CHAPTER 1

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A large proportion of the world population lives and works in the geographic tropical zones of hot environment and desert climate. In some large landmasses like India, seasonal variation led to hot summer climates. In temperate zones, sporadic heat waves result in high heat stress since the inhabitants of those areas are not naturally acclimated to heat. In addition to naturally occurring hot climates in different geographic regions, there are many situations in industries where artificial hot atmospheres are created as a process requirement. Typical of these industries are molten metal operations, glass production, clothes laundering, food processing and hazardous waste clean up. The exposure of industrial workers to hot occupational environment remains a persistent impediment to improve productivity and problems affecting the health of the workers. The potential health and safety consequences resulted from high environmental heat, become evident in physiological disturbances, impaired ability to make fine manipulation, skilled judgements or decisions, which in turn affect the safety of the worker, and industrial productivity (Chad and Brown 1995). Since, the living creatures must find
a satisfactory solution to the problem, an understanding of the heat exchange phenomenon between human body and environment and the process of adaptation play a vital role in dealing with such situations.

**Conditions Affecting Human Adjustment in Hot Condition**

A variety of signs and symptoms like fatigue, headache, abdominal cramps, rapid pulse, fever, collapse, etc., are reported as signs and symptoms of heat exposure. Native residents of hot climate generally show lesser severity of signs and symptoms than the sojourners, which have been attributed to several factors, such as cultural adaptation (Shephard 1978), genetic factor (Horvath 1981), body composition characteristics and habituation. Hence the interest in man's response to hot environment and the search for adaptive techniques to climatic extremes began. The study of physiological functioning of the population of tropics and temperate climate has been the subject of research for years (Davy 1850; Eichna et al. 1945; Bedford 1946).

Extensive studies explore that the human adjustment to hot climate depends on a variety of conditions, e.g., the biophysical characteristic of individual (the body structure, body composition, cardiovascular response and thermoregulation), the degree and duration of exposure and the type of physical activity performed, the state of acclimatization, and the kind of environmental control measures available. They also include behavioral
responses such as the clothing pattern, reduced work rate and movement away from heat source. These two thermoregulatory components (behavioral and biophysical actions) can be regarded as the indicators of the level of strain (Hardy 1972; Parsons 1995). However, the central importance remains with the enormous potential of physiological and behavioral adaptations of human beings that helps to cope with the combined demands of physical work and hot environment (Murray 1992). Horvath (1981) explained heat acclimatization as an adaptive process, which results in a reduction in physiological strain produced by an exposure to a constant environmental stressor. The acclimatization process involves a changing in many physiological function associated with heat balance which influences the performance of human beings. Neilsen (1994) described repeated exposure to hot environment leads to acclimatization. But still it is not clear that what degree of acclimatization is possible to achieve.

Two primary physiological responses sweat rate and skin blood flow assist in heat loss (Tankersley et al. 1991). The cardiac output has to meet up the increased demand for skin circulation in hot environment as well as satisfy the metabolic requirements of blood flow to the exercising muscles. These are achieved by a reduction in renal, splanchnic and hepatic blood flow (Nadel et al. 1979). In spite of this, there might be a reduction in muscle blood flow and alteration in muscle metabolism that
may result in fatigue in hot environment (Nielsen 1994). The thermoregulatory responses are also influenced by personality factors, such as, age (Tankersley et al. 1991; Pandolf et al. 1988), Sex (Ramsey 1978) and training (Michael and Sjoholm 1988; Tankersley et al. 1991).

**Control of Heat Stress**

The reduction of adverse health effects can be accomplished by measurement and assessment of heat stress, control of environment by application of engineering and work practice principles, workers training, acclimatization, medical supervision, use of heat protective clothing and equipment, etc. Several authorities, like International Labour Organization, World Health Organization, International Standards Organizations, European Union have developed standards and guidelines for human exposure to heat (Malchaire 1990). ISO heat exposure guidelines are rigorous to bring together an international picture, but there are inherent difficulties of uniform applicability of the standards because of the regional differences. Due to lack of systematic data on the effect of heat on tropical population (Nag 1996), usability of the international guidelines for the tropical climate is yet to be ascertained. Since the management of tropical heat is a major concern for industrial as well as community environment, there is an obvious need for systematic longitudinal studies to validate guidelines on the local context.
Impetus has been given on the development and application of different rational heat strain indices, based on empirical heat balance relationships. Since the process of acclimatization, changes in work capacity, heat tolerance limits all are dependent on heat exchange phenomena, it has been felt necessary to explore the complex system of physiological reactions that regulates heat balance (Nielsen 1994). For last several decades, researchers are describing heat exchange phenomenon in unique ways. But still the complexity of phenomenon has restricted us to amply understand the real implication of the system.

**Basis of Heat Exchange Phenomena**

The basis of the heat exchange phenomena lies on *heat balance*, whereby the body tends to maintain a core temperature within a narrow range regardless of the variations in the outer environment. Heat balance of human body follows the first law of thermodynamics (Mitchell 1974), which states — in any transformation taking place in a closed system the increase in internal energy is equal to the work done on the system added to the heat absorbed by it. The law speaks of conservation of energy and in the context of thermal physiology, it implies that for any animal at any time:

\[
\text{Net rate of the energy gain} = \text{Rate of energy storage.}
\]
Though physical laws govern the modes of heat exchange, the physiological mechanisms of the body decide the magnitude of heat to be received or released from or to environment. This enables to regulate the rates of heat production (rate and distribution of blood flow, the metabolic level) and the methods of heat lost (the rate of sweating and its evaporation) so the equilibrium could be maintained. Mitchell (1974) designated "Thermal Equilibrium" as "caloric equilibrium" which could be described as:

\[ \delta H = (\text{heat gain}) - (\text{heat loss}) \]
\[ = (\text{Metabolism } \pm \text{ work}) - (\text{Heat exchange }) = 0, \]

where \( \delta H \) is Heat Storage.

Although \( \delta H = 0 \) is an ideal condition, the body continues to exchange heat to attain its steady state. Therefore, Nishi (1981) recommended that heat debt (heat storage) should be calculated through integration of \( \delta H \) for a non-steady state condition. Perhaps, the concept of set point has been originated from this behavioral pattern. It certainly reflects that the body will always try to maintain the initial temperature without any additive and subtractive effect. The uniqueness of the animals, which are considered "temperature regulators", is, therefore, not related to their ability to attain thermal equilibrium but to their ability to attain equilibrium in different environment with only a small change in their own temperature. The question arises —— for maintaining the initial temperature of the system,
from where the required energy is utilized? It might be a portion of metabolic heat production, which is termed, as specific dynamic action that may be responsible for maintaining body's initial temperature. But that is obviously a part of the heat storage. The steady state is identified with unchanging temperatures and although rarely encountered in practice is a useful abstract to which real cases could be related. This assumption might be the basis of thermoregulation.

In case of certain accumulation of heat in the body, thermoregulatory mechanism would respond to dissipate the same to become \( \delta H = 0 \). The rate of heat dissipation or accumulation from different parts of the body is different because of the difference in thermal capacity of individual segments and compartments. For the sake of simplification in the heat conventional balance equation, all components of the equation are added algebraically, which appears to be oversimplified. Since each body segments are having different heat sensitivity factors (Nag and Nag 1992) therefore the magnitude of heat exchange will vary from segment to segment depending on the conductance of the adjacent compartments.

As schematically shown (Figure 1.1), different factors influence heat exchange phenomena of the human body.
Fig. 1.1: Influencing factors of Human heat exchange phenomena.

The principal shortcomings in the existing knowledge are the lack of general-purpose guidelines on the physical, physiological and biophysical aspects of heat exchange between human body and environment. Analytical models have been developed to understand the heat exchange concepts and to predict heat stress and strain (Gagge 1973; Werner and Buse 1988). The limitations are on the heat transfer characteristics through the classical interfaces of the human body, microclimate and the external environment. The majority of the studies have been carried out on theoretical assumptions, which at many places may require to be substantiated by direct experimental observation (McNeill and Parsons 1999). Because the primary variables like body structure, segmental distribution of body mass, thermal sensitivity of the skin surface varies
with the population groups, the input variables considered for developing the models needs to be reexamined with reference to the sample population.

**OBJECTIVES OF THE STUDY**

Based on the above understanding, the present research work has been designed and undertaken with the following objectives:

1) To examine the relationships of heat exchange variables under different thermal conditions and explore the usability of thermodynamic law in the context of experimental outcome.

2) To determine the process of heat acclimatization in a longitudinal heat exposure programmes and evaluates the inter-compartmental pattern of heat exchanges.

3) To examine the effects of consecutive heat exposure on work capacity in human, with reference to maximal oxygen uptake and oxygen debt contraction.

4) To find out the basis of classification of the biophysical environment and criteria formulation for management of thermal environment in industry.