Effect of thermometer screens on accuracy of temperature measurements

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Abstract

A three year project was started by the Hungarian Meteorological Service from 2006 in order to detect effects of climate change in Hungary supported by the National Research Development and Innovation Fund. In the framework of the project a background climate network including 5 measuring stations is planned to establish, where the temporal unchangingness and representativity, the applied measurement technique and the methodology provides possibility to follow up the changes in the basic climatic parameters with the possible highest reliability. One of the climatic paremeters, the air temperature, has definitive significance, so its measurement accuracy is of primary importance to judge authentically the measure of the changes eventuated. In addition to the accuracy of the detectors, the accuracy of the measurement is considerably influenced by the type of the radiation shield, so to use the radiation shield that causes the lowest error has determinative significance in the field of the air temperature measurements. One of the aims of the first year is to study the error values caused by the different radiation shields and to design the most suitable one.
In this presentation the measuring methodology and technique to study the error caused by the radiation shields is shown and the conclusions of the previous results are also concerned.
Furthermore the effect of different shading methods on the reliability of the air temperature measurements in case of different weather conditions is analyzed.

Introduction

It is well-know that the accuracy of temperature measurements can be significantly affected by the radiation shields. Several field study have been made to investigate this effect and these study shows clearly that the error of temperature measurements caused by different type of radiation screen could be very different which depends on designs and weather conditions. Study also show that the uncertainty of temperature measurements due to use of radiation screen sometimes much more higher than the uncertanty coming from the sensors. Despite the fact that there are several results from the thermometer screen intercomparisons we conclude that before installation of our climate network it is important to do thermometer screen comparison at the Hungarian Meteorological Servic to guarrantee the highest level of accuracy of temeperature measurements.
The measuring site was developed in the garden of the Marczell György Observatory of Hungarian Meteorological Service. Character of the terrain is relatively good, the site is opened, covered by grass and its area about 7 hectars. There are no buildings, high trees or other obstacles that can affect the measurements.

Concrete activities connected to the thermometer screen comparison

According to our plan the thermometer screen comparison will be near 1 year long covering winter and summer weather conditions. During the comparison the concrete activities will be as follows:

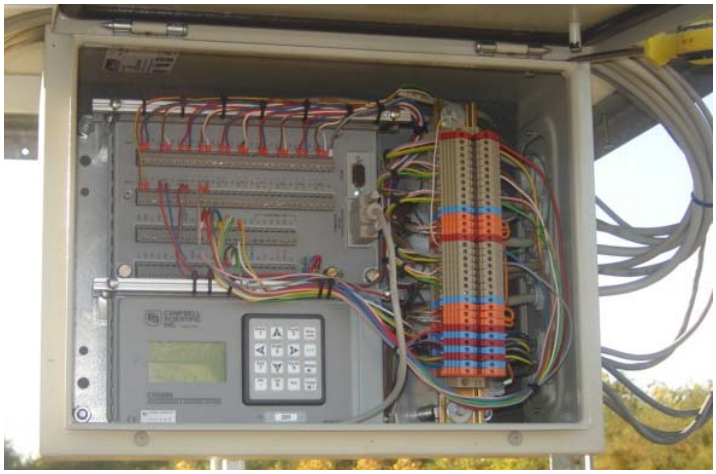
- To establish the measuring site and start measurements in autumn of 2006;

- Coutinue measurements and study until summer of 2007 to beginnig of esthablising of network;
- To study the question of „real air temperature" to estimate the uncertanty of the screens wich are or would be considered as refernece;
- Study of effects of different type of thermometer screens on tempeature measurements to cover all the possible meteorological circumstances;
- Natural ventillated screens are preferred in present state of planning our climatic network;
- To change the design of thermometer screens if there is any idea how to improve it;
- After finishing the measurements and the study, the measuring site will be able to serve another type of projects which concern similar questions.

Measuring system

Sensors:
All tempearture sensors are selected, platinum thread probes Class A. The physical dimensions of the probes were designed to get the best fitting to JOFRA ATC-157 B temperature calibrator. (Picture 6)

Data acquisition:
All signals of temperature sensors and some other supplementary measurements (wind speed, reflected radiation in the surface parallel to thermometer screen plate, surface temperature of plate) are collected by Campbell Scientific CR5000 data acquisition system. For temperature measurements the „Resistance" instruction is used where precision current excitation (1 mA) is applied and system measures a differential voltages. Sampling rate of data acquisition system is 2 seconds, and averaging time is 10 minutes. Data acquisition system can be seen on Pict.1.



Pict. 1

Pict. 2

As it can be seen later in this paper, in study of the effect of different type of thermometer screen on temperature measurements' accuracy, the consideration of the solar radiation parameters is very important. During comparison these solar radiation parameters are measured by separated data acquisition system which is the system for the operational solar radiation measurements at our observatory. In this system the sampling time is 3 seconds, based on which 1 and 10 minute averageas are produced. (Picture 4, Picture 5)

Type of screens tested

Tab. 1 shows the type of radiation screens are tested in our comparison.

Ventilation	Manufacturer	Model	Legend	Materials, design
Artificial	Young	43408	YVN1	UV resistant thermoplastic, ventilation speed ~ 6m/s
	Young	43502	YVN2	New development of Young, UV resistant thermoplastic, ventilation speed ~ 6m/s
Natural	HMS		HMS	Polyester reinforced fiberglass, 15 cups, design is very similar to Vaisala DTR13.
	HMS		HMSS	Same like HMS, but shaded against direct solar radiation
	Vaisala	DTR13	VAI1	Polyester reinforced fiberglass, 12 cups. The surface of the plates are significantly degradated after many years use
	Young	41003	YOU	UV resistant white thermoplastic, 12 cups among which 3 plain ones on the top.
	HMS		TWS	Traditional white painted, double shuttered wood thermometer screen used at HMS.

Tab. 1

As it was mentioned above the purpose of comparison is not only the study of different type of thermometer screens, but the changing of design.

These modified and test type of screens are not listed on the Tab. 1.

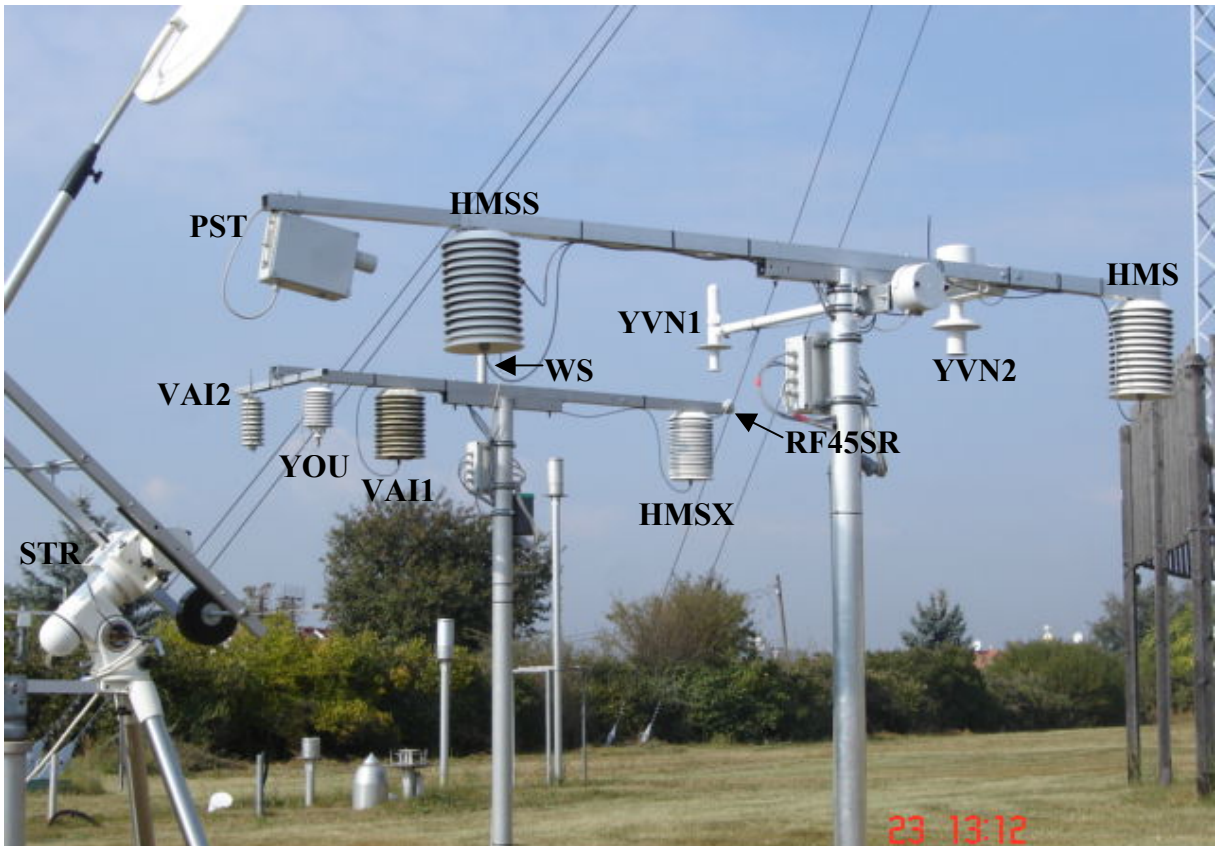
Picture of measuring site can be seen on Pict. 3.

Sensors used to analyse influencing factors:

Influencing factor	Type of sensor	Legend
Direct solar radiation	Kipp&Zonen, CH1	DRSR
Diffuse solar radiation	Kipp&Zonen, CM11	DFSR
Diffuse solar radiation on surface having 45º tilt angle	Kipp&Zonen, CM11	DF45SR
Longvawe downward radiation	Eppley, PIR	LWDW
Reflected solar radiation	Kipp&Zonen, CM11	RFSR
Reflected solar radiation on surface having 45º tilt angle	Kipp&Zonen, CM11	RF45SR
Longvawe upward radiation	Kipp&Zonen, CG1	LWUW
Plate surface temperature	Heimann KT 19.82 radiation pyrometer	PST

Wind speed	Vaisala WAA151 anemometer	WS
	Solar tarcker EQ6	STR

Tab. 2



Pict. 3

Pict. 4

Pict. 5

Calibration

Calibration of the temperature sensors is made by regular field calibration where the reference instrument is the JOFRA ATC 157B temperature calibrator. This type of calibration can give the benefits as follows:

- We can do system calibration (sensors, wires, data acqusition together);
- Calibration can be made without destroy of cabling; (it gives easy way of regular calibration).

Above the regular calibrations the data acquisition system is continuously controlled by a precise 100 Ω resistor.
The field calibration setup can be seen on Pict. 6 and the results of the last calibration in Tab.3.

ref.temp	Channel of CR 5000								
	1.	2.	3.	4.	5.	6.	7.	8.	9.
-20 ºC	-20.13	-20.10	-20.14	-20.11	-20.14	20.15	-20.19	-20.19	-20.15
0 ºC	-0.05	-0.03	-0.03	0.03	-0.04	-0.04	0.03	-0.06	-0.03
20 ºC	19.94	19.95	19.97	20.04	19.97	19.98	19.99	19.95	19.96
40 ºC	39.88	39.90	39.91	39.98	39.89	39.90	39.93	39.88	39.91

Tab. 3

Pict. 6

Results

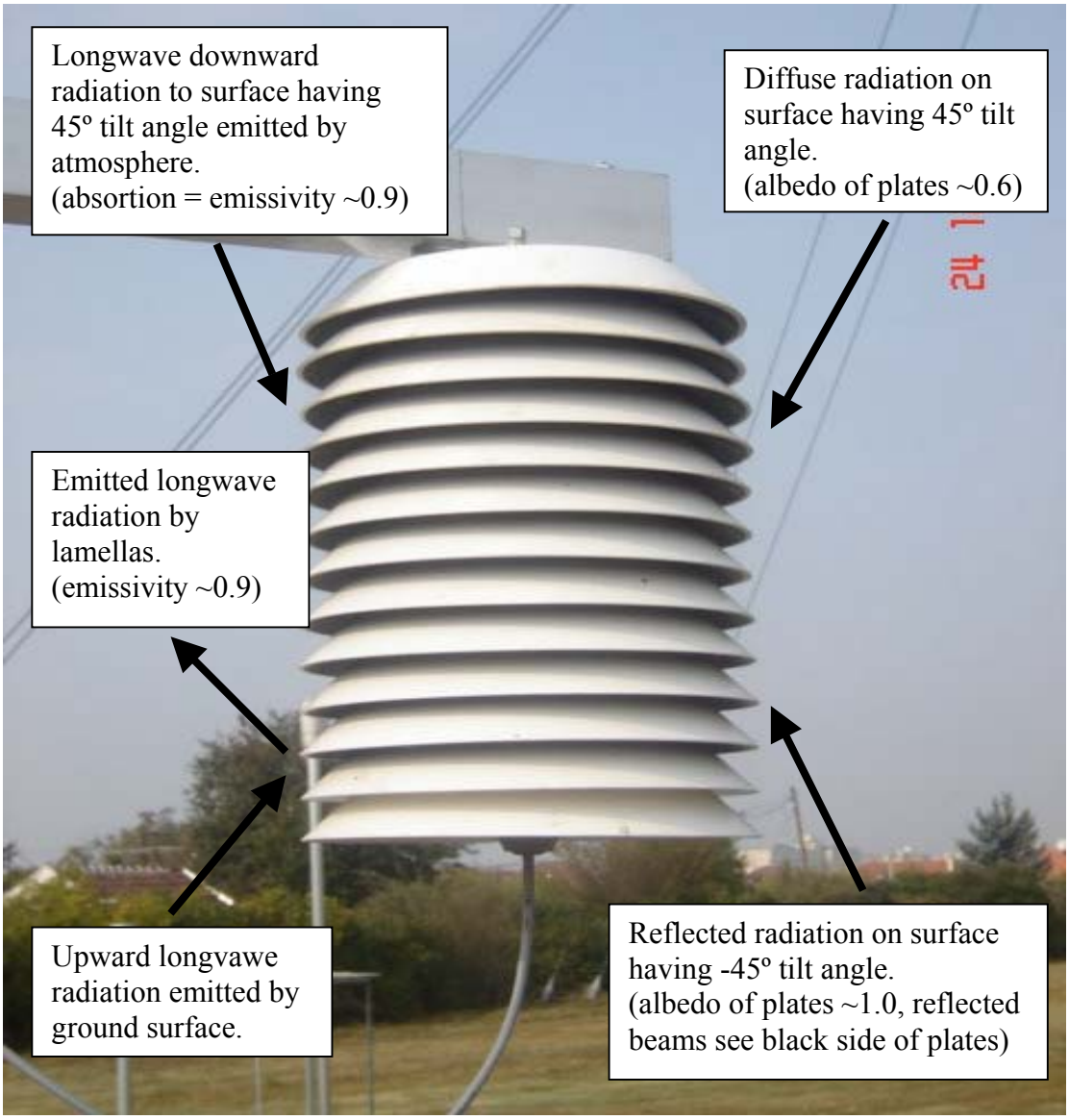
Before analyzing the data of our thermometer screen comparison, the first question is the reference that needs study. Generally in case of any comparison, the reference is the first basic question. At our comparison the Young aspirated radiation shield Model 43408 is used as reference shield that is often used as reference in other thermometer screen comparisons also. Concerning accuracy of Model 43408 the manufacturer gives the next information: „Conservatively rated, radiation errors are less than 0.2 ºC RMS with the shield exposed to solar radiation of 1100 W/m2." The range of the error given by the manufacturer is calming, but to comfirm this value by outdoor comparison would be an interesting question. (It is very frequently mentioned that colder is better when we consider the reference at thermometer screen comparison)

To minimize the error caused by solar (and longwave) radiation the Young aspirated radiation shield uses suitable flow rate of air that transports most part of the heat caused by solar (and longvawe) radiation on surface of the screen. Considering the multiplate radiation shield (and all type of screens) it is clear that the problem comes from the energy changing processes on radiation shields' surface, generating differences between air and equilibrum temperature of radiation shield plates. The solar radiation components that can influence the energy balance of shield are as follows:

- Direct solar radiation;
- Diffuse solar radiation;
- Reflected solar radiation;
- Downward longwave radiation emitted by the atmosphere;
- Upward longwave radiation emitted by ground surface;
- Emitted longwave radiation by screen surface;
- (design of some screen allows that shortvawe reflected beam can reach directly the sensor inside).

The most significant disturbing energy is the direct solar radiation because of amount of its energy flux that can make strong temperature inhomogeneity on screen surface. Our idea is that by shading the screen against the direct solar radiation (STR), we can remove this disturbing effect. Measuring and calculating all other solar radiation parameters (DFSR, DFSR45, RFSR, RFSR45, LWDW, LWUW) that can influence the energy balance of the shaded thermometer screen, we can control the energy changing processes on screen surface and if we can consider this energy to be „neglectable", the shaded thermometer screen would be another reference shield, even if the wind speed is close to zero. (It is supposed that at comparison of unventillated screens the unventillated reference would be more proper solution, and to ventillated screens the ventillated reference would be better). On the Picture… one can see the different solar radiation parameters influencing the energy balance of the shaded plate surface. Because of the fact that there are 3 plates at the top and bottom of screen making thermal protecting to inside space of screen we take the only energy on plates' surface having 45º tilt angle into consideration. From measurements we obtained the information that the albedo of white side of plate is 0.6, the ratio of diffuse radiation on surface having 45º tilt angle to the horizontal surface is 0.7-0.8, the ratio of reflected radiation on surface having - 45º tilt angle to the horizontal surface is 06.-0.7, and the ratio of downward longwave radiation on surface having 45º tilt angle to the horizontal surface is about 1.1.

Daily curves of the above mentioned ratios can be seen on Fig.1 where data from 3 selected days are presented. The reason for there is no curve of downward longwave radiation is the very limited number of mesurements (our backup pyrgeometer is under calibration in WRC in Davos during the weeks when these experiments were performed)


Longwave downward radiation to surface having 45º tilt angle emitted by atmosphere.
(absortion = emissivity ~0.9)
Diffuse radiation on surface having 45º tilt angle.
(albedo of plates ~0.6)
Emitted longwave radiation by lamellas.
(emissivity ~0.9)
Upward longvawe radiation emitted by ground surface.
Reflected radiation on surface having -45º tilt angle.
(albedo of plates ~1.0, reflected beams see black side of plates)

Pict. 7

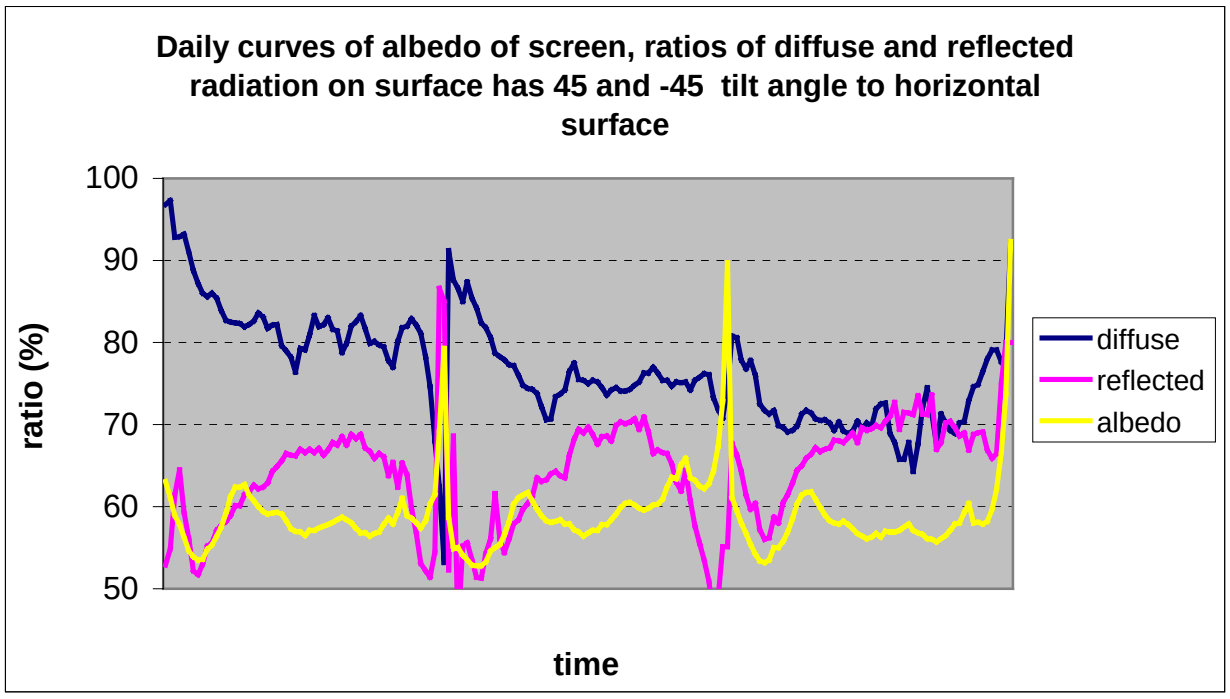

Daily curves of albedo of screen, ratios of diffuse and reflected radiation on surface has 45 and -45 tilt angle to horizontal surface
ratio (%)
100
90
80
70
60
50
time
diffuse
reflected
albedo

Fig. 1

On the Fig. 2 and Fig. 3 a-d one can follow the effect of shading to HMS multi-plate radiation shield.
The time period is near half month including periods with (24.09.- 26.09.; 09.10-11.10.) and without shading (27.09.-08.10.). In the Fig.3.a the differences between HMS and YVN1 can be seen. Differences in the first shaded period at daytime when the sky was clear are practically zero and are a bit higher in the second period (in the first period the wind was stronger than is second). These values of 0.0 - 0.4 ºC occured in the unshaded period. Comparing Fig. 3.a and 3.b shows that the shading procedure can decrease the differences of HMS multiplate radiation shield by 0.1 - 0.3 ºC. In the unshaded period the typical differences are between 0.0 - 0.5 ºC that depends on the wind speed. At night time HMS radiation shields are significantly colder with a maximum difference of -0.2 ºC. On Fig. 2 the value of overheating of screen lamellas as compared with the inside tempeartue of screen shows maximum differences of 1 ºC in shaded period at daytime and 4 ºC differences in ushaded period. At night-time the overcoolings do not exceed 2 ºC.
Taking the solar radiation components that can affect the radiation balance of shield into consideration, from measured values we can calculate the first approximation of energy balance of surface element of plate in cases when wind speed was lower than 1 m/s.
The following empirical equation is used to calculate the energy balance of the plate:

$$E=a1*(1-ALBW)*DFSR45+a2*(1-ALBM)*RFSR45+(\varepsilon*a1*c*LWDW-\varepsilon*\sigma*T^{4)} \quad \text{Eq.1}$$
$$+(\varepsilon*a3*LWUW-\varepsilon*\sigma*T^{4)}$$

Where:
DFSR, DFSR45, RFSR45, LWDW, LWUW: see in Tab. 1
ALBW, ALBM: albedo of white and mixed white-black side of plate
ε: emissivity of plate
σ: Stefan-Boltzmann constant
T: surface temperature of plate
c: ratio of DWLW on surface having 45º tilt angle to the horizontal surface
a1, a2, a3: fitting constants because of geometry of screen lamellas (in the future these constants are to be studied in more details).

Data are calculated by Eq. 1 show that the range of radiation balance of the shaded HMS thermometer screen is some ±10 W/m^2. Fig. 4 shows the relationship between the radiation balance and deviation of surface temperature from the inside temperature of the shaded screen.

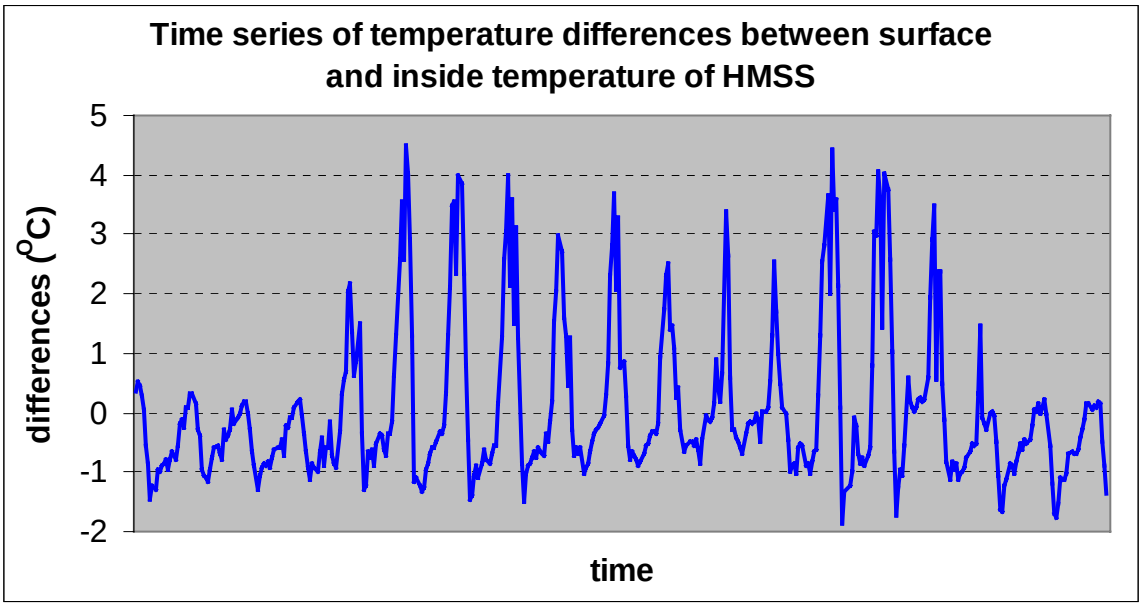


Fig. 2

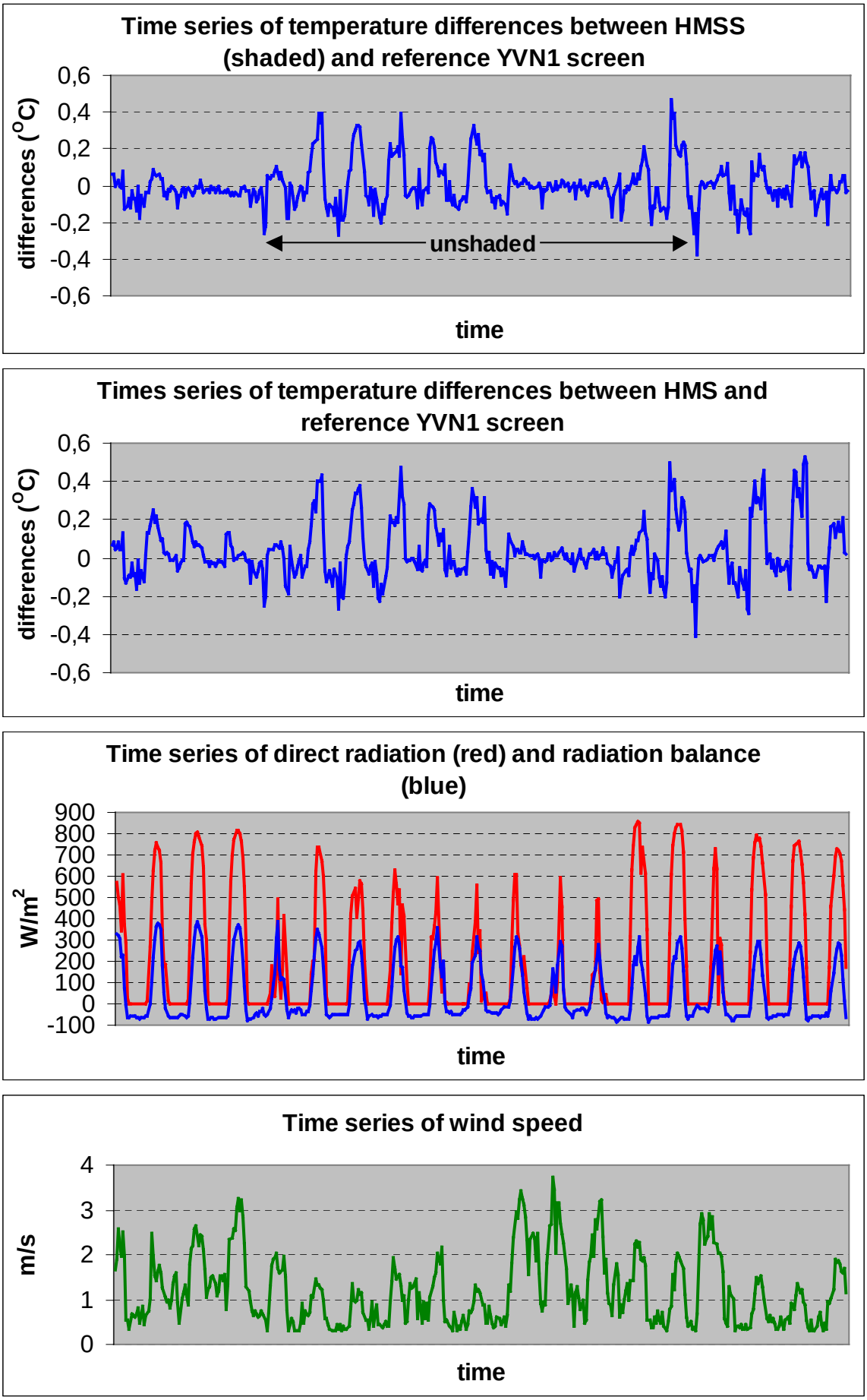

Time series of temperature differences between HMSS (shaded) and reference YVN1 screen
differences (°C)
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
unshaded
time
Times series of temperature differences between HMS and reference YVN1 screen
differences (°C)
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
time
Time series of direct radiation (red) and radiation balance (blue)
W/m2
900
800
700
600
500
400
300
200
100
0
-100
time
Time series of wind speed
m/s
4
3
2
1
0
time

Fig. 3.a-d

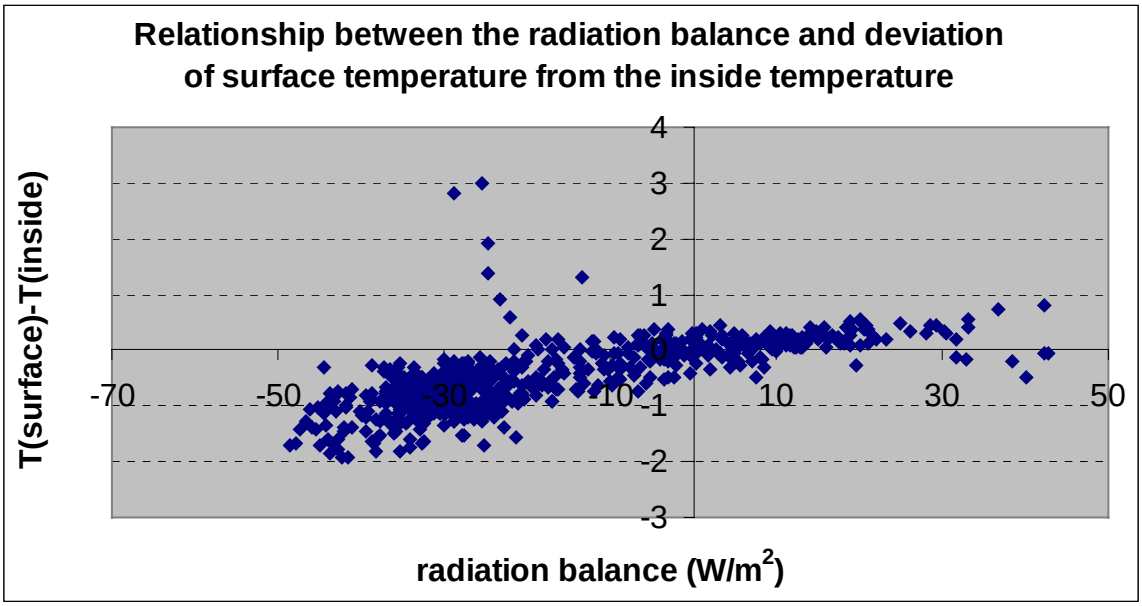


Fig. 4

Results of comparison of other type of screens

On the Fig.5-6 the first results of comparison of other screen types can be seen. The time series of differences for Young Model 43502 (YVN2) that can be considered as more compact version of Model 43408 , show a daytime behaviour, but the differences typically do not exceed 0.1 ºC.
The results of Young multi-plate radiation shield Model 41003 (YOU) that can be considered as other category of radiation shield because it has significantly stronger influence on temperature measurements like other screen that has been studied earlier. The differences at Young multi-plate radiation shield often reach the 1 ºC in daytime and –0.3 ºC in night-time. Similar behaviour is shown by the traditional wooden screen used in the network of Hungarian Meteorological Service. These results have big importance because in the past, and sometimes nowadays also, the air temperature were measured in these screen, thus causing typical error in the air temperature masurements. The information on Fig.7 is also interesting because we can estimate the effect of degradation of multi-plate screen on temperature measurements. On the Figure we can see the diffreneces of degradated HMS (the colour of lamellas is green-grey practically) screen and the new one. The effect of degradation is not so strong (degradation causes maximum temperature differences of 0.2 ºC) as it can be expected.

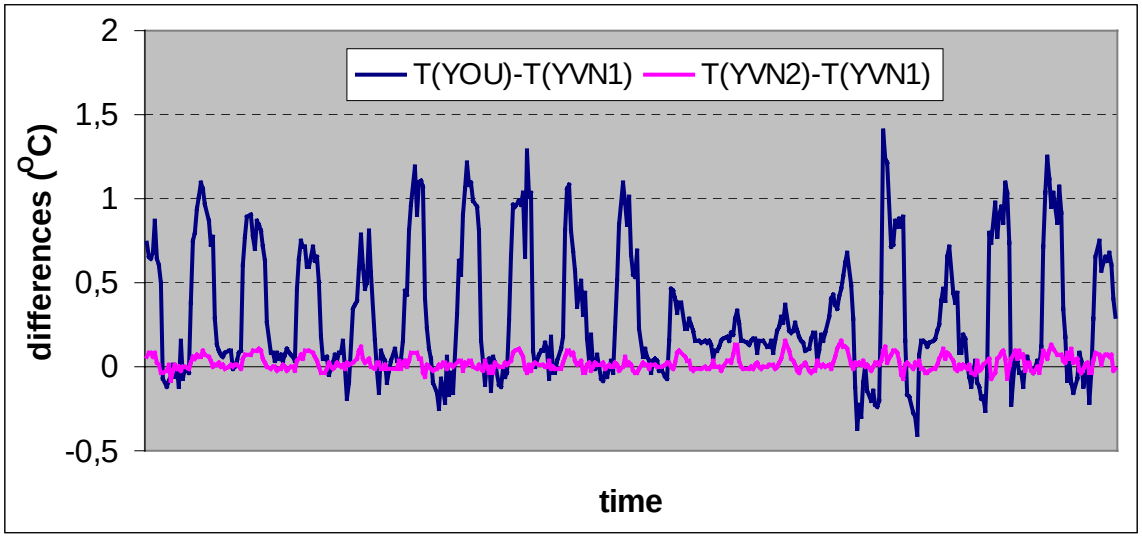


Fig. 5

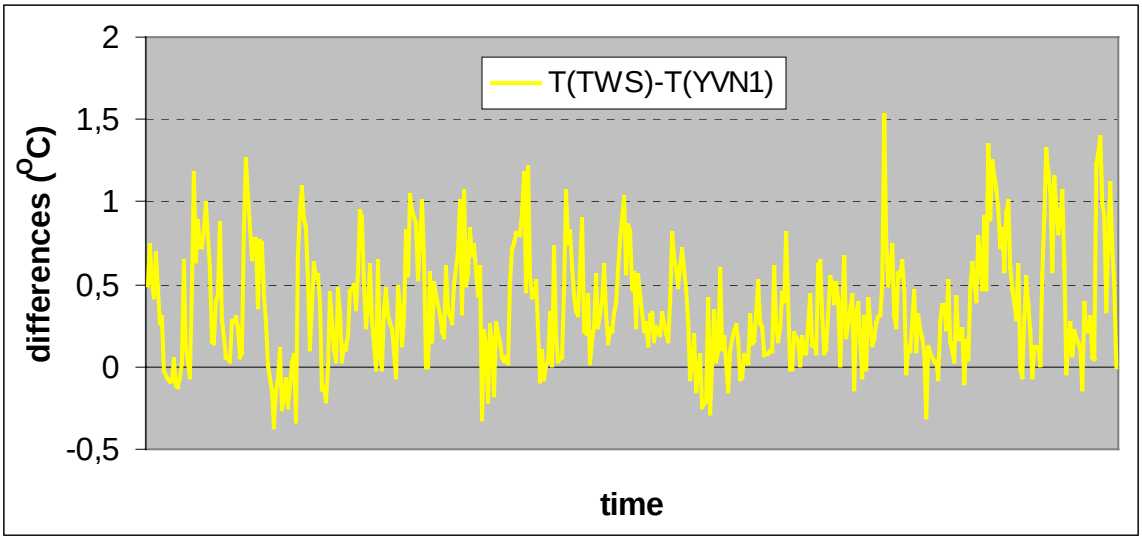


Fig. 6

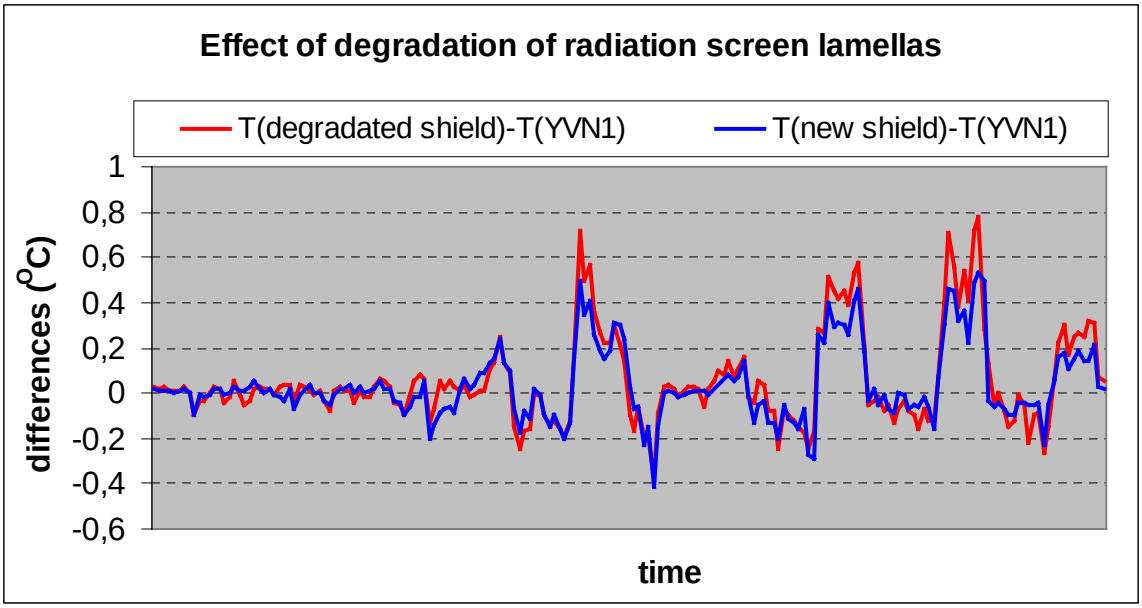


Fig. 7

Conclusions:

- The measuring site has been built at the Hungarian Meteorological Service to study the error of temperature measurements caused by different types of thermometer screens. The data aquisition sytem, calibration facilities and measuring all other, mainly solar radiation parameters, can influence the behaviour of thermometer screen, gives possibility for accurate study of error of different type of screens. The measuring system started to operate in September of this year so now we are at beggining of study of effect of screens on temperature measurements, but the first results show the main characters of behavior of different thermometer screen types. The first results also suggested some modification on screens and need for study of „reference screen"
- In our study the ventillated Young screen Model 43408 was used as reference, but in daytime by shading the multi-plate radiation shield and controlling the energy balance processes of its plates we can have alternative solution for the reference screen. Study of processes of energy balance of multi-plate screens can suggest other solutions for the reference screen also.

- First results show that if one can need accurate temperature measurements, to find the proper screen is very important.
- Changing of thermometer screens can cause inhomogeneity in time series of air temperature measurements (see the differences between traditional wood and multiplate radiation screens that are used in the surface measuring system of Hungarian Meteorological Service)