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by

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1. Foreword

This report is supplementary material to the conference paper titled “Outdoor Micro-Climate: Air Temperature Measurements around an Office Building in Denmark during Summer” and presented at the CISBAT International Conference 2023 by Johra et al. [1].

The aim of this technical report is to give a detailed description of the experimental setup used to measure the local micro-climate (outdoor air temperature) and the local weather conditions around a multi-storey office building used for teaching and research purposes at the university campus of Aalborg University, Aalborg, Denmark [2], during summer 2022.

The measurement data collected during this measurement campaign is attached to this technical report and available in open access on vbn.aau.dk [3].

2. Abstract

The local outdoor micro-climate induced by the presence of buildings can be significantly different from the outdoor conditions around weather stations located outside of urban areas. However, the latter conditions are often used to design buildings and size heating, cooling and ventilation systems. Such a mismatch can have a severe impact on the actual performance of building systems.

To date, most of the micro-climate studies are based on numerical simulations and focus on the heat island effect in large urban areas subjected to heat waves. Consequently, there is a lack of experimental studies assessing the local outdoor micro-climate around buildings.

To remedy that situation, the local micro-climate (outdoor air temperature) and the local weather conditions around a multi-storey office building used for teaching and research purposes at the university campus of Aalborg University, Aalborg, Denmark [2], during the summer of 2022.

The results of this measurement campaign show that, depending on the orientation of the external building surface (South/North façade or rooftop), the distance from the latter and the weather conditions, the temperature in this air boundary layer can vary significantly and differ from the air temperature measured at nearby open fields or recorded by the local weather station. For instance, The gradient between the air temperature at 5 cm from the building envelope and at 200 cm from the building envelope is significant, especially in the case of sunny afternoons. On the South façade, temperature gradients have been measured at up to 3.4 °C and up to 13.6 °C on the building roof. On the North façade, however, no significant temperature gradient has been measured.

Certain correlations can be observed between the temperature gradient on the building roof and the South façade and the wind speed and solar radiation.

These results may help to validate and improve outdoor micro-climate numerical models, and adjust assessment, design and sizing methods for building systems affected by local outdoor air temperature around the building envelope.

3. Study case building

This measurement campaign consists of the monitoring of the local micro-climate (outdoor air temperature) and the local weather conditions around a multi-storey office building used for teaching and research purposes at the university campus of Aalborg University, Aalborg, Denmark [2], during summer 2022.

This study case building (denominated in the rest of the report as "*AAU-TMV*") is located at Thomas Manns Vej 23, 9220 Aalborg Øst, Denmark. The building belongs to a university campus situated on the SouthEast edge of the urban area of the city of Aalborg in the north of Denmark (see *Figure 1*).

Figure 1: *Location of the study case building in the Aalborg urban area.*

Aalborg urban area is not a densely-populated city (population density in the municipality area: 178 habitants/km^2) surrounded by open flatland agricultural fields. Aalborg is situated in the north of Denmark, in the north of the Jutland peninsula. Aalborg city center is roughly 30 km away from the Kattegat (the sea between the Baltic Sea and the North Sea) in the east and 30 km away from the North Sea in the west. This region is very windy with dominant winds coming from the west.

A detailed description of this building study case can be found in a dedicated technical report [4].

The study case building is located at the western edge of the Aalborg University campus (see *Figure 2*).

Figure 2: *Location of the study case building on the Aalborg University campus.*

The study case building is surrounded by low-rise (2-3 floors) office buildings to the north, medium-rise office buildings to the east (5 floors) and flatland open fields to the south and west (see *Figure 3*).

Figure 3: *Aerial view of the AAU-TMV building in its surrounding environment on the Aalborg University main campus.*

Figure 4: *View of the South facade of the AAU-TMV building (credit to Aalborg University).*

Figure 5: *View of the South facade of the AAU-TMV building (credit to Ronge Fotografi).*

Figure 6: *View of the North facade of the AAU-TMV building.*

Figure 7: *Aerial view of the AAU-TMV building in its surrounding environment on the Aalborg University main campus. The South façade, the West façade and the roof of the building are visible. In 2022, a new building was built on the East side of the AAU-TMV building (upper right corner of the AAU-TMV building in the picture) but was not visible yet in that aerial view. This new building on the East side of the AAU-TMV building was completed and opened on October 2022 (https://www.aau.dk/grand-opening-e41542). The measurements on AAU-TMV were carried out in summer 2022, therefore, the external part of the building on the East side was already finished (credit to Aalborg University).*

Figure 8: *Aerial view of the AAU-TMV building in its surrounding environment on the Aalborg University main campus. The South façade, the East façade and the roof of the building are visible. In 2022, a new building was built on the East side of the AAU-TMV building (right side of the AAU-TMV building in the picture) but was not visible yet in that aerial view. This new building on the East side of the AAU-TMV building was completed and opened on October 2022 (https://www.aau.dk/grand-opening-e41542). The measurements on AAU-TMV were carried out in summer 2022, therefore, the external part of the building on the East side was already finished (credit to Aalborg University).*

4. Description of the measurement setup

This measurement campaign aims at measuring the air temperature gradient near the building envelope in 4 different locations, together with the air temperature in an open field far away from the study case building, the air temperature recorded by the reference weather station of the location and the local weather data.

The air temperature is measured with calibrated Pt100 temperature sensors (Resistance temperature detectors: RTDs). These temperature sensors are mounted with a 4-wire configuration to a National Instruments NI 9226 cDAQ C Series temperature input module with 8 measurement channels. The temperature is recorded every 2 seconds and then averaged over 5 minutes.

The Pt100 sensors are calibrated in a dry-block temperature well "Isocal Venus 2140B" with a calibrated reference thermometer "ASL F200" [5]. The uncertainty on the calibrated temperature measurements with these Pt100 sensors is estimated to be +/- 0.1 K with a 3σ (99.7%) confidence level.

The presence of direct solar radiation on bare temperature sensors can heavily affect the measurement of air temperature. To tackle this issue, the Pt100 sensors are shielded in a mechanically-ventilated and silver-coated tube [6][7] (see *Figure 9*). Temperature sensors within mechanically-ventilated, shaded tubes are commonly assumed to have errors below 0.1 K [8].

Figure 9: *Pt100 temperature sensor placed in a mechanically-ventilated and silver-coated tube.*

The temperature sensors are mounted on racks and poles (see *Figure 10* and *Figure 11*) to measure the air temperature (8 temperature sensors) at 5 cm, 10 cm, 20 cm, 30 cm, 40 cm, 50 cm, 100 cm and 200 cm from the building envelope (South façade, North façade and rooftop). On the North and South facades, the temperature sensors are positioned 2 meters above the ground. The shielding ventilated tubes are mounted horizontally in the East-West direction to avoid any solar radiation from reaching the temperature sensor inside the tube.

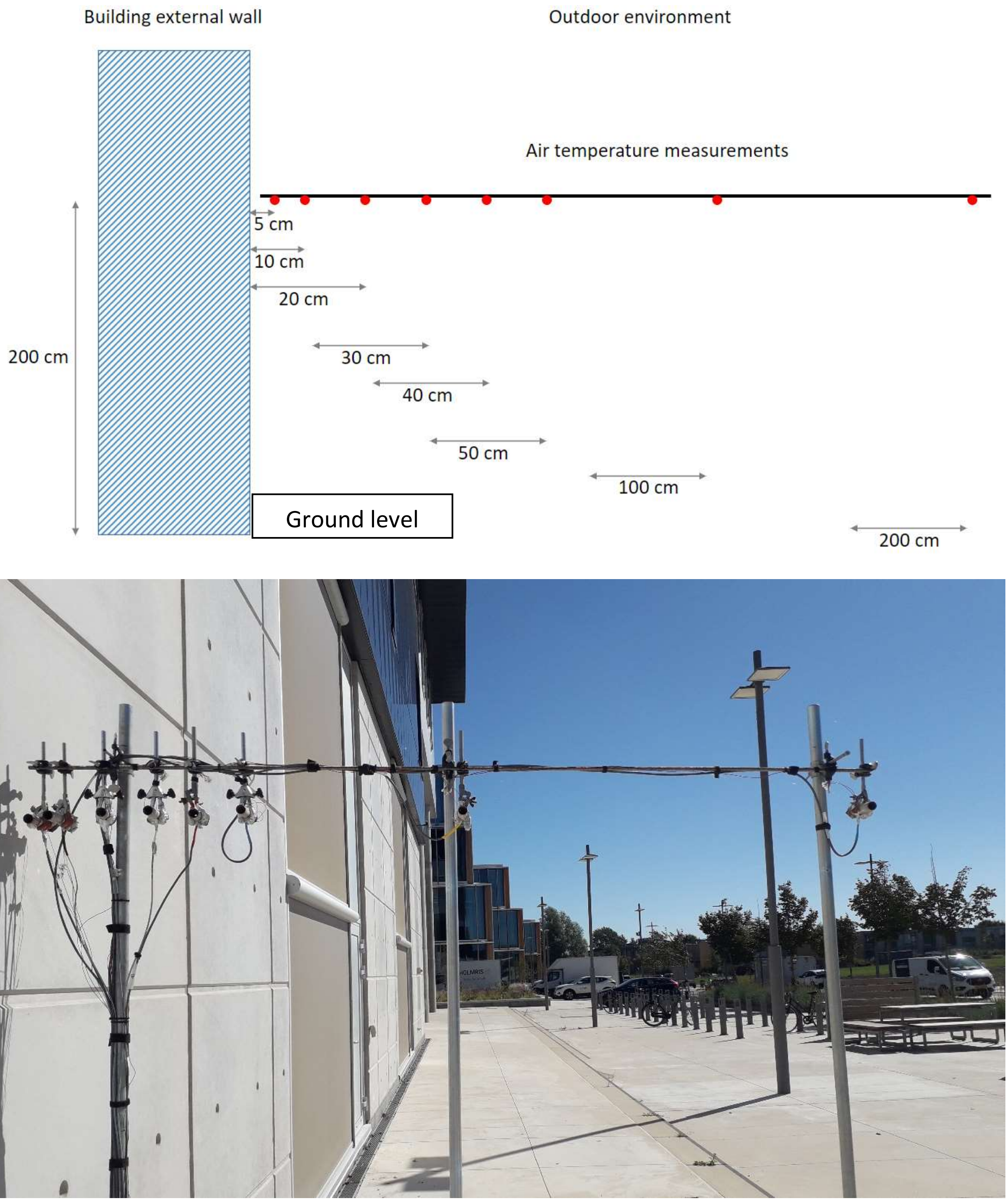

Figure 10: *Air temperature measurement setup mounted on the South façade of the building.*

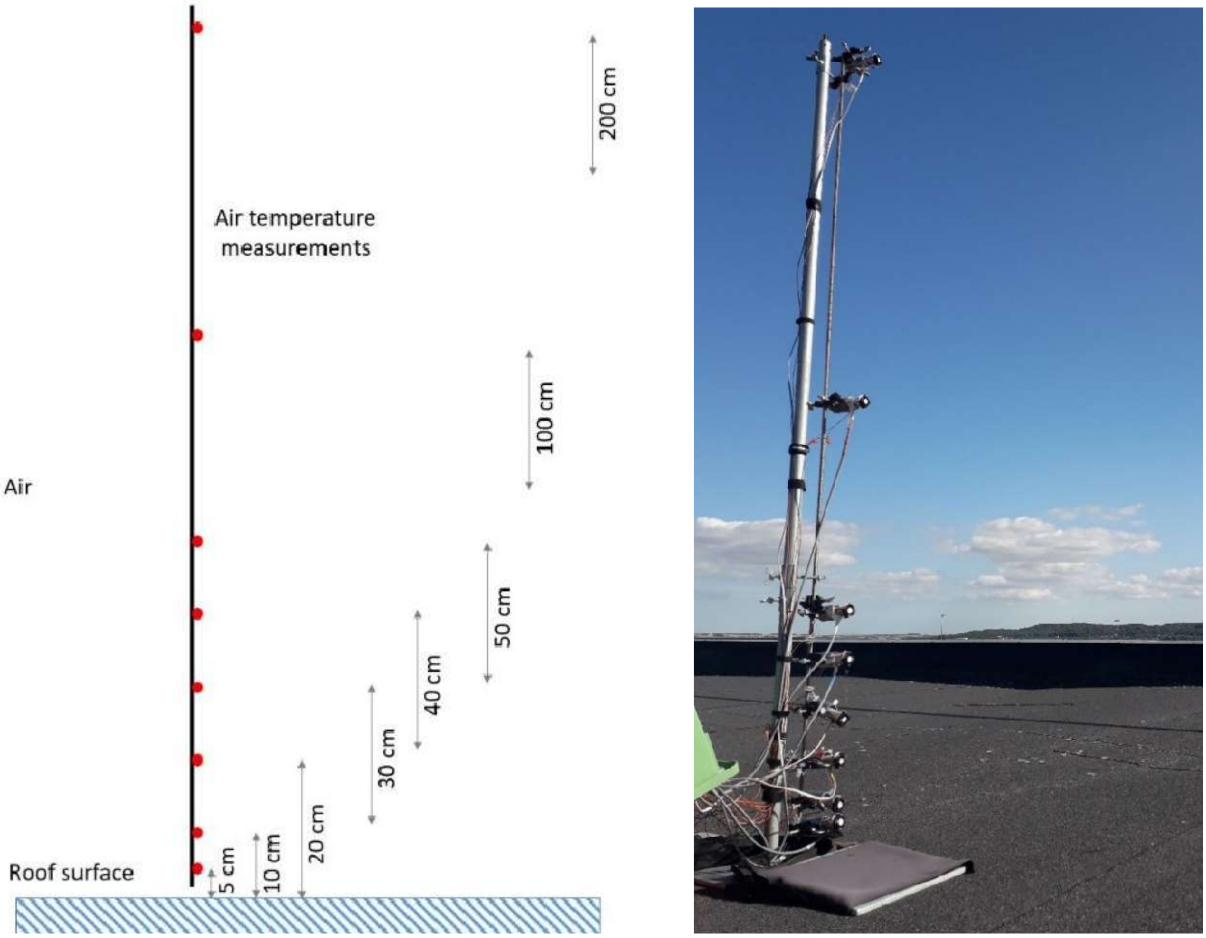

Figure 11: *Air temperature measurement setup mounted on the roof of the building.*

A black fabric was placed over the silver metal plates of the pole for the roof-mounted setup to replicate the albedo of the surrounding roof (see *Figure 11*).

One can see the placement of the 4 air temperature measurement setups around the building envelope in *Figure 12*. 3 setups are placed in the center of the building on the North façade, South façade and on the roof. A fourth setup is placed on the South façade in front of a ventilation exhaust (to assess the impact of ventilation system on local micro-climate around the building).

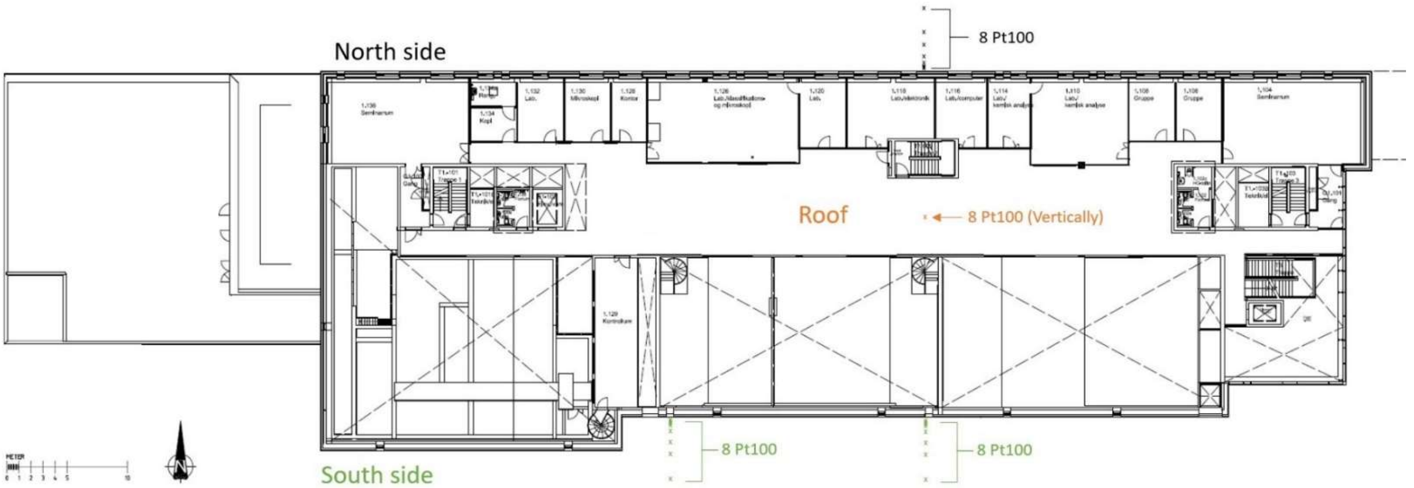

Figure 12: *Placement of the 4 air temperature measurement setups around the envelope of the building study case.*

The air temperature is also measured at a far-open field (football field) located 220 m to the south of the study case building (see *Figure 13*). There is no building around that football field. The air temperature is measured with 3 calibrated “Tinytag data loggers”. The temperature sensors are placed at 2 m height and protected by a ventilated weather station casing (see *Figure 13*). The recorded air temperature is the average of the 3 Tinytag measurements.

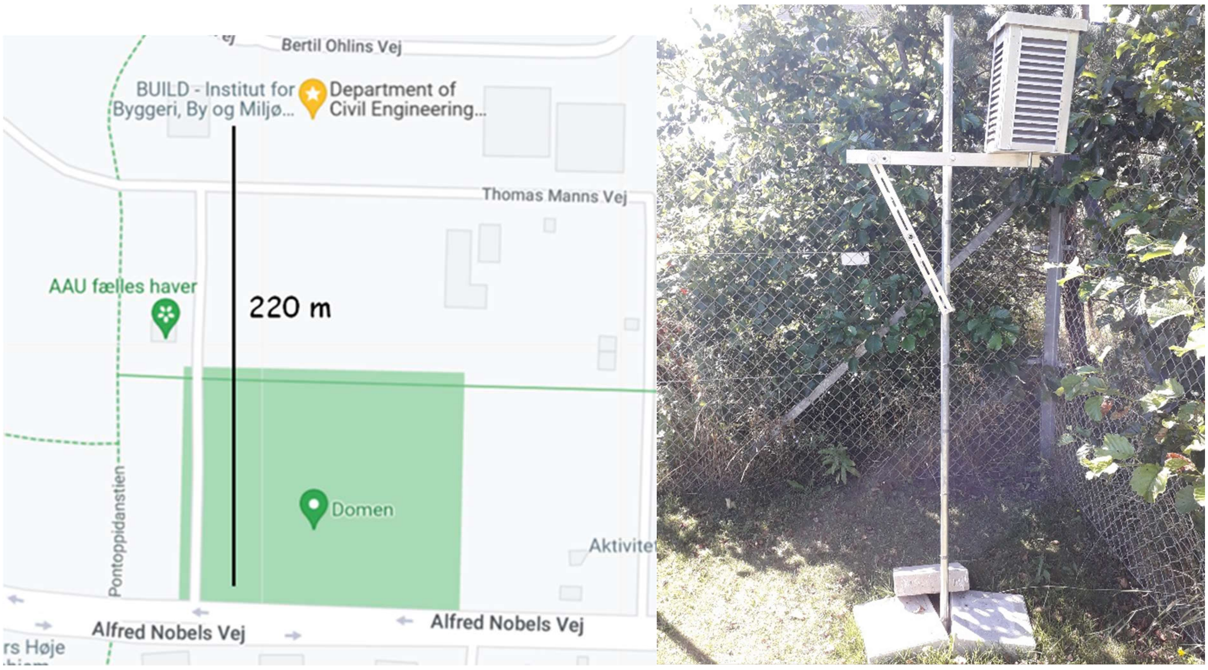

Figure 13: *Air temperature measurement setup located at the far-open field (football field) 220 m away from the study case building.*

The weather conditions at the building study case are measured with a meteorological station mounted on the roof the building case. The data of that meteorological station are in open access:

http://www.vejrradar.dk/weatherstation/TMV23/index.php

Finally, the reference weather data (dry bulb air temperature) is retrieved from the closest reference weather station of the *Danish Meteorological Institute* (DMI). This reference weather station is located in Tylstrup, 25 km north of the building study case (weather station “TYLSTRUP”, weather station number 06031, latitude 57.1852, longitude 9.9526, altitude 13 meters [9]).

5. Measurement raw data

All the raw measurement data collected for this study can be found in the appendix data file (.xlsx) attached to this technical report.

All sensors have been tested and calibrated. The measurement data is collected with a sampling rate of 5-minute time intervals for a period spanning from the 10th of June 2022 to the 19th of August 2022. Most of the data has been originally measured and logged at a sampling rate of 2-second time intervals and then resampled at 5-minute time intervals. For each 5-minute time interval, the standard deviation (noted "std dev") is calculated from the original 2-second time intervals data. The measurement data is sometimes incomplete for certain date-and-time points (empty cells for missing data points).

The different measurement variables in the attached data file "Data_measurement_outdoor_micro_climate_summer_2022_Denmark.xlsx" [3] are as follows:

- Date and time
- air temperature (dry bulb) from Tylstrup DMI weather station [°C]
- Month of the year
- Day of the month
- Time of the day
- Far-open field temperature [°C]
- air temperature south facade 5 cm [°C]
- std dev air temperature south facade 5 cm [°C]
- air temperature south facade 10 cm [°C]
- std dev air temperature south facade 10 cm [°C]
- air temperature south facade 20 cm [°C]
- std dev air temperature south facade 20 cm [°C]
- air temperature south facade 30 cm [°C]
- std dev air temperature south facade 30 cm [°C]
- air temperature south facade 40 cm [°C]
- std dev air temperature south facade 40 cm [°C]
- air temperature south facade 50 cm [°C]
- std dev air temperature south facade 50 cm [°C]
- air temperature south facade 100 cm [°C]
- std dev air temperature south facade 100 cm [°C]
- air temperature south facade 200 cm [°C]
- std dev air temperature south facade 200 cm [°C]
- air temperature gradient south facade 5-200 cm [°C]
- std dev air temperature gradient south facade 5-200 cm [°C]
- air temperature south facade close to ventilation 10 cm [°C]
- std dev air temperature south facade close to ventilation 10 cm [°C]
- air temperature south facade close to ventilation 30 cm [°C]
- std dev air temperature south facade close to ventilation 30 cm [°C]

- air temperature south facade close to ventilation 40 cm [°C]
- std dev air temperature south facade close to ventilation 40 cm [°C]
- air temperature south facade close to ventilation 50 cm [°C]
- std dev air temperature south facade close to ventilation 50 cm [°C]
- air temperature south facade close to ventilation 100 cm [°C]
- std dev air temperature south facade close to ventilation 100 cm [°C]
- air temperature south facade close to ventilation 200 cm [°C]
- std dev air temperature south facade close to ventilation 200 cm [°C]
- air temperature gradient south facade close to ventilation 10-200 cm [°C]
- std dev air temperature gradient south facade close to ventilation 10-200 cm [°C]
- air temperature north facade 5 cm [°C]
- std dev air temperature north facade 5 cm [°C]
- air temperature north facade 10 cm [°C]
- std dev air temperature north facade 10 cm [°C]
- air temperature north facade 20 cm [°C]
- std dev air temperature north facade 20 cm [°C]
- air temperature north facade 30 cm [°C]
- std dev air temperature north facade 30 cm [°C]
- air temperature north facade 40 cm [°C]
- std dev air temperature north facade 40 cm [°C]
- air temperature north facade 50 cm [°C]
- std dev air temperature north facade 50 cm [°C]
- air temperature north facade 100 cm [°C]
- std dev air temperature north facade 100 cm [°C]
- air temperature north facade 200 cm [°C]
- std dev air temperature north facade 200 cm [°C]
- air temperature gradient north facade 5-200 cm [°C]
- std dev air temperature gradient north facade 5-200 cm [°C]
- air temperature roof 5 cm [°C]
- std dev air temperature roof 5 cm [°C]
- air temperature roof 10 cm [°C]
- std dev air temperature roof 10 cm [°C]
- air temperature roof 20 cm [°C]
- std dev air temperature roof 20 cm [°C]
- air temperature roof 30 cm [°C]
- std dev air temperature roof 30 cm [°C]
- air temperature roof 40 cm [°C]
- std dev air temperature roof 40 cm [°C]
- air temperature roof 50 cm [°C]
- std dev air temperature roof 50 cm [°C]
- air temperature roof 100 cm [°C]
- std dev air temperature roof 100 cm [°C]

- air temperature roof 200 cm [°C]
- std dev air temperature roof 200 cm [°C]
- air temperature gradient roof 5-200 cm [°C]
- std dev air temperature gradient roof 5-200 cm [°C]
- air temperature building roof weather station [°C]
- std dev air temperature building roof weather station [°C]
- relative humidity building roof weather station [%]
- std dev relative humidity building roof weather station [%]
- wind speed building roof weather station [m/s]
- std dev wind speed building roof weather station [m/s]
- peak wind speed building roof weather station [m/s]
- std dev peak wind speed building roof weather station [m/s]
- atmospheric pressure building roof weather station [hPa]
- std dev atmospheric pressure building roof weather station [hPa]
- rain rate building roof weather station [mm/h]
- std dev rain rate building roof weather station [mm/h]
- solar radiation building roof weather station [W/m^2]
- std dev peak solar radiation building roof weather station [W/m^2]
- peak solar radiation building roof weather station [W/m^2]
- std dev peak solar radiation building roof weather station [W/m^2]

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