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ORIGINAL ARTICLE

Prediction of air temperature for thermal comfort of people in outdoor environments

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Abstract Current thermal comfort indices do not take into account the effects of wind and body movement on the thermal resistance and vapor resistance of clothing. This may cause public health problem, e.g. cold-related mortality. Based on the energy balance equation and heat exchanges between a clothed body and the outdoor environment, a mathematical model was developed to determine the air temperature at which an average adult, wearing a specific outdoor clothing and engaging in a given activity, attains thermal comfort under outdoor environment condition. The results indicated low clothing insulation, less physical activity and high wind speed lead to high air temperature prediction for thermal comfort. More accurate air temperature prediction is able to prevent wearers from hypothermia under cold conditions.

Keywords Human body · Outdoor environment · Clothing · Thermal comfort · Model

Introduction

A growing number of people spend their leisure time and vacations engaged in outdoor activities, such as camping, skiing, backpacking, etc. According to an epidemiological survey, people spent approximate 10% of time outdoors in summer and about 4% in winter in U.S.A. and Canada (Höppe 2002). To meet the needs of the outdoor vacationers, more companies have manufactured outdoor clothing and equipments. When consumers purchase outdoor garments, they want to know about the thermal properties of the products and at what temperature it will provide them with thermal comfort under intended outdoor conditions. The garment manufacturers often provide consumers with a warmth rating for each product. Unfortunately, there is no consistency among companies regarding their methods for determining the temperature ratings for outdoor clothing. Some company representatives indicated that they have used feedback from consumers who used their garments under different field conditions. Another company arbitrarily assigned a heat retention index to their products, e.g. a 283–340 g wool shirt was assigned an index of 100 and the heat retention capability of other items were compared with it (McCullough and Rohles 1983). The methods for determining temperature ratings for outdoor clothing mentioned above are based on inadequate test procedures that often lack reliability and validity. If a lower temperature rating is linked to the garments, frostbite, trench foot or even hypothermia may occur. Donaldson carried out a survey and found that although the thermal insulation, as well as the number of items, of clothing worn increased significantly with cold, wind, less physical activity and longer periods outdoors across Europe, the geographical difference in cold-related mortality was correlated with insulation and the number of items of outdoor clothing (Donaldson et al. 2001).

Much attention has been drawn to the thermal comfort of people under outdoor conditions (Kaufman et al. 1982; Huck and McCullough 1985; Arens and Bosselmann 1989; Wyon 1989). The thermal insulation and water vapor permeability index of outdoor garments has been measured by a sweating thermal manikin (McCullough and Rohles 1983). The thermal protection characteristics of sleeping bags was quantified in terms of the lower thermal comfort

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threshold, which was expressed by the effective temperature, a terminology with which the wearers were not familiar (Rohles and Munson 1980).

During the past 20 years the cold environment has been assessed in terms of required clothing insulation, (Holmer 1984, 1988; ISO 1993). Nevertheless, the intrinsic insulation value (I_{cl}) of an ensemble is obtainable either from tables (ISO 1995) or measured by thermal manikin (ISO 2004; ASTM 2005). This basic insulation is obtained under static conditions. Clothing insulation decreases with the wind speed and/or higher walking speed (Olesen et al. 1982; Vogt et al. 1983; Nielsen et al. 1985; Havenith et al. 1990, Havenith and Nilsson 2004; McCullough and Hong 1994). The water vapor resistance of clothing also declines due to the wind and to pump effects resulting from body movement (Lotens and Havenith 1991; Parsons et al. 1999b). In addition, the moisture permeability index (i_m) increases due to the wind and to body movement (Havenith et al. 1999). However, ISO/TR 11079 treats moisture permeability index as the same value (0.38) for various circumstances (ISO 1993).

ISO 7730 covers the method for predicting the thermal sensation and degree of thermal dissatisfaction of healthy people exposed to moderate indoor thermal environments (ISO 1994). It was originally derived from the thermal comfort studies of a large number of American college students. The PMV (predicted mean vote) index was defined as the index that expresses the mean vote of the majority of people in terms of a 7-point thermal sensation rating scale. It can be calculated on the basis of the energy balance equation of the human body. Although ISO 7730 has been extensively used as a method for assessing the thermal comfort of the occupants in moderate thermal environments, it is not applicable to the outdoor scenario due to the different conditions encountered. People may be exposed to intense solar radiation and strong winds, which greatly influence the thermal sensation. Solar radiation affects the heat exchange between the body and the environment because of absorption of solar radiation by the human skin. Variations of sun and shade, and in wind speed are to be expected. Direct exposure to solar radiation may provide pleasure in winter and discomfort in summer. The outdoor wind speed is higher than the indoor air speed. It brings a pleasant response in summer, while it is annoying in winter (Givoni et al. 2003). On the other hand, as mentioned earlier, both thermal insulation and evaporative resistance decreases in the presence of wind and body motion. Correction is needed prior to the calculation of heat exchange between a clothed body and the environment.

Several other models have been introduced for assessing outdoor environments. The Munich energy balance model for individuals (MEMI) was based on the energy balance equation of the human body and some parameters of Gagge's two-node model. Based on the calculation of heat flow from the body core to the skin surface, and from the skin surface through the clothing layers to the clothing surface, as well as some thermophysiological considerations, it is possible to calculate the resulting thermal state of the body for any combination of environmental conditions and activity and clothing. MEMI therefore presents a basis for the thermophysiologically relevant evaluation of the thermal component of climate (Höppe 1999). The physiologically equivalent temperature (PET) was defined as the air temperature at which, in a typical indoor setting, the heat budget of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with the same core and skin temperature as under the complex outdoor conditions to be assessed. PET allows a layman to compare the integral effects of complex outdoor thermal conditions with his or her own experience indoors (Höppe 1999). PET is a climate index. Since it is independent of clothing and activity it is not an absolute measure of thermal strain or comfort, it is a tool for assessing the thermal environment. Perceived temperature (PT) was defined as the air temperature of a standardized environment which achieves the same predicted mean vote as the real environment. The actual conditions are converted to the standardized environment by means of the perceived temperature technique. The mean radiant temperature is equal to the air temperature while the wind speed is reduced to 0.1 m/s. The PT refers to a human subject standardized as follows: male, 35 years old, body height 1.75 m, weight 75 kg, walking at 4 km per hour on a horizontal plain related to an internal heat production of 172.5 W. The thermal resistance of clothing between 1.75 clo (winter) and 0.50 clo (summer) is iterated to achieve thermal comfort (Spagnolo and de Dear 2003). None of the above-mentioned models consider the effects of wind and body motion on the thermal insulation and evaporative resistance of clothing.

Materials and methods

Thermal comfort is defined as the condition of mind which expresses satisfaction with the thermal environment (ASHRAE 2004). The thermal comfort of a person depends upon the environmental conditions, the thermal insulation of clothing worn, the activity of the person, and the duration of the exposure.

The environmental factors include the air temperature, mean radiant temperature, air velocity, and relative humidity. Air temperature is defined as the dry-bulb temperature of the air surrounding the occupant (ASHRAE 2004). In a cold environment, more heat is lost from the body via conduction, convection and radiation, so high thermal insulation of the clothing system is required to maintain the body in a thermal equilibrium condition. The mean radiant temperature is defined as the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space (ASHRAE 2004). Air velocity is the rate at which air is moving over a specified distance. It affects the sensible heat exchange between the body and the environment as well as the evaporative heat exchange (Holmer et al. 1999; Parsons et al. 1999b). Relative humidity is the ratio of the partial pressure of water vapor in the air to the saturation pressure of water vapor at the same temperature and the same total pressure (ASHRAE 2004). It directly influences the evaporative heat transfer between the human body surface and the environment.

As the most important mediator between ambient conditions and the human body, clothing has a very important function for thermal comfort. The components of the outdoor clothing system and the degree of clothing closure affect the insulation provided by the system. The user's activity level directly influences his/her thermal comfort because metabolic heat production increases with physical activity. Consequently, less insulation is required if additional heat is generated by the body. In addition, the amount of time the person is exposed to a cold environment in the outdoor clothing system affects his/her thermal comfort. A person can tolerate a colder air temperature for a relatively shorter period of time than those required for steady-state conditions (McCullough and Rohles 1983). Individual differences among peoples' perceptions of comfort vary, and their metabolic rates differ with gender, age, fitness level, and degree of muscle mass (Arciero et al. 1993; Susan and Rosenberg 2006; Pratley et al. 1994; Cunningham 1980).

The general energy balance equation is as follows (ISO 1993; ASHRAE 2005):

$$M - W = C + R + E + C_{res} + E_{res} + S \quad (1)$$

Where:

M = metabolic rate, W/m^2
W = mechanical power, W/m^2
C = convective heat loss from skin, W/m^2
R = radiation heat loss from skin, W/m^2
E = evaporative heat loss from skin, W/m^2
E_{res} = evaporative heat loss from respiration, W/m^2
C_{res} = convective heat loss from respiration, W/m^2
S = rate of body heat storage, W/m^2

The metabolic rate is defined as the rate at which the body utilizes oxygen and food to produce energy (Havenith et al. 2002). For more information about metabolic rate at various activities, see ASHRAE (2005). For most activities, the mechanical power can be made equal to zero (Holmer 1984; Levine 2004). Under a steady-state condition, body heat production is equal to body heat loss. There is neither heat storage in the body, nor heat debt (Burton and Edholm 1955). The heat loss can be calculated for a steady-state condition with the following equations (ASHRAE 2005):

Convective heat loss from the skin (C), (W/m^2)

$$C = \frac{(T_{sk} - T_a)}{R_{tdyn}} \quad (2)$$

Where

T_{sk} = mean skin temperature (°C)
T_a = air temperature (°C)
R_{tdyn} = dynamic total thermal resistance of the outdoor clothing system ($m^2 \cdot °C/W$)

The mean skin temperature of a neutral thermal state of the body is determined by (ISO 1993):

$$T_{sk} = 35.7 - 0.0285 \times M \quad (3)$$

The static total thermal resistance of the outdoor clothing system can be calculated as (Parsons et al. 1999b):

$$R_{tst} = I_{cl} \times 0.155 + R_a / f_{cl} \quad (4)$$

Where:

R_{tst} = static insulation of the clothing, $m^2 \cdot °C/W$
I_{cl} = intrinsic insulation of the clothing, clo
R_a = static insulation of boundary air layer,
f_{cl} = clothing area factor

The static insulation of boundary air layer is approximately 0.11 $m^2 \cdot °C/W$ (Parsons et al. 1999b). The clothing area factor is estimated by (ISO 1995):

$$f_{cl} = 1 + 0.31 \times I_{cl} \quad (5)$$

The insulation of the clothing due to wind and body movement is determined by (Holmer et al. 1999; Parsons et al. 1999b):

$$R_{tdyn} = R_{tst} \times CORR \quad (6)$$

$$CORR = e^{\left(0.043 - 0.398 \times V + 0.066 \times V^2 - 0.378 \times WS + 0.094 \times WS^2\right)} \quad (7)$$

Where:

CORR = correction factor to clothing insulation,
V = air velocity, m/s
WS = walking speed, m/s

The convective heat loss relies on the relative air movement between the body and the environment instead of the absolute air speed. The 'walking speed' depends upon the difference between the metabolic rate and that at rest (58 W/m^2), but this is limited to 0.7 m/s. It is given by (Parsons et al. 1999b):

$$WS = 0.0052 \times (M - 58) \quad (8)$$

Radiation heat exchange, (W/m^2)

The radiation and convective heat exchanges should be considered separately when using the model outdoors. If the surroundings are divided into *n* isothermal surfaces, the mean radiation temperature in outdoor environments is determined by (Ali-Toudert and Mayer 2006):

$$T_{mrt}=\sqrt[4]{\frac{1}{\sigma}\left(\sum_{i=1}^{n}(E_i\times F_i)+\frac{\alpha_k}{\varepsilon_p}\sum_{i=1}^{n}(D_i\times F_i)+\frac{\alpha_k}{\varepsilon_p}f_p\times I\right)}-273 \tag{9}$$

Where:

T_{mrt} = mean radiant temperature, °C

E_i = long-wave radiation, W/m^2

D_i = diffuse and diffusely reflected short-wave radiation, W/m^2

I = direct solar radiation, W/m^2

F_i = angle-weighting factor,

f_p = surface projection factor,

α_i = absorption coefficient of irradiated body surface for short-wave radiation,

εp = emissivity of the human body,

σ = Stefan-Boltzmann constant, 5.67×10^{-8}

The long-wave radiation comprises the radiation from upper hemisphere (sky and buildings) and from the ground. The surface projection factor is a function of the sun's position and body posture. The absorption coefficient of irradiated body surface for short-wave radiation is approximately 0.7. The emissivity of the human body is about 0.97.

The radiation heat exchange (R) between the human body and environment is then calculated as (Parsons 1999a):

$$R = h_r\times F_{cl}\times(T_{sk}-T_{mrt}) \tag{10}$$

Where:

h_r = radiative heat transfer coefficient,

F_{cl} = reduction factor for sensible heat exchange due to the clothes worn,

The radiative heat transfer coefficient is determined by:

$$h_r=\sigma\times\varepsilon_p\times\frac{A_r}{A_{Du}}\times\frac{\left[(T_{sk}+273)^4-(T_{mrt}+273)^4\right]}{T_{sk}-T_{mrt}} \tag{11}$$

Where:

A_r/A_{Du} = the fraction of skin surface involved in heat exchange by radiation, 0.77.

The reduction factor for sensible heat exchange due to the clothes worn is governed by (Parsons 1999a):

$$F_{cl}=\frac{1}{(h_c+h_r)\times I_{cl}\times0.155+1/f_{cl}} \tag{12}$$

Where:

h_c = convective heat transfer coefficient,

The convective heat transfer coefficient depends upon the air velocity:

$$h_c= 3.5 + 5.2\times V \qquad (V<1m/s) \tag{13}$$

$$h_c= 8.7\times V^{0.6} \qquad (V>1m/s) \tag{14}$$

Evaporative Heat Loss from the Skin E, (W/m^2)

$$E =\frac{W\times(P_{sk}-P_a)}{R_{etdyn}} \tag{15}$$

Where

w = skin wettedness,

P_{sk} = saturated vapor pressure at mean skin temperature, kPa

P_a = vapor pressure of the environment (kPa)

R_{etdyn} = dynamic total water vapor resistance of the clothing system (m^2·kPa/W)

The skin wettedness, the wetted fraction of the skin surface involving evaporative heat exchange, ranges from 0.06 for only diffusion to 1 with regulatory sweating and maximum evaporative heat loss of the body. It is calculated by (ISO 1993):

$$w = 0.001\times M \tag{16}$$

The vapor pressure of the environment is the product of saturated vapor pressure and the relative humidity, given by:

$$P_a= P_{sat}(T_a)\times RH \tag{17}$$

Where

P_{sat} = saturation vapor pressure (kPa)

RH = relative humidty (%)

The saturation pressure at a given temperature was calculated by Antoine's formula (ISO 1993):

$$P_{sat} = 0.1333\times e^{(18.6686-4030.183/(T+235))} \tag{18}$$

Where

P_{sat} = saturation vapor pressure, kPa

T = the temperature,°C

The dynamic total water vapor resistance of the clothing system can be estimated by using the Lewis relation (ASHRAE 2005):

$$R_{etdyn}=\frac{R_{tdyn}}{Lr\times i_{mdyn}} \tag{19}$$

where

Lr = the Lewis relation, 16.65°C / kPa

R_{etdyn} = dynamic total water vapor resistance of the clothing system, m^2·kPa/W

i_{mdyn} = dynamic permeability index for the clothing.

The permeability index may increase by a factor of 2–3 due to body movement and wind (Havenith et al.

1999). The dynamic permeability index is determined by (Havenith et al. 1999):

$$i_{mdyn} = i_{mst} \times \left(4.9 - 6.5 \times CORR + 2.6 \times CORR^2\right) \quad (20)$$

Where:

i_{mst} = static permeability index of the clothing,

The static permeability index is derived from the table in ISO 9920. For air permeability garments it is approximately 0.38 (McCullough et al. 1989).

Convective Heat Loss from Respiration C_{res} (W/m^2)

$$C_{res} = m_{res} \times c_{p,a} \times (T_{ex} - T_a)/A \quad (21)$$

where

m_{res} = respiration rate (kg/s)

$c_{p,a}$ = specific heat of air (J/(kg°C))

T_{ex} = temperature of the exhaled air (°C)

A = body surface area, 1.8 m^2

The respiration rate is based on the metabolic activity level (ASHRAE 2005):

$$m_{res} = K_{res} \times M \times A \quad (22)$$

Where:

M = metabolic rate, W/m^2

K_{res} = proportionality constant, 1.43×10^{-6} kg/J

The specific heat of air is approximately 1,007 J/(kg K) at typical conditions based on the enthalpy at the temperature of 0 to 90°C (ASHRAE 2005). The exhaled air temperature, T_{ex}, can be estimated according to (Holmer 1984):

$$T_{ex} = 29 + 0.2 \times T_a \quad (23)$$

Evaporative Heat Loss from Respiration E_{res}, (W/m^2)

$$E_{res} = m_{res} \times h_{fg} \times (W_{ex} - W_a)/A \quad (24)$$

Where

h_{fg} = heat of vaporization of water, kJ/kg

W_{ex} = humidity ratio of the exhaled air,

W_a = humidity ratio of the environment,

The humidity ratio can be determined from the vapor pressure by:

$$W_{ex} = \frac{0.622 \times P_{ex}}{P_t - P_{ex}} \quad (25)$$

$$W_a = \frac{0.622 \times P_a}{P_t - P_a} \quad (26)$$

Where

P_t = total atmospheric pressure, kPa

P_{ex} = saturation pressure of exhaled air temperature, kPa

The sea level value of 101.325 kPa can be used for P_t (ASHRAE 2005).

Under a non-steady state, people can tolerate 40 Wh/m^2 of heat debt in cold outdoor environments (ISO 1993). Accordingly, the mean skin temperature drops 3°C, while the body core temperature remains unchanged at 37°C (Holmer 1984, 1988; ISO 1993). Thus, the body heat debt (S) can be calculated by (Holmer 1984):

$$S = \frac{D}{H} \quad (27)$$

Where:

D = heat debt (W·h/m^2)

H = duration of exposure (hour)

All above heat exchange equations substituted corresponding terms in the general energy balance equation (1). Mathematical iteration method was used to solve this equation so that the air temperature could be predicted for thermal comfort of people under outdoor exposure, see appendix.

Results and discussion

In order to investigate the effects of other environmental variables and activity levels on the air temperature predictions, a wide variety of parameters were input to the model. Suppose the relative humidity is 50%, the air velocity is 0.1 m/s and the mean radiant temperature is the same as the air temperature. Figure 1 shows the air temperatures for thermal comfort of people wearing different clothing insulation at various activity levels. At a given activity level, the higher the insulation that the outdoor clothing provides, the lower is the predicted air temperature. Additionally, a higher metabolic rate generates a lower temperature prediction, since more heat is produced to balance the heat loss due to both the low temperature and the pumping effect resulting from body motion.

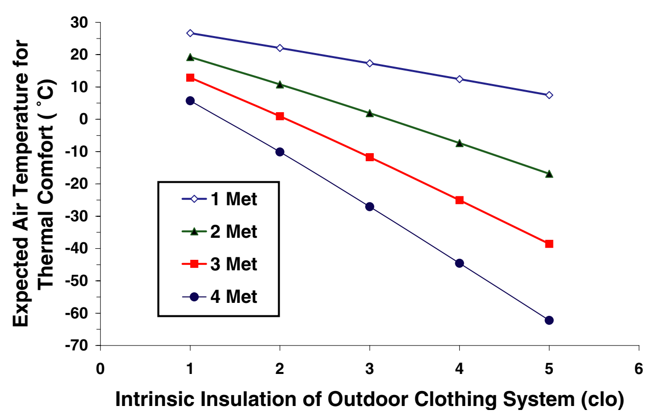

Fig. 1 Expected air temperature for steady-state thermal comfort versus clothing intrinsic insulation at four levels of metabolic rate (air velocity 0.1 m/s, relative humidity 50%, mean radiation temperature equivalent to air temperature, 1 Met = 58.2 W/m^2)

As shown in Fig. 2, the higher the air velocity, the higher the air temperature prediction obtained for thermal comfort. This can be easily explained by the fact that the convective heat loss and evaporative heat loss are increasing with increasing wind speeds. Thus, a high air temperature is needed to compensate. However, as correction factors for clothing insulation and permeability index were empirically derived from the experimental data, the model can only apply to air velocity ranging from 0.2 to 3 m/s (Holmer et al. 1999).

As shown in Fig. 3, the longer duration of exposure, the higher the air temperature for thermal comfort. As the heat debt incurred in the human body is spread over a longer time, people can spend a relatively long period of time at a higher air temperature.

It is difficult for the wearers to interpret the technical information provided by clothing suppliers concerning clothing insulation, since ordinary consumers are not professionals and do not know what the clo value means. The mathematical model illustrated above can be employed to predict the air temperature, which unequivocally indicates what air temperature is capable of maintaining an average adult comfortable under a given environmental condition and at a specific activity level. If more accurate temperature ratings are put on garment labels, it should be easier for consumers to compare the products provided by different manufacturers and to select the garment that is appropriate for its intended conditions of use. Meanwhile, the risk of hypothermia can be diminished. In addition, more accurate ratings should lead to more consumer satisfaction with the product during use.

Conclusions

A mathematical model was developed to predict the air temperature for thermal comfort of people in outdoor

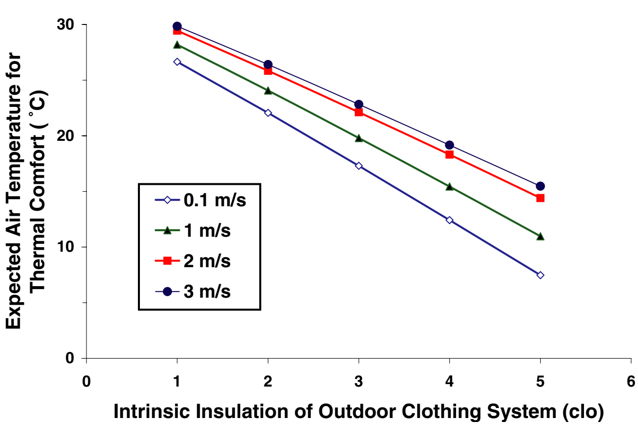

Fig. 2 Expected air temperature for steady-state thermal comfort versus clothing intrinsic insulation at four levels of air velocity (metabolic rate 58.2 W/m^2, relative humidity 50%, air velocity 0.1 m/s, mean radiation temperature equivalent to air temperature)

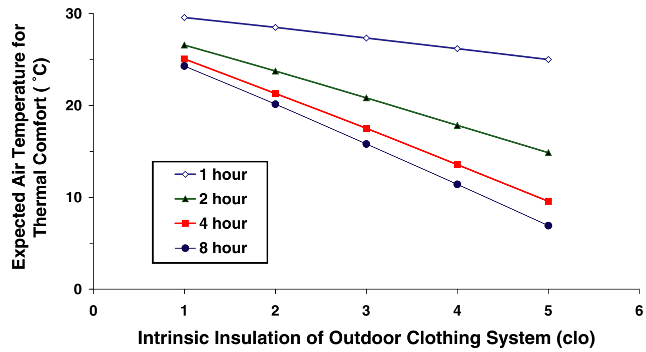

Fig. 3 Expected air temperature for thermal comfort versus clothing intrinsic insulation at different durations of exposure (metabolic rate 58.2 W/m^2, air velocity 0.1 m/s,relative humidity 50%, mean radiation temperature equivalent to air temperature)

environments. The lower the insulation of the clothing, the higher the temperature prediction. A high metabolic rate results in a low temperature prediction. High air velocity leads to high air temperature for thermal comfort. The shorter the exposure time also causes a higher temperature prediction.

Nevertheless, some variables affecting the thermal comfort of people in outdoor spaces in real life are beyond control. People may adjust the garment closures or unfasten the zipper if they feel warm. Different garments are usually chosen when people stay outdoors in the four seasons. In reality, the air temperature is not always at one level and may be cycling during the cold exposure. Therefore, the people would not be spending as much time at that temperature in real life as we expect.

Furthermore, psychological aspects play an important role in outdoor thermal comfort. People may feel warmer if they are told the temperature is higher than it actually is. In summer, people prefer cold environments while the case is precisely opposite in winter. Moreover, the psychological expectancy and thermal history may strongly influence the subjective rating. Subjects on a hot summer day voted 'comfortable' in the PMV-index just because they expected some sun (Höppe 2002). Besides, exposure to outdoor climate is, in general, shorter than indoor exposure. When one moves from a thermal comfort room to a cold outdoor environment, it takes a longer time to approach the steady-state than in hot conditions. In a real situation, thermal steady-state is rarely achieved even though people spend hours in the outdoors (Höppe 2002).

Finally, there are uncertainties in bioclimatic variables and thermophysiological inputs. The weather forecast varies on a daily basis as does the temperature (Evans 2003). And, as mentioned early, metabolism differs among people depending on their gender, age and fitness level.

Appendix

Qbasic computer program for generating air temperature for thermal comfort of people in outdoor environments

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'THE COMPUTER PROGRAM FOR CALCULATION OF AIR TEMPERATURE FOR THERMAL COMFORT OF PEOPLE IN OUTDOOR ENVIRONMENTS.
'THE PROGRAM IS WRITTEN IN QBASIC
'Developed by Jianhua Huang, 2006
'Input initial values
INPUT "metabolic rate (W/m2)", M
INPUT "relative humidity (%)", RH
INPUT "mean radiation temperature(°C)", Tmrt
INPUT "intrinsic clothing insulation (clo)", Icl
INPUT "wind speed (m/s)", V
INPUT "duration of exposure,'9999" for steady-state (hour)", H
'Calculation of the air temperature using stepwise iteration
balance = 100: x = 1: Ta = 40 'Initial estimation value
WHILE (ABS(balance) > .01)
'Calculation of Convective heat loss from the skin
Ra = 1 / 9
fcl = 1+.31 * Icl
IF H = 9999 THEN Tsk = 35.7 - .0285 * M ELSE Tsk = 35.7 - .0285 * M - 3
Rst = Icl * .155 + Ra / fcl
WS = .0052 * (M - 58)
IF WS > .7 THEN WS = .7
corr = EXP(.043 - .398 * V + .066 * V * V - .378 * WS + .094 * WS * WS)
Rdyn = Rst * corr
C = (Tsk - Ta) / Rdyn
'Calculation of radiation heat exchange
hr = 5.67E-08 * .97 * .77 * (EXP(4 * LOG(Tsk + 273.15)) - EXP(4 * LOG(Tmrt + 273.15))) / (Tsk - Tmrt)
IF V < 1 THEN hc = 3.5+5.2 * V ELSE hc = 8.7 * EXP(.6 * LOG(V))
Fcl = 1 / ((hc + hr) * Icl * .155 + 1 / fcl)
R = hr * Fcl * (Tsk - Ta)
'Calculation of Evaporative Heat Loss from the Skin
Psk = .1333 * EXP(18.6686 - 4030.183 / (Tsk + 235))
Pa = RH * .1333 * EXP(18.6686 - 4030.183 / (Ta + 235)) / 100
Im = .38 * (4.9 - 6.5 * corr + 2.6 * corr * corr)
IF Im > .9 THEN Im = .9
Retdyn = Rdyn / Im / 16.65
w = .001 * M
E = w * (Psk - Pa) / Retdyn
'Calculation of Convective Heat Loss from Respiration
mres = 2.58 * .000001 * M
Tex = 29+.2 * Ta
Cres = 1007 * mres * (Tex - Ta) / 1.8
'Calculation of Evaporative Heat Loss from Respiration
Wa = .622 * Pa / (101.325 - Pa)
Pex = .1333 * EXP(18.6686 - 4030.183 / (Tex + 235))
Wex = .622 * Pex / (101.325 - Pex)
Eres = 2423000 * mres * (Wex - Wa) / 1.8
'Calculation of heat debt or heat storage
IF H = 9999 THEN S = 0 ELSE S = 40 / H
balance = M - C - R - E - Cres - Eres - S
IF balance < 0 THEN Ta = Ta + x: x = x / 2 ELSE Ta = Ta - x
WEND
PRINT "Icl="; Icl, "expected air temperature for thermal comfort is"; Ta
END
```

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