# Effects of shelter types on temperature measurements

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## Abstract

To study climate change, long term measurements are required. For reliable research these time series should be homogenous and should preferably contain no changes in the measurement conditions. To study the effects of changing the measurement systems (when changes cannot be prevented) the German meteorological service (Deutscher Wetterdienst, DWD) performs parallel measurements of previous and current (operational) instruments. At German climate reference stations the different instruments are measuring in parallel over several years to quantify the measurement uncertainty and to analyze the comparability. The comparison of automatic and manual parallel temperature measurements revealed that the shelter type which is used to protect the temperature sensor from radiation has an impact on the measurements. To quantify that effect the standard configuration (an automatic sensor PT100 installed in the lamellar shelter LAM 630) is compared with a second automatic sensor installed in a Stevenson screen (which is normally used for manual measurements). The differences between the measurements in these shelter types show a diurnal cycle and seasonal variation. The differences are positively correlated to the differences of successive temperature measurements in the lamellar shelter (temperature tendency). Large tendencies (especially during the morning and afternoon) lead to larger absolute differences. The differences of the temperature measurements in these two different shelter types are influenced by wind speed and radiation. The aim of this analysis is to simulate the differences between the shelter types in a regression model to adapt the temperature measurements.

## Introduction

Precise and representative measurements of air temperature have some challenges. All temperature sensors are affected by radiation (Erell et al., 2005). For that reason the sensors have to be protected against radiation. Different types of screens can be used to protect the instruments against radiation, but have specific advantages and disadvantages (Brandsma and Van der Meulen, 2008; Brunet et al., 2011; Böhm et al., 2010).

One type of shelter used for a long time is the Stevenson screen. This screen has a large housing and is made out of wood which is painted white. The wood lamellae are installed in a way that allows natural ventilation by wind. Nevertheless when the wind is weak there can be a heat accumulation in the housing which influences the temperature measurements.

Nowadays, lamellar shelters out of modern materials are used for protecting the temperature sensors. One example is the lamellar shelter LAM 630 out of glass fiber reinforced epoxy resin. To weaken the heat accumulation in wind still conditions the lamellar shelter has an integrated fan. The shelter is built out of seven white painted plates which are black at the bottom side to prevent heating inside the screen.

Kaspar et al. (2016) reported that the shelter type has an effect on the measurements of daily maximum temperature. If manual and automatic instruments were installed in the same (Stevenson)

shelter this does not result in significant systematic differences of daily maximum temperature and there is no annual cycle in the differences. If the LAM 630 shelter type was used for automatic measurements, the differences show an annual cycle with warmer temperature values for automatic measurements in the LAM 630 compared to the manual measurements inside the Stevenson shelter.

In this study we want to compare temperature measurements inside the two shelter types. Therefore parallel measurements are used to quantify the shelter effect and to understand the differences between the two shelters. Two identical automatic temperature sensors ("PT100") are used for this study with a high temporal resolution.

### Data

The data used in this study is measured at two station sides: Lindenberg and Hohenpeißenberg. Available variables are one minute mean temperature values with a resolution of two digits (Lindenberg) and one digit (Hohenpeißenberg), radiation measurements and wind speed in 2 meter height (Lindenberg) and wind speed in 10 meter height (Hohenpeißenberg), and relative humidity (sensor is inside the LAM 630). The measurements used here are one minute mean values.

For Hohenpeißenberg parallel measurements for this configuration are available since 08.04.2015; for Lindenberg parallel temperature measurements in this configuration and relative humidity data are available since 23.11.2017, wind and radiation instruments at two meter height are installed at Lindenberg since 11.04.2018.

The radiation measurements at Lindenberg used in this study are not quality controlled. Negative values are set to zero. When the altitude of the sun is less than -5.3° the radiation measurements are set to zero. This threshold is found in the Hohenpeißenberg data.

### Results
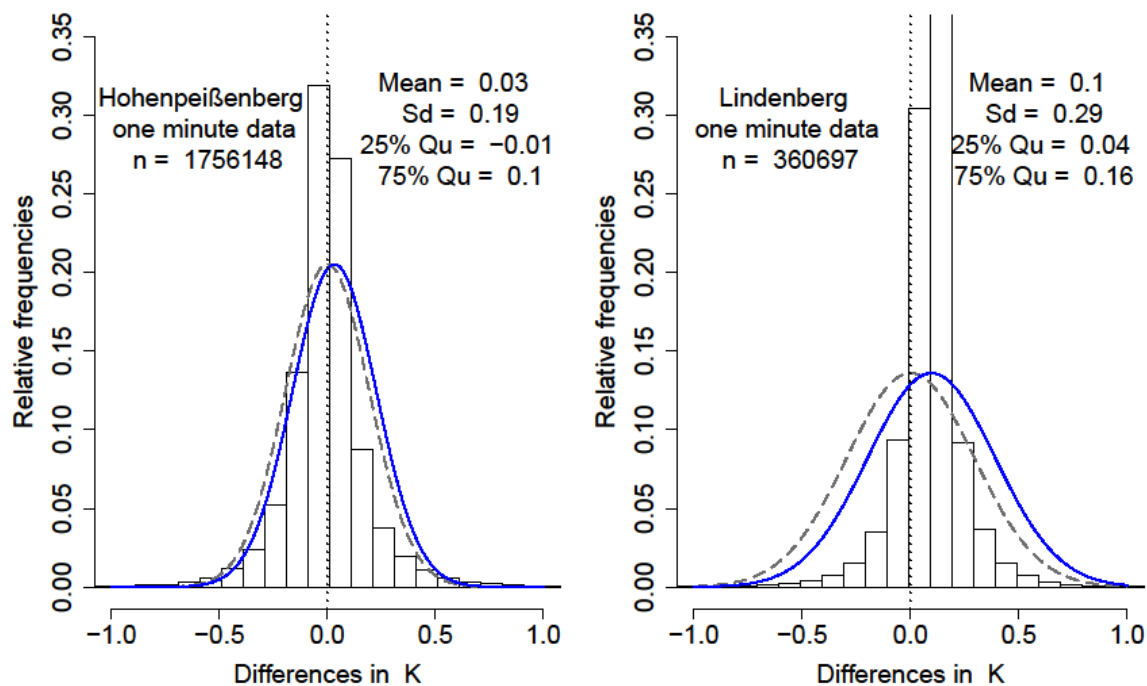
### Differences of temperature measurements



Figure 1: Differences of one minute mean temperature measurements (taken in the LAM630 minus those taken in Stevenson screen) in K of Hohenpeißenberg (left) and Lindenberg (right). The grey line is a normal distribution with mean=0 and the standard deviation out of the statistic of the used data; the blue line is a normal distribution with the mean and the standard deviation of the used data.

With a mean difference at Hohenpeißenberg of 0.03 K both measurements (taken in the LAM 630 and in the Stevenson screen) agree very well. The 25% and the 75% quantiles are not symmetric around zero. In Lindenberg the mean is shifted towards positive values which mean that the measurements in the LAM 630 screen are mostly warmer than in the Stevenson screen. The measurement uncertainty for the used temperature sensor PT100 is 0.1 K. The mean value of the differences is inside the measurement uncertainty of the used sensor. The 25% and 75% quantiles are symmetric around the mean value. Probably the mean difference is a symmetric offset between the sensors and should be corrected by adding 0.1K to data from one of the sensors.

**Differences of temperature measurements – Diurnal cycle**

The differences between the automatic measurements in the different shelter types show a diurnal cycle. To calculate the mean diurnal cycle all measurements at Hohenpeißenberg are used. The measurements are separated by the time they are measured. Mean values with a temporal resolution of 10 minutes are used. For each time of the day the measurements are averaged.

The mean diurnal cycle shows small differences during the night (Figure 1). In the morning the differences become positive with a peak shortly after sunrise. During midday the differences are small. In the afternoon the differences are negative with a peak around sunrise. This diurnal cycle can be explained by the inertia of the Stevenson screen. The Stevenson screen reacts slower to rapid temperature changes especially when there is no or only weak wind.  The lamellar shelter has integrated ventilation which accelerates the reaction to temperature changes from outside the shelter. The inertia of the screen can be (at least partly) seen in the parameter temperature tendency of the sensor in the LAM 630 screen. For that variable the changes of two successive temperature values (here of two successive ten minute mean values) are used to get the temperature tendency. The correlation of the temperature tendency of the sensor in the lamellar shelter to the differences between the temperature measurements in the different screens is high (around 0.5). Also a high correlation during the morning (positive) and afternoon (negative) can be found between the differences of temperature measurements in the different shelter types and radiation measurements, as well as to wind speed but with opposite sign and smaller correlation coefficients (Figure 1, orange and cyan line).

When the solar irradiance gets higher during the morning and wind is weak, the differences reach their maximum values. During that phase of the day, the atmosphere heats up fast and such temperature changes can be measured in the Stevenson screen only with a delay. In the afternoon when the sun goes down, the solar radiation weakens and the temperature falls rapidly to a lower value. Such fast temperature changes can be measured faster in the lamellar shelter than in the Stevenson screen.
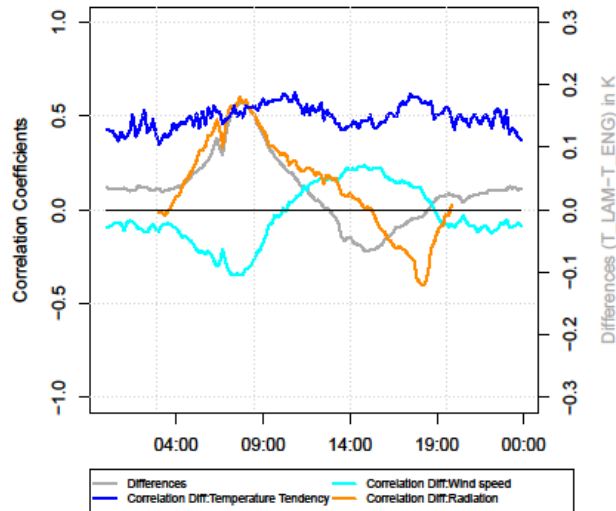
**Figure 2: Mean differences between temperature measurements in lamellar shelter and Stevenson shelter plotted by daytime in K (grey), correlation coefficients between temperature differences per daytime and temperature tendency of temperature measurements in lamellar shelter (blue), correlation coefficients between temperature differences per daytime and wind speed (cyan), and correlation coefficients between temperature differences per daytime and radiation at Hohenpeißenberg.**

The same analysis was done with data at station Lindenberg. Here we used data from May to end of July 2018. The diurnal cycle of the temperature differences is similar to the one at Hohenpeißenberg but the amplitude in the morning is larger for Hohenpeißenberg than for Lindenberg (Figure 2).

The correlation to radiation is positive during the day and there is a negative peak in the afternoon. During midday the correlation are still positive in the dataset of Lindenberg (at Hohenpeißenberg the correlation is around zero during midday/early afternoon). The correlation to wind speed is positive during the night, negative during the morning and there is no correlation from midday to the afternoon.
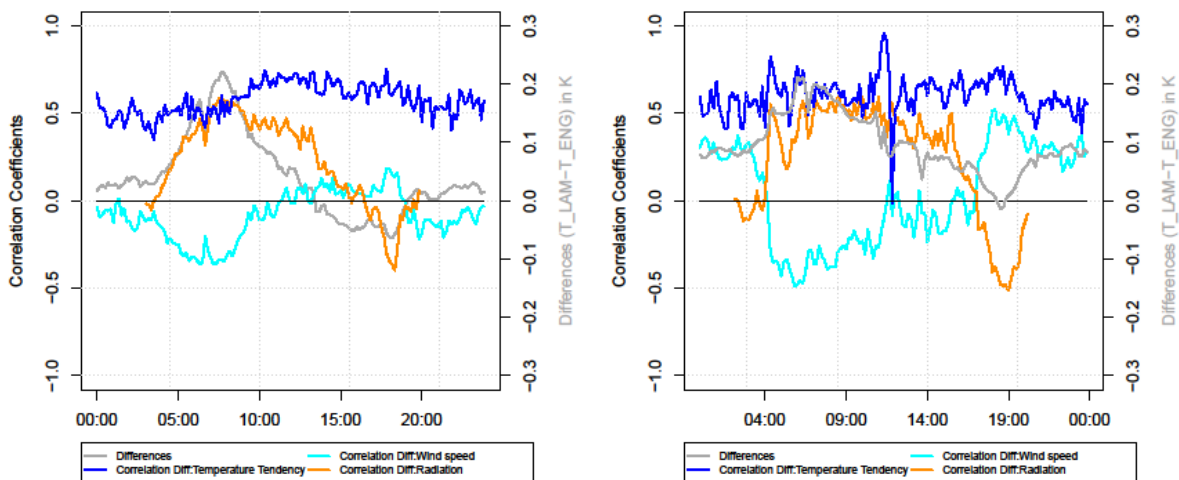


**Figure 3: Mean differences between temperature measurements in lamellar shelter and Stevenson shelter plotted by daytime in K (grey), correlation coefficients between temperature differences per daytime and temperature tendency of temperature measurements in lamellar shelter (blue), correlation coefficients between temperature differences per daytime and wind speed (cyan), and correlation coefficients between temperature differences per daytime and radiation at Hohenpeißenberg (left) and Lindenberg (right). Only data from May to July are used for this plot.**

The two datasets show similar results during the morning. The correlation to temperature tendency is similar around 0.5. During the rest of the day the correlation to radiation and wind speed differs. Probably the wind speed measurements in two meter height are more realistic to determine the measurement condition in the LAM 630 than in ten meter height. Turbulences in ten meter are less developed than in two meter height and small scale changes in two meter are not visible in ten meter measurements.

**Differences of temperature measurements – annual cycle**

There is no annual cycle in the median of the differences between the one minute mean temperature measurements in the different screen types (Figure 4). Monthly variations can be found in the standard deviation of the differences. In summer the standard deviation is larger than in winter months.
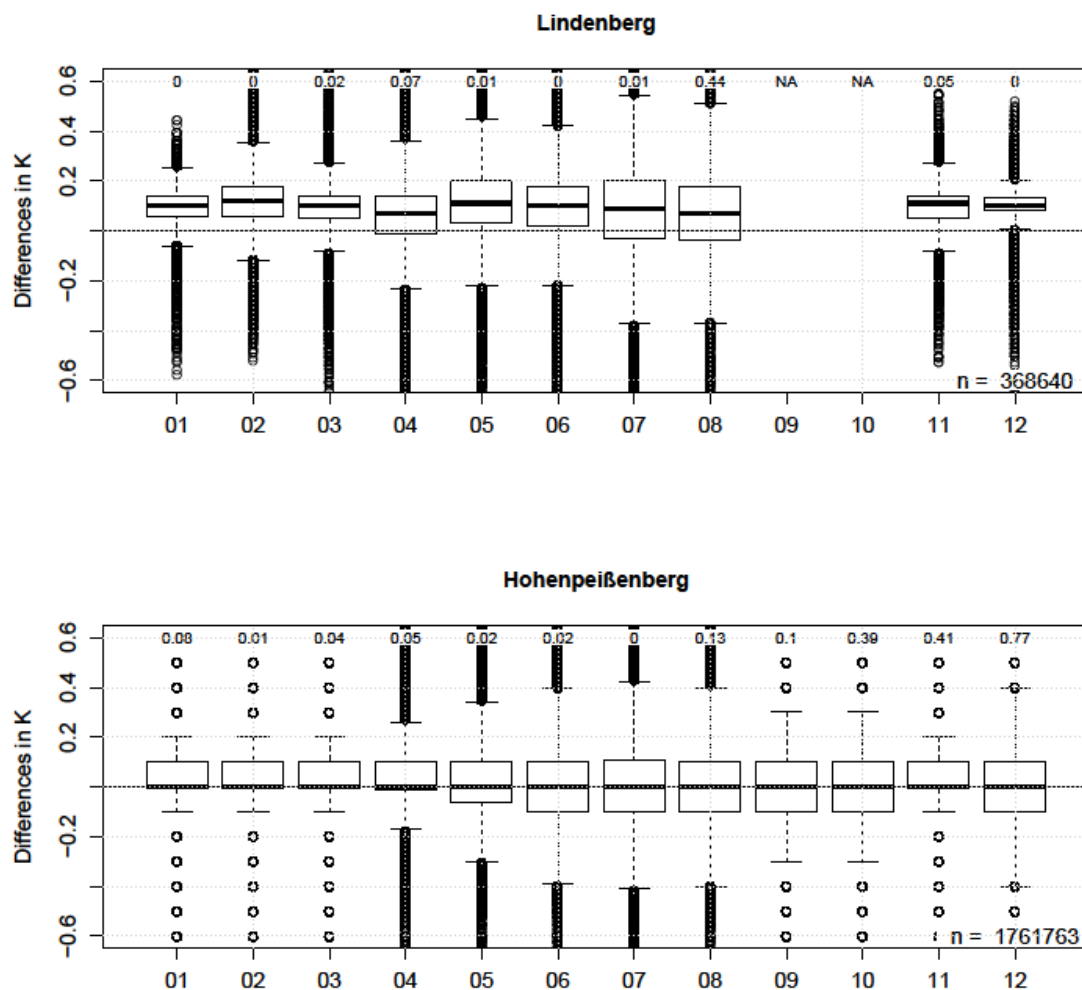


**Figure 4: Differences of one minute mean temperature measurements in different shelter types in K separated by months for Lindenberg data (top) and Hohenpeißenberg (bottom). The values in the top row represent the results of the p value of the t-test.**

After calculating daily maximum temperature values (from one minute mean temperature of the different shelter types), an annual cycle appears in the differences of daily maximum temperature (Figure 5). The median of the differences is larger during summer months than during the winter.

Daily maximum temperature values which are measured in the LAM 630 are warmer during summer than the daily maximum temperature measured in the Stevenson screen.
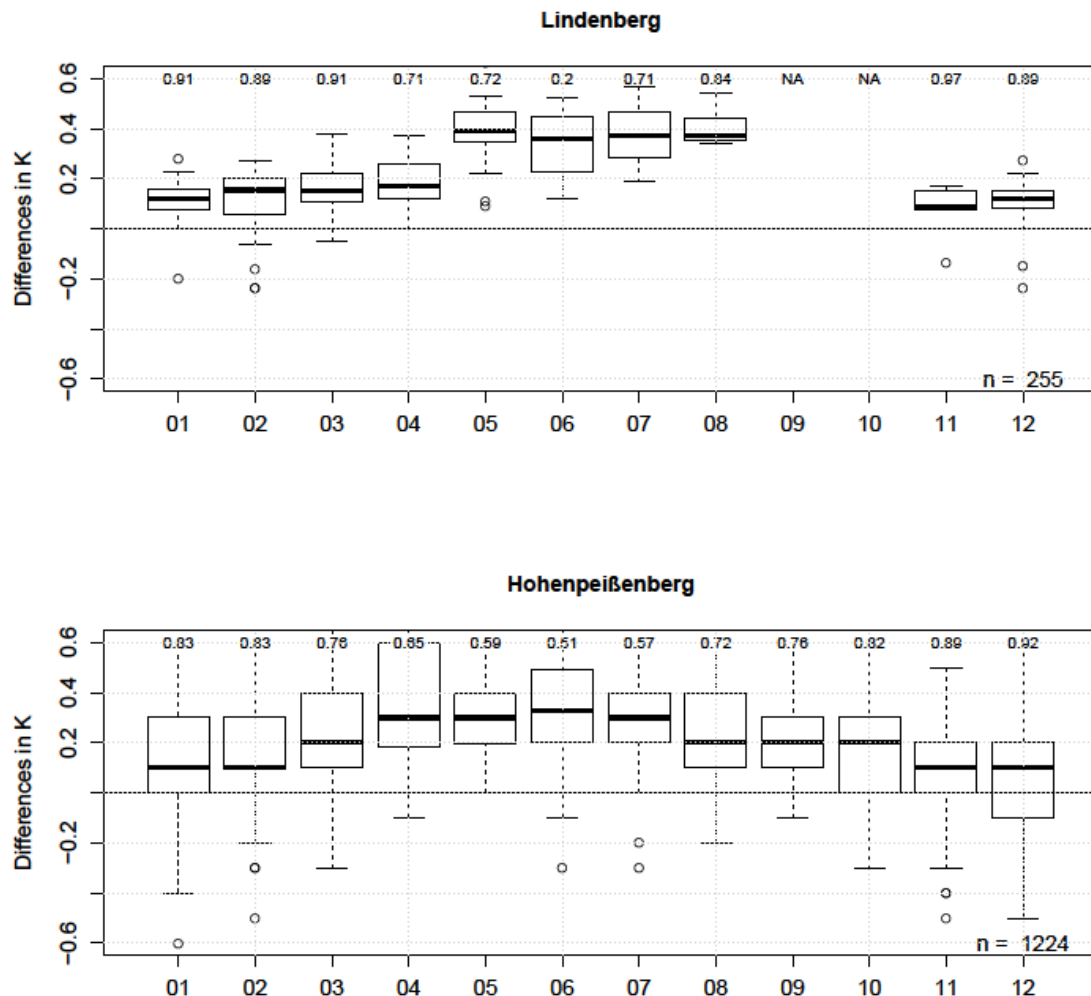


**Figure 5: Differences of daily maximum temperature (calculated with one minute mean temperature measurements in different shelter types) in K separated by months for Lindenberg data (top) and Hohenpeißenberg (bottom). The values in the top row represent the results of the p value of the t-test.**

## Results of correlation analysis

The correlation coefficients are calculated using the full time series. Different temporal resolutions are used to calculate the correlation coefficients after Spearman. "1-min Data" stands for one minute mean values, "10-min mean" stands for ten minute mean values and "10-min actual" stands for one minute mean values every ten minutes.

Table 1: Correlation coefficients between differences of temperature measurements in different shelter types and wind speed (second row), solar irradiance (third row), solar irradiance changes between two successive values (forth row), temperature tendency of temperature measurements inside the LAM 630 (fifth row), relative humidity (sixth row), and relative humidity changes between two successive values (seventh row) at Hohenpeißenberg calculated with different temporal resolution of the data.

| Hohenpeiß-enberg | Diff - v | Diff - RAD | Diff - RADdt | Diff - Tdt | Diff – RH | Diff – RHdt |
|---|---|---|---|---|---|---|
| 1-min Data | -0.049 | 0.026 | 0.084 | 0.275 | 0.069 | -0.092 |
| 10-min mean | -0.061 | 0.044 | 0.263 | 0.511 | 0.082 | -0.335 |
| 10-min actual | -0.051 | 0.025 | 0.207 | 0.272 | 0.068 | -0.250 |

The largest correlation coefficients for Hohenpeißenberg data are calculated with ten minute mean values. The correlation coefficients to temperature tendency and relative humidity tendency are largest. These two variables are connected to each other. Fast temperature changes often result in relative humidity changes. Warm air can include more moisture than cold air which results in relative humidity changes. A relative large correlation coefficient can be found with the variable radiation changes/tendency (RADdt). Strong radiation changes results in temperature changes which can be measured in the LAM 630 faster than in the Stevenson screen.

Table 2: Correlation coefficients between differences of temperature measurements in different shelter types and wind speed in two meter height (second row), solar irradiance (third row), solar irradiance changes between two successive values (forth row), temperature tendency of temperature measurements inside the LAM 630 (fifth row), relative humidity (sixth row), and relative humidity changes between two successive values (seventh row) at Lindenberg calculated with different temporal resolution of the data.

| Lindenberg | Diff - v | Diff - RAD | Diff – RADdt | Diff - Tdt | Diff – RH | Diff – RHdt |
|---|---|---|---|---|---|---|
| 1-min Data | 0.198 | 0.143 | 0.114 | 0.305 | -0.072 | -0.126 |
| 10-min mean | 0.233 | 0.195 | 0.269 | 0.581 | -0.097 | -0.455 |
| 10-min actual | 0.195 | 0.137 | 0.224 | 0.564 | -0.064 | -0.381 |

At Lindenberg the correlation coefficients are larger than at Hohenpeißenberg (especially for radiation and wind speed, see Table 2). At Lindenberg the radiation and wind speed instruments are next to the screen in two meter height. The measurement condition can be observed realistically in the same measuring height as the temperature measurements. That is the reason why the correlation coefficients at Lindenberg are larger than at Hohenpeißenberg.

**Outlook**

The variables which have a large correlation to the differences can be used to simulate the screen effect. The variables temperature tendency, radiation tendency, and relative humidity tendency are possible predictors. Wind speed measurements in two meter height can be useful as well. The next step is to find the best model to simulate the screen effect and to validate the model. When there is a significant improvement using the model, the model can be used to adapt the temperature measurements.

**Summary**

To protect temperature sensor against radiation effects different screen types are in use. In this study the Stevenson screen is compared to the lamellar shelter LAM 630. During the morning and afternoon when the temperature changes are largest during the day, the differences between the temperature measurements in the different screens are largest as well. During the morning the differences are positive, i.e. warmer temperatures are measured in the LAM 630, in the afternoon the differences are negative, i.e. colder temperatures are measured in the LAM 630.

The screen effect is strongest in the comparison of daily maximum temperature. Here an annual cycle in the differences with a bias in summer was observed.

The correlation between the differences and the temperature tendency of the sensor in the LAM 630 is largest (around 0.5). For Lindenberg the correlation to radiation measurements and wind speed is large as well, but this relationship cannot be found in the data of Hohenpeißenberg. At Lindenberg wind speed and radiation is measured in two meter height, at Hohenpeißenberg the wind speed is measured in ten meter height. Small scaled wind changes in two meter height are not present in higher levels which results in smaller correlation coefficients.

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