RIC-Tsukuba (Japan) Intercomparison of Thermometer Screens/Shields in 2009 – 2010

AOSHIMA Tadayoshi, NAKASHIMA Kouichi, KAWAMURA Hiroshi,
KUMAMOTO Mariko, SAKAI Takeshi, KAWANO Saeko and JOKO Minoru
RIC-Tsukuba, Japan Meteorological Agency (JMA)
1-2 Nagamine, Tsukuba City, Ibaraki, 305-0052 Japan
E-mail: aoshima@met.kishou.go.jp

Abstract

In recent years, many types of screens/shields for temperature measurement equipment have been designed. In conjunction with such developments, WMO and National Meteorological Services have organized intercomparisons of a range of screens/shields to clarify their characteristics in the interests of ensuring the quality of temperature observation data.

RIC-Tsukuba performed a characteristic investigation involving the intercomparison of six kinds of artificially ventilated thermometer screens/shields and four kinds of naturally ventilated thermometer screens/shields in Tsukuba from 1 August 2009 to 30 April 2010. With the artificially ventilated screens/shields, some differences were seen in the influence of global solar radiation from the variety of structures used, while the horizontal artificially ventilated screen/shield type was affected by rain as raindrops remained on it. With the naturally ventilated screens/shields, a maximum difference of +3.4°C was seen from the influence of global solar radiation, and some such screens/shields were affected by rain, as raindrops remained on plates or entered between them depending on their structure. From these evaluation results for various screen/shield types, RIC-Tsukuba drew up a comparative table and radar charts classified in terms of rank for the effects of various meteorological elements.

1. Introduction

To aid accurate measurement of air temperature, various screens/shields have been designed and used to protect thermometers from sunshine, radiation, rain and wind and so on.

The CIMO Guide (WMO, 2008) recommends that a radiation shield or screen should be designed to provide an enclosure with an internal temperature that is both uniform and the same as that of the outside air, and adds that screens with forced ventilation, in which air is drawn over the thermometer element by a fan, may help to avoid biases when the microclimate inside the screen deviates from the surrounding air mass. As a shield material, highly polished, non-oxidized metal is favourable because of its high reflectivity and low heat absorption. Nevertheless, thermally insulating plastic-based material is preferable because of its simple maintenance requirements. In this case, thermally insulating material must be used if the system relies on natural ventilation.

RIC-Tsukuba performed a characteristic investigation involving the intercomparison of six kinds of artificially ventilated thermometer screens/shields and four kinds of naturally ventilated thermometer screens/shields in Tsukuba. These screens/shields were selected from among those that have been used in operational synoptic observation and AWS and are available commercially in Japan.

Japan is located in the mid-latitudes in East Asia as shown in Fig. 1. Tsukuba has a temperate rainy climate and high temperatures in summer (Cfa) according to the Köppen-Geiger climate classification. In winter there are many clear days and the climate is cold and dry because of the Siberian anticyclone, while in summer the climate is hot and humid from the influence of the Asian monsoon. There is a rainy season (known as the Baiu) from June to July. Between August and October, typhoons pass and bring heavy rain. The temperature and precipitation climatological normals for Tsukuba during the period 1971 – 2000 are shown in Fig. 2.

2. Intercomparison Overview

2.1 Type of screens/shields tested and sensors

The screens/shields used in the examination were chosen from among types with different ventilation methods (artificial or natural), shapes (vertical type, horizontal type) and materials through marketing research in Japan.

Table 1 shows the main characteristics of the screens/shields involved in the experiment. Here, naturally ventilated screens/shields are indicated with (N) and artificially ventilated screens/shields with (A). In this experiment, the louvered screen was the Japan Meteorological Agency's Type I model (expressed as JMA-W1(N)), which is larger than the Stevenson screen. JMA-W1(N) measures about a square meter, and all of the louvers of the lower parts, the roof and the side have a dual structure.

The experiment was carried out on a test field of RIC-Tsukuba in reference to the examination conditions outlined in ISO 17714. To avoid any artificial influence on air temperature, the distance from heat sources and buildings was set to at least 20 m, and the distance between each screen/shield was at least 2 m. Photo. 1 shows the location of the screens/shields in the intercomparison field, and Photo. 2 shows the screens/shields themselves.

In addition, various thermometers are offered with screens/shields by their manufacturers. In this experiment, the standard thermometer was a Pt 100 Ω (3 mm in diameter) to allow evaluation of their basic performance free of influence from differences between thermometers themselves. The instrument error of each thermometer was pre-compensated by a correction value. For the artificially ventilated screens/shields, the ventilation speed was measured using a Pitot tube. Table 1 shows the results of this measurement and the manufacturer's specifications. The investigation periods were in the summer season from 1 Aug. 2009 to 2 Sep. 2010 and in the winter and spring seasons from 18 Nov. 2009 to 30 Apr. 2010.

2.2 Data and method

To allow comparison of screen performance, JMA-95 type screens/shields (as used in operational synoptic stations by JMA (type name JS-258), expressed here as JMA-95(A)) were adopted as the reference standard. The data sampling interval was every 10 seconds, and data comparison was performed using 10-sec. data (the average of six 10-second momentary data for a minute; referred to below as 10-sec. data). The middle values of 10-minute periods calculated from the moving average of every one minute 10-sec. data for 10 minutes are referred to as 10-min. mov. ave. data.

The temperature difference between the test screens/shields and the reference is called the deviation of temperature (referred to below as Tdev).

3. Results

3.1 Statistical values

Fig. 3 shows the Tdev values of the maximum temperatures for August 2009 (summer) and the minimum temperatures for January 2010 (winter) along with the daily average temperatures for six months (August, December, January, February, March and April) from the 10-sec. data for each screen. Table 1 shows Tdev in a range between 25% and 75% assuming that the maximum value is 100% and the minimum is 0%.

Among the Tdev values of the maximum temperatures for various screens/shields in August (summer), the positive value for AV-040(N) is the largest at +1.8°C (Fig. 3 (a)). The second largest is +1.1°C for YG-41003L(N), the third is +0.9°C for PFT-02(N), and the fourth is +0.7°C for PVC-02(N). Among the average Tdev values of minimum temperatures for January (winter), the negative value for AV-040(N) is the largest at −0.5°C, the second largest is −0.4°C for DTR503A(N), and the third is −0.3°C for YG-41003L(N) and PFT-02(A) (Fig. 3 (b)). Tdev is small for JMA-W1(N), TV-150(A), JS-256(A) and E-834-Z1(A). Among the Tdev values for the daily mean temperature in the six months, the positive value for AV-040(N) is the largest at +0.5°C, and the second largest is +0.3°C for YG-41003L(N), JMA-W1(N) and PFT-02(A) (Fig. 3 (c)).

3.2 Influences of global solar radiation

Tdev was examined in relation to global solar radiation for August. Fig. 4 shows Tdev for the 10-sec. data related to mean global solar radiation for 1 minute depending on each screen. Table 1 shows Tdev in a range between 25% and 75% assuming that the maximum value is 100% and the minimum is 0% when global solar radiation is 700 W/m^2 or more.

There is little influence from global solar radiation on JS-256(A) and E-834-Z1(A). The screen for which the positive Tdev is the most remarkable with increased global solar radiation is AV-040(N), followed by YG-41003L(N), PFT-02(A), PVC-02(A) and JMA-W1(N). The positive Tdev values of the three naturally ventilated screens/shields other than JMA-W1(N) vary widely, and the negative values vary narrowly.

In terms of daily variation, Fig. 5 shows values for 16 August 2009 (when the solar radiation and maximum temperature were high) as follows: (a) 10-sec. temperature data for all screens/shields, (b) Tdev for the naturally ventilated screens/shields, (c) Tdev for the artificially ventilated screens/shields, and (d) global solar radiation. For the naturally ventilated screens/shields, the maximum positive Tdev is +2.6°C for AV-040(N), +2.3°C for YG-41003L(N), +1.6°C for DTR503A(N) and +1.2°C for JMA-W1(N) (Fig. 5 (b)). Tdev for JMA-W1(N) varies less and follows later than that of the others. A positive Tdev is seen from sunrise to the daytime. For the artificially ventilated screens/shields, the maximum positive Tdev is +1.4°C for PFT-02(A), +1.1°C for PVC-02(A) and +0.8°C for PVC-03(A) (Fig. 5 (c)). The positive Tdev also decreases for screens/shields with both ventilation types at 8:00 – 9:00 (Fig. 5 (b), (c)) in line with the reduced global solar radiation at that time (Fig. 5 (d)).

3.3 Influences of radiation budget

The relationship between radiation budget and Tdev was examined for January (when radiative cooling is at its highest during the year) using the Tdev of the 10-min. mov. ave. data. Table 1 shows Tdev in a range between 25% and 75% assuming that the maximum value is 100% and the minimum is 0% when the radiation budget of the 10-minute average is −50 W/m^2 or less.

Fig. 6 shows the relationship between the radiation budget and Tdev for January (when radiative cooling has a major impact) and August (when its effect is minor). 10-minute Radiation budget data are calculated using 10-minute average data from 1-minute data*) for downward shortwave radiation, upward shortwave radiation, downward longwave radiation and upward longwave radiation. Tdev is the monthly mean of the 10-min. mov. ave. for every 10 minutes of the day.

Comparing the radiation budgets for August and January, a negative balance of –60 – −40 W/m² is seen from about 16:10 to 7:40 in January, and a change of the negative Tdev is seen for the naturally ventilated screens/shields other than JMA-W1(N) at about the same time. Tdev is larger for AV-040(N), DTR503A(N) and YG-41003L(N) in that order. Tdev for JMA-W1(N) changes late and gently, and the negative Tdev is small. Tdev for PFT-02(A), PVC-02(A) and PVC-03(A) is small, but a change is seen in this order at about the same time, and the negative Tdev for E-834-Z1(A), TV-150(A) and JS-256(A) is small and in the same degree. The radiation budget reaches its minimum at about 17:10 (around sunset), while Tdev for AV-040(N) reaches its minimum after this at about 19:00 – 20:00.

Comparing the daytime radiation budget changes for August and January shows that the peak at around 12:00 – 13:00 is about 400 W/m² in August and 300 W/m² in January, i.e., the August value is higher. Although the positive Tdev for PFT-02(A), PVC-02(A) and PVC-03(A) is larger in the daytime for August, the difference between the positive Tdev in the daytime and the negative Tdev at night is larger for the naturally ventilated screens/shields in January. The change is also remarkable for screens/shields with both types of ventilation before and after sunrise and sunset in January. On the other hand, the value for JMA-W1(N) changes late and gently.

*) Radiation data are collected at the Aerological Observatory adjacent to the observation field.

3.4 Influences of rainfall

The relationship between rainfall intensity classified by rainfall every 10 minutes and the Tdev for each screen was examined. Fig. 7 shows Tdev differences of the 10-min. mov. ave. related to rainfall intensity depending on each screen in the cases of 31 days when the total rainfall was 10 mm per day or more. Rainfall intensity was divided into seven classes from less than 0.5 mm to 7 mm or more for 10 minutes as shown by the index table in Fig. 7. Table 1 shows Tdev in a range between 25% and 75% assuming that the maximum value is 100% and the minimum is 0% when the rainfall intensity is Class 3 or higher (i.e., 2 mm or more for 10 minutes).

The more rainfall intensity increases, the more negative Tdev for DTR503A(N) becomes. Tdev for AV-040(N), PVC-02(A) and PFT-02(A) is small, but the same tendency is seen. There is little influence from rainfall intensity on JS-256(A), E-834-Z1(A), TV-150(A), YG-41003L(N) and JMA-W1(N).

In terms of daily variation, Fig. 8 shows values for 10 August 2009 and Fig. 9 shows those for 31 August 2009, when rainfall intensity were Class 3 or higher for hours, as follows: (a) 10-sec. temperature data for all screens/shields, (b) Tdev for the naturally ventilated screens/shields, (c) Tdev for the artificially ventilated screens/shields, and (d) global solar radiation. For the naturally ventilated screens/shields, the maximum positive Tdev is +2.6°C for AV-040(N), +2.3°C for YG-41003L(N), +1.6°C for DTR503A(N) and +1.2°C for JMA-W1(N) (Fig. 5).

For the two rainy days with rainfall periods of Class 3 or higher (i.e., 2 mm or more for 10 minutes), Fig. 8 shows a time series of the temperatures for various screens/shields and meteorological data from 10 Aug. 2009 (wind speed 0 – 2 m/s), and Fig. 9 shows the same values for

31 Aug. 2009 (wind speed 3 – 4 m/s).

As shown in Fig. 8, a negative Tdev of between −0.5 and −0.2°C for DTR503A(N) in (b) is seen continuously after the rain stopped. A negative Tdev of around −0.2°C is seen for AV-040(N) after 2:00 when the rainfall intensity is 10 mm/h or more in (e), and this tendency continues until past 8:00 when global solar radiation grows stronger. As shown in Fig. 9, the maximum negative Tdev is −0.5°C for DTR503A(N) in (b) in response to harder rainfall at around 8:00 – 9:00, and at around 13:00 when the rainfall intensity reaches 10 mm/h or more.

3.5 Comprehensive evaluation

Comprehensive evaluation for each screen/shield in this experiment is shown in Table 1. This evaluation was carried out using the recommendation based on achievable measurement uncertainty for air temperature of 0.2°C from the operational measurement uncertainty requirements and instrument performance prescribed in the CIMO Guide (WMO, 2008). Positive Tdev is shown in pink and negative in light blue for cases more than ±0.2 °C. Fig. 10 shows radar charts presenting the experiment results based on rank according to each meteorological element.

In addition, based on the information derived from test operation, Table 2 shows the results of comparing cost performance, maintenance and weather resistance.

4. Discussion

(1) **Influences of global solar radiation:** For the naturally ventilated screens/shields, a maximum positive Tdev of +3.4°C for AV-040(N) is seen from the influence of global solar radiation. This influence produces the largest positive Tdev for AV-040(N) and the smallest for DTR503A(N) in August. The reasons for this are that the screen/shield material has good insulation and the plates on the reverse are black, so may be less prone to thermometer influence from scattered light on the surface of the plates.

For the artificially ventilated screens/shields, Tdev for PFT-02(A), PVC-02(A) and PVC-03(A) shows some influence of global solar radiation, as these screens/shields have no layer of insulating material. For other screens/shields the influence is not seen as much, since they do have a layer of insulating material.

(2) **Influences of radiation budget:** For the naturally ventilated screens/shields, a negative Tdev is seen from the influence of radiative cooling. These negative values are observed for AV-040(N), DTR503A(N) and YG-41003L(N), in that order. The reason is that the influence of radiative cooling differs for each screen/shield because they have different thermal capacities and insulating materials.

For the artificially ventilated screens/shields, some negative Tdev is seen due to differences in thermal capacity, insulating layers and the rate of ventilation.

(3) **Influences of rainfall:** For the naturally ventilated screens/shields, higher rainfall intensity values give a more remarkably negative Tdev for DTR503A(N). One reason for this is that its structure allows the internal thermometer to be seen between the plates from outside, so raindrops or water spray may become attached to the thermometer's sensor. A negative Tdev in the case of rainfall at a wind velocity of 0 – 2 m/s was also seen. One reason for this is that it has a structure in which raindrops tend to remain on the flat edges of the plates. The structure of YG-41003L(N), in which no influence from rainfall is seen, has an internal thermometer covered by plates, meaning that it cannot be seen between the plates from

outside. In addition, the plates gradually become smaller from top to bottom and have an inverted dish shape, making it hard for raindrops to remain on them.

For the artificially ventilated screens/shields, no difference in the influence of rainfall is seen.

5. Conclusions

・Naturally ventilated screens/shields are superior in terms of economy and ease of maintenance. However, in cases where they are used in low-latitude regions, care is required because some types might be affected by strong global solar radiation. It is also necessary to carefully consider the influence of the radiation budget. Such screens/shields should also be used with a good understanding of their structure and characteristics, as some are penetrated by rainwater and do not allow accurate temperature measurement.

・For artificially ventilated screens/shields, an essential requirement to minimize the influence of global solar radiation and the radiation budget is an appropriate insulation structure (insulation material/a heat-insulating layer of air). In addition, the horizontal type of artificially ventilated screens/shields requires care on rainy days because its configuration means that it is easily penetrated by wind and rainwater.

References

Brandsma T., van der Meulen J.P., 2007: Thermometer screen intercomparison in De Bilt (the Netherlands), part II: Description and modeling of mean temperature differences and extremes, International Journal of Climatology.

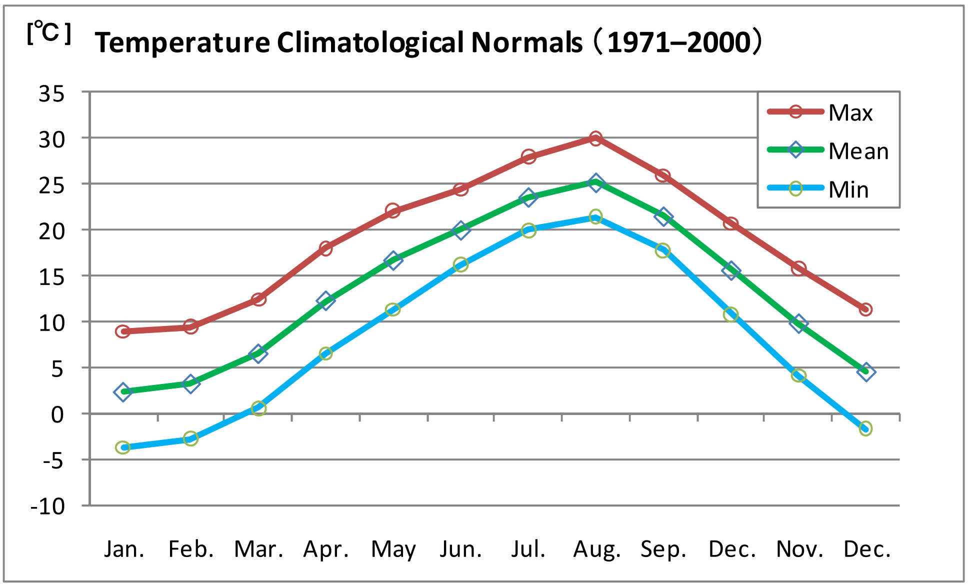
ISO (International Standardization Organization), 2007: Meteorology - Air temperature measurements - Test methods for comparing the performance of thermometer shields/screens and defining important characteristics (ISO 17714), First edition.

Lacombe Muriel, 2008: Acquisition system used by the Algerian ONM for WMO combined intercomparison of thermometer screens/shields in conjunction with humidity measuring instruments, TECO-2008.

WMO, 2008: Guide to meteorological instruments and methods of observation, seventh edition, WMO-No. 8.

Figures

Fig. 1　Location of Tsukuba, Japan



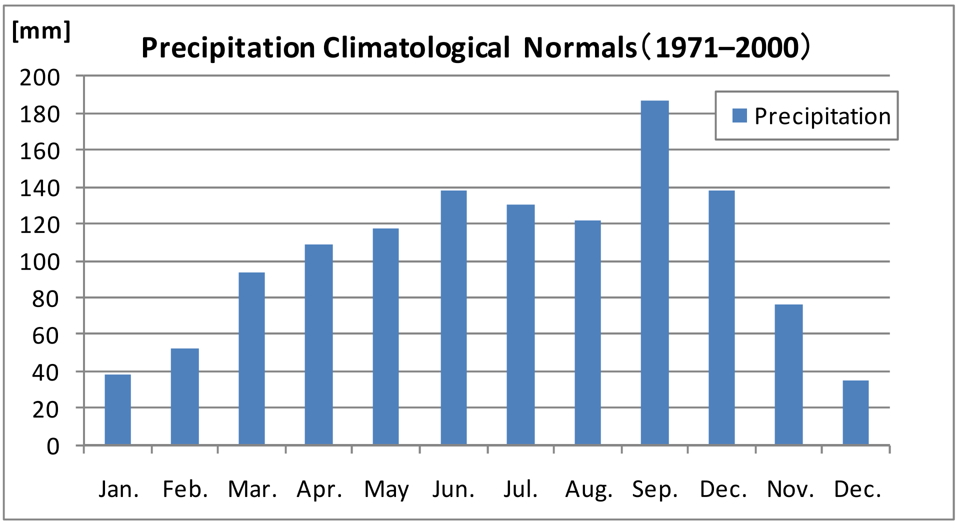


Fig. 2　Climatological normals for Tsukuba (upper: monthly temperature; lower: precipitation)

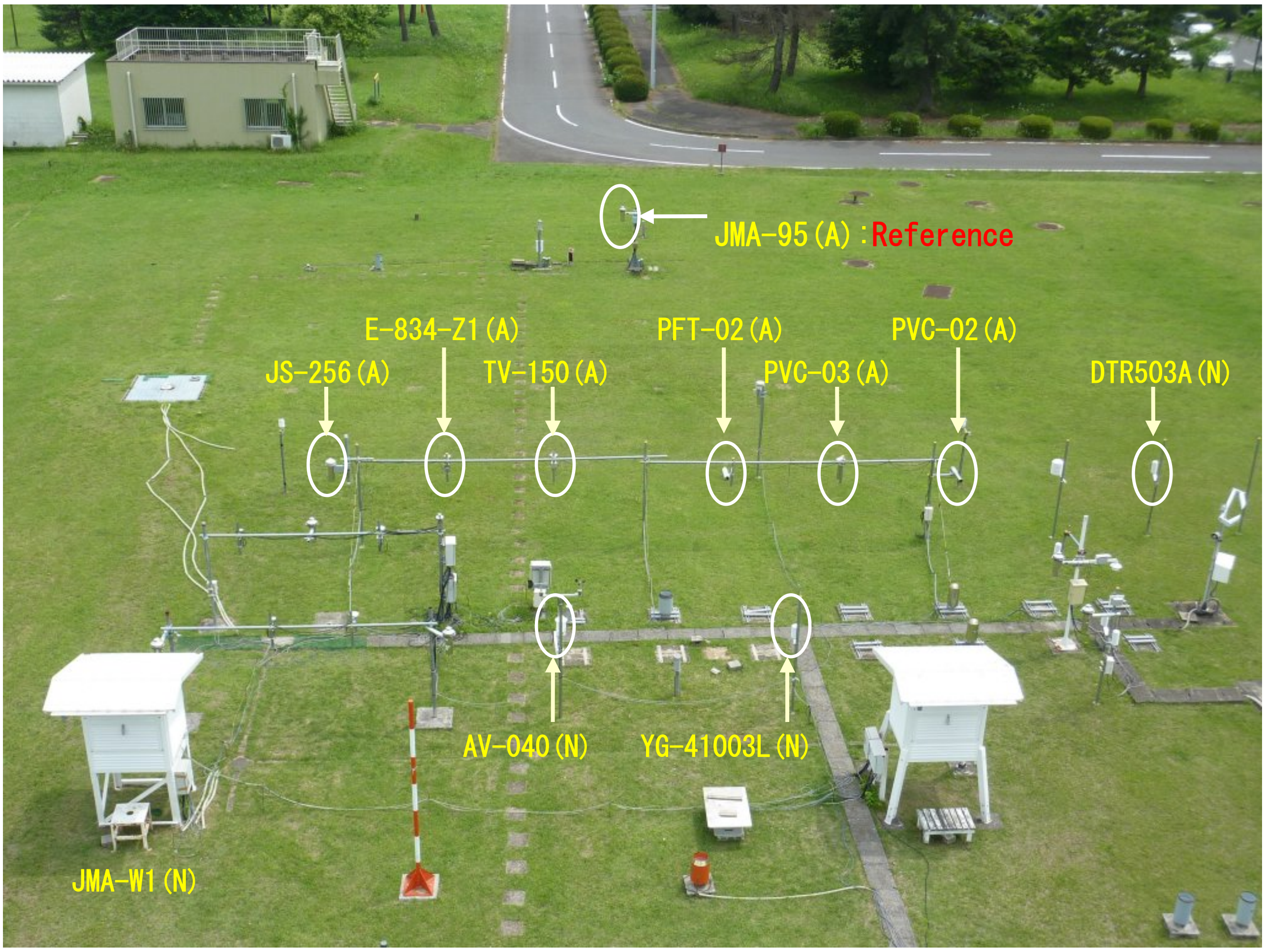


Photo. 1　Location of screens/shields in the intercomparison field
(upper: north – south side view; lower: west – east side view)

Photo. 2 Pictures of screens/shields (upper: side view; lower: view from underneath)

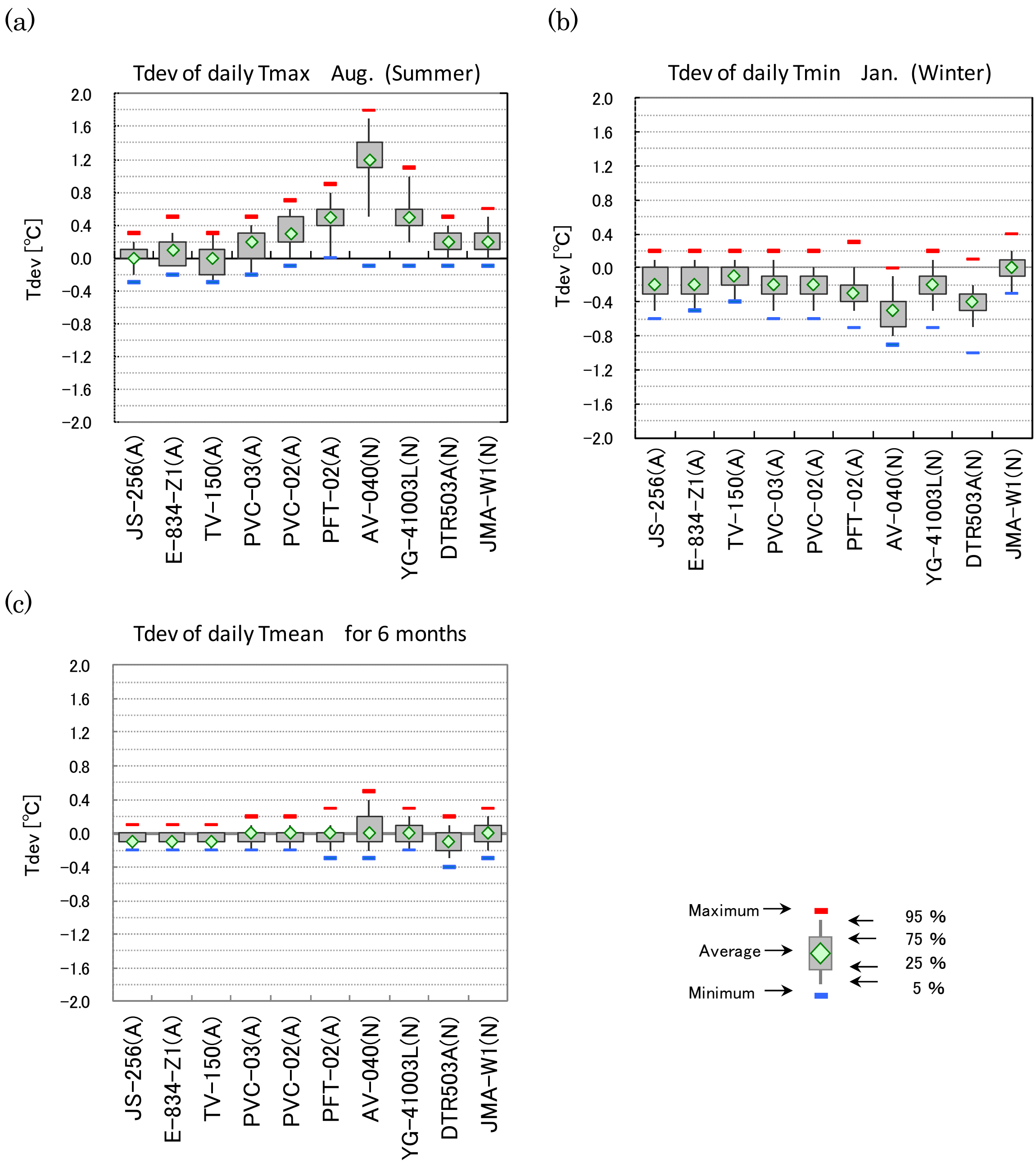


Fig. 3 Tdev of daily temperature (ref.: JMA-95(A)): (a) maximum temperature, Aug. 2009 (summer), (b) minimum temperature, Jan. 2010 (winter), (c) average temperature, 6 months (Aug., Dec., Jan., Feb., Mar. and Apr.)

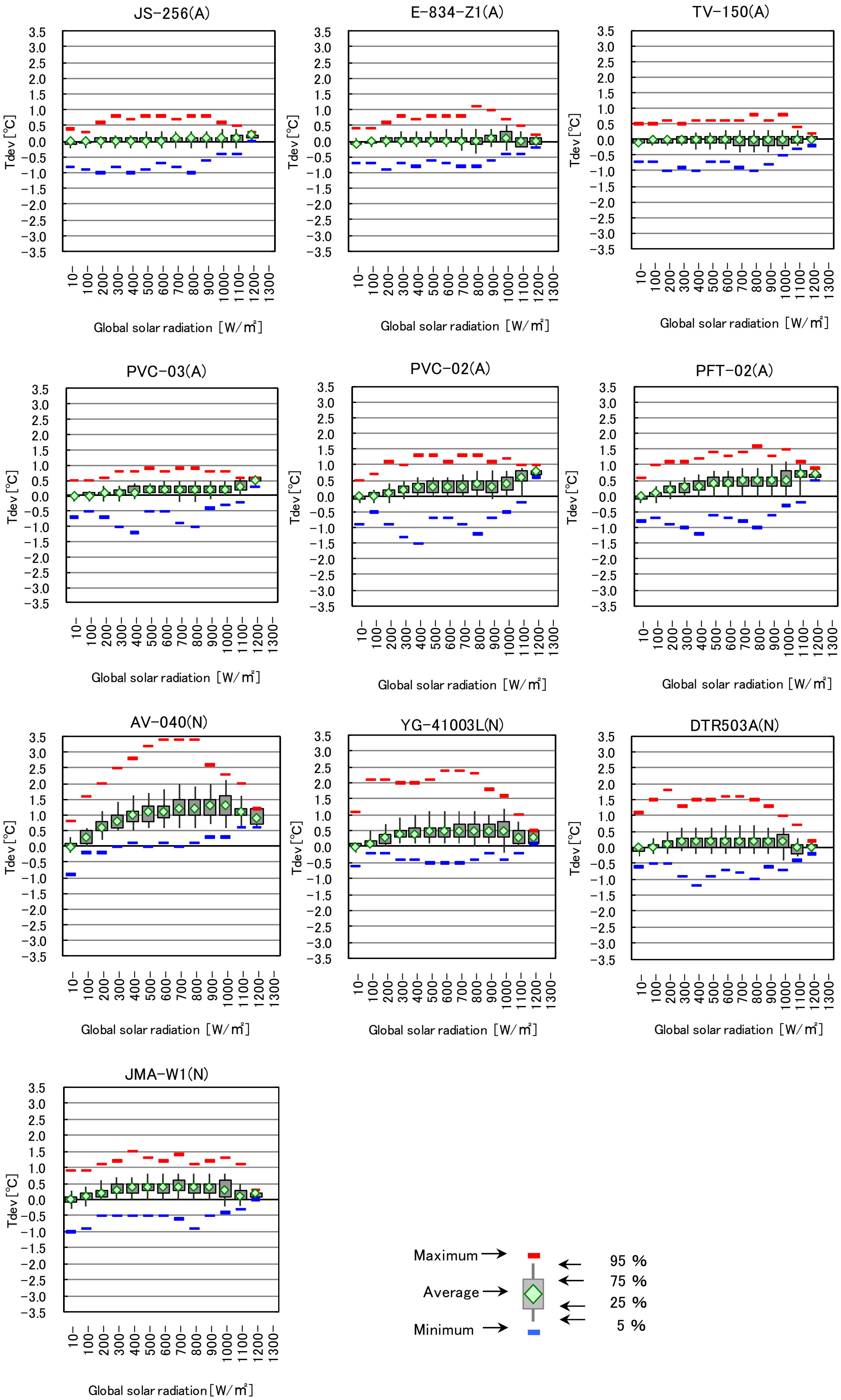


Fig. 4 Box plots showing Tdev differences related to global solar radiation depending on each screen/shield, Aug. 2009

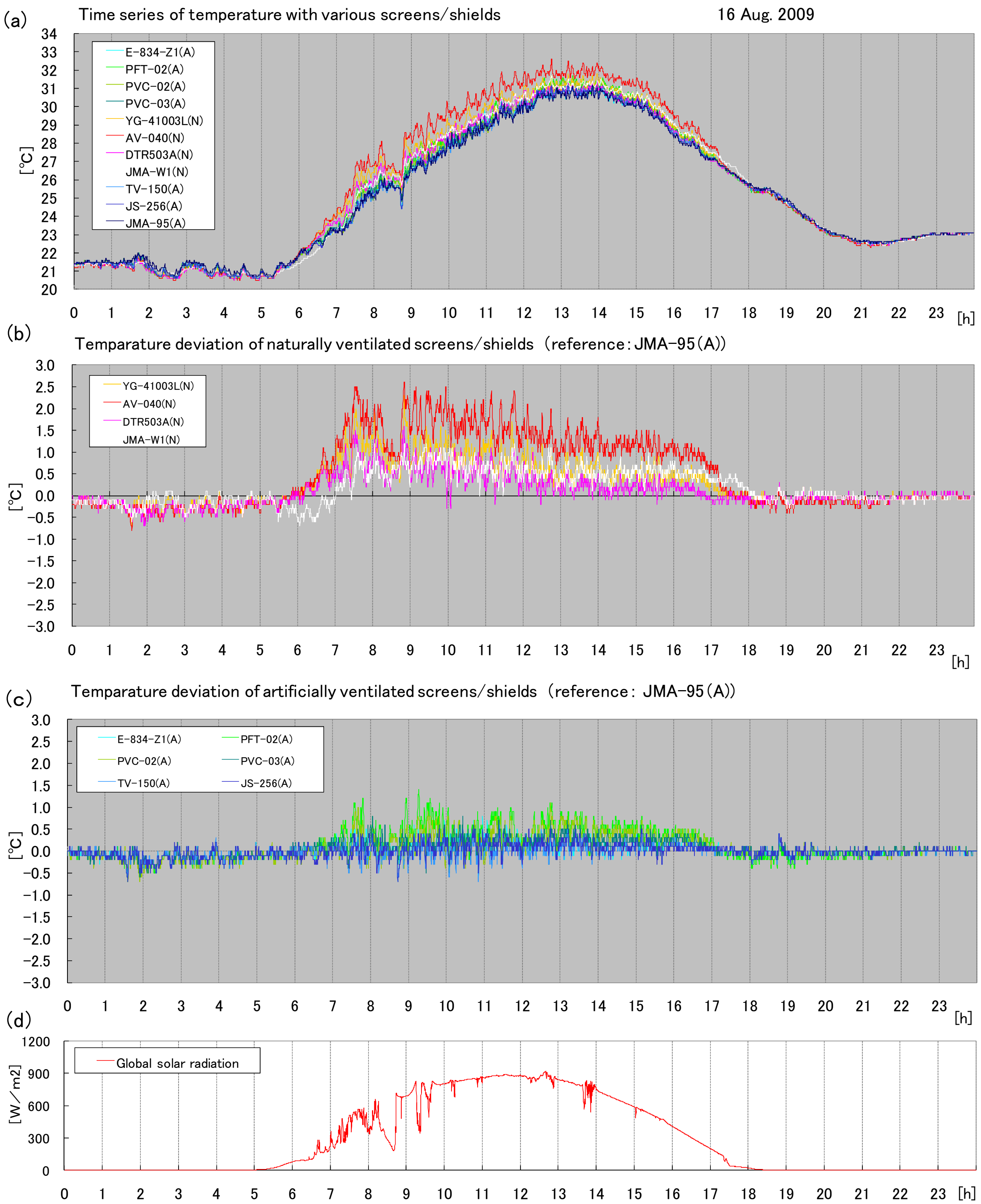


Fig. 5 Time series representations of temperature for various screens/shields and solar radiation, 16 Aug. 2009 (summer): (a) temperature, (b) Tdev for naturally ventilated screens/shields, (c) Tdev for artificially ventilated screens/shields, (d) global solar radiation

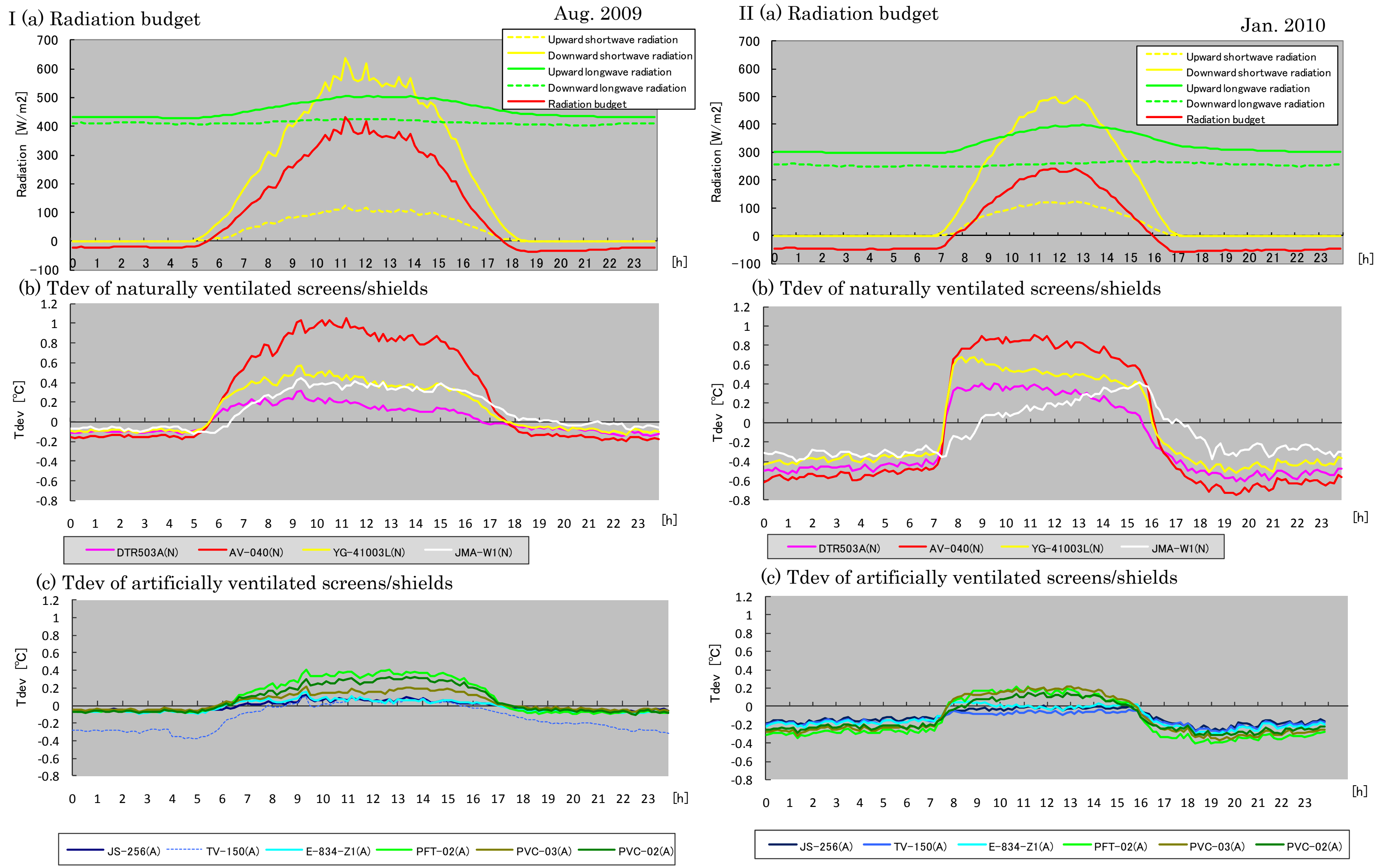
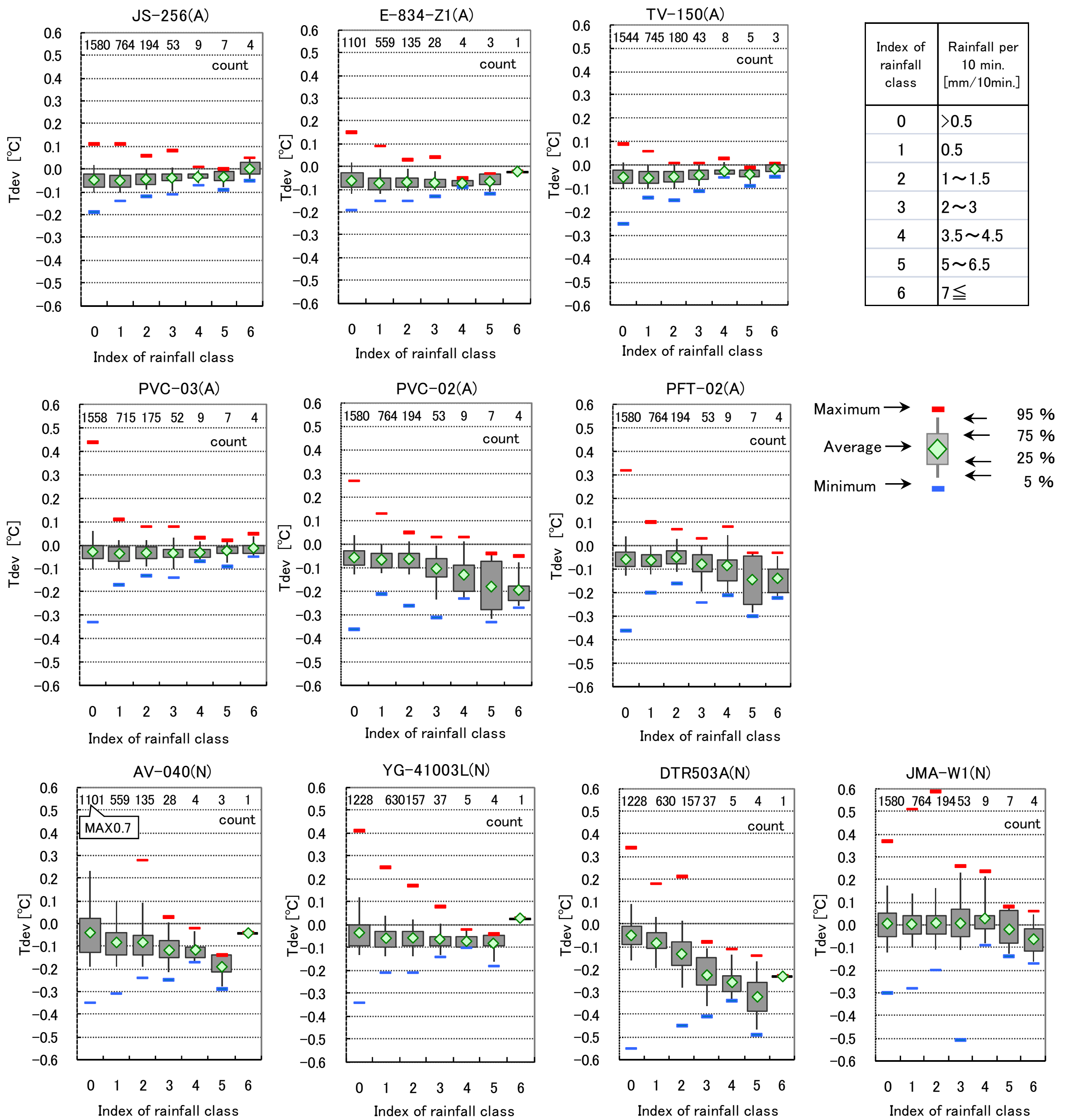


Fig. 6 Time series representations of monthly mean Tdev and radiation budget (left : I Aug. 2009; right : II Jan. 2010): (a) time series of monthly mean 10-minute radiation budget, (b) time series of Tdev for monthly mean of 10-min.mov.ave. temperature every 10 minutes for naturally ventilated screens/shields, (c) time series of Tdev as per (b) for artificially ventilated screens/shields. Reference: JMA-95(A). The dotted line in (c) includes missing data over periods of two days or more.



Index of rainfall class	Rainfall per 10 min. [mm/10min.]
0	>0.5
1	0.5
2	1～1.5
3	2～3
4	3.5～4.5
5	5～6.5
6	7≦

Fig. 7 Box plots showing Tdev differences related to rainfall intensity depending on each screen/shield for 31 days when the total rainfall was 10 mm per day or more

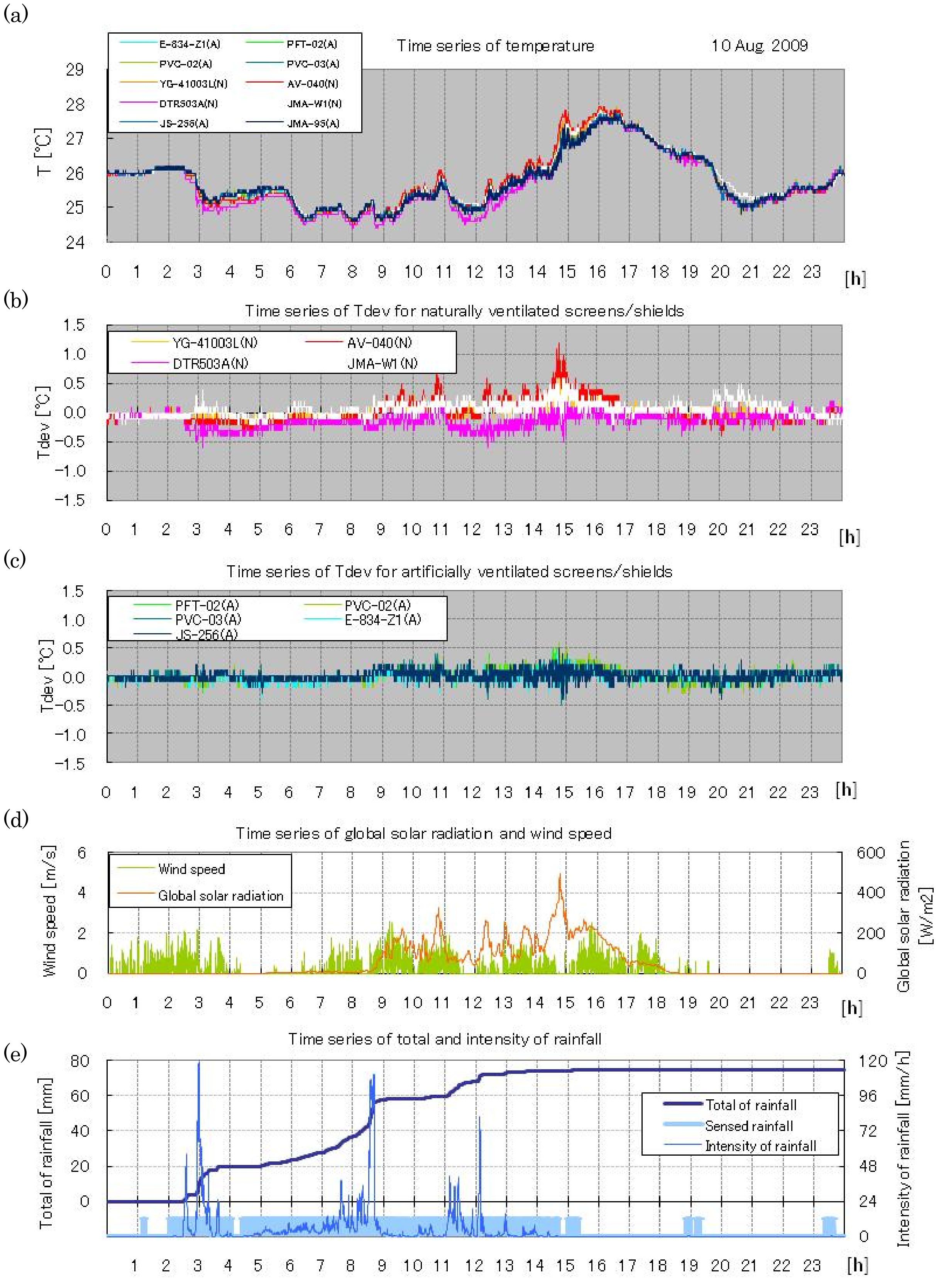


Fig. 8 Time series representations of temperature for various screens/shields and meteorological data from 10 Aug. 2009 (a rainy day): (a) temperature, (b) Tdev for naturally ventilated screens/shields, (c) Tdev for artificially ventilated screens/shields, (d) global solar radiation (at the same height as the screens/shields) and wind speed, (e) total rainfall and rainfall intensity (the latter obtained using a visibility meter)

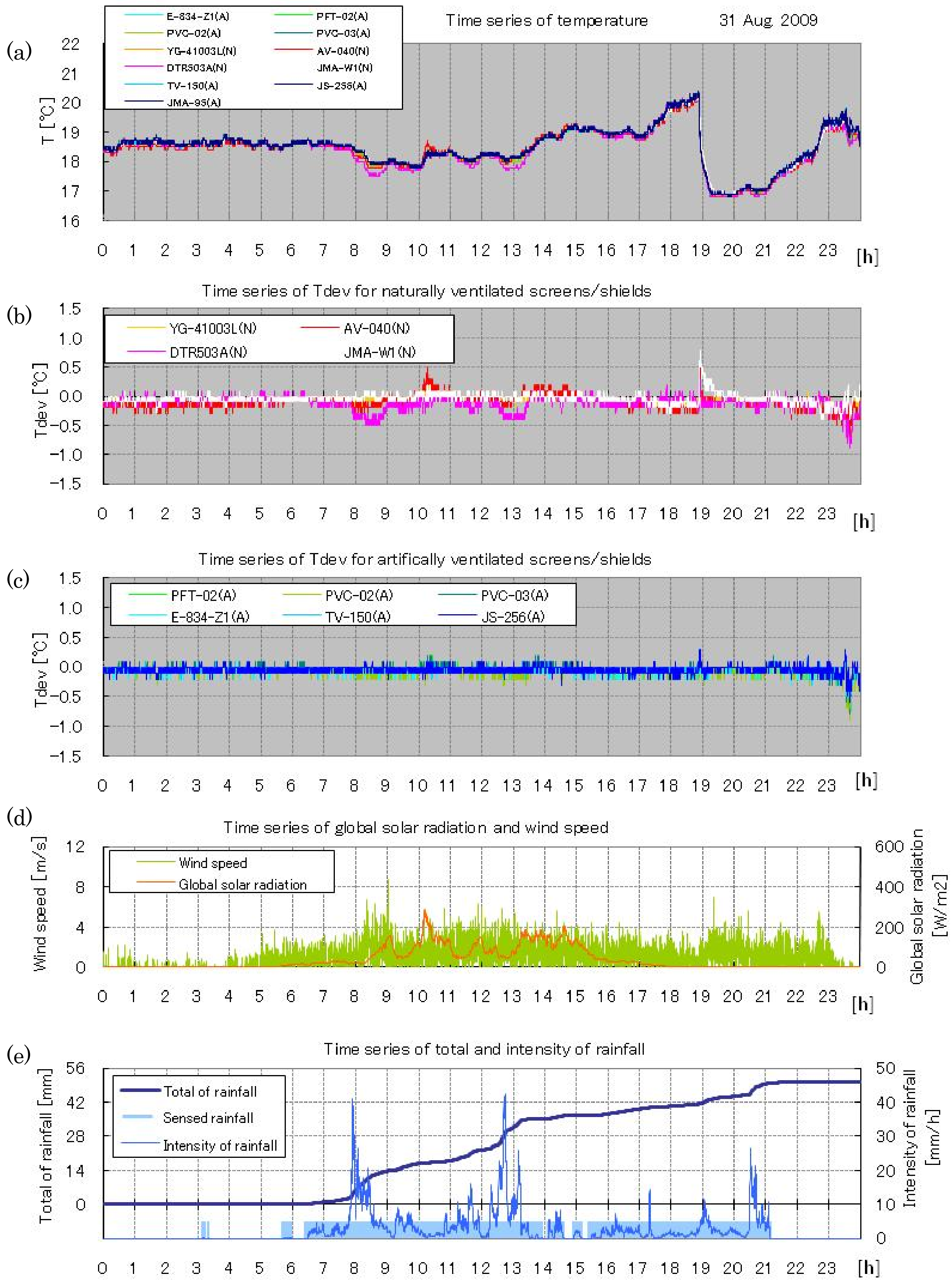


Fig. 9 Time series representations of temperature for various screens/shields and meteorological data from 31 Aug. 2009 (a rainy day): (a) temperature, (b) Tdev for naturally ventilated screens/shields, (c) Tdev for artificially ventilated screens/shields, (d) global solar radiation (at the same height as the screens/shields) and wind speed, (e) total rainfall and rainfall intensity (the latter obtained using a visibility meter)

Table 1 Characteristics and variation of Tdev related to various meteorological factors for each screen/shield

Ventilation		Artificially							Natural			
Type		JMA-95 (A) (JS-258)	JS-256 (A)	E-834-Z (A)	TV-150 (A)	PVC-03 (A)	PVC-02 (A)	PFT-02 (A)	AV-040 (N)	YG-41003L (N)	DTR503A (N)	JMA-W1 (N)
Manufacturer		Ogasawara	Ogasawara	Yokogawa	Ogasawara	Prede	Prede	Prede	Ogasawara	R. M. Young	Vaisala	Hidakosya
Structure of screen	Form	Vertical type					Horizontal type (pole)	Horizontal type (roof)	10 plates (flat) +snow umbrella	14 plates (dish upside down) inner: curved downward	12 plates (dish) rim: flat	Roof, blinds, base: duplication
	Inside structure	Duplication tube							–			
	Insulator/underneath shield plate	○				–			–			
	Material	Stainless steel (SUS304)	Stainless steel (SUS304) Aluminium	Stainless steel (SUS314)	Stainless steel (SUS304)	Stainless steel (SUS304) Portion: aluminium	Stainless steel (SUS304)	Stainless steel (Portion: aluminium, bakelite)	Shade: aluminium Arm: steel plate [Steel]	UV stabilized white thermoplastic plates Arm: aluminium	Polycarbonate (20% glassfiber) Reverse: black	Wood
	Diameter[mm]	117	117	100	89	88	88	76	200	130～120	105	1125 (W) 930 (L) 1511 (H)
	Length[mm]	475	457	370	358	423	586	630	420	270	238	
Ventilation speed *)	Measured	5.0 m/s	5.9 m/s	4.7 m/s *	4.3 m/s	2.0 m/s	2.5 m/s	3.6 m/s	–			
	Manufacturer	4 – 7 m/s	4 – 7 m/s	4 – 8 m/s	4 – 7 m/s	About 3 m/s	About 3–4 m/s	About 3 m/s				
Tdev : Temperature deviation [°C]	Daily Tmean 6 months *1)	Standard	−0.1 – 0.0 (−0.2 – +0.1)	−0.1 – 0.0 (−0.2 – +0.1)	−0.1 – 0.0 (−0.2 – +0.1)	−0.1 – 0.0 (−0.2 – +0.2)	−0.1 – 0.0 (−0.2 – +0.2)	−0.1 – 0.0 (−0.3 – +0.3)	−0.1 – +0.2 (−0.3 – +0.5)	−0.1 – +0.1 (−0.2 – +0.3)	−0.2 – 0.0 (−0.4 – +0.2)	−0.1 – +0.1 (−0.3 – +0.3)
	Daily Tmax Aug.		0.0 – +0.1	−0.1 – +0.2	−0.2 – +0.1	0.0 – +0.3	+0.2 – +0.5	+0.4 – +0.6	+1.1 – +1.4	+0.4 – +0.6	+0.1 – +0.3	+0.1 – +0.3
	Daily Tmin Jan.		−0.3 – 0.0	−0.3 – 0.0	−0.2 – 0.0	−0.3 – −0.1	−0.3 – −0.1	−0.4 – −0.2	−0.7 – −0.4	−0.3 – −0.1	−0.5 – −0.3	−0.1 – +0.1
	Effect of global solar radiation Aug. *2)		−0.1 – +0.1	−0.1 – +0.1	−0.2 – 0.0	0.0 – +0.3	+0.1 – +0.5	+0.2 – +0.6	+0.9 – +1.4	+0.3 – +0.7	0.0 – +0.3	+0.2 – +0.5
	Effect of radiation budget Jan. *3)		−0.3 – −0.1	−0.3 – −0.1	−0.3 – −0.1	−0.4 – −0.2	−0.4 – −0.2	−0.4 – −0.2	−0.9 – −0.4	−0.6 – −0.2	−0.7 – −0.4	−0.4 – −0.1
	Effect of rainfall *4)		0	−0.1 – 0.0	−0.1 – 0.0	0.0	−0.2 – −0.1	−0.1 – 0.0	−0.1	−0.1 – 0.0	−0.3 – −0.2	−0.1 – +0.1
Thermometer recommended		Pt 3 mmϕ		Pt 6 mmϕ		Pt 3 mmϕ HMP155 etc.	Pt 3 mmϕ	Pt 3 mmϕ HMP155 etc.	Pt 6 mmϕ	Pt 3 mmϕ HMP155 etc.	HMP155	Pt 3 mmϕ HMP155
Notes		JMA-95 for synoptic station		JMA-89 for old AWS	JMA-04 for AWS		Horizontal type alike PVC-03					JMA-1 louvered screen

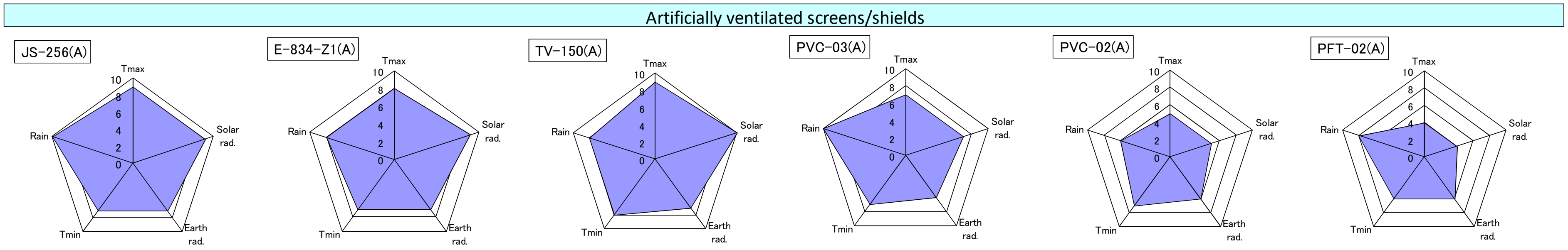
*1) For the artificially ventilated screens/shields, the ventilation speed was measured using a Pitot tube indoors. This tube is the same length (100 mm) as the thermometer (Pt 100 Ω (3 mm in diameter)). In most cases, a 3.2 mm in diameter type was used. However, in case where this size could not be fixed, a shorter 3.1 mm in diameter tube was used.

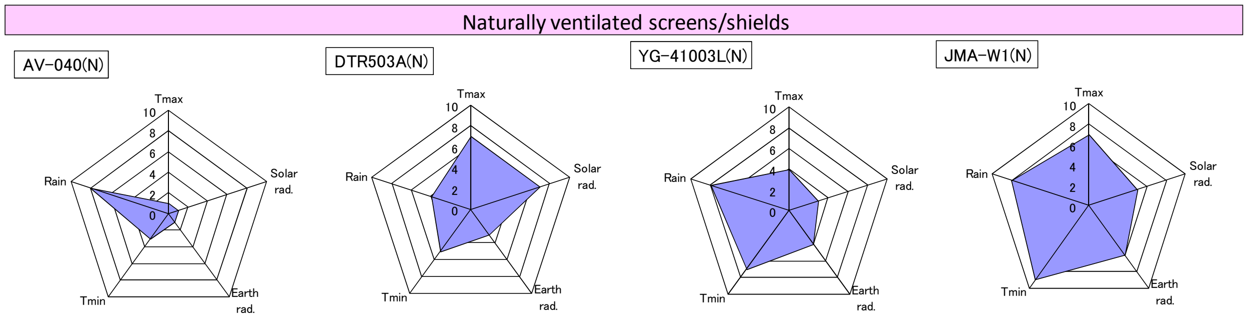
*2) Tdev is in a range between 25% and 75% assuming that the maximum value is 100% and the minimum is 0% for each meteorological element. Positive Tdev is shown in pink and negative in light blue in cases where the value is more than ±0.2 °C. *3) Daily average temperature for 6 months (August, December, January, February, March and April) from the 10-sec. data. The values in ( ) show the minimum and maximum. *4) 1 minute average global solar radiation data when the global solar radiation was 700 W/m^2 or more in Aug. *5) 10-min. mov. ave. data when the radiation budget was −50 W/m^2 or less in Jan. *6) 10-min. mov. ave. data when the rainfall intensity was Class 3 or higher (i.e., 2 mm or more for 10 minutes) for the 31 days when the total rainfall was 10 mm per day or more.

Table 2　Comparative table of operationally effective elements for each screen/shield

Ventilation		Artificially ventilated							Naturally ventilated			
Category	Item \ Type	JMA-95(A)	JS-256(A)	E-834-Z1(A)	TV-150(A)	PVC-03(A)	PVC-02(A)	PFT-02(A)	AV-040(N)	YG-41003L(N)	DTR503A(N)	JMA-W1(N)
Cost performance	Electric power supply	△	△	△	△	△	△	△	◎	◎	◎	◎
	Periodic replacement parts	△	△	△	△	△	△	△	◎	◎	◎	◎
Maintenance	Ease of installation	△	△	○	○	○	○	○	◎	◎	◎	△
	Thermometer cleaning work	△	△	○	○	○	○	△	◎	◎	◎	◎
	Ease of maintenance	△	△	○	○	○	○	△	◎	◎	◎	◎
Weather resistance	Corrosion resistance	◎	◎	◎	◎	△	△	△	△	◎	◎	△
	Resistance to ultraviolet radiation	◎	◎	◎	◎	◎	◎	◎	◎	△	△	◎
	Insect resistance	◎	◎	○	○	○	△	△	△	△	△	△

◎ better　　○ normal　　△ not so good





Item	Tmax	Solar rad.	Tmin	Earth rad.	Rain
Tdev [°C] / Class	Daily Tmax (Aug.)	Concerning global solar radiation (Aug.)	Daily Tmin (Jan.)	Concerning radiation budget (Jan.)	Concerning rainfall
10	0 –		0 –		0 –
9	+0.1 –		−0.1 –		
8	+0.2 –		−0.2 –		−0.1 –
7	+0.3 –		−0.3 –		
6	+0.4 –		−0.4 –		−0.2 –
5	+0.5 –		−0.5 –		
4	+0.6 –		−0.6 –		−0.3 –
3	+0.7 –		−0.7 –		
2	+0.8 –		−0.8 –		−0.4 –
1	+0.9 –		−0.9 –		

Fig. 10 Radar charts of Tdev differences related to various meteorological factors for each screen/shield