original article

Performance evaluation of two wet bulb globe temperature equipment for heat stress assessment in hot/dry and hot/wet conditions

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Access this article online

Quick Response Code:

Website: www.ijehe.org

DOI: 10.4103/2277-9183.148282

ABSTRACT

Aims: The purpose of this study was to compare performance of two these WBGT measuring devices.

Materials and Methods: This study was performed in the climatic chamber located in Health School of Isfahan University of Medical Science. The $WBGT_{Casella}$ and the $WBGT_{Model\ 686}$ were placed a wide range of hot/dry (28.5-38.5°C) and hot/wet conditions (25.9-37.7°C) in 3 air flow velocity (0.16, 0.27, 0.31 m/s) for 10 h in the climatic chamber. Wet bulb temperature (t_{nw}), the dry temperature (t_a), the globe temperature (t_g) and the WBGT were measured every 3 min for both instruments in the total period. The data obtained were analyzed by descriptive method, T-paired test and Regression analysis.

Results: The result of this study showed that there were statistically significant differences in the meteorological parameter (t_{nw}, t_a, t_g, WBGT) obtained from the $WBGT_{Casella}$ and $WBGT_{Model\ 686}$ ($P < 0.001$). A high correlation also was seen between the values obtained by the $WBGT_{Casella}$ and the $WBGT_{Model\ 686}$ ($r = 0.993$). Furthermore, there were statistically significant differences in the air flow velocity parameter (0.157 m/s) and (0.27 m/s) and (0.314 m/s) in a hot/dry ($r = 0.994$) and (0.980) and (0.994) respectively. There were statistically significant differences in the air flow velocity parameter (0.157 m/s) and (0.27 m/s) and (0.314 m/s) in a hot/wet ($r = 0.980$) and (0.992) and (0.973) respectively.

Conclusion: Since there is a high correlation between the values recorded by two devices and a remarkable cost — efficacy of $WBGT_{Model\ 686}$, using $WBGT_{Model\ 686}$ is an acceptable method for measuring the heat stress if the prediction equations are utilized. According to the different temperature conditions, was obtained dry temperature, wet temperature and globe temperature both devices measurement in different climatic conditions equation $WBGT_{Casella} = 2.04 + 1.03$ ($WBGT_{Model\ 686}$). About 2 units $WBGT_{Model\ 686}$ lower than the $WBGT_{Casella}$ and recommend the measures to be considered in this case as well as the manufacturers also, recommend doing that the reform of sensor measurements and the calculation methods.

Key words: Climatic chamber, heat stress, wet bulb globe temperature index, workplace

This article may be cited as:
Dehghan H, Shakerian M, Khodarahmi B, Habibi P. Performance evaluation of two wet bulb globe temperature equipment for heat stress assessment in hot/dry and hot/wet conditions. Int J Env Health Eng 2014;3:1-6.

INTRODUCTION

Heat stress exposure considered as a permanent issue for workers in many industries.[1]

The workers' safety in the workplaces can be affected by several factors. The studies show that there is a significant relationship between high productivity level and learning capacity of workers and the appropriate climatic conditions in the workplace.[2] In extremely hot environments there is a significant decrease in productivity[3] and a high rate of accidents as well as the risk of workers suffering heat disorders.[4]

The continuous heat exchange between the body and the environment can result in physiological and psychological strain on the people that is also affecting the workers' health as well as their performance and effectiveness.[5]

Heat-related illnesses occur mostly during the summer at high environmental temperature.[6-8]

Heat-related illnesses also may happen in most of the hot workplaces especially at long-term exposures following by possible inappropriate heat adaptation.[9]

Some heat-related illnesses[10] are included heat syncope, heat cramps, heat exhaustion and classic heat stroke.[11,12]

As some environmental factor such as the ambient temperature,[13] radiant temperature,[14] humidity[15] and air velocity as well as clothing and activity level are effective to induce heat strain on the workers, there has been always an attempt to concise all these factors to an index referred to as "heat index."[16]

Many indices have been developed to measure the intensity of heat stress on the workers[17,18] these indices are classified into two groups as follow:

- The analytical indices based on the heat exchange principles.

The empirical indices developed based on the human responses to different environmental factors. Out of the empirical indices,[19] the wet bulb globe temperature (WBGT) index has the most applicability to measure the heat stress in the hot environments, inside buildings and outside buildings without solar load.[16,20]

The WBGT index is the most applicable index in Iran. This index, however, has several restrictions. One of the important applied limitations is that the WBGT measuring devices was built in foreign countries and it is expensive therefore commercially unavailable.

A new WBGT measuring device $WBGT_{Model\ 686}$ that is nearly 0.1 cheaper than foreign-made WBGT device ($WBGT_{Casella}$), has been recently built by Iranian experts.

The present study, therefore, aimed to compare and validate the result obtained from the $WBGT_{Model\ 686}$ with those of the $WBGT_{Casella}$.

MATERIALS AND METHODS

This study was conducted under controlled experimental conditions [Table 1] in a Climatic Chamber located in the Health School in Medical University of Isfahan.

Two WBGT measuring devices performance were under study including the WBGT instrument made in Iran ($WBGT_{Model\ 686}$) and the foreign — made WBGT instrument ($WBGT_{Casella}$).

Both devices were firstly placed into the climatic chamber for 5 h under a wide range of hot/dry temperature (28.5-38.5°C) and for another 5 h under a wide range of hot/wet temperature (25.9-37.7°C). Furthermore, air flow velocity, both climatic conditions hot/dry and hot/wet temperature, were 0.16, 0.27 and 0.31 m/s.

The environmental factor including wet bulb temperature (t_w), the dry bulb temperature (t_a), the globe temperature (t_g) and the WBGT index measured and recorded[17,21] every 3 min for both WBGT instruments.

The variation range of the meteorological parameters during the experiment under both hot/dry and hot/wet conditions is represented in Table 1.

The WBGT instruments under study were both placed into the Climatic Chamber and mounted on a tripod with equal heights of 1/5 m from the floor.

The $WBGT_{Casella}$ had been bought nearly 6 months before the experiment. The $WBGT_{Casella}$, therefore, was considered as an initial standard in this study.

When the experiment ended, data were recorded for each meteorological experiment including t_w, t_a, t_g, WBGT under both hot/dry and hot/wet climatic condition.

The data were finally statistically analyzed by the descriptive method, T-paired test and regression analysis.

Table 1: Wide variety of environmental factor for hot/dry and hot/wet climatic conditions

Climatic condition	WBGT (C)	Tg (°C)	Tw (°C)	Ta (°C)
Hot/dry				
Start	23.1	29.4	20.5	28.5
End	32.4	38.7	30.5	38.5
Hot/wet				
Start	23.3	26.9	21.9	25.9
End	36.2	37.8	35.5	37.7

WBGT: Wet bulb globe temperature

RESULTS

The study result indicated that the mean values of t_{nw}, t_a, t_g and WBGT recorded by the $WBGT_{Casella}$ and the $WBGT_{Model\ 686}$ are significantly different under hot/dry condition ($P < 0.001$).

Table 2 represents mean, standard deviation and correlation co-efficient of t_{nw}, t_a, t_g and WBGT under hot/dry conditions, recorded in hot/dry climatic condition by the $WBGT_{Casella}$ and the $WBGT_{Model\ 686}$.

Table 3 shows mean, standard deviation and correlation co-efficient of t_{nw}, t_a, t_g and WBGT under hot/wet conditions, recorded in hot/dry climatic condition by the $WBGT_{Casella}$ and the $WBGT_{Model\ 686}$.

Table 2: Mean (SD) and correlation coefficient of WBGT measured by both $WBGT_{Model\ 686}$ and $WBGT_{Casella}$ in hot/dry climatic conditions

WBGT meters	WBGT index	Tg	Ta	Tw
$WBGT_{Model\ 686}$	26.2 (2.2)	34.8 (2.9)	29.8 (2.5)	22.5 (1.9)
$WBGT_{Casella}$	28.7 (2.8)	34.6 (3.1)	34.3 (3.1)	26.5 (3)
Correlation coefficient	0.990	0.995	0.992	0.98

WBGT: Wet bulb globe temperature

Table 3: Mean, standard deviation and correlation coefficient of t_{nw}, t_a, t_g and WBGT under hot/wet conditions, recorded in hot/dry climatic condition by the $WBGT_{Casella}$ and the $WBGT_{Model\ 686}$

WBGT meters	WBGT index	Tg	Ta	Tw
$WBGT_{Model\ 686}$	29.7 (2.4)	36.4 (2.5)	32.4 (2.3)	27.8 (2.3)
$WBGT_{Casella}$	33.1 (2.9)	34.8 (2.4)	34.6 (2.7)	32.3 (3.1)
Correlation coefficient	0.998	0.991	0.990	0.984

WBGT: Wet bulb globe temperature

Figure 1 also shows the scatter plot and regression line of the values measured by the $WBGT_{Casella}$ based on the values measured by $WBGT_{Model\ 686}$ under hot/dry conditions.

Figure 2 represents the scatter plot and regression line related to the values obtained from the $WBGT_{Casella}$ based on the values obtained from $WBGT_{Model\ 686}$ under the hot/wet climatic condition.

Figure 3 also shows the scatter plot and regression line of the values measured by the $WBGT_{Casella}$ based on the values measured by $WBGT_{Model\ 686}$ under hot/dry conditions in the air velocity (0.157 m/s).

Figure 4 also shows the scatter plot and regression line of the values measured by the $WBGT_{Casella}$ based on the values measured by $WBGT_{Model\ 686}$ under hot/dry conditions in the air velocity (0.27 m/s).

Figure 5a also shows the scatter plot and regression line of the values measured by the $WBGT_{Casella}$ based on the values measured by $WBGT_{Model\ 686}$ under hot/dry conditions in the air velocity (0.314 m/s).

Figure 5b also shows the scatter plot and regression line of the values measured by the $WBGT_{Casella}$ based on the values measured by $WBGT_{Model\ 686}$ under hot/wet conditions in the air velocity (0.157 m/s).

Figure 6 also shows the scatter plot and regression line of the values measured by the $WBGT_{Casella}$ based on the values measured by $WBGT_{Model\ 686}$ under hot/wet conditions in the air velocity (0.27 m/s).

Figure 7 also shows the scatter plot and regression line of the values measured by the $WBGT_{Casella}$ based on the values measured by $WBGT_{Model\ 686}$ under hot/wet conditions in the air velocity (0.314 m/s).

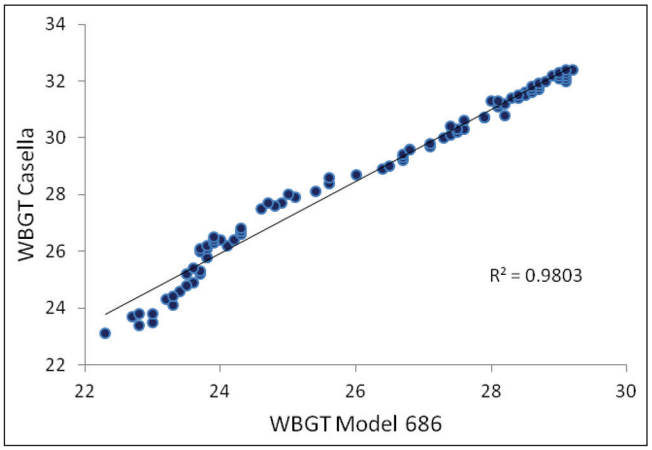

Figure 1: Scatter plot and regression line of the wet bulb globe temperature ($WBGT_{Casella}$) values based on the $WBGT_{Model\ 686}$ values under the hot/dry climatic conditions

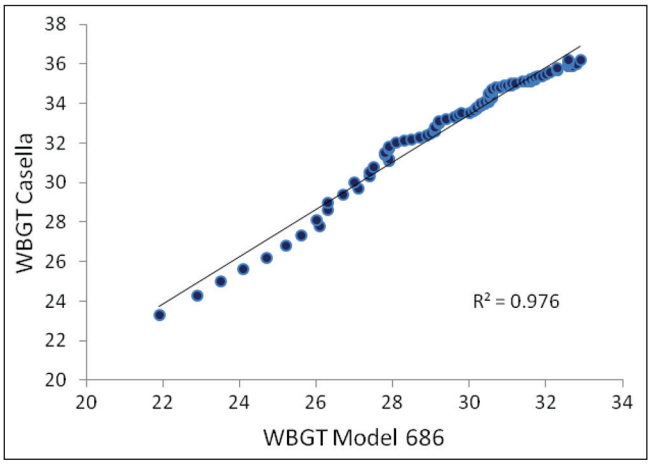

Figure 2: Scatter plot and regression line of the wet bulb globe temperature ($WBGT_{Casella}$) values based on the $WBGT_{Model\ 686}$ values under the hot/wet climatic condition

Table 4 prediction equations below accounts for the values obtained from the $WBGT_{Casella}$ based on the $WBGT_{Model\ 686}$ under the hot/dry and hot/wet climatic conditions and the values obtained from the $WBGT_{Casella}$ based on the $WBGT_{Model\ 686}$ under the hot/dry and hot/wet climatic conditions in 3 air velocity.

DISCUSSION

T-test showed that under the both hot/dry and hot/wet conditions, there was a significant difference between t_{nw}, t_a, t_g and WBGT measured by $WBGT_{Casella}$ and $WBGT_{Model\ 686}$.

The values recorded by $WBGT_{Model\ 686}$, however, were lower than those of the $WBGT_{Casella}$.

Table 4: Prediction equations in hot/dry and hot/wet conditions

Climatic conditions	Prediction equation
Hot/dry conditions + no air movement	$WBGT_{Casella} = -4.49 + 1.2\ (WBGT_{Model\ 686})$
Hot/wet conditions + no air movement	$WBGT_{Casella} = -2.49 + 1.19\ (WBGT_{Model\ 686})$
Hot/dry conditions + air velocity 0.157 m/s	$WBGT_{Casella} = 2.70 + 0.99\ (WBGT_{Model\ 686})$
Hot/dry conditions + air velocity 0.27 m/s	$WBGT_{Casella} = -1.31 + 1.13\ (WBGT_{Model\ 686})$
Hot/dry conditions + air velocity 0.314 m/s	$WBGT_{Casella} = -3.33 + 1.03\ (WBGT_{Model\ 686})$
Hot/wet conditions + air velocity 0.157 m/s	$WBGT_{Casella} = -0.41 + 0.95\ (WBGT_{Model\ 686})$
Hot/wet conditions + air velocity 0.27 m/s	$WBGT_{Casella} = -0.94 + 0.96\ (WBGT_{Model\ 686})$
Hot/wet conditions + air velocity 0.314 m/s	$WBGT_{Casella} = -2.76 + 1.22\ (WBGT_{Model\ 686})$

WBGT: Wet bulb globe temperature

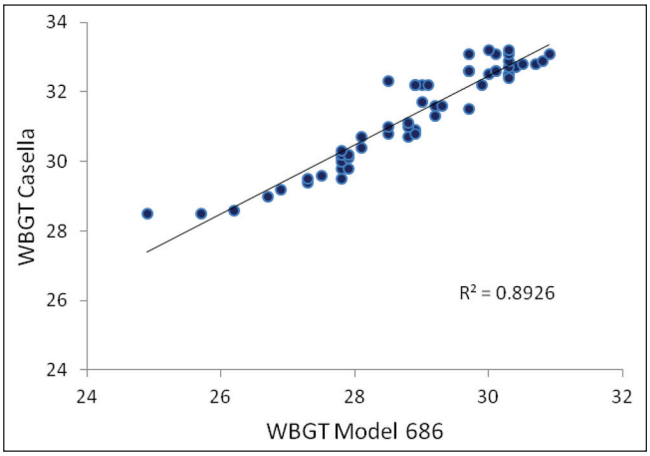

Figure 3: Scatter plot and regression line of the wet bulb globe temperature ($WBGT_{Casella}$) values based on the $WBGT_{Model\ 686}$ values under the hot/dry climatic condition in the air velocity (0.157 m/s)

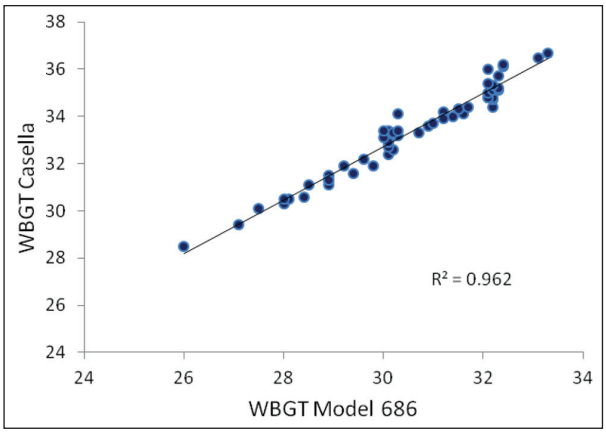

Figure 4: Scatter plot and regression line of the wet bulb globe temperature ($WBGT_{Casella}$) values based on the $WBGT_{Model\ 686}$ values under the hot/dry climatic condition in the air velocity (0.27 m/s)

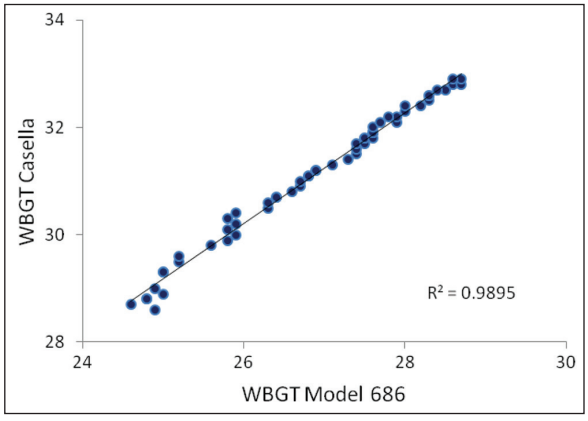

Figure 5a: Scatter plot and regression line of the wet bulb globe temperature ($WBGT_{Casella}$) values based on the $WBGT_{Model\ 686}$ values under the hot/dry climatic condition in the air velocity (0.314 m/s)

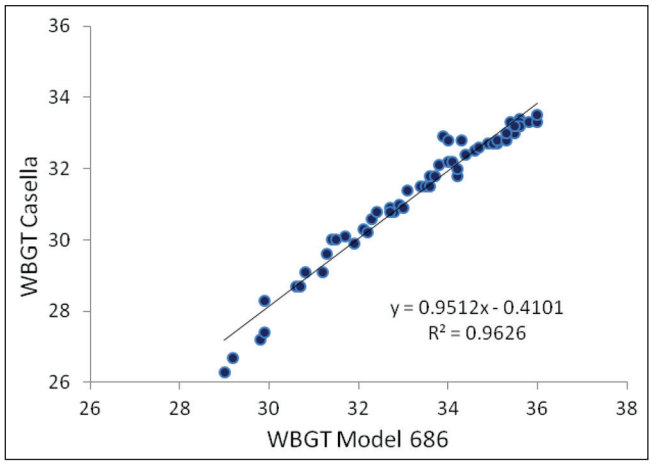

Figure 5b: Scatter plot and regression line of the wet bulb globe temperature ($WBGT_{Casella}$) values based on the $WBGT_{Model\ 686}$ values under the hot/wet climatic condition in the air velocity (0.157 m/s)

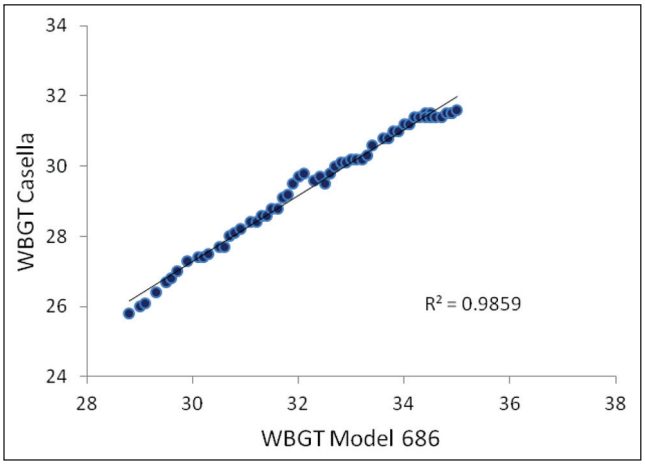

Figure 6: Scatter plot and regression line of the wet bulb globe temperature ($WBGT_{Casella}$) values based on the $WBGT_{Model\ 686}$ values under the hot/wet climatic condition in the air velocity (0.27 m/s)

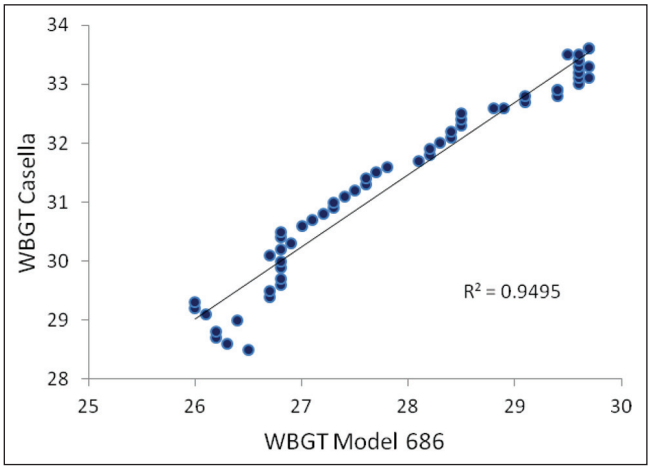

Figure 7: Scatter plot and regression line of the wet bulb globe temperature ($WBGT_{Casella}$) values based on the $WBGT_{Model\ 686}$ values under the hot/wet climatic condition in the air velocity (0.314 m/s)

Also, *t*-test showed that under the both hot/dry and hot/wet conditions in the air velocity (0.16, 0.27, 0.31 m/s), there was a significant difference between t_{nw}, t_a, t_g and WBGT measured by $WBGT_{Casella}$ and $WBGT_{Model\ 686}$ ($P < 0.001$).

The values recorded by $WBGT_{Model\ 686}$, however, were lower than those of the $WBGT_{Casella}$.

Nevertheless, as it can be inferred from Tables 1 and 2. As well as Figures 1 and 2 show the correlation coefficient of the values measured by the WBGT devices under study was higher than 0.98.

The $WBGT_{Model\ 686}$, therefore, can be easily afforded in terms of its lower price and shorter time to be provided than the $WBGT_{Casella}$.

Moreover, regarding the study results, the $WBGT_{Model\ 686}$ is possible to be replaced with the $WBGT_{Casella}$, if obtained values by $WBGT_{Model\ 686}$, are put in the WBGT prediction equation based on the values measured by $WBGT_{Casella}$.

This study was performed only under hot/dry and hot/wet condition, so to achieve more precise results as well as more practical predator equations a variety of climatic parameters and environmental conditions such as different wind velocities and different intensity level of thermal radiant are required to be investigated by $WBGT_{Casella}$ and $WBGT_{Model\ 686}$.

CONCLUSION

This study showed a high correlation between the values obtained by the $WBGT_{Casella}$ and those by the $WBGT_{Model\ 686}$ in a similar environmental condition. Furthermore, the $WBGT_{Model\ 686}$ is easier and cheaper to be applied than the $WBGT_{Casella}$ provided that the WBGT predictor equation is used for the values measured by the $WBGT_{Model\ 686}$ based on the $WBGT_{Casella}$ measurement results.

According to the different temperature conditions, was obtained dry temperature, wet temperature and globe temperature both devices measurement in different climatic conditions equation $WBGT_{Casella} = 2.04 + 1.03$ ($WBGT_{Model\ 686}$).

About 2 units $WBGT_{Model\ 686}$ lower than the $WBGT_{Casella}$ and recommend the measures to be considered in this case as well as the manufacturers also, recommend doing that the reform of sensor measurements and the calculation methods.

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Source of Support: Isfahan University of Medical Sciences, **Conflict of Interest:** None declared.