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Drying Potential of Wood Frame Walls Subjected to Accidental Water Infiltration

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Abstract. *Wood frame construction is the most widespread building method. In Belgium the number of wood frame buildings has grown in the last years: in 2018 over 10% of all new built dwellings were wood frame buildings. This increase can be partly attributed to the growing attention for energy performant buildings with a low environmental impact. In contrary to masonry construction, wood frame is more vulnerable to moisture problems, mould growth and wood rot. An important risk is water infiltration through imperfections in the building envelope as a result of driving rain. Therefore it is important for the design to be resilient and allow drying without consequential damage. To analyze the drying potential, an experimental set-up with 8 wood frame compartments was built. The compartments differ in the type of insulation material (mineral wool or cellulose) and the type of vapour retarder (OSB or smart vapour retarder) that were used. In this way 4 types of compartments were obtained, each having a different combination of insulation and vapour retarder. Of each combination there are 2 identical compartments. This allows to insert water in one of both, to mimic rain water infiltration from the outside into the compartment. Temperature, relative humidity and moisture content were measured on different locations in the construction (in total 92 sensors). In this way, the hygrothermal performance of the compartments with and without water infiltration can be analyzed, as well as the drying rate.*

Keywords: *Wood Frame Construction, Measurements, Drying, Water Infiltration.*

1 Introduction

Though masonry is the most common construction method in Belgium, wood frame construction is gaining more popularity. On the one hand this can be attributed to the stricter energy requirements and the associated thicker insulation layers. On the other hand, there is also a growing attention for sustainable construction, *i.e.* CO_2 captured in wood. In 2018, over 10% of all new dwellings were wood frame buildings and that number has increased over the last years. Also for renovations and extensions to existing buildings, wood frame is interesting due to its limited weight (Houtinfobois, 2019).

Scandinavian countries or countries such as Canada where wood frame is the main construction type, are characterised by a cold climate that limits the conditions for mould growth. In contrast to that, Belgium has a moderate maritime climate with a dominant wind-driven rain from south-west orientation. It is therefore crucial to design constructions in a resilient way to guarantee drying without consequential damage in case of accidental water infiltration.

This paper therefore investigates the hygrothermal performance and the drying potential of different wood frame wall constructions subjected to water infiltration, using in-situ measurements on a test wall.

2 Experimental Set-up

2.1 Pavilion and Test Wall

A test pavilion (6,60m x 4,37m) called “STEAMlab21” was built in Kortrijk and consists of two adjacent rooms. Figure 1 shows the floor plan and a vertical section of the pavilion.

The exterior north-west facing wall is replaceable and used as a test wall. The test wall is a wood frame wall with 8 compartments. The compartments consist of I-joists filled with insulation material, wood fibre board and a ventilated wooden cladding at the outside. At the inside a service cavity with a gypsum fibreboard finishing is installed. All other exterior walls of the pavilion are constructed with SIP panels.

The test pavilion and the test wall were built about one year prior to the measurements described in this paper and therefore subjected to the outdoor climate.

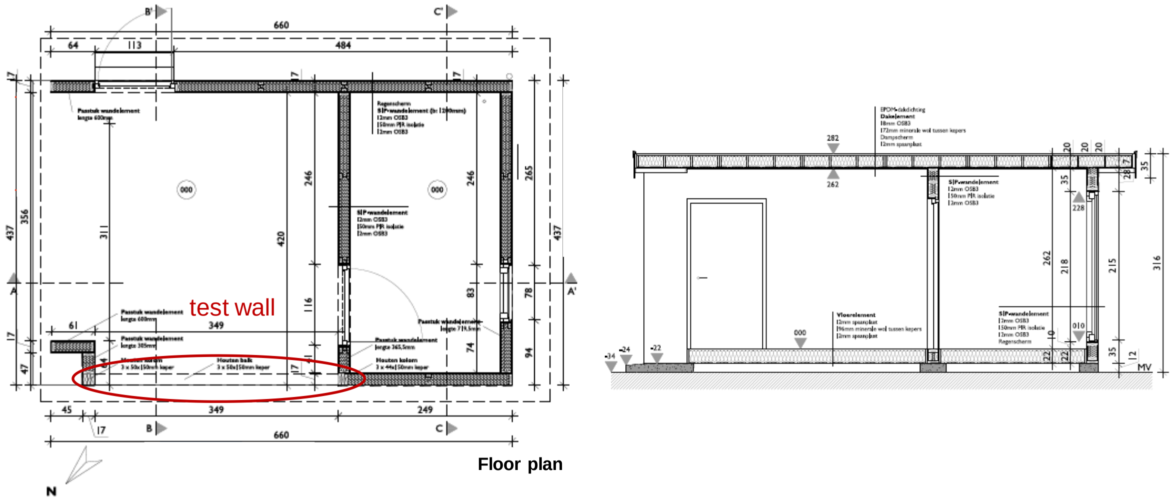

Figure 1. Floor plan (left) and section AA’ (right).

Each compartment of the test wall measures 34,4 cm width and 266 cm height. The compartments differ in the type of insulation material and the type of vapour retarder that were used. Two types of insulation material were used: mineral wool and cellulose; and two types of vapour retarder: a smart vapour retarder (SVR) and oriented strand board (OSB). In this way 4 types of compartments were obtained, each having a different combination of insulation and vapour retarder. Two identical compartments of each combination of insulation type and vapour retarder were available.

Water is added from the outside in one of the two identical compartments, mimicking rain water infiltration. In order to avoid mutual influence between the compartments, a vapour tight coating was applied to the I-joists between the compartments. Figure 2 lists the characteristics of each wall compartment, while Table 1 shows an overview of the most important material properties. The U-value of the test wall was 0,10 W/m²K for the compartments with mineral wool and 0,11 W/m²K for the compartments with cellulose.

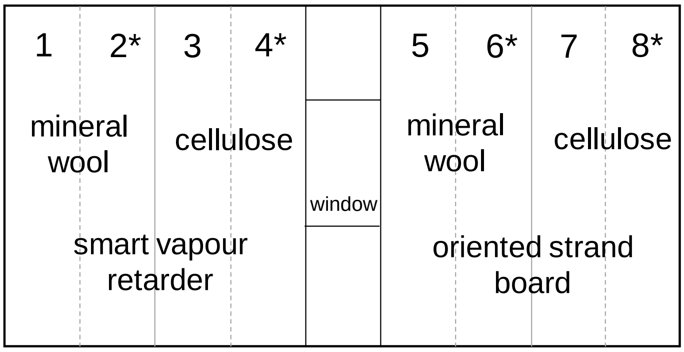

Figure 2. Schematic overview of the test wall with 8 compartments. Compartments with water injection are marked with *.

Table 1. Characteristics of the materials used in the test wall.

Material	Thickness (m)	Thermal conductivity (W/mK)	Vapour diffusion resistance factor (-)
Wooden cladding	0,026	0,090*	-
Ventilated cavity	0,022	-	-
Wood fibre board	0,022	0,048	5
Glass wool (blown in)	0,300	0,034	1
Cellulose (blown in)	0,300	0,038	1-2
Smart vapour retarder	0,0004	0,170	Sd 0.25 → 25 m
OSB3 board	0,015	0,130	175
Service cavity	0,06 - 0,072	-	1
Gypsum fibre board	0,0125	0,320	13

All data are based on technical specifications, (*) data based on the material database in WUFI.

2.2 Measurement Equipment

Temperature, relative humidity and moisture content were measured on different locations in the test wall. In total 92 sensors were installed. At the following locations, also indicated in Figure 3, thermocouples type K (accuracy ±0,1°C) and RH sensors (HIH-40000 Series Humidity Sensors, accuracy ±3,5% RH) were installed:

- On the inner surface of the wall at two locations: in the middle of the left and right wall side, at half height
- In the service cavity of each compartment at ± 1,80m height (illustrated in Figure 4, left photo)
- On the interior side of the insulation layer for each compartment, at two heights: at ± 0,80m and at ± 1,80 m height
- On the exterior side of the insulation layer for each compartment, at ± 1,80 m height
- In the ventilated cavity of the wall at two locations: in the middle of the left and right wall side, at ± 0,80m and at ± 1,80 m height (illustrated in Figure 4, photo on the right)

All sensors were connected to a data logger that registers the measurements every 15 minutes. Additionally, in each compartment of the test wall two moisture pins were installed and connected to the data logger: one in the bottom plate and one in the I-joist to measure the moisture content of the wood. Unfortunately, the results of these moisture content measurements showed to be unreliable and therefore they are not included in this paper.

Furthermore the temperature and relative humidity of the indoor and outdoor climate were monitored. A HOBO U12-013 was used to monitor the indoor temperature (accuracy ± 0,21°C) and relative humidity (accuracy ± 2,5 % RH). A HOBO U23 Pro v2 logger was located outside shielded from direct sun irradiation and precipitation for measuring temperature (accuracy ± 0,21°C) and relative humidity (accuracy ± 2,5 %RH).

A convector was installed in the test room to control the indoor climate. The set point was 20°C. Furthermore, a fan was used to ensure well-mixed air conditions.

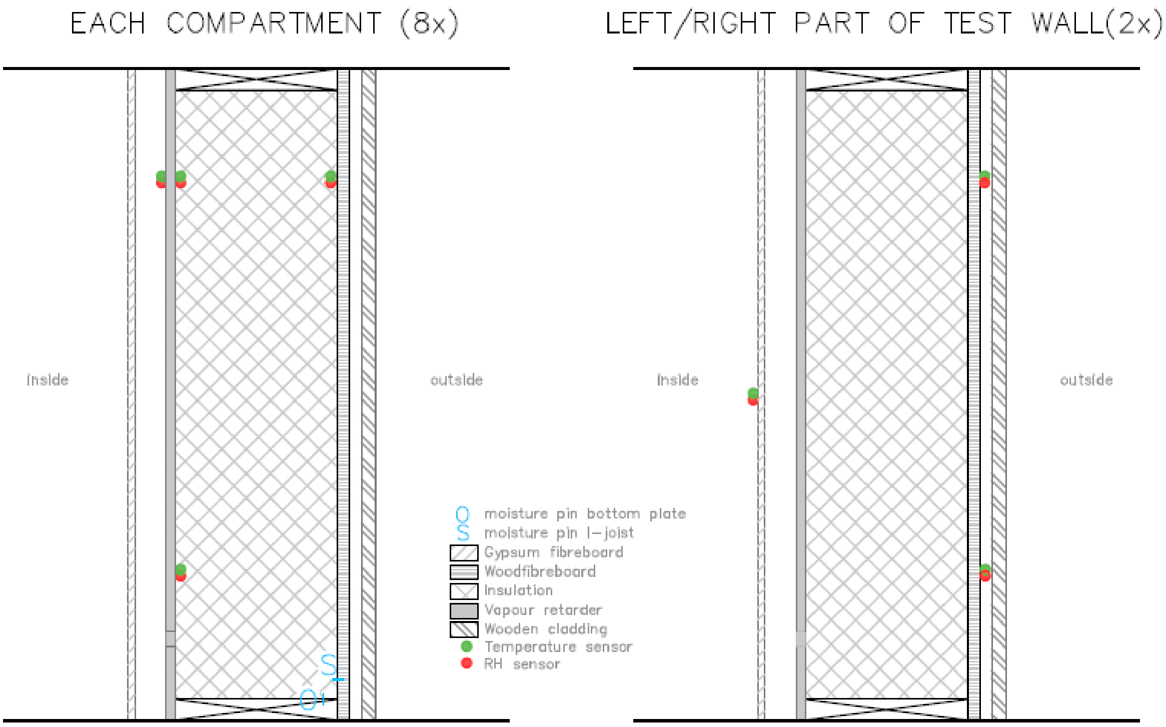

Figure 3. Scheme with location of the sensors in the test wall.

2.3 Water Infiltration

In 4 compartments (2, 4, 6 and 8) 0,2323 l water was injected into the insulation layer. Figure 4 (photo on the right) shows the outside of the test wall with the infiltration tubes at half height. The tubes were installed in such a way that the water is infiltrates between the wood fibre board and the insulation layer.

The amount of water was calculated based on the horizontal rain load during a heavy rain shower with a duration of 4 hours in Belgium (rain load 72,4 mm or 18,1 mm/h based on data from RMI), the measured wind speed during a realistic rain event (based on Van Goethem, 2014) and a worst case infiltration percentage of 0,6% of the incident rain that infiltrates in the construction. The latter was based on water infiltration measurements in a typical cavity wall construction (Geldof, 2016). In this way, a rather high amount of rain water infiltration was obtained, based on the maximum rain load.

Figure 4. View on the compartments from the inside (photo left) and view on the outside with water infiltration tubes, indicated with a red circle (photo right).

3 Measurement Results

Measurements were carried out for 30 days from April 28th to May 27th 2019 every 15 minutes. Water was injected on April 30th 2019 at 2 pm. After the water was injected, measurements ran for 27 days.

3.1 Moisture Buffering Effect

Figure 5 shows the course of the relative humidity in the insulation layer for a compartment filled with mineral wool (compartment 5) and a compartment filled with cellulose insulation (compartment 7). In both compartments, there was no water infiltration.

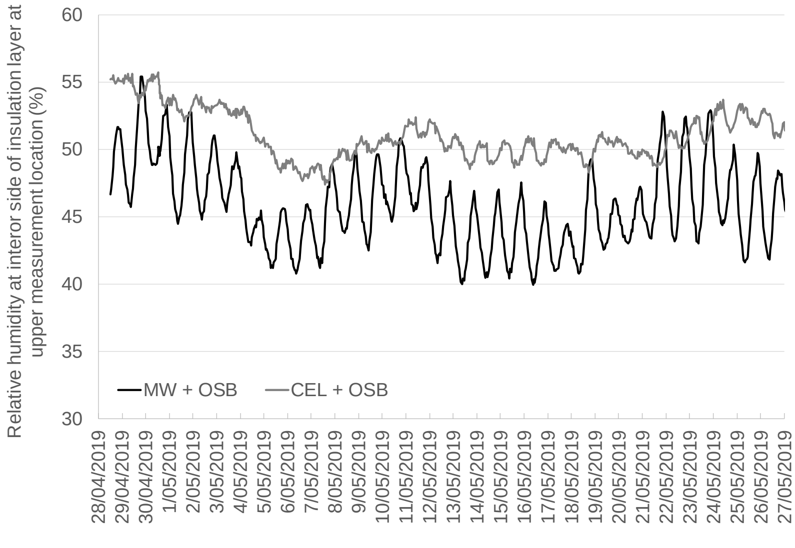

Figure 5. Course of the RH measured at the inside of the insulation layer (upper measurement location) for a compartment with mineral wool (comp. 5) and cellulose (comp. 7), both without water infiltration.

Figure 5 shows that the relative humidity fluctuates a lot more in the compartments filled with mineral wool compared to the compartments filled with cellulose insulation. This observation is expected and can be explained by the hygroscopic characteristics of cellulose. The oriented strand board has similar moisture buffering characteristics, but because the thickness of the layer is limited (0,015m), this effect is rather small.

3.2 Moisture Increase and Drying Rate

When the measurement results were analyzed it was clear that the injection of water was mainly visible at the interior side of the insulation (lower measurement location). The relative humidity clearly increases when water is injected.

Figure 6 compares the relative humidity of the wall compartments with and without water infiltration for each combination of insulation and vapour retarder. The moment water is injected into the construction can be clearly read from the graphs (also indicated with a black arrow). The graphs show that the relative humidity increase is higher for the compartments with mineral wool than for the compartments with cellulose insulation. This can again be attributed to the hygroscopic characteristics of cellulose.

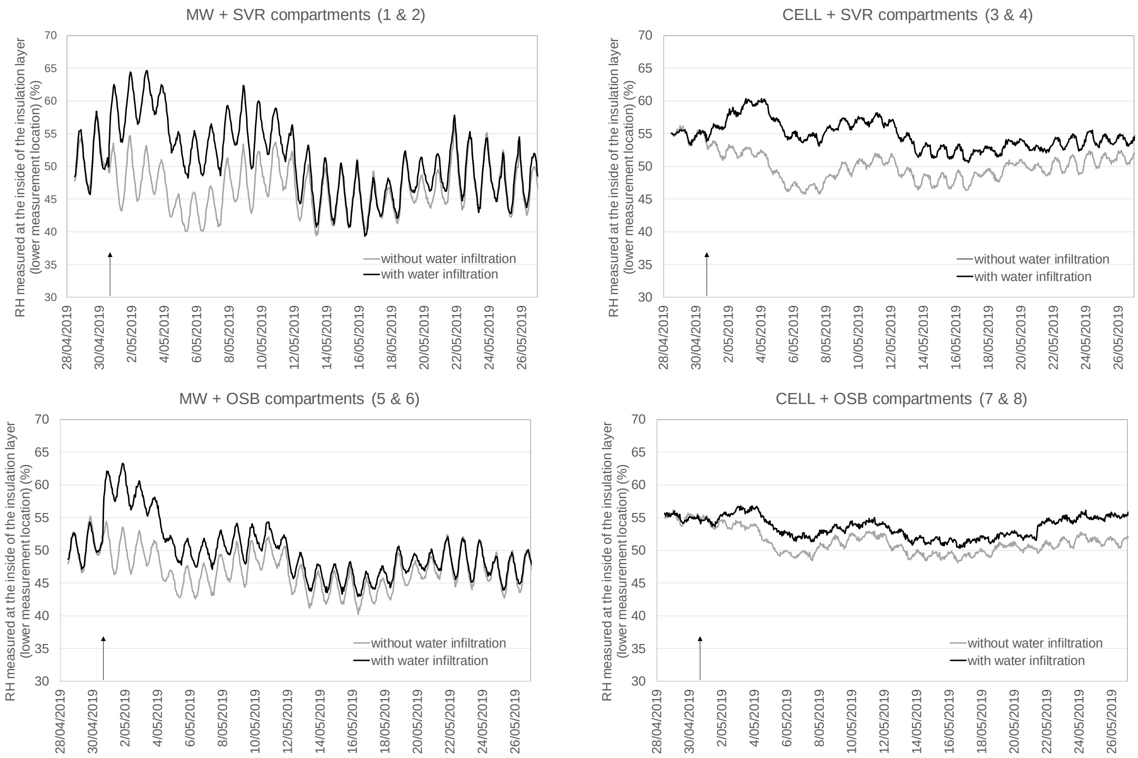

Figure 6. Course of the RH measured at the inside of the insulation layer (lower measurement location) for all compartments, with and without water infiltration.

Figures 7 and 8 show the relative humidity course measured at the interior side of the insulation (upper measurement location) and at the exterior side of the insulation for compartments 1 and 2, and 3 and 4 respectively. It is clear that the water injection is harder to observe from these measurement locations. For the compartments with mineral wool (Fig. 7) the relative humidity of the dry compartment is slightly higher than the relative humidity of the wet compartment, although the difference is still within the accuracy of the sensor. For the compartments with cellulose insulation (Fig. 8) the relative humidity of the wet compartment is slightly higher than the relative humidity of the dry compartment, but the difference is very limited. For the other compartments, similar observations were made. This suggests that the injected water mainly runs down at the interior side of the insulation layer, especially for the compartments with mineral wool because the moisture buffering capacity of mineral wool is very low.

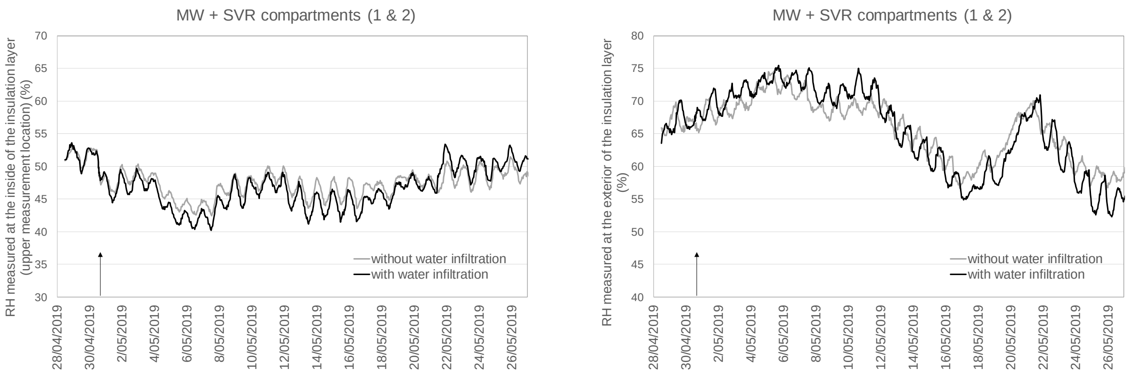

Figure 7. Course of the RH measured at the inside of the insulation layer (upper measurement location) (left) and at the exterior side of the insulation layer (right) for the compartments with mineral wool and SVR (1 & 2).

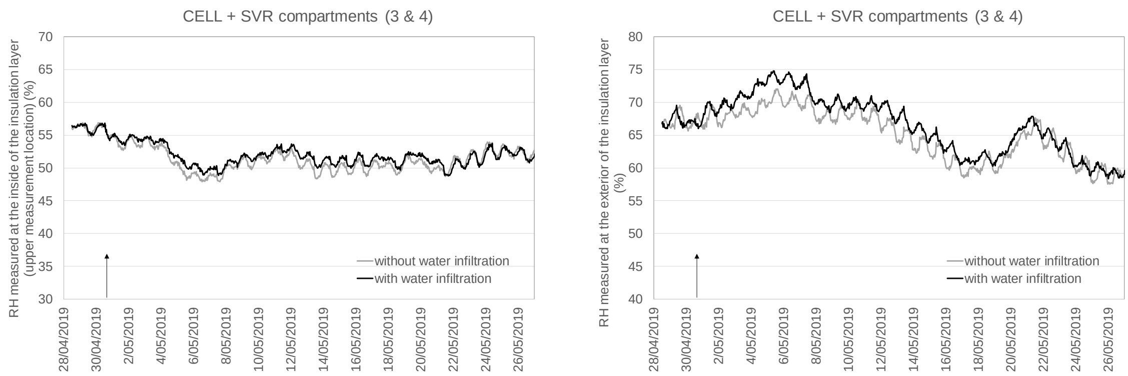

Figure 8. Course of the RH measured at the inside of the insulation layer (upper measurement location) (left) and at the exterior side of the insulation layer (right) for the compartments with cellulose and SVR (3 & 4).

In order to estimate the drying rate of the test compartments, the relative humidity of the wet and dry compartment of each construction type are compared (lower measurement location at interior side of insulation) in Figure 9 (graph left). The relative humidity difference increases faster in the compartments filled with mineral wool compared to the compartments filled with cellulose. Similarly, the drying rate of the compartments with cellulose is lower.

For the compartment with mineral wool and SVR (compartment 2) and with mineral wool and OSB (compartment 6), the drying period is ± 14 days and ± 21 days respectively. For the compartments with cellulose (compartments 4 and 8), the drying period is considered longer then the measurement period (> 27 days). For compartment 8 an increase in RH is noted after 21 days (May 21th), but no explanation for this observation could be found.

Drying out is considered mainly towards the inside of the construction. Figure 9 (right-hand graph) compares the measured vapour pressure in the insulation layer (interior side, lower measurement location) with the vapour pressure in the service cavity. For compartment 2 with mineral wool drying starts immediately after water infiltration, while for compartment 4 with cellulose there is a time delay and drying starts later. During measuring, there were no internal moisture loads.

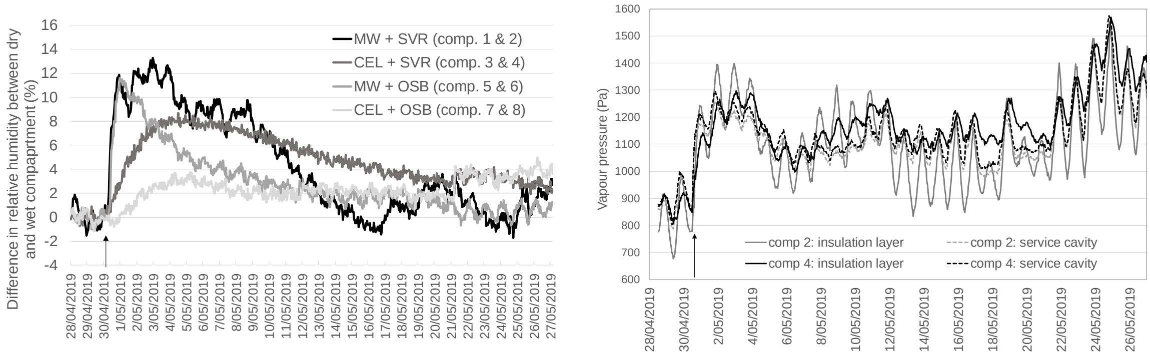

Figure 9. Difference in RH between wet compartment and the dry compartment (left) and vapour pressure in the insulation layer and service cavity for compartments 2 (MW + SVR) and 4 (CELL + SVR).

4 Conclusions

The aim of the study was to analyze the hygrothermal performance of wood frame construction subjected to accidental water infiltration. The results showed that the drying rate was faster for the compartments with mineral wool, and for the compartments where a smart vapour retarder was used. Also moisture buffering in the cellulose was clearly observed. In all cases, the construction dries out and no moisture damage is expected at first glance. However, further research should give insight in the moisture content of the wooden elements (bottom plate, I-joists) when water runs down. In the experiment water was injected at only one moment in time. In reality, water could leak into the construction in a more contentious way. This was not taken into account here. Also, parameters such as the moment of water injection, orientation of the test wall and boundary conditions (*e.g.* presence of internal moisture loads) will have an effect on the resulting drying rate and should be studied in more detail.

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