Renewable and Sustainable Energy Reviews 14 (2010) 2626–2640

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Thermal comfort: A review paper

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ARTICLE INFO

Article history:
Received 5 July 2010
Accepted 16 July 2010

Keywords:
Thermal comfort
Residence
Review paper
Thermal environment

ABSTRACT

This paper presents a literature review of thermal comfort. Both rational and adaptive thermal comfort approaches are presented. An overview of the human body thermoregulatory system as well as the mathematical modelling of heat exchanged between human body and its environment in the situations of both awaked and sleeping people is presented.

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2010.07.040

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C	convective heat loss (W/m^2)
C_p	specific heat (J/kg K)
C_{res}	sensible heat loss due to respiration (W/m^2)
E	evaporative heat loss (W/m^2)
F_{cl}	clothing area factor
h	heat transfer coefficient (W/m^2 K)
L_R	Lewis ratio (K/kPa)
m	body mass (kg)
M	metabolic heat production (W/m^2)
p	pressure (kPa)
q	heat flow (W/m^2)
R	radiative heat loss (W/m^2)
R_a	thermal resistance of air layer (m^2 °C/W)
R_{cl}	thermal resistance of clothing (m^2 K/W)
$R_{e,cl}$	evaporative resistance of clothing (m^2 kPa/W)
$R_{e,t}$	total evaporative resistance (m^2 kPa/W)
R_t	total resistance of a bedding system including the air layer around a covered body (m^2 °C/W)
S	heat storage (W/m^2)
t	time (s)
T	temperature (K or °C)
v	air velocity (m/s)
w	skin wettedness
W	external work (W/m^2)
Greek letters	
α_{sk}	fraction of total body mass concentrated in skin compartment
Subscripts	
a	water vapour in ambient air
a,s	water vapour in saturated air at ambient temperature
b	body tissue
c	convective
cl	clothing
cr	core compartment
dif	moisture diffusion through skin
e	evaporative
o	operative
r	radiant
res	respiration
rew,req	regulatory sweating required for comfort
rsw	regulatory sweating
sk	skin compartment
sk,req	skin required for comfort
sk,s	water vapour in saturated air at skin temperature

1. Introduction

Thermal comfort has been defined by Hensen as “a state in which there are no driving impulses to correct the environment by the behaviour” [1]. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defined it as “the condition of the mind in which satisfaction is expressed with the thermal environment” [2]. As such, it will be influenced by personal differences in mood, culture and other individual, organizational and social factors. Based on the above definitions, comfort is not a state condition, but rather a state of mind. The definition of thermal comfort leaves open as to what is meant by condition of mind or satisfaction, but it correctly emphasizes that the judgment of comfort is a cognitive process involving many inputs influenced by physical, physiological, psychological, and other factors [3].

Thermal sensations are different among people even in the same environment. Even though the sensors render the same results regardless to the geographical position where a measurement is being taken, this is not the case for persons. Indeed, persons staying in very similar spaces, subjected to the same climate, and belonging to a common culture, issue very different opinions on thermal comfort due to the combination of a large number of factors that affect the perception of human beings. Subjects’ diagnosis is therefore an indispensable tool to achieve an overall evaluation of the study parameters [4]. Conventionally, thermal discomfort is treated as a subjective condition while thermal sensation is an objective sensation [1]. Satisfaction with the thermal environment is a complex subjective response to several interacting and less tangible variables [5]. In other words, there is really no absolute standard for thermal comfort. In general, comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized. Comfort also depends on behavioural actions such as altering clothing, altering activity, changing posture or location, changing the thermostat setting, opening a window, complaining, or leaving a space. In 1962, Macpherson defined the following six factors as those affecting thermal sensation: four physical variables (air temperature, air velocity, relative humidity, mean radiant temperature), and two personal variables (clothing insulation and activity level, i.e. metabolic rate) [3]. Thermal comfort standards determine the energy consumption by a building’s environmental systems; therefore, they play an important role in building sustainability [6]. This energy often involves the combustion of fossil fuels, contributing to carbon dioxide emissions and climate change [7]. Thermal comfort is also a key parameter for a healthy and productive workplace [8,9].

With the urgent need to reduce the economic and environmental cost of energy consumption, investigations covering many aspects related to thermal comfort in indoor environments have attracted authors for decades. These include establishing models [10,11] and indices [12], carrying out experiments in climate chambers [10,13] and field surveys [3,14], establishing thermal