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ORIGINAL ARTICLE

Assessment of Thermal Comfort within Dormitory of Isfahan University of Medical Sciences Based on ASHRAE Standard

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ABSTRACT
Thermal comfort is a condition, by which individuals are mentally satisfied from the ambient temperature conditions. The feeling of discomfort may emerge all over or in specific parts of the body. The present study was done with the aim of evaluating thermal comfort within dormitory of Isfahan University of Medical Sciences according to ASHRAE standards. The descriptive – analytical study was done on 167 male students of Isfahan University of Medical Sciences. Subjective thermal sensation of students was measured in a 7-point scale, regarding dry temperature, wet temperature, radiant temperature, relative humidity of each student room, and predicted mean vote (PMV). The collected data were analyzed by SPSS-20 software. The mean rates for dry temperature, radiant temperature, humidity, and PMV were 20.326 °C, 23.04 °C, 56.78%, and -1.37 °C, respectively. The rate of 50.3% of the dry temperature and 51.5% of measured radiant temperature were in the range of standard temperature for winter season (20-23 °C), and only 4.2% of PMV index was in the acceptable ASHRAE standards range. The most subjective thermal sensations in the students were in neutral scale with frequency percent of 29.9%. PMV had no significant relation with the subjective thermal sensation in the students. PMV index in this study is not suitable for estimating people's thermal sensation from environment in winter, and dry and radiant temperatures be set in ASHRAE standards temperature range by applying appropriate changes in the ventilation and heating system of the dormitory, for more people to be satisfied from the ambient temperature conditions.

KEYWORDS: *Thermal Comfort; PMV-PPD Indices, Radiant Temperature; Metabolism*

INTRODUCTION

Thermal comfort is a subjective concept that indicates satisfaction from the ambient or environment temperature conditions [1]. Thermal comfort is defined as a subjective term, provided by building residents with all the effective factors in the experienced thermal conditions. Thus, it is complicated to comprehensively define the concept of thermal comfort conditions [2]. Thermal comfort sensation can be defined with a relationship to heat transfer between the human body and the environment

[3]. The thermal sensation is a dependence factor from the human body's heat balance. Moreover, the heat balance is affected by personal and environmental factors including physical activity and clothing, and environmental factors such as weather temperature, mean radiant temperature, air velocity, and air humidity [4].

Moreover, evaluating thermal comfort is one of the necessities of design and engineering heat, ventilation, and air-conditioning (HVAC) systems for creating suitable thermal environments for the residents of buildings or other indoor places. Different thermal stress factors are considered by using environmental parameters for investigating the physiological strain in individuals in warm environments. ET (Effective Temperature), WBGT (Wet Bulb Globe Temperature), P4SR (Predicted Four Hour Sweat Rate), etc. are usually used to thermal stress evaluation [5]. The first thermal index was allocated according to the heat balance of the stable state between the body and the environment as well as the sensation vote to the physiological strain, in comparisons with the indices, which provides more deductible result [6]. Recently, international standards including ISO 7730 and ASHRAE 55-92 are issued.

According to ASHRAE standards, a 7-point scale is used for estimating the subjective thermal sensation based on PMV (Predicted Mean Vote), where it is classified from the range of the hot thermal sensation (+3) to cold thermal sensation (-3) [1, 7]. According to ISO 7730 and ASHRAE 55-92, the thermal comfort temperature range is considered with minimum the thermal satisfaction sensation of 90% of the residents (the predicted percentage of dissatisfied “PPD” of less than 10%) based on the relation (-0.5 <PMV<0.5), and the optimum defined temperature is related to the ambient temperature at PMV=0. The presented thermal comfort PMV model is used extensively in the world. According to international standards, the optimum temperature in winter and summer seasons is 22 °C (with the acceptable range of 20-23 °C) and 24.5 °C (with the acceptable range of 23-26 °C), respectively. Environmental and personal parameters in this regard are: 40-60% relative humidity with the mean rate of 50%, relative air velocity less than 0.15 m/s, average radiant temperature equal to the weather temperature, metabolism rate for mainly light activities with mainly sitting position of 70 W/m2 or 1.2 met, and clothing resistance of 0.9 clo in winter and 0.5 clo in summer [6]. In analyzing thermal comfort in Sri Lanka, Johansson et al. reported that unsuitable thermal conditions in buildings lead to reducing productivity and possibly increasing human errors. Proper adjustments of thermal comfort parameters can provide appropriate environments for the personnel or different individuals [8]. Mohebian and et al indicated that with increase of heat stress in hospital reduced the levels of human productivity and efficiency [9]. Alfano et al. reported that thermal comfort in education environments is quite an important issue, and lack of thermal comfort in such environments leads to reducing the performance and learning by the students, causing hazardous condition for their health [10].

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According to the above, thermal comfort is a condition, in which individuals are mentally satisfied about the temperature conditions. Feeling discomfort (feeling extensive heat or cold) may emerge all over or in some specific parts of the body.

Due to extensive difference in what people sense, providing an environment for everybody to be satisfied is difficult. However, the conditions may be provided so that an acceptable number of people to be satisfied. Thus, the present study was done with the aim to thermal comfort evaluation of the dormitory environment of Isfahan Medical Sciences University based on ASHRAE standards.

MATERIALS AND METHODS

The current descriptive – analytical study was done in the dormitory of Isfahan University of medical sciences in the winter 2017. Systematic random sampling method was used for collecting the required data. Evaluations were done on 167 male students of Isfahan Medical Science after considering the inclusion criteria regarding lack of cardiovascular, pulmonary, neurological, orthopedic diseases, epilepsy, diabetes, heat exhaustion, chilblain, and no medicine consumption for therapeutic means. To observe moral considerations, some explanations were given about the aims of the study to the participants by the professional health specialist, and each student was evaluated in case of having proper consent. The stages of collecting the data were as follows:

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Stage 1: A demographic information questionnaire consisting of age, height, weight, the field of education, and year of education was completed for each of the participants.

Stage 2: According to ASHRAE standards, a 7-point scale was used to estimate the subjective thermal sensation. The students were asked to mark their feelings about the surrounding ambient temperature in one of the 7-point scales, including hot (+3), warm (+2), slightly warm (+1), neural (0), slightly cool (-1), cool (-2), and cold (-3).

Stage 3: Wet temperature, dry temperature, radiant temperature and relative humidity were measured at this stage, by WBGT meter (TES-1369B model) at the residential place of the participating students (students' rooms). WBGT meter were placed in the required environments for 30 minutes to be set to the ambient temperatures. Then, the related temperatures and humidity rates were read and recorded, accordingly.

Stage 4: At this stage, the rate of PMV index value was calculated online software (PMV 2008 ver 1.0, Ingvar Holmer) [11, 12]. In fact, regarding the personal specifications such as rate of metabolism and clothing thermal resistance, and the students surrounding environment specifications such as air velocity and dry and radiant temperatures, PMV index was determined [13]. After completion of each questionnaire and collecting the information, the data were analyzed by SPSS Ver. 20 software.

RESULTS

In the present study, all students had the same metabolism (light activity). The range of clothing resistance of the students was 0.2-0.35 clo with regards to the type of clothing. Places for residence of students were in the windowed rooms with the areas of almost 12-18 m2, and the ratio of the windows to the floor areas were calculated to be 0.093. The fan coil heating unit of the dormitory for winter season had central control system.

Average age range of the participants was 21.53+2.1 years, and their average heights and weights were 177.646+6.64 cm and 73.07+11.39 kg, respectively. The rate 58.7% of students were in their bachelor degree course, 24% were in their general doctoral degree years, and 10.7% were studying master's degree. The mean rates for measured parameters are indicated in Table 1.

Table 1: Mean and standard deviation of measured parameters

Environmental parameters	M± SD
Dry temperature (°C)	**20.326 ± 1.667**
Wet temperature (^{0}C)	**14.968 ± 1.57**
Radiant temperature (^{0}C)	**23.04 ± 1.78**
Relative humidity (%)	**56.78 ± 5.25**
Air velocity (m/s)	**0.099 ± 0.002**
Subjective thermal sensation	**0.39 ± 1.31**
PMV (^{0}C)	**-1.37± 0.59**
PPD (%)	**45.4 ± 22.91**

Regarding the calculated PMV, 95.2% was in the range less than -0.5°C, and only 4.2% was in the acceptable range of ASHRAE standards. According to Fig. 1, the highest rate of students' subjective thermal sensation from their surrounding ambient temperatures was in neutral and slightly warm scales with the frequency percentage of 29.9% and 26.3%, respectively, and 23.4% of the subjective sensation of the students about the ambient temperature was in cold, Cool and slightly cool scales.

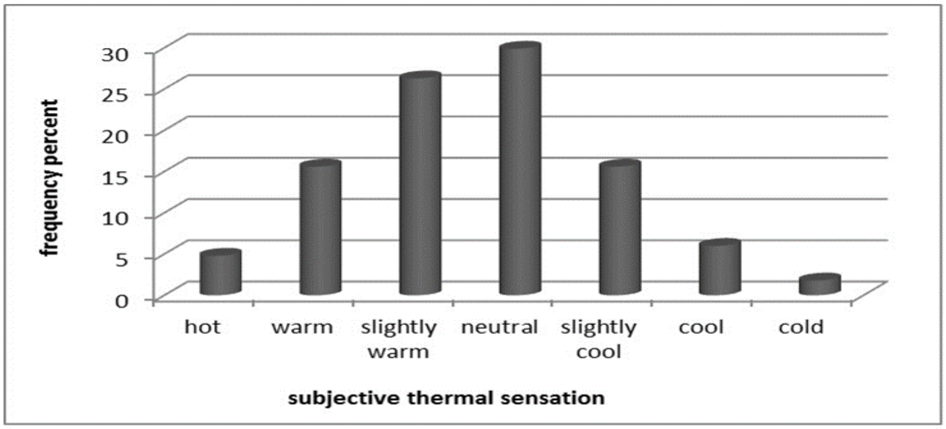

Fig 1. Fig. 1: Frequency percentage of subjective thermal sensation of the students about the ambient temperature

Since the present study was done during winter, 50.3% of the dry temperature or air temperature and 51.5% of the measured radiant temperature were in the range of standard temperature for winter (20-23°C). The rates 49.7% and 48.5% were the dry and radiant temperatures, respectively, of more or less than the range of standard temperature. The rate 77.2% of the measured humidity was in the standard humidity range. Thus, according to the findings, 45.4% of the students' dissatisfaction about ambient conditions is comprehensible with regards to the obtained results. Table 2 shows the comparison of dry and wet temperatures and relative humidity with ASHRAE standards.

Table 3 shows the relation of PMV index with dry, wet and radiant temperatures as the subjective thermal sensation. According to Pearson correlation test, PMV index had direct correlation and significant relations with dry, wet, and radiant temperatures, while it had significant relation and negative correlation with PPD. In other words, PPD reduced by extensive increasing or decreasing of PMV. In this study, PMV had no significant relation with the subjective thermal sensation of the students.

Table 2. Comparison of dry temperature, radiant temperature and relative humidity with ASHRAE standards

P	The optimum parameter based on standard	The optimum parameter range based on standard	Frequency per cent of measured parameters (%)			Range of measured parameter
Dry temperature (^{0}C)	22	20-23	Less and equal of 20	23-20	More than 23	15 – 23.5
			49.1%	50.3%	0.6%	
Radiant temperature (^{0}C)	22	20-23	Less and equal of 20	23-20	More than 23	17.1-26.8 ^{0}C
			44.3%	51.5%	4.2%	
Relative humidity (%)	50%	40% - 60%	Less than 40%	40% - 60%	More than 60%	42.8% - 74.14%
			0	77.2%	22.8%	

Table 3. Relationship between PMV index with dry, wet, and radiant temperatures and the subjective thermal sensation

Variable	The correlation coefficient (R)	P_{Value}
PPD	- 0.978	**< 0.001**
Dry temperature	0.951	**< 0.001**
Wet temperature	0.856	**< 0.001**
Radiant temperature	0.948	**< 0.001**
Subjective thermal sensation	0.085	**0.277**

DISCUSSION

Average dry, wet, and radiant temperatures of the students' dormitory rooms were 20.326, 14.968, and 23.04 °C. The mean rate of PMV was -1.37 °C and the mean rate for subjective thermal sensation was 0.39, and 45.5% of the students on average were dissatisfied from the ambient conditions. The highest rate of students' subjective thermal sensation was in neutral scale, and 46.7% of their subjective thermal sensation in winter was obtained in positive scales (warm, slightly warm, and hot). The rates 49%/7 and 48.5% of dry and radiant temperatures and 22.8% of the humidity were not in ASHRAE standards range, and only 4.2% of PMV index was in the acceptable ASHRAE standards range. PMV index had direct correlation and significant relations with dry, wet, and radiant temperatures, while it had significant relation and negative correlation with PPD. In other words, PPD reduced by extensive increasing or decreasing of

PMV. PMV had no significant relation with the subjective thermal sensation of the students, according to this study.

Since most of the students' subjective thermal sensation was obtained in neutral scale, it was in conformity with the results obtained in Khan et al. studies. They reported that in the regions with tropical conditions, high humidity level causes the tendency of people towards the positive scale of thermal sensation in summer season, while people tend mainly towards neutral and stable conditions in winter. They stated in tropical weather, the difference of PMV from real sensation is estimated 8% less than the real sensation in summer and 33% more than the real sensation in winter. The reason for the difference is that according to Fanger, prediction of the ambient temperature condition by PMV is applicable for hot weather. Hence, using PMV model in winter time increases PMV difference with the real sensation. Thus, more studies are necessary to be done in this respect [14].

Indraganti estimated the thermal comfort range for the Indians to be 26-32.45 °C with 29.23 °C of neutral temperature. In that study, it was stated that although according to ASHRAE standards, the range of standard indoor temperature is 23-26 °C during summer and 20-23 °C during winter for all the weather conditions, but considering thermal sensation for Indians in different temperature conditions, a better prediction can be done for their thermal responses [15]. In analyzing PMV thermal model for the Indians thermal responses, Maiti stated that in considering human thermal response, the other effective parameters on his/her thermal sensation, such as skin temperature or the inner body temperature should also be analyzed [6].

In investigating the indoor environment variables on the thermal comfort of people, Kim et al. reported that PMV has significant relation and positive correlation with dry temperature, mean radiant temperature, and humidity, and this conclusion was in conformity with the results of this study. They showed that PMV has negative correlation with airspeed, and air speed is one of very effective environmental parameters in PMV index. They stated that there are significant relation and positive correlation between PMV and thermal sensation in individuals, and PMV thermal comfort index is suitable for reflecting people's subjective thermal comfort [16]. Wei et al. obtained an appropriate correlation between PMV and the mean radiant temperature in cool season. The results of their studies are in conformity with the results obtained in this study. They showed that PPD has proper correlation with PMV, and their correlation coefficients are close to "1". They stated that by changing in PMV and effective parameters on it, PPD can have changes up to 99% and the suitable thermal comfort conditions can be achieved [17].

Studies by Oliviera et al. show that the proposed PMV model by Fanger is not suitable for predicting thermal comfort of Brazilian users. This is in conformity with the results of the present studies. According to the fulfilled studies, ambient temperature, speed and direction of wind, relative humidity, and the mean radiant temperature are quite important parameters, each affecting the buildings thermal performance [18]. Thermal comfort depends on physical, physiological, and mental factors. Jang et al. stated that when the temperature in the navy cabins to 23 °C, 4 people out of 20 crew members in the cabins were not satisfied from the thermal conditions. They stated that the difference of the people's feelings is due to the difference in the clothing specifications and activities of the people. Thus, navy cabins have different optimum temperatures determined according to people's clothing and activities, in every country [19]. However, it was stated in another study that one reason causing PMV deviation from real sensation is mistaken interpretation about the expected metabolism rates in PMV equation [14]. Thermal sensation points to and indicates people's feelings about the environmental heat levels, such as warm, hot, neutral, cool conditions. Feeling of comfort is not a direct sense regarding the weather temperature, and the feeling of thermal comfort is one of the essential points in design and engineering of heating and ventilation systems and an important point in air conditions, to provide satisfaction of residents in buildings or other places, with regards to the ambient temperatures. Research reports that thermal stability status of PMV equation effectively provides problems in estimating thermal comfort, since PMV and PPD do not consider the effects of other compatibilities such as physiological or mental compatibilities and adjusting body temperature in individuals. Thermal compatibility is specific for each region, and the body temperature of every person is affected by the local weather conditions. Skin and inner body temperatures indicate body temperature adjustment system, equally determining thermal comfort. In fact, the average skin and inner body temperatures compromise with the ambient temperature. However, these two temperatures are not considered in PMV calculations [6], which causes discrepancies between PMV index and the thermal sensation in individuals.

Dry, wet, and radiant temperatures, air velocity, and personal parameters such as clothing resistance and metabolism rate are among the effective parameters in calculating PMV [20]. Perhaps the reason for lack of relations between PMV and students' subjective thermal sensation in the present study is considering similarity of metabolism (light activity) for all the students and equal air velocity in all the dormitory rooms. Moreover, the range of clothing resistance of the students was considered to be 0.2-0.35 clo with regards to the type of clothing. These together with other parameters (dry temperature, radiant temperature, wet temperature, and relative humidity) are replaced in PMV equation, for its value to be calculated, causing 95.2% of the calculated PMV to be in the range less than -0.5 °C. On the other hand, places for residence of students were in the windowed rooms with the areas of almost 12-18 m2, and the ratio of the windows to the floor areas were calculated to be 0.093. The fan coil heating unit of the dormitory for winter season had central control system. In other words, if a person had hot feelings, he could not adjust his own room temperature conditions according to his desires. Thus, it caused the student to have positive scale thermal sensation. Probably, the mentioned points caused no significant relation between PMV index and thermal comfort feelings.

According to the reported records, 80% of human age is spent indoors in closed environments, and this rate in industrial countries is over 90%. Hence, lack of thermal comfort in indoor environments has damaging effects on human productivity and health. When administration staffs are satisfied from the environment thermal conditions, their productivity can increase up to 15%. According to the fulfilled studies, by increasing the rate of knowledge about improving indoor temperatures and rate of energy consumption, searching for controlling methods of thermal stress, evaluation of indoor ambient temperature, and reducing energy consumption shall be important issues to be considered [17]. Hence, in addition to reducing thermal energy consumption and related costs, and by creating thermally appropriate and controllable conditions this causes the people efficiency and productivity as well as their health to be provided in that regard.

CONCLUSION

The highest rate of students' subjective thermal sensation was in neural scale, while only a very small rate of calculated PMV was within acceptable ranges of ASHRAE standards. Moreover, 49.7% and 48.5% of dry and radiant temperatures were in the range of ASHRAE standards, and almost half of the students were dissatisfied from the ambient temperature conditions. There was no significant relationship between the PMV index and subjective thermal comfort in winter. Finally, it can be concluded that PMV index in this study was not suitable to estimate people's thermal sensation in winter season condition, and by applying appropriate changes in the ventilation and heating systems of the dormitory, the dry and radiant temperatures should be placed within the temperature range considered by ASHRAE standards, for more people to be satisfied from the ambient temperature conditions. These changes may improve productivity and individuals' satisfaction whereas reduce energy consumption.

In addition to physical parameters, thermal comfort also depends on physiological conditions. It was proposed that in addition to effective parameters in PMV equation, physiological parameters such as skin and inner body temperatures to be investigated, and if possible, all the mentioned parameters to be measured directly. Finally, it is recommended that same study would be implemented for other seasons as summer.

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Conflict of Interests

The authors declare that there is no conflict of interest in this study.

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