CHAPTER 2

REVIEW OF LITERATURE

2.1 HISTORICAL REVIEW

The aim of building up design is the creation of an artificial microclimate, which satisfies contemporary definitions of thermal comfort: temperature, humidity, radiation and air speed.

This aim becomes particularly apparent in a study of successive dwelling forms undertaken in these terms, but a reduction to this single definition would not be sufficient. Current descriptive methods take into account many other factors, such as defensive, non climatic, environmental and historic.

More recently, the building performance concept has been used in an attempt to provide a basis for the appraisal and specification of buildings.

2.1.1 Examples in Nature

The most complex applications appear in termite nests, and it would appear that all the most desirable techniques have been brought into use.
The performance of these examples are very exact; the activity of the termitary is directly related to its temperature, as the external environment is much more hostile for termites than for humans.

Termitaries do not seem to use other energy sources to control humidity, ventilation or temperature.

2.1.2 Other Examples

The Australian termite *Harmitermes Meridionalis* builds a vertical nest of laminar form (exceeding 5 m in height) in which the major axis of the horizontal section is invariably in north south orientation, thus offering a maximum surface area to the low sun and a reduced surface to the strong sun.

Cellular structure of the termitary possesses insulation properties. These properties allow the inhabited areas of the nest to remain at 30°C whether the outside temperature is at 70°C in sunlight or 10°C at night.

In the nests of a different termite (*Macroterma Natalensis*), the outer walls are more than 50 cm thick and provide thermal inertia as shown in Fig. 2.1 (Charles Chauliaguat *et al.*, 1977).

Man's basic needs whether he lives in a cave or a hut or a castle, are similar. He must have food, clothing and shelter. Shelter provides protection from extremes of climate and other sources of danger or discomfort.

According to Fitch and Branch (1960), "... it would be hard to conceive better shelter against arctic winter than the igloo". Fig. 2.2 shows the
WARM AIR IS DRAWN BY CONVECTION THROUGH THE NEST FROM ITS BASE TO A HIGH CHAMBER (1). FROM HERE THE AIR RETURNS TO THE BASE VIA DUCTS (2), WHICH PASS THROUGH THE OUTER REGIONS OF THE WALL WHERE IT UNDERGOES MODIFICATION OF TEMPERATURE, HUMIDITY, AND GASEOUS COMPOSITION.

FIGURE 2.1 THERMAL OPERATION OF A TERMITARY (MACROTERMA NATALENSIS)
FIGURE 2.2: DAILY VARIATION IN THE INSIDE AIR TEMPERATURE OF AN IGLOO (AT SLEEPING PLATFORM LEVEL) UNDER TYPICAL ARCTIC TEMPERATURE CONDITIONS (FROM FITCH, J. M., AND BRANCH, D. P.; SCI AM., 203, 6, 1960 BY SCIENTIFIC AMERICAN INC.)

FIGURE 2.3: DAILY VARIATION IN THE INSIDE AIR TEMPERATURE OF AN ADOBE HOUSE UNDER HIGH DAYTIME TEMPERATURE CONDITIONS (FROM FITCH, J. M., AND BRANCH, D. P.; SCI AM., 203, 6, 1960 BY SCIENTIFIC AMERICAN INC.)
remarkable temperature achieved within an igloo, where the occupants and their lamps are the only available source of heat.

Fig 2.3 shows what is feasible at another end of climatic scale, with a well-designed adobe house. In this instance, the wide daily external temperature swing is reduced, and the effect of the high daytime peak delayed until late evening. In his analysis, Knowles (1974) graphically illustrated how this building type was designed to obtain maximum benefit from winter sunshine, while minimising summer heat gain. (Fig. 2.4).

Other examples of primitive man’s awareness of climatic design principles include the structural forms that were used to cope with tropical climatic conditions of high solar radiation and heavy rainfall combined with moderate temperatures, and the variation that have evolved to cope with subtropical conditions.

By comparison, they suggest, western man consistently underestimates the environmental forces of nature and overestimates his own technological capacities Fig. 2.5 for example, gives the results of tests on indigenous mud-brick buildings in Egypt and Oman in comparison with modern concrete buildings in the same locations. Figure 2.5A illustrates the capacity of mud-brick to mitigate the outside temperature. By contrast, the inside air temperature of the concrete building (Fig 2.5B) exceeds that of outside, and the temperature swing is several times that of the mud-brick building.

There appears to be very little published quantitative analysis of the performance of buildings constructed by the Greek, Roman, and other pre-industrial civilizations. However there is ample evidence, that designers of
FIGURE 2.4: DAILY VARIATION IN SOLAR ENERGY TRANSMISSION AT PUEBLO BONITA, N.M. (11TH CENTURY A.D.) UNDER SUMMER AND WINTER CONDITIONS.

NOTES:
1. THE SUMMER EFFICIENCY HAS THE DESIRABLE CHARACTERISTIC OF AN EARLY MORNING PEAK FOLLOWED BY A GRADUAL REDUCTION AS THE DAY PROGRESSES.
2. THE VERTICAL SUN-FACING WALLS HAVE HIGH THERMAL TRANSMISSION COEFFICIENTS AND HIGH HEAT STORAGE CAPACITIES, BY COMPARISON WITH THE HORIZONTAL ROOF STRUCTURES. (FROM KNOWLES, R., ENERGY AND FORM: AN ECOLOGICAL APPROACH TO URBAN GROWTH, MIT PRESS, CAMBRIDGE, MASS., 1974. WITH PERMISSION.)

FIGURE 2.5 A AND 2.5 B: COMPARISON OF THE INSIDE AIR TEMPERATURES IN A MUD-BRICK ROOM (FIG. 2.5 A) AND A PREFAB CONCRETE (2.5 B) ROOM (FROM CAIN, A., AFSHAR, F., AND NORTON, J., ARCHITECTURAL DESIGN 4/75, 207.)
these times were well aware of climatic considerations and applied energy conscious principles where necessary. This does not imply that earlier generation always gave a high priority to climatic considerations when designing buildings. Then, as perhaps now, “Socio cultural factors” were of fundamental importance, with “modifying factors” such as climate, construction, materials, and techniques having a lower order of priority (George Baird et al., 1984).

The Greeks were well aware of the solar design principles applicable to their latitudes and temperature conditions. Individual houses had openings oriented south to allow sun penetration in winter, but were appropriately shaded to keep it out in summer.

The Romans were also inventive when it came to the design and application of heating and ventilating systems in their buildings. Under floor warm air-heating systems had been employed to heat bathhouses and villas, but the furnaces required large quantities of wood or charcoal. In the face of the resulting shortages of firewood, the Romans adopted many of the design principles previously used by Greeks. In practice, these were adjusted to take account of the wider climatic range embraced by Roman empire, modified to take account of new developments such as the glazed window, and enhanced by the use of such devices as solar absorbing floor coverings. The writings of the first century B.C. Roman architect Vitruvius, embody many recommendations that relate directly to climate responsive architectural design (Butti and Perlin, 1980).

The interest by architects and historians in the primitive and vernacular form is, according to Rykwett (1972), a universal manifestation of a
search for roots. It is a validation of what we do, in terms both of what has gone before and of where we are going... 'Paradise is a promise as well as a memory'. Certainly, Vitruvius shows this interest. He describes the beginnings of the house as being connected with the discovery of fire and indeed, of language. A storm causes the branches of trees to rub together; they catch fire and cause a forest conflagration; on its subsidence the savage creatures drew near, found comfort both in the fire and in each other's company; developed language and soon, the first houses. At first, these were in caves, bent boughs and even nests. Soon they set up forked stakes, connected with twigs and covered in mud, for the walls. The flat roofs, were inadequate to keep out the rain so they were pitched and had eaves; reeds and leaves were used as a cover. Vitruvius finds confirmation of his theory in the survival of such huts in various parts of Europe (Granger, 1970).

Vitruvius' work is deeply influenced by climatic awareness and advice. This starts from principles of site choice and town layout – to avoid the funnelling of prevailing winds; the avoidance of south winds and heat, as well as of excessive humidity, in the choice of sites as well as a whole chapter devoted to the climate as a determinant of the style of the house. Houses should conform to diversity of climate, being of southerly exposure, and roofed, in the north and of northerly exposure, and more open, in the south. Vitruvius was aware of the Greek writers' view on health, city planning and building – particularly the work of Aristotle, Xenophon and Hippocrates. He must have seen Aristotle's recipes for laying out a town so that it faces east, or is sheltered from the north. Xenophon's advice to provide porticos for shade against high summer sun but allowing low angle winter sun to penetrate deeply and for making the south side loftier and north side lower, 'to keep out the cold wind'.
Vitruvius may have been read and the practical aspects of his work used during the Middle Ages. However, it was in the 15th century that the series of great theories, many of them commentaries on, or critiques of, Vitruvius starts with the publication of Alberti’s Ten Books on Architecture in 1485. His picture of the beginnings of architecture is simpler and more general than Vitruvius’:

‘In the beginning, men looked out for settlements in some secure country; and having found a convenient spot suitable to their occasions, they made themselves a habitation ... Lastly, in the sides of the walls, from top to bottom, they opened passages and windows, for going in and out, and letting in light and air, and for the convenience of discharging any wet or gross vapours which might chance to get into the house’ (Alberti, Ten books on Architecture translated by Leoni, 1955).

From this he goes on to describe the evolution of more complex specialised buildings. His work, like Vitruvius’, devotes substantial parts to the selection of the site, microclimate, suitable materials for keeping space warm or cold and protection against sun and wind. He gives one of the earliest descriptions of advection and frost hollows:

‘...a city standing at the foot of a hill, and looking towards the setting sun is accounted unhealthy, more for this reason than any other, that it feels too suddenly the cold chilling breezes of the night’.

He warns against valley currents and eddies, reflected solar radiation from land or water (whereby a house suffers a ‘double sun’) in hot climates and also deals with lightweight linings to walls, in the form of wool and flax, for
insulating and rapid cooling. So the picture of the primitive shelter and of more refined architectural ways of controlling climate and achieving comfort emerges strongly.

Alberti's examples were followed by others. Palladio refers to Vitruvius' description of the original hut and elaborates on the changes from flat to pitched roofs. He too advises against valley sites, on account of humidity, wind and the reflection of the sun's rays creating excessive heat.

In practice, however, the Renaissance, 17th and 18th century architects did not realise to the full, the implication of their climatic differentiation theories any more than the Roman architects had before them. This is not to say the buildings were environmentally or climatically unsound – far from it. Generally of massive construction, with limited window area, they had achieved a technology which had the universal merit of thermal mass, limited heat loss and gain through windows and reasonable thermal resistance of walls and roofs. This served well in both western and cold climates and against diurnal swings – and internal thermal standards and expectations were, by all accounts, low. During 18th and 19th century, it was mainly pictorially handled and there was little of any greater analytical depth.

Rykwett shows that the preoccupation, obsession perhaps, with the primitive hut runs through 19th and the first half of the 20th centuries. Loos, the futurist Sant'Elia, Mendelsohn, Frank Lloyd Wright, Corbusier, Gropius, Neutra each in his own way returned to the purity and harmony of this natural source. However, the descriptions are now more in terms of landscape, unselfconscious forms and honest use of materials than of climatic factors.
It must be emphasized that climatic principles, as they saw them, deeply influenced the thought and work of these architects. To refer merely to the last four in the list, Wright used solar geometry in a number of houses; notable is Sturges house, Los Angeles, where the varying projections of the eaves on each elevation was related to solar angles, Gropius (1929) put climate as foremost in basic design conception: According to him.

“…true regional character cannot be formed through sentimental or imitation approach by incorporating either old emblems or the newest local fashions which disappear as they appear. But if you take... the basic difference imposed on architectural design by the climatic conditions..... diversity of expression can result... if the architect will use the utterly contrasting indoor-outdoor relations... as focus for design conception.”

Much of Gropius housing and planning design was based on angles suitable for sun penetration.

Hippocrates (1849) probably made the first major contribution to the early thinking on the subject of thermal comfort through scientific analysis. Through experience and observation, he recognised the seasonal nature of some illnesses and identified these as weather dependent.

Le Corbusier, from 1920 onwards, was deeply concerned in his design research and writing to use the sun and wind as formative influences in city planning.

Hutington (1924) enumerated the effect of climate on the development of civilization, the general conclusion drawn from his studies is
that human health is the best and the human being is most efficient at a mean daily temperature of 18°C when mean relative humidity is 80% (Sharma, 1977). The occurrence of early civilization in Egypt, Palestine, Sumeria, Persia and Indus Valley were shown related to the climatic conditions by Markham (1947). According to him, the annual mean isotherm of 20°C passes on the world map through or close to these centres of these civilizations and people living in these regions did not have to put up a continuous struggle with the climatic elements for survival. According to Brunt (1945), civilization in Western Europe made big strides after the introduction of indoor heating systems, which made the houses relatively comfortable in all weathers.

The twentieth century has brought new dimensions to our living conditions and environment through successive industrial and scientific revolution. The invention of various 'comfort gadgets', like air-conditioning and the use of new materials and building techniques have altered our approach to the design of buildings. Recent scientific investigations have helped in determining the factors and materials affecting building design in different climates. However, there have been very few attempts for an organised study of these techniques and materials in the hot and humid climates.

The history of shelter design reveals an unremitting effort by mankind to provide itself with an indoor climate to which man is best adapted. Man’s preference for appropriate thermal environment is the main reason for constructing buildings. The design of buildings and the choice of building materials owe a great deal to the external climate and the thermal requirements of human beings. As a first step to systematic building design, it is therefore, necessary to appreciate the indoor conditions, which are likely to be acceptable, and the conditions, which have to be avoided. These conditions serve as
guidelines in assessing the range of values of physical parameters in which one would feel thermally comfortable.

Scientific analysis of climate, buildings and people's thermal responses is not a complete substitute for learnt and understood experiences. However, experience is impossible to obtain at the rate of change and settlement in many parts of the world. Therefore, it is a big step forward from the normal planning and architectural methods of today, which lack both such experience and science (Markus and Morris, 1980).

2.2 CLIMATE RESPONSIVE DESIGN

Climate responsive design is an approach by which the energy cost of a building is reduced comprehensively. The building design is the first "line of defence" against the stress of outside climate. In all climates, buildings built according to climatic design principles reduce the need for mechanical heating and cooling by using natural energy available from the climate at the building site. The long-term energy cost savings that results, make climatic design techniques, the best financial investment for any building owner. There are many cost effective techniques requiring only climatic design knowledge.

The entire topic of climate responsive design can be understood quite simply. The physical comfort we feel in a building is the result of the heat energy balance between the surrounding space and ourselves. Heat energy exchanged between us and the physical surfaces and materials of our buildings is seemingly complex. It is described by four principles of the physics of heat flow- conduction, convection, radiation and evaporation (Fig. 2.6). In summer and other hot months, the objectives would be to resist gain of solar heat, such
FIGURE 2.6: PATHS OF HEATING ENERGY EXCHANGE AT THE BUILDING MICROCLIMATE

CONDUCTION CONVECTION RADIATION EVAPORATION

SOLAR RADIATION (DIRECT + DIFFUSE) THERMAL RADIATION SURFACE EVAPORATION EXTERIOR AIR FLOW

CONDUCTION W/ GROUND

INTERIOR AIR FLOW

FiguRE 2.7: SUMMARY OF THE PRINCIPLES AND STRATEGIES OF CLIMATIC RESPONSIVE DESIGN

WINTER

SUMMER

CONVECTION RADIATION EVAPORATION

PROTECT GAIN PROMOTE SOLLAR GAIN

RESIST LOSS MINIMIZE CONDUCTIVE HEAT FLOW MINIMIZE EXTERNAL AIR FLOW MINIMIZE INFLATION

RESIST GAIN MINIMIZE CONDUCTIVE HEAT FLOW MINIMIZE INFLATION MINIMIZE SOLAR GAIN

PROTECT LOSS PROMOTE EARTH COOLING PROMOTE VENTILATION PROMOTE RADIANT COOLING PROMOTE EVAPORATIVE COOLING

FIGURE 2.8: THE IDEAL OF CLIMATIC DESIGN - SUCCESSIVE MODULATION OF AMBIENT CONDITIONS SO AS TO BRING INTERNAL CONDITION WITHIN THE COMFORT ZONE

A. CONTEXT ECOLOGICAL AND PHYSICAL
B. CONTEXTUAL AND SITE PLANNING - DESIGN
C. BUILT FORM PLAN AND 3-D CONFIGURATION
D. BUILDING ENVELOPE, FENESTRATION AND MATERIAL
E. INTERNAL PLANNING AND DESIGN
F. BAND OF APPROPRIATE DESIGN
as through sun shading and to promote loss of heat from the building interior. To achieve this, there are nine practical climatic design principles (Watson and Lobs, 1983) as shown in Fig. 2.7.

The idea of climatically responsive design is to modulate the condition such that they are always within or as close as possible to the comfort zone. This is shown conceptually in Fig. 2.8 (Koenigsberger, 1993). The line A shows the ambient conditions over the twenty-four-hour period. For a majority of the time it is outside the comfort zone. Modulations introduced by landscape built form, envelope, materials and other control measures bring the conditions within the comfort range throughout the twenty-four hour cycle. This is the goal of climatically responsive design.

2.3 HOT AND HUMID REGIONS – A REVIEW

In the coastal areas, the effects of temperature are magnified by humidity. However, the average annual rainfall of nearly 140 cm combines with ocean and undrained low land evaporation to produce unpleasantly high humidity during majority of the year. Lynch (1969) reports that 'the limit of human tolerance' - the maximum air temperature at which extended work may be performed without raising body temperature has a threshold of 65.5°C in dry air, but is reduced to only 32.2°C in full humidity. This limit is completely within the Hot and Humid region.

In a report of the United Nations Centre for Human Settlement (U.N.C.H.S.) Habitat (1984), it is said that there is no proven passive technique, for reducing humidity in hot and humid climate. The same U.N.C.H.S. Habitat report also gives the natural cooling systems – climatic conditions matrix (Table 2.1) in the design of buildings in developing countries.
Table 2.1 Natural cooling system - climatic conditions matrix

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<td>Passive Evaporative Cooling by roof ponds</td>
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a/ Rain protection is needed during ventilation
b/ Apertures have to be well-built to reduce winter infiltration
c/ for cloudless sky in summer
d/ the soil surrounding the building should be kept dry.

Note: H = High effectiveness  F = Proven
M = Medium effectiveness  E = Experimental
L = Low effectiveness

Source: UNCHS report, 1984
The matrix, however suggests the various natural cooling systems for hot and humid regions. It can be seen from the matrix, that comfort ventilation, radiant cooling through mass storage and earth cooling through surface shading are the strategies that can be applied in these regions.

Due to the adverse effects of solar radiation, it is necessary to utilise the positive natural modulating influences of shade and wind to produce comfortable living environments during overheated periods. Olgyay (1964) suggests that shading is required 88% of the year, while wind is advantageous 62% of the time in order to bring down temperature and humidity to the comfort range.

The climatic conditions found in hot and humid areas dictate the need for climatic improvements to improve human comfort. The primary cause of discomfort in Hot and Humid areas is solar radiation and humidity.

The physical placement of buildings in relation to the sun's path is a highly important factor in the hot and humid region. The majority of adverse solar loading occurs when the low and angled sun in the east and west penetrates windows and other wall openings and heats the building’s interior. When the sun is high during midday, only minor wall exposure is encountered and major radiation falls on the horizontal surfaces. Since the building roofs are of monolithic character (without openings) and often constructed with thick roofs or positively insulating materials, roof surfaces are efficient in the reflection (especially of light colour or insulation) of radiation.

The most appropriate building shape for the hot and humid region is rectangular and optimum orientation places the short sides towards the east and
the west, in order to limit the area, which is exposed to a low angle sun. Because of the south easterly wind prevailing in Chennai, the building face is shifted 5 degrees east of the south and building plan is shifted by 10 degrees in either direction to deal with individual site requirements without seriously impeding functional efficiency.

If the surfaces of structures are shaded from the sun, the impact of radiation will be significantly reduced. Shading solutions are possible as stated below:

i. Architectural treatment of buildings

ii. Use of vegetation: Locating buildings beneath mature tree canopies and the strategic placement of trees which will provide required shade at various times of the day. The analysis of the existing situations and careful analysis of the dynamics of solar movement will make such functional planting possible.

One of the greatest climatic moderators in hot and humid region is wind. Coastal areas generally exhibit fewer temperature extremes than the Inland areas. They are hotter in summer and warmer in winter. Overly dense and low canopies may prevent cool breeze and trap humidity in a pocket of 'dead air'. Higher canopy trees, however, may provide needed shade, while allowing breeze to pass beneath them.

In order to increase the wind flow and cooling effect of wind on a site, the following parameters are generally considered:
a. Removal of restrictions to natural air flow patterns on a site
b. Pruning all the lower branches of tall trees
c. Curtailment of all low plant growth which inhibits wind flow between one and ten feet high
d. Location of outdoor activities in areas which have the maximum access to wind on a particular site
e. Building up of decks or platforms on the windward areas on the site in order to take advantage of natural breeze
f. Creation of natural wind tunnels or breezeways using either plant materials, earth forms, fences, or walls and
g. Location of activities of areas on the sides of a valley wall to take advantage of the day and night wind flow pattern.

As previously stated, the best orientation of design of houses should be along east-west axis. It is suggested that the axis should be slightly rotated towards the direction of the prevailing winds in the local area. The siting of individual structure should attempt to use existing vegetation to maximum functional advantage, and large trees to the east and west of building area generally desirable in reducing the wall radiation loads produced by low sun angles, provided they do not impede the flow of cool air.

The desirability of proper utilisation of natural elements on a building is very important. Trees provide shade and can selectively channel desirable breezes or block adverse winds. Vines spread on walls or roofs will reduce radiation.

Some of the books in the field under study are reviewed below. The works reviewed are covered chronologically based on the authors.
1) Baker, N.V., (1987) 'Passive and Low Energy Building Design for Tropical Island Climates'. As the name suggests, this book specifically written for Tropical Islands deals with climate and comfort in a greater depth and also gives methodologies of climate comfort analysis along with examples and recommendations.

2) Bansal et al., (1994) 'Passive Building Design – A Handbook of Natural Climatic Control'. The chapter on cooling clearly summarises the problem of high humidity, its effect on indoor environment and building materials. It also mentions concepts and methods of dehumidification. A brief account of thermal human comfort and heat exchange processes between the body and the surroundings are given.

3) Bansal N.K and Minke. G., (1988) ‘Climatic Zones and Rural housing in India’. The diverse variations in climate across the Indian sub-continent are classified along with the criteria for classification and characteristic features of each classified zone. The book further illustrates traditional responses to climate of rural houses selected as representative examples. It gives a good database of traditional building materials used across the country.

4) Givoni. B., (1976) 'Man, Climate and Architecture' Gives an account of the Biophysical effects of environmental factors, thermal comfort, ventilation function and requirements, principles of design and appropriate materials for corresponding climate.

5) Baruch Givoni, (1994) Passive and Low Energy Cooling of Buildings. The book discusses a number of cooling techniques utilising natural, renewable energies as well as low energy systems consuming far less electricity than conventional air conditioning, daytime and nocturnal
ventilative cooling for buildings, besides the conventional systems. A special chapter deals with cooling options for outdoor spaces. This book deals with scientific fundamentals relevant to the various cooling techniques as well as with the practical and architectural design issues involved in the application.


10) Martin Evans, (1980) "Housing Climate and Comfort" – this book includes recommendations for cold and hot seasons and more intended for practitioners. This book is intended to help the climatic designer achieve good value for the investment devoted to housing, its form and thermal performance.

11) Moore Fuller, (1993) “Environmental Control System”. The chapter on climate and shelter theoretically covers with cited examples, the biological response of the structures to the climate.


13) ASHRAE (1963) “Handbook of Fundamentals”, gives clear understanding of the physiological principles, namely thermal interchanges between the body and its environment, acclimatization, environmental conditions and comfort.

14) Handbook on Functional Requirements of Buildings (1987) brought out by Bureau of Indian Standards. This handbook provides detailed information on climatology, heat insulation, ventilation and lighting in non industrial buildings, which would be helpful in the planning and functional design of buildings as applicable to Indian conditions based on Indian Standards and other relevant literature in the subject. Part I, Part II and Part III of this book covers extensive analysis. A very useful book for climatic designers.

Various passive techniques including simple and advanced are used, with details well illustrated. A few case studies have been discussed to illustrate the use of various passive concepts and to demonstrate their effectiveness. Post occupancy evaluation, besides building byelaws, which set minimum standards for comforts, are included.