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Healthy ageing: differences between elderly and non-elderly in temperature sensation and dissatisfied

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ABSTRACT
The key question in this study is: 'To which extent is the difference in thermal comfort mathematically to describe by temperature sensation and the percentage of dissatisfied, between the elderly and non-elderly, related to the Fanger model?'. This study proves that it is possible to mathematically describe the difference in thermal comfort between elderly and non-elderly by means of a comparison between the calculation results of a thermophysiological two-node model, adjusted for individual characteristics, and different experimental studies. Since the various subgroups of elderly are increasing in number disproportionately to other age groups, adapting the existing thermophysiological human models, for predicting the thermal response of people depending on age and sex, is important. In this way, useful insights can be realized from modelling the thermal behaviour and response patterns of the elderly for the future design of buildings and climate installations.

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KEYWORDS
Elderly; individual characteristics; mathematical modelling; non-elderly; predicted percentage of dissatisfied; temperature sensation; thermal comfort

Introduction

To increase the vitality of the elderly the design criteria for the indoor climate should be adapted (Roelofsen 2014), because it appears that:

- Elderly people and non-elderly, in the same environment, experience the indoor climate differently;
- Elderly people have a lower tolerance for uncomfortable situations than non-elderly.

Since the various subgroups of elderly are increasing in number disproportionately to other age groups, adapting the existing thermophysiological human models, for predicting the thermal response of people depending on age and sex, is important. In this way, useful insights can be realized from modelling the thermal behaviour and response patterns of the elderly for the future design of buildings and climate installations (Novieto 2013).

In this study it is investigated to which extent the differences in thermal comfort between elderly and non-elderly are mathematical to describe in the form of temperature sensation and the percentage of dissatisfied in relation to the Fanger model.

By means of a comparison between different experimental studies and a thermophysiological two-node model, adjusted for individual characteristics, it is proved that it is possible to mathematically describe the differences in thermal comfort between elderly and non-elderly.

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Functional changes with age

With age functional changes occur in the body which impact the thermoregulatory system of the human body. The result is the alteration of the older individual's response to variations in the ambient temperature in contrast with the non-elderly. Reduced cardiac output, reduced muscle mass, reduced temperature sensitivity, atrophy of the skin, an increase in body fat and reduction in basal metabolic rate are some of the effects of ageing. There is a gradual age-related loss of neural tissue up to 46% in humans over the age of 50 years. From the age of 20–60 years, neural losses are only around 0.1% per year but the process speeds up thereafter with reported cerebral blood flow decreasing by 20%. The progressive loss of neurons and the associated reduction in impulse velocity and changes within the spinal cord typically lead to a slowing of reaction times. This can create problems for older people encountering painful or harmful stimuli. Neurotransmitters in the body also suffer from age-related decline in their synthesis and receptors. The peripheral nerve cells often show a progressive degeneration with age which results in the slowing of the conduction of nerve impulses by around 5–10%. These depletions of the neurotransmitters and alterations in nerve density, electrophysiological and neurochemical properties of the afferent pathway to the brain significantly alter structures and functions of the nervous system. Indeed, all these changes affect how an older individual's body responds to the thermal challenge of either hot or cold stress (Stevens and Choo 1998). Some of the risk factors of an older individual's response to heat include, increased threshold of sweating with a diminished sweating response which has the likelihood of inducing heat accumulation in the older individual's body. Other risk factors include reduced vasodilation (the widening of blood vessels) and ability to adapt. These conditions are likely to expose the older people to thermal injuries including hyperthermia (elevated body temperature due to failed thermoregulation) and heat stroke (hyperthermia with a body temperature greater than 40.6°C). In response to cold exposure, the risk factors of ageing include delayed onset of shivering, which has a high likelihood of causing drastic fall in the older individual's core body temperature. Other risk factors include diminished shivering response and vasoconstrictions (the narrowing of blood vessels) which may expose older people to thermal cooling including moderate to severe hypothermia (a body core temperature below 35°C) (Novieto 2013).

The key question in this study is; 'To which extent are the differences in thermal comfort mathematically to describe by temperature sensation and the percentage of dissatisfied, between the elderly and non-elderly, related to the Fanger model?'

Methods and results

Fanger model

The Fanger model (Fanger 1972), as described in NEN-EN-ISO-7730 (2005), is based on experiments with young subjects. By far the greatest number of comfort studies have been carried out with young people as subjects, and consequently the existing knowledge on the influence of age on the comfort conditions is less. In order to investigate this aspect, Fanger conducted an experiment with 128 elderly Danish people (age 68.0 ± 4.7 years) who were exposed to exactly the same environmental conditions as the 128 Danish students (age 23.1 ± 2.2 years). The large age difference (45 years) between the two groups was primarily chosen to investigate whether a significant age-conditioned difference exits at all. As half of the subjects were females and half males, it was possible to study the influence of the sex on the comfort conditions also. The experiments showed no difference in comfort conditions between elderly and college-age people, and it seems reasonable, therefore, to assume that the comfort equation applies to all adults. The results of the experiment showed however that the insensible perspiration for the elderly is lower than that for the college-age group. The decrease found in the evaporative heat loss for the elderly is about the same as the decrease in metabolic rate. These offset each other in the heat balance, and offer a reasonable explanation why no difference was found in the preferred temperature between the two age groups. The reason for decreased insensible perspiration for the elderly could be that a change in the vapour diffusion resistance of the skin occurs as a consequence of age. Furthermore it should be remarked that behaviour, at least for very elderly people, tends towards quiet activity, and should be taken into account in the design of environments for older people (Fanger 1972).

Hwang and Chen (2010)

Hwang and Chen (2010) investigated the behaviour, the adaptation and thermal comfort of elderly people (age 71 ± 7 years) in residential environments. The research results are also compared with a similar study carried out previously, by Chen and Hwang, with young people (age 34 ± 10 years). In this research two curves were derived for the predicted percentage of dissatisfied (PPD) as a function of the mean thermal sensation vote (MTSV); one for the elderly and one for younger people. The research results are displayed graphically in Figure 1.

The equations for the overall PPD, developed by Hwang and Cheng, are:

Non-elderly

$$\mathrm{PPD} = 100 - 86 * \exp(-0.2272 * \mathrm{MTSV}^2 - 0.0479 * \mathrm{MTSV}^4).$$

Elderly

$$\mathrm{PPD} = 100 - 97 * \exp(-0.3338 * \mathrm{MTSV}^2 - 0.01972 * \mathrm{MTSV}^4).$$

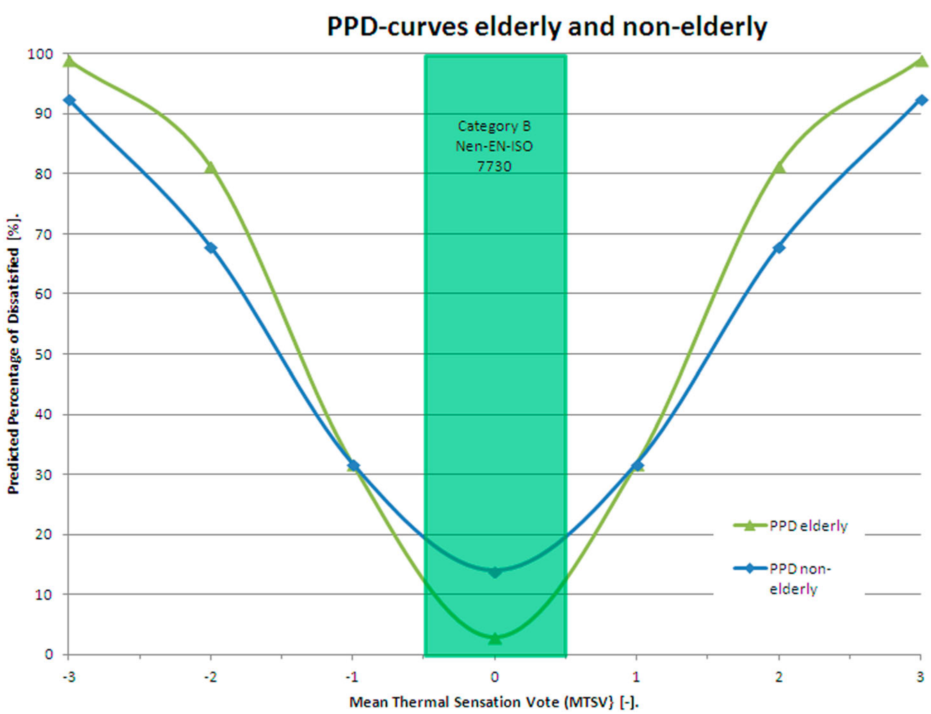

Figure 1. Hwang and Chen (2010).

Herein is

$$\text{MTSV} = \text{Mean Thermal Sensation Vote } (-).$$

The neutral temperature for the elderly was in this research 25.2°C and 23.2°C, respectively, for the summer and winter situations. The area with 80% thermal acceptance in summer ranged for the elderly between 23.2°C and 27.1°C operative temperature relative to 23.0°C and 28.6°C operative temperature for young people. The area with 80% thermal acceptance in the winter situation ranged for the elderly between 20.5°C and 25.9°C operative temperature. In this study data from non-elderly in the winter situation are not published. The research results show that older and younger people, even in the same environment, respond differently to the thermal indoor climate.

Also, the research results of Hwang and Chen show that in the case of the elderly, outside the area, where we can still reasonably speak about comfort (i.e. $|\text{MTSV}| \leq 0.8$), there is more dissatisfaction about temperature underruns and temperature overruns than in the case of young people. Research by Roelofsen (2002) and a later research by Roelofsen and ‘t Hooft (2008) demonstrated for the office situation that if performance is included in the evaluation, it does not make sense to design climate installations on the basis of temperature underruns and temperature overruns. The research results of Hwang and Chen reflect that it makes sense not to do so also in the living arrangements of the elderly, especially with professional care. The literature also indicates that mild cold exposure (20° C at 0.04 clo) can lead to increased systolic blood pressure in the elderly (He and Whelton 1999). Therefore, it is wise to protect the elderly against thermal fluctuations, even though they are minor (Schellen 2012).

Schellen et al. (2010)

Schellen et al. studied the effects of a moderate temperature drift on physiological responses, thermal comfort and productivity of eight young adults (age 22–25 years) and eight older subjects (age 67–73 years). They were exposed to two different conditions: a control condition; constant temperature of 21.5°C; duration: 8 h (S1 session); and a transient condition (S2 session); temperature range: 17–25°C, duration: 8 h, temperature drift: first 4 h: +2 K/h, last 4 h: –2 K/h. The results indicate that thermal sensation of the elderly was, in general, 0.5 scale units lower in comparison with their younger counterparts. Furthermore, the elderly showed more distal vasoconstriction during both conditions. Nevertheless, temperature sensation of the elderly was related to air temperature only, while temperature sensation of the younger adults was also related to skin temperature. During the constant temperature session, the elderly preferred a higher temperature in comparison with the young adults. A temperature drift up to ±2 K/h in the range of 17–25°C is assessed as applicable and did not lead to unacceptable conditions. Although the Fanger model is developed for steady-state conditions, Schellen et al. (2010), in accordance with other researchers (cited in Schellen et al.’s article), conclude that the predicted mean vote (PMV) might also be applicable for transient conditions.

Individualized model of human thermoregulation

In order to calculate the thermal differences between the elderly and non-elderly, a computer program, assembled for the calculation of the performance loss as a function of thermal discomfort or heat stress (Roelofsen 2015), on the basis of the two-node Gagge model (Gagge, Fobelets, and Berglund 1986), is adjusted with individual characteristics, according to a study of Havenith (2001).

These individual characteristics, besides the personal parameters that are already incorporated in the Gagge model (i.e. metabolic rate, mechanical efficiency, length, weight, skin fold and clothing resistance), are:

- Gender;
- Age;
- Percentage of body fat;
- Fitness (i.e. VO_{2max});
- Number of acclimated days.

The adjusted two-node model is used to simulate the S1 and S2 sessions of the research of Schellen et al. (2010). Some of the calculation results, as well as the measured results of the research of Schellen et al., are displayed in the Figures 2–4.

Without the adjustment of specific control parameters (e.g. sweat control), the model appears to overestimate the maximum skin temperature for the elderly (Figure 2(a) and (b)).

The results of the experiments of Schellen et al. (2010) (see Figure 3(a)) indicate that thermal sensation of the elderly was 0.5 scale units lower in comparison with their younger counterparts.

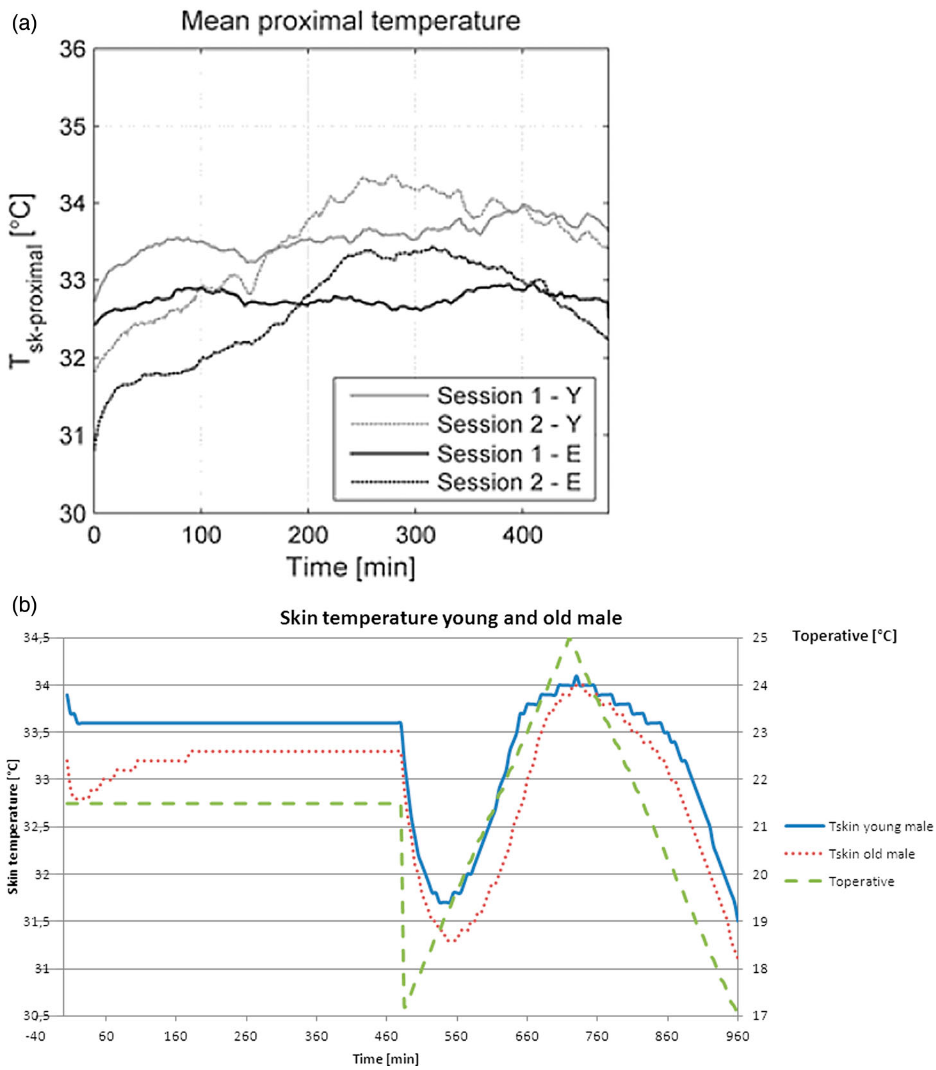

Figure 2. (a) Measured skin proximal temperature S1 and S2 sessions (Schellen et al. 2010). Y = Non-elderly, E = Elderly. (b) Calculated skin temperature with the adjusted two-node model (this study).

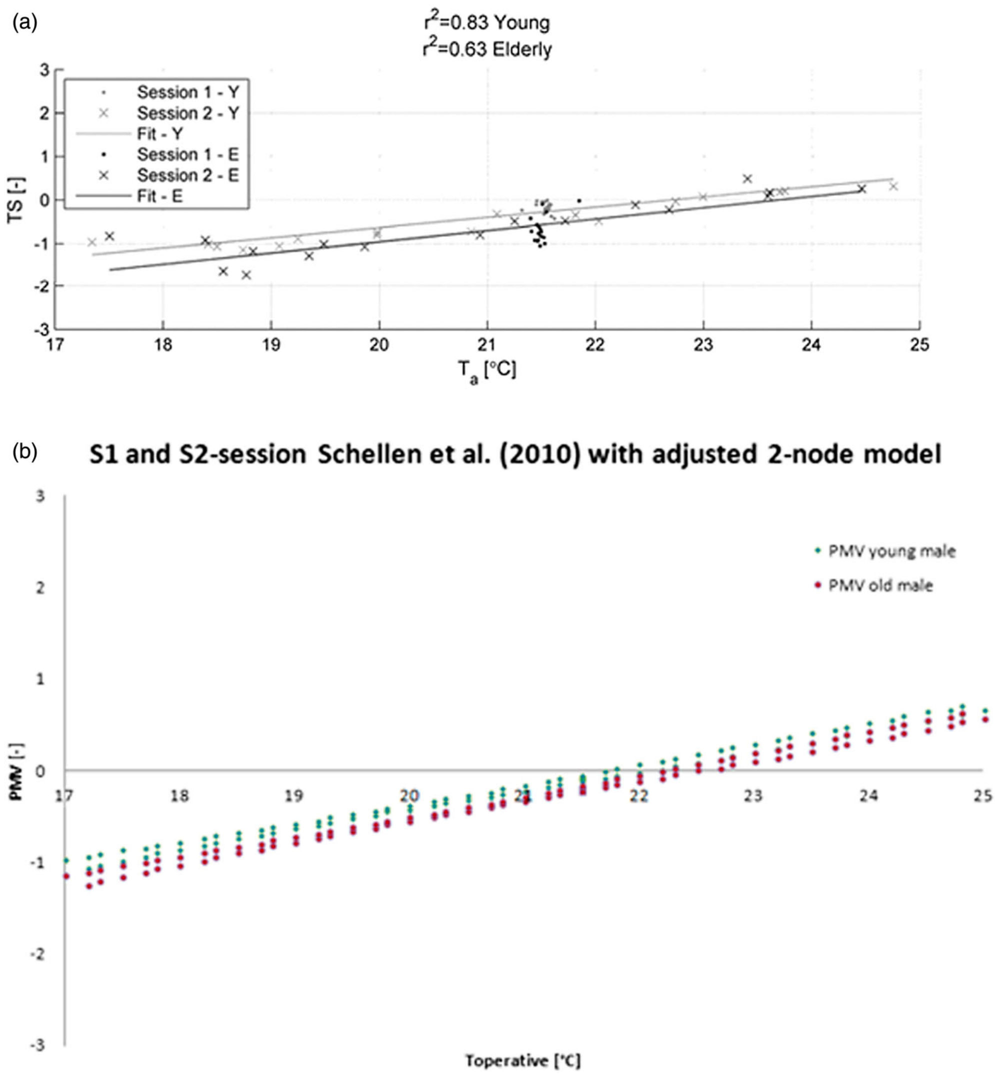

Figure 3. (a) Linear regression analysis S1 and S2 sessions (Schellen et al. 2010). (b) Linear regression analysis calculated PMV for S1 and S2 sessions with the adjusted two-node model (this study).

In the case of the adjusted two-node model, the difference is around 0.3 scale units lower (Figure 3(b)).

The calculated PMV and PMVset temperature sensations, with the adjusted two-node model, appear to be in the same order of magnitude as the measured temperature sensations by Schellen et al. (2010) (Figure 4(a)–(c)).

Gonzalez (1977)

This article reviews laboratory studies and research needs in human physiology that will be important in specifying thermal acceptability; it compares these results with guidelines proposed by the Federal Energy Administration (FEA) for summer and winter months. Male and female subjects, in both younger and older age groups, were exposed while sedentary or slightly active, to

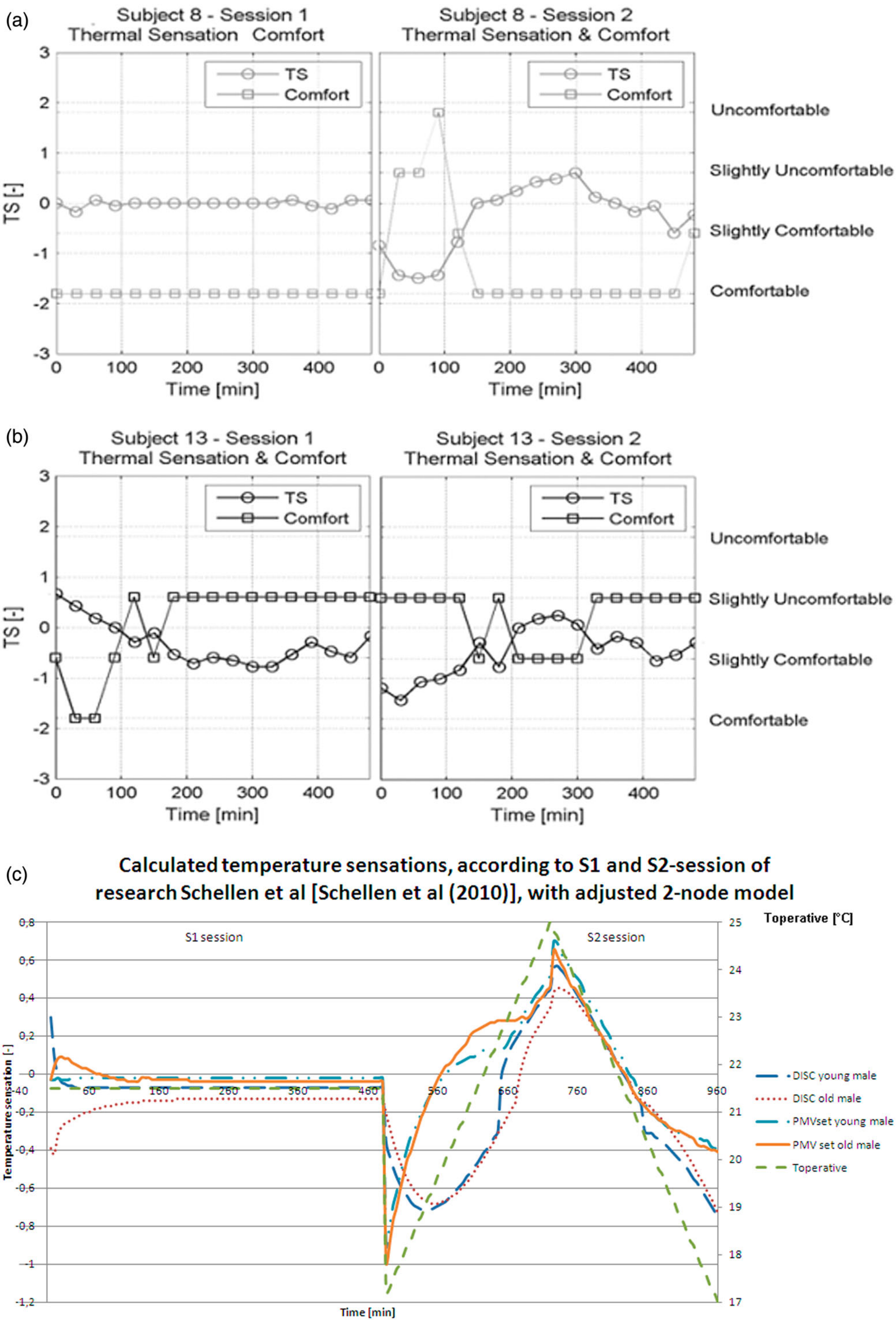

Figure 4. (a) Temperature sensation young individual (Schellen et al. 2010). (b) Temperature sensation old individual (Schellen et al. 2010). (c) Calculated temperature sensations S1 and S2 sessiona with adjusted two-node model (this study).

fluctuating dry-bulb temperature (at 50% relative humidity) and to constant dry-bulb temperatures (at 40%, 60% and 80% relative humidity) in summer experiments. In winter condition the experimental subjects were exposed to 20°C and colder environments and were allowed extra outer clothing to avoid cold discomfort. Clothing insulation was directly evaluated. In both studies evaluations of whole body thermal discomfort and thermal sensation were made; additionally, in winter studies direct votes of acceptability by the subjects, as well as regional thermal sensation (face, trunk and extremities) were taken. A method of estimating preferred comfort and neutral thermal sensation temperatures is described for fluctuating air temperature conditions. The results of summer studies indicate that 60% relative humidity at 26.7°C is the maximum limit for thermal acceptability which corresponds to a 28 ET* or 2°C above the optimal ASHRAE neutral/comfort zone. The results of the winter experiments showed that the FEA winter temperature guideline lower limit (20°C) proved 80% acceptable. Specific groups of individuals have been identified for whom winter and summer guidelines will be wholly acceptable. Relative humidity in the first part of the experiments was kept constant at 50% and dry-bulb temperature altered ±5 K from a starting temperature of 25°C with the room control set at an average rate of ±0.3 K/min over a 2 h period (Gonzalez 1977).

From the point of view of comfort this temperature fluctuation in the aforementioned did not meet the criterion of Sprague and McNall (1970), as mentioned in the thesis of Fanger (1972):

$$(\text{cph}) * \Delta t^2 < 4.6\ (^\circ\text{C}^2/\text{h}).$$

Herein is:

$$\Delta t = \text{The peak to peak amplitude of air temperature } (^\circ\text{C}),$$

$$\text{cph} = \text{is the cycling frequency } (\text{h}^{-1}).$$

According to Gonzalez the differences in thermoregulatory response between sexes as well as between the elderly and non-elderly, as shown in several investigations of different researchers, become apparent especially under fluctuating temperature conditions (Gonzalez 1977). This could be the reason why Fanger did not find any differences, other than a difference in metabolic rate and evaporation, taken into account in advance.

Sometimes fluctuations in air temperature may be beneficial because they may have a stimulating and invigorating effect on the organism. However, this assertion is purely speculative and lacks documentation. In rooms occupied by many people, over a period, when the temperature fluctuates beyond the limits stated above (viz. criterion of Sprague and McNall (1970)) creates a larger number of dissatisfied people than when the temperature is kept constant, according to Fanger (1972).

Equations for average thermal sensation estimates as a function of standard effective temperature (SET*) or standard operative temperature (STO) at 50% relative humidity with fluctuating temperature conditions were developed for young females (Iclo = 0.3), older females (Iclo = 0.5) and young males (Iclo = 0.3) in a summer situation. The regression equations are:

Young females (Age 22 ± 3 years)

$$\text{Tsens} = 0.360 * \text{SET}^* - 8.57.$$

Older females (Age 44 ± 11 years)

$$\text{Tsens} = 0.318 * \text{SET}^* - 8.01.$$

Young males (Age 25 ± 4 years)

$$\text{Tsens} = 0.232 * \text{SET}^* - 5.15.$$

Data from the elderly males were not available at the time of this part of the experiments.

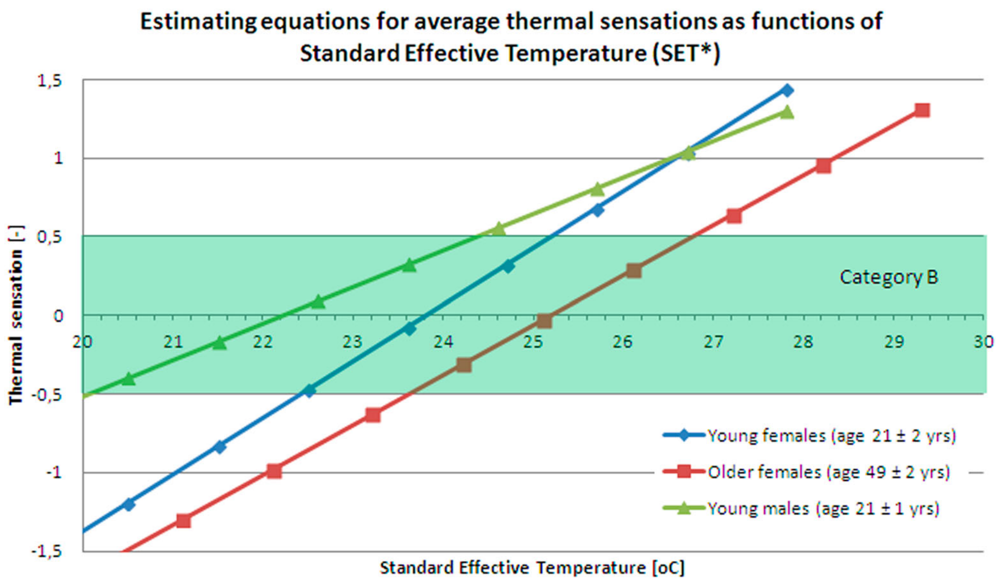

Figure 5. Regression equations.

The three regression equations are graphically displayed in Figure 5. The green shaded area in Figure 5 is the comfort zone, according to category B in NEN-EN-ISO-7730 (2005), NPR-CR-1752 (1999) and category II in NEN-EN-15251 (2007).

The mean difference of the thermal sensation of older females with their younger counterparts is about 0.5 scale units. This agrees with the findings of Schellen et al. (2010).

Rewriting the regression equations

It is possible to rewrite the aforementioned regression equations in:

Young females

$$\text{Tsens} = 1.100 * \text{PMV} - 0.040.$$

Older females

$$\text{Tsens} = 0.972 * \text{PMV} - 0.472.$$

Young Males

$$\text{Tsens} = 0.709 * \text{PMV} + 0.347.$$

In Figure 6 the SET*-regression equations are graphically displayed as well as the mean of the three SET*-regression equations and the PMV, according to NEN-ISO-7730, as a function of the SET*.

The mean of the three SET*-regression equations is almost the same as the line PMV, according to NEN-EN-ISO-7730, as a function of SET*. Therefore, it looks like that the Fanger model predicts well the mean of thermal sensation of the elderly and non-elderly together. However, for the calculation of the thermal sensation of each of the groups of the elderly and non-elderly separately, one needs to correct the PMV, according to NEN-EN-ISO 7730, with each of the PMV-regression equations above.

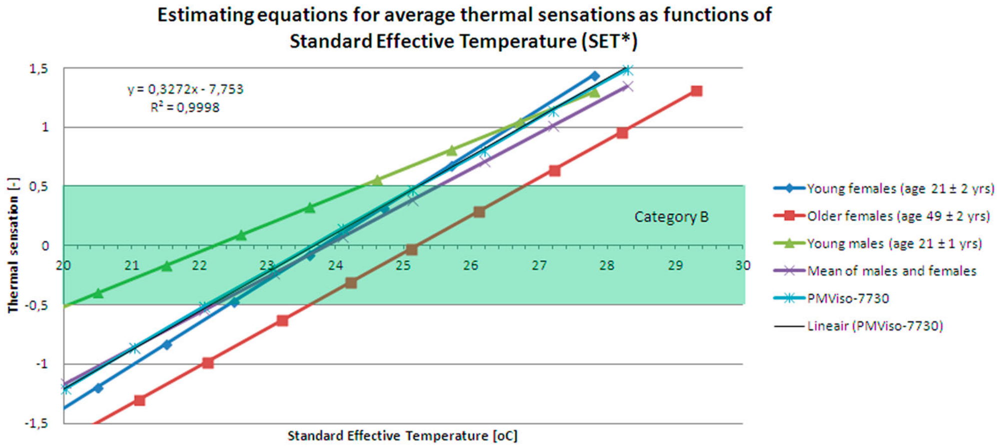

Figure 6. SET*-regression equations.

Discussion

Transients

Schellen et al. (2010), in accordance with other researchers, found that for all slopes the relation between instantaneous mean thermal sensation and the prediction by the PMV-model (NEN-EN-ISO-7730 2005) was in reasonably good agreement.

When the ambient temperature changes rapidly, the thermal sensation changes are far more rapid than the body temperatures. In a series of experiments by Gagge, Stolwijk, and Hardy (1967), men exposed to sudden changes in temperature, immediately experienced thermal sensation changes when the air temperature changed, even though it took many minutes for the skin and deep body temperature to change. The sensation anticipated the changes in air temperature and the subject felt as warm as he would in steady-state conditions in that air temperature, even though his physiological temperatures were nowhere near the steady-state value.

In transient conditions, therefore, thermal comfort may be predicted more accurately from a knowledge of the air temperature than from a knowledge of the mean skin temperature and body temperature. Rather surprisingly, this holds true for more normal conditions and several investigators have found higher correlations between warmth votes and air temperatures than between warmth votes and skin temperature (McIntyre 1980).

Temperature sensation

An individual cannot actually sense air temperature directly. An individual senses the heat flow at his/her nerve endings, which are situated below the surface of the skin. It would be desirable if an individual's sensation of warmth and comfort is to predict entirely from a knowledge of his physiological state. This has proved surprisingly difficult to do and it is often possible to predict warmth sensation more accurately from the air temperature than from mean skin temperature (e.g. DISCC-scale in the Gagge model (Gagge, Fobelets, and Berglund 1986) and deep body temperature (e.g. Tsens and the DISC-scale in the Gagge model) (McIntyre 1980) or even the degree of sweating (e.g. DISCW- and DISC-scale in the Gagge model)).

That the aforementioned is consistent with the experiments of Gonzalez (1977) is shown in Figure 7. In Figure 7(a) the results of Gonzalez are displayed. In Figure 7(b) the calculation results of the adjusted two-node model are displayed.

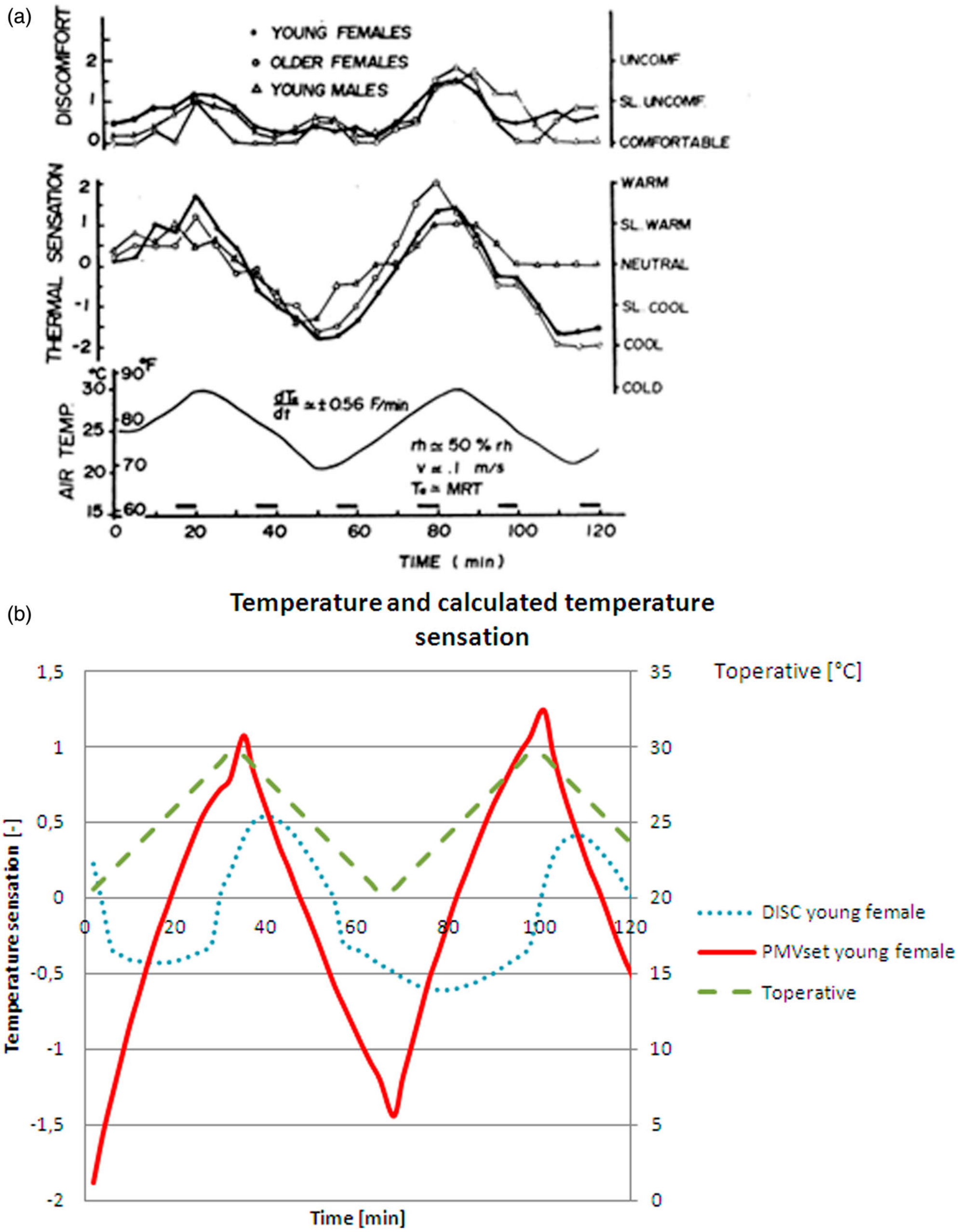

Figure 7. (a) Results (Gonzalez 1977). (b) Calculation results of the adjusted two-node model (this study).

The results of Gonzalez (Figure 7(a)) show that the temperature sensation immediately changes with a change in the air temperature. However, in the case of the simulation with the adjusted two-node model (Figure 7(b)) the calculated discomfort (DISC) is not present but only the calculated PMVset, as developed by Gagge, Fobelets, and Berglund (1986), is present. The calculated DISC is a function of the mean body temperature and the degree of sweating (Gagge, Fobelets, and Berglund 1986). The PMVset however is a function of the SET* (Gagge, Fobelets, and Berglund 1986) and the external thermal load on the body. The SET* is defined as the dry-bulb temperature of a hypothetical isothermal environment at 50% relative humidity in which a human subject, while wearing clothing, standard for the activity concerned, would have the same skin wetness and heat exchange at the skin surface as he would have in the actual test environment. The PMVset is proposed by Gagge for any dry or humid environment by simply replacing the operative temperature in Fanger's comfort equation with SET*. With this the classical difference between PMV and DISC as predictors of warm discomfort, occurring at very high and very low humidity, is solved, according to Gagge, Fobelets, and Berglund (1986).

The conclusion of Schellen et al. (2010) and other researchers (cited in Schellen et al.'s article)) that the PMV might also be applicable for transient conditions is in accordance with the experiments of Gonzalez (1977).

Conclusion

The relationship between the percentage of dissatisfied and the PMV in the Fanger model was developed on the basis of an analysis of the experiment with 128 Danish elderly and 128 Danish non-elderly as well as the American experiments of Nevin et al. (1966) and Rohles (1970) who used mainly young subjects. The experiments of Fanger (1972, chapter 3) showed that there was no significant difference in the preferred temperature between the elderly and the non-elderly in the steady-state situation. However, a possible difference in the percentage of dissatisfied between the elderly and non-elderly was not shown by Fanger. On the other hand, Hwang and Chen (2010) developed two relationships, one for the elderly and one for non-elderly, which offered the possibility of difference between the elderly and non-elderly regarding the percentage of dissatisfied.

According to Gonzalez the differences in thermoregulatory response between sexes and the elderly and non-elderly, as shown in several investigations of different researchers become apparent especially under fluctuating temperature conditions (Gonzalez 1977). This could be the reason why Fanger did not find any differences, other than a difference in metabolic rate and evaporation that in advance can be taken into account.

The Fanger model predicts well the mean of thermal sensation of the elderly and non-elderly together in steady-state and fluctuating temperature conditions. However for the calculation of the thermal sensation of each of the groups of the elderly and non-elderly separately one needs to correct the PMV.

The results of the experiments of Schellen et al. (2010) (see Figure 3(a)), as well as the PMV-calculations with the adjusted two-node model (see Figure 3(b)), indicated that thermal sensation of the elderly was, in general, 0.5 scale units lower in comparison with their younger counterparts. A temperature drift up to ±2 K/h in the range of 17–25°C was assessed as applicable and will not lead to unacceptable conditions.

In the experiments of Gonzalez (1977) a dry-bulb temperature alternating ±5 K from a starting temperature of 25°C, with the room control set at an average rate of ±0.3 K/min, over a 2 h period, resulted also in a temperature sensation of older females of about 0.5 scale units lower in comparison with the young females.

Furthermore:

- SET* preferred temperature is significantly different between the young male and both female groups;
- The SET* preferred temperature for younger females is lower as compared with the older female group. This may be the result of a lower metabolic heat production in older females;
- Young females and older females have a significantly higher warmth sensitivity than the male group;
- There was no significant difference in warmth sensitivity between the young and older groups;
- In the winter study, the older individuals complained less of the cold than the younger females and had less cool discomfort at both 20°C and 15°C, which agrees with the findings of Hwang and Chen (2010).

The decrease found in the evaporative heat loss for the elderly is a reason for concern because of the diminished vasodilations, vasoconstrictions and shivering response, for example in the case of temperature overshoots of the comfort zone. The experiments of Gonzalez showed that elderly are not excessively disturbed by warm situations. However, because of the general lower physical fitness and resulting lower sweat secretion and poor skin circulation, the level of skin wetness does not serve as an early cue for thermal discomfort in the elderly as it does for more fit individuals. Other symptoms of distress (i.e. syncope, headache, etc.) are less ostensible and can occur at higher levels of humidity and ambient temperature. Therefore, special consideration should be given to the elderly (Gonzalez 1977).

The calculated PMV and PMVset temperature sensations, with the adjusted two-node model, appear to be in the same order of magnitude as the observed temperature sensations by Schellen et al. (2010) and Gonzalez (1977).

The PMV might also be applicable for transient conditions, according to experiments of Schellen et al. (2010) and other researchers (cited in Schellen et al.'s article).

Havenith (2001) mentions that his study was to determine the possibilities of individualization, wherein the average gain was less important than the differentiation in gain between individuals. For that reason this topic was not further pursued. Leads to follow on this subject are, for example, sweat evaporative efficiency and sweat delay. In order to provide a better understanding of the processes which take place in heat exposure, control equations with realistic control parameters would obviously be preferable and therefore this point should be addressed in future. However, the introduction of individual characteristics in the computer simulation model of human thermoregulation significantly contributes to the model's predictive power for individual's heat stress response. Nevertheless, still a substantial part of the differences in individual responses remains unexplained (Havenith 2001).

Since the various subgroups of elderly are increasing in number disproportionately to other age groups, adapting the existing thermophysiological human models, for predicting the thermal response of people depending on age and sex, is important (Havenith 2001; Novieto 2013; Rida et al. 2013; Takada, Kobayashi, and Matsushita 2009; Van Marken Lichtenbelt et al. 2004; Zhang et al. 2001). In this way, useful insights can be gained, from modelling the thermal behaviour and response patterns of elderly, for the future design of buildings and climate installations (Novieto 2013).

The elderly and non-elderly experience the indoor climate differently. The elderly have a lower tolerance than the non-elderly for uncomfortable conditions. The proper performance requirements for the well-being of the elderly are evident. Therefore, as a matter of urgency the standards and guidelines are to be adapted (Roelofsen 2014).

Disclosure statement

No potential conflict of interest was reported by the author.

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