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Responses of Disabled, Temporarily Ill, and Elderly Persons to Thermal Environments

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ABSTRACT

This paper presents a part of the findings of ASHRAE research project RP-885, a literature review on the responses of disabled persons to thermal environments. An extensive literature review on the impairment of thermoregulation and thermal sensation has been carried out to collect data on physical, physiological, and psychological responses of persons who suffer from various disabilities, diseases, or genetic disorders, as well as those taking medications, and elderly persons. Characterization of skin temperature, blood pressure, heart rate, skin blood flow, and core temperatures of the different populations was collected, when such information existed. Based on the literature review, thermoregulation abnormalities are present for different types of categories of persons. However, the data were not applicable or pertinent in all instances. In addition, in the literature review there was no mention of the variables that might differ between healthy and disabled subjects, e.g., posture, clothing distribution.

Definite and solid conclusions could only be drawn to specific conditions set in the articles under study. Variations in experimental conditions, types and number of subjects, physiological parameters, and effects of drugs, missing data, etc., made the task of drawing conclusions complex. When adequate information was found, it was compared to ASHRAE Standard 55-1992.

INTRODUCTION

Many studies on thermal comfort have been carried out throughout the world (Fanger 1970; Gagge 1973; Stolwijk et al. 1971; Haslam et al. 1987; Vogt et al. 1983; Gagge et al. 1986; Haghighat et al. 1999a, 1999b). However, these studies concern a homogeneous population with similar physical characteristics (neither ill nor old). Age, race, habits, health, and origin are some parameters that must be taken into account when the thermal comfort of the human body is considered.

ASHRAE Standard 55-1992 states in reference to Table 3, "For infants, certain elderly people, and individuals who are physically disabled, the lower limits of Table 3 should be avoided." The statement wishes to accommodate, in a general fashion, the ill or physically handicapped. The manner in which it is treated needs to be addressed, considering increasing concerns over thermal comfort for persons with physical disabilities has been brought to light by many health care professionals.

A brief review of the different types of thermal comfort predictive models is given. A critical literature review is followed by a comparative study of the results collected from different experimental studies and ASHRAE Standard 55. Presently, there are two types of comfort models, simplified and detailed.

Simplified Models

The simplified models available include simple calculations of the indices according to ASHRAE (1992) and to international standard ISO 9920 1993.

ASHRAE Standard 55 uses the ET*-DISC model to delineate lines of comfort on a psychrometric chart. The lines form a parallelogram on the chart defining the "comfort zone." If the physical conditions that you are testing lie within the comfort zone, a person exposed to those conditions is presumed comfortable provided that the person's activity is sedentary and the person is wearing clothing values of 0.6 clo (summer) or 0.8 clo (winter).

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The international standard ISO 9920 is based on Fanger's expansion of the classic studies by Gagge et al. and the ASHRAE-sponsored studies of comfort in its chamber in Cincinnati and subsequently at Kansas State University. These standards use Gagge's thermal balance equation applied to the human core. The human core produces an energy (metabolic rate) and heat exchange with the environment via conduction, convection, radiation, and evaporation. This thermal balance is reduced to a comfort index. The predicted percentage of dissatisfied index (PPD) is deduced from the predicted mean vote index (PMV) using a diagram established from a large number of experiments. The calculation of the PMV and PPD is under steady state.

The PMV index predicts the mean value of the thermal votes of a large group of persons exposed to the same environment. But individual votes are distributed around this mean value, and it is of particular interest to predict the number of people likely to feel uncomfortably warm or cool since it is such thermally dissatisfied persons who are inclined to complain about the environment. PMV gives values in the range of −3 to +3 corresponding to cold and hot thermal sensation (see the seven-point thermal sensation scale in Table 1). The PPD index established a quantitative prediction of the number of thermally dissatisfied persons. The PPD predicts the percentage of a large group of persons likely to feel thermally uncomfortable. The PMV and PPD indices provide an evaluation of comfort for individual points in a room. PS represents the cumulative percent of people choosing a particular air velocity at the specific temperatures tested (Fountain et al. 1994). DISC (discomfort) predicts a vote on a scale of thermal discomfort as defined in Table 1 using skin temperature and skin wettedness. Table 1 shows the two most common thermal comfort scales used.

The operative temperature is determined by the combination of the heat transfer by radiation and the speed and humidity of the air. The input parameters for the basic thermal comfort model are air temperature, mean radiant temperature, air velocity, relative humidity, metabolic rate, clothing value, barometric pressure, and turbulence intensity. The output parameters are effective temperate, standard effective temperature, thermal sensation, neutral temperature, discomfort (DISC), PMV, PPD, and PS (see also In-Hout 1990).

TABLE 1
Thermal Comfort Scales

Thermal Sensation Scale		Discomfort or "DISC" Scale	
+3	Hot	0-0.3	Comfortably pleasant
+2	Warm	1.3	Slightly uncomfortable
+1	Slightly Warm	2.7	Uncomfortable
0	Neutral	3.9	Very uncomfortable
-1	Slightly Cool	4.7	Limited tolerance
-2	Cool		
-3	Cold		

Detailed Models

The detailed models are human thermoregulation models. In the literature, the node number varies between 2 and almost 250. However, we consider two important models: (1) Gagge's model, or the 2-node model (skin and core nodes) (Gagge 1973) and (2) local thermal sensation models, such as the 6-node model (Stolwijk et al. 1971) and the 25-node model (Haslam et al. 1987). The responses of the model concern a local part of the body, such as the head, hand, trunk, and foot. The input parameters for the two-model are body mass, body surface, exposure time, sweating coefficient, vasodilation, and vasoconstriction coefficient. The output parameters are skin blood flow, skin wetness, skin temperature, and core temperature.

LITERATURE REVIEW AND ANALYSIS

An extensive literature review was conducted on the impairment of thermoregulation and thermal sensation to collect data on physiological and psychological responses of persons who suffer from various disabilities, diseases, and genetic disorders, as well as those taking medications. Based on this extensive literature search, it was found that thermal sensations vary from one population to another. Physically disabled, elderly, and ill persons do not portray the same impairments, and, thus, thermal sensations also follow a distinct behavior. Therefore, it was decided to treat a specific population on its own.

This study is divided into four principal categories:

- the physically disabled (patients with spinal cord injuries, cerebral vascular accident victims, etc.),
- elderly persons (healthy or ill),
- patients in hospitals (patients on artificial respiration, operating-room patients, and personnel), and
- other ailments.

Physically Handicapped persons

Poliomyelitis (a viral disease marked by inflammation of the nerve cells of the spinal cord, deformity, and paralysis) patients portray vasomotor (related to nerves controlling the inner diameter of blood vessels) abnormalities in the affected limbs. It has been classically shown that cool environmental temperatures have the effect of making limbs markedly cold and the skin color violet to deep, dark, blue violet. Impairment in sympathetic vasoconstrictor outflow in poliomyelitis patients allows passive dilatation and engorgement of cutaneous venous beds. Consequently, poliomyelitis patients tend to radiate their heat into the environment (Bruno et al. 1985). Physically handicapped subjects suffer from the impaired functioning of efferent, afferent (nerves carrying impulses to a nerve center and blood and lymph vessels supplying a particular organ or part), and surface receptor systems in the insentient portion of the body. Other clinical manifestations range from impaired sweating in hot environments to the absence of shivering in cold environments. Disrupted thermoregulatory responses found in the insentient portion will leave that portion to react like a heat exchanger, thereby rendering the physically handicapped poikilothermic (Guttmann 1976). The physically handicapped show decreased core temperatures when exposed to the cold and elevated core temperatures when exposed to the heat.

Yoshida et al. (1993) studied the thermal environment of physically handicapped persons in both Hungary and Japan. The subjects involved are 15 disabled (male and female) and 11 healthy controls in a climatic chamber. The measured thermal sensation of these physically handicapped persons was compared with the prediction of the ASHRAE model, which requires a number of input parameters. Air velocity and metabolic rate were not reported in the paper (Yoshida et al. 1993); therefore, they were assumed.

Since thermoregulatory deficit is specific to each population, the different handicaps are presented individually. Figures 1 and 2 compare the global thermal sensation vote, as calculated using ASHRAE with the head, trunk, hand, and foot thermal sensation vote measured, for polio patients. Figures 3 and 4 compare the global thermal sensation vote, as calculated using ASHRAE with the measured trunk and foot thermal sensation vote, for the spinal cord injured in Japan and Hungary. Figures 5 and 6 compare the global thermal sensation vote, as calculated using ASHRAE with the measured trunk and foot thermal sensation vote, for cerebral palsied in Japan and Hungary.

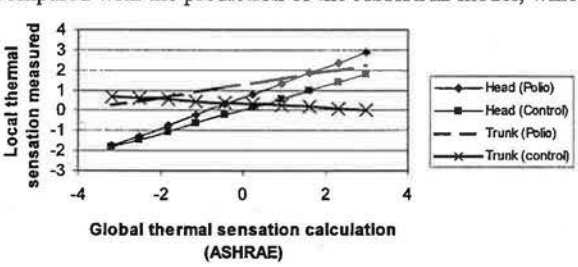

Figure 1 *Comparison of thermal sensation votes—global vs. local (Yoshida et al. 1993).*

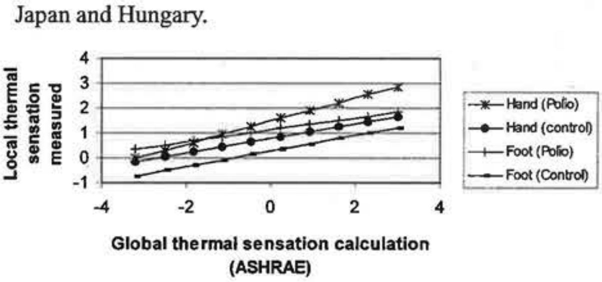

Figure 2 *Comparison of thermal sensation votes—global vs. local (Yoshida et al. 1993).*

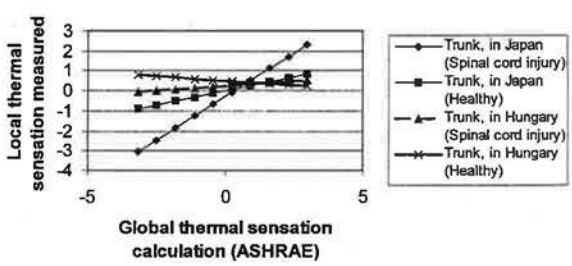

Figure 3 *Comparison of thermal sensation votes—global vs. local (Yoshida et al. 1993).*

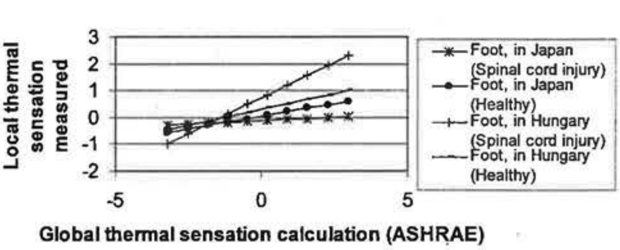

Figure 4 *Comparison of thermal sensation votes—global vs. local (Yoshida et al. 1993).*

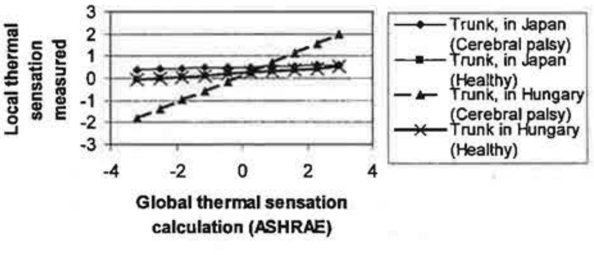

Figure 5 *Comparison of thermal sensation votes—global vs. local.*

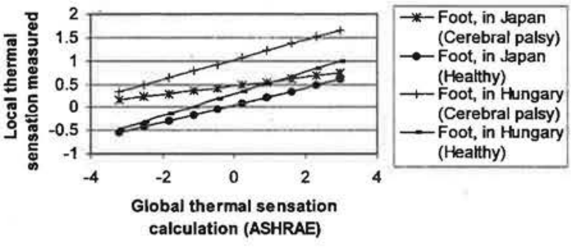

Figure 6 *Comparison of thermal sensation votes—global vs. local.*

It is clear from Figures 1 through 6 that the thermal sensations measured are different from those calculated using ASHRAE Standard 55. This difference can be explained by the comparison of t e globa thermal sensatyon calc lated v . the loc l thermal sensa ion mea ured. A number f assum - tions were required to calculate the PMV, such as metabolic rate and air velocity. Metabolic rate and air velocity have a pronounced effect on the prediction and can be a determining factor in the discrepancy between the calculated data and the measured data. A met rate of 1.0, which describes a healthy person seated, will probably not be appropriate for a disabled person. Even small changes in these assumptions can have a big effect on the outcome of the calculation. In addition, the correlation coefficient of the regression line, which expresses the relationship between the local thermal sensation (trunk, foot, etc.) and the same local temperature (trunk and foot) given in Yoshida et al. (1993) is too small and, in general, varies between 0.106 and 0.480, probably due to the different degrees of damage between these individual patients. Generally, the PMV calculated using ASHRAE is overestimated, particularly for high negative values. The complexity of the thermoregulatory deficits and the varying degrees of handicaps (i.e., high and low paraplegics) in the study resulted in the nonconforming curves presented. The spinal cord injured and control curves demonstrate a divergence at both extremes of the PMV values. However, no general tendencies were observed for the cerebral palsy patients and controls.

Attia et al. (1983) studied the effect of thermal conditions on healthy controls and on the spinal cord injured. Their experimental data were used to predict the rectal temperature of subjects. Figure 7 shows the measured rectal temperatures for two categories, paraplegics and healthy, vs. room temperature. Figure 8 shows the measured rectal temperatures for the same two categories but as a function of time of exposure. The rectal temperature is almost constant in the three cases, varying between 36.5°C and 37.3°C. The rectal temperature calculated using the thermal comfort model (ET* model) is always slightly less than the others measured. The ET* model-predicted rectal temperature is not influenced by the exposure time and varies very little in relation to room temperature.

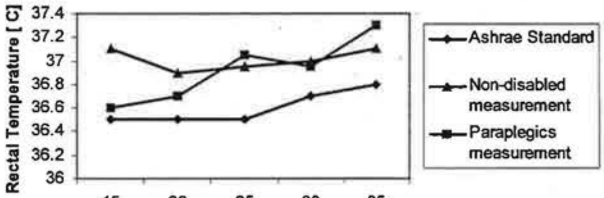

Figure 7 *Comparison of rectal temperature (Attia et al. 1983).*

Elderly persons

It is assumed in *ASHRAE Standard 55-1992* that the preferred temperature of the elderly is the same as for the young. Epidemiological studies have shown that the elderly are particularly susceptible to extremes in temperature (Bull et al. 1978; Keatinge 1986; Taylor et al. 1994). It is generally assumed that since the elderly are less active than the young, the elderly would require more external heat to maintain neutral conditions. Temperature control mechanisms have been shown to deteriorate with age (Collins et al. 1977, 1980). However, since the elderly have a lower level of metabolic heat production and a reduced evaporative loss of heat, the two phenomenon cancel each other, implying that the elderly do not prefer higher temperatures than the young. It has been shown, however, that the elderly may not be able to sense a decrease in ambient temperature as well as the young since the peripheral temperature perception becomes impaired. Furthermore, it has been shown that the elderly may have an impaired autonomic function, a lower sudomotor response, an altered sensitivity of the cutaneous vasculature to thermal stress, and more variable body core temperature control (Collins et al. 1980; Foster et al. 1976; Kenney et al. 1988; Collins et al. 1985; Wagner et al. 1985; Marion et al. 1989).

There was little evidence in past research work to suggest that healthy elderly people preferred a different ambient temperature than that of the young. This was shown in experimental studies where subjects were exposed to several thermal environments (Rohles et al 1972; Griffiths et al. 1973; Fanger 1970). Fanger (1972) found that the neutral temperature was equivalent and 25.6°C for both young and old. McIntyre (1975) also did not find any differences in preferred temperature after high and low temperature exposures. The predicted optimal temperature using the PMV equation was 23°C. Collins et al. (1981) found that elderly people preferred the same mean comfort temperature as the young, though they did so less precisely when given control over their environment.

Taylor et al. (1995) studied age-related differences between young and old males with respect to the inability to regulate room temperature. A comparison between the measured skin temperature shows that it varies between

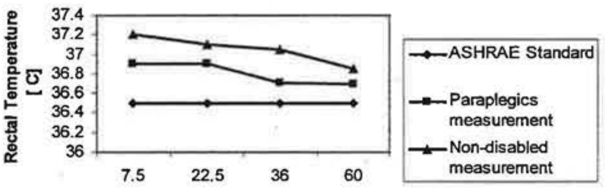

Figure 8 *Comparison of rectal temperature as function of time of exposure, air temperature, 20°C (Attia et al. 1983).*

28.3°C and 29 °C during the cold changes and between 31.4°C and 32.3°C for hot changes for elderly and young persons, respectively.

Patients in Hospitals

There are no doubts as to the applicability of the standard thermal comfort assessment technique to ward areas. The thermal environment conditions in a hospital may vary from room to room. The activities and clothing also vary between surgeons, nurses, patients, etc., and in some rooms there may be special requirements (clean rooms, operating theatres). This makes it impossible to specify one temperature level for the whole hospital. One point of view is to identify the patient as being the primary user; other users would be expected to change their clothing to suit their comfort needs. The literature review yielded very scarce results. No comparisons were calculated.

Other Ailments

The literature review yielded a very limited amount of data with which to work. Consequently, only one article was retained for the analysis. Andersen et al. (1976) evaluated the thermoregulation parameters and comfort of persons with ischemic heart disease (IHD) (those who suffer from inadequate blood supply to the heart due to obstruction or constriction of the blood vessels) during moderate heat stress.

The variation of mean skin temperature, in time, during heat stress, of all subjects is shown in Figure 9 (all subjects are shown together since there was no difference between the groups according to the ASHRAE calculations). The ambient temperature varied between 23°C and 29°C. As calculated using ASHRAE, the mean skin temperature varied from 33.6°C to 35.5°C during the heat stress. However, according to Andersen et al. (1976) the results were 32.6°C to 34.5°C.

The variation of rectal temperature, in time, during heat stress, of all subjects is shown in Figure 10. As calculated using the ASHRAE model, the rectal temperature varied from 36.5°C to 36.7°C during the heat stress. The results from the paper are 36.9°C to 37.6°C. The variation of mean skin temperature, in time, during control conditions, of all subjects is shown in Figure 11. The rectal temperature (36.5°C) is not shown since it did not vary under the control conditions. However, according to Anderson et al. (1976), it varied from 36.7°C to 37.5°C. As predicted by the ET* model, the mean-skin temperature varied from 31.8°C to 33.6°C during the control conditions. The results from the paper are 31.7°C to 32.8°C.

Next, the thermal sensation (PMV), as predicted by the PMV-PPD model, is compared with the mean dial vote of the subjects tested. There are no differences between the three categories (patients I and II and controls) according to the PMV-PPD model. However, the difference given in the paper between the three categories is significant.

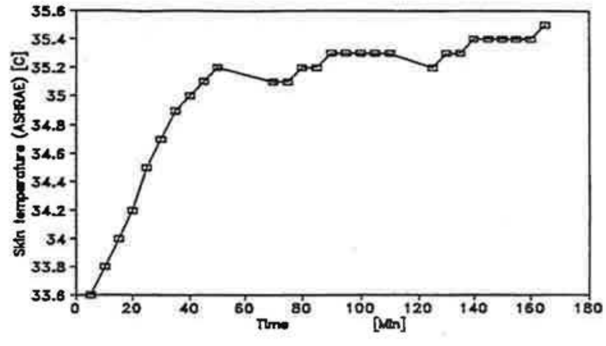

Figure 9 *Variation in mean skin temperature during heat stress (Anderson et al. 1976).*

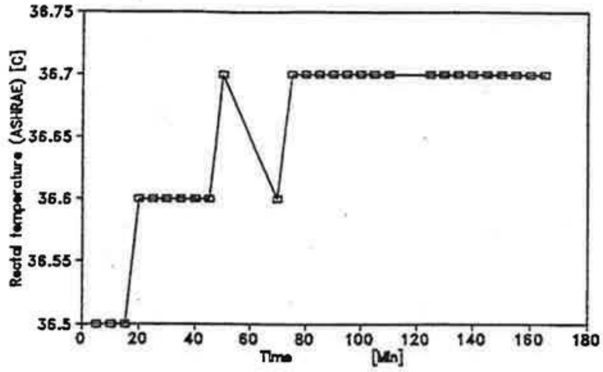

Figure 10 *Variation in rectal temperature during heat stress (Anderson et al. 1976).*

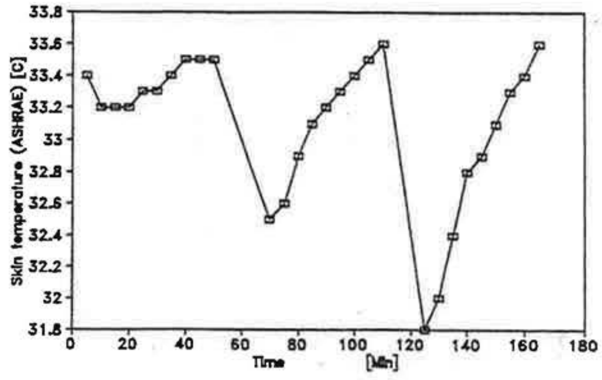

Figure 11 *Variation in mean skin temperature during control conditions (Anderson et al. 1976).*

CONCLUSIONS AND RECOMMENDATIONS

Prediction of human thermal response to the environment, using several thermal comfort models, exists for healthy college-aged subjects. An extensive literature review on the impairment of thermoregulation and thermal sensation has been carried out to collect data on physical, physiological, and psychological responses of the elderly, persons who suffer from various disabilities and genetic disorders, and those taking medications.

The result of the literature review has yielded a tremendous amount of data on thermoregulation. Different categories of diseases were found to present thermoregulatory deficits. Tables and charts characterizing thermoregulatory parameters, such as skin blood flow, core temperatures, etc., were presented. However, the applicability and/or pertinence of the data collected are limited to the test protocols and/or parameters of the studies reviewed. General conclusions or trends were difficult to determine. Very few articles on thermal sensation and comfort votes were found.

Several studies responded to the objectives of the study and, therefore, generally contained the complete information required to do the comparative analysis using predictive models. However, we observed that general conclusions or tendencies could only be drawn to the publication under study, and no further projections were possible. Therefore, our conclusions were limited to the specific conditions set in the articles.

Following our literature review, we found that much information exists concerning disabled persons. However, the information was generally not useful or pertinent to respond to the objectives described above. The populations found that did not satisfy most of the objectives outlined earlier were patients with affective disorders, asthmatics, cerebrovascular diseases (diseases that affecting the largest division of the brain and the blood vessels that supply it), cystic fibrosis patients (a hereditary disease of infants, children, and young adults that is attributable to the dysfunction of the exocrine glands and is marked by pancreatic deficiency, respiratory problems, and loss of salt in the sweat), diabetics, Grave's disease, Hansen's disease patients (leprosy), hospital patients, hypertensive patients, hypohydrosis/anhydrosis patients, multiple sclerosis (hardening of tissue) patients, myocardial infarction patients, Parkinson's disease patients, rheumatic patients (those who suffer from inflammation or pain in joints, fibrous tissues, or muscles), and patients with skin disorders.

Physically handicapped persons studied demonstrate thermoregulatory abnormalities in the affected portion of their bodies. They were generally found to be heterogeneous (poliomyelitis anterior acuta, infantalis cerebralis paresis, paraplegia, spina bifida, and quadriplegia). Other observed differences included ethnic origins and number of subjects studied and their habits, as well as geographical population distribution. Lack of data for air velocity and metabolic rate in the study compared to the PMV-PPD model required that assumptions for this information be made. Following this analysis of physically handicapped persons, we observed that the ASHRAE thermal sensation vote (PMV) is sensitive to the variation of temperature, particularly for cold temperature, compared to the results of Yoshida et al. (1993). Measured thermal sensation for the physical handicapped, when compared to the ASHRAE standard, were found to have no general tendencies. Measured rectal temperatures of paraplegics were generally slightly elevated when compared to the ET* model.

Elderly patients are assumed to have slurred functioning of temperature perception and temperature control mechanisms because of increasing age. Spinal cord injured persons portray impaired sensations to thermal environments and impaired responses to heat (sweating impaired) or cold (shivering response blunted). The elderly demonstrate thermal responses that are not in line with those described for those with spinal injuries. Here, we see impairments in recognition of temperature variations (Lee et al. 1991). In light of these facts, this area must certainly be treated so that the thermal environment is adapted for the comfort of the disabled. The existing data or recommendations pertain particularly to young and healthy subjects. *ASHRAE Standard 55-1992* touches on this point in less detail. General conclusions on elderly subjects' thermal sensation votes, based on the studies reviewed, could not be determined when compared with the PMV-PPD model's prediction. The PMV-PPD model-predicted skin temperatures for hot change and cold change conditions in the elderly were found to be higher than measured skin temperature from the studies.

Thermal sensation votes calculated using ASHRAE for patients with ischemic heart disease and controls were found to be less sensitive when compared to measured thermal sensation votes during heat stress conditions and vice versa for control conditions. The ET* model-predicted skin temperature and rectal temperature for ischemic heart disease patients under heat stress conditions were found to be relatively similar to measured skin temperatures. However, the ET* model-predicted rectal temperature was found to be slightly lower than the measured rectal temperatures for control conditions.

Following this comparative and literature-based review, several points must be explored in order to develop the data to fully understand the categories of populations studied. Clear performance of experimental studies for thermoregulatory responses of different categories of persons (disabled, diseased, etc.) must be documented. Experimental data should be divided into categories of similar populations with respect to geographic locations, ethnic origins, and habits. A pleurae-disciplinary team of professionals should be established. A comparative study may be done between the six-node model (Stolwijk et al. 1971) and the measurement results given for local thermal sensations. Thermoregulation and thermal sensation in humans for different types of illnesses and categories should be studied to better understand the thermoregulatory responses and sensations. Experimental measurements should be done in parallel with detailed models. The models and experimental results will then enable us to obtain data relative to each category (e.g., sick infants, tetraplegics, etc.).

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