CHAPTER III

CLIMATIC FORCES

3.1 General Concept of Climatic Forces

Atmospheric phenomena occur at all scales of time, from fractions of a second to several years. Meteorologists classify these phenomena into two major divisions, "weather" and "climate," based on their temporal characteristics. Weather consists of those phenomena that occur over periods of time of a few days or less; climate is the integration of these phenomena as perceived over periods of a year or more. Climate is composed of many forces and complex relationships and cannot be completely expressed by only one of them (Griffith, John F., 1976).

The forces of climate are those phenomena that characterize the atmosphere and consist of:

1) solar radiation
2) long-wave radiative heat loss
3) temperature
4) precipitation
5) humidity

6) cloudiness

7) evaporation

8) wind speed and direction

9) turbulence

10) turbidity (Givoni, B., 1969).

When human sensations and comfort are to be considered, as in the environmental aspects of building design, those climatic forces of greatest concern are:

1) radiation (solar and long-wave)

2) air temperature

3) atmospheric moisture (precipitation and humidity)

4) wind (Olgyay, Victor, 1963, p. 32).

Through the following pages, these climatic forces were briefly discussed.

3.1.1 Radiation

The sun is man's primary source of energy - and the fossil fuels may be thought of as a kind of concentrated store of solar energy, fixed in chemical form through the processes of biological photosynthesis over the enormous eons of pre-history. Solar heat and light create on earth the basic conditions, of temperature etc., which make life possible at all. It is the sun's energy which provides the motive power, through its unequally distributed heating effects, for the circulation of the atmosphere, the oceanic currents and the transport of water through the cycle of evaporation, precipitation as rain or snow, and flow through streams and rivers (Steadman, Philip, 1976, p. 69).

Spatial and temporal variations in the quantity of solar energy received at the earth's surface make solar radiation the primary force in the determination of climate (Griffith, John F. and Driscoll, Dennis M., 1982). Figure 3.1 shows a schematic representation of heat exchange at noon on a summer day.

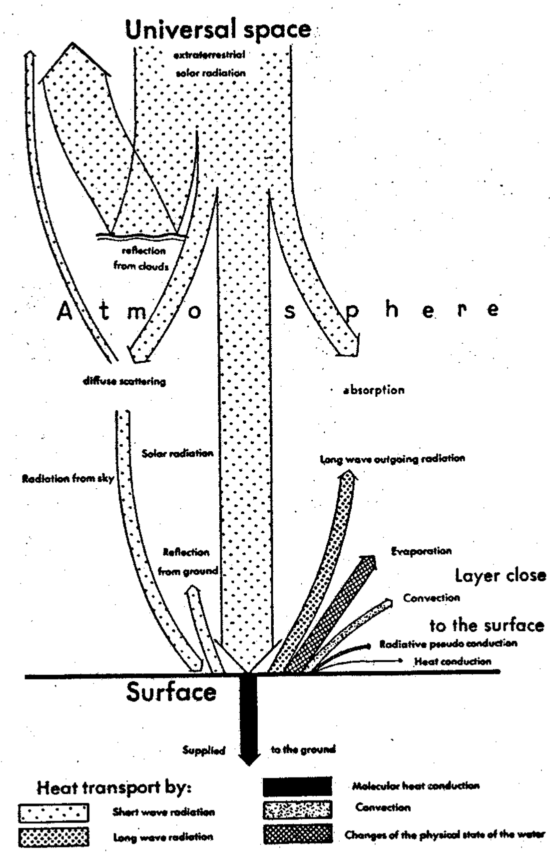

Fig. 3.1 Surface heat exchange at noon on a summer day (Olgyay, 1963, p.33)

As solar radiation penetrates the atmosphere, its intensity is decreased and its spectral distribution is altered by absorption, reflection and diffusion. A portion of the solar radiation absorbed by the earth's surface is re-radiated toward space as long-wave radiation.

Particles in the atmosphere also emit long-wave radiation, and those components directed downward are absorbed by the surface. Most of the outgoing long-wave radiation is absorbed by atmospheric water vapor and carbon dioxide, and the rest is lost to space (Givoni, B., 1969).

3.1.2 Air Temperature

The heat of the air is a decisive climatic force. There are few, if any, natural or artificial substances unaffected by this heat (Griffith, John F. and Driscoll, Dennis M., 1982). Through the process of conduction, the earth's surface, heated by absorbed solar radiation, warms the air layer in contact with it.

Upper layers are warmed through convection and mixing. Because of their ability to distribute heat more rapidly, bodies of water are affected less extremely by this condition of solar radiation than are land masses. At night the earth's surface cools more rapidly than does the air, causing the air layer nearest the ground to be colder than the layers above. This reversal of the normal vertical temperature gradient is known as an inversion. During condition of inversion, the heavier, colder air is nearest the ground, suppressing vertical air movement. Conditions promoting inversions are long nights, clear skies, dry air, and an absence of wind. An inversion may also be produced when a warm air mass meets and is lifted over a cold air mass (Givoni, B., 1969).

When solar radiation is decreased, as during the night and during the winter, long-wave radiation is emitted by the surface, causing the surface to cool, thereby cooling the air in contact with it. With a clear sky, a large amount of incoming radiation during the day and unobstructed outgoing radiation at night cause a wide diurnal temperature range.

An overcast sky, while restricting the incoming radiation during the day, captures the outgoing radiation and re-radiates it toward the surface, thus decreasing the diurnal variation in temperature (Olgyay, Victor, 1963, p. 32).

The temperature of an air mass is also altered by changes in elevation. The adiabatic heating and cooling processes cause rising air to expand and cool while descending air is compressed and warmed. Water vapor in rising air condenses to form liquid droplets, releasing latent heat and thereby slowing the rate of cooling. On the average, the rate of cooling, known as the lapse rate, is greatest near the ground and decreases with altitude, up to the stratosphere.

Pressure difference associated with variations in heating and cooling at the surface cause the migration of air masses. The prevailing weather conditions of a location are altered by the arrival of an air mass with a temperature acquired in a different region (Givoni B. 1969).

3.1.3 Atmospheric Moisture

In its various forms, water is nearly as significant to climate as in temperature. Its function is twofold. First, climate may be spatially and temporally differentiated by the relative presence or absence of atmospheric moisture. Second, the changes of state of water release or require energy, making them an integral part of the energy exchange processes (Griffith, John F and Driscoll, Dennis M., 1982). Water vapor enters the atmosphere through evaporation.

Primarily from bodies of water, but also from moist land surfaces and through transpiration from vegetation, and returns to the surface through precipitation. This cyclic process is known as the hydrologic cycle. Figure 3.2 shows this cycle. The atmosphere's capacity for holding water vapor is principally a function of the temperature of the air. As Figure 3.3 shows, the global distribution of atmospheric moisture therefore parallels those of solar radiation and temperature, being greatest near the equator and diminishing toward the pole. The temperature at which air becomes saturated is known as the dew point.

Cooling air below its dew point generally causes condensation of the vapor that is in excess of the air's capacity. Cooling air that is not in contact with a cold surface causes the formation of fog (Givoni, B., 1969).

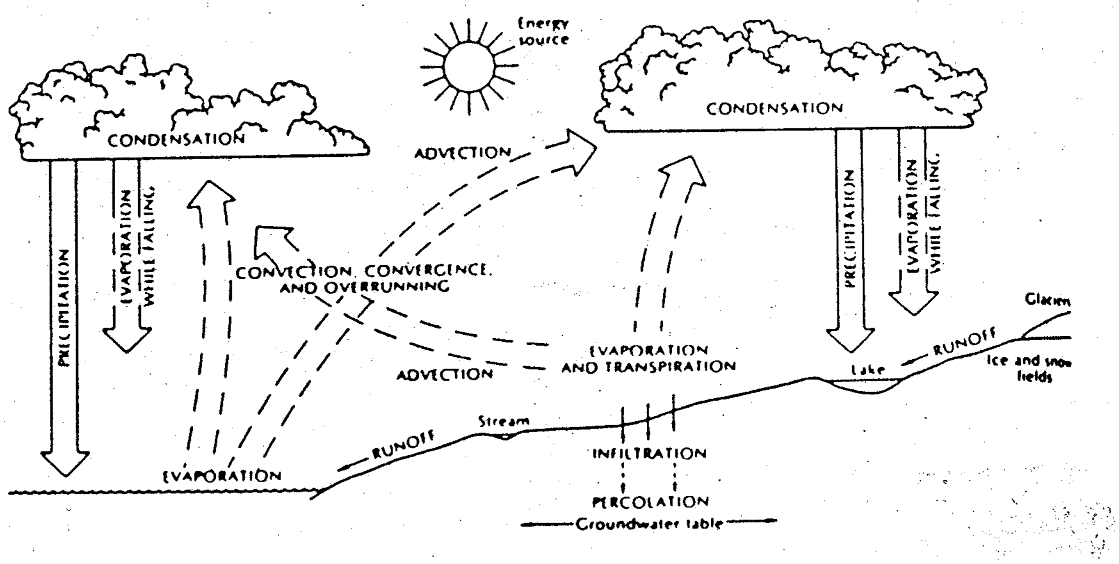

Fig. 3.2 The hydrologic cycle
(Griffiths and Driscoll, 1982)

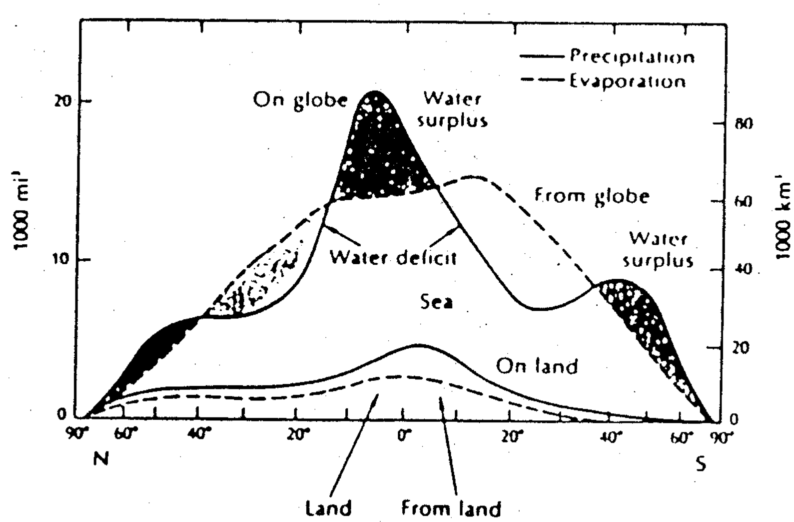

Fig. 3.3 Latitudinal variation of evaporation and precipitation for the earth as a whole and for land and sea areas (Griffiths and Driscoll, 1982)

3.1.4 Air Movement

The unequal distribution of the sun's heat on the earth's surface produces variations in density in the atmospheric mass. The rising air of the equatorial zone descends around the 30° latitude, to be pushed toward the south and the north where it later meets the cold polar flow. The unequal distribution of continents and oceans also causes distortions in the series of atmospheric pressure belts. And geographical characteristics lend local peculiarities to the prevailing winds (Olgyay, Victor, 1963).

Over both the northern and southern hemispheres of the earth are belts and centers of high and low atmospheric pressure. These belts are shifted poleward during the summer and toward the equator during the winter. Quasi-permanent zones of high pressure are maintained at the poles while the principal zone of low pressure is maintained near equator (Givoni, B., 1969). As air flows from high pressure to low pressure, the direction does not follow that of the greatest gradient, but is deflected by a phenomenon known as the Coriolus force, which results from the earth's rotation. This deflection is to the right in the northern hemisphere and to the left in the southern, Thus, the pattern of divergence from centers of high pressure is clockwise in the northern hemisphere and counter-clockwise in the southern. The patterns of convergence at centers of low pressure are the reverse (Givoni, B., 1969).

3.2 Climatic Forces on Human Comfort

Man's energy and health depend in large measure on the direct effects of his environment. It is also well known that in certain climatic areas, where excessive heat or cold prevails, energy is diminished by the biological strain of adaptation to the extreme conditions (Olgyay, Victor, 1963, P. 14). Means by which the body exchanges heat with its surroundings can be classified into four main processes: radiation, conduction, convection, and evaporation. Figure 3.4 shows the concept of heat exchange between body and surroundings.

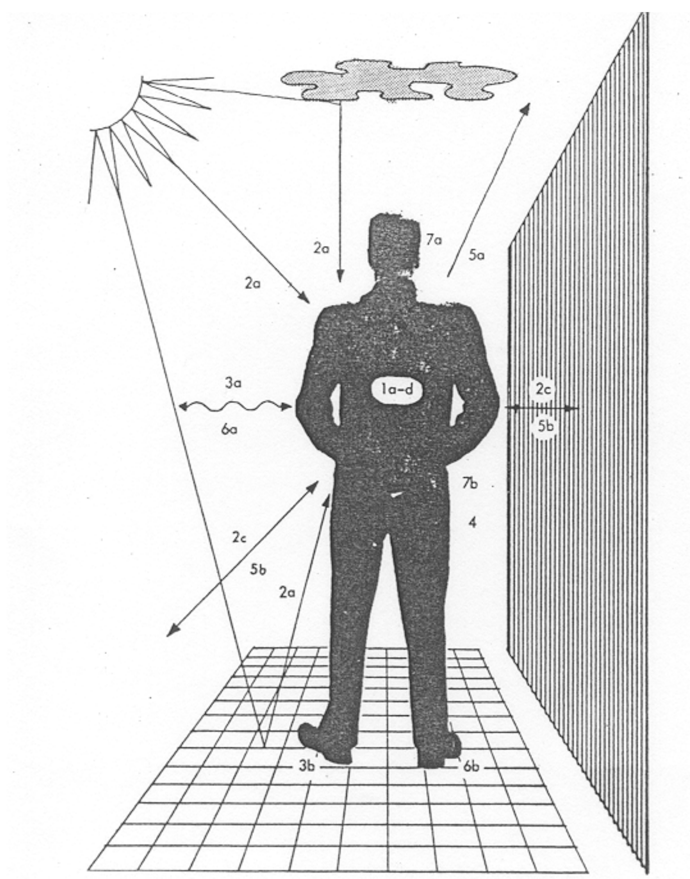

Fig. 3.4 Heat exchange between man and surroundings (Olgyay, Victor, 1963, p. 16)

Winslow and Herrington, and Bedford discussed the body's response to thermal stresses in detail. The factors involved in the heat balance of the body can be summarized in the following way.

1) Gains

(1) Heat produced by:

a) basal process,

b) activity,

c) digestive, etc. process,

d) and muscle tensing and shivering in response to cold.

(2) Absorption of radiant energy:

a) from sun directly or reflected,

b) from glowing radiation,

c) and from non-glowing hot object.

(3) Heat conduction toward the body:

a) from air above skin temperature,

b) by contact with hotter objects,

(4) Condensation of atmospheric moisture (occasional)

2) Losses

(5) Outward radiation:

a) To sky and colder surroundings

(6) Heat conduction away from the body:

a) to air below skin temperature (hastened by air movement-convection)

b) and by contact with colder objects.

(7) Evaporation:

a) from respiratory tract

b) and from skin (Olgyay, Victor, 1963, PP. 14-16).

Maintenance of thermal equilibrium between the human body and its environment is one of the primary requirements for health and comfort. This involves keeping the temperature of the tissues of the core of the body within a narrow range, regardless of the ambient conditions of the external environment. Many factors affect the processes through which this balance may be attained. Some of these forces are individual characteristics such as the activity, acclimatization, and clothing of the subject (Givoni, B., 1969). Figure 3.6 shows the concept of the body's heat balance.

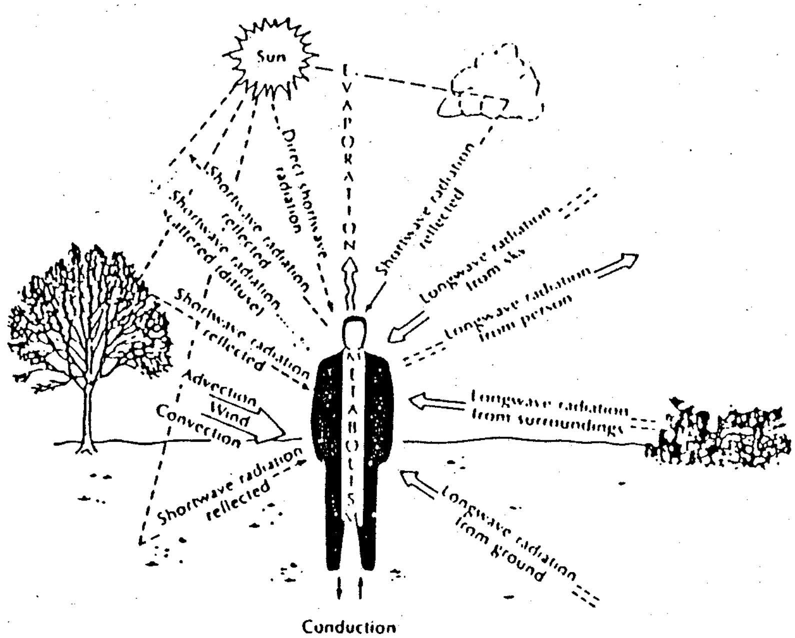

Fig. 3.5 The body's heat balance
(Griffiths and Driscoll, 1982)

3.2.1 Radiation

Solar radiation has both biological and thermal effects on the human body. Ultraviolet radiation affects the body biologically by causing the accumulation of the pigment melanin in the outer layer of the skin, which results in the tanning of fair-skinned people. Solar radiation in the visible and infrared portions of the spectrum affect the body by imposing a thermal load on it. Calculations indicate that a change in solar radiation of 12.5 Kcal (50 Btu) has the same effect as a change in dry-bulb temperature of 2.15 ^{o}C (3.85 ^{o}F). This means that at conditions of low air temperature, heat loss can be counteracted by exposure to solar radiation. However, heat gain is increased by exposure to solar radiation and protection may be required (Givoni, B., 1969).

3.2.2 Temperature

The human body has a considerable tolerance to a wide range of temperatures, and this tolerance can be increased through acclimatization. When air is advanced across the skin, a cooling sensation results if the air temperature is lower than the skin temperature, and a warming sensation occurs if the air temperature is greater than the skin temperature. However, extremely high temperatures may lead to heatstroke and desiccation, whereas extremely low temperatures may lead to frostbite of the extremities, and the inhalation of icy air diminishes the efficiency of the lungs, which may strain the heart

(Griffith, John F. and Driscoll, Dennis M. , 1982)

When extreme temperatures are combined with other climatic forces, such as humidity and wind, suffering is greatest. Under conditions of constant humidity and air velocity, the body responds to changes in air temperature, primarily through changes in skin temperature and sweat rate. These physiological parameters change at rates dependent of the humidity and air velocity. When low temperatures are combined with wind movement, the cooling effect is magnified and is expressed as the wind-chill equivalent temperature. When high temperatures are combined with high humidity and sweat rate increases and may lead to skin irritations and, in extreme situations, heatstroke (Griffith, John F. and Driscoll, Dennis M., 1982).

3.2.3 Atmospheric Moisture

Atmospheric humidity does not directly affect the body's heat load, but does play a large part in determining the evaporation capacity of sweating. In extremely hot conditions, the limits of human endurance are determined by the level of humidity, since it is humidity that restricts evaporation. As long as the skin is dry, sweat is evaporated as it is secreted from the pores of the skin, and variations in atmospheric humidity have no physical effect on the body. When the rate of sweat production exceeds the rate of sweat evaporation, a layer of liquid is formed around the pores, increasing the effective area of the skin. In this manner, evaporation occurs at the surface of the skin and the cooling efficiency remains high (Givoni, B., 1969).

A hot climate with low humidity may cause excessively dry lips and mucous membranes of the upper respiratory tract. This may be not only unpleasant but may reduce the ability of the upper respiratory tract to filter out dust and microorganisms. Excessive dryness may also from cracks and fissures in the skin, causing discomfort and skin disturbances. At high levels of temperature and humidity, the outer layers of skin cannot maintain an adequate rate of water transfer from the inner tissues to the environment. This causes the skin to become water-logged and swell and the pores are narrowed or occluded, providing a good medium for microorganisms that may lead to certain skin diseases (Givoni, B., 1969).

3.2.4 Air Movement

Air movement affects body cooling. It does not decrease the temperature but causes a cooling sensation due to heat loss by convection and increased evaporation (Olgyay, Victor, 1963, P 19).

Convective heat loss is a function of air velocity and the temperature difference between the skin and the air. Evaporative heat loss is a function of air velocity and humidity, which have opposing effects on the evaporative capacity of the air. When the air temperature is below the skin temperature, the convective and evaporative effects of air movement work in conjunction so that an increase in air velocity always produces a cooling effect. When the air temperature is above the skin temperature, these two effects of air movement oppose each other. An increase in air velocity increases the evaporative capacity of the air, thereby increasing the potential heat loss, but the convection of heat from the warmer environment to the skin increases heat gain. When skin is wet, an increases in air velocity affects the sweating efficiency more than does convective heating. This condition continues only until the skin is dry. At that point, any increase in air velocity has no effect on the cooling efficiency of sweating, but convective heating continues (Givoni, B., 1969).