BUILDING DIGEST
CENTRAL BUILDING RESEARCH INSTITUTE, INDIA

EVALUATION OF THERMAL STRESS–TROPICAL SUMMER INDEX

Introduction

The climate of a region has a profound bearing on the quality and type of buildings for human habitation. In the design of buildings, the main aspects to be considered are the climate itself, the acceptable indoor thermal environment and the achievement of such conditions indoors. The primary function of a building is to provide a barrier between the desirable conditions inside and the extreme conditions outside. The basic criterion for an efficient building from climate point is therefore its ability to modify the external climate into something indoors which produces none or minimum thermal stress on the human body.

Body Heat Regulation

The human body acts like a heat engine, converting a small part of the chemical energy of its food into work and the rest into wild heat. In order that the temperature of the internal organs may be kept from rising or falling beyond its optimum value for physical well-being and efficiency, the wild heat must be rejected from the body surface at an adequate rate. Excessive or deficient rates of heat loss can produce harmful physiological stresses within the body. The rate of heat loss from the body depends upon the thermal environment which is made up of air temperature, humidity, air motion and radiation from surrounding surfaces. Several non-environmental factors like level of activity, clothing, acclimatisation, age, sex, state of health etc. are also important for the determination of an optimum thermal environment and therefore while defining acceptable environmental conditions specific mention is also necessary of the levels of these factors.

The Thermal Stress

The thermal stress experienced by the human body results from the combination of all the factors which influence its heat exchange with the environment. Therefore a proper evaluation of the thermal stress depends upon a successful accounting of the influencing envirommental factors. These factors individually and collectively influence the bodily heat-gains and losses For instance the air temperature affects the convective heat exchanges, the humidity affects evaporative heat losses, air movement influences both and the temperature of the surrounding influences the radiative heat exchange.

Evaluation of Thermal Stress

Precise evaluation of the combined influence of all the environmental factors on the human body can be best made by means of a single index embodying all the relevant constituents of the thermal environment. This index is generally termed 'Thermal Stress Index.' Many attempts have been made in various countries and at various times to develop appropriate Indices of Thermal Stress but no index appears to be universally applicable. The variants influencing body heat exchanges are many and therefore each index is relevant only within its limited context. The indices are expressed in the form of formulae or nomograms derived on theoretical or empirical grounds.

Tropical Summer Index

An index called 'Tropical Summer Index' (TSI) has been developed at this Institute for the hot dry and warm humid conditions of Northern India. It combines into a single value the effects of air temperature, humidity, air motion and radiation on the thermal sensation of human subjects. It is defined as that temperature of still air at 50 per cent relative humidity which induces the same thermal sensation as the given environmental conditions. This index has been developed from the subjective thermal sensations of a number of fully acclimatised, young male adults, clad in their customary light summer clothing in a sedentary

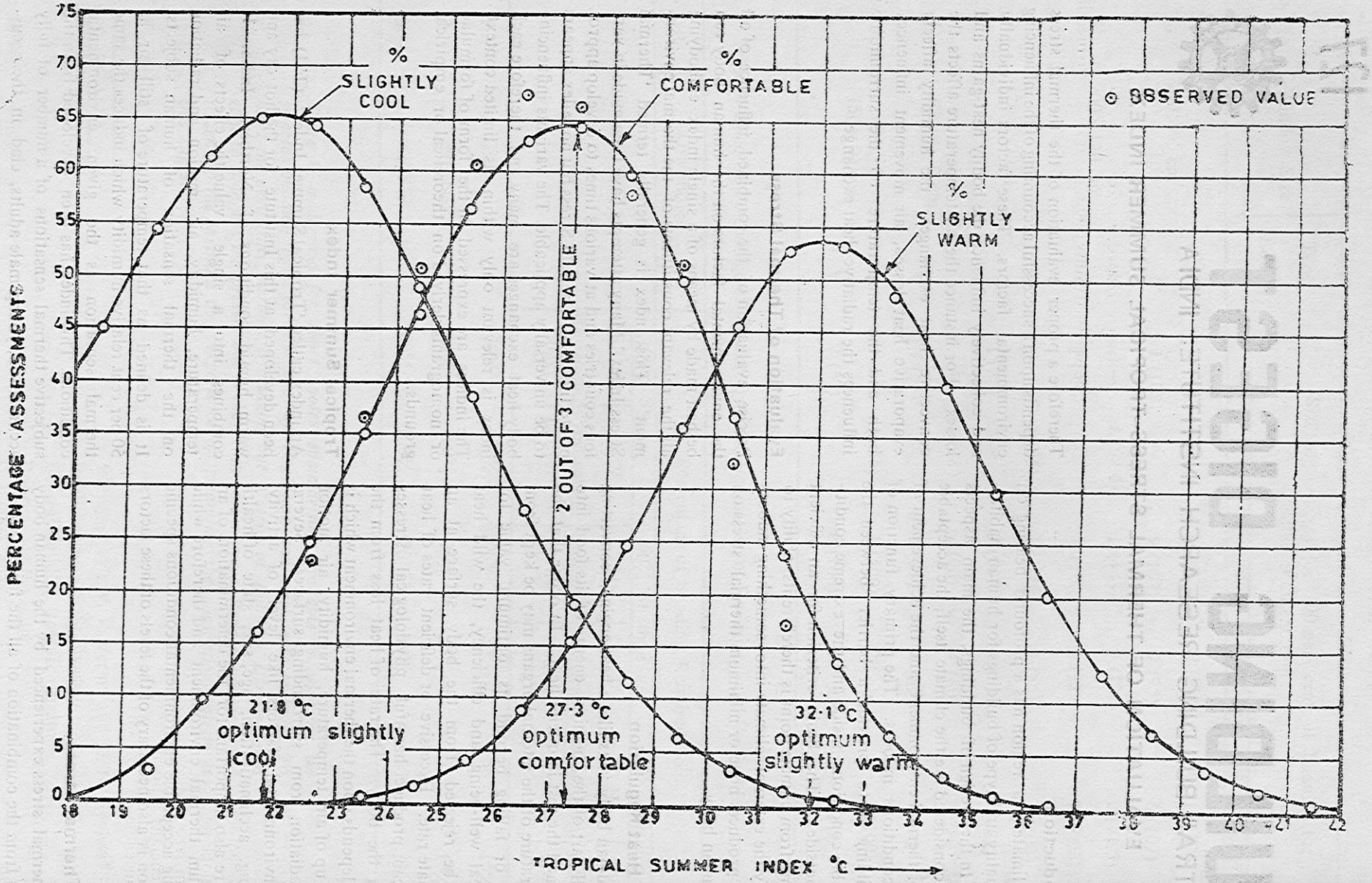

Fig. 1.—Percentage Assessments for Three Levels of Thermal Sensation as Functions of Tropical Summer Index

posture or with slight indoor activity. The observations were taken by 24 subjects, spread over a period of three consecutive summer seasons.

The numerical value of the Tropical Summer Index is given by the equation :

$$TSI = 0.308\ tw + 0.743\ tg - 2.06\ \sqrt{V} + 0.80 \quad \ldots\ldots (1)$$

where tw = wet buld temperature, °C.
tg = globe temperature, °C.
V = air velocity, m/sec.
and TSI is expressed in °C.

It can be seen from the distribution of percentage votes against TSI values for various thermal sensations, that the maximum number (65%) of thermally comfortable assessments lie at a TSI value of 27.3°C (Fig.1). It has been found that the various thermal sensations lie within the TSI ranges given in Table 1.

Table-1

Ranges and Optimum Value of TSI for Various Thermal Sensations.

Thermal sensation	Range	Optimum value
Slightly Cool	19—25°C	22°C
Comfortable	25 —30°C	27.5°C
Slightly warm	30 —34°C	32°C

The equation for TSI also represents the equivalence between various environmental parameters vis-a-vis the thermal sensation. For instance, during summer season, a decrease in TSI value of 1 unit can be caused by say 3°C (=1 / 0.308) decrease in wet bulb temperature or 1.35°C (=1 / 0.743) decrease in globe temperature or an increase in air velocity from zero to 0.25 m/sec. This equivalence can be beneficially utilised in working out the economics of mechanical aids for producing thermally comfortable conditions.

Rapid Determination of TSI

A simple and approximate equation for the rapid determination of TSI for any combination of environmental variables is —

$$TSI = \tfrac{1}{3}\ tw + \tfrac{3}{4}\ tg - 2\ V^{1/2} \quad \ldots\ldots (2)$$

In this equation the constant term is taken care of in the approximation of the coefficients of tg and tw terms. The TSI values computed from the above approximate equation are sufficiently close to those obtained from the exact equation.

Diagrammetic Representation of TSI

From the practical utility point, it is necessaryto present the Tropical Summer Index in the form of a diagram. For this purpose the lines of equal TSI are drawn on the psychrometric chart (Fig. 2) for different combinations of dry bulb and wet bulb temperatures. The simplifying assumption made here is that dry bulb and globe temperatures are considered synonymous which is actually found to be very nearly so inside conventional buildings. As such, the chart shown in Fig. 2 is perfectly valid for indoor conditions. The TSI lines shown in the chart are for still air conditions and the needed reductions in TSI values with increasing air motion are presented as inset in Fig. 2.

It can be seen from the psychrometric chart that for relative humidity values below 50% level, TSI values are lower than the air/globe temperatures; above this level they are higher. Along the 50% relative humidity curve, the TSI values coincide with air temperature values in the absence of air movement, and thus satisfy the basic postulate of the tropical summer index.

Practical Utility of the Tropical Summer Index

From the practical point of view, the equation for TSI shows that in a warm environment, the aim should be to reduce globe and wet bulb temperatures and to increase air movement. The extent to which each variable should be controlled will, of course, depend on the climatic conditions and the economics of controlling a particular climatic factor. There may be several solutions depending on circumstances, economics and efficiency.

Application to Building Design

Several methods of computing indoor temperatures for known outdoor climatic conditions are in vogue at present. These methods take account of the

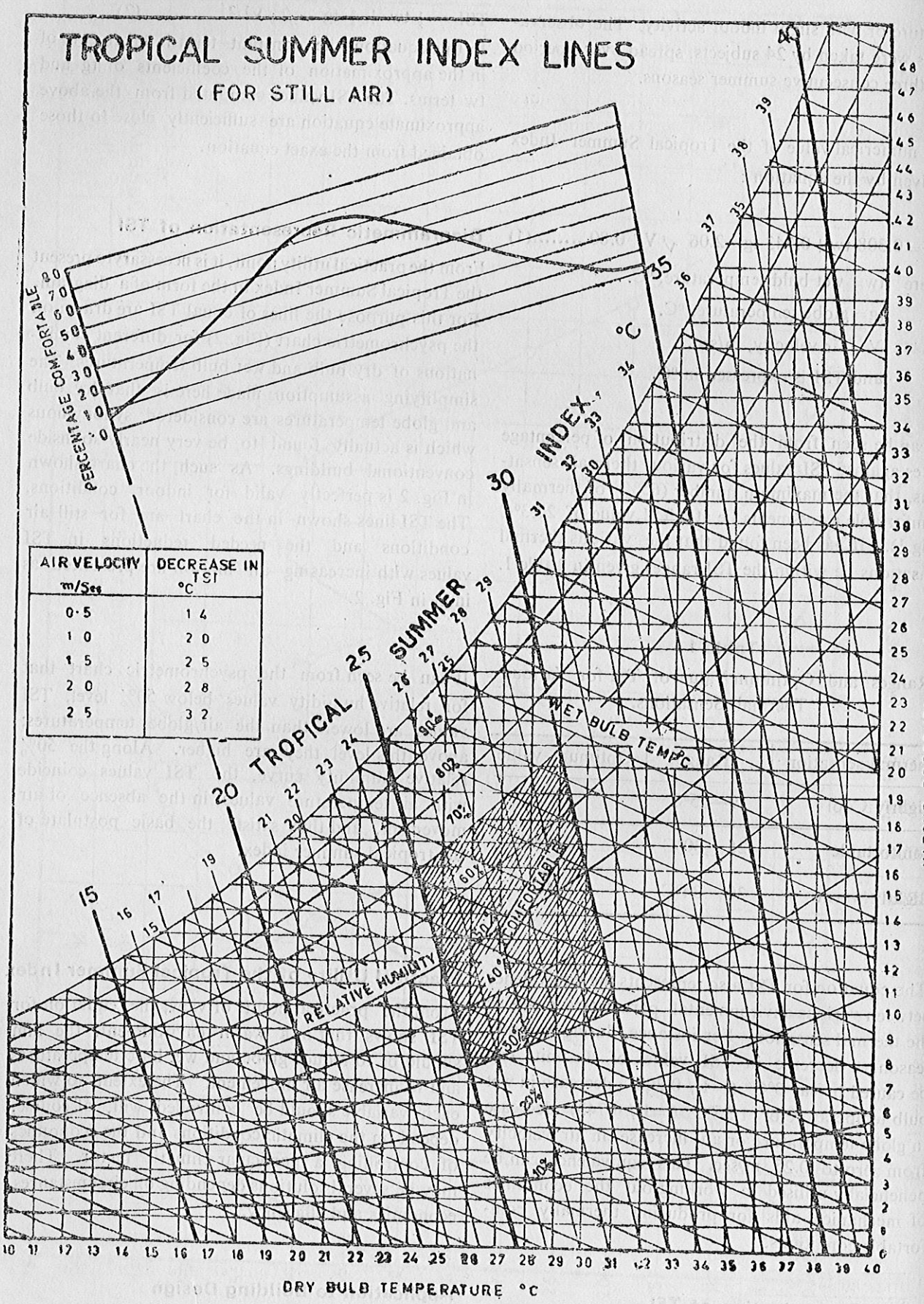

Fig. 2. Lines of Equal Tropical Summer Index

thermal resistance and thermal capacity of the building materials together with the outdoor climatic conditions. Using one such method it is possible to compute the indoor environment and to judge it against the requirements of thermal comfort. It is thus possible to study the influence of orientation, ventilation and other aspects on the indoor environment and to evolve an optimum building design and also to study the relative merits of various designs in the context of thermal comfort.

There is a demand for short notes summarising available information on selected building topics for the use of Engineers and Architects in India. To meet the need, this Institute is bringing out a series of Building Digests from time to time and the present one is the 127th in the series. Readers are requested to send to the Institute their experience of adopting the suggestions given in this Digest.

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