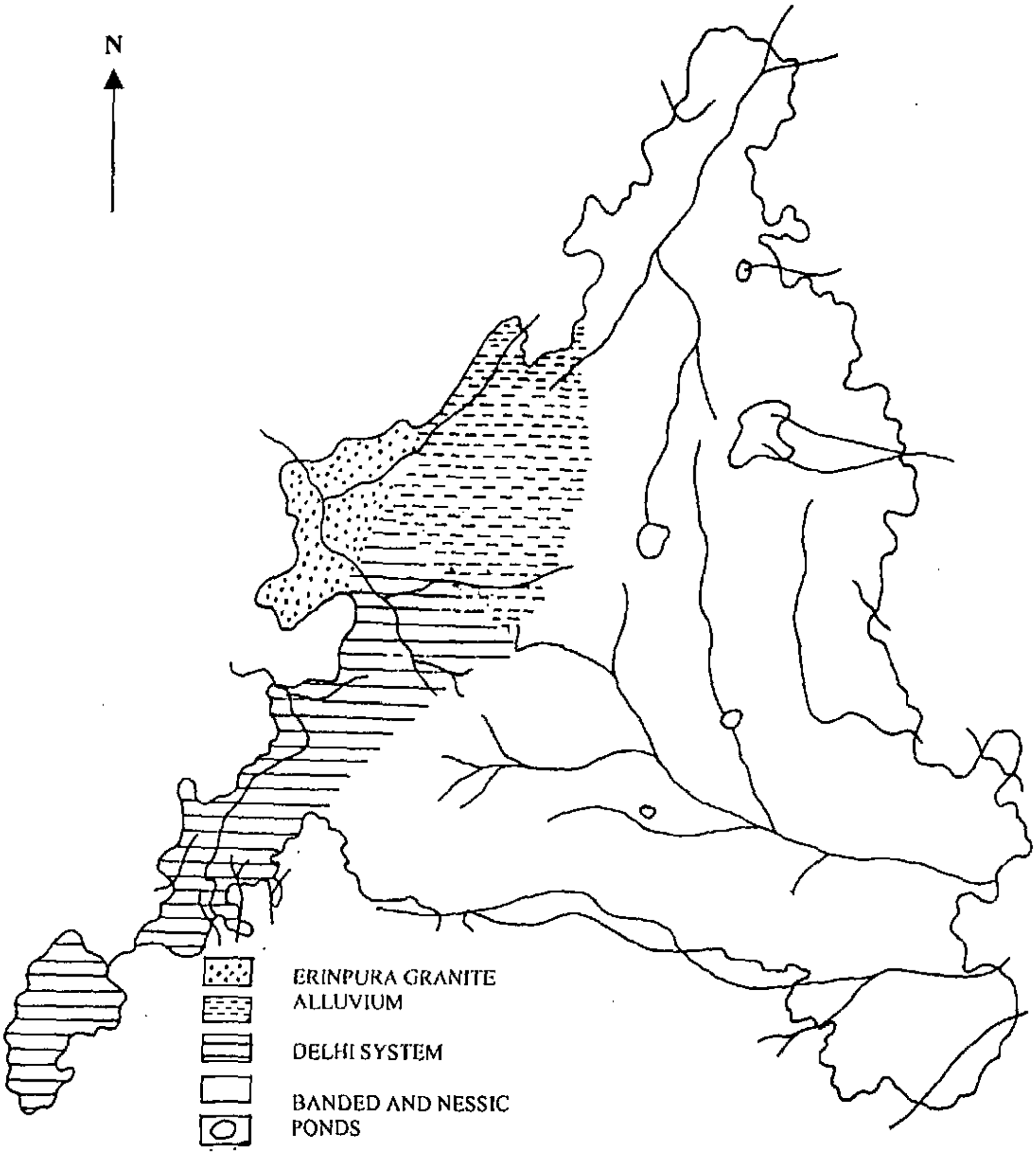
Aravali range, which divides the plains of Marwar from the high table land of Mewar, passes through this district. The range comes in to prominence near Ajmer city where it appears in a parallel succession of hills. The highest point in the district is about 870 mt. MSL. On which Taragarh fortress is situated. The Nagpahar at a distance of 5 km. West of Ajmer city attains a scarcely inferior elevation. The range marks the dividing watershed of the region. The rain, which falls on the southern side of Nasirabad, finds its way through the Chambal into the Bay of Bengal, the rain, which falls on the other side, is discharged by the Luni into the Gulf of Kutch.

There are five rivers, which flow through the district namely the Banas, the Khari, the Sagarmati, the Saraswati and the Rupan garh. All the rivers are reduced to narrow trickles of water in hot weather but become torrential streams in the rains. River Banas, which rises in the Aravali hills, enter this district near village Jeetapara in Kekri Tehsil. [15]



MAP-6 RELIEF MAP OF AJMER DISTRICT

Source: AJAY SHARMA, "FOREST DEVELOPMENT IN AJMER DISTRICT," THESIS REPORT, DEPARTMENT OF GEOGRAPHY, GOVERNMENT COLLEGE, AJMER.



MAP-7 DRAINAGE OF AJMER DISTRICT

Source: AJAY SHARMA, "FOREST DEVELOPMENT IN AJMER DISTRICT," THESIS REPORT, DEPARTMENT OF GEOGRAPHY, GOVERNMENT COLLEGE, AJMER.

9.5.2 RAINFALL:

The normal annual rainfall was recorded 52.73-cm. While the actual rainfall was 73.62 cm in 1983 and 45.13 cm in 1984. There are large variations in rainfall from year to year and the distribution of rainfall is also fairly arratic and at times there is a gap of fortnight or more. (Fig. 2)

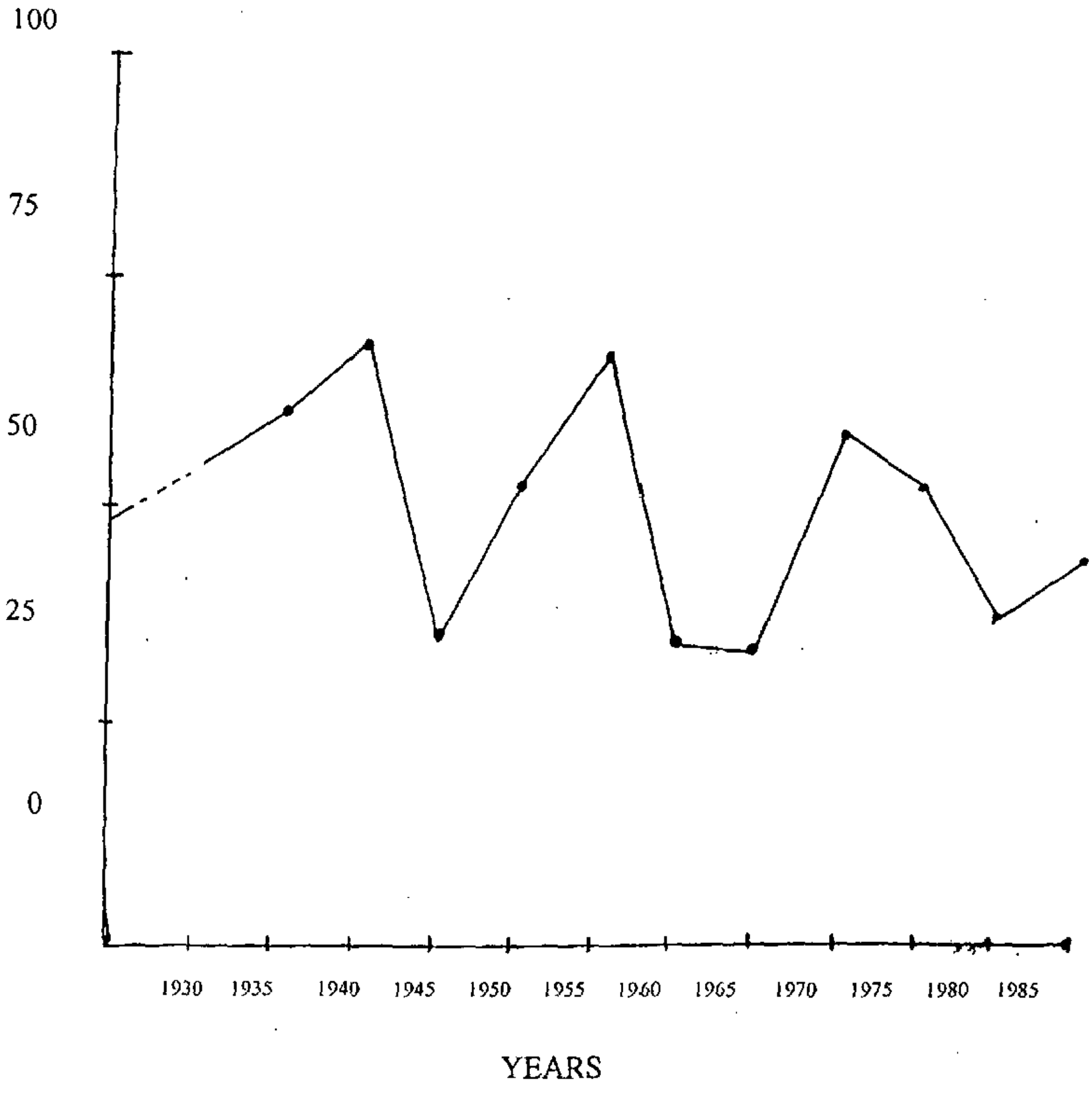


FIG-2 RAINFALL VARIATION IN AJMER DISTRICT

9.5 CLIMATE

9.5.1 TEMPERATURE

The district has a hot dry summer and cold tracing winter. The rainy season is comparatively short in this region. The maximum temperature ever recorded was 45.6°C and the minimum ever recorded is -2.8°C at Ajmer center during 1980. During this period the mean temperature remained 22.5° C (Fig. 1)

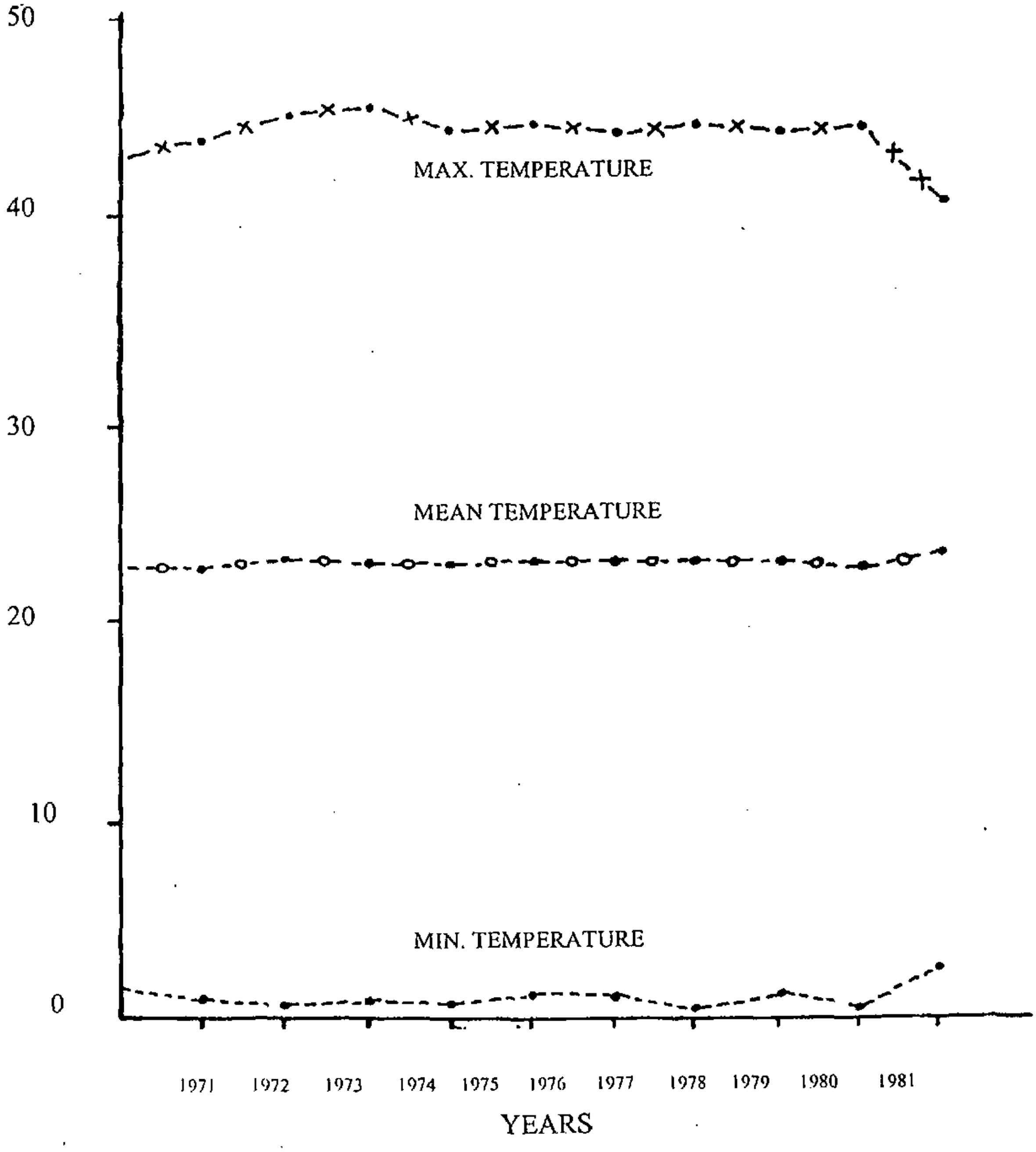


FIG-1 TEMPERATURE VARIATION OF AJMER DISTRICT

9.6 SOIL

The soil resulting from the disintegration of these rocks is of a sandy nature. Which results from scbists and quartaites and contains large proportion of sand and it is found in most of the blocks of Ajmer, Beawar, Kishangarh and Sarwar ranges. In most of the areas it is very shallow dry and of poor quality. Soil resulting from granite and gneiss contains a certain amount of clay and is comparatively good and is found in Kishangarh, Sarwar and Beawar and in some blocks of Raoli ranges. In some of the reserves a great deal of deep, sandy soil is found at the foothills and in the village. In some cases sand dunes are formed due to wind blown sand, are found near Ajmer and Pushkar, the hillsides are generally covered with rock debris or sheets of rock and the soil is generally very shallow. The rocks generally split into layers, which are almost vertical, so that the roots of the trees can penetrate into them to some extent. In brief it may be said that the soils are very dry, of poor quality and very shallow on the hillsides.

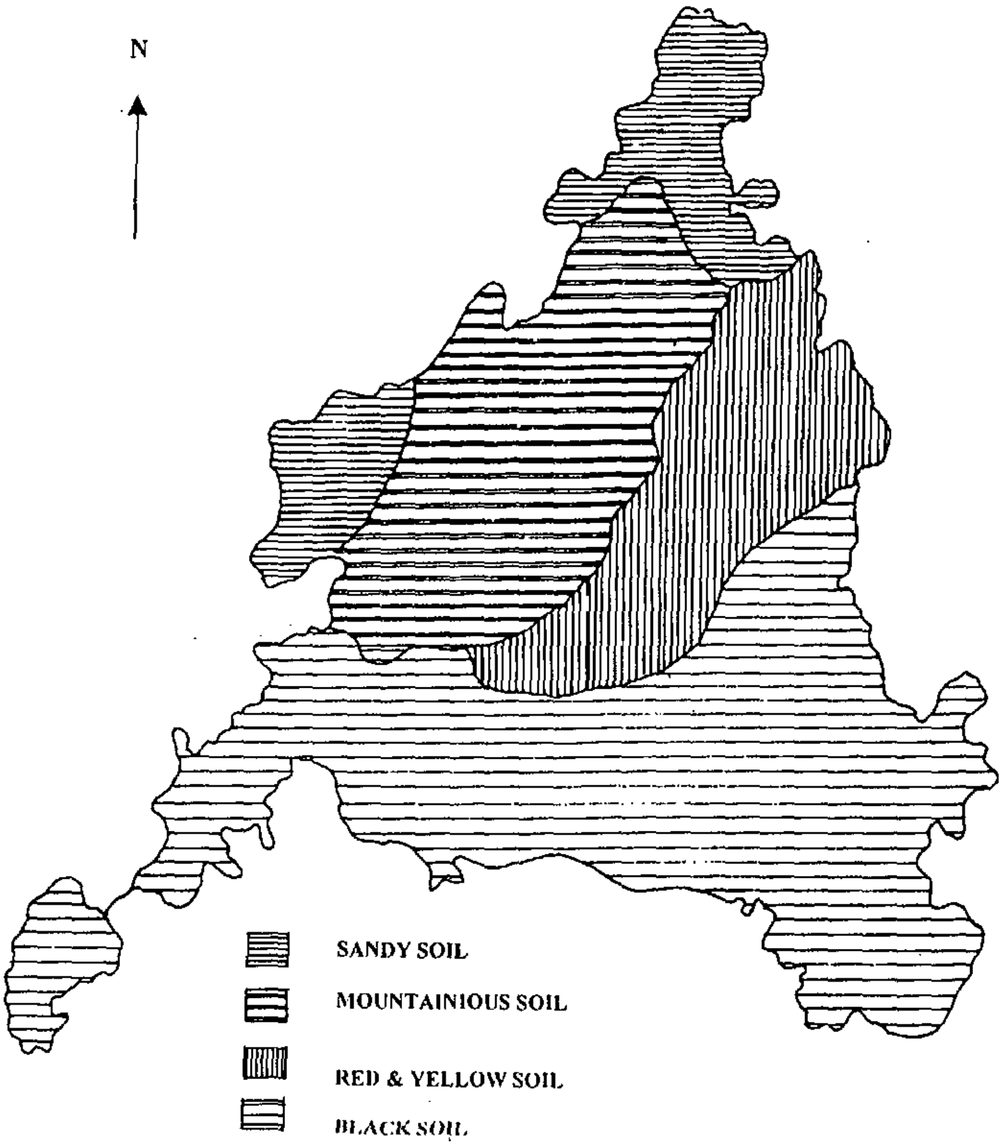
9.7 MINERAL PRODUCTION

Main minerals of the area are felspar, quartz, asbestos, soapstone, magnesitie, calcite, limestone, mica, emerald, marble, granite, and masonry stone. Fairly good reserves of barytes fluorit, wolastonite and vermiculite have also been found.

TABLE: 12 MINERAL PRODUCTION IN AJMER DISTRICT

	Production: 1999-00 (Tonnes)
Limestone	17,77,000
Limestone burning	11,672
Masonry stone	1,50,400
Marble I Block	13,453
Marble II Khanda	1,44,455
Quarty	23,324
Brick earth	40,285
Jhanjhar Kankar	11,983
Asbestos	2,519
Felspar	54,290
Magnesite	8
Mica	10

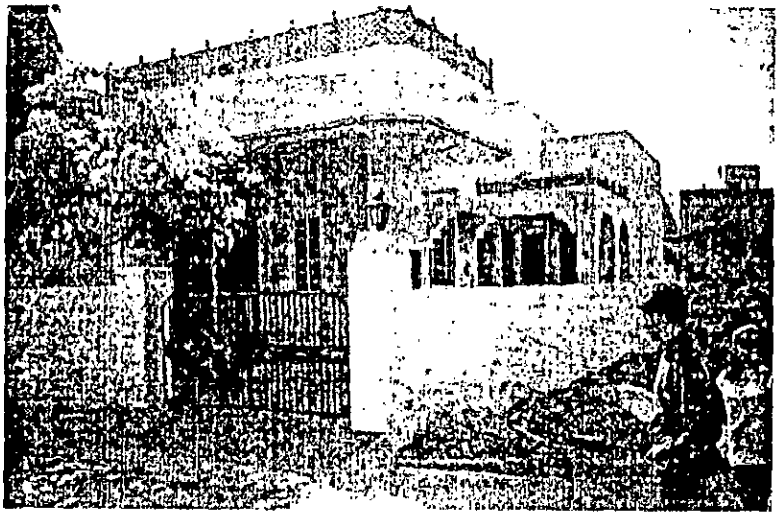
Source: MASTER PLAN OF AJMER



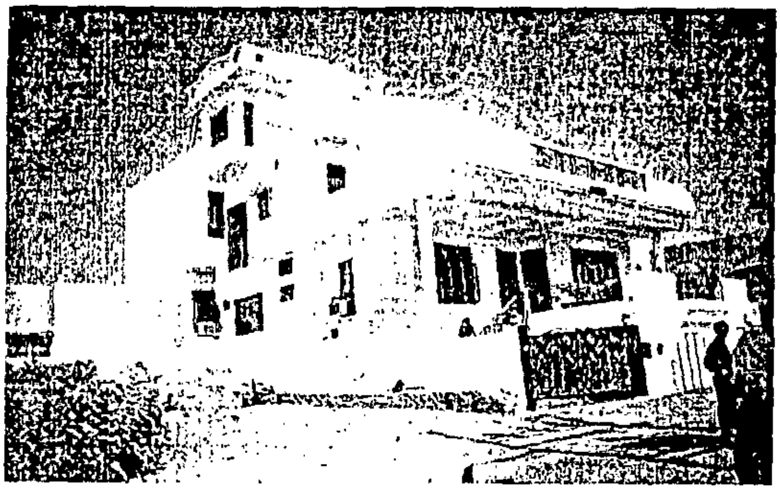
MAP-8 SOILS FOUND IN AJMER DISTRICT

Source: AJAY SHARMA, "FOREST DEVELOPMENT IN AJMER DISTRICT," THESIS REPORT, DEPARTMENT OF GEOGRAPHY, GOVERNMENT COLLEGE, AJMER.

1. THE OVERHANGS LARGE ENOUGH TO PROVIDE SHADE



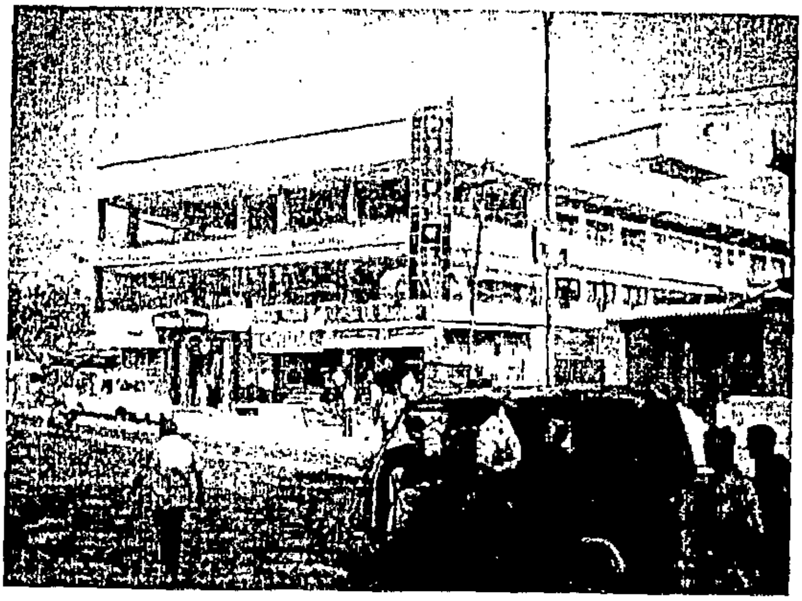
2. THE HOUSE IS ORIENTED E-W, NORTH FACE IS ALWAYS SHADED



3. THE USE OF WHITE COLOR INCREASES RELECTIVITY, BUT PRODUCES GLARE

PLATE-7 CURRENT HOUSING PRACTICES AT AJMER

1. USE OF REFLECTING GLASS ON EASTERN FACE 2.



3. USE OF GLASS ON SOUTHERN AND WESTERN FACADE

PLATE-8 THE USE OF GLASS ON EXTERNAL FACADES IN BUILDINGS

CHAPTER-10
RECOMMENDATIONS AND CONCLUSIONS

10.1 OVERVIEW

There is evidence that many recent buildings designed to be energy efficient are not performing as well as expected. A factor, which is often overlooked, is that energy is comparatively cheap and accounts for only 1-2 % of total occupancy costs including salaries. This means that there is not the incentive to incur extra expenditure to modify systems to meet the original performance specification.

It must be said, however, that this in the context of relatively low energy prices. However, the picture changes when energy costs are related to profits where they can range from 10-20% of the total. Where an environmentally effective building really does score is in the sphere of staff well-being.

Not all the fault lies with clients. Many professionals are reluctant to negotiate new design territory for fear of falling victim to untried technology or because they will not make the effort to learn new construction techniques. All construction professionals operate in the shadow of 'professional indemnity', which tends to make them over cautious and not ask questions after completion.

While design professionals are urged to work as a team, this is often difficult in practice. Operating against integrated design procedures is fee competition, which sometimes reduces returns for design work to less than cost. In a cut-throat world, designers across all disciplines are more often competitors than collaborators. A consequence of this is that services designers are often brought into the project at a late stage. Furthermore, a fee structure, which is based on contract or sub-contract cost, operates as a disincentive to services engineers. They are less likely to embrace low energy design, which involves excluding engineering hardware, the costs of which would enhance their fees.

10.2 FINDINGS

10.2.1 WHY DO THINGS GO WRONG?

a) THE HIGH TECH DEMAND

Some designers are seduced by the imagery of advanced technology and install hardware that greatly exceeds the real demands of the building and its occupants. Avoiding the technological fix and installing only essential technology that is efficient, not over-complex, easy to use and maintain, should be the aim of designers. Over-complex systems, which require elaborate maintenance, tend to deteriorate fairly rapidly because service managers are not up to the demands of the technology. In extreme cases the system is abandoned altogether.

One problem facing clients is the relative scarcity of information, which is accessible to the non-specialist. Even the professionals have problems in this respect.

b) OPERATIONAL DIFFICULTIES

It is unfortunately the case that guidance/instruction manuals are often poorly written and inadequate in terms of information. There is a universal problem with instruction manuals because experts write them on the system in question that find it impossible to empathize with the uninitiated installer and operator. They cannot conceive the breadth of the knowledge gap. This problem seems to be especially acute in terms of services technology.

Another problem, which is all too common, is that installers are expected to be able to comply with almost impossibly short completion dates. If the system goes into operation at a sub-standard level of efficiency due to time constraints, service managers and office staff are at a disadvantage from the start. This is a recipe for high-energy consumption and less than perfect comfort conditions.

c) BUILDING RELATED ILLNESS

Over recent years there has been awareness of the phenomenon ‘sick building syndrome’, more accurately termed ‘building-induced sickness’. Factors like off gassing from plastics in furnishings and fittings or the frequency of fluorescent lights have been implicated. Poorly designed heating and ventilation systems have also been identified as culprits. There have been numerous horror stories of badly maintained systems providing a comfortable habitat for all manner of unmentionable life forms as well as closed systems recycling bacteria and viruses resulting in high levels of absenteeism.

d) INHERENT INEFFICIENCIES

A system designed to be energy efficient can be totally undermined if the whole system has to be operated to meet a small demand. For example, in small-scale buildings. It is not unusual to find an entire heating plant being run in summer to supply hot tap water. Unreasonable over-capacity is another problem. An elaborate and expensive chiller may be installed to meet the cooling demand. The scale of such inefficiencies may go unnoticed because of the absence of proper monitoring systems. System efficiency can drop dramatically without the management being aware of the problem. Often a catastrophic failure is the first indication that something is wrong.

Sophisticated controls and electronic management systems combined with zonal sub-metering will ensure that faults are pinpointed and system inefficiencies identified. The relatively small capital costs involved in such equipment will quickly be paid back. The operation of such systems must be supplemented by adequate supervisory and analytical input from knowledgeable staff.

e) COMMON ARCHITECTURAL PROBLEMS

- Adverse effects of glass being underestimated. Maximization of daylight can produce problems.
- Inappropriate window design lacking refinement and ease of control.
- Poor controls and user interfaces.
- Fitting out which may contradict original design intentions, leading to poor performance.
- Tendency to highlight the positive and play down the negative. Downside risks not given the same weight as upside visions.

f) COMMON ENGINEERING PROBLEMS

- Adoption of inappropriate standards regarding climate control, lighting and distribution of services.

- Optimized engineering solutions, which may not be robust and flexible.
- A blind faith in technology tends to underrate the human factor and fails to focus down to the finely tuned needs of occupiers.
- Mechanical ventilation inappropriately designed in terms of rate of ventilation, efficiency, operating hours and zoning. Special problems occur with night ventilation.

10.3 RECOMMENDATIONS

- Extravagant use of energy had been a feature of the past century. Little consideration has been given to resource depletion; now that the energy costs are rising and reserves of some energy sources are causing concern, it is pertinent to evaluate proposed energy systems as to the effectiveness of their energy use. In other words, it would appear rational to reduce energy wastage before adopting any alternative energy source, since all energy is likely to be relatively expensive.
- Heating, ventilation and air conditioning systems can use less energy if operated on the economic cycle, which uses outside air for cooling whenever the temperature is low enough.
- An overall assessment would determine whether the benefits of a solar energy system matched the expenditure for it.
- It can be said that a new era in which solar energy supplies a significant fraction of the energy demand for the arid zone is possible but not here. While solar energy may be environmentally acceptable, the fact that it is capital intensive in an economy starved for capital may deter its use.
- In an age of resource depletion and a continued desire for development, it is probable that every energy source will be needed. Then the intrinsic advantages of solar energy in the arid zone, that is, relatively high flux density and availability at the point of use, may make it the logical choice.
- For most of the conventional buildings, consumption can be reduced by adopting energy conservation techniques, which begins at the planning stage.

  -Orientation

  -Use of common walls

-Zoning of spaces

- In hot dry climate, the form of dwellings should provide protection from solar radiation and shelter from hot dusty winds. These requirements can be satisfied by building forms that are compact and low rise, using small courtyards to provide light and air. These small courtyards will also provide outdoors spaces sheltered from the sun and wind. With inward-looking dwelling forms and windowless boundary walls, the building form can be continuous, with one building sheltering the next.
- Massive buildings with a high volume-to-surface ratio are advantageous since this will reduce the high range of external air temperature.
- Isolated high rise apartment blocks are totally unsuited to this climate as they are highly exposed to solar radiation and hot dusty wins, and do not provide sheltered outdoor spaces for the occupants.
- Medium rise apartment blocks are suitable to provide a dense and continuous urban form. They should avoid west-facing windows and minimize the area of well exposed to the west.
- Outdoor spaces if closely related to the dwelling, it can be used as outdoor living spaces and will be maintained by the occupants, and these outdoor spaces should be protected by walls.

10.4 DESIGN TIPS FOR A HOT DRY CLIMATE

<u>BECAUSE OF THE INTENSE SUNSHINE WE NEED: -</u>

- Pale surfaces (especially the roof) to reflect the sun;
- Double roof;
- Reflective foil insulations in the roof and walls is essential;
- Small north-facing windows set high under wide eaves. The hotter the summer, the smaller the windows and the wider the eaves. There is a tradeoff, however: small windows reduce night ventilation.
- No windows on eastern or western side of the house;
- Shading for any south-facing windows, if house site is north of 23.5 degrees S;

- Vegetation and/or verandahs around the house, if water supply permits, to provide shade;
- Earth-sheltered and underground housing are ideally suited to this climate;
- This is the perfect climate for solar power.

BECAUSE OF THE LOW HUMIDITY OF THE AIR: -

- Evaporative coolers work well in the dry atmosphere, and use little energy;
- The natural evaporative cooling effect of plants will be specially effective;
- Water features such as fountains and little garden pools are beneficial, if water supply permits.

BECAUSE OF THE LARGE DAY/NIGHT TEMPERATURE SWING: -

- Considerable heat storage capacity (bricks, stone, concrete) is needed in living areas, to keep daytime temperatures down;
- Bedrooms should be of lighter construction, so they cool quickly at night;
- Through ventilation on summer nights is essential (check the prevailing wind direction on warm summer nights). Roof-mounted exhaust fans can cool buildings at night by extracting hot air via grilles in the ceiling and replacing it with cool air drawn in through open windows;

BECAUSE BLOWING DUST CAN BE A PROBLEM IN DRY CLIMATE: -

- Vegetation around the house is desirable, to filter dust from the air, by impaction. Plant trees to block this wind, if blowing dust is a problem in the area.

10.5 DESIGN PROPOSAL

CALCULATION METHODS

If the calender date is expressed as the number of day of the year (NDY) then DEC. can be calculated from the following expression. To synchronize the sine curve with the calender, the distance from March equinox to the end of year 284 days is added to the NDY. As the year365 days corresponds to full circle 360°, the ratio 360/ 365=. 986 must be multiplied. Therefore:

DEC = 23.45 sin [.986(284+NDY)]

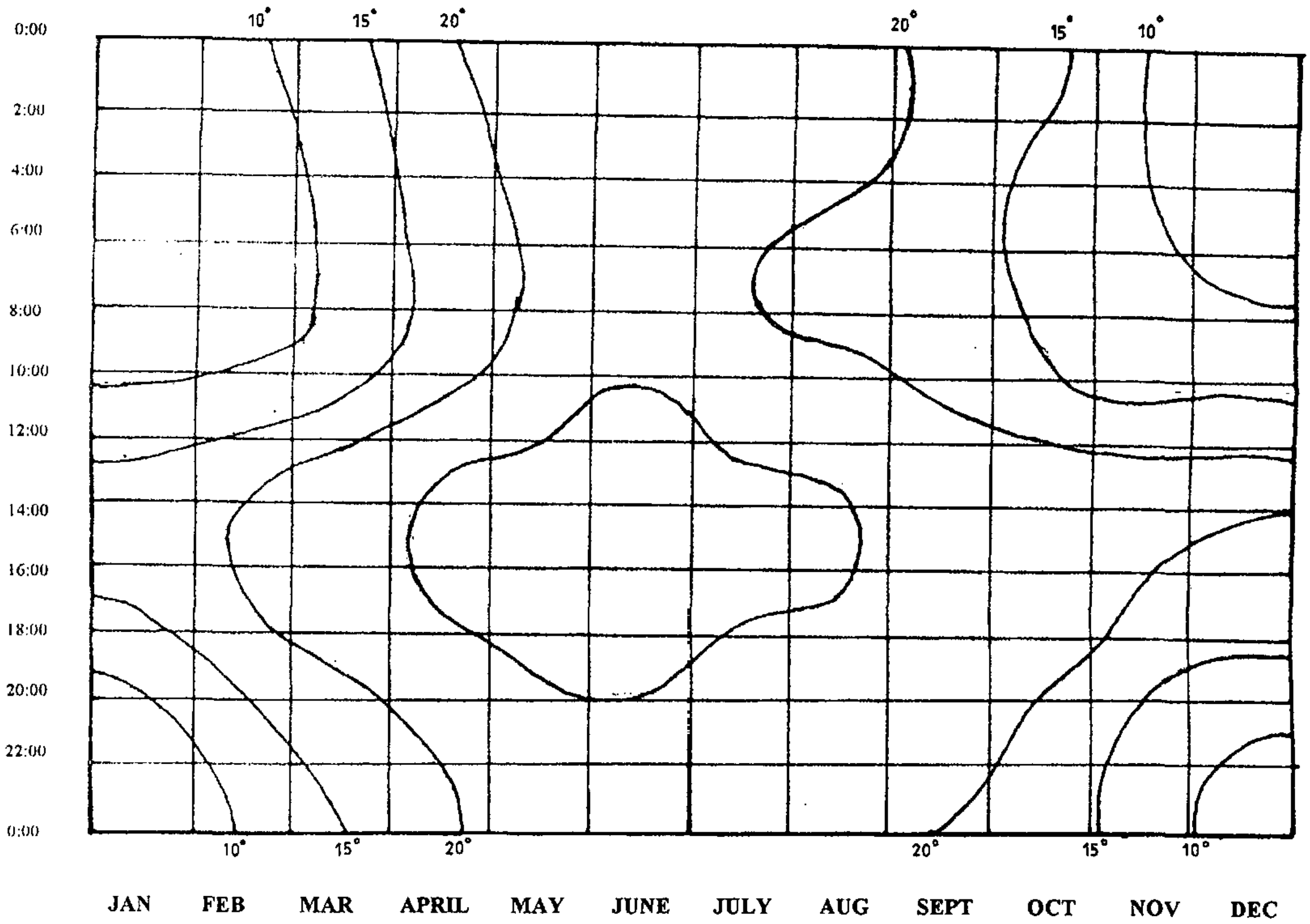
ALT = arc sin (sin DEC sin LAT + cos DEC LAT cos HRA)

AZI = arc cos [(cos LAT sin DEC – cos DEC sin LAT cos HRA)/ cos ALT **[16]**

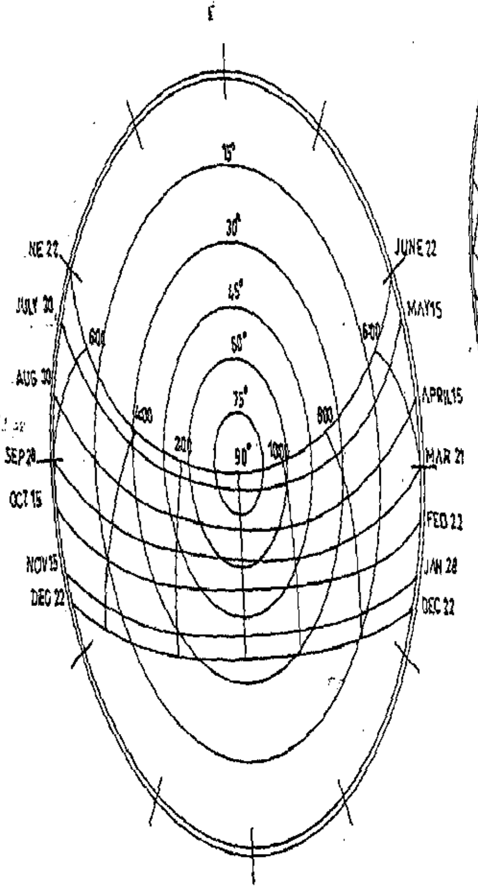
	JUNE 22		**15 MAY 30 JULY**		**15 APRIL 30 AUG**		**21 MARCH 28 SEPT**		**28 FEB 15 OCT**		**28 JAN 15 NOV**		**DEC 22**	
TIME	**AZI**	**ALT**	**AZI**	**ALT**	**AZI**	**ALT**	**AZI**	**ALT**	**AZI**	**ALT**	**AZI**	**ALT**	**AZI**	**ALT**
6:00	68.7	10.2	73.08	8.2	81.59	4.15	90.40	-.199	97.8	-3.86	106.7	-8.15		
8:00	79.17	36	84.6	34.5	94.2	30.9	104.8	26.3	112.3	22	121	16.4	125	13.5
10:00	89.7	62.6	99.2	61.3	115.4	56.8	128.1	50.5	136.2	44.3	143.9	36.3	147.1	32.2
00:00	180	86.9	180	82.3	180	72.9	180	63	180	54.8	180	44.9	180	40.1
14:00	270.3	62.6	260.7	61.3	244.6	56.8	231.8	50.5	223.7	44.35	216.1	36.3	212.8	32.2
16:00	280.8	36	275.3	34.5	265.7	30.9	255.2	26.36	247.4	22	238.1	16.4	235	13.5
18:00	291.2	10.2	286.9	8.2	278.4	4.15	269.6	-.199	262.2	-3.86	253.3	-8.15		

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Mean Max	23.7	26.91	32.6	37.03	39.35	37.8	33.3	32.13	32.97	32.4	28.4	25.03
R.H.*pm* %	34.63	29	22.2	23.29	26.5	43.25	59.42	61.75	50.91	37.57	38.05	40.44
W.B.T:°C	14.5	15.8	17.8	21.2	23.5	26.5	24.5	25.2	26.3	21.3	18.8	16.4
24 HOURS WIND SPEED	.97	1.08	1.48	1.89	2.59	2.85	2.59	2.16	1.84	1.10	.94	.85
ET: MAX°C	18.9	21.9	23.8	26.3	27.8	28.5	26	26	27	24.8	22.8	20.2
MEAN MIN. D.B.T°C	6.97	9.93	16.6	22.07	26.25	26.48	25.17	24.24	22.41	17	11.15	8.25
R.H. *am* %	65	55	40	36.2	44.8	63.1	75.2	74.4	66.1	58.6	59.9	65.1
W.B.T °C	4.3	6	9.3	13.2	18.2	21.5	21.8	20.7	18.2	12.5	7.2	5.2
ET: MIN °C	2.9	5.2	11.2	16.2	20	20.5	20	19.5	18	13.2	7.3	4.5

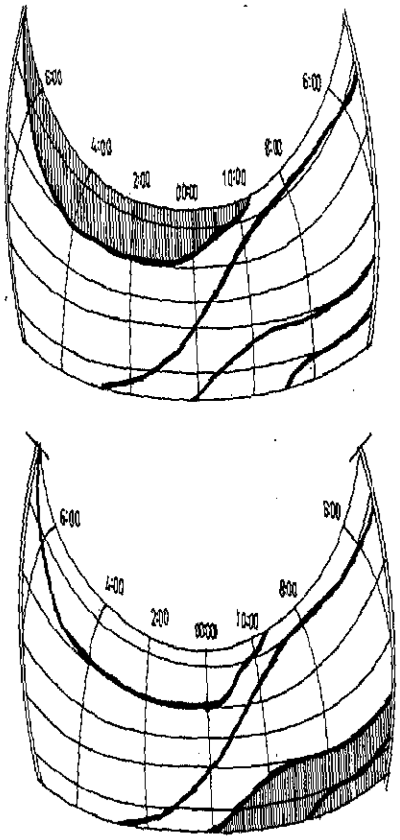
CLIMATIC DATA FOR THE AJMER CITY



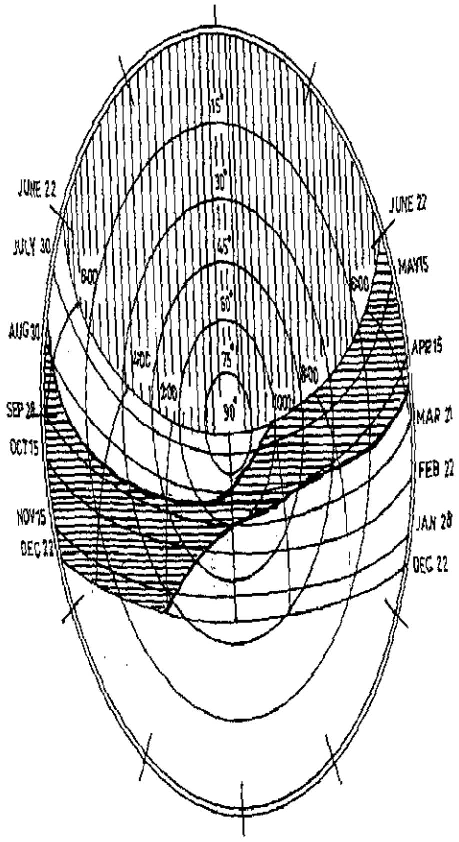
TEMPERATURE ISOPLETH FOR AJMER CITY



SOLAR PATH DIAGRAM FOR AJMER (LAT=26°27')
FROM 6:00 A.M. TO 6:00 P.M.



TRANSFERENCE OF TEMP. ISOPLETH OVER SUNPATH

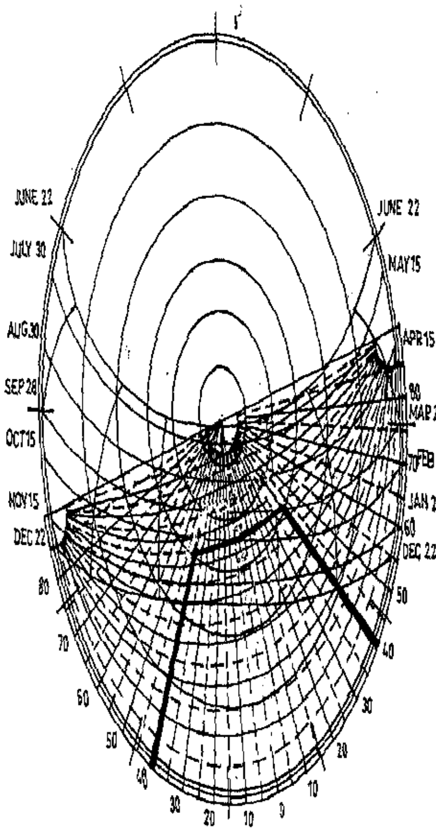


HATCHED SUN PATH DIAGRAM AND ANALYSIS OF THE SUN PATH DIAGRAM

Much of the energy demand can be reduced by proper fenestration design, including solar control and shading devices, two most important climatic factors that influence the thermal behaviour of a building are air temperature and solar radiation. The first task would be to determine when solar heat input is desirable and when solar radiation is to be excluded and then to provide appropriate solar control. A prerequisite of designing the solar control is to know the sun's position at any time of the year and then related it to the building.

Temperature isopleth is transferred over sun path diagram to establish the overheated and under heated periods.

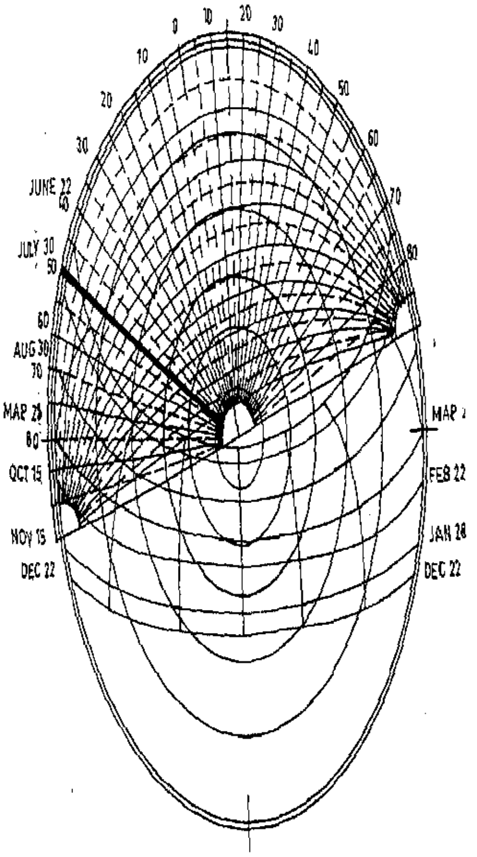
1. Part of the sky, which the sun never crosses
2. Part of the sky, which the sun crosses when average temperatures are hot. The windows facing west will receive low angle sun when air temperatures are too hot and it will be difficult to shade. Any opening facing the first half of this part of sky will receive radiation when air temperatures are hot both from high angle sun and low angle sun from the west.
3. Part of the sky, which the sun crosses when average temperatures are comfortable. Any opening facing the first half will receive morning sun and may cause glare. Windows facing the later half part will receive sun from low angle when it is cool and from high altitude when it is hot.
4. Part of the sky, which the sun crosses when temperatures are cool or cold. Any opening facing first half of solar path will receive morning sun from low altitude. Windows facing the later half part will receive radiation from high altitude and will also cause glare



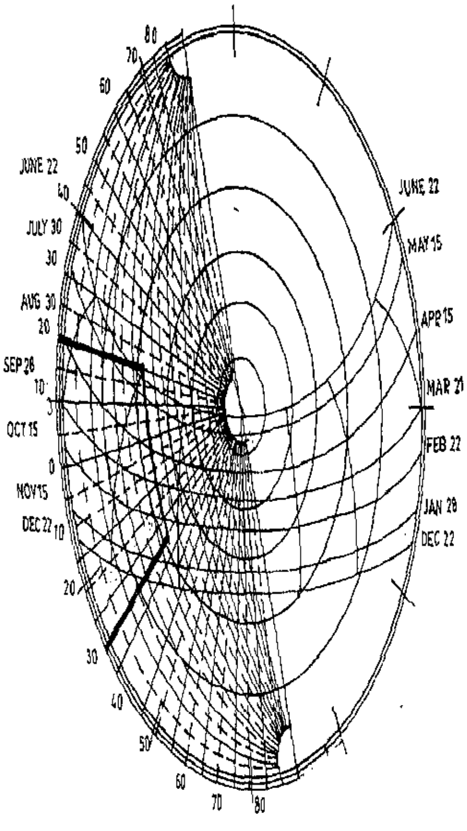
1. OVERLAPING OF SHADOW ANGLE PROTRACTOR OVER S-E FACE

1.SOUTHERLY ORIENTATION CALLS FOR THE COMBINATIVE SHADOW MASK, BECAUSE OF EGG CRATE'S HIGH SHADING RATIO AND WINTER HEAT ADMISSION FROM LOW ALTITUDE. IT WOULD BE BEST SUITABLE FOR THIS ORIENTATION

3. FOR NORTH WESTERLY ORIENTATION . VERTICAL DEVICE WOULD SERVE WELL HAVING RADIAL MASK, WHEN INCLINED TOWARDS THE NORTH, THEY WILL GIVE MORE PROTECTION FROM SOUTHERN POSITIONS OF SUN.



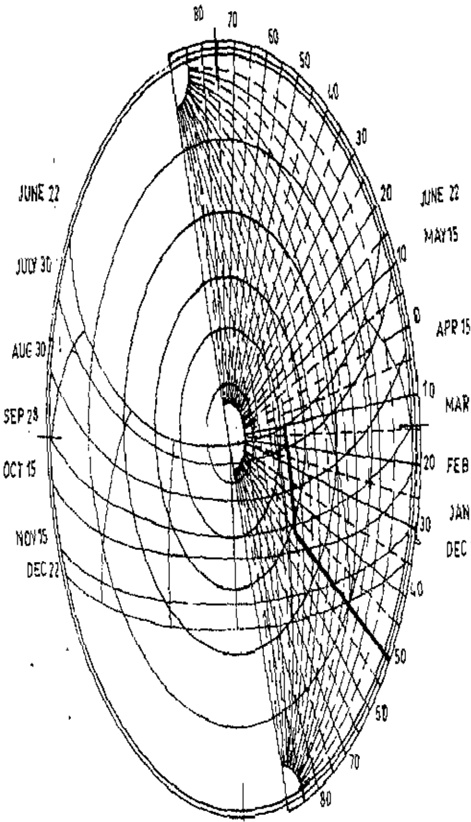
3. OVERLAPING OF SHADOW ANGLE PROTRACTOR OVER N-W FACE



"RLAPING OF SHADOW ANGLE PROTRACTOR OVER S-W FACE

2. WESTERLY ORIENTATION WILL RECEIVE SOLAR RADIATION WHEN AIR TEMPERATURES ARE HIGH FROM HIGH ALTITUDE AS WELL AS FROM LOW ANGLE SUN. HENCE WEST-FACING WINDOWS SHOULD BE AVOIDED, AS IT WOULD BE DIFFICULT TO SHADE THEM.

4. EAST FACING WINDOWS WILL RECEIVE MORNING SUN AT LOW ANGLE WHEN IT IS HOT WHILE IT WOULD BE COMFORTABLE IN THE WINTERS.



4. OVERLAPING OF SHADOW ANGLE PROTRACTOR OVER N-E FACE

FIG. 1, SHOWS THAT A HORIZONTAL SHADING DEVICE ALONE WOULD BE INEFFECTIVE FOR THE EARLY NOON AND AFTER NOON PERIODS AND THEREFORE VERTICAL SHADING DEVICES e.g. BAFFLES TOWARDS THE EAST AND WEST SIDE OF THE WINDOW SHOULD BE PROVIDED TO ASSIST.

THE FOLLOWING REQUIREMENTS CAN BE READ OUT FOR A WINDOW FACING S-E

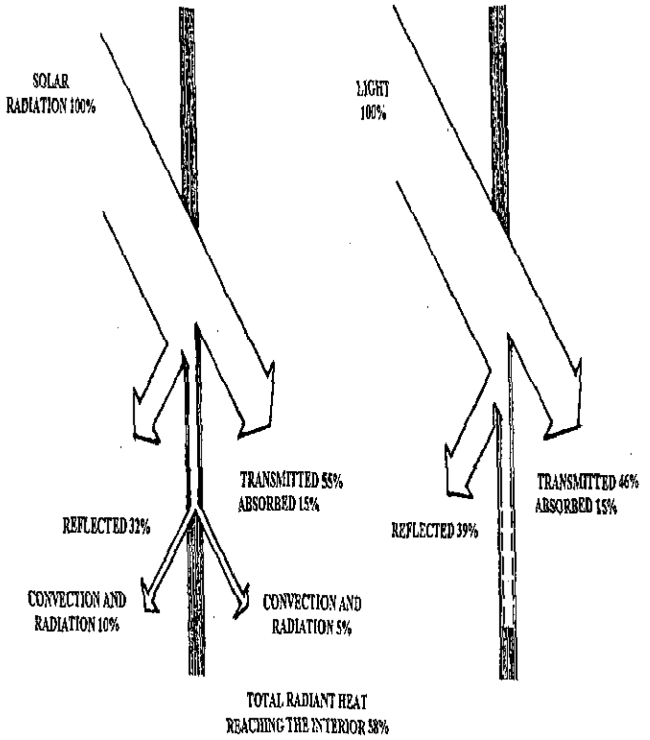
1. FEB 28 VSA 60°
2. HAS FOR MARCH 21= 40°-90°
   FOR FEB 28 = 40°-90°

THE PROJECTION OF HORIZONTAL LOUVRE AT THE WINDOW HEAD LEVEL WOULD BE

X=1.2/TAN 60°=.69≅.7 mt

THE WEST AND EAST SIDE BAFFLE SHOULD BE

Y=1.5/TAN 40°=1.78, WHICH IS RATHER TOO LARGE, SO PERHAPS TWO BAFFLES OF SIZE .8 mt CAN BE ADOPTED TO GIVE THE SAME HSA



HEAT REFLECTING SOLAR CONTROL GLASS

FIG. 2. AGAIN SHOWS THAT A HORIZONTAL SHADING DEVICE ALONE WOULD BE INEFFECTIVE FOR THE AFTERNOON PERIODS FOR BOTH HIGH AND LOW ALTITUDES OF SUN AND VERTICAL DEVICES ON WESTERN AND SOUTHERN FACES OF THE WINDOW WILL ASSIST AND THEREFORE MUST BE PROVIDED.

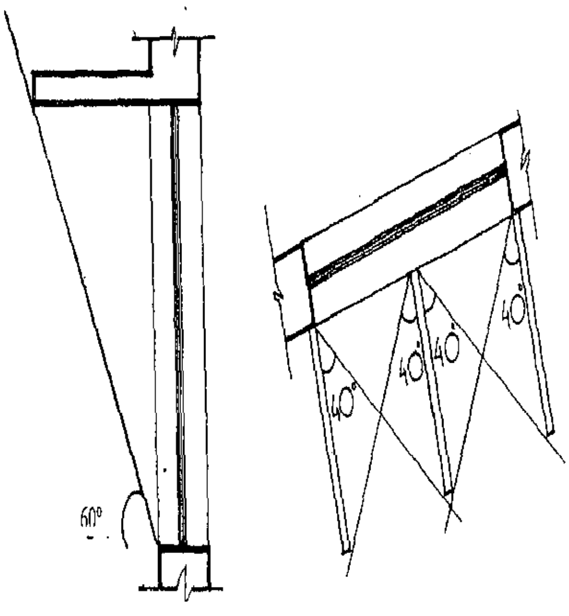
THE FOLLOWING REQUIREMENTS CAN BE READ OUT FOR A WINDOW FACING S-W

1. WINDOW FACING S-W, VSA= 40°
2. WITH HAS FOR JUNE 22 = 35-90°
   FEB 28

THE PROJECTION OF THE SHADING DEVICES WOULD BE

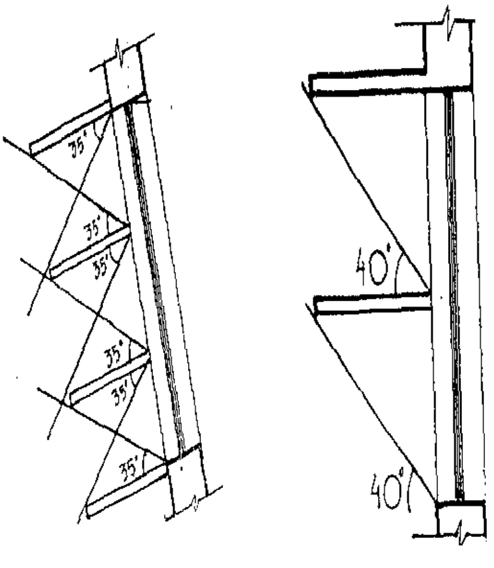
X=1.2/TAN 40°=1.4 mt. PERHAPS TWO HORIZONTAL LOUVRES OF .7 mt. EACH CAN BE ADOPTED.

Y= 1.5/TAN 35°=2.1 mt.. SO PERHAPS 3 BAFFLES OF SIZE .7 mt. CAN BE ADOPTED.



SECTION PLAN

SHADING DEVICES FOR THE S-E FACE.



PLAN SECTION

SHADING DEVICES FOR THE S-W FACE.

FIG. 3. SHOWS THAT NO HORIZONTAL DEVICE BUT ONLY A VERTICAL DEVICE ON THE WESTERN FACE OF WINDOW FACIGN NORTH WOULD BE EFFECTIVE.

THE FOLLOWING REQUIREMENTS CAN BE READ OUT FOR A WINDOW FACING N-W

1. JUNE 22FHSA= 50°-90°

THE SIDE BAFFLE SHOULD PROJECT

Y= 1.5TAN/50°

= 1.25 mt.

WHICH IS RATHER TOO LARGE, SO PERHAPS TWO BAFFLES OF SIZE .6 mt. ON EAST SIDE OF THE WINDOW CAN BE ADOPTED TO GIVE THE SAME H.S.A.

FIG. 4. SHOWS THAT A HORIZONTAL SHADING DEVICE IS INEFFECTIVE FOR THE EARLY NOON PERIODS. A VERTICAL SHADING DEVICE-A BAFFLE ON THE SOUTHERN SIDE OF THE WINDOW SHOULD BE USED TO ASSIST.

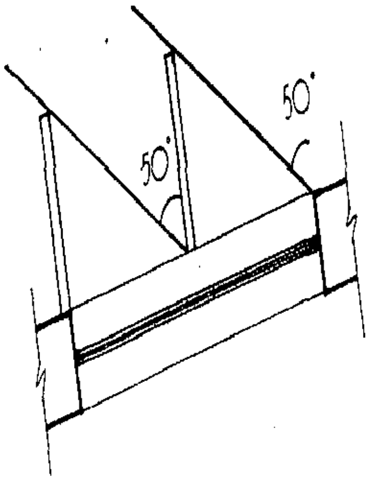
THE FOLLOWING REQUIREMENTS CAN BE READ OUT FOR A WINDOW FACING N-E

1. MARCH 21 VSA = 60°
2. WITH HSA FOR JUNE 22= 50-90°

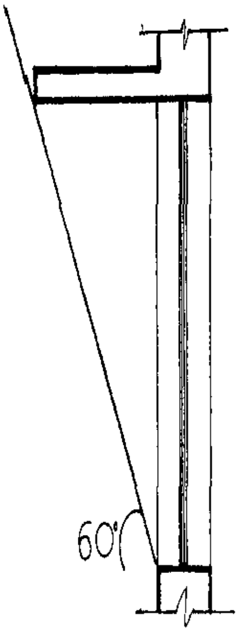
THE PROJECTION OF HORIZONTAL LOUVRE AT THE WINDOW HEAD LEVEL WOULD BE

X=1.2/TAN 60°=.69≅.7 mt

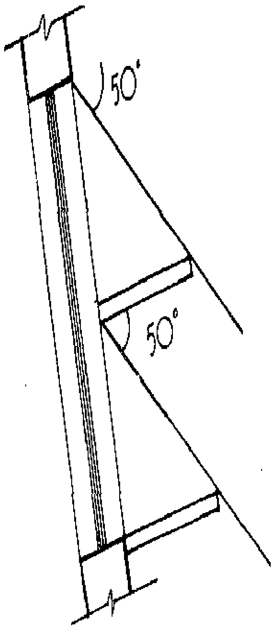
THE WEST AND EAST SIDE BAFFLE SHOULD BE Y=1.5/TAN 50°=1.25, WHICH IS RATHER TOO LARGE, SO PERHAPS TWO BAFFLES OF SIZE .6 mt CAN BE ADOPTED TO GIVE THE SAME HAS.



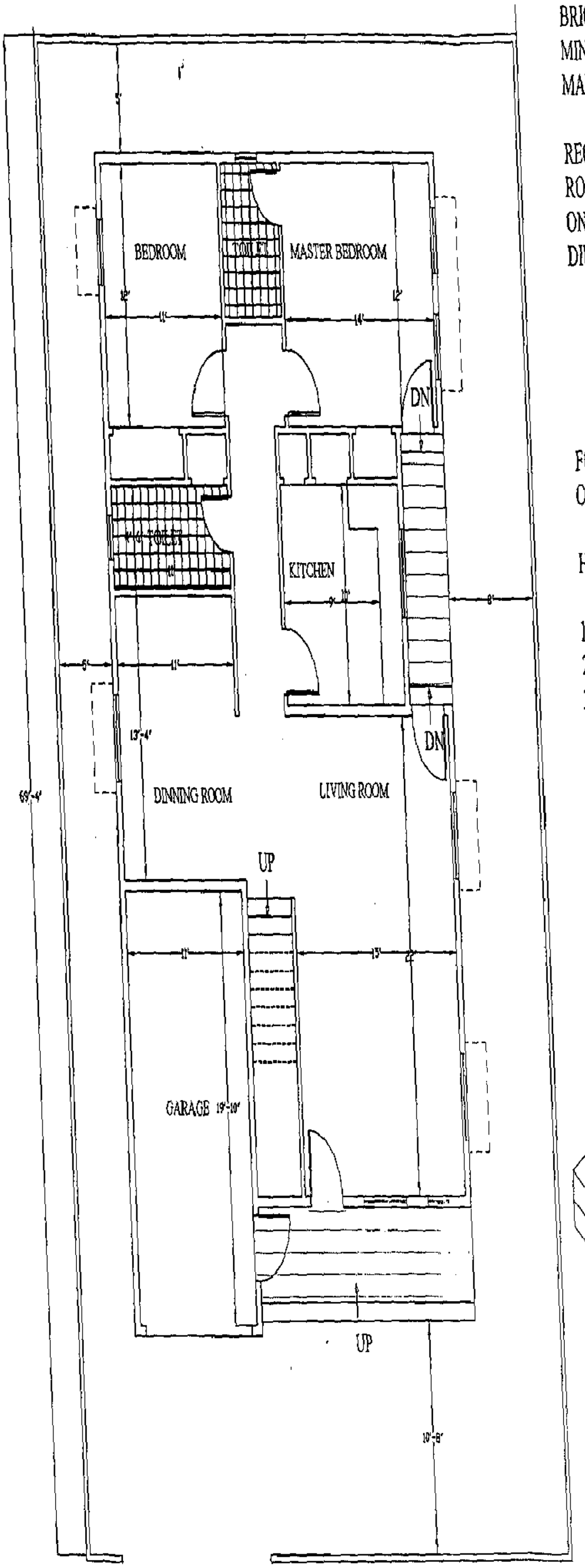
PLAN



SECTION



PLAN



BRICK	THICKNESS(MM)	TIME-LAG(HR)	U-VALUE
MIN	250	7	.41
MAX		9	

RECOMMENDED

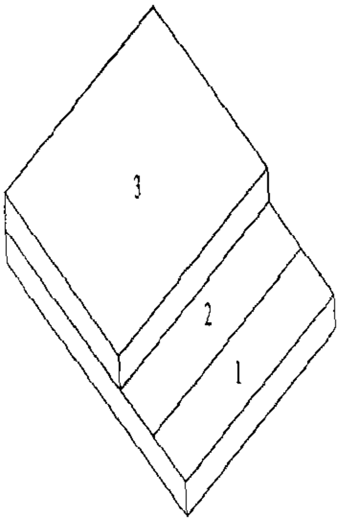
ROOMS FOR NIGHT USE ONLY		U-VALUE	TIME LAG
DIURNAL RANGE	10°C	.90	8-14
	12.5°C	.85	8-14
	15°C	.80	8-14
	17.5°C	.75	8-14
	20°C	.70	8-14
FOR DAY USE ONLY	-	-	8-14

HEAT REFLECTING GLASS FUNCTION

1. REDUCE HEAT GAIN
2. ALLOW A VIEW OUT
3. ALLOW DAYLIGHT TO ENTER
4. PREVENT GLARE
5. PROTECT FROM DIRECT SOLAR RADIATION

EXTERIOR SURFACE

COLOUR	% TOTAL INCIDENT HEAT REFLECTED
LIGHT GREEN	65



1. 100 mm reinforced concrete slab
2. two layers of roofing felt
3. khafgi (mix of cement, sand, lime and small chips of red bricks)

U-value of roof is more important than walls since they will be more effective in reducing total heat loss from the building

GROUND FLOOR PLAN

INTEGRATED SOLAR HEATING AND COOLING SYSTEMS

The use of incident solar radiation to meet the energy requirement of the building is appropriate for the location. The lack of rainfall diminishes one particular disadvantage of solar applications, the intermittent nature of the energy source. The low humidity allows for higher levels of intensity in the energy source and thus provides for greater flexibility in utilizing the solar radiation.

The key elements of an active solar system consist of:

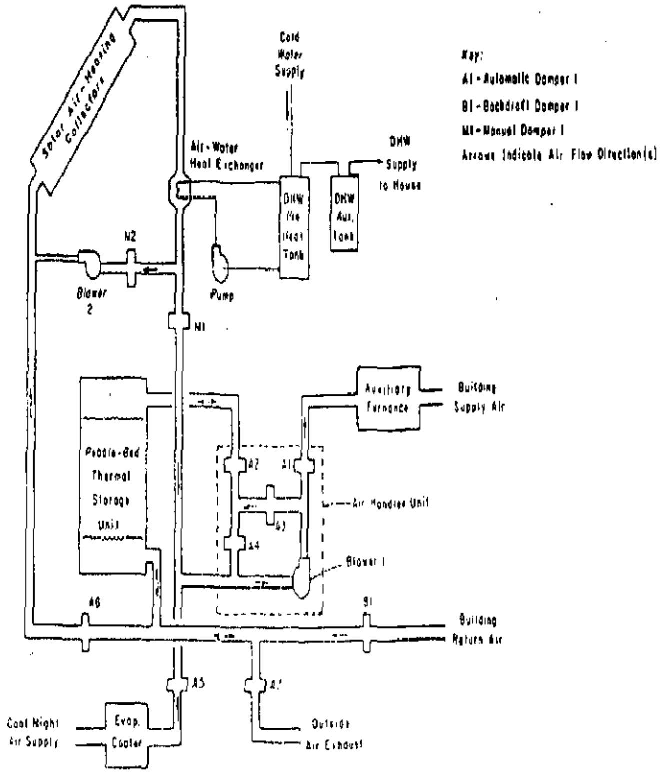
1. Solar collector array
2. A heat storage unit.
3. A heat transfer circuit.
4. A space-cooling machine.

The solar collector intercepts solar radiation, converts it to heat, and utilizing some heat transfer fluid, transfers the collected energy to a thermal storage unit-which is an essential element because it provides for use of solar generated heat available during periods of low solar radiation and at night.

Since the collectors utilize an aqueous solution as the collector heat transfer fluid-there are problems of freezing, boiling and corrosion. Then, using air as the collector fluid-freezing, boiling and corrosion difficulties are eliminated.

NOCTURNAL COOLING

Because of the substantial differentiation between day and night temperatures, it is possible to use nocturnal cooling by storing the cool night air in pebble-bed storage and then use the cool rocks to extract heat from the building during the day. The figure shows a solar system incorporating these features. This system provides solar space heating during the winter, solar domestic hot water and converts to a nocturnal cooling/cool storage system during the summer months. It is, of course, necessary that a changeover between the winter heating and summer cooling systems be made on a semi-annual basis. During the winter heating season, the solar system would be sized large enough to provide 50 to 70 percent of the space and domestic hot water heating loads. During the spring, summer, the solar system would provide 100 percent of the domestic hot water load.



SCHEMATIC OF A SOLAR HEATING/COOLING SYSTEM, WHICH USES A SOLAR AIR-HEATING COLLECTOR (PEBBLE BED)

10.6 CONCLUSION

Today modern architecture still uses traditional materials. People want to have abode homes, but adobe is expensive; it requires a great amount of labor, and no one except the very poor is willing to dig the mud from the backyard in order to build his house. Modern homeowners also insist on large windows, which as a design concept are in contradiction with the tradition of a tightly closed living space. To provide an acceptable environment in a building in a hot dry area, the prime concern should be given for controlling the micro climate or the climate within the space enclosed by a structural shell i.e. dealing with various elements of climate which have an effect on human comfort, when considered together and interpreted in design terms, the physical factors determine the performance of building in a specific situation.

One way modern architecture, with modern materials such as reinforced concrete, would fit perfectly into the design of new houses; at the same time there is an attraction to traditional architecture, adding to this the problem of energy conservation, ideas about solar energy and other modern notions.

The fledging solar industry is no longer a backyard operation and has many enthusiasts will shape the future way of living for the better: better use of our Earth resources, for cleaner air, healthier life.

Solar energy can contribute greatly to an improvement in living conditions in India, all the more so because India is blessed with an abundance of sunshine. The sky is usually could free and radiation is thus available when it is most required. The use of solar energy for local applications by means of small units is by far the most realistic approach, particularly in India.

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