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Original

Thermal Comfort Study Based on PMV-PPD in the Building of a Screening Center for COVID-19

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ABSTRACT

Background: One way to achieve a standard heating, ventilating, and air conditioning system with maximum satisfaction is to use a thermal index to identify and determine the thermal comfort of people. In this study we intend to evaluate thermal comfort based on PMV-PPD (Predicted Mean Vote/Predicted Percentage Dissatisfied) model in workers of screening center for COVID-19. **Methods:** The study period was from March 1 to October 31, 2020. In this study, we used the ISO 7730 model to determinate PMV-PPD index. PMV index was used to determine thermal comfort at different scales in Birjand city with arid and hot climate. All data were analyzed using R software (version 3.3.0) and IBM SPSS statistics softwares. **Results:** The maximum and minimum recorded physical PMV values in the study period were observed in June as (2.09 ± 0.03) and March as (-1.27 ± 0.14), respectively. The amplitude of the thermal sense in the study period was varied between slightly cool (-1.5) and warm (+2.5). The PPD in spring was 40% which indicated slightly warm to hot condition. **Conclusions:** The October was the only month during the study in which thermal stress was in comfort or neutral thermal condition. Our results suggest that thermal comfort has dimensions and indices which are helpful in managing energy consumption.

Keywords: Thermal comfort; Predicted mean vote; Predicted percentage dissatisfied; Screening center; COVID-19

Introduction

Most environmental problems are related to energy consumption. Building is one of the most important examples of energy consumption worldwide. 40% of the world's energy consumption is consumed in buildings. [1] About 40% and 50% of global energy consumption is consumed by heating, ventilating, and air conditioning (HVAC) systems. [2] Energy consumption in residential and office environments has significantly increased in Iran. Intermittent power and gas outages in the southern regions during the summer have been one of the most important consequences of increasing energy consumption in the HVAC system to achieve thermal comfort. There are two main reasons for unconventional energy consumption in buildings and HVAC systems. The first reason is irrational temperature regulation and the second is irrational load distribution in HVAC systems. [3]

The workplace is made up of different people with different temperaments. The variability and the movement affect the thermal comfort of people.

Satisfaction with workplace climate has a direct effect on the increase of the employee's productivity. On the

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other hand, the mismatch between the workplace and weather factors increases stress, premature fatigue and decreases employees' productivity. [4] Working in the healthcare environment has become more difficult since the emergence of the COVID-19 virus. The use of clothing, layered masks and other protective measures has affected the thermal comfort of people working in these workplaces.

Various indices have been explained to determine thermal comfort. [5-9] Two important and applicable indices to determine the thermal comfort indoors are the PMV (Predicted Mean Vote) index and PPD (Predicted Percentage Dissatisfied) index. These indices are approved by ISO 7730. [10] The PMV index consists of six parameters. These six environmental parameters are the most important pillars of the HVAC system in the workplace. Clothing insulation, metabolic rate, air temperature, mean radiant temperature, air velocity and humidity are the six parameters used in the PMV index. The PMV indicates the extent of heat sensation. The PPD index is used to predict the percentage of people who are dissatisfied with feeling cold or hot in the given environments. [11] This index is thermal discomfort or thermal dissatisfaction.

Managing energy consumption in the HVAC system of an office or residential environment requires a plan and knowledge of the thermal comfort of the people in that environment. One way to achieve a standard HVAC system with maximum satisfaction is to use a thermal index to identify and determine the thermal comfort of people. In this study we intend to evaluate thermal comfort based on PMV-PPD model in workers of screening center for COVID-19.

Method

Study setting

The case study report period was from March to October 2020. Birjand is located in Eastern Iran with a resident population of 187,020 according to the recent census. This city is located in a region with arid and hot climate (coordinates: 32°86′ N 59°22′ E, elevation: 1,491 m). The Köppen climate classified Birjand as an arid area (BWk). [12] In this classification, Birjand has arid climate with cool winters, hot summers and, there is a significant difference between night and day temperatures. Figure 1 shows the location of Birjand (study area) in Iran.

Description of the building

The building used in this study (coordinates: 32°86′ N 59°22′ E, elevation: 1,491 m) is newly opened. It has two floors and the walls are made of brick, which are plastered inside. The floor of the building is white ceramic. The winter heating system is hot water radiators for all sections supplied by an engine room. In summer, the air conditioning is provided by two water coolers located on the roof of building. The cooling system is active 6 hours a day. This system is active from 8 am to 2 pm, local time. The windows in this building are double glazed (two panes of glass) and the entrance door is made with minimal energy loss, but due to the conditions related to the spread and transmission of coronavirus, the doors and windows are open in summer and half-open in winter. The twelve rooms of this building are located on two floors. There are 25 people (6 males and 19 females) involved in the screening center. The purpose of opening the doors and windows is to establish air flow inside and outside the building. In this building, the first stage of coronavirus screening, follow-up care after having patients with COVID-19, and educational and health actions were performed.

Figure 1. Location of Birjand city (study area) in Iran.

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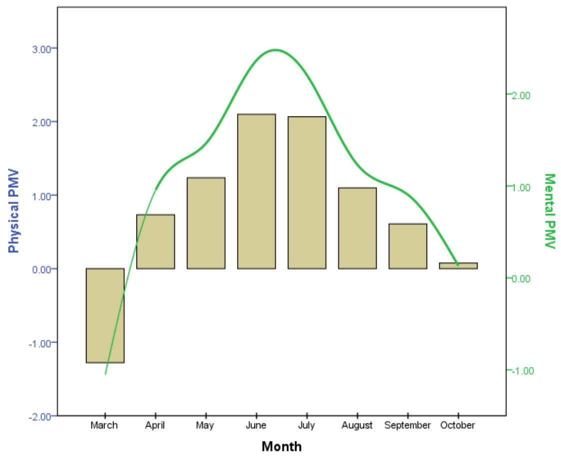

Figure 2. The relationship between physical PMV value and mental PMV value in different months during the study (2020).

Thermal comfort model

The thermal comfort of people at work affects the efficiency of the system. There are different variables involved in the thermal comfort of people which can be generally divided into three categories: environmental, personal and contributing factors. Environmental factors used in thermal comfort include air temperature, humidity, air flow rate and radiation. Personal factors used also include clothing insulation and metabolism. Other contributing factors affect the thermal comfort in the environment, include gender, age, food, drink, body shape, subcutaneous fat and health status. In this study, ISO 7730 model was used to determine PMV-PPD index. [5] The PMV index was used to determine thermal comfort at different scales (Table 1). This index was calculated based on the following formula (PMV):

$$PMV = (0.303 \times e^{-0.036M} + 0.028)\,S$$

Where

$$S = \{(M - W) - 3.05[5.733 - 0.000699(M - W) - Pa] - 0.42[(M - W)] - 0.0173M(5.867 - Pa) - 0.0014M(34 - Ta) - 3.96 \times 10^{-8} fcl\,[(Tcl + 273)^4 - (Tmrt + 273)^4] - fcl \times hc(Tcl - Ta)\}$$

And

$$hc = \begin{cases} 2.38(Tcl + Ta)^{0.25} & 2.38(Tcl + Ta)^{0.25} \geq 12.1\sqrt{Vair} \\ 12.1\sqrt{Vair} & 2.38(Tcl + Ta)^{0.25} \geq 12.1\sqrt{Vair} \end{cases}$$

And

$$Tcl = 35.7 - 0.028(M - W) - 0.155Icl\,\{3.96 \times 10^{-3} fcl[(Tcl + 273)^4 - (Tmrt + 273)^4] - fcl \times hc(Tcl - Ta)\}$$

In this model M is metabolic rate (w/m^2), S is the amount of storage or the equivalent of the body energy budget defined as the difference between the heat production and the heat loss to the environment, W is the effective mechanical power or the external work, which is equal to zero for most activities (w/m^2), Pa is the partial water vapor pressure (pa), Ta is temperature (° C), Tmrt is mean radiant temperature (° C), Tcl is the surface temperature of the clothing (° C), hc is the convective heat transfer coefficient (W/m^2 k), fcl is the ratio of the surface area of the body with clothes to the surface area of the body without clothes, Icl is the thermal resistance of clothes (clo).

If the PMV index is known, the PPD index can be estimated from the following formula:

$$PPD = 100 - 95\exp(-0.03353 \times PMV^4 - 0.2179 \times PMV^2)$$

The estimation of parameters and measurement

The parameters measured in this study are divided into two parts (Table 2). Measuring metabolic rate and clothing insulation is difficult. In general, the values of these parameters are estimated. The metabolic rate was determined according to the gender and job type. It's different from 85 w/m^2 (resting room) to 135 w/m^2 (passageways). [6] The clothes used in men and women, and the type of clothing in two seasons (summer and winter) were examined separately. Environmental measurements are taken daily and entered into Excel form. The thermal conditions of the employees were also assessed using a questionnaire [8] and the results were entered into the data form. All data were stored from March to October 2020. After collecting the environmental parameters and the human factors data, we used the R software (version 3.3.0) and IBM SPSS statistics

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software (version 22) to calculate the PMV and PPD index and draw curves.

Results

In this study, the screening center staff were observed from March to October, 2020. All the data in the study period were provided on a daily basis. There are 25 people involved in the screening center. The highest and lowest recorded mental PMV values in the study period was 2.36±0.04 in June, and -1.05±0.12 in March, respectively. The maximum and the minimum values of –subjective PMV index were observed in summer as 1.66 ± 0.07and winter as -1.22 ± 0.17, respectively. The maximum and minimum physical PMV values recorded in the study periodwere 2.09 ± 0.03 in June and -1.27 ± 0.14 in March, respectively. The highest and lowest physical PMV values recorded in the study period were 1.48 ± 0.06 in summer and -1.48 ± 0.19 in winter, respectively (Table 3).

The amplitude of the thermal sense in the study period varied from slightly cool (-1.5) to warm (+2.5). The slightly cool sensation (-1.27) observed in March and in winter, (-1.48). The warm sensation observed in June (+2.09) and July (+2.06). The stress category in this study period varied based on thermal sensation from slight cold stress to moderate heat stress. This scale of stress corresponds to thermal sensation and physical PMV value. The relationship between physical PMV value and subjective PMV value in different months and seasons of the study period has been shown in Figure 2 and Figure 3, respectively.

The maximum and minimum PPD index in the study period were obtained in June as 80.32 ± 1.18, and October as 8.31 ± 0.96, respectively. In the case of comparison of the PPD index between the four seasons, the results showed that the maximum and minimum PPD values were correspond to winter (57.92 ± 6.50) and autumn (7.70 ± 0.77)., respectively. PPD value in different seasons and months of the study period has been shown in Figure 4 and Figure 5, respectively.

Table 1. Thermal sensation value of PMV and stress category in each scale.

PMV Value	Thermal Sense	Stress category
	Very cold	Extreme cold stress
- 3.5		
	Cold	Strong cold stress
- 2.5		
	Cool	Moderate cold stress
- 1.5		
	Slightly cool	Slight cold stress
- 0.5		
	Comfortable	No thermal stress
+ 0.5		
	Slightly warm	Slight heat stress
+ 1.5		
	Warm	Moderate heat stress
+ 2.5		
	Hot	Strong heat stress
+ 3.5		
	Very hot	Extreme heat stress

Table 2. The parameters used in the study, definition, unit of measurement and measuring equipment.

Parameters	Definition	Unit of measurement	Measuring equipment
Ta	Air Temperature	Degrees Celsius (° C)	WBGT Meter
RH	Relative Humidity	%	WBGT Meter
Va	Air Velocity	m/s	WBGT Meter
Tr	Mean Radiant Temperature	Degrees Celsius (° C)	WBGT Meter
M	Metabolism	Met (w/m^2)	ISO 8996 (2004)
Icl	Thermal resistance of clothing	Clo (m^2. ° C/w)	ISO 9220 (2009)
Pa	Partial water vapor pressure	Pascal (pa)	Formula

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Table 3. Descriptive statistics on the daily average of PPD, subjective PMV and physical PMV.

Variable	PMV Subjective M*± *SD*	Physical M± *SD*	PPD (%) M± *SD*
Month			
March	-1.05 ± 0.12	-1.27 ± 0.14	46.61 ± 5.10
April	0.95 ± 0.08	0.73 ± 0.07	19.59 ± 2.20
May	1.46 ± 0.11	1.23 ± 0.11	41.80 ± 5.17
June	2.36 ± 0.04	2.09 ± 0.03	80.32 ± 1.18
July	2.20 ± 0.04	2.06 ± 0.03	78.97 ± 1.49
August	1.22 ± 0.10	1.09 ± 0.08	33.64 ± 3.84
September	0.90 ± 0.09	0.60 ± 0.08	17.07 ± 2.26
October	0.13 ± 0.05	0.07 ± 0.07	8.31 ± 0.96
Season			
Spring	1.18 ± 0.10	0.95 ± 0.10	40.57 ± 2.95
Summer	1.66 ± 0.07	1.48 ± 0.06	51.79 ± 3.11
Autumn	0.19 ± 0.04	0.07 ± 0.05	7.70 ± 0.77
Winter	-1.22 ± 0.17	-1.48 ± 0.19	57.92 ± 6.50

* Daily average

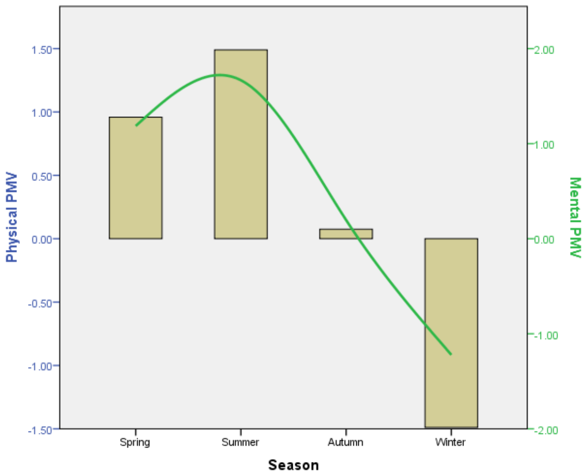

Figure 3. The relationship between physical PMV value and subjective PMV value in different seasons during the study .

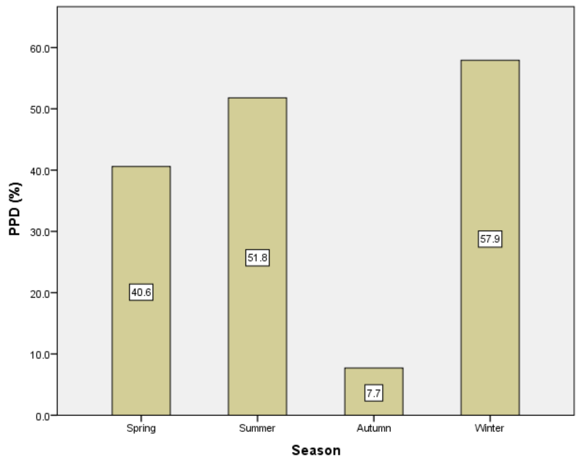

Figure 4. The PPD index (percentage) in different seasons during the study.

The thermal comfort condition during the study was in October was 0.07 ± 0.07. In this month, the PMV value was in the acceptable range (-0.5, +0.5) and the thermal sensation was comfortable. The only month in which no thermal stress was observed, was October. The thermal sensation in spring was slightly warm to slight heat stress (PPD = 40%).

Discussion

This study provides detailed evidence from Birjand on the evaluation of thermal comfort based on PMV-PPD model in workers of screening center for COVID-19. We studied thermal sensation and comfort indices from March 1 to October 31, 2020 in workers of screening center for COVID-19. The result showed that PMV scale in summer (1.48), is higher than other seasons and PMV scale in October (0.07), is in an acceptable range (comfortable stress).

In this study period, we studied the PMV-PPD model in workers of screening center for COVID-19 in Birjand. This city is located in an arid climate with cool winters and hot summers ,and there is a significant difference between night and day temperatures. The result in this study showed PPD in winter is higher than other seasons.

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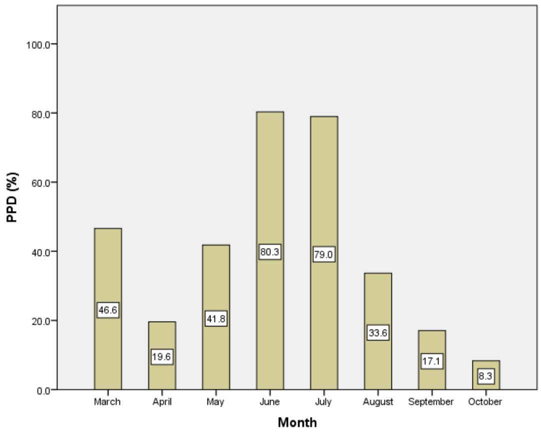

Figure 5. The PPD index (percentage) in different months during the study.

The difference in PPD index between winter (57%) and summer (51%) was unsignificant, but in other seasons (spring (40%) and autumn (7%)), this difference was significant. On the other hand, the heating system in winter and cooling system in summer were not effective. The thermal conditions in winter tend to coldness and thermal conditions in summer tend to heat stress situation. This result means ineffectiveness of cooling system, heating system and the waste of energy.

The slight difference in subjective and physical PMV values may be explained by the protective clothing of the staff. The use of clothing, layered masks and other protective measures has affected the thermal comfort of people working in these workplaces. Ventilation and comfort are reduced by surgical masks and highly impaired by FFP2/N95 face masks in healthy individuals. [13] The thermal comfort in this study is influenced not only by environmental parameters, but also by the features of clothing. The important role of clothing has been expressed in other studies, too. [14, 15] The windows in this building are double glazed (two panes of glass) and the entrance door is made with minimal energy loss, but due to the conditions related to the spread and transmission of coronavirus, the doors and windows are open in summer and half-open in winter. As a result, clothing insulation is reduced significantly in the presence of the wind. [16, 17]

Air circulation in corona virus period causes energy loss. The body's need for thermal comfort requires the use of more energy to keep warm in winter. This could justify our findings in this study indicated by PPD in winter which is higher than other seasons. People who live in hot areas feel more comfortable in hot environments and feel uncomfortable in cold and dry environments. [18-20]

The PPD index in winter and summer were higher than other seasons. Previous studies have shown this, well. [6, 21] In October, the PMV value was in an acceptable range (-0.5, +0.5) and thermal sensation was comfortable. Environmental parameters in this month can be used as a model for other months of the year, so that employees are at a desirable level of thermal comfort.

Despite this study's originality, regarding the study group in this paper, several limitations should be noted. First, comparison of the inside of the building with the outside based on thermal conditions in the studied models was not possible. Second, in this study period, the effects on individual's characteristics and sensitive subgroups were not taken into consideration; these include age, gender, cultural conditions, and socioeconomic variables. The previous studies showed that the level of thermal sense is different in females and males, and thermal comfort indices must be examined in them separately. [22] Third, experts' opinions about the effect of temperature on the corona virus have affected people's minds in such a way that basically, the removal of corona in high heat affected people's behavior. Fourth, lack of control over the use of energy resources in this country has led to increase in energy waste. Power outages in summer and gas outages in winter are examples of these problems.

Conclusion

We studied thermal sensation and heat stress indices from March 1 to October 31, 2020 in

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workers of screening center for COVID-19. The results showed that PMV scale in summer is higher than other seasons, and in October is acceptable. Environmental parameters in this month can be used as a model in other months of the year, so that employees are at a desirable level of thermal comfort. Thermal comfort has dimensions and indices which are helpful in managing energy consumption. The effective cooling system and heating system plays an important role on thermal comfort. The result showed a steady trend between subjective PMV index and physical PMV index in this study.

Conflict of Interest

The authors declare that there is no conflict of interest.

Acknowledgements

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Authors contribution

All authors contributed to the final version of the manuscript, equally

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