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Studies of hygrothermal processes in a façade by long term high resolution measurements

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Abstract. Processes for moisture concentration and temperature at different depths in a rather thick wall with mineral wool insulation are studied with a resolution of 1 minute. Damp processes in walls with thick layers of mineral wool differs a lot depending on the weather conditions. Any modelling of heat and moisture in building constructions need to consider this. The fact that the peaks in moisture concentration in some cases come hours before the peak in temperature is something that takes an explanation. It is possible, but not really sure, that this also may have influence on the risk for damage on the structures.

1. Introduction

Undervisningshuset at KTH – Royal Institute of Technology, in Stockholm Sweden is a building, commissioned 2017, is a building intended for teaching, with classrooms and group rooms and lounges of various kinds, but without office premises. The house has a gross area of 2780 m^2 and is certified to the level “Gold” according to the Swedish environmental certification system “Miljöbyggnad” [1].
With the intention that the building would not only contain teaching but also be an object for teaching and study, it is equipped with a large number of sensors. In total there are 767 sensors in the building and data from these sensors are logged every minute the day around. Among these sensors this building has temperature meters and meters for relative humidity at 6 locations around the building envelope, and at different depths in the walls, which will be described below. This offers a possibility to obtain a detailed view of hygrothermal processes in the building envelope. The directions and the identity numbers of the rooms in which walls the sensors are installed are shown in Figure 1. There are two sets of sensors in the south/west corner, and another two sets of sensors at the north/east corner. In the opposite corners there were one more set of sensors facing south and also one more set of sensors facing north.

Mundt Petersen [2], in his thesis, did measurements in detached single family houses with wood stud constructions. Sensors were placed at different depths of walls and also in the attic. Temperature and RH were recorded every hour. The thesis concludes that in general it is a good agreement between blindly calculated values from WUFI and the measured data.
Goto et al [3] tested wall modules in natural weather and in full scale in the HSB living lab at CTH in Gothenburg. Measurements of temperature and RH were done at four depths in the wall element during 1 year. The wall element was a CLT-structure thermally insulated by PIR. The data were recorded every hour. Conclusion of the study was that the simulation with WUFI give results well in line with the measurements, and that any deviations are explained by how WUFI handles moisture buffering.

Lindberg at al [4] compared a steady state method for energy consumption with a dynamic method. The effects of thermal inertia in an AAC-wall was noted. Temperature was logged every 10 minutes. In the paper the authors did invite other researchers to proceed doing evaluations using these data.
Kvist Hansen et al [5] studied the effects of moisture accumulation of driving rain. Registration of data for temperature and RH were done every minute and mean values were recorded every hour. They concluded that “the wind-driven rain (WDR) loads have an influence on the moisture conditions in the masonry and behind the applied internal insulation. The direct connection between the measurement of the WDR and the detection of WDR rain events behind the insulation or beam ends was not achieved. A distinct coherence between moisture content and internal and external humidity conditions was however established”.
De Masi et al [6] have data where it seems like the peaks for relative humidity comes before the temperature. This is however not really discussed in the report.
M I Nitzoutzev et al [7] in their study, includes laboratory and full scale experiments for evaluation of of thermal insulation solutions for facades also having channels for air transport. One result was that moisture and heat transport occurred in the channels in the thermal insulation in the façade. In this study temperature and RH were measured in the walls.
Mlakar and Shrankar [8] measured temperature and RH at different depths in wall constructions. Data were logged every 3 minute.This study could have given a possibility to study the time scale of the moisture process, but this was not the intention of their work.

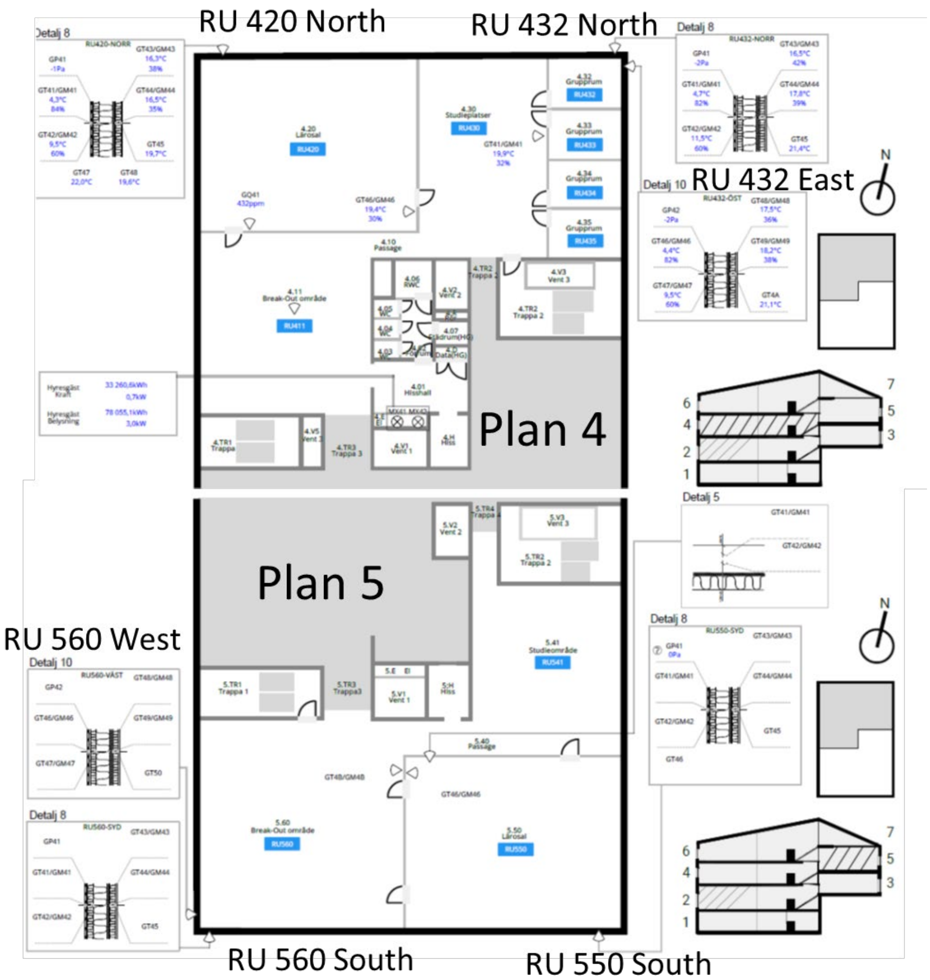

Figure 1
Plan of the building showing where the sensors are placed, with room identity numbers and directions.

2 Aim of the study

It is not the intention to validate any HAM-model by using these data. But data of this kind will be helpful in further development of models. In order to develop the understanding of physical processes observations are needed. So, in this study two observations will be presented. The point of these observations are to bring some more light in what the processes of heat and moisture will be like in thick walls thermally insulated by mineral wool.

Aim of this little study is to show how this quite high frequency in data logging, 1 per minute, offers some opportunities to look at natural processes in a building envelope. Focus will be on two processes.

Process 1: A period of late winter weather typical for the city of Stockholm with cold clear nights and sunny days, with quite big diurnal changes in temperature. This happened February 28, 2021.

Process 2: In late spring in the month of May. Temperatures in night during rainfall are quite low, but raises after the rain when the sun reappears and shines on the facades. This happened May 28 2021.

3. Experimental

3.1 Description of the wall structure

The walls in this building are infill walls with a structure of steel studs. This is illustrated by the drawing in Figure 2. The main structure is 195 mm steel studs placed between the floor slabs, and with mineral wool insulation between them. On the inner side it is a vapour barrier of PE-foil and two layers of gypsum board (12,5 mm thick) on the inside. Next towards the inside are horizontal steel studs 95 mm, with mineral wool in between them. The inner lining are gypsum boards.

Towards the outside it is also 95 mm horizontal steel studs with mineral wool between them. Outside of these studs is a wind stopper made of cellulose fibre reinforced cement board, 9 mm thick, with a sd-value of 0,3 m. Trade mark of this board is Cembrit. The facades are covered with wall tiles that are assembled on wood battens. This façade type is very seldom used in Sweden. The tiles are about 12 mm thick and 30 cm long. They are placed in a way so they overlap in two layers. So the last 15 cm of each tile is exposed to the air and the weather. In total, the wall is a bit more than 400 mm thick, and with 385 mm of thermal insulation.

3.2 How sensors are placed

The sensors for temperature and relative humidity are placed at different depths in the wall as illustrated in Figure 2. The sensor 1 is placed just under the wall slates, fixed to one of the horizontal battens carrying the slates. Sensor 2 is placed between outer layer of thermal insulation and the insulation at the main structure. Sensor 3 is placed on the inner side of the thermal insulation of the main structure, and on the outer side of the vapour barrier. Sensor 4 is on the inner side of the gypsum boards and the vapor barrier.

The sensors are installed with care to avoid disturbances by any heat transport in the steel studs. The sensors are Vaisala "HMP 110 T and RH-sensors". It is also a weather station on the building that collects data every minute.

In this study we have used data for temperature and calculated moisture concentration out of data for relative humidity. We have also used the dew point meter in the weather station.

4 Results

Data from the weather station, for the two days, with temperature, moisture concentration and also dew point are presented in Figure 3. Moisture concentration is calculated from the data for temperature and relative humidity. Data for February 28 for two places of the building envelope are presented in Figure 4, this is Process 1. Data for May 28 for two places of the building envelope are presented in Figure 5, this is Process 2. There are in many cases peaks in the curves for temperature or moisture concentration. The times for these peaks are presented in Table 1.

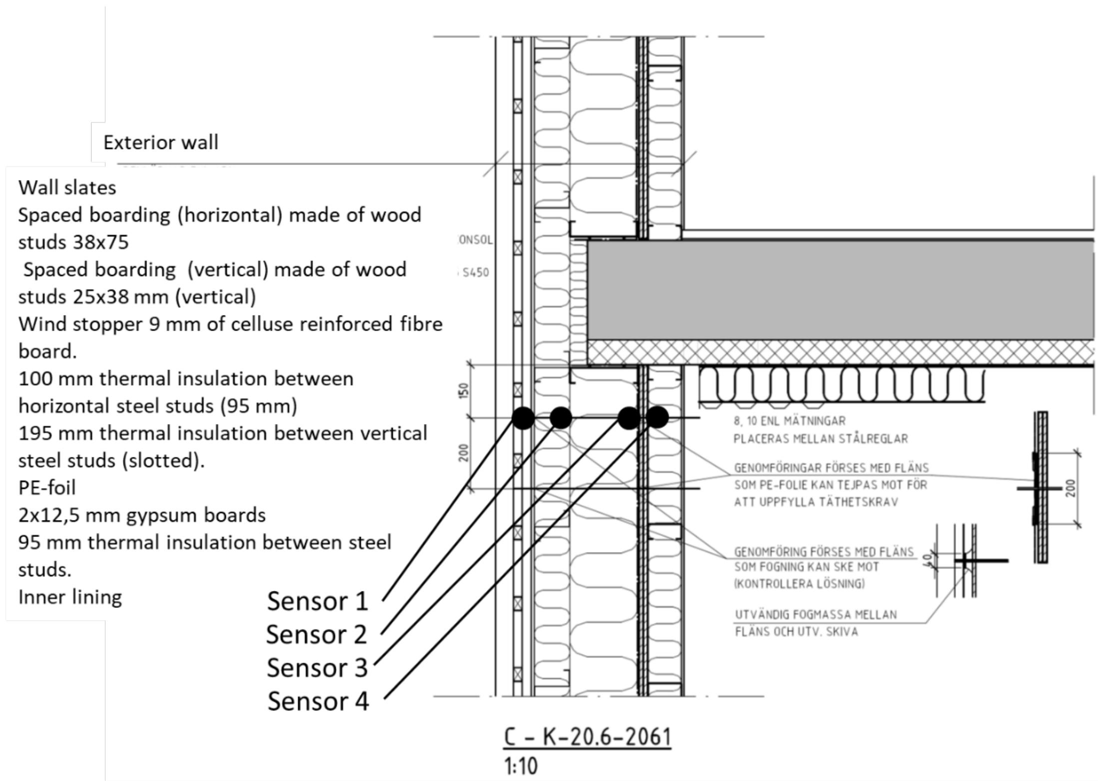

Figure 2. Drawing of a floor to wall connection with the details of the wall construction and a description of where the sensors are installed.

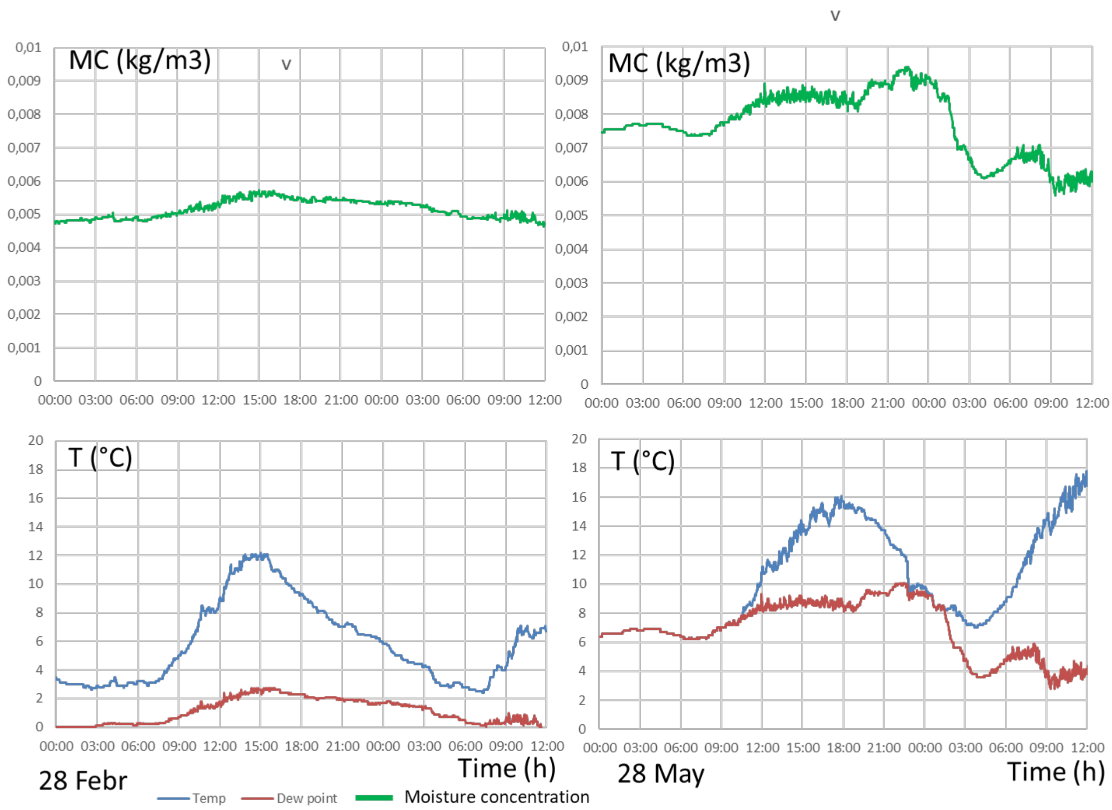

Figure 3. Data from the weather station. February 28 2021 (left) and May 28 2021 (right). Upper charts are for moisture concentration and lower charts for temperature and dew point.

Process 1 means winter weather with clear nights and days. There are rather big diurnal changes in temperature over the day. So, after the night, temperatures behind the facades are quite low.
Data from the weather station for February 28, 2021, are presented in the left-hand part in Figure 3. The temperature raises from about 3°C in the night to a peak of about 12°C at about 12 pm. The temperature peak is not very sharp but quite wide. Moisture concentration in the air, calculated from data for temperature and RH are also presented in the diagram. The moisture concentration varies between 0,0048 and 0,0056 kg/m^3. The dew point is all the time well below the outdoor temperature.
The temperature process along with the process of moisture concentration in a wall part facing south, RU 560 south, are presented in the left hand part of Figure 4. We can look at the peaks of the curves to understand, or at least notice, what happens.
For the outermost sensor, S1, the peak for moisture concentration comes on hour before the peak in temperature. It is a time delay from S1 to S2. The temperature rise depends on solar radiation and the time delay is because of thermal inertia in the wall construction. The peaks in temperature and moisture concentration for sensor S2 comes here 2 hours after the peaks in S1, and again with the peak in moisture concentration about 1 hour before the peak in temperature. Temperatures in S3 and S4 are to a very small extent influenced by the temperature processes further out in the wall. But the moisture concentration for sensor S3 is as sharp as the peak for sensor S2. It comes about 25 minutes after the peak in S2, and reaches at about the same level of moisture concentration. Moisture concentration at S4 is not influenced of the outdoor process.

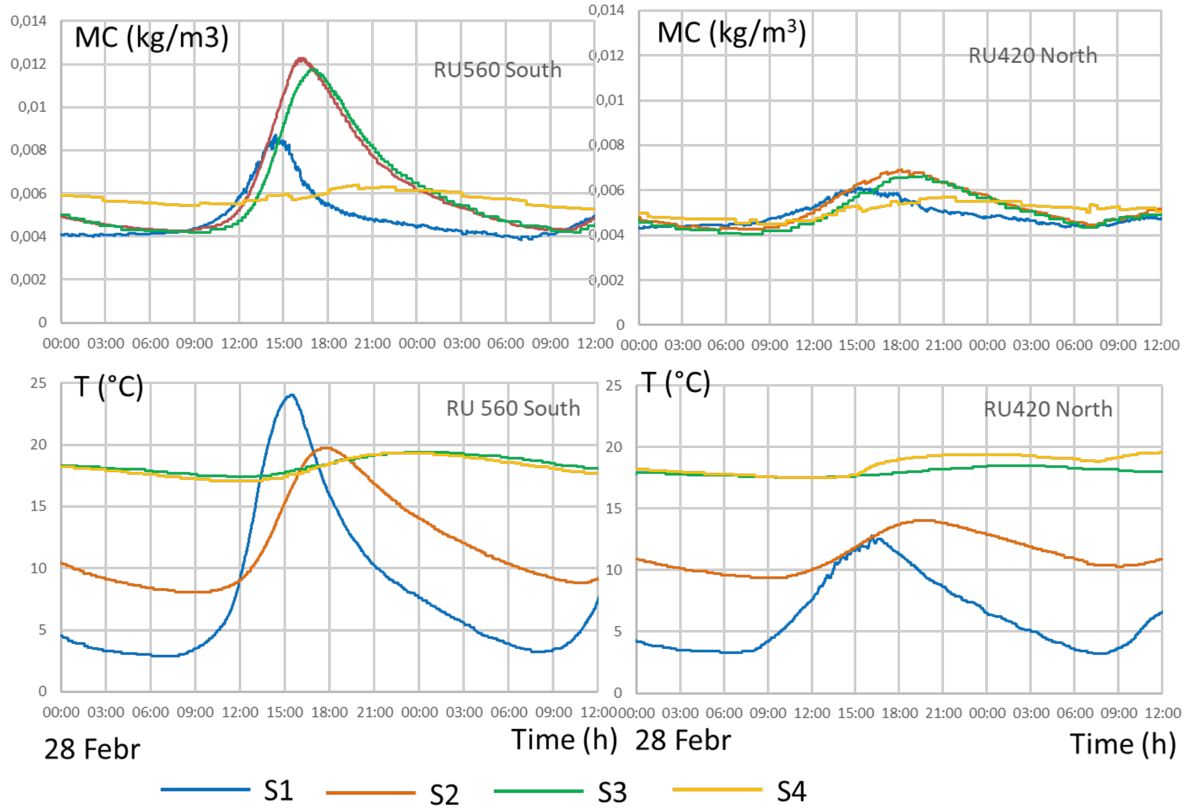

Figure 4. Data for the sensors at R560 south, and R420 North, February 28 2021.

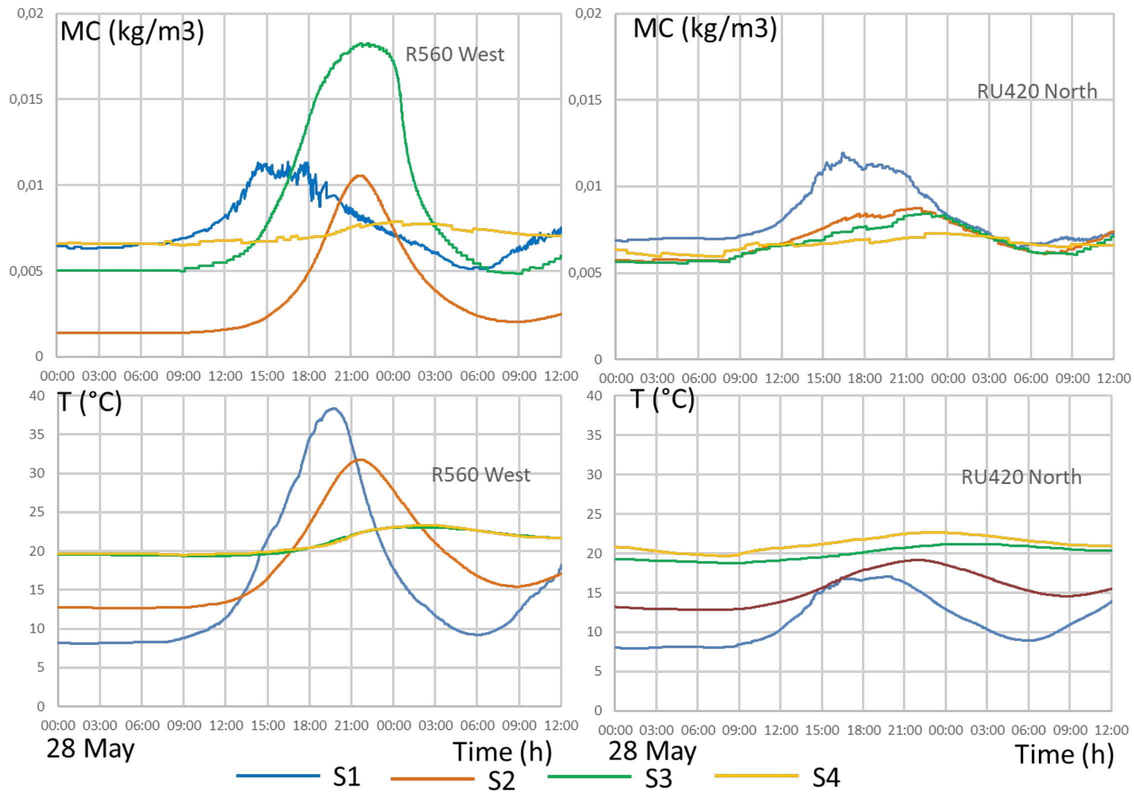

Figure 5. Data for the sensors at RU 560 West and RU 420 North May 28 2021.

Table 1. Times for peaks in temperature and moisture concentration.

Location	Sensor	Peak in T	Peak in MC
Febr 28 2021			
RU 560 south	S1	15:21	14:24
	S2	17:26	16:21
	S3	23:01	16:48
	S4	21:30	19:38
RU 420 north	S1	16:07	14:50
	S2	18:58	18:06
	S3	00:02 (next day)	19:33
	S4	20:53	20:53
May 28 2021			
RU 560 west	S1	19:39	14:22
	S2	21:26	21:26
	S3	No peak	21:37
	S4	No peak	No peak
RU 420 north	S1	16:24	16:24
	S2	21:29	21:29
	S3	No peak	23:35
	S4	No peak	18:14

In the same day, at the point facing north, RU 420 north, right hand part of Figure 4, the temperature in S1 follows quite well the outdoor temperature, although a bit delayed in time. The peak in outdoor temperature, Figure 3 left-hand side, is however quite wide and not very distinct.
The peak in damp, for S1 at RU 420 north, comes about 1 hour before the peak in temperature.
The temperature peak for S2 comes about three hours after the peak in temperature peak in S1, and the peak in moisture concentration also comes about 1 hour before the temperature peak. Also in the north façade temperatures in sensors S3 and S4 are very little influenced by the outdoor temperature. Also here it is a peak in moisture concentration at S3, and this comes 1,5 hours after the peak in moisture concentration at S2.

Process 2 comes after a few days of rainy weather in the month of May, in late spring. Temperatures in night during rainfall is quite low, but raises after the rain when the sun reappears and shines on the facades.
When looking at outdoor temperature and dew point in the right-hand part of Figure 3 it can be seen how they overlap in the night, which is an indication of rain. The temperature starts to raise at about 10 30, so then the rain is over.

Here we look at RU 560 west, which is facing west. Data are presented in the left hand part of Figure 5. The peak in moisture concentration at S1 comes about 5 hours before the peak in temperature. The peak in temperature at S2, comes about 2 hours after the peak in temperature at S1. Temperatures at S3 and S4 are not influenced by the outdoor temperature. However, the moisture concentration has its peaks at the same time as the temperature peak in S2. Moisture concentration at S3 has its peak at a much higher level than the peak at S2.

When we look at the sensors in the wall facing north, right hand part of Figure 5, the temperature process at S1 is very similar to the process in the outdoor air although the temperature is a bit higher at S1 compared to outdoors. The peak in moisture concentration comes about the same time as the peak in temperature.

The peak in temperature at S2 comes about 5 hours after the peak at S1, and the peak for moisture concentration comes at the same moment. Also here temperatures in S3 and S4 are not much influenced by what happens outdoors, but the moisture concentration in sensor 3 has a peak 2 hours after the peak in sensor S2. A possible peak at sensor S4 is also noted although this is isolated by the vapour barrier from the processes in the wall.

Discussion
In the literature measurement data and also the models have usually a resolution of one hour. This is enough in most cases, still we will never be aware of details that might happen in between the recorded data points. So, a report about these processes have a value of itself for improving the basic understanding and to develop new ideas.
The unique thing with this study is that the processes can be followed in detail in quite short time intervals. So it will be possible to conclude whether the level of moisture content in the structures varies and if moistening at different parts of the construction may occur.
These things can be studied by modelling, but here it is possible to follow the processes in an experimental way. The fact that the peaks in moisture concentration in some cases come hours before the peak in temperature is something that takes an explanation.

Conclusions
My reflection about this is that damp processes in walls with thick layers of mineral wool differs a lot depending on the weather processes. Any modelling of heat and moisture in building constructions need to consider this.
It is possible, but not really sure, that this also may have influence on the risk for damage on the structures.

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