# CHAPTER - 2

## CLIMATE AND BUILDINGS

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### 2.1 INTRODUCTION

The weather of a place represents the state of the atmospheric environment over a brief period of time. Integrated weather condition over several years is generally referred to as climate or more specifically, as the 'macro-climate'. An analysis of the climate of a particular region can help in assessing the seasons or periods during which a person may experience comfortable or uncomfortable conditions. It further helps in identifying the climatic elements, as well as their severity, that cause discomfort. The information helps a designer to build a house that filters out adverse climatic effects, while simultaneously allowing those that are beneficial. Discomfort and the corresponding energy demand for mechanical systems can be significantly reduced by judicious control of the climatic effects. The built-form and arrangement of openings of a building can be suitably derived from this analysis. For example, in a place like Mumbai, one feels hot and sweaty owing to intense solar radiation accompanied by high humidity. Here, the building design should be such that (a) it is sufficiently shaded to prevent solar radiation from entering the house and, (b) it is ventilated to reduce discomfort due to high humidity. On the other hand, in a place like Shimla, it is necessary to maintain warmth inside the building due to the predominantly cold climate. Climate thus plays a pivotal role in determining the design and construction of a building.

In this chapter, we will review the various aspects of climate and the methods of its analysis. This includes a brief description of the various climatic factors and climatic zones of India. The design requirements of buildings in different climatic zones are discussed and tabulated. Illustrative examples provide information on how to analyse the climatic conditions of a place.

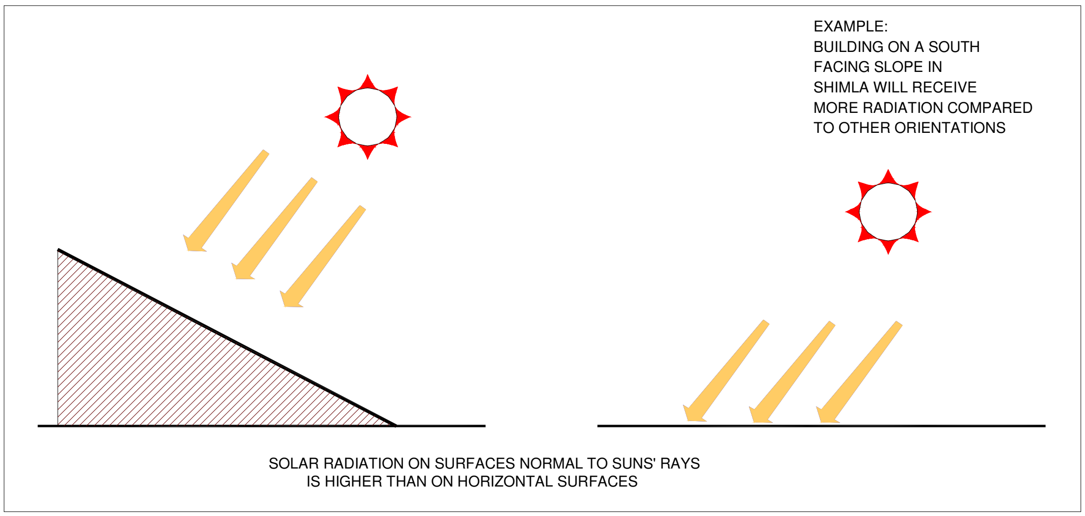
### 2.2 FACTORS AFFECTING CLIMATE

Both weather and climate are characterised by the certain variables known as climatic factors [1]. They are as follows:

(A) Solar radiation
(B) Ambient temperature
(C) Air humidity
(D) Precipitation
(E) Wind
(F) Sky condition

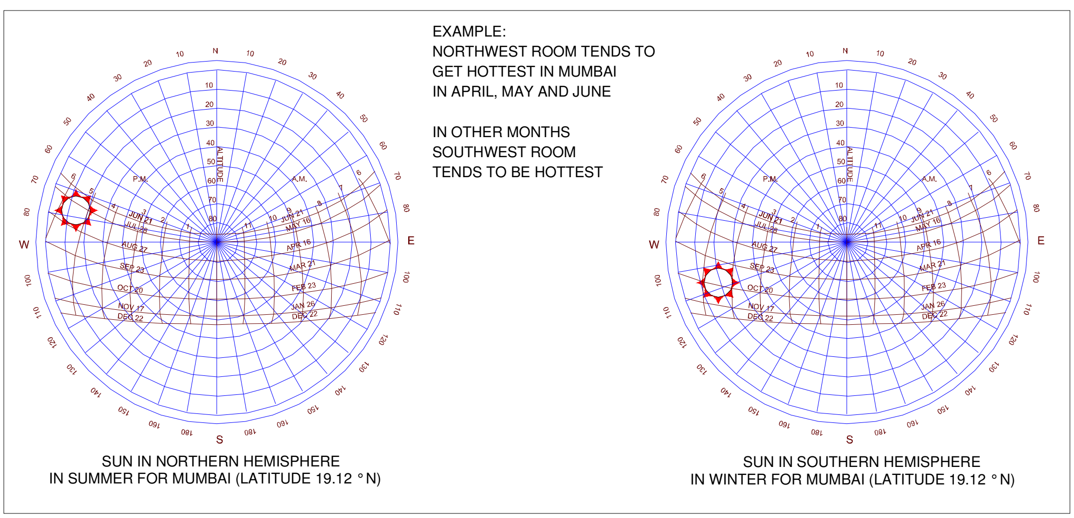
### (A) Solar radiation

Solar radiation is the radiant energy received from the sun. It is the intensity of sunrays falling per unit time per unit area and is usually expressed in Watts per square metre ($W/m^2$). The radiation incident on a surface varies from moment to moment depending on its geographic location (latitude and longitude of the place), orientation, season, time of day and atmospheric conditions (Fig. 2.1). Solar radiation is the most important weather variable that determines whether a place experiences high temperatures or is predominantly cold. The instruments used for measuring of solar radiation are the pyranometer and the pyrheliometer. The duration of sunshine is measured using a sunshine recorder.




EFFECT OF ORIENTATION

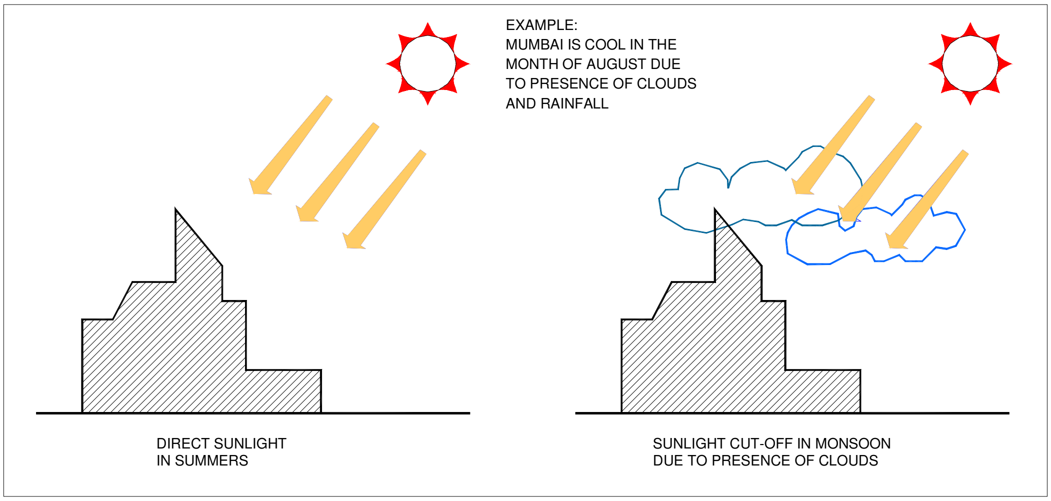
**(a)**




EFFECT OF SEASON

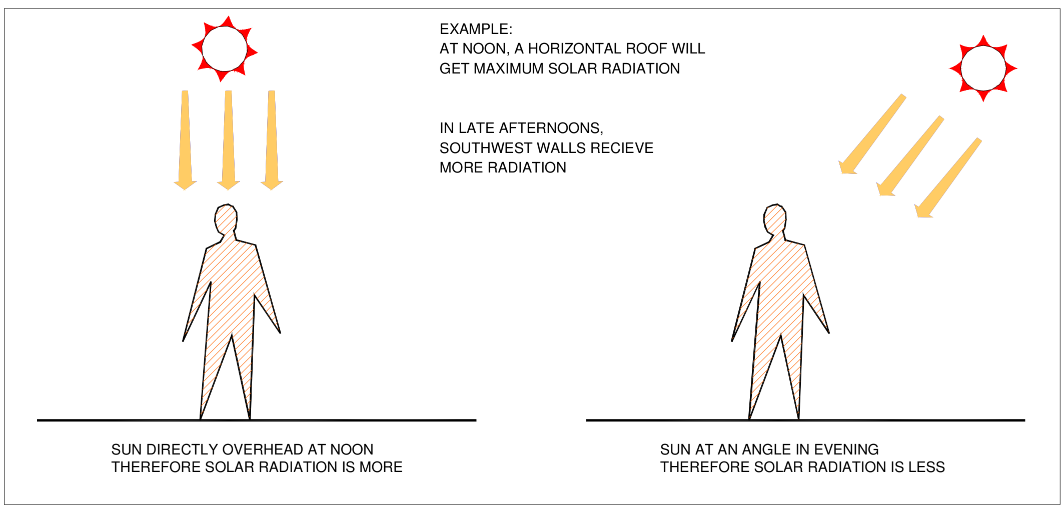
**(b)**

**Fig. 2.1 Factors affecting solar radiation**
**(a) effect of orientation, (b) effect of season**




EFFECT OF SKY COVER

**(c)**



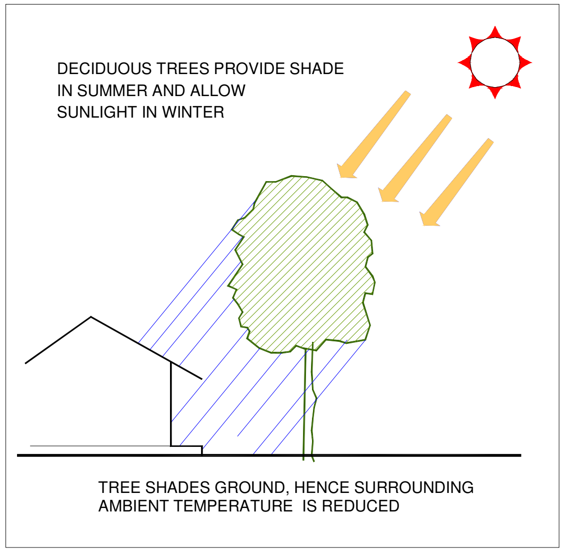

EFFECT OF TIME

**(d)**

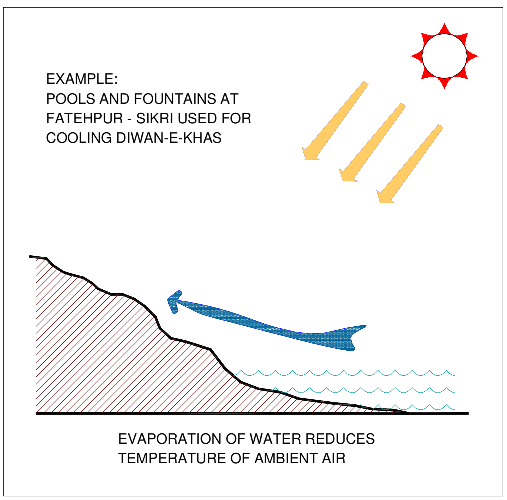
**Fig. 2.1 Factors affecting solar radiation (cont.)**
**(c) effect of sky cover, (d) effect of time**

### (B) Ambient temperature

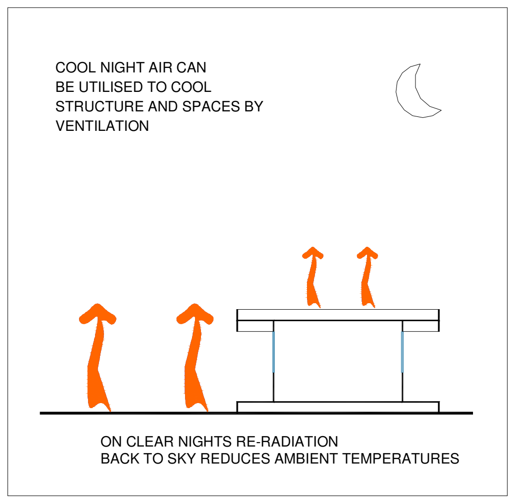
The temperature of air in a shaded (but well ventilated) enclosure is known as the ambient temperature; it is generally expressed in degree Celsius (ºC). Temperature at a given site depends on wind as well as local factors such as shading, presence of water body, sunny condition, etc. When the wind speed is low, local factors strongly influence on temperature of air close to the ground. With higher wind speeds, the temperature of the incoming air is less affected by local factors. The effect of various factors on the ambient temperature is shown in Fig. 2.2. A simple thermometer kept in a Stevenson's screen can measure ambient temperature.




EFFECT OF SHADING




EFFECT OF WATER BODY




EFFECT OF SKY CONDITION

**Fig. 2.2 Factors affecting ambient temperature**

**(C) Air humidity**

Air humidity, which represents the amount of moisture present in the air, is usually expressed in terms of 'relative humidity'. Relative humidity is defined as the ratio of the mass of water vapour in a certain volume of moist air at a given temperature, to the mass of water vapour in the same volume of saturated air at the same temperature; it is normally expressed as a percentage. It varies considerably, tending to be the highest close to dawn when the air temperature is at its lowest, and decreasing as the air temperature rises. The decrease in the relative humidity towards midday tends to be the largest in summer. In areas with high humidity levels, the transmission of solar radiation is reduced because of atmospheric absorption and scattering. High humidity reduces evaporation of water and sweat. Consequently, high humidity accompanied by high ambient temperature causes a lot of discomfort. The effects of various combinations of humidity and ambient temperature are presented in Fig. 2.3.

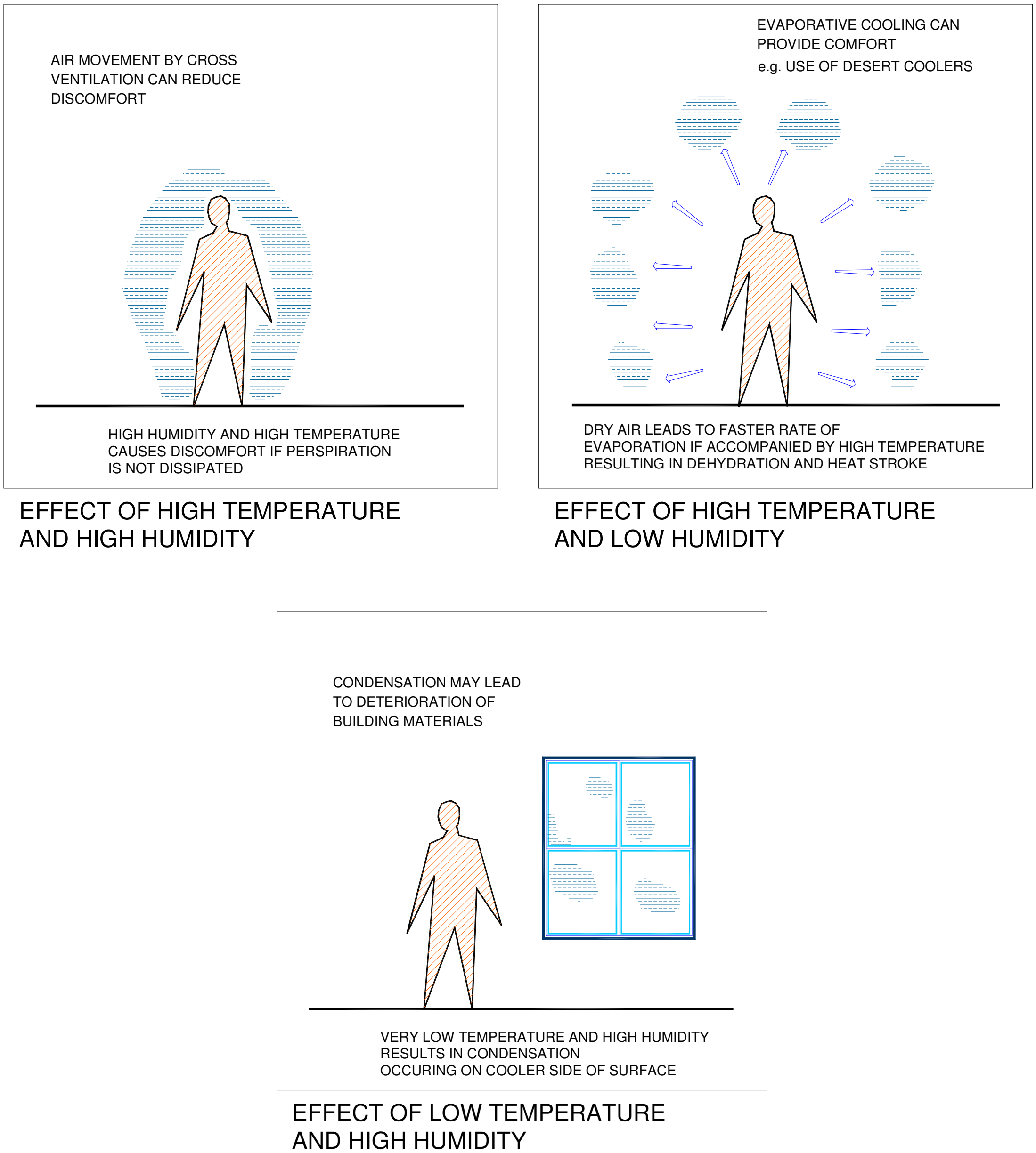



**Fig. 2.3 Effects of air humidity**

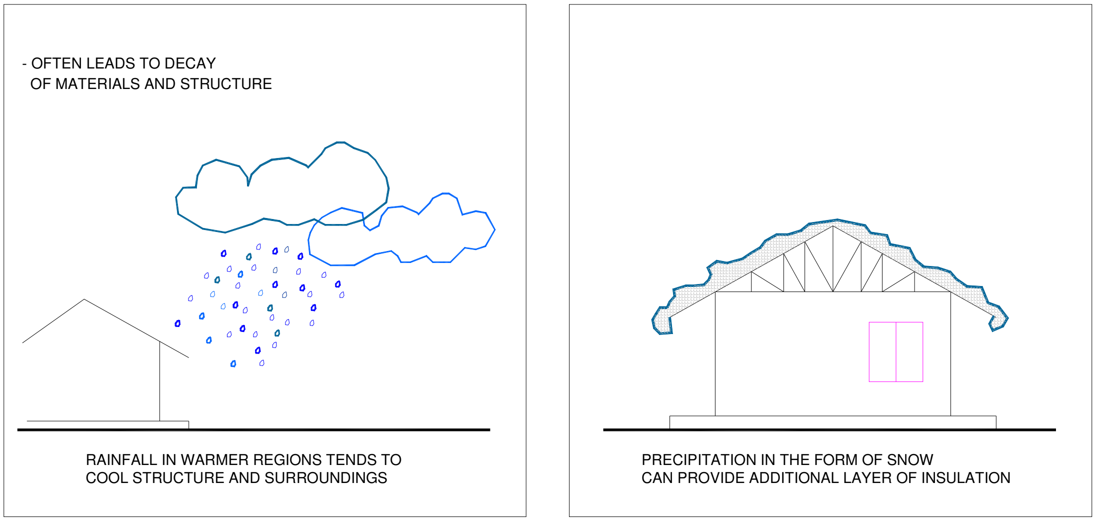
### (D) Precipitation

Precipitation includes water in all its forms rain, snow, hail or dew. It is usually measured in millimeters (mm) by using a rain gauge. The effects of precipitation on buildings are illustrated in Fig. 2.4.

### (E) Wind

Wind is the movement of air due to a difference in atmospheric pressure, caused by differential heating of land and water mass on the earth's surface by solar radiation and rotation of earth. Wind speed can be measured by an anemometer and is usually expressed in metres per

second (m/s). It is a major design consideration for architects because it affects indoor comfort conditions by influencing the convective heat exchanges of a building envelope, as well as causing air infiltration into the building (Fig. 2.5).




EFFECT OF RAINFALL

EFFECT OF SNOW

**Fig. 2.4 Precipitation**

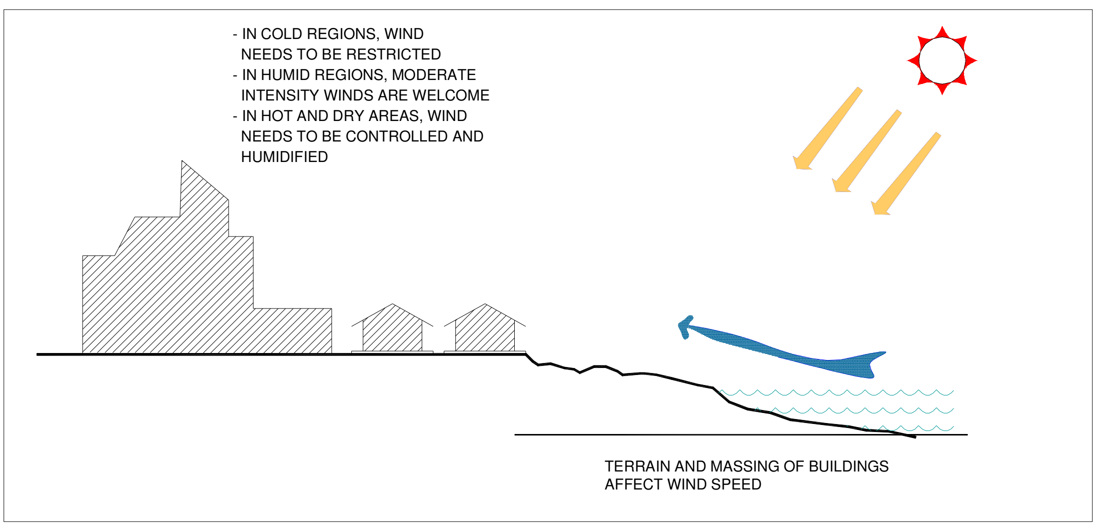



**Fig. 2.5 Factors affecting wind**

**(F) Sky condition**

Sky condition generally refers to the extent of cloud cover in the sky or the duration of sunshine. Under clear sky conditions, the intensity of solar radiation increases; whereas it reduces in monsoon due to cloud cover. The re-radiation losses from the external surfaces of buildings increase when facing clear skies than covered skies. This is illustrated in Fig. 2.6. The measurement of sky cover is expressed in oktas. For example, 3 oktas means that 3/8$^{th}$ of the visible sky is covered by clouds.

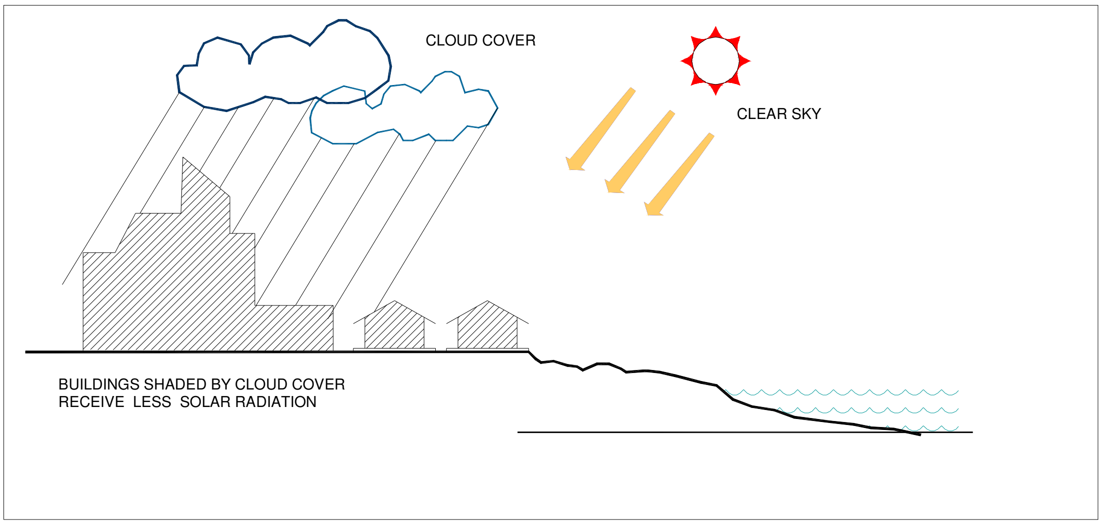



**Fig. 2.6 Effect of sky condition**

In addition to these factors, a number of natural elements such as hills, valleys, waterbodies, vegetation, etc. affect the climate locally. Buildings, cities and other man-made features also have an impact on the climate. The effects of such features are discussed in the section 2.6 under 'Microclimate'.

### 2.2.1 Weather Data

The data of all weather variables are recorded at various meteorological stations by the Indian Meteorological Department (IMD), and are also available in a number of books [1-5]. Synthetic data for solar radiation have been generated by ISHRAE [6] as well as Mani and Rangarajan [7]. The distributions of hours of sunshine, global and diffuse solar radiation on an annual basis are presented in Fig. 2.7-2.9 [2]. It can be seen from Fig. 2.7 that Rajasthan, Gujarat, west Madhya Pradesh and north Maharashtra receive more than 3000 to 3200 hours of bright sunshine in a year. Over 2600 to 2800 hours of bright sunshine are available over the rest of the country, except Kerala, the north-eastern states, and Jammu and Kashmir where they are appreciably lower. The corresponding information for different months of the year is also available in the handbook [2]. During monsoon (June – August), a significant decrease in sunshine occurs over the whole country except Jammu and Kashmir where the maximum duration of sunshine occurs in June and July, and minimum in January due to its location. The north-eastern states and south-east peninsula also receive relatively less sunshine during October and November due to the north-east monsoons. As far as the availability of global solar radiation is concerned, more than

2000 kWh/m$^2$-year are received over Rajasthan and Gujarat, while east Bihar, north West Bengal and the north-eastern states receive less than 1700 kWh/m$^2$-year (Fig. 2.8). The availability of diffuse solar radiation varies widely in the country (Fig. 2.9). The annual pattern shows a minimum of 740 kWh/m$^2$-year over Rajasthan increasing eastwards to 840 kWh/m$^2$-year in the north-eastern states, and south wards to 920 kWh/m$^2$-year. The monthly availability of global and diffuse solar radiation over entire country is presented in the 'Handbook of solar radiation data for India' by Mani [2].

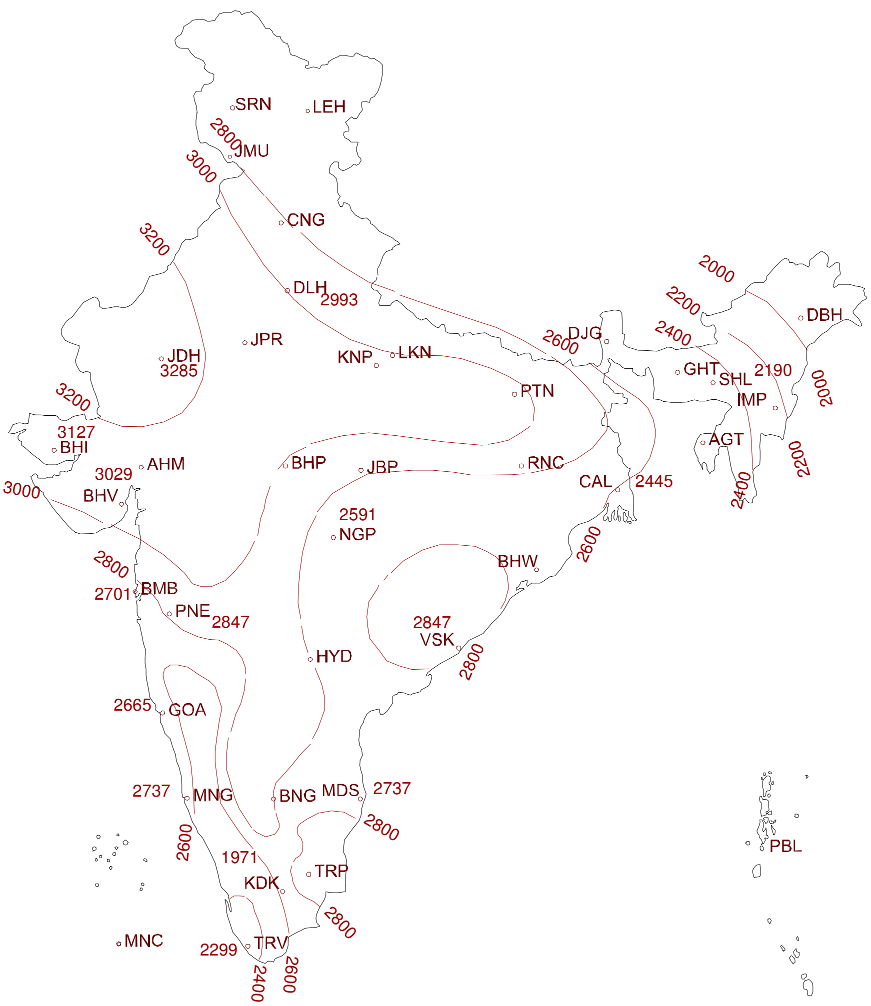



**Fig. 2.7 Distribution of annual sunshine hours [2]**

The ambient temperature varies across the country. The maps showing the highest maximum and lowest minimum temperature isopleths are shown in Fig. 2.10 and 2.11 [8]. A map showing the average rainfall along with main direction of winds is presented in Fig. 2.12 [8].

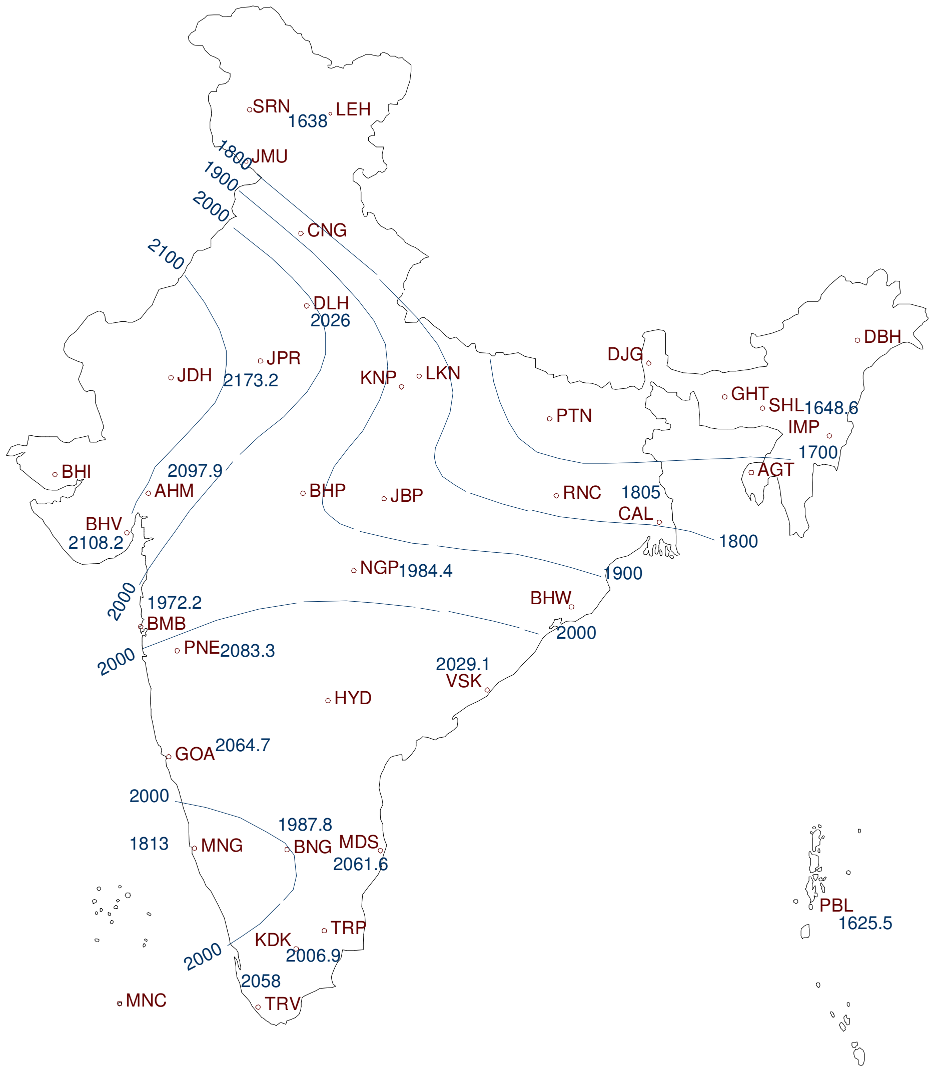



**Fig. 2.8 Distribution of annual global solar radiation (kWh/m²-year) [2]**

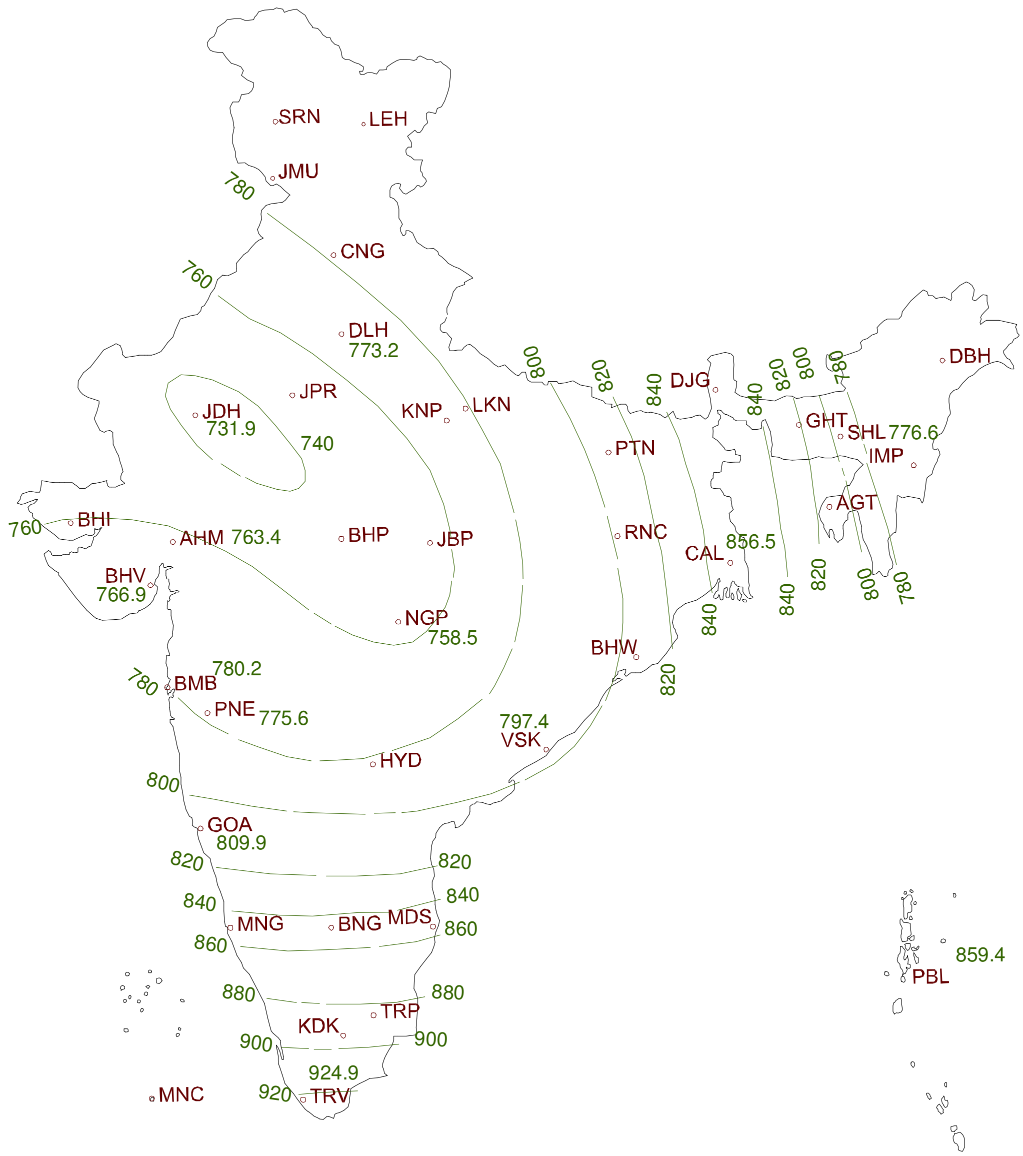



**Fig. 2.9 Distribution of annual diffuse solar radiation (kWh/m$^2$-year) [2]**

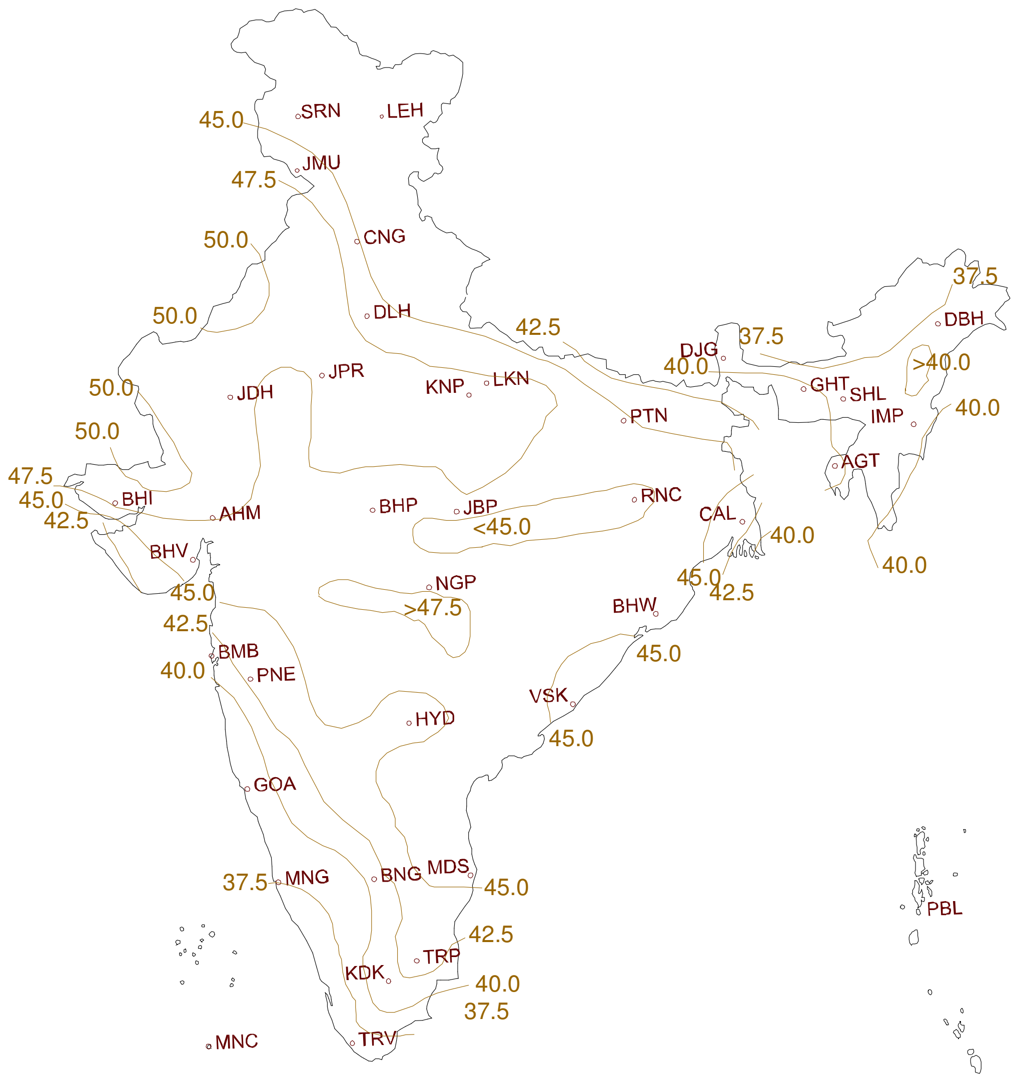



**Fig. 2.10 Maximum temperature isopleths [8]**

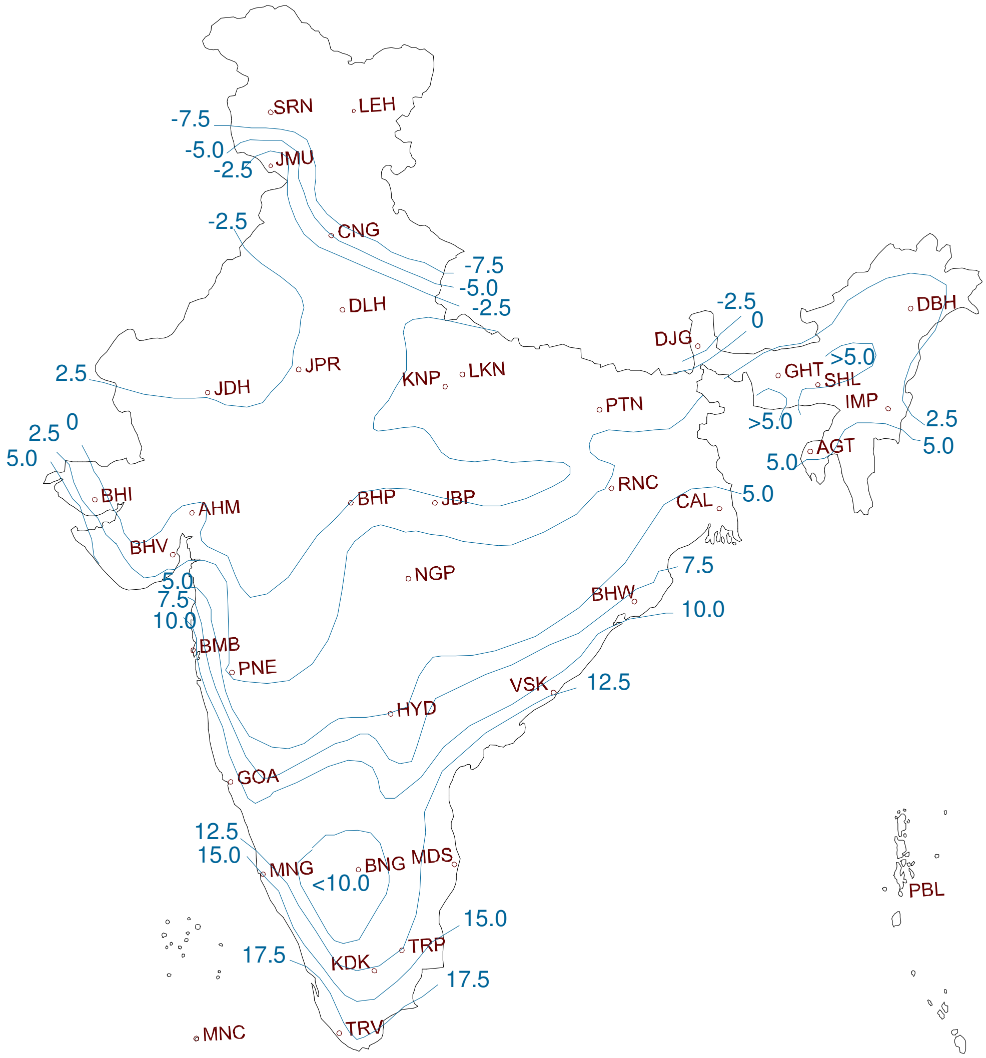



**Fig. 2.11 Minimum temperature isopleths [8]**

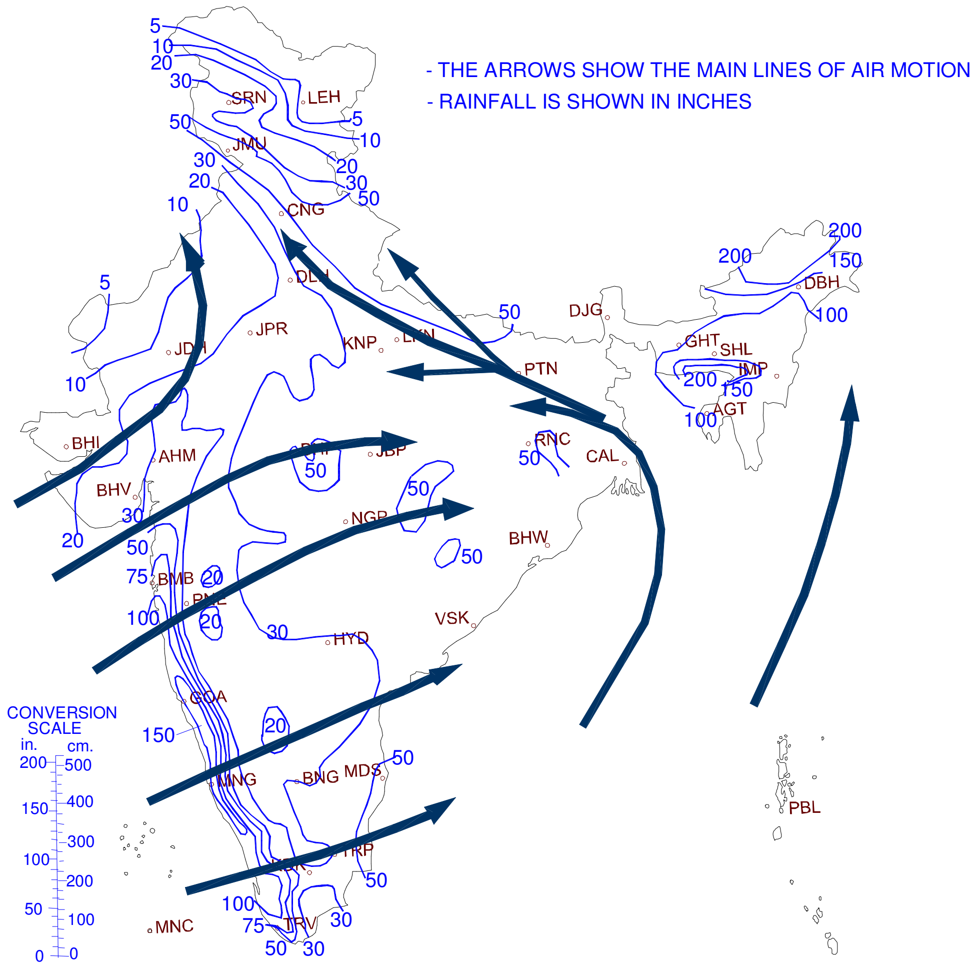



**Fig. 2.12 Average rainfall and main wind direction [8]**

## 2.3 CLIMATIC ZONES AND THEIR CHARACTERISTICS

Regions having similar characteristic features of climate are grouped under one climatic zone. Based on the climatic factors discussed in the previous section, the country can be divided into a number of climatic zones. Bansal et al. [1] had carried out detailed studies and reported that India can be divided into six climatic zones, namely, hot and dry, warm and humid, moderate, cold and cloudy, cold and sunny, and composite. The criteria of classification are presented in Table 2.1 and Fig. 2.13(a) shows the climatic zones. A place is assigned to one of the first five climatic zones only when the defined conditions prevail there for more than six months. In cases where none of the defined categories can be identified for six months or longer, the climatic zone is called composite [1]. According to a recent code of Bureau of Indian Standards [9], the country may be divided into five major climatic zones. Table 2.1 presents the criteria of this classification as well; Fig. 2.13(b) shows the corresponding climatic classification map of India. It is seen that the recent classification is not very different from the earlier one except that the cold and cloudy, and cold and sunny have been grouped together as cold climate; the moderate climate is renamed as temperate climate. However, a small variation is noticed as far as the land area of the country corresponding to different zones is concerned (Fig. 2.13(a) and (b)). In this book, we have followed the former classification. It may be mentioned that each climatic zone does not experience the same climate for the whole year. It has a particular season for more than six months and may experience other seasons for the remaining period.

**Table 2.1 Classification of Climates**

| **Criteria of Bansal et al. [1]** | | | **Criteria of SP 7: 2005 [9]** | | |
|---|---|---|---|---|---|
| **Climate** | **Mean monthly temperature (°C)** | **Relative humidity (%)** | **Climate** | **Mean monthly maximum temperature(°C)** | **Relative humidity (%)** |
| Hot and dry | >30 | <55 | Hot and dry | >30 | <55 |
| Warm and humid | >30 | >55 | Warm and humid | >30<br>>25 | >55<br>>75 |
| Moderate | 25-30 | <75 | Temperate | 25-30 | <75 |
| Cold and cloudy | <25 | >55 | Cold | <25 | All values |
| Cold and sunny | <25 | <55 | | | |
| Composite | This applies, when six months or more do not fall within any of the above categories | | Composite | This applies, when six months or more do not fall within any of the above categories | |

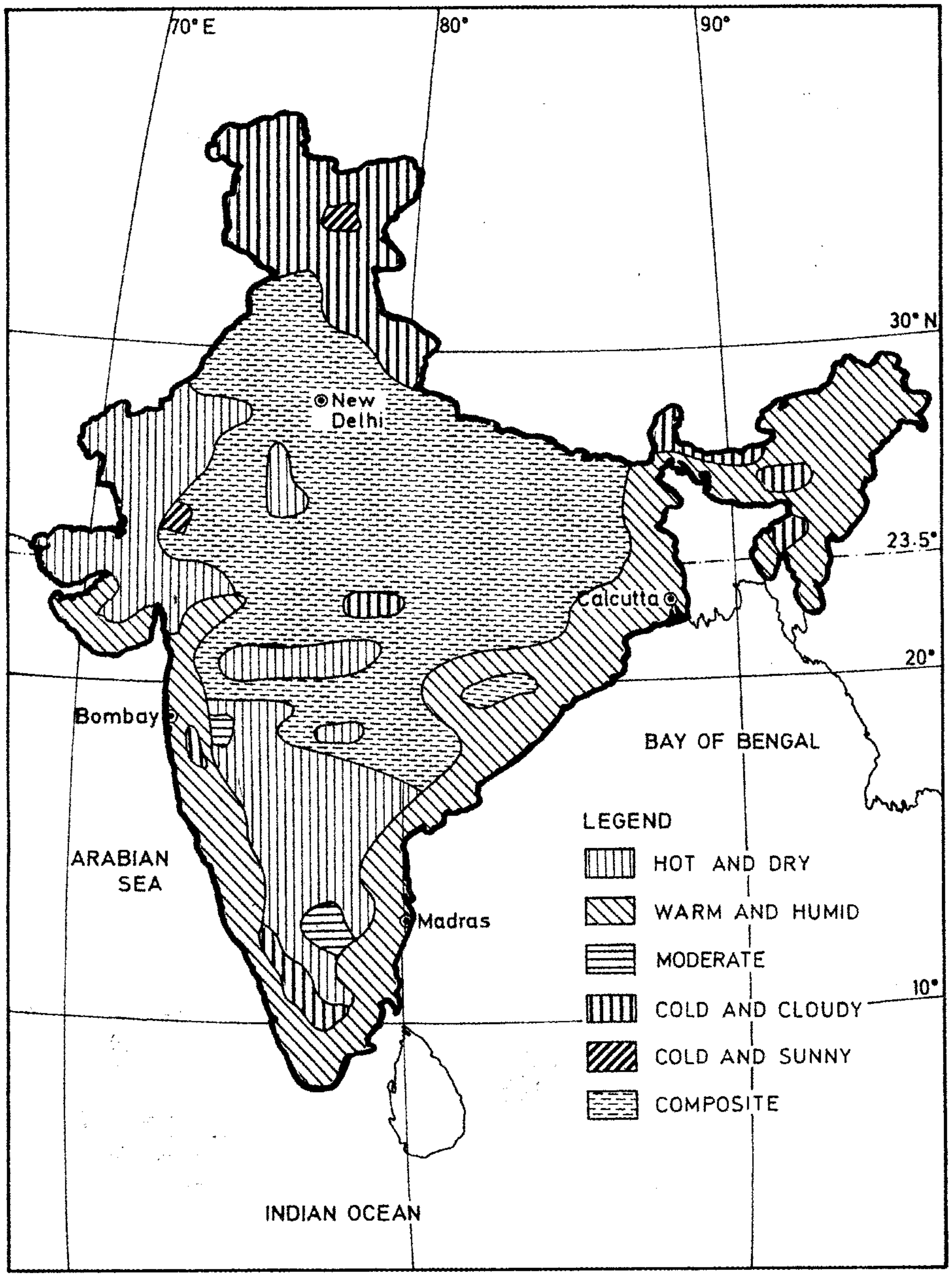



**Fig. 2.13a Climatic zones of India [1]**

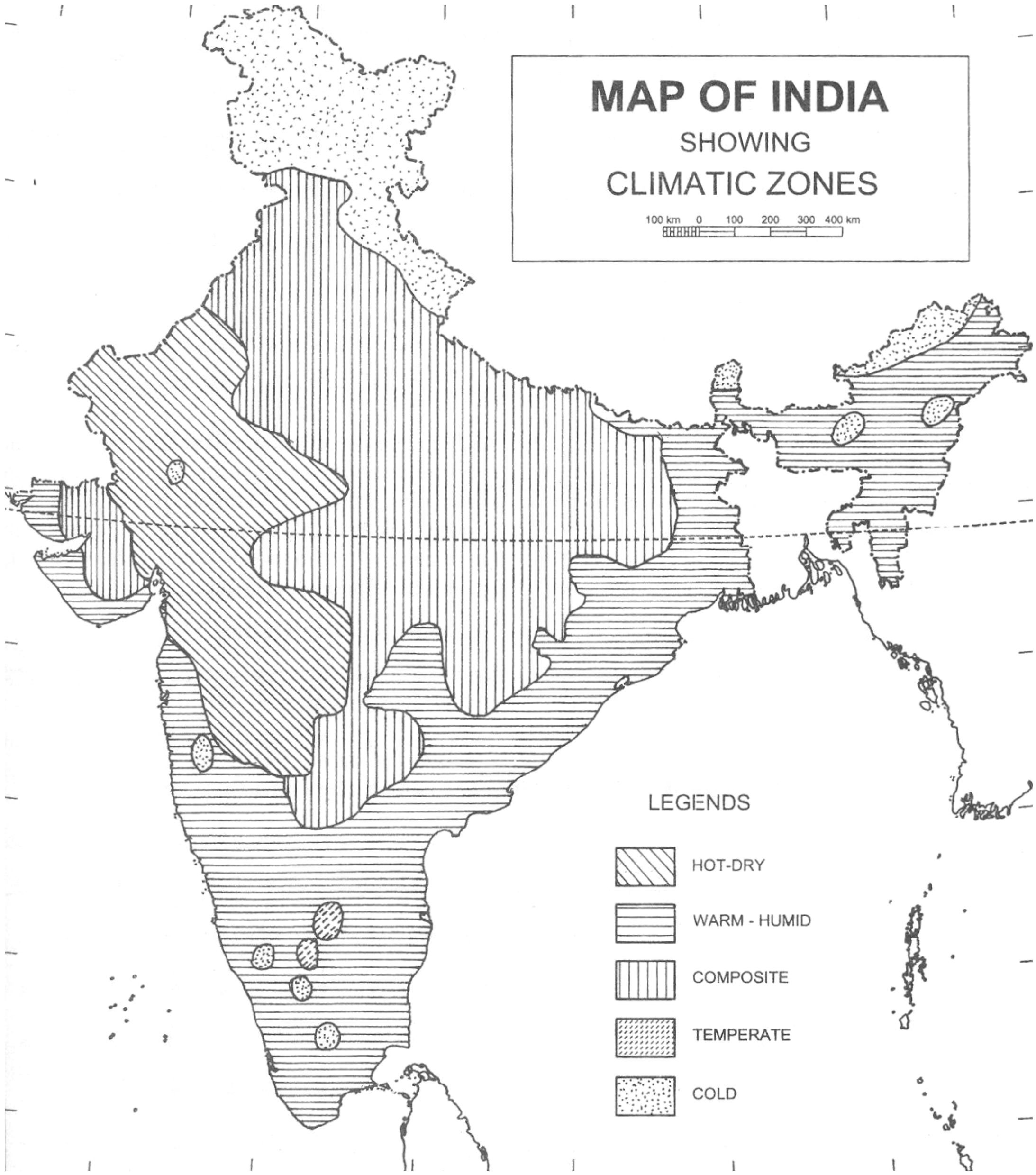



**Fig. 2.13b Climatic zones of India [9]**

The characteristic features of each climate are described briefly in the following subsections.

### 2.3.1 Hot and Dry

The hot and dry zone lies in the western and the central part of India; Jaisalmer, Jodhpur and Sholapur are some of the towns that experience this type of climate.

A typical hot and dry region is usually flat with sandy or rocky ground conditions, and sparse vegetation comprising cacti, thorny trees and bushes. There are few sources of water on the surface, and the underground water level is also very low. Due to intense solar radiation (values as high as 800-950 $W/m^2$), the ground and the surroundings of this region are heated up very quickly during day time. In summer, the maximum ambient temperatures are as high as 40–45 ºC during the day, and 20–30 ºC at night. In winter, the values are between 5 and 25 ºC during the day and 0 to 10 ºC at night. It may be noted that the diurnal variation in temperature is quite high, that is, more than 10 ºC.

The climate is described as dry because the relative humidity is generally very low, ranging from 25 to 40 % due to low vegetation and surface water bodies. Moreover, the hot and dry regions receive less rainfall- the annual precipitation being less than 500 mm.

Hot winds blow during the day in summers and sand storms are also experienced. The night is usually cool and pleasant. A generally clear sky, with high solar radiation causing an uncomfortable glare, is typical of this zone. As the sky is clear at night, the heat absorbed by the ground during the day is quickly dissipated to the atmosphere. Hence, the air is much cooler at night than during the day.

In such a climate, it is imperative to control solar radiation and movement of hot winds. The design criteria should therefore aim at resisting heat gain by providing shading, reducing exposed area, controlling and scheduling ventilation, and increasing thermal capacity. The presence of “water bodies” is desirable as they can help increase the humidity, thereby leading to lower air temperatures. The ground and surrounding objects emit a lot of heat in the afternoons and evenings. As far as possible, this heat should be avoided by appropriate design features.

### 2.3.2 Warm and Humid

The warm and humid zone covers the coastal parts of the country. Some cities that fall under this zone are Mumbai, Chennai and Kolkata. The high humidity encourages abundant vegetation in these regions.

The diffuse fraction of solar radiation is quite high due to cloud cover, and the radiation can be intense on clear days. The dissipation of the accumulated heat from the earth to the night sky is generally marginal due to the presence of clouds. Hence, the diurnal variation in temperature is quite low. In summer, temperatures can reach as high as 30 – 35 ºC during the day, and 25 – 30 ºC at night. In winter, the maximum temperature is between 25 to 30 ºC during the day and 20 to 25 ºC at night. Although the temperatures are not excessive, the high humidity causes discomfort.

An important characteristic of this region is the relative humidity, which is generally very high, about 70 – 90 % throughout the year. Precipitation is also high, being about 1200 mm per year, or even more. Hence, the provision for quick drainage of water is essential in this zone.

The wind is generally from one or two prevailing directions with speeds ranging from extremely low to very high. Wind is desirable in this climate, as it can cause sensible cooling of the body.

The main design criteria in the warm and humid region are to reduce heat gain by providing shading, and promote heat loss by maximising cross ventilation. Dissipation of humidity is also essential to reduce discomfort.

### 2.3.3 Moderate

Pune and Bangalore are examples of cities that fall under this climatic zone. Areas having a moderate climate are generally located on hilly or high-plateau regions with fairly abundant vegetation.

The solar radiation in this region is more or less the same throughout the year. Being located at relatively higher elevations, these places experience lower temperatures than hot and dry regions. The temperatures are neither too hot nor too cold. In summers, the temperature reaches 30 – 34 ºC during the day and 17 – 24 ºC at night. In winter, the maximum temperature is between 27 to 33 ºC during the day and 16 to 18 ºC at night.

The relative humidity is low in winters and summers, varying from 20 – 55%, and going upto 55 – 90% during monsoons. The total rainfall usually exceeds 1000 mm per year. Winters are dry in this zone. Winds are generally high during summer. Their speed and direction depend mainly upon the topography. The sky is mostly clear with occasional presence of low, dense clouds during summers.

The design criteria in the moderate zone are to reduce heat gain by providing shading, and to promote heat loss by ventilation.

### 2.3.4 Composite

The composite zone covers the central part of India. Some cities that experience this type of climate are New Delhi, Kanpur and Allahabad. A variable landscape and seasonal vegetation characterise this zone. The intensity of solar radiation is very high in summer with diffuse radiation amounting to a small fraction of the total. In monsoons, the intensity is low with predominantly diffuse radiation. The maximum daytime temperature in summers is in the range of 32 – 43 ºC, and night time values are from 27 to 32 ºC. In winter, the values are between 10 to 25 ºC during the day and 4 to 10 ºC at night.

The relative humidity is about 20 – 25 % in dry periods and 55 – 95 % in wet periods. The presence of high humidity during monsoon months is one of the reasons why places like New Delhi and Nagpur are grouped under the composite and not hot and dry climate. Precipitation in this zone varies between 500 – 1300 mm per year. This region receives strong winds during monsoons from the south-east and dry cold winds from the north-east. In summer, the winds are hot and dusty. The sky is overcast and dull in the monsoon, clear in winter and frequently hazy in summer.

Generally, composite regions experience higher humidity levels during monsoons than hot and dry zones. Otherwise most of their characteristics are similar to the latter. Thus, the design

criteria are more or less the same as for hot and dry climate except that maximising cross ventilation is desirable in the monsoon period.

### 2.3.5 Cold and Cloudy

Generally, the northern part of India experiences this type of climate. Most cold and cloudy regions are situated at high altitudes. Ootacamund, Shimla, Shillong, Srinagar and Mahabaleshwar are examples of places belonging to this climatic zone. These are generally highland regions having abundant vegetation in summer.

The intensity of solar radiation is low in winter with a high percentage of diffuse radiation. Hence, winters are extremely cold. In summer, the maximum ambient temperature is in the range of 20 – 30 ºC during the day and 17 – 27 ºC at night, making summers quite pleasant. In winter, the values range between 4 and 8 ºC during the day and from -3 to 4 ºC at night, making it quite chilly.

The relative humidity is generally high and ranges from 70 – 80 %. Annual total precipitation is about 1000 mm and is distributed evenly throughout the year. This region experiences cold winds in the winter season. Hence, protection from winds is essential in this type of climate. The sky is overcast for most part of the year except during the brief summer.

Conditions in summer are usually clear and pleasant, but owing to cold winters, the main criteria for design in the cold and cloudy region aim at resisting heat loss by insulation and infiltration, and promoting heat gain by directly admitting and trapping solar radiation within the living space.

### 2.3.6 Cold and Sunny

The cold and sunny type of climate is experienced in Leh (Ladakh). The region is mountainous, has little vegetation, and is considered to be a cold desert.

The solar radiation is generally intense with a very low percentage of diffuse radiation. In summer, the temperature reaches 17 – 24 ºC during the day and 4 – 11 ºC at night. In winter, the values range from -7 to 8 ºC during the day and -14 to 0 ºC at night. Winters thus, are extremely cold. The relative humidity is consistently low ranging from about 10 – 50 % and precipitation is generally less than 200 mm per year. Winds are occasionally intense. The sky is fairly clear throughout the year with a cloud cover of less than 50%.

As this region experiences cold desert climatic conditions, the design criteria are to resist heat loss by insulation and controlling infiltration. Simultaneously, heat gain needs to be promoted by admitting and trapping solar radiation within the living space.

## 2.4 IMPLICATIONS OF CLIMATE ON BUILDING DESIGN

The characteristics of each climate differ and accordingly the comfort requirements vary from one climatic zone to another. Before proceeding further, it would be useful to define comfort and the conditions that affect it. According to ASHRAE [10], thermal comfort is, “that condition of mind which expresses satisfaction with the thermal environment”. It is also, “the range of climatic conditions within which a majority of the people would not feel discomfort either of heat or cold”. Such a zone in still air corresponds to a range of 20 – 30 ºC dry bulb temperature with 30 – 60 % relative humidity. Besides, various climatic elements such as wind speed, vapour pressure and radiation also affect the comfort conditions.

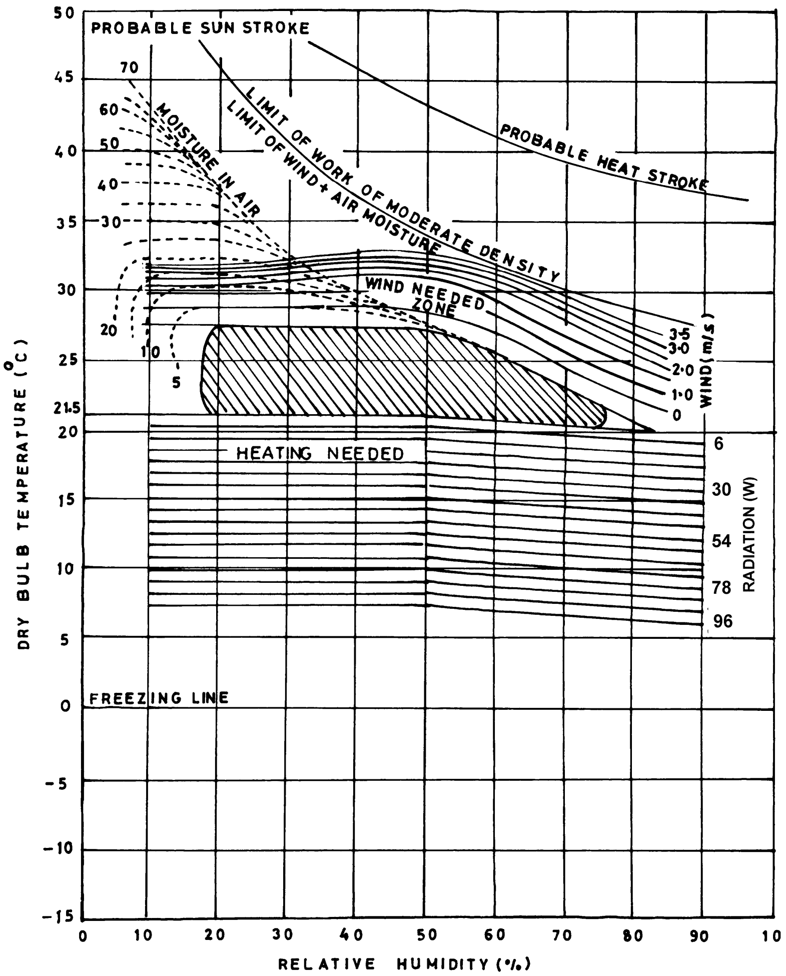



**Fig. 2.14 Bio-climatic chart**

Figure 2.14 illustrates a 'Comfort Zone' on a bio-climatic chart [11] – a simple tool for analysing the climate of a particular place. It indicates the zones of human comfort based on ambient temperature and humidity, mean radiant temperature, wind speed, solar radiation and evaporative cooling. On the chart, dry bulb temperature is used as the ordinate, and relative humidity as the abscissa. Based on the dry bulb temperature and humidity of a place, one can locate a point on the chart. If it lies within the comfort zone, then the conditions are comfortable. In case it is above the zone, cooling is required; if it is below the zone, heating is needed. If the point is higher than the upper perimeter of the comfort zone, air movement needs to be increased. For conditions when the temperature is high and relative humidity is low, air movement will not help. On the other hand, evaporative cooling is desirable. If the point lies below the lower perimeter of the comfort zone, heating is necessary to counteract low dry-bulb temperature. If the point lies to the left of the comfort zone, either radiant heating or cooling is necessary. Thus, a bio-climatic chart can give ready information about the requirements of comfort at a particular time. Design decisions can be taken accordingly.

Based on the characteristics of climate, the comfort requirements for each climatic zone are presented in Table 2.2. The corresponding physical manifestations are also mentioned in the table.

**Table 2.2 Comfort requirements and physical manifestation**

**1)Hot and Dry Region**

| OBJECTIVES | PHYSICAL MANIFESTATION |
|---|---|
| 1)Resist heat gain | |
| • Decrease exposed surface area | Orientation and shape of building |
| • Increase thermal resistance | Insulation of building envelope |
| • Increase thermal capacity (Time lag) | Massive structure |
| • Increase buffer spaces | Air locks/ lobbies/balconies/verandahs |
| • Decrease air exchange rate (ventilation during day-time) | Weather stripping and scheduling air changes |
| • Increase shading | External surfaces protected by overhangs, fins and trees |
| • Increase surface reflectivity | Pale colour, glazed china mosaic tiles etc. |
| 2)Promote heat loss | |
| • Ventilation of appliances | Provide windows/ exhausts |
| • Increase air exchange rate (Ventilation during night-time) | Courtyards/ wind towers/ arrangement of openings |
| • Increase humidity levels | Trees, water ponds, evaporative cooling |

**2)Warm and Humid Region**

| OBJECTIVES | PHYSICAL MANIFESTATION |
|---|---|
| 1)Resist heat gain | |
| • Decrease exposed surface area | Orientation and shape of building |
| • Increase thermal resistance | Roof insulation and wall insulation. Reflective surface of roof. |
| • Increase buffer spaces | Balconies and verandahs |
| • Increase shading | Walls, glass surfaces protected by overhangs, fins and trees |
| • Increase surface reflectivity | Pale colour, glazed china mosaic tiles, etc. |
| 2)Promote heat loss | |
| • Ventilation of appliances | Provide windows/ exhausts |
| • Increase air exchange rate (Ventilation throughout the day) | Ventilated roof construction. Courtyards, wind towers and arrangement of openings |
| • Decrease humidity levels | Dehumidifiers/ desiccant cooling |

**3)Moderate Region**

| OBJECTIVES | PHYSICAL MANIFESTATION |
|---|---|
| 1)Resist heat gain | |
| • Decrease exposed surface area | Orientation and shape of building |
| • Increase thermal resistance | Roof insulation and east and west wall insulation |
| • Increase shading | East and west walls, glass surfaces protected by overhangs, fins and trees |
| • Increase surface reflectivity | Pale colour, glazed china mosaic tiles, etc. |
| 2)Promote heat loss | |
| • Ventilation of appliances | Provide windows/ exhausts |
| • Increase air exchange rate (Ventilation) | Courtyards and arrangement of openings |

**4)Cold and Cloudy Region** (Applies for Cold and Sunny also)

| OBJECTIVES | PHYSICAL MANIFESTATION |
|---|---|
| 1)Resist heat loss | |
| • Decrease exposed surface area | Orientation and shape of building. Use of trees as wind barriers |
| • Increase thermal resistance | Roof insulation, wall insulation and double glazing |
| • Increase thermal capacity (Time lag) | Thicker walls |
| • Increase buffer spaces | Air locks/ Lobbies |
| • Decrease air exchange rate | Weather stripping |
| • Increase surface absorptivity | Darker colours |
| 2)Promote heat gain | |
| • Reduce shading | Walls and glass surfaces |
| • Utilise heat from appliances | |
| • Trapping heat | Sun spaces/ green houses/ Trombe walls etc. |

**5)Composite Region**

| OBJECTIVES | PHYSICAL MANIFESTATION |
|---|---|
| 1)Resist heat gain in summer and Resist heat loss in winter | |
| • Decrease exposed surface area | Orientation and shape of building. Use of trees as wind barriers |
| • Increase thermal resistance | Roof insulation and wall insulation |
| • Increase thermal capacity (Time lag) | Thicker walls |
| • Increase buffer spaces | Air locks/ Balconies |
| • Decrease air exchange rate | Weather stripping |
| • Increase shading | Walls, glass surfaces protected by overhangs, fins and trees |
| • Increase surface reflectivity | Pale colour, glazed china mosaic tiles, etc. |
| 2)Promote heat loss in summer/ monsoon | |
| • Ventilation of appliances | Provide exhausts |
| • Increase air exchange rate (Ventilation) | Courtyards/ wind towers/ arrangement of openings |
| • Increase humidity levels in dry summer | Trees and water ponds for evaporative cooling |
| • Decrease humidity in monsoon | Dehumidifiers/ desiccant cooling |

## 2.5 URBAN CLIMATE

The air temperatures in densely built urban areas are often higher than the temperatures of the surrounding countryside. This is due to rapid urbanisation and industrialisation. The term “urban heat island” refers to increased surface temperatures in some pockets of a city, caused by an ever changing microclimate. The difference between the maximum city temperature (measured at the city centre) and the surrounding countryside is the urban heat-island intensity. An urban heat island study was carried out in Pune, Mumbai, Kolkata, Delhi, Vishakapatnam, Vijayawada, Bhopal and Chennai [12,13]; the heat-island intensities of these cities are presented in Table 2.3. It is seen that, among the cities listed in the table, the heat island intensity is greatest in Pune (about 10 °C) and lowest in Vishakhapatnam (about 0.6°C). In the metropolitan cities of Mumbai, New Delhi, Chennai and Kolkata, the corresponding values are 9.5, 6.0, 4.0 and 4.0$^{o}$C respectively. Clearly, the values are quite high. The density of the built environment and the extent of tree cover or vegetation primarily affect the heat-island intensity. Pollution and heat due to vehicular traffic, industrialisation and human activities are other contributing factors.

**Table 2.3 Heat island intensities in some Indian cities [12,13]**

| Station | Heat Island Intensity ( $^{o}$C) |
|---|---|
| New Delhi | 6.0 |
| Bhopal | 6.5 |
| Kolkata | 4.0 |
| Mumbai | 9.5 |
| Pune | 10.0 |
| Vishakhapatnam | 0.6 |
| Vijayawada | 2.0 |
| Chennai | 4.0 |

Normally, the central business district (CBD) or the centre of a city experiences higher temperatures than the other parts. This is because the CBD mainly consists of concrete buildings and asphalted roads, which heat up very quickly due to radiation from the sun. Most of this heat is stored and released very slowly, sometimes even upto the night. This phenomenon does not allow the daily minimum temperature to become too low. Though it may be a welcome phenomenon in cold regions during winters, it makes life unbearable for people in the hot regions. Thus, in tropical climates, the provision of sufficient ventilation and spacing between buildings is required to allow the accumulated heat to escape to the atmosphere easily.

Street patterns and urban blocks can be oriented and sized to incorporate concerns of light, sun, and shade according to the dictates of the climate. For example, the densely built areas produce, store and retain more heat than low-density areas. Thus, the temperature differential between urban areas and the surrounding countryside increases as the surrounding areas cool at night. As a result, cooler air from the surrounding countryside flows towards the centre. This kind of circulation is more pronounced on calm summer nights and can be utilised to flush dense areas of heat and pollutants. To achieve cool air movement, a belt of undeveloped and preferably vegetated land at the perimeter of the city, can be provided to serve as a cool air source. Radial street patterns can also be designed for facilitating movement of air from less dense to more dense areas.

A system of linear greenways or boulevards converging towards the city centre will help to maintain the movement of cool air. Provided the soil is adequately moist, a single isolated tree may transpire upto 400 litres of water per day. This transpiration together with the shading of solar radiation, creates a cooler environment around the tree. On a hot summer day, the temperature can drop significantly under trees due to cool breezes produced by convective currents and by shading from direct sunlight. Planted areas can be as much as 5– 8 $^{o}$C cooler than built-up areas due to a combination of evapotranspiration, reflection, shading, and storage of cold.

Local wind patterns are created when the warm air over a dense built up area rises, and is

replaced by cooler air from vegetated areas. Having many evenly distributed small open spaces will produce a greater cooling effect than a few large parks. Studies suggest that for a city with a population of about one million, 10-20% of the city area should be covered by vegetation for effectively lowering local temperatures. As the vegetation cover in the city increases from 20 to 50%, the minimum air temperature decreases by 3-4 $^{o}$C, and the maximum temperature decreases by about 5 $^{o}$C [14]. Figure 2.15 illustrates the temperature drop as a function of tree cover in the city of Montreal. Similar findings were reported in another study conducted in Sacramento, Phoenix, USA [14].

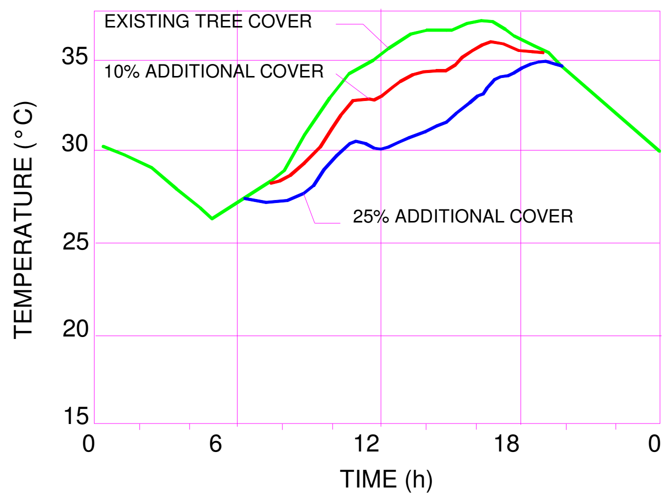



**Fig. 2.15 Cooling due to tree cover [14]**

The heat released from combustion of fuels and from human activities, adds to the ambient temperature of the city. Air pollution, caused mainly by emissions from vehicles and industries, reduces the longwave radiation back to the sky thereby making the nights are warmer. Global solar radiation during daytime is also reduced due to increased scattering and absorption by polluted air (this can be upto 10-20% in industrial cities). Pollution also affects visibility, rainfall and cloud cover. Effective land use to decongest cities, and the provision of proper vegetation would mitigate the effects of pollution. It is also important to use cleaner fuels and more efficient vehicles.

Meteorological studies and remote sensing by satellites can be used to ascertain drastic changes in the climate, land use and tree cover patterns. Remote sensing can also be used to map hot and cool areas across a city by using GIS tools (Geographical Information System). Such mapping can help to reduce unplanned growth of a city, in preparing a proper land use plan, and to identify future vulnerable areas (those devoid of natural vegetation, parks and water bodies). These measures would certainly help in reducing urban heat island intensity.

## 2.6 MICROCLIMATE

The conditions for transfer of energy through the building fabric and for determining the thermal response of people are local and site-specific. These conditions are generally grouped under the term of 'microclimate', which includes wind, radiation, temperature, and humidity experienced around a building. A building by its very presence will change the microclimate by causing a bluff obstruction to the wind flow, and by casting shadows on the ground and on other

buildings. A designer has to predict this variation and appropriately account for its effect in the design.

The microclimate of a site is affected by the following factors [15,16]:

(A) landform
(B) vegetation
(C) waterbodies
(D) street width and orientation
(E) open spaces and built form

An understanding of these factors greatly helps in the preparation of the site layout plan. For example, in a hot and dry climate, the building needs to be located close to a waterbody. The waterbody helps in increasing the humidity and lowering the temperature by evaporative cooling.

**(A) Landform**

Landform represents the topography of a site. It may be flat, undulating or sloping. Major landforms affecting a site are mountains, valleys and plains. Depending on the macroclimate and season, some locations within a particular landform experience a better microclimate than others.

In valleys, the hot air (being lighter) rises while cooler air having higher density, settles into the depressions, resulting in a lower temperature at the bottom. Upward currents form on sunny slopes in the morning. By night, the airflow reverses because cold ground surfaces cool the surrounding air, making it heavier and causing it to flow down the valley. Moreover, the wind flow is higher along the direction of the valley than across it due to unrestricted movement. On mountain slopes, the air speed increases as it moves up the windward side, reaching a maximum at the crest and a minimum on the leeward side. The difference in air speed is caused due to the low pressure area developed on the leeward side.

Temperature also varies with elevation. The cooling rate is about $0.8^{0}$C for every 100m of elevation [14]. Air moving down the slope will thus be cooler than the air it replaces lower down, and vice versa. Further, the orientation of the slope also plays a part in determining the amount of solar radiation incident on the site. For example a south-facing slope will get more exposure than a north-facing one in the northern hemisphere. Studies conducted in Mardin, Turkey showed that building groups located on a south facing slope in the city needed approximately 50% less heat to maintain the same indoor temperature as buildings located on the plain land [14].

Careful positioning of a building with respect to landform can thus help in achieving comfort.

**(B) Waterbodies**

Waterbodies can be in the form of sea, lake, river, pond or fountains. Since water has a relatively high latent heat of vapourisation, it absorbs a large amount of heat from the surrounding air for evaporation. The cooled air can then be introduced in the building. Evaporation of water also raises the humidity level. This is particularly useful in hot and dry climates. Since water has a high specific heat, it provides an ideal medium for storage of heat that can be used for heating purposes.

Large waterbodies tend to reduce the difference between day and night temperatures because they act as heat sinks. Thus, sites near oceans and large lakes have less temperature variation between day and night, as well as between summer and winter as compared to inland sites. Also, the maximum temperature in summer is lower near water than on inland sites.

The wind flow pattern at a site is influenced by the presence of a large waterbody in the following way. Wind flow is generated due to the difference in the heat storing capacity of water and land, and the consequent temperature differentials. During the day, the land heats up faster than the water, causing the air over the land to rise and be replaced by cool air from water. Hence, the breeze blows towards the land from water during the day and in the reverse direction at night. (as land cools more rapidly than water).

Evaporative cooling can help to maintain comfort in buildings in hot and dry climate. This feature was successfully adopted in vernacular architecture. For example, the Deegh palace in Bharatpur is surrounded by a water garden to cool the neighbourhood. Other examples include the Taj Mahal at Agra and the palace at Mandu. The evaporation rate of water in such an open spaces depends on the surface area of the water, the relative humidity of the air, and the water temperature.

**(C) Vegetation**

Vegetation plays an important role in changing the climate of a city, as seen in section 2.5. It is also effective in controlling the microclimate. Plants, shrubs and trees cool the environment when they absorb radiation for photosynthesis. They are useful in shading a particular part of the structure and ground for reducing the heat gain and reflected radiation. By releasing moisture, they help raise the humidity level. Vegetation also creates different air flow patterns by causing minor pressure differences, and thus can be used to direct or divert the prevailing wind advantage.

Based on the requirement of a climate, an appropriate type of tree can be selected. Planting deciduous trees such as mulberry to shade east and west walls would prove beneficial in hot and dry zones. In summer, they provide shade from intense morning and evening sun, reduce glare, as well as cut off hot breezes. On the other hand, deciduous trees shed their leaves in winter and allow solar radiation to heat the building. The cooling effect of vegetation in hot and dry climates comes predominantly from evaporation, while in hot humid climates the shading effect is more significant.

Trees can be used as windbreaks to protect both buildings and outer areas such as lawns and patios from both hot and cold winds. The velocity reduction behind the windbreak depends on their height, density, cross-sectional shape, width, and length, the first two being the most important factors. When the wind does not blow perpendicular to the windbreak, the sheltered area is decreased. The rate of infiltration in buildings is proportional to the wind pressure. Therefore, it is more important to design windbreaks for maximum wind speed reduction in extreme climates, than to attempt to maximize the distance over which the windbreak is effective.

In cold climates, windbreaks can reduce the heat loss in buildings by reducing wind flow over the buildings, thereby reducing convection and infiltration losses. A single-row of high density trees in the form of a windbreak can reduce infiltration in a residence by about 60% when planted about four tree heights from the building. This corresponds to about 15% reduction in energy costs [14].

Thus, trees can be effectively used to control the microclimate. The data for various trees found in India are presented in Table 2.4 [4, 17].

## Table 2.4 Properties of some Indian Trees [17]

| S. No | Botanical Name | Common Name English | Height (m) | Spread (m) | Rate of Growth | Root System | Drought Resistance | Foliage |
|---|---|---|---|---|---|---|---|---|
| 1 | Eugenia jambolana | Jamun | 12.2 to 13.7 | 9.1 to 10.7 | Medium | Medium | Medium | BLE |
| 2 | Azadiracta indica | Margosa | 13.7 to 15.2 | 10.7 to 12.2 | Fast | Medium | Good | BLE |
| 3 | Mimusops elengi | Bulletwood tree | 12.2 to 13.7 | 10.7 to 12.2 | Slow | Large | Good | BLE |
| 4 | Peltrophorum ferrigeum | Copper pod tree | 13.7 to 15.2 | 10.7 to 12.2 | Fast | Small | Good | BLE |
| 5 | Tamarindus indica | Tamarind | 10.7 to 12.2 | 9.1 to 10.7 | Slow | Medium | Medium | BLE |
| 6 | Pithecellobium dulce | Goras | 12.2 to 13.7 | 9.1 to 10.7 | Slow | Large | Medium | BLE |
| 7 | Samanea saman | Raintree | 10.7 to 12.2 | 9.1 to 10.7 | Fast | Medium | Medium | BLE |
| 8 | Bauhinia variegata | Variegated bauhinia | 6.1 to 9.1 | 7.6 to 9.1 | Fast | Small | Medium | D |
| 9 | Cassia fistula | Indian laburnum | 7.6 to 10.7 | 6.1 to 9.1 | Fast | Small | Very Good | D |
| 10 | Cassia javanica | Pink cassia | 7.6 to 9.1 | 9.1 to 10.7 | Medium | Medium | Good | D |
| 11 | Cordia sebestena | Cordia | 4.6 to 6.1 | 4.6 to 5.5 | Medium | Small | Good | D |
| 12 | Delonix regia | Royal poincana | 7.6 to 9.1 | 7.6 to 8.5 | Fast | Large | Medium | E |
| 13 | Erythrina indica | Indian coral tree | 7.6 to 9.1 | 4.6 to 6.1 | Fast | Small | Good | D |
| 14 | Gliricidia maculata | Madra tree | 6.1 to 7.6 | 4.6 to 6.1 | Fast | Small | Poor | BLE |
| 15 | Largerstroemia spriosa | Pride of India | 7.6 to 9.1 | 6.1 to 7.6 | Fast | Medium | Very good | BLE |
| 16 | Morus indica | Mulberry | 9.1 to 10.7 | 7.6 to 8.5 | Medium | Medium | Medium | D |
| 17 | Plumeria alba | White frangipani | 4.6 to 6.1 | 4.6 to 5.5 | Fast | Small | Medium | D |
| 18 | Pogamia glabra | Pongam | 4.6 to 6.1 | 4.6 to 6.1 | Fast | Small | Medium | D |
| 19 | Psidium guyava | Guava | 6.1 to 7.6 | 5.5 to 6.1 | Fast | Medium | Medium | BLE |
| 20 | Mornga oleifera | Drumstick tree | 9.1 to 10.7 | 7.6 to 9.1 | Fast | Small | Medium | BLE |
| 21 | Pustrajiva roxburghil | Lucky bean tree | 7.6 to 9.1 | 4.6 to 6.1 | Slow | Small | Medium | BLE |
| 22 | Tecoma undulata | Wary leaved tecoma | 6.1 to 7.6 | 4.6 to 5.5 | Fast | Small | Very good | BLE |
| 23 | Thespesia populnea | Portia tree | 7.6 to 9.1 | 7.6 to 9.1 | Fast | Small | Medium | BLE |
| 24 | Thevital peruviana | Yellow oleander | 4.6 to 5.5 | 3.0 to 4.6 | Fast | Small | Medium | D |
| 25 | Nesium oleander | Oleander | 4.6 to 5.5 | 3.0 to 4.6 | Fast | Medium | Good | D |
| 26 | Zapota | Zapota | 6.1 to 7.6 | 7.6 to 9.1 | Fast | Medium | Good | BLE |

BLE = Broad Leaf Evergreen, D = Deciduous, E = Evergreen

### (D) Street width and orientation

The amount of direct radiation received by a building and the street in an urban area is determined by the street width and its orientation. The buildings on one side of the street tend to cast a shadow on the street on the opposite building, by blocking the sun's radiation. Thus the width of the street can be relatively narrow or wide depending upon whether the solar radiation is

desirable or not. For instance in Jaisalmer (hot and dry climate), most of the streets are narrow with buildings shading each other to reduce the solar radiation, and consequently the street temperature and heat gain of buildings [18]. Figure 2.16 shows the street temperatures in summer and winter in Jaisalmer as compared to temperatures recorded at the meteorological station. It is seen that street temperatures can be upto 2.5°C lower than the ambient air temperatures due to mutual shading of buildings. At high latitudes in the northern hemisphere, the solar radiation is predominantly from the south, hence wider east-west streets give better winter solar access.

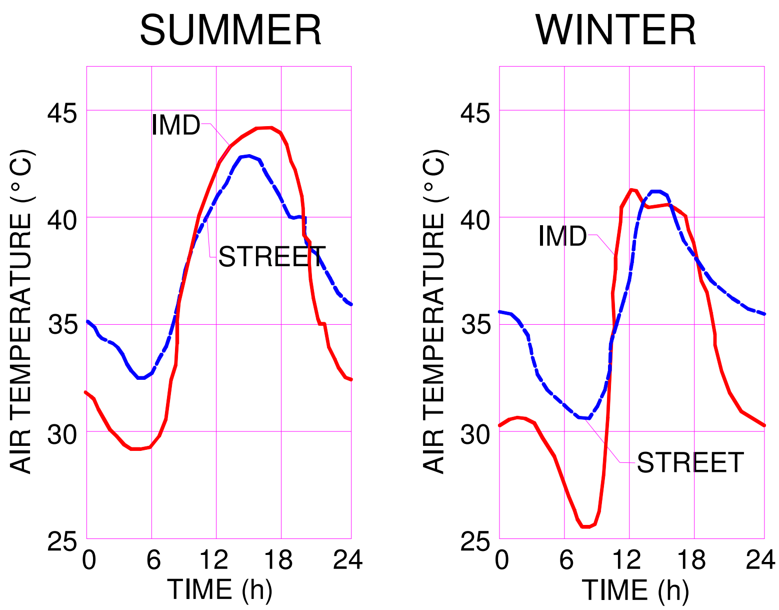



**Fig. 2.16 Street temperatures in Jaisalmer [18]**
**(a) Summer, (b) Winter**

The orientation of the street is also useful for controlling airflow. Air movement in streets can be either an asset or a liability, depending on season and climate. The streets can be oriented parallel to prevailing wind direction for free airflow in warm climates. Smaller streets or pedestrian walkways may have number of turns (zigzags) to modulate wind speed. Wind is desirable in streets of hot climates to cool people and remove excess heat from the streets. It can also help in cross ventilation of buildings. This is important in humid climates, and at night in arid climates. In cold regions, wind increases heat losses of buildings due to infiltration. For restricting or avoiding wind in cold regions, the streets may be oriented at an angle or normal to the prevailing wind direction. For regular organisations of buildings in an urban area, tall buildings on narrow streets yield the most wind protection, while shorter buildings on wider streets promote more air movement. When major streets are parallel to winds, the primary factors affecting the wind velocity are the width of streets and the frontal area (height and width) of windward building faces.

**(E) Open spaces and built form**

The form of a building and the open spaces in its neighbourhood affect the radiation falling on the building's surface and the airflow in and around it. Open spaces such as courtyards can be designed such that solar radiation incident on them during daytime can be reflected on to building façades for augmenting solar heat. This is desirable in cold climates, and it is possible if the

surface finish of the courtyard is reflective in nature. Inside a courtyard, wind conditions are primarily dependent on the proportion between building height and courtyard width in the section along the wind flow line. Courtyards can also be designed to act as heat sinks. Grass and other vegetation in a courtyard can provide cooling due to evaporation and shading. Water sprayed on the courtyards would cause cooling effect due to evaporation. Consequently, the air temperature in the courtyard can be much lower compared to street or outdoor air temperatures in a hot and dry climate. Figure 2.17 presents the measured temperature at Jaisalmer, showing the maximum of courtyard temperature as 4 $^{o}$C less than that of the outdoor air temperature [18].

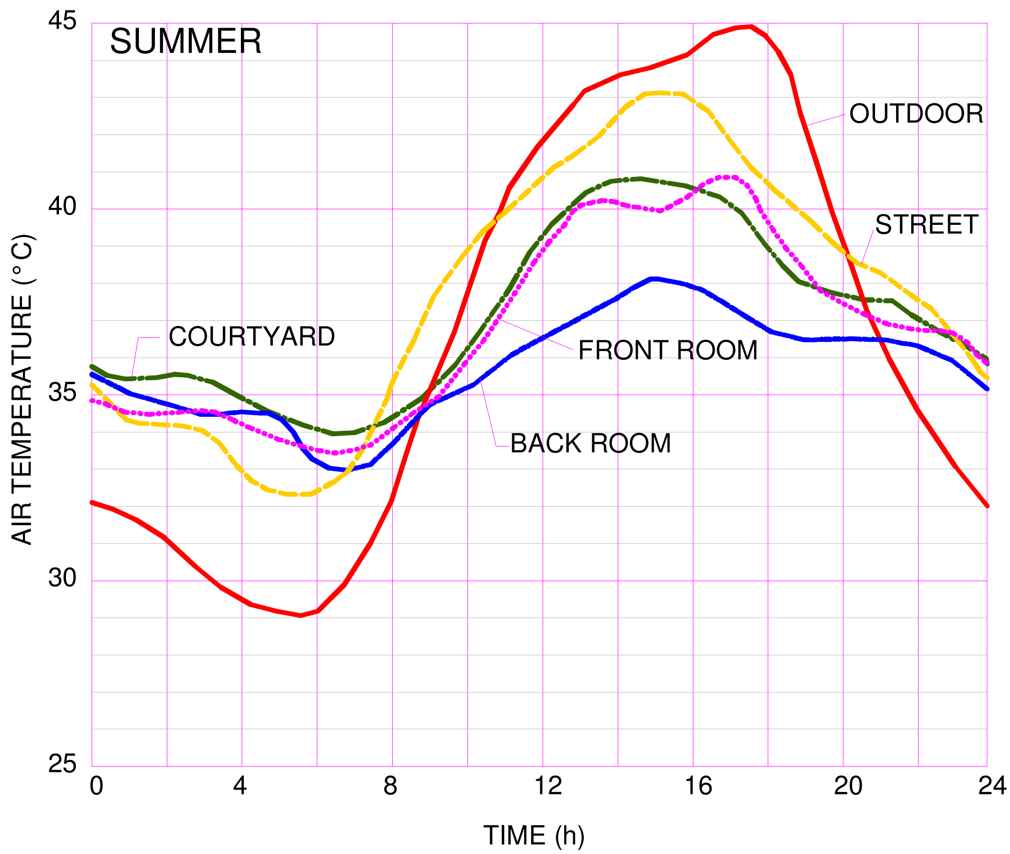



**Fig. 2.17 Effect of courtyard [18]**

The air in open spaces shaded by surrounding buildings would be cooler and can be used to facilitate proper ventilation and promote heat loss through building envelope. Built forms can be so oriented that buildings cause mutual shading and thus reduce heat gain. For ensuring unobstructed airflow, taller structures can be planned towards the rear side of a building complex. Thus, open spaces and built form can be appropriately used to modulate the microclimate.

## 2.7 TOOLS FOR ANALYSING WEATHER DATA

The effects of sun, wind and light on a particular site can be analysed in many ways depending on the type of information available for a place. They can be graphical in nature (such as bioclimatic chart [4, 11] and psychrometric chart [11]), or in worksheet format (such as Mahoney table [19]). One could also use computer software such as Climate Consultant [20] or Therm [21]. For example, the effects of temperature and humidity can be plotted on a bioclimatic

or psychrometric chart [11] to understand the climate and suggest ways of expanding the comfort zone. Similarly, Mahoney tables facilitate diagnosis of climate and provide design recommendations. The computer software ‘Therm’ evaluates climatic factors and predicts the adaptive comfort index. Climate Consultant, in addition to analyzing weather variables, provides recommendations for building design from the point of view of comfort requirements.

To generate relevant information on the climate of a place, one can use graphical procedures or adopt the measurement route, or resort to computational techniques. The measurement route can be either analysis of the recorded data available from Indian Meteorological Department and other sources (section 2.2), or for conducting on-site measurements. Table 2.5 lists various techniques that can be adopted to generate and analyse climatic factors.

The procedure to be adopted for the analysis of the climate of a place is as follows:

1. Obtain weather data.
2. Find out which months are comfortable (hot or cold), using mean temperature and relative humidity. This also gives an indication of the severity of the climate.
3. Identify the climatic zone to which the city belongs for adopting appropriate strategies to achieve comfort.
4. Establish the positive and negative aspects of climate for a particular season. For example, shading from the sun may be needed during overheated periods. Which are those seasons, and what is the position of the sun in the sky ? During the same period, wind may be required to alleviate discomfort. What are the speed and the direction of the wind during that period ?
5. Adjust the impact of local microclimatic conditions and the urban context in the analysis. For example, in northern hemisphere, larger buildings in the south create shadow zones in the north. Thus the amount of direct solar radiation falling on a smaller building in the north is affected. Also, the presence of a large building, or the orientation of the street can impact the speed and direction of wind.
6. Finalise the zoning of the site. For example, the presence of water bodies on the site may be advantageous in a hot and dry zone. The wind, if allowed to pass over the water body can increase the potential for evaporative cooling. So the building has to be oriented facing the wind.

**Table 2.5 Techniques for analysis of climatic factors**

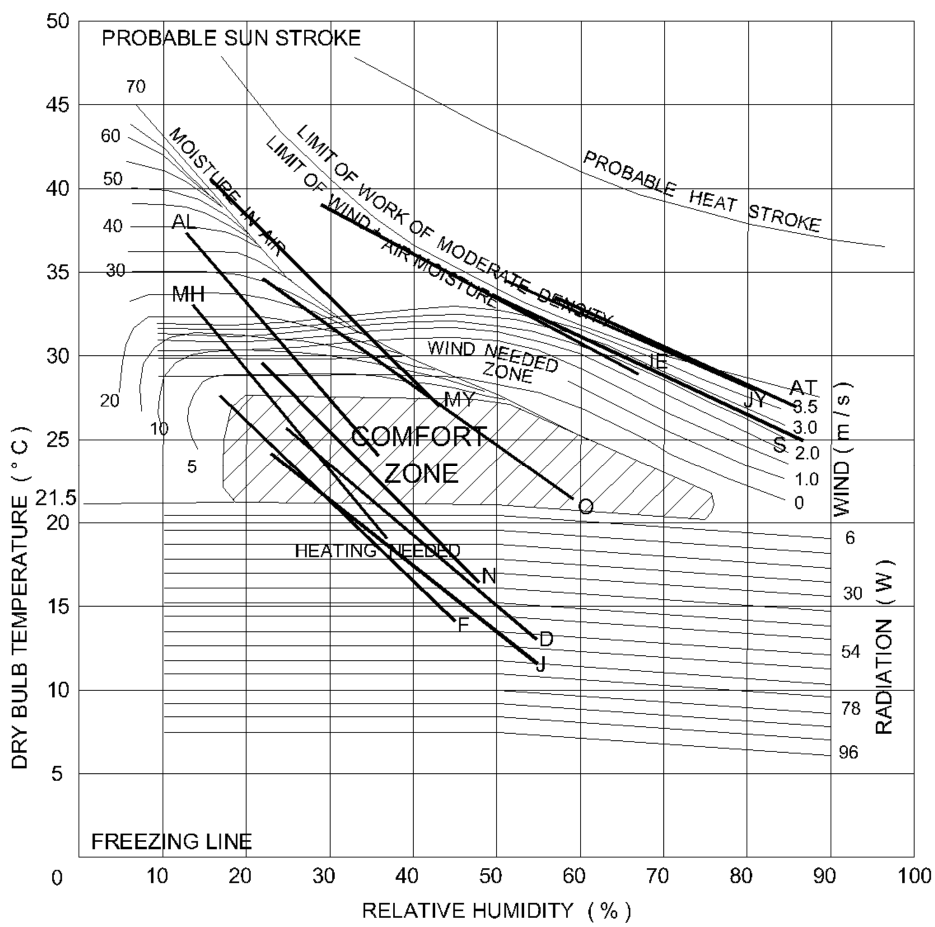
| Technique | | Solar radiation | Wind | Temperature, humidity, precipitation |
|---|---|---|---|---|
| Graphical method | | Maps for shading analysis [22]<br>Photographic survey [22]<br>Shadow angle protractor [19]<br>Shadow throw angles [3]<br>Solar envelope [14,22]<br>Solar radiation distribution maps [2]<br>Sundial [14]<br>Sundial and scale model [14]<br>Sun path diagrams [3,4,11,14,19] | Wind rose [4]<br>Wind square [14] | Temperature and humidity isopleths on [2,8] |
| Measurement | Recorded data | Mean, minimum and maximum global, diffuse and direct solar radiation data [1,2,3] | Mean, minimum and maximum with prevailing wind direction data [1,2,3] | Mean, minimum and maximum data [1,2,3]. |
| | Instruments | TNO sunlight meter [14],<br>Pyranometer,<br>Pyrheliometer<br>Sunshine recorder | Anemometer<br>Wind Tunnel Testing | Hygrometer,<br>Thermometer<br>Rain gauge |
| Software | | Solar 2 [23], Suntool [24] | - | - |

## 2.8 ILLUSTRATIVE EXAMPLE

As an illustrative example, the use of bioclimatic charts for analysing the climatic zones of six places, namely Jodhpur (hot and dry), Mumbai (warm and humid), Pune (moderate), New Delhi (composite), Srinagar (cold and cloudy) and Leh (cold and sunny) are discussed in this section.

**a) Jodhpur (Latitude: 26.30° N, Longitude: 73.02 ° E, Elevation: 224 MASL)**

The climate in Jodhpur is predominantly hot and dry. The months from April to June are very hot with temperatures in excess of 37 $^{o}$C during daytime. The chart (Fig. 2.18) shows that the evaporating cooling method is desirable in April and May. Mechanical air-conditioning is required from June to August due to high humidity coupled with high temperatures. September is a relatively cooler month, during which ventilation may be adequate to provide comfort. Nights in October are comfortable, but days are hot and dry. Thus, evaporating cooling is desirable during daytime in this month. Daytime conditions are comfortable during January, February, November and December. Nights are cool in these months.

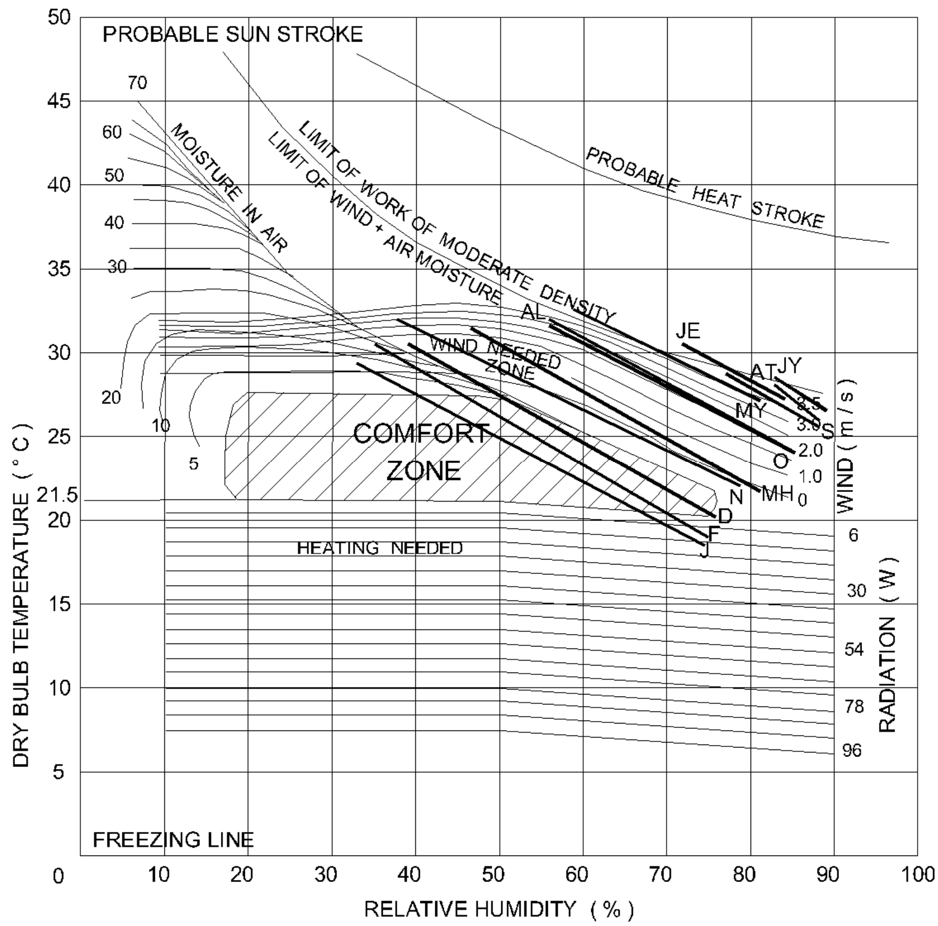



J=January, F=February, MH=March, AL=April, My=May, JE=June, JY=July, AT=August, S=September, O=October, N=November, D=December

**Fig. 2.18 Bioclimatic chart of Jodhpur**

**b) Mumbai (Latitude: 19.12° N, Longitude: 72.85 ° E, Elevation: 14 MASL)**

The climate in Mumbai is predominantly warm and humid. Although temperatures are not very high in summer, conditions are uncomfortable due to the high humidity. May is the hottest month with the monthly average daily maximum temperature reaching as high as 32 °C, coupled with a humidity of about 60% during daytime. The chart (Fig. 2.19) shows that mechanical air-conditioning is required from April to October during the day. At nights, wind or fan induced ventilation can provide comfort. In March, only ventilation cooling is needed. The months of January, February, November and December are mostly comfortable.

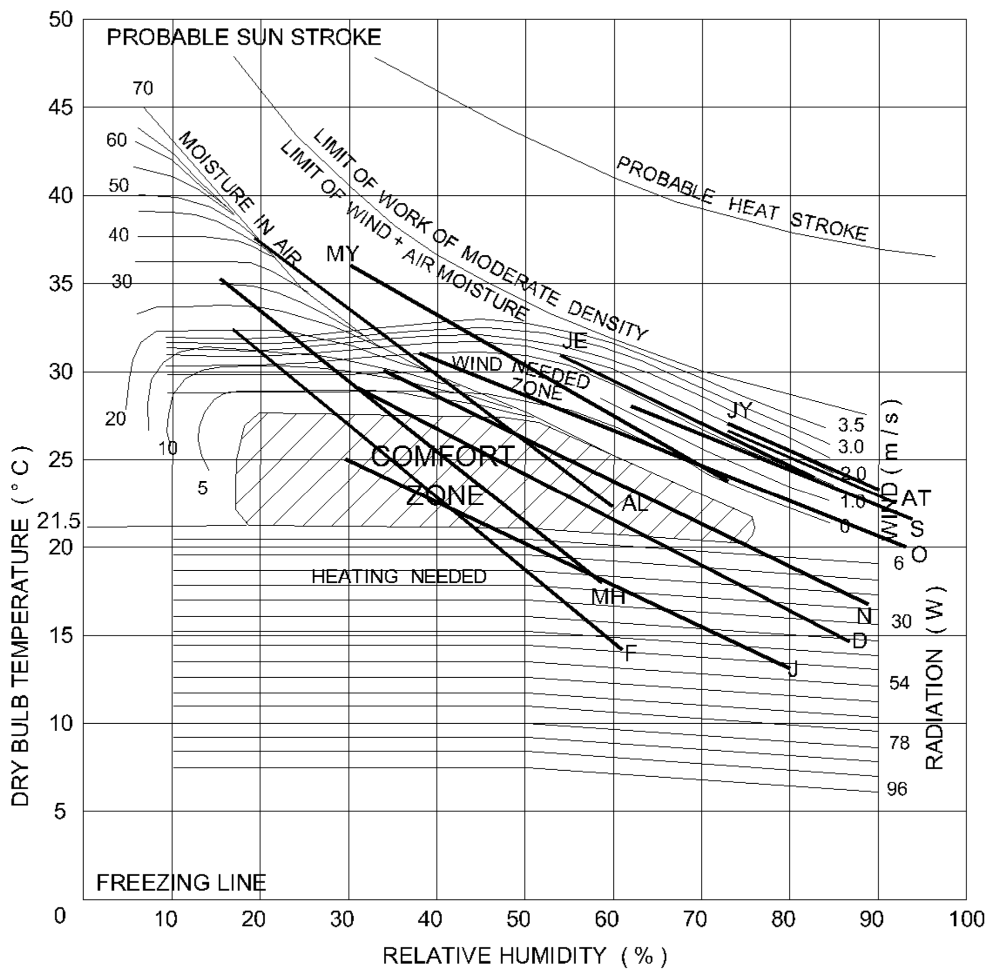



J=January, F=February, MH=March, AL=April, My=May, JE=June, JY=July, AT=August, S=September, O=October, N=November, D=December

**Fig. 2.19 Bioclimatic chart of Mumbai**

c) **Pune (Latitude: 18.53° N, Longitude: 73.85° E, Elevation: 559 MASL)**

The climatic conditions in Pune are mostly warm (Fig. 2.20). The day temperatures are relatively high during March, April and May; the corresponding night temperatures are within comfort level. April is the hottest month with the monthly average daily maximum temperature of 37.4 °C and a corresponding relative humidity of 19%. Evaporative cooling is indicated in these months during daytime. Ventilation can be adopted to achieve comfort at night, as the conditions are relatively cooler. In monsoon months (June to October), ventilation is required to provide comfort throughout the day. Winter months (January, February, November and December) are generally comfortable during the day and cool at night.

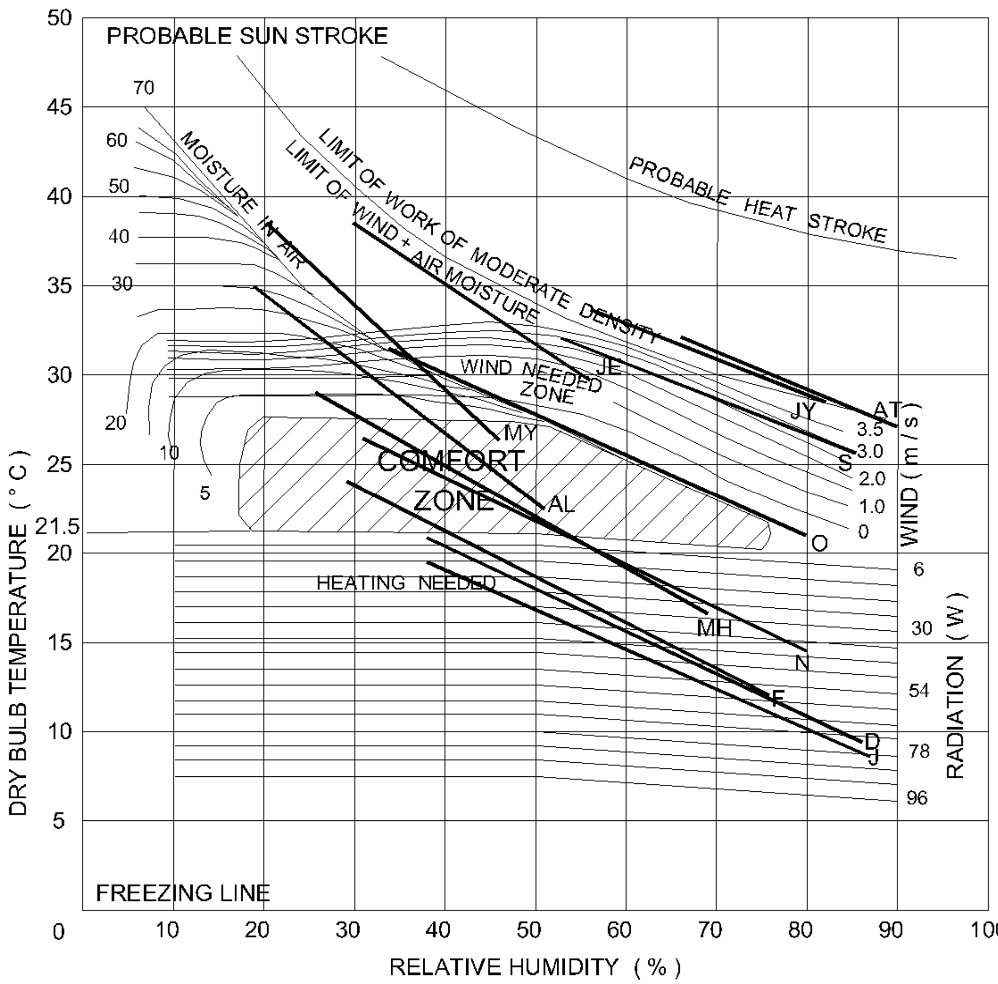



J=January, F=February, MH=March, AL=April, My=May, JE=June, JY=July, AT=August, S=September, O=October, N=November, D=December

**Fig. 2.20 Bioclimatic chart of Pune**

**d) New Delhi (Latitude:28.58$^{o}$ N, Longitude: 77.20° E, Elevation: 216 MASL)**

The climate in New Delhi is predominantly hot. It also has distinct cool and humid seasons. April to June is very hot; May and June are particularly harsh, with maximum daytime temperatures of about 39$^{o}$ C. Evaporating cooling is desirable in April and May (Fig. 2.21). Mechanical air-conditioning is required from June to August due to high humidity coupled with high temperatures. September is warm and humid; air movement in the form of ventilation can help in achieving comfort. In October, days are hot and dry, nights are comfortable. From November to March, the days are pleasant and nights are cool. January is the coolest month.



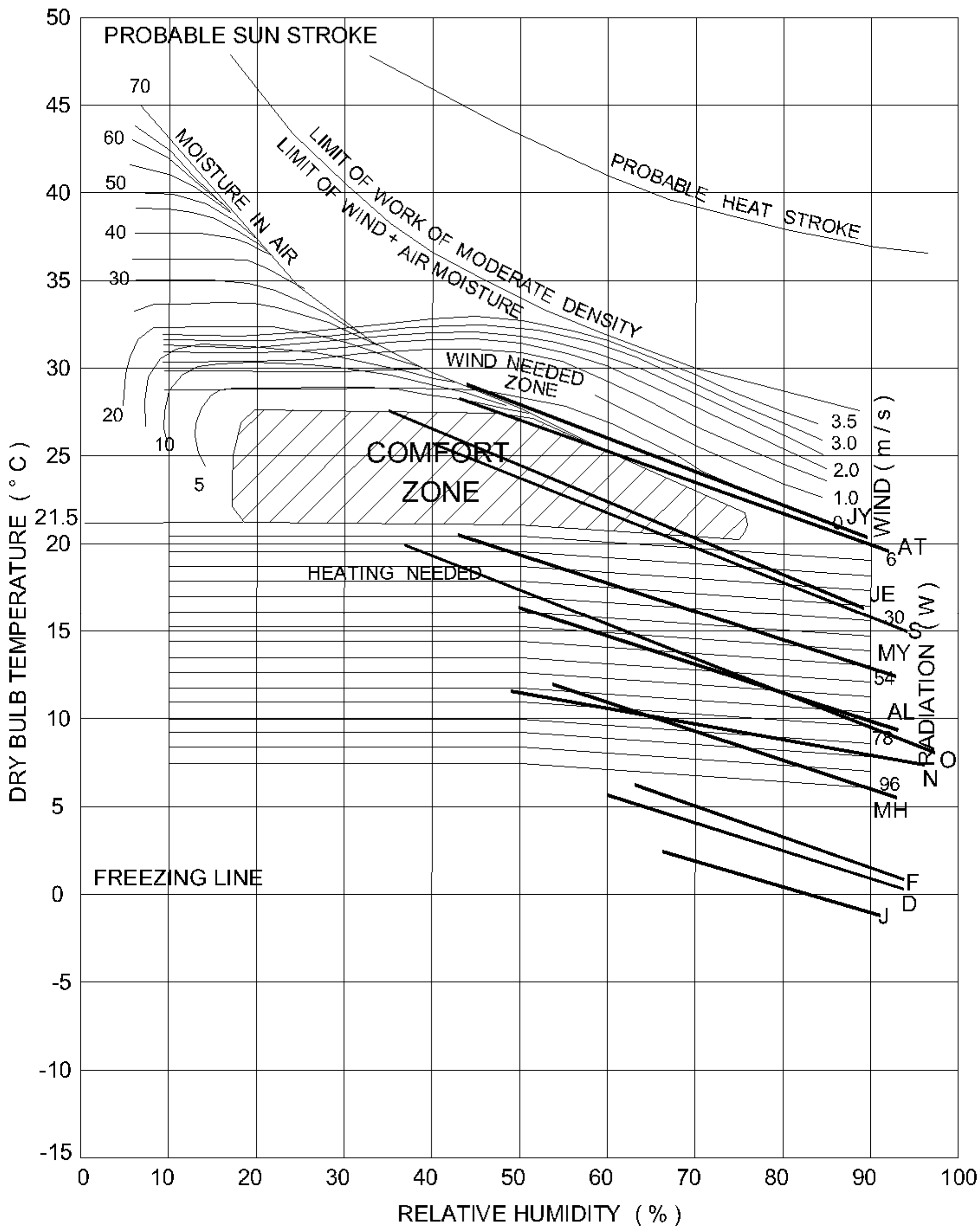

J=January, F=February, MH=March, AL=April, My=May, JE=June, JY=July, AT=August, S=September, O=October, N=November, D=December

**Fig. 2.21 Bioclimatic chart of New Delhi**

**e) Srinagar (Latitude: 34.08$^{o}$ N, Longitude: 74.83° E, Elevation: 1587 MASL)**

Figure 2.22 shows that Srinagar is predominantly cool. The months from October to May are uncomfortably cold. The conditions during December, January and February are extremely cold with night temperatures falling below freezing line. Mechanical heating is required during these

months. Days are comfortable in June and September; but some heating is required at night. July and August are just above the comfort limit and some cooling may be required. Ventilation should be able to provide comfort during these months. In the months of April, May and October, days can be made comfortable by providing heating through direct solar radiation. The daytime heat can also be trapped for nighttime use by providing adequate thermal mass.

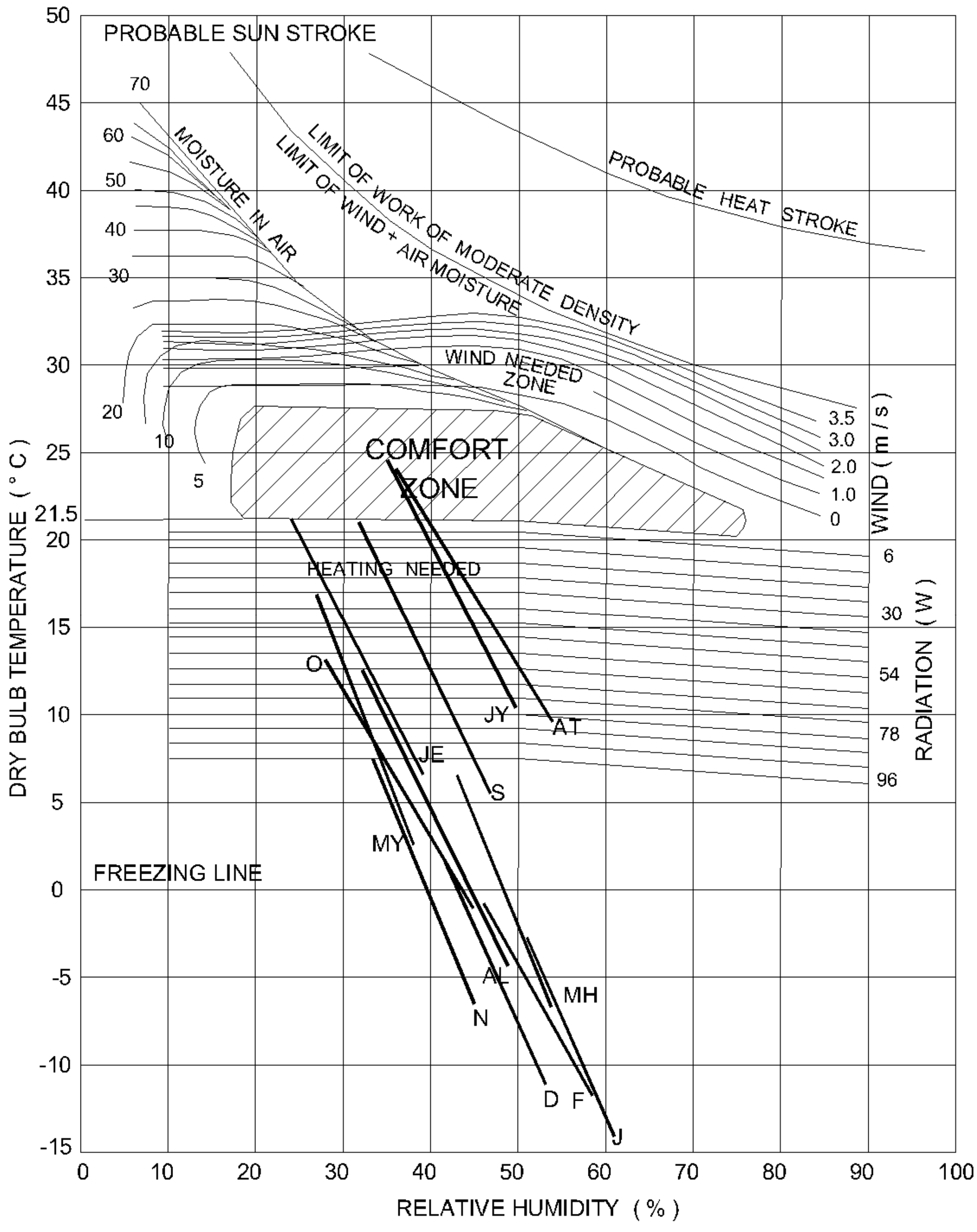



J=January, F=February, MH=March, AL=April, My=May, JE=June, JY=July, AT=August, S=September, O=October, N=November, D=December

**Fig. 2.22 Bioclimatic chart of Srinagar**

**f) Leh (Latitude: 34.15° N, Longitude: 77.57° E, Elevation:3514 MASL)**

The chart (Fig. 2.23) shows that Leh is predominantly cold throughout the year. Outside conditions are rarely within the comfort zone except during daytime in the months of July and August. In fact, the months of December, January and February experience sub-zero temperatures almost throughout the day and night.




J=January, F=February, MH=March, AL=April, My=May, JE=June, JY=July, AT=August, S=September, O=October, N=November, D=December

**Fig. 2.23 Bioclimatic chart of Leh**

Nights are severely cold with temperatures ranging from –14$^{o}$ C in January to –11$^{o}$ C in December. January is the coldest month (minimum and maximum temperatures being –14$^{o}$C and –3$^{o}$C respectively). March, April, October and November are less severe. However, the temperatures at night are below freezing point. Therefore, heating is a must in the months from October to April. In other months, the limit of comfort can be extended if adequate radiation from the sun is incident on the interior surfaces of the building. In May and October, additional heating is required at night. The global solar radiation available at this place is quite high; it has more than 300 days of clear sunshine. The radiation can therefore be trapped for use in the building both during day and night, to alleviate discomfort.

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