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The Persuasibility of Globe Thermometer in Predicting Indoor Thermal Comfort Using Non-standard Globe Diameter: Row Houses of Semi-Arid Climates as Case Studies

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Abstract The assessment of accuracy of thermal comfort is critical for designing thermally comfortable and energy-efficient buildings. The Predicted Mean Vote (PMV) index is widely recognized by national and international specifications to predict thermal comfort. The main purpose of this work is to evaluate PMV inside row houses in semi-arid climates using lower-cost equipment rather than high-cost and difficult-to-access instruments while maintaining acceptable accuracy. This is accomplished by using a smaller black globe thermometer than standard ones. The effects of airspeed as a critical factor on PMV were considered. Therefore, case study methodology has been applied in this study, and two sets of six-row residences with a similar typology oriented to the south and north were chosen and explored in summer. CBE Thermal Comfort Tool as a computer program has been applied to obtain the easiest accessible measurement for investigating thermal comfort inside buildings. The outcome demonstrated that the difference in the size between the black globe thermometer and standard ones becomes considerable when the air velocity inside the building increases above 0.12 m/s. Therefore, the limitations were introduced in the current study for applying the small globe thermometer in the prediction of thermal comfort inside buildings in the study area and some recommendations have been suggested for future studies. The outcomes shared significant facts to increase our understanding regarding the use of low-cost methods in evaluating thermal comfort.

Keywords PMV-PPD, Black Globe Thermometer, Globe Temperature, Mean Radiant Temperature, Thermal Comfort

1. Introduction

Thermal comfort is responsible for 50% of energy consumption inside the buildings in the post-occupancy stage [1]. Therefore, the measurement of thermal comfort inside the building is one of the important factors in the environmental design process and assures comfort for the end users [2]. Due to climatic changes and environmental crises, it becomes crucial to control environmental problems through successful environmental building design to reduce energy consumption [3,4]. The estimation of thermal comfort conditions in the buildings is a quite difficult task because it has several petameters which must be evaluated and considered to reach the final result. Many methods with different accuracy levels have been developed [5].

The most widely used and prevailed method is PMV-PDD [6]. Therefore, the current study will focus on this method in approaching thermal comfort evaluation. The method deals with environmental and psychological factors, each of which has several parameters to be measured [7]. Since the environmental parameters are directly measurable through measurement tools, the differences in the types of these measurement tools may result in insignificant different outcomes based on the accuracy of the measurement tools. One of the measurable factors is the globe temperature (*Tg*), which is used to evaluate the thermal environment by using the black globe thermometer (BGT).

BGT is commonly used to obtain mean radiant temperature (MRT) based on passive radiometry [8]. BGT is changing in size (diameter) according to the accuracy and sophistic of the applied tools to evaluate thermal comfort.

The study tries to answer questions such as: 1) To what extent, the size of a BGT may have an impact on the precision of the thermal comfort test results. Estimation? 2) Does the difference in the size of BGT from the standard one has significant results on the PMV-PPD index inside raw houses in semi-arid climates of 'Garmian'- Northern Iraq? 3) What is the inner air velocity role on PMV-PPD results when the black globe thermometer's size is non-standard?

According to Khrit et al.[9], the size of BGT (50 or 150 mm) is not intrinsic in the estimation of MRT. This will result in insignificant changes in the evaluation of thermal comfort. Vargas-Salgado et al. [10] have supported the previous study through their research. The outcomes of the research demonstrate that a smaller BGT with an acceptable accuracy is able to be utilized to estimate a building's thermal comfort than a BGT with a standard diameter. On another side, a study by d'Ambrosio Alfano et al. [11] has mentioned that experimental findings revealed a consistent underestimating of the mean radiant temperature anticipated for tiny BGT by more than 10 ℃ in forced convection and at high radiation loads. In another study, d'Ambrosio Alfano et al. [12] have discovered that a small BGT (36mm dia.) underestimates the mean radiative temperature by up to 6 ℃ when there is natural convection, and when the airspeed was zero. Moreover, it has been noted that at high air velocities, the globe temperature difference between a small and a standard one increases considerably [13]. The impact of air temperature and velocity is larger when the smaller BGT diameter is used. Consequently, this will reduce the accuracy of the measurement of MRT, which will underestimate thermal comfort in the buildings. Moreover, when radiant heat is excessive, BGT with a 50-mm or smaller is not recommended [14].

Generally, applying smaller BGT is prevalent and cheaper, therefore, there's a desire to understand the accuracy of these globes' achievement compared with the standard ones based on the observation and analysis results. Therefore, the study hypothesizes that if the smaller size of globe thermometers were used in the process of thermal comfort evaluation, then the accepted accuracy could be obtained. Hence, this study was conducted on the basis of measurements using the 40-mm non-standard globe, and 150-mm standard globe inside row houses climatically characterized as semi-arid in 'Garmian' in the Kurdistan of Iraq, considering the inner airspeed as a critical factor. This is through evaluating the results of PMV by a smaller black globe thermometer and comparing it with the results of the standard ones, considering the change in airspeed as a critical factor. Hence, an anemometer with the aid of the CBE Thermal Comfort Tool has been employed to reach the easiest accessible measurement for the investigation of thermal comfort inside buildings in hot and arid climates.

The paper aims to estimate thermal comfort through the PMV-PPD index inside the buildings with lower cost instruments than the high cost and difficult access ones, keeping the acceptable accuracy of the results. The PMV index enables the exploration of thermal interaction between a human and their surroundings. Therefore, the main objective of this paper is to analyze the deviation in the results of PMV, based on the different sizes of BGT (40mm and 150mm Dia.). Also, relating these two globes' temperature readings with the changes in the airspeed inside the building makes a change in the readings of globe temperature and consequently may affect thermal comfort evaluation.

2. Materials and Methods

2.1. Thermal Comfort Based on PMV-PPD Index

It is difficult to describe thermal comfort since many environmental and individual factors must be taken into account. Thus, according to Fanger [15], a person's feeling of thermal comfort depends on the physiological strain that the environment places on her/him. Thermal comfort according to ASHRAE Standard 55, is a mental condition that displays satisfaction with the thermal ambient and can be evaluated by subjective assessment." [16].

PMV-PPD index is a method to estimate human thermal comfort inside buildings. It was suggested for the first time by Fanger in 1970, based on a thermal balance model [17]. The approach is predicated on the idea that interactions between the human body and the environment only happen through thermal physics and cooperative exchanges [18]. Fanger created a set of correlations and incorporated them into the model, creating six variables for the PMV physical factors.

Air temperature (*Ta*), Mean Radiant Temperature (MRT), airspeed (*Va*), and air relative humidity (RH) are the four environmental characteristics; the other two are personal parameters, including metabolic rate (MET) and clothing insulation (Clo) [6]. This approach is used by the most appropriate international standards, such as ASHRAE or ISO 7730, and is advised for assessing the thermal comfort levels in air-conditioned or naturally ventilated buildings [6,19]. PMV method calculates the average value of many people's votes on a thermal scale of sensation. This scale has seven levels: (3) is hot, (2) is warm,' (1) is slightly warm, and (0) is neutral. Also (-1) is slightly cool, (-2) is cool, and (-3) is cold. The value of PMV should be kept at ('neutral' 0) with a tolerance of +/- 0.5 on the ASHRAE seven-point scale [6,17]. Fanger's analysis has shown that about 5 percent of the tested people can be dissatisfied even with the thermal comfort status. Therefore, he added (Personal Perception Discomfort) PPD, a quantitative measure of thermal comfort as a percentage of a large group of subjects likely to feel too warm or too cold was introduced. In the PPD index, people who have (+/- 2 and 3) in the PVM estimation are considered thermally unsatisfied.

2.2. Mean Radiant Temperature (MRT)

MRT is described as the "uniform temperature of the imaginary enclosure where the radiant heat flows from the body of a person, and equals the amount found in the actual non-uniform enclosure" [6]. In order to measure the impacts of complex radiant environments and account for all radiation fluxes directed at a human body, the MRT concept was developed. One of the most crucial factors affecting how the human body balances its energy is MRT. It can be employed to assess how thermally comfortable a building is [20]. The implementation of the rational indices produced by thermo-physiological modeling necessitates sufficient MRT accuracy [17,21].

Equation '1' can be employed to calculate the value of MRT through the temperature of the air (Ta), (Tg), and speed of the air (Va). (Moss, 2015; 1]:

$$\mathrm{MRT} = [Tg \times (1 + 2.35) \times Va^{0.5} \ - (2.35 \times Ta \times Va^{0.5}\ )] \quad (1)$$

In the current study, MRT has been calculated by the CBE tool.

2.3. MRT Calculation by Using Globe Thermometer

The total radiation from the various heating and cooling sources at any particular point is measured by a globe thermometer GT, which is detailed. A globe thermometer is a handy, portable device that shows the combined effects of convection and radiation [22].

Commonly, BGT is a matt black copper sphere with a thermometer in the middle, and the size of the sphere is typically 150 mm in diameter. Once equilibrium is attained, a thermometer should be placed in space; the globe (sphere) will respond to the net radiation from or to the surrounding surfaces (in 10-15 minutes), [23]. See Figure 1.

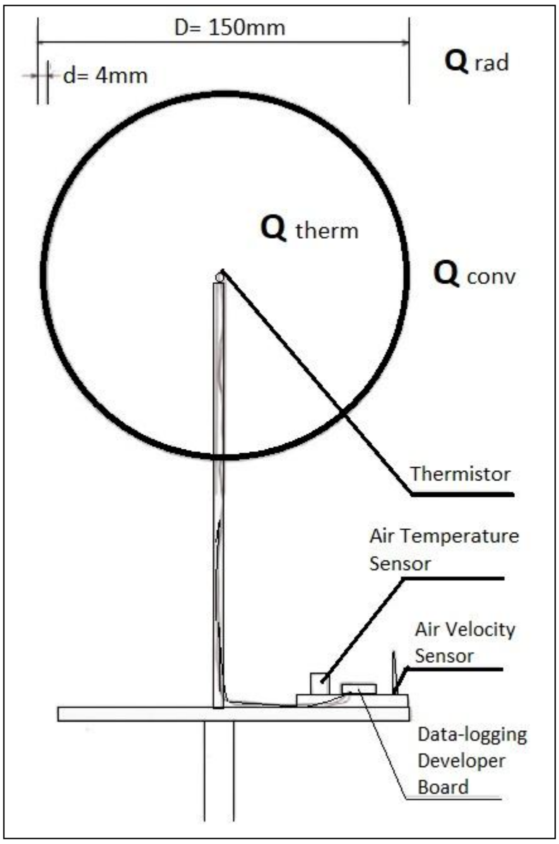

Figure 1. Globe thermometer schematic. [14]

Globe temperature (Tg) is the uniform temperature of an imaginary black enclosure with emissivity equal to 1, where a human body positioned with a given azimuth and posture would receive the same amount of radiant heat as it would in a nonuniform enclosure. [20]. Through globe temperature Tg, the compound impact of air velocity, air temperature, and long-wave radiation on heat stress of individuals can be accurately predicted. Tg is affected by changes in air temperature, air velocity, and radiant temperature.

Therefore, GT method is a significant way to calculate MRT, which is one of the main factors to estimate human thermal comfort by the PMV - PPD index. Thus, the correct observation of Tg is something that must be duly observed by professionals.

The globe thermometer method involves observations of Tg as well as air temperature and wind velocity. Kuehn et al., [24] thoroughly defined its theory. The process of establishing equilibrium in a globe thermometer is challenging because three things must be in harmony: the thermometer, the air inside the globe, and the globe's substance. When the heat lost or acquired by convection is equal to the heat obtained through radiation, a globe thermometer will be in equilibrium [25].

The empirically derived link between convective heat exchange and air velocity was used by Bedford and Warner. This is demonstrated using data from two 150mm diameter globes: one silver with low emissivity and primarily convective exchange, and the other blackened with high emissivity and mixed radiant and convective exchange. The main obstacle to be solved in the Bedford and Warner work was correcting for convection due to shifting air movements around the world [26]. According to Vernon's definition of the emissivity of matte black globes from 1932, black body states with spectral range that adhere to Plank's law of blackbody radiation were previously expected [22]. Bedford & Warner calculated the black paint's black body emissivity to be 0.95 [25]. However, according to Guo et al. [25], air velocity has a considerable impact on the MRTs estimated using globe thermometers.

3. Methodology

As mentioned previously, six basic parameters are required to determine human thermal comfort based on the PMV-PPD index [7]. Four of them are environmental parameters: Ta, Mean Radiant Temperature (MRT), airspeed, and relative humidity (RH); the other is personal parameters, the level of activity (MET), and clothing insulation [6,7]. The globe black thermometer (GBT) is a device that is commonly used to obtain mean radiant temperature (MRT) based on passive radiometry. This is by measuring globe temperature *Tg* through BGT [26,8].

In this study, a comparative analysis between two sizes of globe diameters (Dia. 40mm, and 150mm) to evaluate globe temperature has been conducted to understand the accuracy of using these types, and what is the effect of airspeed on the accuracy of final result.

For this purpose, case study methodology has been approached in this study. The study area is known as 'Garmian', which means in the Kurdish language "the warm region". According to the Köppen classification, the study area is situated in the southeast of Iraqi Kurdistan and is classified as a subtropical steppe (BSh) [27]. Iraq in common, and the 'Garmian' region in the Kurdistan of Iraq have a very long and warm summer and mild cool winter [28]. This made summer the most critical season in the region. Since the current study's goal was to examine how air velocity affects thermal comfort estimation based on the PMV-PPD index in row houses in semi-arid climates. Therefore, two groups of six-row houses in each group with the same typology (see Figure 2) oriented to the southern and northern directions were selected and investigated in summer. In the region of study, the houses which are oriented to the north have more opportunity for natural ventilation than the ones oriented to the south. Therefore, the inner airspeed is more than southern oriented buildings. This is because in general northerly, northwesterly summer wind reduces the temperature in the region of study because it blows under the impact of Mediterranean anticyclones. Other blows from the south and southeast rise from the Arabian Peninsula during summer and early winter; it is often a hot and dust-laden wind [29]. However, the buildings that are oriented to the south are more exposed to heat radiation than the ones oriented to the north [30]

- Since the black globe thermometer BGT is related to the radiation heat gain/ loss, and air velocity heat loss/ gain by convection. Therefore, the southern orientation and Northern orientation have been selected in the case studies to examine if the effect of radiation could change the results of thermal evaluation when it is present along with the inner air velocity.
- Hence, the ventilation in summer and due to the sand-laden wind of the southern wind is avoided by the occupants in the study area. The study applies comparative analysis to evaluate the differences in the final result of PMV, and PPD based on the changing in the airspeed, inside these buildings. CBE Thermal Comfort Tool as a computer tool has been provided to achieve empirical parts of the calculation to estimate PMV-PPD in this study as one of the most professional and accessible tools online for these types of studies. For obtaining metrological data the observation of different tools has been used; Electronic weather station 'Hama' for measuring air temperature (*Ta*), (RH); (*Va*) was observed using an Anemometer DA02 model; and the globe temperature (*Tg*) was measured using an EXTECH- H30 Glob Thermometer.
- Five observations in different places of each house have been achieved for each orientation. Hence, thirty site observations have been implemented inside the buildings during the summer from July, 17 to August 10 between 10:30 am to 5:00 pm. The required statistical power was achieved with 30 observations. Each site observation was consisting of a globe thermometer using both (40mm dia. and 150mm dia. globe thermometers). At each observation in different locations inside the houses, the following parameters have been considered:
- *Tg*, Globe temperature (using 40mm, and 150mm globe diameter), the measurement should be distant at least one meter from the walls according to ASHRAE-55.
- Ta, the air temperature is inside the building, because the Psychrometric (air temperature) method has been conducted using CBE Thermal Comfort Tool.
- The level of activity or the metabolic rate (MET) is determined according to the observation space, and the Clothing Insulation for summer was considered 0.5 (Clo), based on ASHRAE-55, [6].

Va, airspeed has been measured by a meter per second in the site through an anemometer. See Table 1.

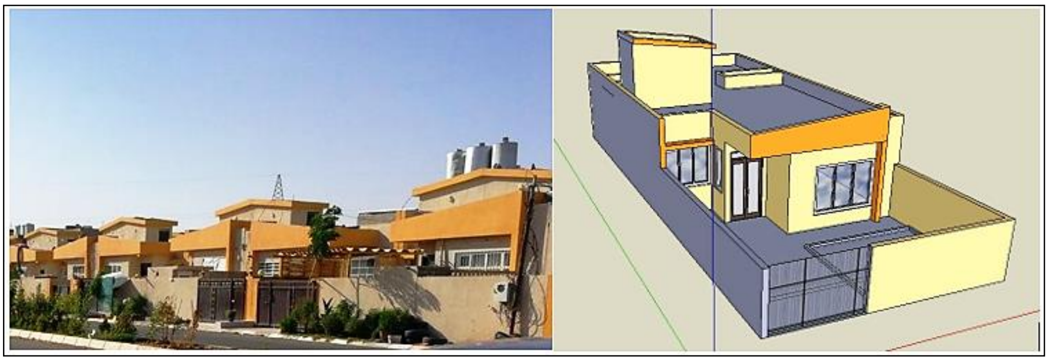

Figure 2. (Left) The selected row-houses facades in 'Garmian', 3D model for single typical row house. (By Researchers)

Table 1. The used Tools & instruments and the determined values for the parameters in the study to be applied in CBE Tool.

No.	Parameter	Tool model	The location	Clo	Met
	Environmental Parameters				
1	40mm Dia.- Globe temperature (*Tg*).	EXTECH- H30, Glob Thermometer	Inside the building		
	150mm Dia.- Globe temperature (*Tg*).	Delta, TP3275, PT100	Inside the building		
2	Air Temperature (*Ta*) &	The Electronic Weather Station 'HAMA'.	Inside the building		
3	Relative Humidity (RH)	The Electronic Weather Station 'HAMA'.	Inside the building		
4	Air Speed (*Va*)	Anemometer DA02 model (TACK LIFE)	Inside the building		
	Personal Parameters				
5	The metabolic rate (MET)		Guest Room		1.0 Met
			Living room		1.0 Met
			Kitchen		1.6 Met
			Master Bedroom		0.8 Met
6	Clothing Insulation (Clo)		Guest Room	0.5	
			Living room	0.5	
			Kitchen	0.5	
			Master Bedroom	0.5	

The outcomes from both groups (BGT 40mm dia., and 150mm dia.) have to be tested by using inferential statistics to understand the difference in the outcomes from both groups due to changing the size of BGT.

Therefore, the t-test statistic method has been applied to assess the differences in the outcomes of MRT as the essential factor which can be calculated through *Tg* observation and also can be directly affected by changing the size of BGT. This is done for the MRT results in the northern-oriented group of the row houses and also for the southern-oriented houses, as it is shown in the analysis and discussion part.

A statistical test known as the t-test is employed to compare the means of two groups. This test has three main types; independent sample, paired sample, and one-sample [31]. The p-value, which is determined through a statistical t-test, is a figure that indicates the probability that your data may have been true under the null hypothesis. If the p-value from the t-test is less than 0.05, a result is considered statistically significant. If the p-value is greater than 0.05, the result is not statistically significant. [32-33].

A paired t-test has been applied to compare the differences in the group thermal comfort estimation mean results of the group before and after an intervention or the changing of BGT size. Also, a two-tailed test has been used, considering the possibility of both a positive and a negative effect on the results.

4. Analysis & Discussion

The objective of this research is to examine the deviation in PMV outcomes based on different sizes of BGT (the standard and non-standard sizes). Moreover, the study tries to test the link between these two globes' *Tg* measurements with the changes in airspeed inside the building and the changes in the globe temperature readings, which finally result in their impact on thermal comfort evaluation. To display common depictions of the outcomes, Tables. 2 &3 illustrate the differences in the MRT results based on the difference of the globe temperatures because of the different sizes of BGT (40mm and 150mm dia.) in the tests carried out in the row houses in both northern and southern orientations.

Table 2. Mean radiant Temperature (MRT) in Northern oriented row houses

No.	Air Speed *Va* (m/s)	MRT from *Tg*40mm	MRT from *Tg*150mm	P-value (t-test)
1	0.12	23.3	23.1	
2	0.1	25.6	25.2	
3	0.18	25.6	24.8	
4	0.09	24.1	24.5	
5	0.03	26.8	26.7	
6	0.1	23.0	22.8	
7	0.06	25.5	25.4	
8	0.18	25.4	24.6	
9	0.03	24.0	23.9	
10	0.05	26.7	26.7	
11	0.07	23.3	23.2	
12	0.04	25.6	25.5	
13	0.13	24.7	24.0	
14	0.06	24.1	24.0	
15	0.02	26.9	26.9	**0.181**
16	0.11	22.9	22.8	
17	0.07	25.9	25.7	
18	0.16	24.8	24.1	
19	0.09	23.7	23.4	
20	0.04	26.9	26.9	
21	0.02	23.0	23.0	
22	0.05	25.8	25.6	
23	0.18	24.6	23.7	
24	0.02	23.8	23.7	
25	0.06	26.6	26.6	
26	0.14	23.7	37.7	
27	0	25.9	26.9	
28	0.17	25.0	34.3	
29	0.09	24.0	30.5	
30	0.02	26.3	26.0	

Table 1. Mean radiant Temperature (MRT) in Southern-oriented row houses

No.	Air Speed *Va* (m/s)	MRT from *Tg*40mm	MRT from *Tg*150mm	P-Value (t-test)
1	0	31.10	31.10	
2	0.04	27.11	27.01	
3	0.06	31.05	31.50	
4	0.02	28.43	28.35	
5	0	30.20	30.20	
6	0	30.70	30.70	
7	0.09	26.98	26.73	
8	0.05	31.04	30.89	
9	0.01	27.84	27.76	
10	0.02	30.73	30.60	
11	0	30.80	30.80	
12	0.05	26.32	26.10	
13	0.02	30.97	30.90	
14	0.04	27.97	27.79	
15	0	30.90	30.90	**0.005**
16	0	30.90	30.90	
17	0.04	26.38	26.30	
18	0.07	30.42	30.30	
19	0.06	27.81	27.70	
20	0.02	30.87	30.75	
21	0	30.80	30.80	
22	0.04	26.58	26.40	
23	0.05	30.68	30.50	
24	0.07	27.70	27.50	
25	0.01	30.91	30.90	
26	0	30.80	30.80	
27	0.03	26.66	26.60	
28	0.03	30.57	30.60	
29	0.05	27.73	27.60	
30	0.05	31.19	31.10	

This test was achieved because both orientations could give different results of globe temperatures when the convection level and radiation level are different between the two oriented row houses. Therefore, these scenarios can highlight the effect of each of the previous factors on the MRT result, taking into consideration that the airspeeds in the northern-oriented houses are higher than in the southern houses and vice-versa for the radiation. The results from the *Tg* observation through Two different BGT to predictive thermal comfort based on PMV-PPD are calculated for every six houses in North and south orientation. The results of MRT for each group of BGT were identified. Table 2 shows the result of MRT based on the different sizes of BGT, for northern-oriented row houses.

The t-test statistic method shows that the P-value is equal to (0.181). This indicates that there are differences between the results of MRT when BGT 40mm has been used to be compared with the standard BGT-150mm. Thus, the differences obtained in MRT results between the two groups when the 40mm and 150mm globe diameters are considered in the northern-oriented row houses give a special indication. This indication is that the differences in MRT are affected particularly by air velocity. However, the results of the southern row houses were different than the ones in the northern orientation. Table 3 shows the result of MRT based on the different sizes of BGT, for southern-oriented row houses with different *Va*.

Table 3 has demonstrated a similarity in the MRT of the two groups of the results despite the difference in BGT sizes. Through the t-test statistic method, the P-value was found equal to (0.005), which indicates a strong similarity in the results of both groups and no differences, since the p-value is very low. In other words, there are no differences between the results of MRT when BGT 40mm has been used to be compared with the standard BGT-150mm in the southern row houses. The reason is the effects of the air velocity in these row houses are lower than the ones in the northern. The *Va* in northern houses reaches 0.18 m/s, while in the southern houses not exceeding 0.09 m/s. See Tables '2 & 3'.

Table 4. The prediction of thermal comfort in North oriented row houses in summer, using both BGT (150mm and 40mm diameter), based on PMV-PPD Index

	TG 150mm			TG 40mm		
Va(m/s)	PMV150mm	PPD150mm	Sensation	PMV40mm	PPD40mm	Sensation
0	0.18	0.06	Neutral	0.1	0.05	Neutral
0.02	-0.61	0.13	Slightly Cool	-0.54	0.11	Slightly Cool
0.02	-0.56	0.12	Slightly Cool	-0.56	0.12	Slightly Cool
0.02	-1.03	0.27	Slightly Cool	-1.03	0.27	Slightly Cool
0.02	-1.81	0.67	Cool	-1.79	0.66	Cool
0.03	-0.54	0.11	Slightly Cool	-0.52	0.11	Slightly Cool
0.03	-1.75	0.64	Cool	-1.73	0.63	Cool
0.04	0	0.05	Neutral	0.02	0.05	Neutral
0.04	-0.51	0.1	Slightly Cool	-0.51	0.1	Slightly Cool
0.05	0	0.05	Neutral	0.04	0.05	Neutral
0.05	-0.65	0.14	Slightly Cool	-0.65	0.14	Slightly Cool
0.06	0.04	0.05	Neutral	0.06	0.05	Neutral
0.06	-0.69	0.15	Slightly Cool	-0.69	0.15	Slightly Cool
0.06	-1.8	0.67	Cool	-1.78	0.66	Cool
0.07	0.1	0.05	Neutral	0.13	0.05	Neutral
0.07	-0.91	0.23	Slightly Cool	-0.89	0.22	Slightly Cool
0.09	-0.2	0.06	Neutral	-1.77	0.65	Cool
0.09	-1.76	0.65	Cool	-1.7	0.61	Cool
0.09	-1.91	0.73	Cool	-1.84	0.69	Cool
0.1	-0.14	0.05	Neutral	0.07	0.05	Neutral
0.1	-1.02	0.27	Slightly Cool	-0.98	0.25	Slightly Cool
0.11	-1.16	0.33	Slightly Cool	-1.14	0.32	Slightly Cool
0.12	-0.96	0.25	Slightly Cool	-0.91	0.22	Slightly Cool
0.13	0.31	0.07	Neutral	0.95	0.24	Slightly Warm
0.14	1.68	0.61	Warm	-0.85	0.2	Slightly Cool
0.16	0.29	0.07	Neutral	0.88	0.21	Slightly Warm
0.17	1.14	0.32	Slightly Warm	0.87	0.21	Slightly Warm
0.18	0.4	0.08	Neutral	0.95	0.24	Slightly Warm
0.18	0.33	0.07	Neutral	0.89	0.22	Slightly Warm
0.18	0.23	0.06	Neutral	0.78	0.18	Slightly Warm

When the difference between the regular convection test and the higher air speed trial is calculated; the MRT of the *Tg* for 40mm and 150mm diameter has been evaluated and the differences have been tested by using T-test. Despite the MRT being one of the main factors to predict thermal comfort in the PMV-PPD method, the final sensation of thermal comfort is the target in the application of this index. Hence, the results of the MRT from both BGTs have been tested to see their effects on the sensation of thermal comfort based on the PMV-PPD index. See Tables 4 and 5:

The outcomes in Table '4' demonstrates that the predicted thermal comfort in the northern-oriented row houses has differences by 23%, and essentially the differences start when the *Va* reaches 0.09 m/s and more. However, the differences in the sensation results reach 86% when the *Va* is 0.13 m/s and above, as seen in Tables 3 & 4.

Table 2. The prediction of thermal comfort in south-oriented row houses in summer, using both BGT (150mm and 40mm diameter), based on PMV-PPD Index

	Tg 150mm			*Tg* 40mm		
Va (m/s)	PMV150mm	PPD	Sensation	PMV40mm	PPD	Sensation
0	1.89	0.72	Warm	1.89	0.72	Warm
0	1.25	0.38	Slightly Warm	1.25	0.38	Slightly Warm
0	1.91	0.73	Warm	1.91	0.72	Warm
0	1.88	0.71	Warm	1.9	0.73	Warm
0	1.48	0.5	Slightly Warm	1.48	0.5	Slightly Warm
0	1.93	0.74	Warm	1.93	0.73	Warm
0	1.88	0.71	Warm	1.88	0.71	Warm
0	1.94	0.74	Warm	1.94	0.74	Warm
0.01	-0.2	0.06	Neutral	-0.2	0.06	Neutral
0.01	1.45	0.48	Slightly Warm	1.45	0.48	Slightly Warm
0.02	0.03	0.05	Neutral	0.05	0.05	Neutral
0.02	1.34	0.42	Slightly Warm	1.34	0.42	Slightly Warm
0.02	1.6	0.56	Warm	1.98	0.76	Warm
0.02	1.36	0.43	Slightly Warm	1.39	0.45	Slightly Warm
0.03	0.31	0.07	Neutral	0.33	0.07	Neutral
0.03	1.54	0.53	Warm	1.94	0.74	Warm
0.04	0.38	0.08	Neutral	0.4	0.08	Neutral
0.04	-0.1	0.05	Neutral	-0.07	0.05	Neutral
0.04	0.34	0.07	Neutral	0.35	0.08	Neutral
0.04	0.35	0.07	Neutral	0.38	0.08	Neutral
0.05	1.53	0.52	Warm	1.99	0.76	Warm
0.05	0.37	0.08	Neutral	0.45	0.09	Neutral
0.05	1.51	0.51	Warm	1.97	0.76	Warm
0.05	-0.15	0.05	Neutral	-0.13	0.05	Neutral
0.05	1.48	0.5	Slightly Warm	1.5	0.51	Slightly Warm
0.06	1.79	0.67	Warm	2	0.77	Warm
0.06	-0.28	0.07	Neutral	-0.25	0.06	Neutral
0.07	1.51	0.51	Warm	2.01	0.77	Warm
0.07	-0.2	0.06	Neutral	-0.15	0.05	Neutral
0.09	0.39	0.08	Neutral	0.41	0.08	Neutral

On another side, the outcomes of the evaluation of thermal comfort in the row houses of the south side demonstrate that there are no differences in the predicted thermal comfort based on the PMV-PPD, either with using 40 mm dia. BGT or using 150 mm dia. BGT in the process of thermal comfort prediction, as seen in Table ‘5’. This is because the *Va* inside the buildings has been found between 0.00 m/s to 0.09 m/s. See Table ‘3’.

On the northern side, the differences in the prediction between 150mm dia. BGT, and 40 mm dia. BGT start to change when *Va* reaches 0.09 m/s and above. See Table ‘2’. It is critical to emphasize that thermal feeling is same when *Va* is 0.09 m/s in the row houses with south orientation, while it changing with the same *Va* (0.09 m/s) in the northern oriented houses demonstrated differences in PMV-PPD sensation by 33%, as seen in Table ‘4’. This could be returned to the effect of the difference in solar radiation in both orientations. In the study region, the effect of radiation in this part is higher than the one in the northern part [29,30,34]. According to Auliciems and Szokolay [23], this could create some equilibriums between the convection and radiation effects on the BGT and consequently, adjust the results of MRT.

Therefore, more studies involving solar radiation measurements are required to assess the impact of this factor on the results of predicted thermal comfort in the houses in the region of study. Also, other studies involving different orientations are required to understand the effect of the orientation as another external factor on the evaluation of thermal comfort using non-standard BGT in the process of PMV-PPD evaluation.

5. Conclusions

The study investigated the impact of convection (windspeed) on final estimation of thermal comfort inside the buildings in the row houses in the climate of ‘Garmian’ in the Kurdistan region of Iraq when the non-standard GT is used to predict thermal comfort condition inside the buildings. Therefore, to understand the validity of employing these types of GT and how airspeed affects the accuracy of the end result, a comparison examination between two sizes of GT (Dia. 40mm and 150mm) has been undertaken in this study.

In general, northerly and northwesterly summer wind are the welcomed wind in summer, and the one blows from the south and southeast is often hot and dust-laden wind [22,24,34]. Hence, the northern-oriented houses are expected to have higher windspeed inside the buildings than the ones oriented to the south. Therefore, two groups of six-row houses in each group with the same typology oriented to the southern and northern directions were selected and investigated in summer, as the more critical seasons in the region of study. MRT as a pivotal factor in the estimation of thermal comfort by the PMV-PPD method has been obtained by using both *Tg* obtained from two different GT diameters responding to the convection with existing airspeed inside the buildings in both orientations. The study has demonstrated *Va* inside the northern-oriented row houses varied from 0.00 m/s to 0.18 m/s, while the southern-oriented ones had between 0.00 m/s to 0.09 m/s only. A comparison of the results between the outcomes of smaller and standard BGT has been done by using an inferential statistic test (t-test).

The results of MRT in the north-oriented buildings were different when compared to the results of *Tg* from smaller BGT and the standard one and the statistical test (t-test) has showed high p-value. However, the results from the southern-oriented houses demonstrate similarity in the results of obtained MRT based on t-test statistical analysis (low p-value). This indicates the significant effect of the convection or airspeed on the results of MRT, as seen in Tables ‘2 and 3’, and consequently, on the sensation of thermal comfort based on the PMV-PPD index. The study shows the conditional use of smaller BGT with 40 mm dia, in the assessment of thermal comfort in the study area. Though, the study demonstrates that it is acceptable in predicting thermal comfort using PMV-PPD, only when the inner airspeed is lower than 0.13 m/s. Thus, the outcomes of the current study provide preliminary evidence supporting the hypothesis mentioned in the beginning.

In addition to this, the study recommended extra research by involving solar radiation along with convection in the study area to get an understanding of the impact of irradiation on thermal comfort evaluation. Especially, when some slight differences have been observed in the results between south and north buildings when the airspeed was less than 0.13 m/s, as seen in Tables ‘4 and 5’. The study also has recommended applying this study to other orientations and comparing the result with the result of the current study for a more comprehensive understanding.

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