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Effect of Gender and Body Fitness on the Thermal Sensation of Sleeping Occupants Under Task-Ambient Air Conditioning System

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ABSTRACT: Providing thermal comfort conditions in a sleeping environment can significantly affect the occupants' health. So, the parameters of the air conditioning system must be properly set to satisfy thermal comfort criteria for persons with different physiological characteristics. In the present study, a task/ambient air conditioning system is modeled and the effect of gender and body mass index on the thermal sensation has been analyzed by an individualized three-node model. Results show that although Gagge standard model predicts pleasant thermal comfort condition, thermal sensation index varies from -0.63 to 0.66 based on the individualized three-node model, and in some cases exceed the thermal comfort region. Moreover, healthy and fat people have a warm sensation in clothed parts of the body and underweight people, especially women, have a cold sensation in bare parts of the body. Also, based on the results of women compared with men, and underweight people compared with overweight people feel colder. By changing body mass index, the thermal sensation index can change up to 0.36, which is very significant in the assessment of thermal comfort.

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1. INTRODUCTION

People spend about one-third of their time sleeping. Therefore, having a quiet and comfortable sleep has a significant effect on increasing the efficiency of individuals during daily activities. Improving the quality of sleep is of particular importance due to its significant effect on the physical and mental health of humans. Research shows that the thermal condition of the environment is one of the factors which contribute to the improvement of sleep quality [1] and the quality of sleep decreases when the thermal condition is out of the thermal comfort range [2]. Due to the immobility of the person, while sleeping, Task-Ambient Conditioning (TAC) systems are suitable for conditioning the sleep environment. These systems allow building residents to individually make thermal adjustments to each area of the building [3]. These systems can provide suitable thermal conditions in addition to controlling local temperature and improving air quality in the inhalation area [4, 5]. Also, they can significantly reduce energy consumption [6]. Ning et al. [7] and Mao et al. [8] concluded that by approaching the inlet and outlet vent to the person's position, energy efficiency can be increased, but this will result in uneven distribution of speed and temperature at the occupied zone. In another study, Mao et al. [9] showed that TAC systems exacerbated the uneven distribution of skin temperature. Zolfaghari et al. [10] studied thermal comfort and dissatisfaction due to draught in a TAC system for the sleeping environment. The results show that the system can prevent dissatisfaction due to draught while maintaining the desired thermal comfort condition. In all researches about thermal comfort in the sleeping environment, the Fanger model has been used. Fanger's model is steady and doesn't simulate a biological thermoregulatory system of the body. Also, this model is a one-node model which simulate the body as a one unit. Zolfaghari and Marefat [11] presented a 3-node model based on Gagge standard model [12] which simulates the bare and clothed skin and body core temperature. Davoodi et al. [13] develop the 3-node model and introduced an individual model which simulates personal factors such as gender, basal metabolic, age and body mass index. In the present study, using the mentioned individual 3-node model, thermal sensation for a sleeping person is simulated in the bare and clothed part of the body according to gender and body mass index.

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2. METHODOLOGY

TAC system is investigated under 3 different settings (A, B and C) with different 3 different supply airflow (60 l/s, 80 l/s, and 100 l/s). All of them provide favorable thermal sensations according to Gagge standard model. To simulate the effect of gender and Body Mass Index (BMI) on thermal comfort, the Individual 3-node model is used. This model has three special features which improve the accuracy of the simulations compared to the Fanger's model [18]:

1. The thermoregulatory mechanism of the body is included at the individual 3-node model.

Table 1. $TSENS_{ov}$ in the warmest location

Gender	BMI	Thermal Sensation		
		setting A	setting B	setting C
men	normal	0.34	0.35	0.36
	<18.5	0.14	0.18	0.21
	>25	0.45	0.47	0.49
women	normal	0.4	0.33	0.33
	<18.5	0.17	0.2	0.22
	>25	0.47	0.49	0.53

Table 2. $TSENS_{ov}$ in the coldest location

Gender	BMI	Thermal Sensation		
		setting A	setting B	setting C
men	normal	-0.15	-0.12	-0.12
	<18.5	-0.27	-0.2	-0.22
	>25	0	0	0.02
women	normal	-0.18	-0.14	-0.14
	<18.5	-0.34	-0.3	-0.33
	>25	-0.05	0.04	0.06

Table 3. $TSENS_{br}$ in the coldest location

Gender	BMI	Thermal Sensation		
		setting A	setting B	setting C
men	normal	0.55	0.58	0.58
	<18.5	0.22	0.3	0.36
	>25	0.58	0.6	0.62
women	normal	0.59	0.59	0.59
	<18.5	0.26	0.31	0.37
	>25	0.61	0.63	0.66

Table 4. $TSENS_{cl}$ in the coldest location

Gender	BMI	Thermal Sensation		
		setting A	setting B	setting C
men	normal	0.55	0.58	0.58
	<18.5	0.22	0.3	0.36
	>25	0.58	0.6	0.62
women	normal	0.59	0.59	0.59
	<18.5	0.26	0.31	0.37
	>25	0.61	0.63	0.66

2. In this model, the body is divided into 3 parts: core body, bare skin and clothed skin.

3. This model simulates personal factors like age, gender, weight, and height.

Above mentioned personal factors are given to the model as input and dependent factors like body fat percentage, body heat capacity and a heat resistance of body tissue are calculated using them. In the present study, based on BMI, individuals in each gender are classified as normal weight ($18.5<BMI<25$), underweight ($BMI<18.5$) and overweight ($BMI>25$). To analyze the most critical situations, the warmest and coldest location near the person is considered.

3. RESULTS AND DISCUSSION

The overall thermal sensation ($TSENS_{ov}$) for the warmest and the coldest locations is presented in Table 1 and Table 2. As can be seen, according to the individual 3-node model, thermal sensation for men and women with different BMIs lies in the comfort range ($0.5<TSENS_{ov}<0.5$). Also, results show that overall thermal sensation for women is more effected by cold conditions compared with men. Underweight people feel colder and overweight people feel warmer compared with normal people.

Table 3 presents the thermal sensation for the bare part of the skin at the coldest location. Although the overall thermal sensation lies in the comfort range, people have a cold sensation at the bare part of the skin. As seen, the situation is more critical for underweight women with $TSENS_{br}$= -0.63 for setting A. Table 4 presents the thermal sensation for the clothed part of the skin at the warmest location. As shown, normal and overweight people have a warm sensation at the clothed part of the skin but underweight people experience the favorable thermal condition.

4. CONCLUSIONS

In this study, a task/ambient air conditioning system is modeled and the effect of gender and body mass index on thermal sensation has been analyzed by an individualized 3-node model. TAC system is investigated under 3 different settings which all of them provide favorable thermal conditions according to the Gagge standard model. Results show that although Gagge standard model predicts pleasant thermal comfort condition, thermal sensation index varies from -0.63 to 0.66 based on the individualized three-node model, and in some cases exceed the thermal comfort region. Moreover, healthy and fat people have a warm sensation in clothed parts of the body and thin people, especially women, have a cold sensation in the bare parts of the body. Also, based on the results of women compared with men, and thin people compared with overweight people feel colder. By changing BMI, the thermal sensation index can change up to 0.36, which is very significant in the assessment of thermal comfort.

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