Procedures for Verification of Instruments for Thermal Environment Measurement

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Abstract. Accuracy and verification of instruments for thermal environment measurement are important to determine the reliability of measured parameters. The purpose of this study is to propose simple procedures for consistency check on four groups of instruments used in thermal environment measurement: indoor air temperature, outdoor air temperature, relative humidity, and air velocity. For indoor air temperature measurement, the existing instruments were checked with the new thermocouple connected to a data logger in an air-conditioned room. The measurement was conducted under different set point temperatures. For relative humidity measurement, the readings of the measurement instruments were measured in a naturally ventilated room and compared with those of the digital ventilation psychrometer. For air velocity measurement, the instruments were set in a mini handmade wind tunnel. The air velocity readings obtained from the instruments were compared to verify the result consistency. Finally, for outdoor air temperature measurement, all instruments were placed in a fan aspirated solar shield which was set outdoors. For each group of the instruments, the obtained readings were evaluated based on the coefficient of determination and standard deviation from the mean values. The results have shown that all air temperature and relative humidity instruments have strong correlation owing to the high coefficient of determination obtained. The mean air velocity obtained from all measurement instruments ranged from 3.24 to 3.40 m/s with the standard deviation of 0.07 to 0.1. Furthermore, the mean outdoor air temperature ranged from 25.3 to 25.6°C with the standard deviation of 1.04 to 1.08. The simple procedures carried out in this work successfully verified the consistency of all measurement instruments, and this is essential before the instruments are used in actual field measurements.

1. Introduction
Thermal environment measurement is an important method in thermal comfort research [1]–[5], besides numerical simulation [6]–[9]. Several thermal environmental parameters that are measured include indoor and outdoor air temperatures, relative humidity, and air velocity [10]–[13].

Accuracy and verification of measurement instruments influence the reliability of a research that deals particularly with thermal environment measurement. To ensure the accuracy of measured parameters, a measuring instrument must go through a calibration process periodically conducted by authorized personnel according to the recommendation of the manufacturer [14]. In addition, verification of consistency among similar types of instruments needs to be conducted in between periodical calibrations by comparison with a new or calibrated instrument [15].

In most previous studies wherein the thermal environment measurement was performed, the procedures and methods of verification on instruments were not discussed [10]–[13], but instead only
the type and setup of instruments were discussed. The study on the procedures and methods of verification is lacking and requires further exploration. The purpose of this study is to propose simple procedures for checking the consistency of the measurement instruments which are classified into four groups of respective parameters measured in the thermal environment measurement: indoor air temperature, outdoor air temperature, relative humidity, and air velocity.

2. Methodology
In this study, methods of instrument verification vary among the parameters measured. The existing air temperature measurement instruments were verified with the new thermocouple connected to data loggers that are placed in an air-conditioned room. On the other hand, the measurement instruments for relative humidity were placed in a naturally ventilated room and the measured data were compared against those obtained using the digital ventilation psychrometer. With regard to air velocity measurement, the instruments used were placed in a mini handmade wind tunnel and the readings of the instruments were compared for verification. Finally, the verification of the outdoor air temperature measurement instruments was conducted by housing all instruments in a fan aspirated solar shield set in an outdoor environment for comparison.

2.1. Instruments
Instruments used in this study are shown in Table 1. The HOBO U12-013 temperature/humidity data logger with the TMC1-HD external sensor was used to measure indoor and outdoor air temperatures. The same data logger with an internal sensor was used to measure relative humidity. For the verification of indoor air temperature, type k thermocouple wires connected to the Graphtec data loggers, i.e. GL820 and GL220, were used. Furthermore, the CYS-7001 digital Assmann ventilation psychrometer was used to measure relative humidity. Finally, air velocity was measured using the Kanomax 6501-series hot-wire anemometer for which the sensor was the 6542-2G external needle probe.

| Instrument | Parameter | Manufacturer, Country | Sensor Type | Resolution | Accuracy and Range |
|------------|-----------|-----------------------|-------------|------------|-------------------|
| HOBO U12-013 temperature/humidity data logger | Indoor and outdoor air temperature, Relative humidity | Onset, USA | TMC1-HD external sensor Internal sensor | 0.03 °C, 0.05% RH | ±0.35 °C [0 °C to 50 °C], ±2.5% RH (10% to 90%) |
| GL820 data logger | Air temperature | Graphtec, Japan | Type k thermocouple | - | ± (0.05% of reading +1.0 °C) |
| GL220 data logger | Air temperature | Graphtec, Japan | Type k thermocouple | - | ± (0.05% of reading +1.0 °C) |
| CYS-7001 digital Assmann ventilation psychrometer | Relative humidity | Climatec, Japan | Platinum resistance temperature detector thermometer | - | 0 to 100% RH |
| 6501-series hot-wire anemometer | Air velocity | Kanomax, Japan | 6542-2G needle probe | 0.01 m/s | ±2% of reading or ±0.015 m/s whichever is greater |
2.2. Air Temperature Instruments

Twenty units of HOBO thermo recorders with six units of thermocouple (i.e. three units each for GL820 and GL220) were setup in a room equipped with an air conditioner (AC), as shown in Figure 1. The measurement was conducted under different AC set point temperatures for 45 minutes within a one-minute interval. The measurement was started at a room temperature, approximately 29°C. After 15 minutes, the AC in the room was switched on and the temperature was set to 24°C according to the recommended indoor temperature by the Department of Standards Malaysia [16]. The measurement was continued for another 30 minutes.

As shown in Figure 2, one of the six thermocouples with the lowest standard deviation (S.D) was selected to operate as a reference for the other HOBO sensors. The thermocouple channel (CH) 1 of GL820 data logger which had the lowest S.D. value of 1.9 was taken as a reference to compare the correlation among all thermocouples. The S.D. values of other thermocouples ranged between 2.0 to 2.3. All thermocouples displayed a strong correlation with one another, having the coefficient of determination, $R^2 > 0.98$. Furthermore, to determine the correlation between the HOBO sensors and the reference thermocouple, a regression line was plotted for each HOBO sensor against the reference sensor. This was also done to check the consistency of results by comparing the coefficient of determination as shown in Figure 2.

![Image](https://example.com/image1.png)

Figure 1: Photo of experimental setup for verification of air temperature sensors.

![Image](https://example.com/image2.png)

Figure 2: Consistency checking of air temperature measurement instruments. Notes: CH refers to ‘channel’ and $R^2$ refers to the coefficient of determination.
Figure 3: Example on the comparison of the measured air temperature from the HOBO 20 sensor and the thermocouple connected to GL820 channel 1. Note: $N$ refers to the number of samples and $R^2$ refers to the coefficient of determination.

2.3. Relative Humidity Instruments
As shown in Figure 4 (a), twenty units of HOBO thermo recorders were examined in a naturally ventilated room with opened windows for 5 hours at a 15-minute interval. To use the Assmann psychrometer functioned with two thermometers (dry bulb and wet bulb), water was applied to the wet bulb gauze with a dropper for every 15 minutes, as shown in Figure 4 (b). This was also done to maintain the moisture level in the wet bulb. The readings of relative humidity from the psychrometer were recorded manually three minutes after water was applied. The readings from every instrument were compared with those obtained using the psychrometer. As shown in Figure 5, all HOBO thermo recorders were strongly influenced by the readings from the digital Assmann ventilation psychrometer, with a high value of the determination coefficient ($R^2 > 0.97$). Figure shows an example of the comparison.

![Figure 4: (a) Photo of experimental setup for consistency checking of relative humidity sensors with digital Assmann ventilation psychrometer. (b) Water applied to the wet bulb gauze in the Assmann psychrometer with a dropper for every 15 minutes.](image)

![Figure 5: Consistency checking of relative humidity measurement instruments.](image)
2.4. Air Velocity Instruments

The consistency reading of the Kanomax anemometer was checked by placing the needle probe into a mini handmade wind tunnel with 300 mm (width) × 300 mm (height) × 600 mm (length), as shown in Figure 7 (a). Figure 7 (b) shows a 80 × 80 × 25 mm DC axial fan (1.8 W 5 V) which was used to supply a constant air flow rate at approximately 1 m³/min in the wind tunnel.

Seven needle probes labeled as K1 to K7 were checked in this study. Measurement was taken for a duration of 5 minutes at a 5-second interval. Figure 8 shows the mean value with standard error bars of air velocity recorded from each needle probe. The results of the consistency checking illustrated by the time-series plots are shown in Figure 9. The mean values of all measurement results ranged between 3.24 and 3.50 m/s with the standard deviation values between 0.07 and 0.1.

Figure 7: (a) Experimental setup for verification of air velocity sensors. (a) Consistency check on air velocity instruments using a mini handmade wind tunnel, (b) 5V DC axial fan.

Figure 8: Box plot with the mean value and standard error bars of air velocity for all the probes. The difference between 25% and 75% quartile for all probes range from 0.10 to 0.15 m/s.
### 2.5. Outdoor Air Temperature Instruments

When the Hobo thermo recorder was used in outdoor measurement, the external sensor was housed in a fan aspirated solar shield, as shown in Figure (a). Figure 10 (b) shows the assembled solar shield which is wrapped with aluminium foil. This was to prevent any direct or indirect solar radiation to the sensor, which will otherwise affect the accuracy of the measurements. A 12 V DC fan was used to allow adequate airflow to ventilate the sensor and enable contact with atmospheric air at ambient temperature.

![Diagram of the fan aspirated solar shield](image)

![Image of the assembled solar shield](image)

Figure 10: Construction of the fan aspirated solar shield. (a) Components of the fan aspirated solar shield, (b) Assembled solar shield wrapped with aluminium foil.

Seven units of fan aspirated solar shields were tested on the consistency of measurements, all of which were placed in an outdoor environment as shown in Figure . Measurement was taken in a one-minute interval started from 22:00 until the next day at 18:00, for a duration of 20 hours. This time duration covered the daytime and nighttime periods with different outdoor air temperatures.
Figure 11: Consistency checking on fan aspirated solar shields labeled 1 to 7.

The result of the consistency checking represented by the time-series plot is shown in Figure 1. The mean values of all measurement results ranged from 25.3 to 25.6°C with the standard deviation values ranged from 1.04 to 1.08.

Figure 12: Comparison between seven solar shields on the measured outdoor air temperature.

3. Conclusion

The objective of this study which was to propose the simple procedure for consistency check on four groups of instruments (i.e. indoor air temperature, outdoor air temperature, relative humidity, and air velocity) used in thermal environment measurement was achieved. The results showed that all air temperature instruments had a strong correlation, with the high coefficient of determination i.e. $R^2 > 0.98$. The high value of the coefficient of determination ($R^2 > 0.97$) was also proven for the relative humidity instruments. However, the mean values of all air velocity instruments ranged from 3.24 to 3.40 m/s with the standard deviation from 0.07 to 0.1. The mean values for all measurements of the outdoor air temperature instruments ranged from 25.3°C to 25.6°C, with the standard deviation ranged from 1.04 to 1.08. The proposed simple procedure managed to verify the consistency of all instruments used in thermal environment measurement. The simple procedures of verification carried out in this study shall be recommended as the standard procedures for the field measurement on thermal environment.

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