Intercomparison of Shelters in the RMI AWS Network

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Abstract

The Royal Meteorological Institute of Belgium (RMI) has a network of 18 automatic weather stations (AWS) recording meteorological parameters such as pressure, temperature at different levels, relative humidity, wind speed and direction, radiation and precipitation. In this paper we present the results of the intercomparison of the different types of shelters used in the network. Besides an artificially ventilated Stevenson shelter used as reference temperature, an internally developed shelter is also used for additional height measurements at 2, 10 and 30m. In addition, the Barani Helix shield has also been compared to the RMI shelters.

1 Introduction

RMI is responsible for the Belgian civil meteorology. Civil and military aviation AWS are managed by Belgocontrol [4] and Meteo Wing [11], which also is responsible for the road safety warnings. Environmental measurements and monitoring are the responsibilities of the regions (Brussels-Capital region [5], Walloon region [3] and Flemish region [8]). Besides this AWS network, RMI collects data from a voluntary network of precipitation and temperature measurements of over 200 stations.

The first AWS has been installed in the RMI headquarters at Uccle in 1995. Since then additional stations have been added all over the country. In the last years a renovation of the network has been conducted with an improved acquisition and meta data management(see [6] for details). More recently the environmental classification of the network has been carried out (see [7] for details).

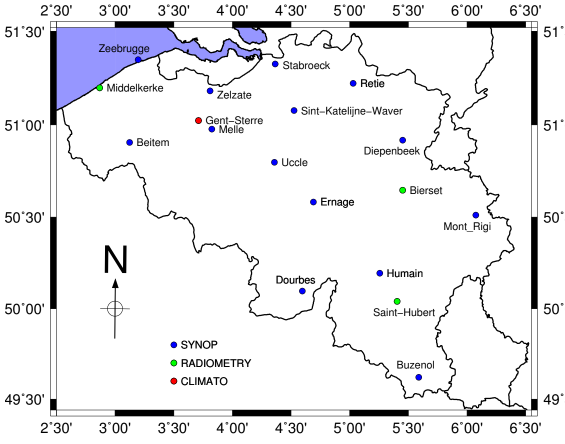


Figure 1.1: RMI AWS Network (courtesy of Cédric Bertrand)

2 Air Temperature Measurement Requirements

To accurately measure the air temperature, the sensor should be protected from influences of the environment like solar radiation, terrestrial radiation, rain and snow. But using a shelter introduces also errors in the air temperature measurement. These errors are linked to the micro meteorology inside the screen, the dirt on the shelter, the ventilation and thus the air speed.

Since there are no defined reference standard for shelters, the World Meteorological Organisation (WMO) recommends to compare shelters between them. An International Standard has been developed by the International Standard Organisation (ISO) to define the most relevant screen characteristics and to provide the methods to determine and compare screen performance [2]. WMO has also published in its reference guide for meteorological observation absolute requirements for air temperature measurement (see table 1).

Variable	Range	Reported resolution	Mode of measurement / observation	Required measurement uncertainty	Sensor time-constant	Output averaging time	Achievable measurement uncertainty	Remarks
Air temperature	−80 – +60 °C	0.1 K	I	0.3 K for ≤-40°C 0.1 K for ≥-40°C and≤40°C 0.3 K for ≥40°C	20 s	1 min	0.2 K	Achievable uncertainty and effective time- constant may be affected by the design of the thermometer solar radiation screen Time constant depends on the airflow over the sensor
Extremes of air temperature	−80 – +60 °C	0.1 K	I	0.5 K for ≤-40°C 0.3 K for ≥-40°C and≤40°C 0.5 K for ≥40°C	20s	1 min	0.2 K	

I = Instantaneous: In order to exclude the natural small-scale variability and the noise, an average value over a period of 1 min is considered as a minimum and most suitable; averages over periods of up to 10 min are acceptable.

Table 1: WMO air temperature requirements

(a) RMI Stevenson shelter. The wet/dry measurement is done by a PT100 in the left/right pipe. Below and outside the shelter a ventilator is aspirating the air trough a flexible pipe connected to the two measurement pipes. In the center a relative humidity device.

(b) RMI compact shelter.On the left, the shelter with a high reflective stainless steel protection. On the right the fan for the artificial ventilation

(c) Barani Helix radiation shelter. Two shelters of this type have been used in the comparison, having the second one an additional blackening inside the lamellas.

Figure 2.1: Shelters used in the intercomparison

3 Description of Shelters used in the AWS Network

3.1 RMI Stevenson artificially ventilated shelter

The reference temperature in our network is measured by a Pt100 in an artificially ventilated pipe inside a double louvered Stevenson screen. Two pipes are used: one for the dry temperature and one for the wet temperature. At the upper side, through a flexible pipe the air is aspirated by a ventilator outside the shelter. The speed of the air has not been measured but estimated using the ventilator data sheet to about 13.5 m/s. This speed is probably too high. This too high speed has two known drawbacks: a possible wet-bulb episode by aspirating water droplets and a lowered real measuring height compared to the physical sensor height. The required range of air speed past the sensor is between 2.5 and 10 m/s ([1]). This temperature measurement will be referred to as **STEVENSON.FAN.DRY**.

Besides the dry and wet artificially ventilated temperature measurement, the relative humidity (RH) is measured using a Vaisala HMT 337. The temperature is also measured by the Vaisala device. This temperature measurement can't be considered as a naturally ventilated temperature measurement since the aspirated air is probably affecting the air surrounding the RH sensor. The RH device is placed at the same height than the PT100 between the two pipes of the dry and wet temperature measurement. This temperature measurement will be referred to as **STEVENSON.HR**. The height of both temperature measurements is 1.42m.

3.2 RMI Compact artificially ventilated shelter

For the temperature measurement at 2m, 10m and 30m, an internally developed shelter is used. It is a double concentric pipe. The outside pipe is made of stainless steel and the inner pipe is made of plastic. This inner pipe is prolongated until a ventilator which is separated by about 1m.This temperature measurement will be referred to as **RMI.FAN.2M**.

3.3 Barani Helix shelter

The Barani Helix shelter is a traditional multi-plate radiation shield made of plastic. The innovation is that the plates form a double helical path. This construction is supposed to improve the ventilation and therefore avoiding the overheating under strong solar radiation. Two different Barani shelters have been installed for intercomparison: a standard one and another one which has a blacked helix internal face. These temperature measurements will be referred to as **BARANI.STANDARD** and **BARANI.BLACKED**. The height of both temperature measurements is 1.42m.

4 Field test site

The site is the RMI synoptic station at Humain (06472 - 50.193663°N 5.255236°E). It is a countryside site with grass area, crop fields and low height trees in the surroundings. The station is a class 2 for environment according to the WMO classification.

During the intercomparsion, the following weather has been observed:

	1 minute	10 minutes
Mean temperature	9.87	
Maximum temperature	33.87	34.34
Minimum temperature	-10.37	-10.37
Precipitation time	9.4%	
Maximum precipitation amount	1.36mm	7.84mm
Number of days with precipitation	228	
Maximim snow depth	13.81cm	
Mean wind speed (2m)	2.70m/s	
Maximum wind speed (2m)	19.03m/s	14.97m/s
Mean wind speed (10m)	3.46m/s	
Maximum wind speed (10m)	19.58m/s	16.33m/s
Daily mean sunshine duration	5h23	
Mean okta	5.64 okta	
Overcast days	125 days	
Clear days	26 days	

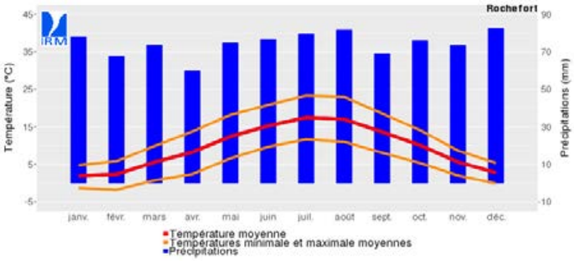


Figure 4.1: Weather statistics during intercomparison (left, 2016/10/12 to 2017/10/12) and temperature and precipitation statistics (right, 1981-2010) at Humain

According to the Köppen-Geiger climate classification [9], the site is of template oceanic climate (Cfb - Temperate without dry season and a warm summer). The mean annual number of days of snow precipiation is 21.4 days per year (reference period from 1985 to 2014).

5 Calibration

The calibration of all the sensors has been carried out in our laboratory. The absolute uncertainty associated to the calibration is about 0.1°C for PT100 sensors in a liquid bath and 0.2°C for the calibration in a climate chamber. In the intercomparison of shelters, it is the difference which is used. Since we are using the same standard for all the sensors whatever the calibration has been done in the bath or in the chamber. The uncertainty of the difference is roughly estimated to be 0.03°C for the sensors calibrated in the bath (**STEVENSON.FAN.DRY**, **BARANI.STANDARD**, **BARANI.BLACKED**, **RMI.FAN.2M**). For the RH, the calibration is done in a chamber where inhomogeneities are higher than in the calibration bath. We expect an uncertainty higher about 0.1°C in difference (**STEVENSON.RH**).

6 Data description

All temperatures are measured using a four wire resistance measurement circuit. The ratio between the PT100 and a very accurate 100Ω resistance is measured. The measurement is done every 5 seconds. Then the Callendar-Van Dusen is applied to transform the resistance value to temperature. A correction is then applied to take into account the calibration of the PT100. The power and the fans have been monitored. The grass has been regularly cut to respect WMO recommendations (lower than 10cm).

The period of intercomparison is one year: from 2016/10/12 to 2017/10/12. The data has been checked manually for any period where the difference between two shelters is higher than 1°C. Several periods of wet-bulb temperature have been observed mainly for the three RMI shelters but also for the **STEVENSON.FAN.DRY** shelter. There were several periods of power break where the station worked with the back-up battery. During failure of main power, the temperature measurement are taken but the fans are not connected to the back-up battery to avoid emptying the battery too quickly. Those periods have been removed from the comparison.

7 Additional meteorological variables

The following variables have been taken during the period of intercomparison:

Instrument type	Variables	Brand	Type	S/N
Radiometer	Global solar radiation, reflected solar radiation, thermal radiation from sky, thermal radiation from Earth	Kipp&Zonen	CNR1	100397
Pluviometer	Precipitation quantity	OTT	Pluvio1	231679
Barometer	Pressure	Vaisala	PTB330	K3740019
Precipitation Monitor	Precipitation presence	Thies	5.4103.10.000	0707919
Hygrometer	Relative humidity, Temperature	Vaisala	HMT337	K3810133
Nivometer	Snow Height	Sensor Partners	uss-110/IU/HV/M30	
Radiometer	Direct solar radiation	Kipp&Zonen	CSD3T	110733
Thermometer	Temperature at 2m	Thermibel	PT100	T_66843_1_5
Thermometer	Temperature at 10m	Thermibel	PT100	T_66843_1_3
Thermometer	Temperature at 30m	Thermibel	PT100	T_66843_1_8
Thermometer	Dry temperature in Stevenson shelter	Thermibel	PT100	T_66843_1_6
Thermometer	Wet temperature in Stevenson shelter	Thermibel	PT100	T_66843_1_7

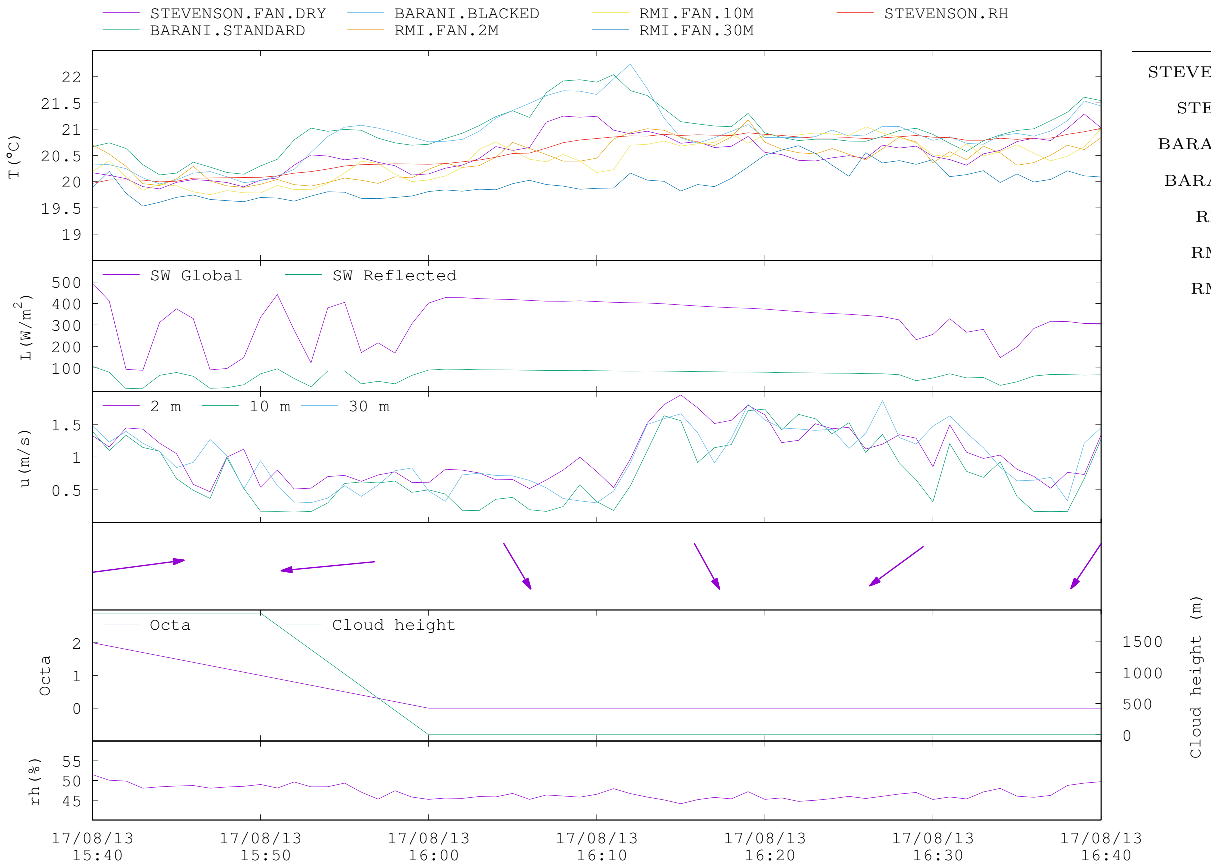
Instrument type	Variables	Brand	Type	S/N
Thermometer	Grass temperature	Thermibel	PT100	T_66843_3_14
Thermometer	Naked ground temperature	Thermibel	PT100	T_66843_3_3
Thermometer	Naked ground temperature at -5cm	Thermibel	PT100	T_66843_3_5
Thermometer	Naked ground temperature at -10cm	Thermibel	PT100	T_66843_3_1
Thermometer	Naked ground temperature at -20cm	Thermibel	PT100	T_66843_3_13
Thermometer	Naked ground temperature at -50cm	Thermibel	PT100	T_66843_3_2
Thermometer	Naked ground temperature at -100cm	Thermibel	PT100	T_66843_3_4
Thermometer	Barani standard	Rodax	PT100	133
Thermometer	Barani blacked	Rodax	PT100	135
Wind Vane	Wind direction at 10m	Thies	First Class 4.3150.00.141	03130277
Anemometer	Wind speed at 2m	Thies	First Class 4.3351.00.141	04130162
Anemometer	Wind speed at 10m	Siggelkow	LISA i WG12	MV442
Anemometer	Wind speed at 30m	Siggelkow	LISA i WG12	MV391
Ceilometer	cloud cover, cloud height at maximum 5 levels	Vaisala	CL51	130810005

8 Typical conditions

The data have been analyzed and representative or peculiar situations have been detected. Several plots have been generated but they are not reproduced here for the sake of brevity except for figure 8.1 as an example.

The following conclusion can be drawn from this analysis:

- During very stable periods, the temperature is quite the same for all the shelters. The maximum difference is observed between the **RMI.FAN.2M** and the others shelters and is about 0.1°C. The difference between the reference and the Barani shelters is very low (less than 0.03°C). The data has not been corrected by this difference as in [10]. It remains unclear if the difference is linked to a difference of measurement height or a calibration difference. In the former case the correction is probably depending on the wind speed and only valid for this meteorological situation.
- The **RMI.FAN.2M** seems influenced by the thermal energy exchange with the ground. The snow on ground seems to have a strong influence on the measured values.
- Long-wave cooling seems equivalent for all the shelters.
- On sunny days with low wind, the Barani shelters are measuring a higher temperature but it usually happens with a median solar radiation.
- In winter season, a significant difference seems to happen around the sunset, more precisely when the latent and or sensible heat exchange are changing of direction. Unfortunately it is not possible to verify this hypothesis for the moment. A eddy covariance measurement will be placed in the next months and will probably help to better understand that episodes.
- As expected, the response time of the Barani's shelters is usually shorter than the other shelters but depends on the wind speed.



Shelter	max
STEVENSON.FAN.DRY	21.29
STEVENSON.RH	21.02
BARANI.STANDARD	22.04
BARANI.BLACKED	22.24
RMI.FAN.2M	21.18
RMI.FAN.10M	21.04
RMI.FAN.30M	20.69

Figure 8.1: Case study example.

9 Statiscal Analysis

9.1 Difference at 1 minute sampling

A general sketch of the comparison of the four tested screens to the reference one is available in figure 9.1. More detailed numbers are available in table3. The mean difference is quite low even lower than the uncertainty of calibration for three of the shelters (0.03°C see Calibration 5). For the **RMI.FAN.2M** shelter, the mean is significantly different from zero and higher than zero.

It appears that the two Barani shelters have a more compact distribution. This is confirmed with standard deviations that are the lowest for the two Barani shelters. The **STEVENSON.RH** device has a slightly higher standard deviation. The **RMI.FAN.2M** standard deviation is nearly the double of the Barani.

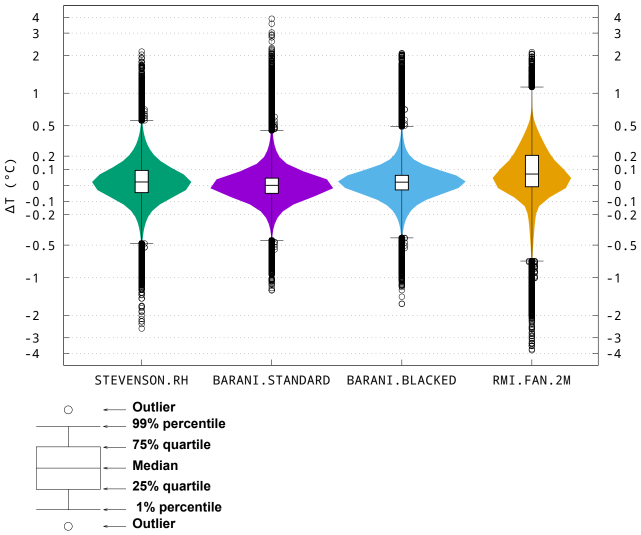
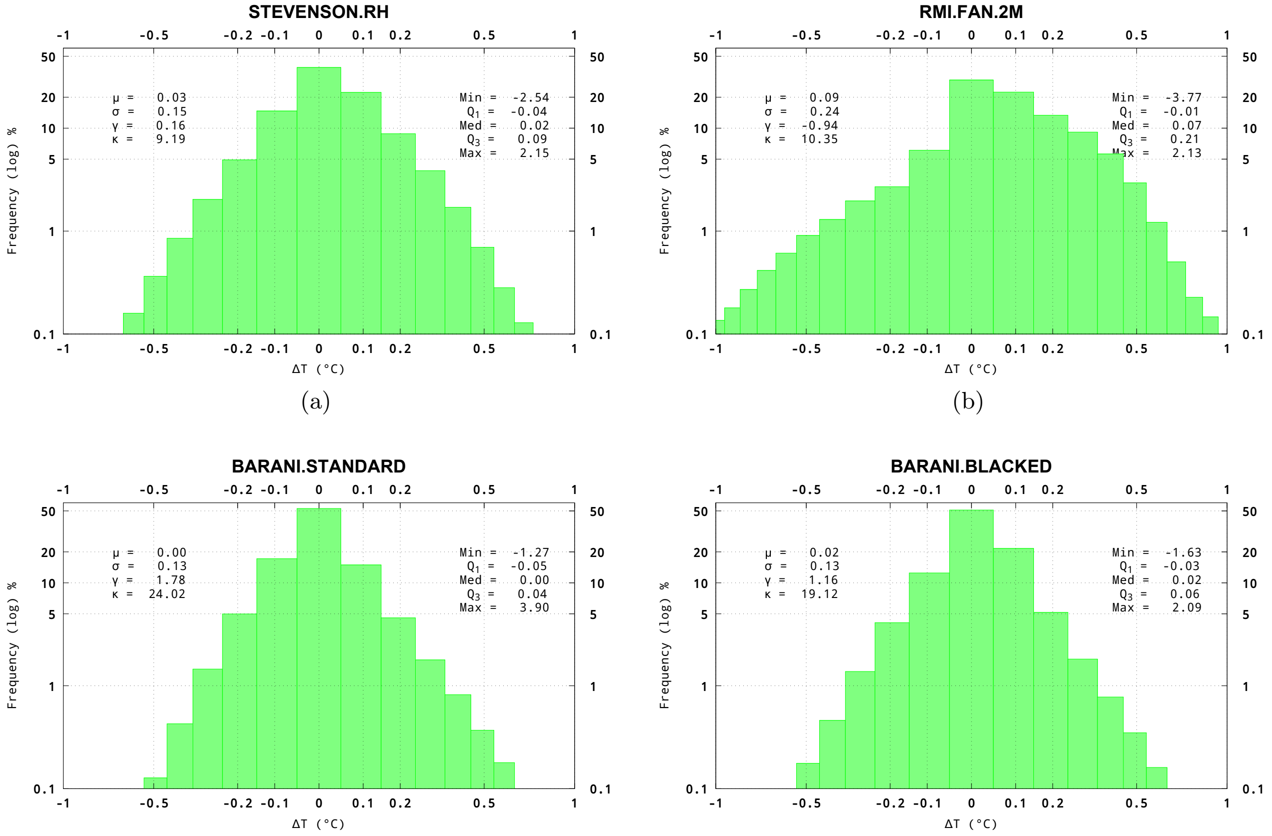


Figure 9.1: Mirrored density difference of one minute value.

The skewness is positive except for **RMI.FAN.2M.** So the tails above the mean are larger than below except for the **RMI.FAN.2M** for which it is the reverse. The larger tail above the mean is for the **BARANI.STANDARD**. It also has the higher maximum which is nearly the double of the other maximums. The response time of the Barani shelters are depending on the wind speed and are usually shorter than the other devices from the conclusion in typical cases analysis. This could explain the larger tail above the mean. It usually happens during the day with strong heating of the ground and turbulent heat exchange. In this case fluctuations up to 2°C can happen.



(a) (b)

(c) (d)

Figure 9.2: Histogram of difference between . Both axis have logarithmic scale.

The kurtosis, which is the double for the Barani shelters than for the other shelters, shows that despite a lower standard deviation, the tails of the distribution of the Barani are quite large compared to the other two shelters. Again the response time is probably the reason of this higher kurtosis.

At this stage it is unclear whether the two Barani's shelters are statistically different. A Kolmogorov-Smirnov test to ascertain if the difference of each Barani shelter to the reference could be drawn from the same distribution is negative (p-value $< 2.2e\text{-}16$). The cumulative distribution function of **BARANI.STANDARD** lies above that of **BARANI.BLACKED** according to the same test (p-value $= 0.2453$).

	STEVENSON.RH	BARANI.STANDARD	BARANI.BLACKED	RMI.2M
Mean	0.0296	0.0022	0.0183	0.0899
Std Dev	0.1560	0.1282	0.1287	0.2390
Skewness	0.2178	1.7372	1.1332	-0.9279
Kurtosis	8.9594	22.7900	18.1133	10.1833
Minimum	-2.5354	-1.2693	-1.6281	-3.7704
1st Quart	-0.0415	-0.0520	-0.0295	-0.0066
Med	0.0216	-0.0010	0.0182	0.0724
3rd Quart	0.0967	0.0427	0.0618	0.2126
Maximum	2.1492	3.8993	2.0872	2.1311
#	520171	520171	520171	520171

Table 3: Statistics of difference to reference

9.2 Radiation influence

The main expected influence of the global solar radiation is an increased measured temperature in comparison to the reference for higher solar global radiation. This increase is expected to be linked to the heating of the shelter by a lack of sufficient ventilation. For artificially ventilated shelters, the influence should be limited. However, during strong solar radiation, the ground is heating faster than the air above and the temperature will decrease with height. If the reference height of measurement is not the same for two shelters, the difference will be a composite of both influences, positive and negative.

A complete analysis should include the influence of the the global solar radiation but also the influence from the direct solar radiation, the diffuse solar radiation, the reflected solar radiation, the ground albedo, the azimuth and zenith angle and should distinguish between low wind speeds (less than 1m/s), medium wind speeds (between 1m/s and 5m/s) and high wind speed (higher than 5m/s). The conclusions are by shelter:

STEVENSON.RH The influence is very limited, from -0.1°C to 0.1°C as mean difference. The real height of measurement is probably slightly higher than the reference.

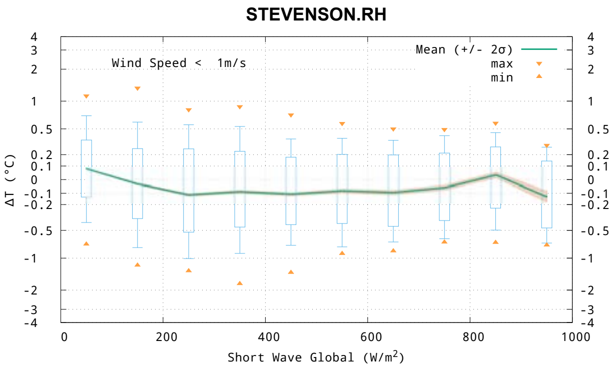


Figure 9.3: Temperature difference related to global solar radiation for speed lower than 1m/s.

RMI.2M The influence is more pronounced, from -0.3°C to 0.5°C higher. The main influence is coming from the reflected short wave radiation. The real height of measurement is higher than the reference and this difference of height makes drawing a clear conclusion difficult about the real error. Anyway the error is very high and even non ventilated shelters have better results. The influence is also increasing with the wind speed (0.4°C for 1000W/m^2 and wind speed higher than 5m/s), probably linked to an influence of the wind in the artificial ventilation flow.

BARANI.STANDARD, BARANI.BLACKED The two shelters show the same behavior. The influence is very limited and varies between 0°C and 0.2°C. The higher influence are for global solar radiation around 500 W/m^2 and low wind speed (see figure 9.5 for **BARANI.STANDARD**, the figure for the other Barani is similar and not showed here). It is unclear why the influence is higher for medium values of radiation. It should be expected a higher influence for higher radiation. The same behavior is seen with the zenith angle. It could be a geometric issue.

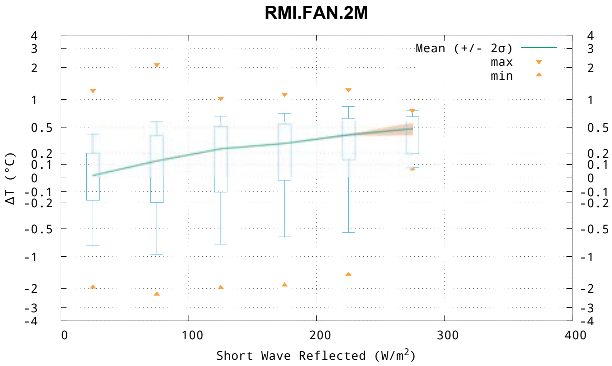
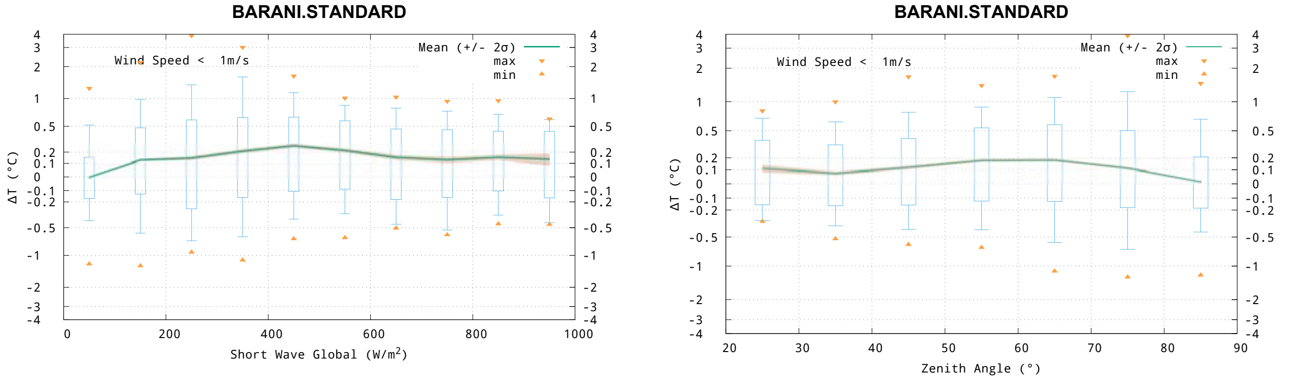


Figure 9.4: Temperature difference related to reflected solar radiation.



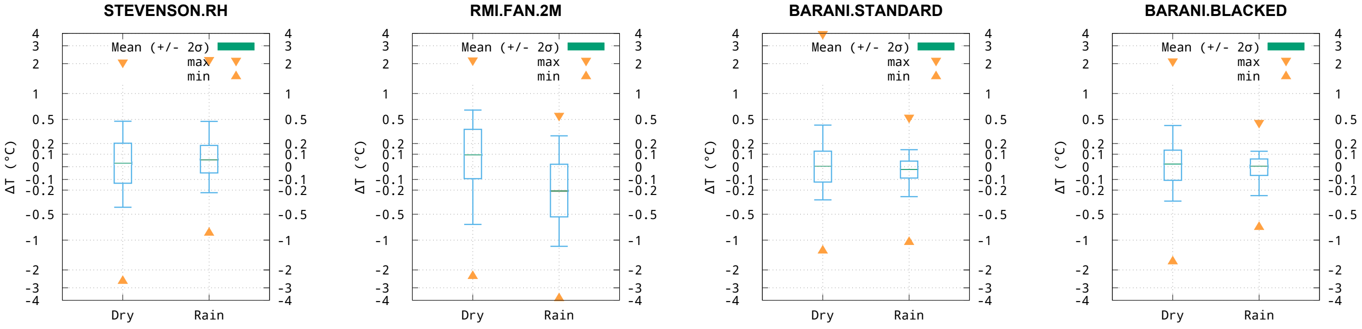
(a) Global solar radiation

(b) Zenith angle

Figure 9.5: Temperature difference related to global solar radiation and zenith angle for speed lower than 1m/s.

9.2.1 Influence of rain

For rainy days, the influence is, as expected, only significant for **RMI.FAN.2M** (see figure 9.6). The wet-bulb events are the reason of this influence.



(a)

(b)

(c)

(d)

Figure 9.6: Temperature difference related to rainy and dry days.

9.2.2 Influence of reflected short wave with snow covered ground

For the shelter **RMI.FAN.2M**, the influence of the reflected short wave with a snow covered ground is positive and quite high (1.0°C) (see figure 9.7).

For the other shelters, the influence is limited (lower than 0.02°C).

9.3 Daily Statistics

The daily statistics are available in the table 4. The daily statistics are computed on 10 minutes average. The difference are very limited except for **RMI.FAN.2M** The cumulated distribution curves are available in figure 9.8. It can be seen that the daily maximums are usually lower for the **STEVENSON.RH** compared to the reference and the minimums are higher. This is prob-

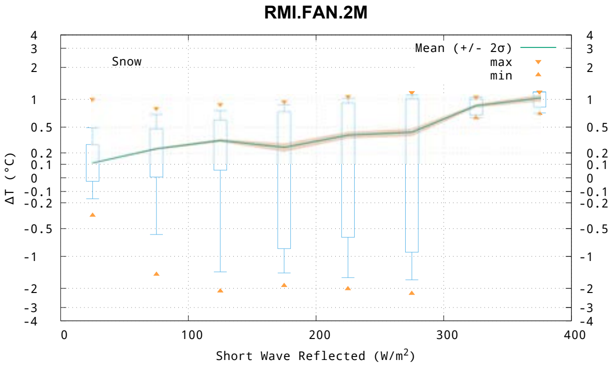
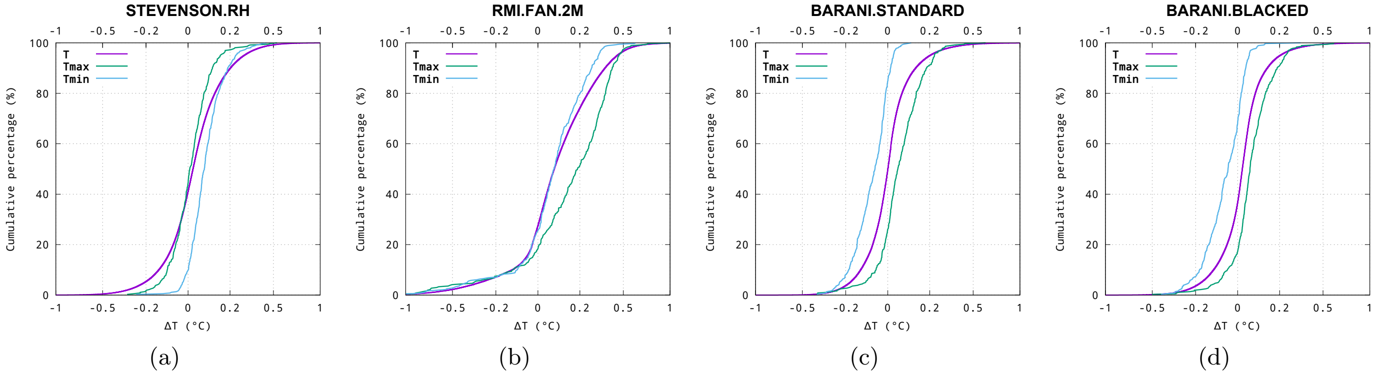


Figure 9.7: Temperature difference related to reflected solar radiation for snow days.

		STEVENSON.RH	**BARANI.STANDARD**	**BARANI.BLACKED**	**RMI.FAN.2M**
ΔTmean	Max	0.16	0.22	0.14	0.39
	Mean	0.03	0.00	0.02	0.09
	Min	-0.16	-0.08	-0.08	-0.35
ΔTmax	Max	0.53	0.61	0.60	1.02
	Mean	0.01	0.05	0.06	0.16
	Min	-0.32	-0.39	-0.50	-1.28
ΔTmin	Max	0.44	0.10	0.33	0.61
	Mean	0.08	-0.07	-0.06	0.06
	Min	-0.26	-0.39	-0.43	-1.43

Table 4: Daily statistics

ably linked to the fact that the time response of the shelter is longer with a higher thermal inertia. The two Barani have similar curves with lower minimum and higher maximum. The **RMI.FAN.2M** shelter is most of the time higher for the maximum and the minimum but with a long negative tail again linked to the wet-bulb episode during rain events.

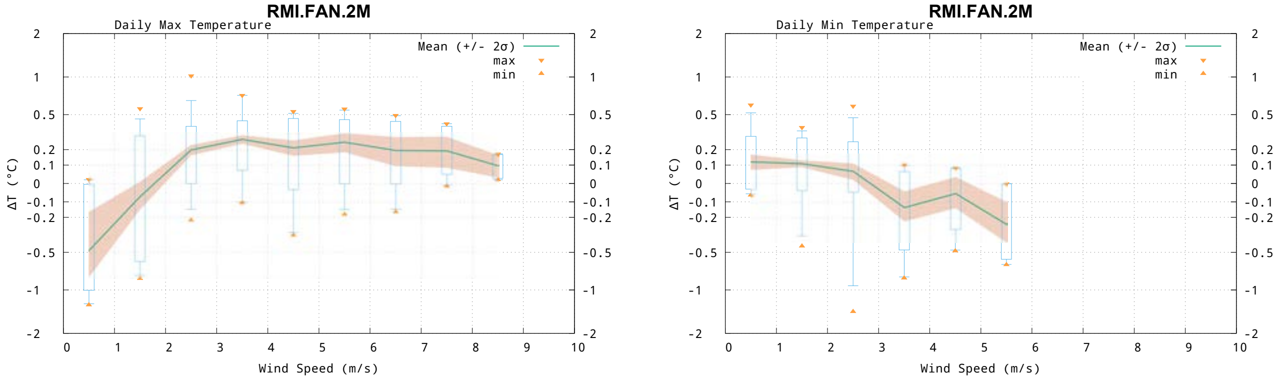


(a) (b) (c) (d)

Figure 9.8: Cumulated distribution curves of differences between the tested screens and the reference (number of days: 361).

9.3.1 Maximum/Minimum Daily Temperature vs Wind Speed

The influence of the wind speed on daily minimum and maximum is rather limited (0.1°C) except for **RMI.FAN.2M** The difference is linked to the overheating of the shelter but also to the difference of measurement reference height.



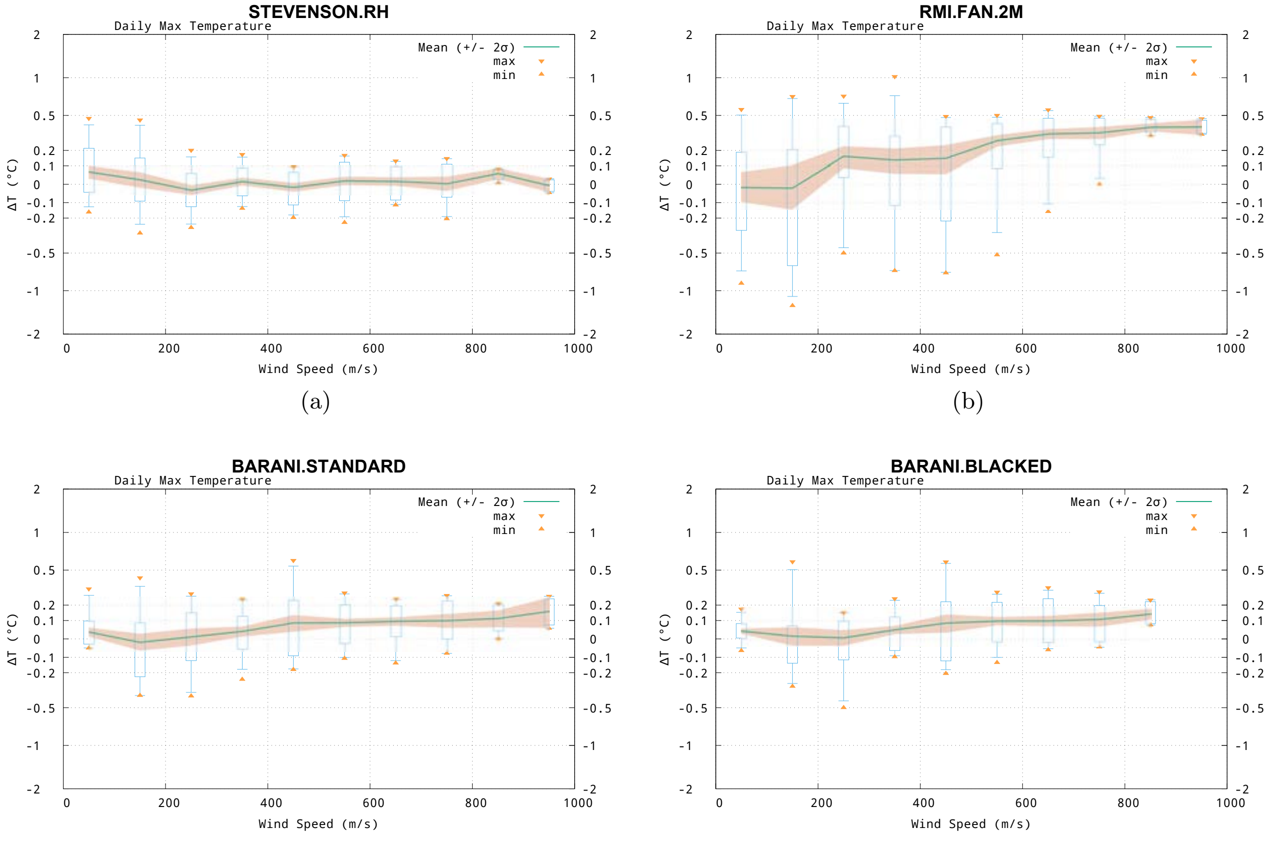
(a) Daily maximum temperature.

(b) Daily minimum temperature.

Figure 9.9: Extreme temperature difference related to wind speed.

9.3.2 Maximum Daily Temperature vs Global Short Wave

The influence of the global short wave radiation on daily maximum can be seen on figure 9.10. The influence is rather limited (0.1°C) except for **RMI.FAN.2M**. The influence increase with the amount of short wave radiation up to 0.4°C.



(a) (b)

(c) (d)

Figure 9.10: Daily maximum temperature difference related to global short wave.

10 Model of temperature difference

A non linear model of the difference in temperature has been carried out. The input parameters used were the wind speed, the radiation measurements, the snow height, the rain precipitation, the radiative temperature of the sky and the ground. As already mentioned the difference is not only linked to the shelters but also to the real height of measurement. The results showed that the model is greatly impacted by the difference of height of measurement. The fitted model is composed of a mix of shelter difference model and local micro-meteorological model to compensate the difference in height. With this mix the usefulness of the model is limited to interpret the difference between the shelters. It seems difficult to overcome the problem since the real measurement height is probably depending on the wind by a modification of the artificial ventilation flow.

11 Conclusion and future

In this study, four shelters have been compared to our reference which is a wood double louvered Stevenson screen with an added artificial ventilation (**STEVENSON.FAN.DRY**). The other shelters are: in the same Stevenson shelter a relative humidity with a temperature measurement but without direct ventilation (**STEVENSON.RH**), a compact artificially ventilated shelter built at RMI **(RMI.FAN.2M)** and two Helix Barani shelters (**BARANI.STANDARD**,**BARANI.BLACKED**). The conclusions that can be drawn from this study are:

- The aspiration rate of the RMI shelter **RMI.FAN.2M** and the **STEVENSON.FAN.DRY** is too high leading to wet-bulb events under rain.
- The temperature measurement of the relative humidity sensor **(STEVENSON.RH)** has shown good results with limited overheating under solar radiation. The time response of this shelter is expected to be longer as the artificial ventilation is not directed towards the sensor and this could explain most of the difference observed.
- The RMI shelter **RMI.FAN.2M** has an issue with the reflected radiation with an overestimation of up to 1°C in adverse conditions.
- The RMI shelter **RMI.FAN.2M** has an issue with the radiation heating under high winds with a overestimation of up to 0.4°C at 1000W/m^2.
- The real measurement height of our reference should be determined. This could probably be done by adding an additional Barani at a lower height. This height is also probably depending on the wind speed.
- The Barani's shelters have shown excellent results with a very limited heating under strong radiation. The mean overheating is as low as 0.2°C for medium global solar radiation and low wind speed (<1m/s). It is unclear why the overheating is lower for higher global solar radiation.
- Despite the fact that the Barani shelters are not artificially ventilated, their performances are better than our artificially ventilated compact shelter.

Not all the ISO recommendation ([2]) have been fulfilled. In particular the determination of the time response with the wind speed would be useful to interpret the results. Unfortunately we do not have the facilities to realise the estimation of the time response. In addition, the real inside shelter ventilation measurement should also be very interesting. Additional testing will be carried out in the next months depending on priority and time availability.

References

[1] Guidance on automatic weather systems and their implementation. TD 862, WMO/IOM, 1997.

[2] Meteorology – air temperature measurements – test methods for comparing the performance of thermometer shields/screens and defining important characteristics. International Standard 17714:2007, ISO, 2007.

[3] Agence Wallonne de l'Air et du Climat (AWAC). `http://airclimat.wallonie.be`.

[4] Belgocontrol. `http://www.belgocontrol.be/`.

[5] Bruxelles Environnnement Leefmilieu Brussel. `www.ibgebim.be/`.

[6] Luis González Sotelino, Nicolas De Coster, Peter Beirinckx, and Pieter Peeters. New concept for belgian aws network. *WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation*, (WMO), 2014.

[7] Luis González Sotelino, Nicolas De Coster, Peter Beirinckx, and Pieter Peeters. Environmental classification of rmi automatic weather station network. *WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation*, (WMO), 2016.

[8] Vlaamse Milieumaatschappij. `http://www.vmm.be/`.

[9] M. C. Peel, B. L. Finlayson, and T. A. McMahon. Updated world map of the köppen-geiger climate classification. *Hydrology and Earth System Sciences*, 11(5):1633–1644, oct 2007.

[10] J. P. van der Meulen and T. Brandsma. Thermometer screen intercomparison in de bilt (the netherlands), part i: Understanding the weather-dependent temperature differences). *International Journal of Climatology*, 28(3):371–387.

[11] Meteo Wing. `http://www.mil.be/fr/unites/meteo-wing`.