

RESEARCH ARTICLE

Air temperature dependencies on the structure of thermometer screens in summer at Daejeon, South Korea

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Abstract

Results and accuracy of air temperature measurements made by meteorological thermometers hosted in thermometer screens strongly depend on the structure of the thermometer screen itself. In this study, the experiment was designed and conducted to understand the effect of radiation on air temperature observation. In order to control radiation sensitivity of thermometer screen, an umbrella made of Al alloy was installed over the thermometer screen (KTU). Air temperatures measured from five thermometer screens have been studied for several weather conditions using a 2-month field experiment at Korea Research Institute of Standards and Science (KRISS). The experiments comprised two version of KRISS type, which artificially ventilated thermometer screen (KTE and KTU) and three naturally ventilated round-shaped multi-plate thermometer screens (BT1, BT2, VT). The results showed that the air temperature of the KTU was approximately 0.10–0.50°C lower than the other group of thermometer screens without an umbrella, which blocked direct solar radiation. During the night, the umbrella minimizes the longwave energy from the KTU to the atmosphere. So the air temperature was roughly 0.10–0.18°C higher than that of the other group without the umbrella. It is confirmed that the umbrella installed over the thermometer screen minimizes the radiation sensitivity of the thermometer screen, and it has a significant effect on air temperature measurements.

KEYWORDS

air temperature, artificially ventilated, naturally ventilated, radiation, radiation sensitivity, thermometer screen, umbrella

1 | INTRODUCTION

In meteorology, air temperature is observed by mounting a thermometer on the thermometer screens (WMO, 2008). The main functions of thermometer screens are to protect the thermometer from direct or indirect solar

radiations during the day and radiation from the thermometer towards the sky at night (Mawley, 1897), and wetting (van der Meulen & Brandsma, 2008). Wetting of the thermometer and thermometer screen is caused by rain, drizzle, or fog, which causes a negative bias as the thermometer starts acting like a wet-bulb thermometer

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(van der Meulen & Brandsma, 2008). Therefore, while observing the air temperature, a thermometer screen is used to reduce the measurement errors caused by external factors. There has been advancement in technology; however, learning how to observe accurate air temperatures is still challenging (Lopardo et al., 2014). Thermometers have international traceability when calibrated as per the ‘International temperature scale of 1990’. However, the thermometer screen does not have traceability since international guidelines exist to have uniformity in measurement (WMO, 1996), and internationally standard thermometer screens do not exist. Therefore, a thermometer screen with various structures is designed and used to observe air temperature (van der Meulen & Brandsma, 2008). However, the thermometer screens of various designs have different structures, therefore, they have their thermal characteristics (Coppa et al., 2021). While observing the temperature, the inherent thermal characteristics of the thermometer screen get influenced, causing differences between the structures of the thermometer screen even in the same weather station (WS) (Aoshima et al., 2010).

Previous studies have demonstrated that since the thermal characteristics of the thermometer screen differ depending on the structure of the thermometer screen, comparability among different systems and screen designs is reduced and uncertainty increased. Therefore, this study minimizes errors with respect to values considered closer to the ‘true value’ of the measurand, while observing temperature. In this study, the measurement

error that occurs while observing the air temperature was considered to be the biggest cause of heating and cooling inside the thermometer screen by radiation energy. Therefore, to determine whether this idea is true, an umbrella capable of controlling radiant energy was installed at the WS, the experimental site of this study, to observe the air temperature.

In this study, we drew an intercomparison of a set of thermometer screens for the air temperature in South Korea in summer. In the experiment, three types of thermometer screens were compared (two Korea Research Institute of Standards and Science [KRISS] types, two BARANI types, and one VAISALA type). All the thermometer screens were operated for the same period.

The emphasis in this paper was laid on understanding the solar radiation energy in summer temperature differences between the thermometer screens. This paper can help those who want to observe the air temperature value that is closest to the ‘truth’.

In Section 2 of this paper, we described the experimental set-up, calibration, and methodology. The thermometer screens are compared in Section 3, for conditions of clear, cloudy, and rainy days. Section 4 contains the Discussion and Conclusions.

2 | METHODOLOGY

The experiment was conducted in an approximately 2-month period between 9 July 2020, and 31 August

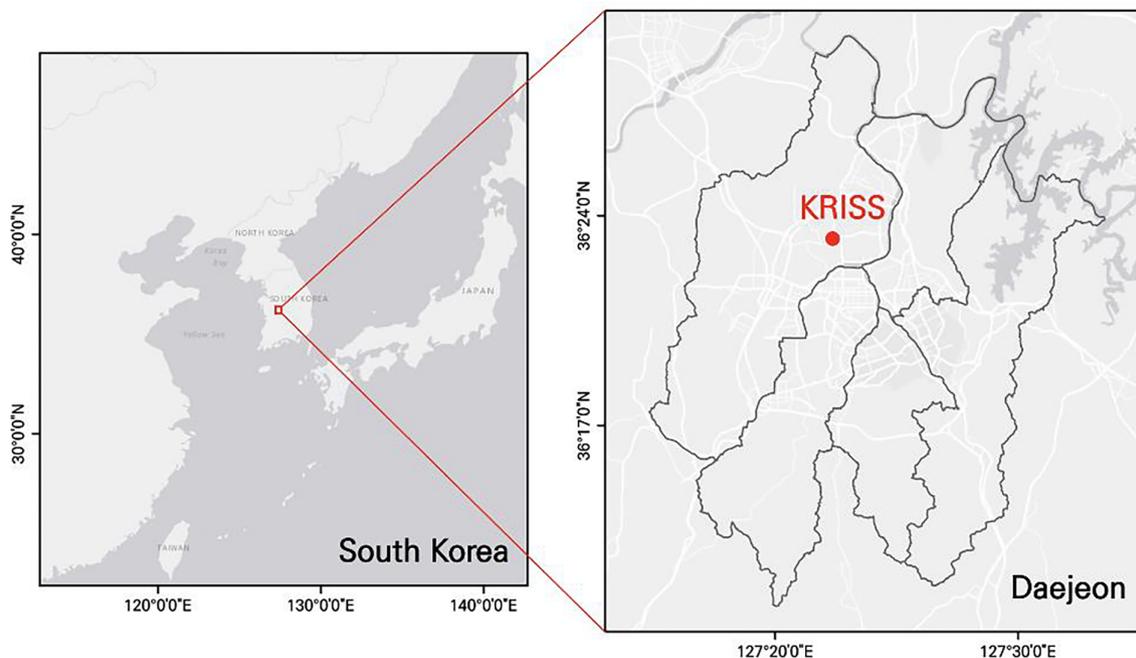


FIGURE 1 Location of weather station (WS) at Korea Research Institute of Standards and Science (KRISS)

2020 at the WS of KRISS in Daejeon (Figure 1). The measurements were performed on flat open terrain with shortcut grass cover, sufficiently far from major obstacles like building, forests, or lakes, which could give unpredictable impacts. WS and artificial obstacles have a distance of at least over 30 m, which corresponds to class 2 of WMO.

The experiment compared five thermometer screens. Figure 2 presents an overview and sectional drawing of the WS. Figure 3 presents detailed pictures of thermometer screens and Figure 4 presents a sectional drawing of the thermometer screens. All thermometer screens were mounted at a position of 1.5 m above ground to minimize the effect on heating and cooling by radiation from the ground (WMO, 2008). Additionally, to reduce each other's influence within the same place, they were mounted in shape such as Figure 2 at a distance of at least 60 cm from each other.

Table 1 presents some details of the screens and thermometers in this test. The abbreviations for the screens in this table are used throughout this paper. In this experiment, to examine the mutual difference of ventilation in thermometer screens, we used artificially ventilated thermometer screens (KRISS type under umbrella and a second KRISS type exposed outside the

umbrella protection) and natural ventilated thermometer screens (BT and VT). The interior of all the thermometer screens is black to absorb heat energy, which affects the thermometer. Additionally, artificially and naturally ventilated thermometer screens were used to confirm the difference in circulation inside the thermometer screens.

2.1 | KRISS type of thermometer screens

Figures 3 and 4 present the KTU and KTE used in this experiment. KRISS type is an artificially ventilated thermometer screen produced by the KRISS for this study. It uses ceramic wool insulators as built-in materials for parts of the body coloured in Figure 5a. This is a way to prevent heat exchange with the outside environment. Additionally, the insulators used are characterized by low density, low heat storage, low heat loss, low thermal conductivity, and excellent insulation. One of the major features of the KRISS type is that, unlike the commonly used artificially ventilated thermometers screen, the fan used for ventilation is located at the bottom of the thermometer screen. The role of

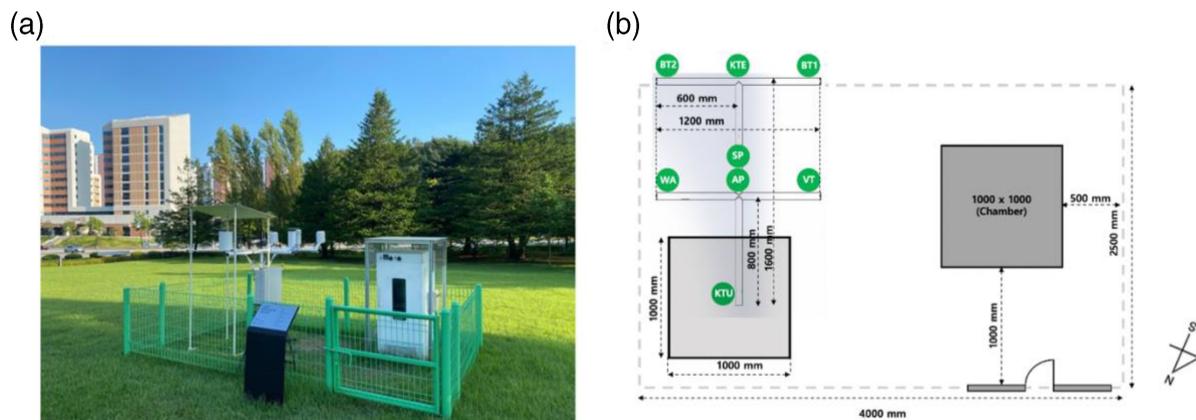


FIGURE 2 Experimental set-up for weather station (WS): (a) overview of WS; (b) sectional drawing of WS

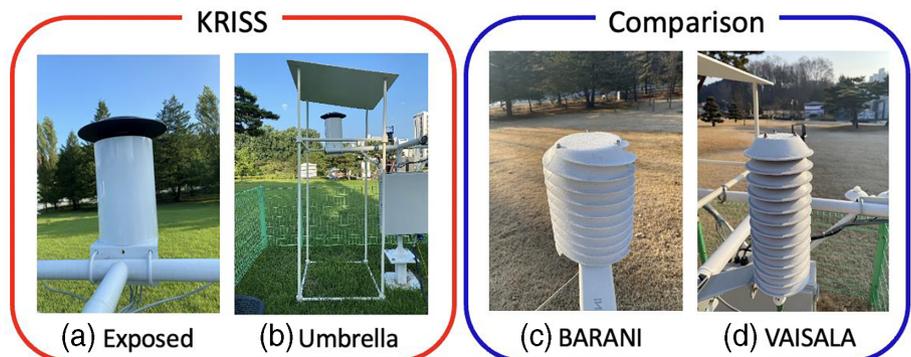


FIGURE 3 Overview of thermometer screens: (a) Korea Research Institute of Standards and Science (KRISS) type exposed, (b) KRISS type with umbrella, (c) BARANI type, and (d) VAISALA type

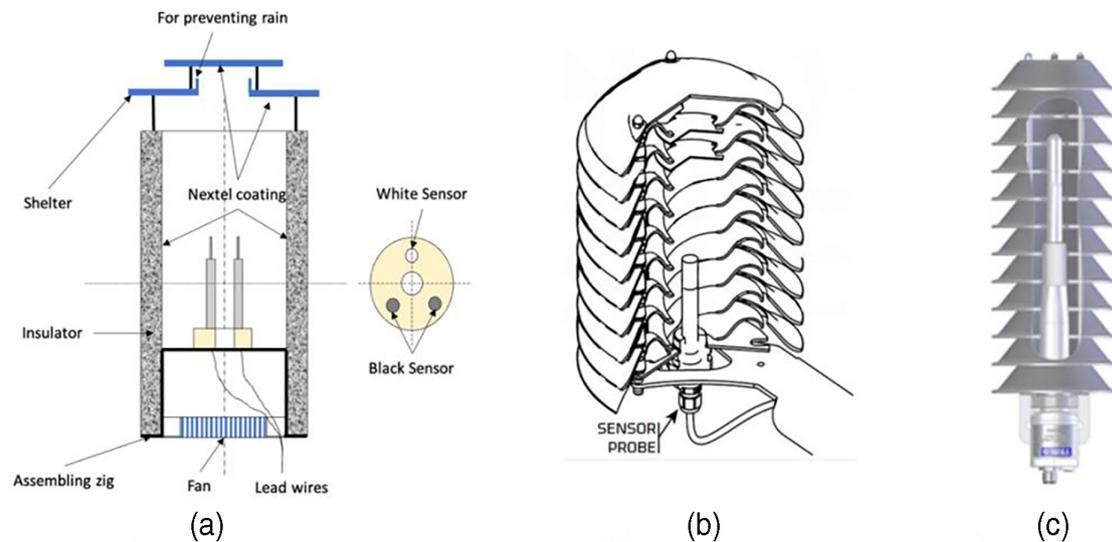


FIGURE 4 Sectional drawings of thermometer screens: (a) Korea Research Institute of Standards and Science type, (b) BARANI type, and (c) VAISALA type

TABLE 1 Details of temperature measurements

Type	KRISS		BARANI		VAISALA
Abbreviation	KTE	KTU	BT1	BT2	VT
Manufacturer	KRISS	KRISS	BARANI DESIGN	BARANI DESIGN	VAISALA
Model	KRISS	KRISS	MeteoShield Pro	MeteoShield Pro	DTR503A
Ventilation Installed thermometers	Artificial 3 (1 typical, 2 black)	Artificial 3 (1 typical, 2 black)	Natural 1 (typical)	Natural 1 (typical)	Natural 1 (typical)
Installation method	Exposed	Umbrella	Exposed	Exposed	Exposed

the fan is to circulate air inside of the KRISS type from top to bottom. In addition, the fan has a flow rate of 2 m/s and reduces errors caused by internal heating secondary to radiation generated on the thermometer screen (Brock et al., 1995).

To investigate the effects of radiation on temperature observation, one of the KRISS types was placed under an umbrella and designated as KTU. The umbrella has a square shape with width of 1000 and 5 mm thick, made of Al alloy. In addition, the umbrella is designed to have a tilt northward to effectively block direct solar radiation energy. Furthermore, in order to minimize the effect of turbulence caused by the umbrella, it was installed at a distance of 250 mm from the KRISS type (KTU).

The thermometer screen under the umbrella is expected to correct errors caused by various weather phenomena, such as conditions of rainfall and dew in the morning and radiation reaching the surface of the thermometer screen during the day (Figure 5).

2.2 | Thermometer and calibration

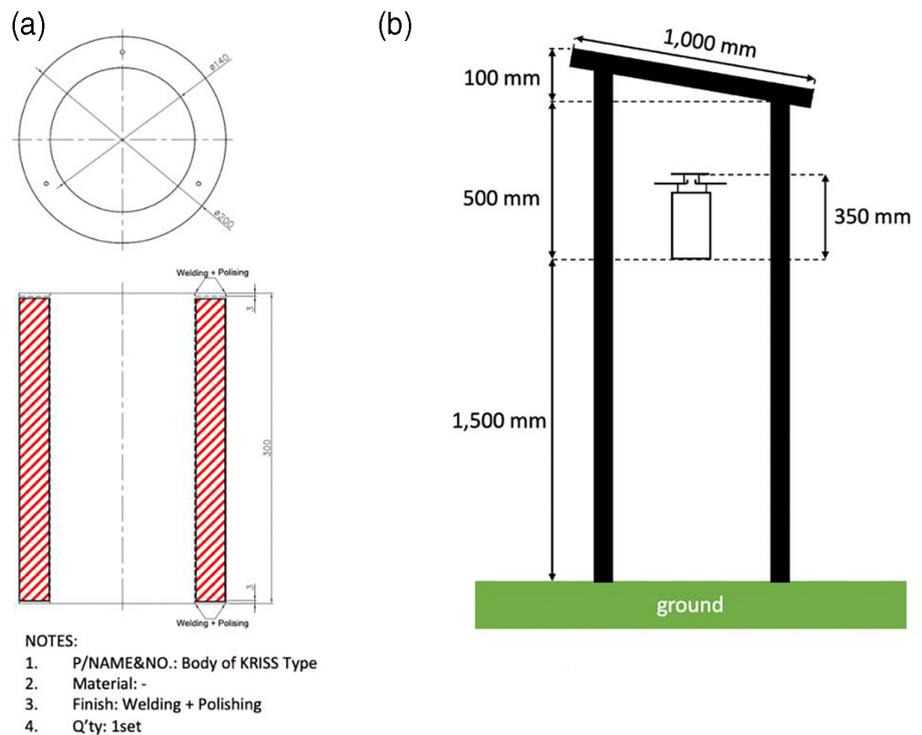
Five thermometers were used in this experiment, all of which were four-wired platinum (Pt)-resistance thermometers. This is the most widely used thermometer, indicating a resistance of 100 Ω at 0°C. Thermometers used for KRISS types (KTU and KTE) and BARANI types (BT1 and BT2) were mounted a GHM's GTF111-P-D. In contrast, the VAISALA type was mounted a VAISALA's HMP-155.

The calibration uncertainty of the temperature measurements (GTF111-P-D and HMP-155) is 0.05°C ($k = 2$). This was satisfied with the measurement of air temperature in line with WMO regulation, indicating the same temperatures when the ambient conditions were the same.

2.3 | Data

Air temperature is sampled and archived instantly every minute with a resolution of '0.00390 Ω ' (0.01°C). In addition,

FIGURE 5 Details of Korea Research Institute of Standards and Science (KRISS) type: (a) sectional drawing of KRISS Type's body; (b) sectional drawing of umbrella from the side



the same thermometer screen was used for all BARANI types, the mounted thermometer was the same, and the average values of BT1 and BT2 were used to indicate the same temperature under any theoretical conditions. Unless stated otherwise, 10-min mean air temperature values are used in the analysis. This averaging period was selected to minimize the local spatial differences of the true air temperature secondary to small-scale turbulence (occasionally greater than $0.5^{\circ}\text{C}/\text{min}$) (van der Meulen & Brandsma, 2008). To study the effects of other meteorological elements on the air temperature difference between the thermometer screens, the following operationally measured elements at the 'Daejeon Regional Office of Metrology', located approximately 2 km away from WS were used: Cloud cover 'N' and Precipitation 'prcp'. Furthermore, wind speed 'u', radiation 'k', and anemometer 'pa' were measured in WS. WS observed metrological data, and the data from the Daejeon Regional Office of Metrology represented local data. Thus, the elements used in the analysis were representative of this WS.

2.4 | Methodology

In the remaining paper, we focused on understanding the radiation-dependent air temperature difference between the thermometer screens, with their different structures. In Section 3.1, we defined a working reference thermometer screen of the experiment. It was important to compare several thermometer screens quantitatively. In Section 3.2, we discussed the characteristics of the

thermometer screens for special conditions like sunrise and sunset, hot and clear days, fog, and rainfall.

3 | RESULTS

3.1 | Defining working reference of thermometer screen

We initially established a working reference thermometer screen to make quantitative comparisons between thermometers screens. According to ISO 17714:2008 (International Standard Organization, 2008), comparing two or more temperatures, thermometer screens, which observe low temperatures during the day and high temperatures at night, are considered closer to the 'true value' of the measured with minimal errors of radiation. Additionally, the ideal reference thermometer should respond rapidly without being interrupted by other factors (Lacombe, 2010). Thermometers that are shielded by a thermometer screen generally achieve these requirements. This was since it was necessary to react quickly to the temperature changes in the thermometer screen to accurately observe the temperature changes every minute. In addition, thermometer screens, which protect solar radiation energy and weather phenomena, such as rain, snow, dew, and frost, are most likely to measure the most accurate temperature from thermometers (Lacombe, 2010). Therefore, the working reference was selected from the thermometer screens used in the experiment according to these criteria.

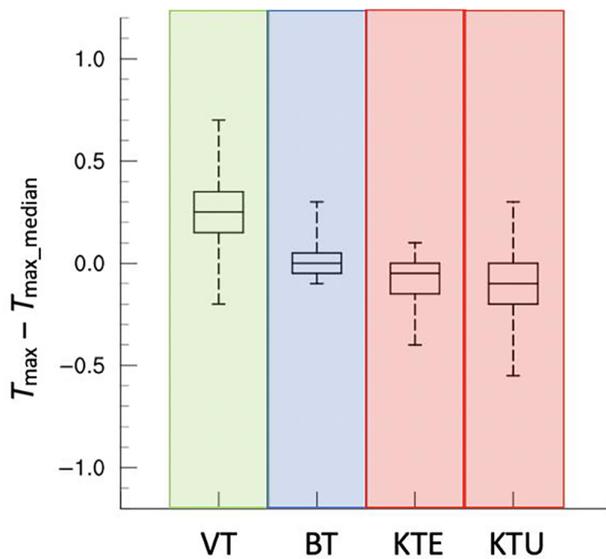


FIGURE 6 Defining a working reference

TABLE 2 Weather conditions according to the cloud cover based on the ASOS data provided by the Daejeon Regional Office of Meteorology, South Korea

	Cloud cover	Precipitation	Date
Clear	≤ 5	X	11
Cloudy	> 5	X	3
Rainy	Not applicable	O	37

Firstly, we observed the working reference by observing the daily maximum temperature (T_{\max}) for each thermometer screen to determine which thermometer screen indicated the lowest value when receiving the same amount of energy. Secondly, to exclude the excessively large or small T_{\max} values (spark), we observed the median of T_{\max} (T_{\max_median}) for each thermometer screen. Thirdly, to determine which thermometer screen recorded the lowest value during the day, we represented $T_{\max} - T_{\max_median}$ (ΔT) for each thermometer screen in boxplot (Figure 6). Figure 6 presents that ΔT has the largest value in VT and gradually decreased in the order of BT, KTE, and KTU. Therefore, in this experiment, the KTU with the lowest ΔT was selected as the working reference.

3.2 | Behaviour of thermometer screens for special conditions

In this experiment, solar radiation was the most important variable affecting the thermometer screens. Further, cloud cover determines the amount of solar radiation energy. Based on this, we categorized the experimental

period into three parts (Table 2) using cloud cover data provided by the Daejeon Regional Office of Meteorology.

3.2.1 | Clear day

It is well known that differences between thermometer screens are most significant on clear days with low wind speeds. Here, we discussed the differences between thermometer screens on clear days. A clear day was defined as a day with a mean hourly cloud cover under 5 in this study.

Figure 7 compares the screens for clear days that were average in every case during intercomparison periods. The figure presents a distinct behaviour of the control group (T : observed air temperature inside of the KTE, BT, VT) and working reference (T_{ref} : Observed air temperature inside of KTU). And these thermometer screens present a noisy pattern during the entire day, albeit mainly positive values during daytime and negative values at night-time. The control group presented similar observations. Before sunrise, the control group mainly presented negative values owing to the umbrella. The role of the umbrella at that time was to prevent radiation from KTU and minimize radiant cooling. During the daytime, the control group mainly presented positive values. Following sunrise, the radiation increased rapidly and the behaviour of the thermometer screen began to change. The tilt of the $T - T_{\text{ref}}$ was determined by the radiation sensitivity (thermal properties) of the thermometer screen. VT had the largest tilt, and the temperature difference rose at a high speed. The temperature difference between BT and KTE increased at the same tilt after a time difference. Further, around 10 AM, the temperature difference with the control group stabilized and the tilt approached zero. The maximum temperature difference occurred near noon when solar radiation was most intense (VT's maximum difference was 0.51°C and KTE's maximum difference was 0.18°C). However, BT had a maximum value just before 6 PM (0.34°C). Before sunset and solar radiation decreased rapidly, the temperature difference between the control group and the KTU decreased rapidly. During the daytime, behaviour of the thermometer screen varied the most depending on the umbrella. The role of the umbrella in the daytime was to prevent solar radiation from contacting the surface of the thermometer screen and prevent the inside from becoming heated. After sunset, the difference from the KTU was similar to before sunrise, secondary to less solar radiation. The negative phase of KTE in the morning was believed to be owing to dew. The KTU observed high temperature while preventing umbrellas from falling into the sky and cooling caused by the evaporation of dew.

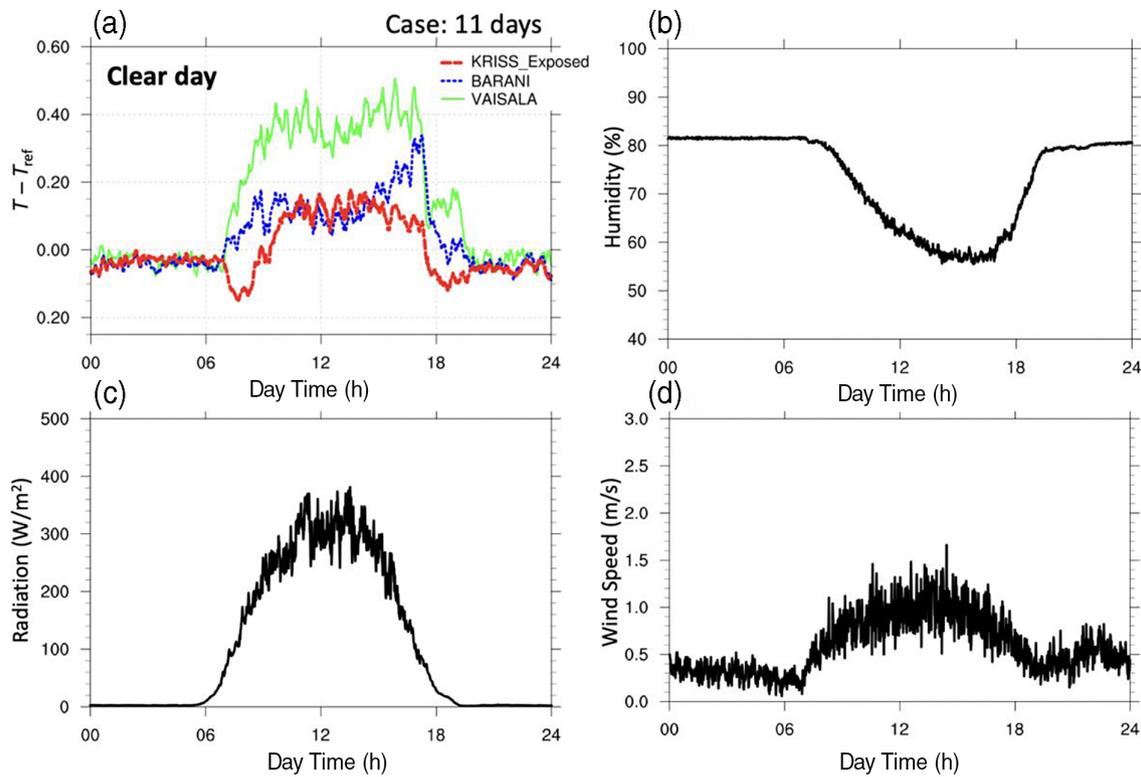


FIGURE 7 Temperature differences for clear days (T_{ref} : Observed air temperature inside of KTU). The figure also presents the relative humidity: Rh, solar radiation: K, and wind speed: U.

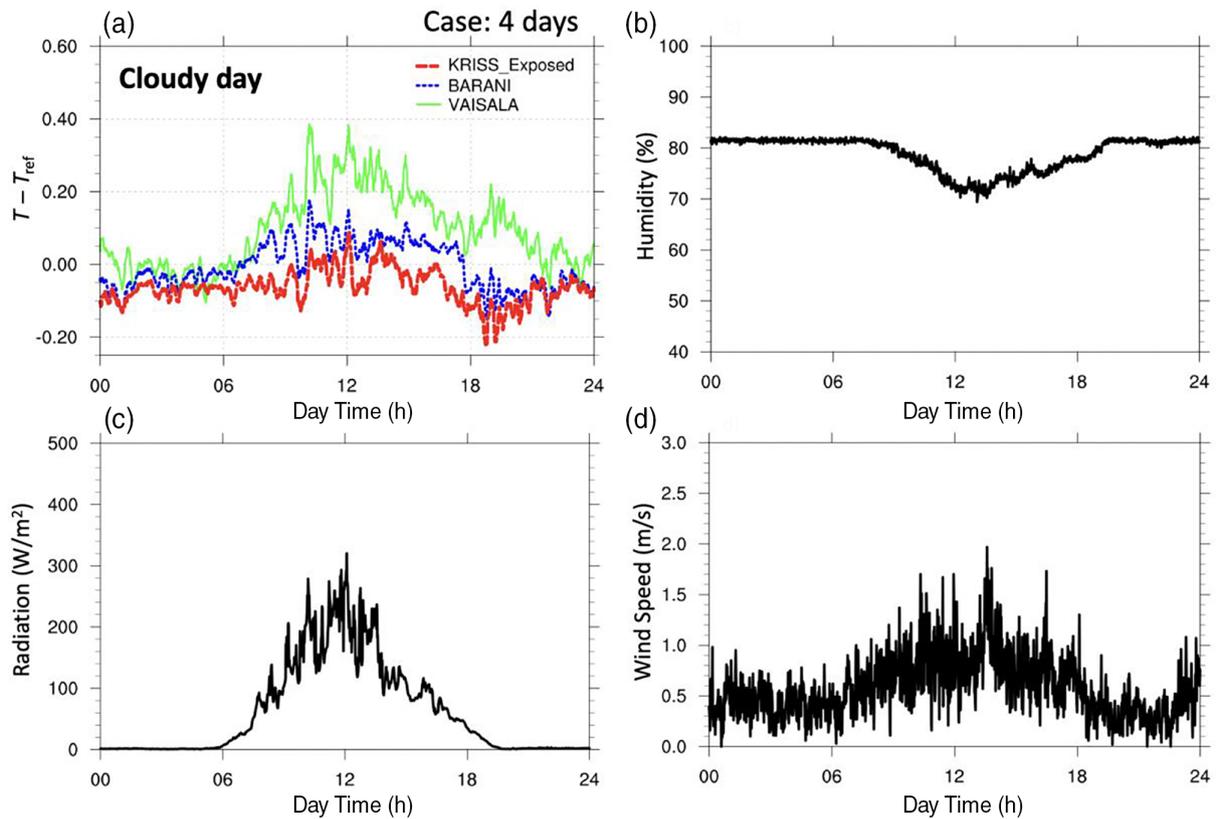


FIGURE 8 Temperature differences for cloudy days (T_{ref} : Observed air temperature inside of KTU). The figure also presents the relative humidity: Rh, solar radiation: K, and wind speed: U.

3.2.2 | Cloudy day

Cloudy days may have an effect on the thermometer screen owing to solar radiation absorbed or reflected by clouds, reducing the amount of solar radiation entering the surface of the thermometer screen. Here, we discussed the differences between thermometer screens for cloudy days. In this study, a cloudy day was defined as a day with a mean hourly cloud cover of over 5 according to ASOS data at Daejeon Regional Office of Metrology.

Figure 8 compares the screens for cloudy days. The figure presents a similar pattern to that of a clear day. However, the quantitative value moved downwards compared with that of a clear day. Therefore, the maximum temperature difference is lower than that on clear days (VT was 0.39°C, BT was 0.18°C, and KTE was 0.09°C). The difference compared with clear days was KTE. The difference between KTE and KTU was mainly negative values during the day. This phenomenon was believed to be owing to radiant cooling and the umbrella. Radiant cooling always occurred. It happened more during the daytime than at night. The radiation from KTU was prevented by the umbrella. So, KTU minimized the influence of radiant cooling. However, KTE continued to release radiation into the sky. Therefore, KTE observed a lower temperature than KTU for all the cloudy days. In

contrast, BT and VT had stronger internal heating by solar radiation than radiant cooling, therefore, having mainly positive values during daytime.

3.2.3 | Rainy day

Rainy days were selected through the ASOS precipitation data. The day of precipitation observed in Daejeon Regional Office of Metrology above 0.0 mm was selected as rainy days. In addition, precipitation was extracted only during rainy days and used for analysis.

Figure 9 compares the thermometer screens for rainy days. The figure depicts precipitation that contacted the surface of thermometer screens such as the control group and evaporates of precipitation effect to air temperature observation. All the control groups presented mainly negative values almost every day due to the absence of the umbrella. The umbrella prevented contacting precipitation on KTU's surface and prevented cooling. Furthermore, cooling caused by evaporation was prevented. In addition, it prevented solar radiation from heating inside of KTU and blocked the factors that had the largest influence on temperature observations in this experiment. However, owing to high radiation sensitivity, VT was observed to be higher or same than KTU from 12 AM to 6 PM. On rainy day

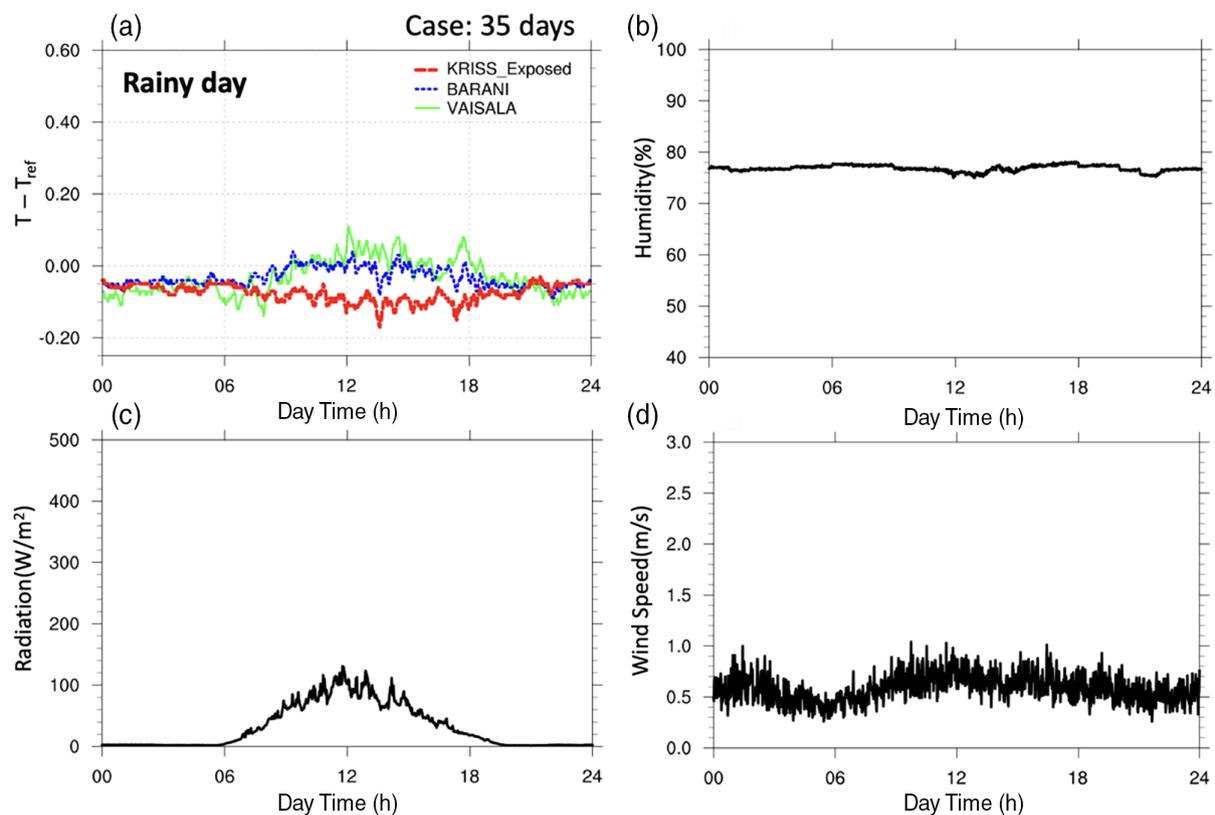


FIGURE 9 Temperature differences for rainy days (T_{ref} : Observed air temperature inside of KTU). The figure also presents the relative humidity: Rh, solar radiation: K, and wind speed: U.

days, the maximum differences between the KTU were 0.19°C for VT, 0.03°C for BT, and −0.04°C for KTE. In addition, the minimum differences were −0.11°C for VT, −0.08°C for BT, and −0.04°C for KTE.

4 | DISCUSSION AND CONCLUSIONS

We compared five air temperatures depending on the structures of the thermometer screen. An important aspect of the study was the thermometer screen with an umbrella. Our results demonstrated that the thermometer screen can roughly be classified into three groups with distinct behaviour: (1) the artificially ventilated thermometer screen with an umbrella (KTU); (2) the artificially ventilated thermometer screen was exposed (KTE); and (3) the naturally ventilated thermometer screen was exposed (BT and VT). The artificially ventilated thermometer screen with an umbrella was influenced by the umbrella. The umbrella blocked the factors that influenced the air temperature observation.

The umbrella prevented solar radiation from contacting the surface of the thermometer screen during the daytime. Hence, the umbrella can minimize heating inside of thermometer screen, and the differences were 0.1–0.5°C. Radiations from the thermometer screen were also prevented at night and radiant cooling was minimized (0.1–0.23°C). In the morning, the umbrella prevented dew from falling at the dewpoint and prevented cooling (0.1–0.18°C) caused by dew and evaporation of dew. Furthermore, the umbrella prevented precipitation-induced cooling by preventing precipitation from falling on the thermometer screen and cooling when it evaporated (0.07–0.12°C).

Our results suggest that solar radiation is a major factor involved in determining thermometer screen temperature differences. Additionally, we confirmed that an umbrella can block factors interfering with air temperature observation.

We only used summer data and could not analyse snow conditions. Therefore, we need to confirm how umbrellas affect air temperature observation in certain snow conditions. So we will report the effects of thermometer screen structure on air temperature measurement in winter.

AUTHOR CONTRIBUTIONS

Jae-Woo Park: Conceptualization (supporting); data curation (supporting); formal analysis (equal); methodology (supporting); project administration (equal); software (equal); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Joo-Wan Kim:** Formal analysis (equal); visualization (supporting); writing – review and editing (supporting). **Sungjun Lee:** Data curation

(lead); software (equal). **Yong-Gyoo Kim:** Conceptualization (lead); formal analysis (equal); methodology (lead); project administration (lead); visualization (supporting); writing – review and editing (supporting).

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REFERENCES

- Aoshima, T., Nakashima, K., Kawamura, H., Kumamoto, M., Sakai, T. & Kawano, S. et al. (2010). RIC-Tsukuba (Japan) intercomparison of thermometer screens/shields in 2009–2010. In: WMO technical conference on meteorological and environmental instruments and methods of observation.
- Brock FV, Semmer SR & Jirak C 1995 Passive solar radiation shields: wind tunnel testing. In: 9th Symposium on Meteorological Observations and Instrumentation. American Meteorological Society: Charlotte, North Carolina, pp. 179–183.
- Coppa, G., Quarello, A., Steeneveld, G.J., Jandrić, N. & Merlone, A. (2021) Metrological evaluation of the effect of the presence of a road on near-surface air temperatures. *International Journal of Climatology*, 41(6), 3705–3724.
- International Standardization Organization. (2008) ISO 17714: 2008. Meteorology—air temperature measurements—test methods for comparing the performance of thermometer shields/screens and defining important characteristics, 1st ed.
- Lacombe, M. (2010) Results of the WMO intercomparison of thermometer screens/shields and hygrometers in hot desert conditions. In: *Proceedings of the TECO-2010—WMO technical conference on meteorological and environmental instruments and methods of observation, Helsinki, Finland* (vol. 30).
- Lopardo, G., Bertiglia, F., Curci, S., Roggero, G. & Merlone, A. (2014) Comparative analysis of the influence of solar radiation screen ageing on temperature measurements by means of weather stations. *International Journal of Climatology*, 34(4), 1297–1310.
- Mawley, E. (1897) Shade temperature. *Quarterly Journal of the Royal Meteorological Society*, 23(102), 69–87.
- van der Meulen, J.P. & Brandsma, T. (2008) Thermometer screen intercomparison in De Bilt (The Netherlands), Part I: understanding the weather-dependent temperature differences. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 28(3), 371–387.
- WMO Guide (1996) Guide to meteorological instruments and methods of observation.
- WMO.int. (2008) *Guide to meteorological instruments and methods of observation (“CIMO guide”)*, WMO guide 8, 7th edition. WMO: Geneva. Available at: https://community.wmo.int/activity-areas/imop/wmo-no_8

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