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Deep renovation of an old single-family house including application of an water repellent agent – a case story

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Abstract. The 145 year old rural case building presented in this paper has undergone a deep renovation including internal insulation of the external walls to reduce the heat loss and improve the indoor thermal comfort. The internal insulation was a PUR-based insulation with channels of calcium silicate, experiencing to some extent capillary active behaviour. Sensors were installed between the existing wall and the internal insulation to monitor the development of hygrothermal conditions. The external façade was later hydrophobized with a water repellent agent to minimize the wind driven rain load. Measurements show that it takes time to get rid of the built-in moisture due to the application of internal insulation, however the moisture content expressed in relative humidity is slowly decreasing, although still high about two years after hydrophobizing the wall. Simulations show that the order of hydrophobizing the wall and applying internal insulation is important to promote drying of the wall.

Keywords – Deep renovation; historic building; internal insulation; hydrophobization.

1. Introduction

About 30 % of the European building stock is more than 70 years old and needs to be renovated to improve the energy performance and the indoor thermal comfort. As many of these buildings have architectural or heritage value, internal insulation is the only possible measure to reduce heat loss through the external walls, however seen as risky, as the original wall becomes colder and more humid. Therefore, best practice cases, showing the possibilities of applying internal insulation are needed.

The case presented in this paper has undergone a deep renovation including internal insulation based on PUR-foam, to considerably bring down the high energy demand for heating. The PUR-foam is prepared with an array of channels filled with calcium-silicate, making the insulation material capillary-active to some extent. Two years later, a water repellent agent was applied, to reduce the wind driven rain load. Measurements and analysis of the hygrothermal conditions after installing the internal insulation and water repellent agent took place as part of the RIBuild project (www.ribuild.eu) and the Danish project 'Moisture safe energy renovation of worth preserving external masonry walls'. The case is also presented as best-practice in IEA/SHC Task 59 on deep renovation (https://task59.iea-shc.org/).

2. Building documentation

2.1. Building description

Klitgaarden is a free standing single-family house from 1875 in two stories with a thatched roof, solid masonry walls and a foundation of granite boulders on top of a stone foundation. The original façades and gables are 350 mm (one and half brick) and 230 mm (one brick) thick, respectively. A comprehensive renovation was finished in early 2017, after which the house looks like as shown at Figure 1, lower right.

The case building, originally part of a farm with four buildings around a square, is located in Hundested, a minor town close to the sea at Northern coast of Zealand, about 70 km NW of Copenhagen, Denmark. The site is situated outside the city centre in rural area and in the first row to the sea, though a bit farther away from the sea than nearby houses (Figure 1, left). Especially at the NW corner, wind-driven rain and sea fog is observed by the owner.

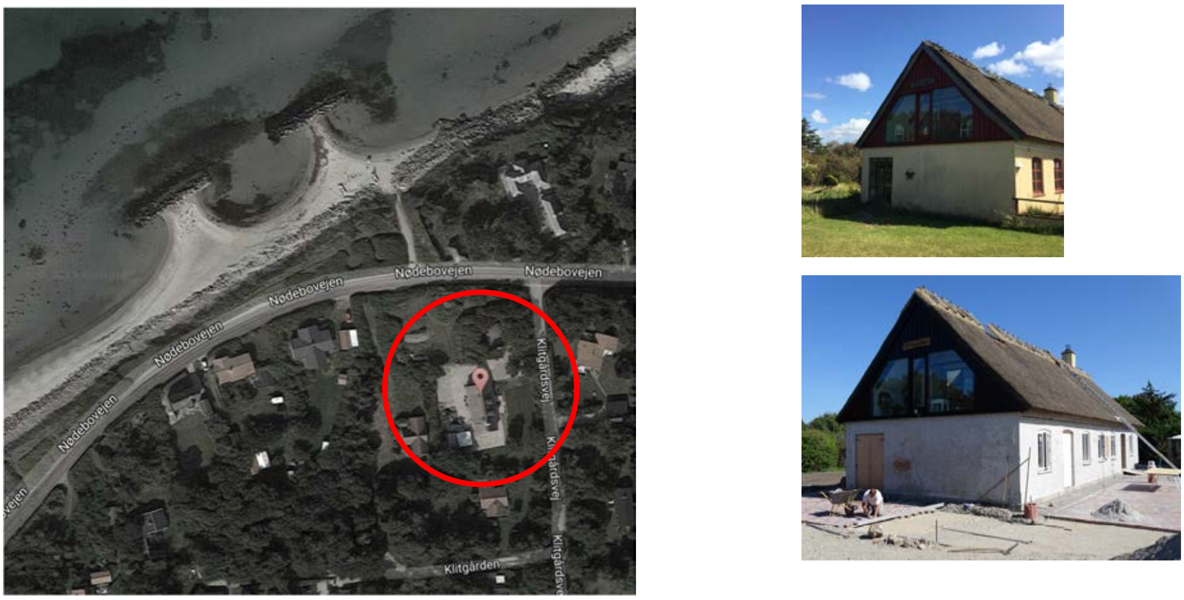

Figure 1. Left: Location of Klitgaarden, 100 m from the Northern coast of Zealand, Denmark. Right: North gable of the building before (top) and after renovation (bottom). As part of the renovation, the vegetation around the house was replaced by pavements of bricks. Photos (right): Thomas Svendsen.

2.2. Modernization concept

Due to the state of the 145 year old building, not being used for 20 years, and the owner's demands, significant renovation was needed. The building was very costly to heat by means of electric radiators and an electric water heater and had single glazing windows. Also, the owner wanted to get rid of the poorly maintained 30 mm exterior insulation (stone wool) (Figure 2, at left) that had changed the original appearance of the building. Thus motivation was not only to reduce energy use to an absolute minimum, but also to somewhat restore the building's architecture to preserve original outdoor façade details. Instead internal insulation was chosen to improve the energy performance of the external walls. The renovation included updating the windows and changing the room layout to fit the user's need. After renovation, the building was planned to be used as a holiday home, but will include all functions and could therefore expect future use as full time occupancy also.

Figure 2. Exterior façade of the building during renovation. Left: exterior insulation removal, mid-left: added protection (sand and concrete) to the foundation, mid-right: cleaned brickwork, right: facade with washed mortar applied. Photos: Thomas Svendsen.

2.3. Exterior wall constructions
After removing the external insulation, the exterior surface of the walls was sandblasted and plastered with a thin layer of bank sand mortar (mortar washed), with exception of the southern gable where the wall condition required eight millimetres of plaster. Both the facades and the gable walls were internally insulated with 80 mm PUR-foam with channels filled with capillary active material (iQ-Therm) and a thermal conductivity of 0,031 W/(m K), reducing the U-value of the original wall from 1,2 W/(m K) (without the later added external insulation) to 0,3 W/(m K) on the façade. Similar effect on the gable walls. The interior surface is given by the insulation system as a painted plaster (diffusion open). After renovation, the external walls were 471 mm (façades) and 351 mm (gables) thick, respectively. Two years later, a water repellent agent (type Funcosil Remmers FC cream 40%) was applied with a paint roller in the specified amounts of 0.15–0.20 l/m^2 [1].

2.4. Other renovation measures
The renovation further included (not detailed in this paper): thermal insulation at the thatched roof and the ground floor, replacing single glazing with triple glazing windows, replacing electric radiators with floor heating and a ground heat pump, installing mechanical ventilation with heat exchanger, installing a drain around the building, and water proofing the foundation.

3. Monitoring system and modelling of the hydrophobic treatment
Sensors measuring relative humidity (RH) and temperature (type Tramex Hygro-i) every 30 minutes were installed in all exterior walls at the ground floor, in the interface between masonry and insulation, except for one sensor placed in the window sill, about 1,65 m above floor (Figure 3**)**. In addition to the build-in sensors, reference sensors measuring RH and temperature were placed inside and outside the house (type climaSpot). At those locations where two sensors are shown in Figure 3, one is placed 50 cm above the floor and the other one 180 cm above the floor (50 cm below the ceiling).

The humidity accuracy is +/- 1.8% RH in the 10% - 90% RH range for both types of sensors, and +/- 4%RH at RH above 90%. Temperature accuracy is +/- 0.3 °C (Tramex) and 0.3 % (climaSpot). Further measurements using Karsten tube are reported in [2]. No data collection from nearby weather stations has been carried out, e.g. to measure wind speed and direction.

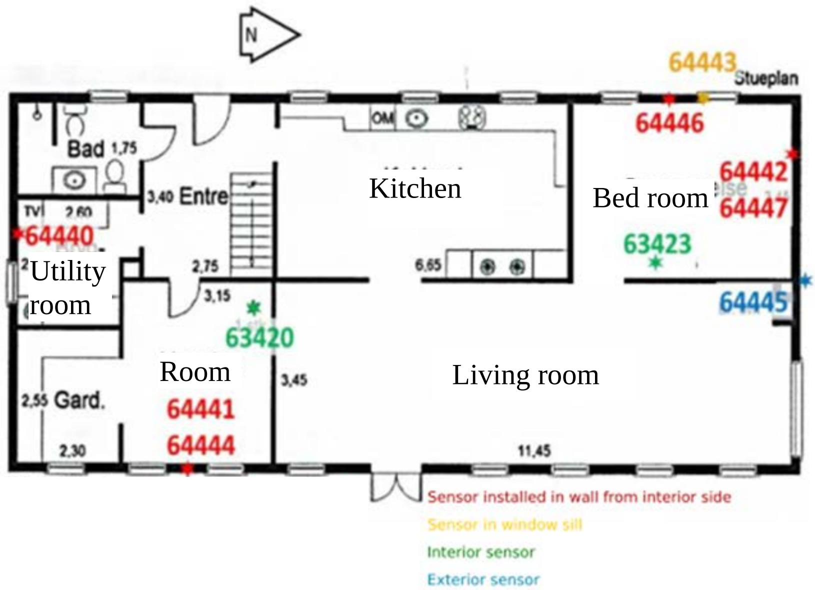

Figure 3. Sensor monitor points at ground floor (original layout, both living room and kitchen later split into two rooms). In the interface between original wall and internal insulation (red, Tramex Hygro-i sensor), in a window sill (yellow, Tramex Hygro-i), indoor climate (green, climaSpot), and outdoor climate (blue, climaSpot). Numbers refer to sensor IDs.

Simulations of the hygrothermal conditions of the wall for different scenarios were made with DELPHIN software [3]: A five year period where internal insulation and hydrophobic treatment were added simultaneously, and a five year period with internal insulation only, followed by a five period with both internal insulation and hydrophobic treatment, to study the timing of the two measures. The hydrophobic treatment is modelled as a separate layer of the masonry, having its own moisture transport properties based on [4]. Hydrophobization reduces the capillary water uptake by more than 99 % compared to an untreated material, while the water vapour diffusion coefficient is almost the same [5,6].

4. Measurement results

Daily mean values of outdoor and indoor temperature and relative humidity covering July 2016 – December 2020 are presented in Figure 4. For the same period, Figure 5 shows daily mean values of temperature (a) and relative humidity (b) at the different positions in the interface between original wall and internal insulation, and at the window sill, according to Figure 3. Both Figure 4 and Figure 5 include the timing of applying internal insulation and hydrophobization. Notice, that some sensors stopped functioning during the measurement period, not being replaced.

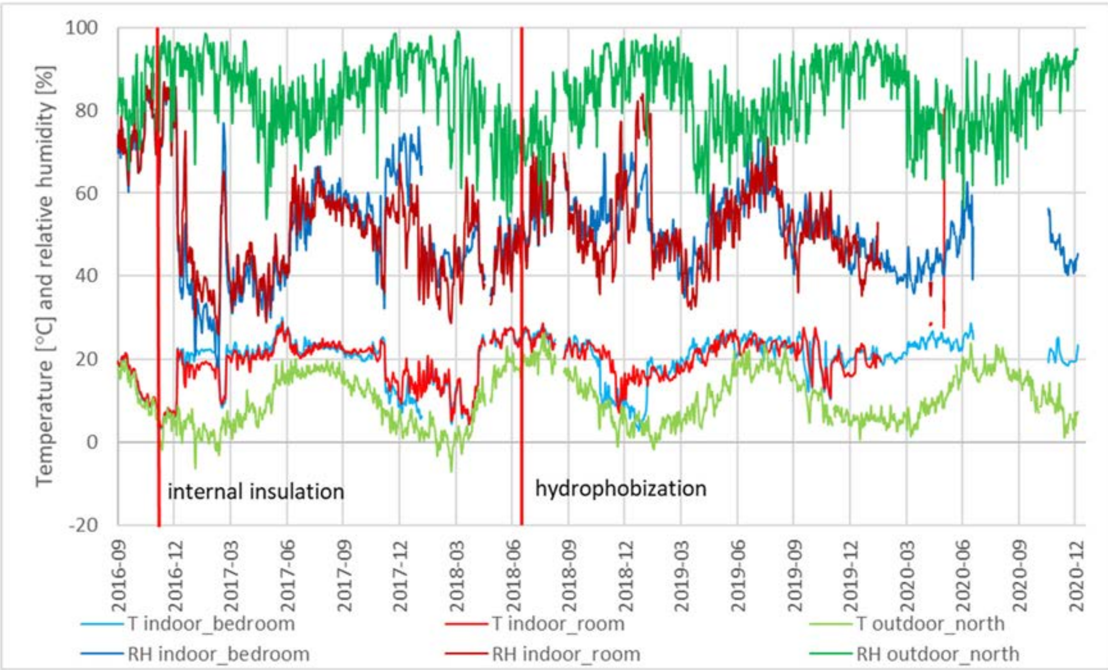

Figure 4. Indoor and outdoor temperature and relative humidity (RH). Daily average values from September 2016 to December 2020. Indoor measurements in the bedroom (blue curves) at northwest corner (Figure 3) and the room at east façade (red curves).

5. Discussion

5.1. Indoor and outdoor climate

While the outdoor temperature and relative humidity (Figure 4) follow the seasonal changes with some deviations, e.g. a wet, not so sunny summer (2017), a dry sunny summer (2018), or a wet mild winter (2019-2020) [7], the pattern of the indoor relative humidity (and to some extent the indoor temperature) is not quite typical. The measurements started before the renovation was finished in early 2017, explaining why indoor and outdoor measurements for the first 6 months are alike; the heating was not yet turned on. In 2017, the owner had problems with controlling the heating, giving rise to temperatures quite far from the scheduled 21 °C, while later the use of the house mainly heated during weekends may explain extremes. The wet, not so sunny summer 2017 [7] had a lower drying potential than what can be expected. The following winter 2018 had conditions as they can be expected. A moist construction therefore experienced minimal drying effect in 2017-2018. Opposed to this, 2018-2019 was a better period in terms of drying conditions; a dry summer followed by a warm winter (2019). This insight will be beneficial in evaluation of the walls condition (section 5.2).

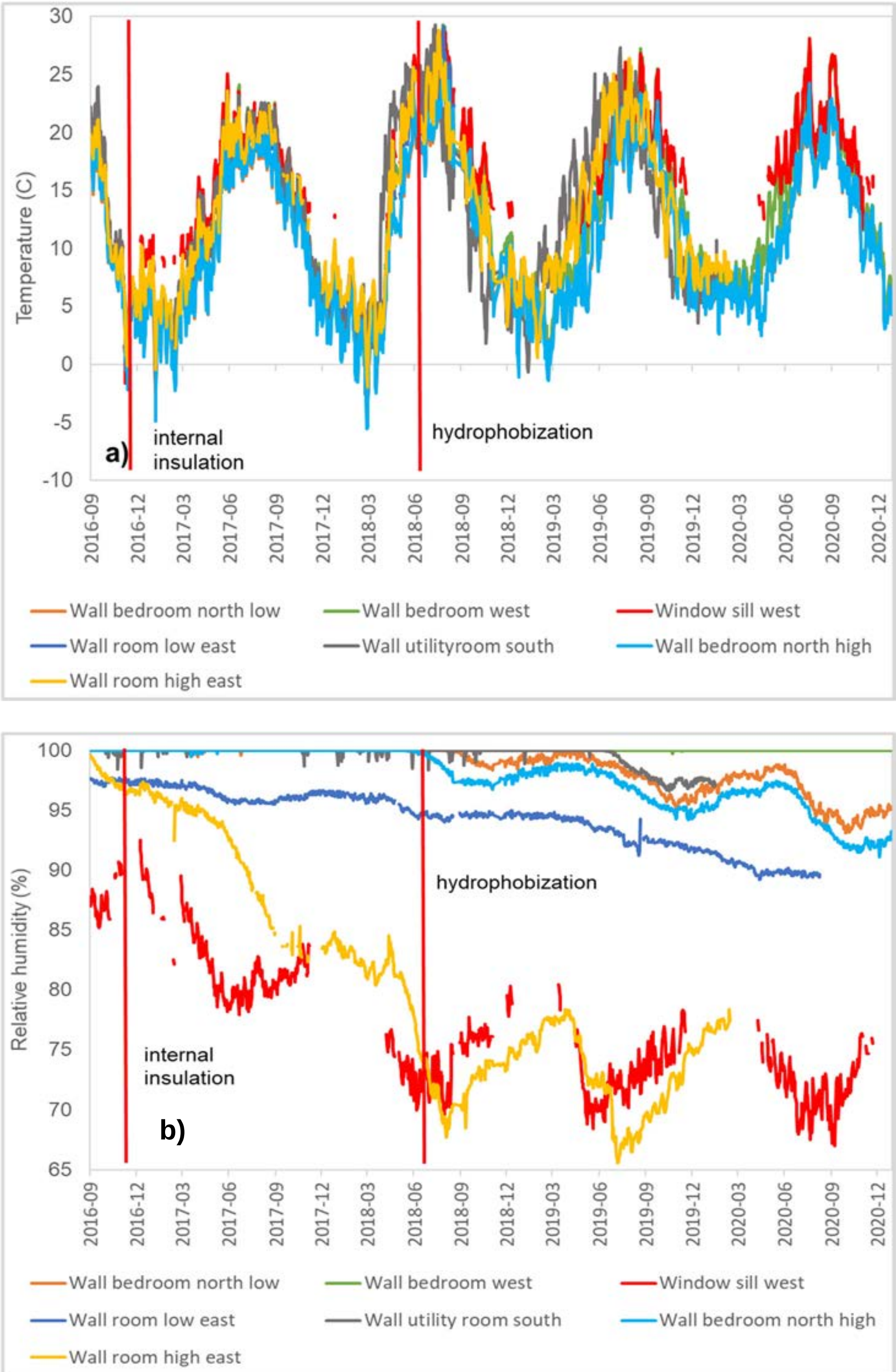

Figure 5. Temperature (a) and relative humidity (b) at the interface between the original wall and the internal insulation and at the window sill (red curve) (daily mean values). Vertical lines: Timing of applying internal insulation and hydrophobization (water repellent agent). For some periods, some sensors contains no data, indicating that they are defect or the signal is unstable.

5.2. Measured and simulated conditions inside the wall

Measurements from inside the wall of daily mean temperatures (Figure 5a) all show similar trends and show temperatures within 7 °C of each other. The temperature is generally between 0-5 °C (winter) and 20-25 °C (summer). Temperatures tend to be lowest at 'bedroom north', which is to be expected having the north wall oriented towards the nearby coast and with minimum solar radiation. The highest temperature is seen in the utility room at south, however at spring only. In autumn, the highest temperature is seen in the window sill at west, being closer to the interior. In general, orientation of walls is more important than whether measurement takes place at a high or low position on a wall.

The relative humidity at the different positions develop very differently (Figure 5b). While relative humidity high in the east-oriented wall drops below 100 % almost at once, reaches 85 % after a year during a not very "drying" summer (2017) (section 5.1) and reaches 75 % after two years, showing seasonal changes, nothing seems to have happened at the west oriented wall, although it might be a defect sensor, since the sensor in the window sill on the same orientation illustrates a significant reduction in relative humidity. RH in the north oriented wall seems to be independent of the position of the sensor, not being the case in the east oriented; the sensor at low position does not even show any seasonal changes, questioning to some extent the results from this sensor as well. The orientation towards east results in solar radiation (opposed the north oriented bedroom) and less precipitation than towards west. The pattern of the relative humidity in the window sill at west, is comparable with what is seen at the east façade; the even earlier drop in relative humidity is explained by the position close to the interior.

The application of internal insulation alone seems to have no effect on the relative humidity, which starts to decline soon after the walls becoming hydrophobized. However, this effect is not seen at the south oriented wall until a year after the application, i.e. the beneficial drying conditions during summer 2018 and winter 2019 were not enough to dry out the wall. This indicates that the walls still contain built-in moisture 2-3 years after applying the internal insulation and that it takes a couple of years before the level at the east wall and the window sill is reached. Also notice, that even before the walls becoming hydrophobized, the interface in the east oriented wall (high position) becomes dryer than the window sill. The development of the moisture conditions might have looked different, resulting in lower relative humidity in the first two years after applying internal insulation, if a water repellent agent was applied in connection with the internal insulation as suggested by simulation results, seen in Figure 6.

Applying a water repellent agent at the same time (green curve) as applying this type of internal insulation, showing capillary behaviour to some extent – or better, before applying the internal insulation – can accelerate the drying of the wall sufficiently to get rid of the built-in moisture, as it eliminates moisture penetration from wind-driven rain. In the long run, though, hydrophobization will still be beneficial even if done at a later stage (blue curve), as doing nothing (red curve) will keep the relative humidity at a very high level. In accordance to simulations performed in [8] the hydrophobization in Klitgaarden was applied in the optimal season with regard to drying of the wall. While the timing for applying a water repellent agent might not be that important when using PUR-foam with capillary active channels (iQ-Therm), as long as it is done after some time, on the contrary, the timing is very important in the case of applying a vapour tight insulation system (e.g. mineral wool and a vapour barrier). In this case, hydrophobization has to be applied no later than the internal insulation to avoid moisture problems at the early stage (Figure 7), but it is still positive in the long term if done after e.g. five years. This phenomenon has been further studied in [4], showing that in the case of calcium silicate based insulation, being capillary active, hydrophobizing the wall in parallel with the internal insulation or five years later, gives almost the same result. In line with the findings of the current paper, previous studies based on numerical results, reported that the hygrothermal performance of an internally insulated facade can be improved by hydrophobization [8, 9].

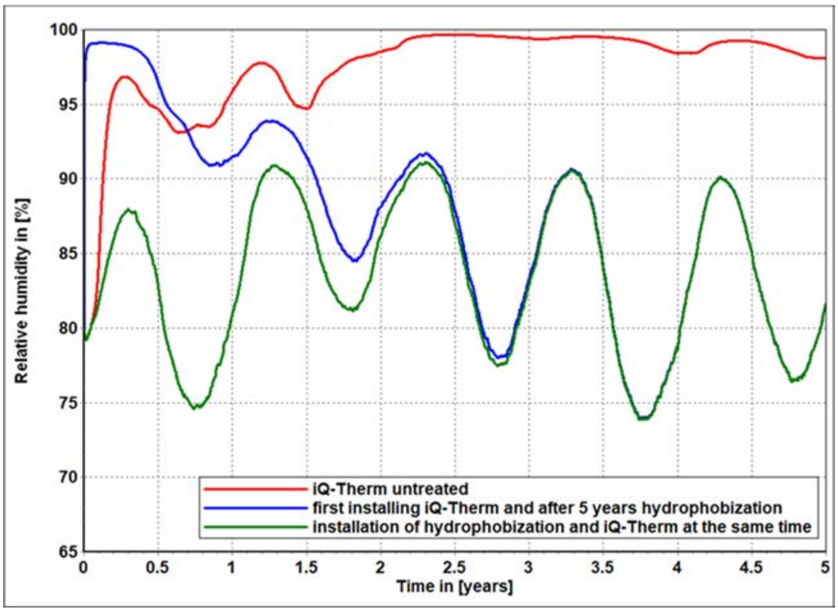

Figure 6. Simulation of relative humidity in the interface between internal insulation (iQ-Therm) and solid masonry in SW-oriented wall configurations for a five year period, when no water repellent agent is applied (red curve), then after five years becoming hydrophobized (blue curve), and if internal insulation and hydrophobization takes place in parallel (green curve). The blue curve should in principle be shown at a 5-10 year scale as it starts where the red curve ends, using the average relative humidity of the internally insulated wall as initial condition for the simulation, but for comparison with the other curves, it is shown on a 0-5 year scale. Simulations were performed with DELPHIN software [3] with climate data for Copenhagen 2020-2024 (www.climateforculture.eu). Characteristics of an untreated and hydrophobized wall were based on [5] for the hygric properties and [4] for the hydrophobic model.

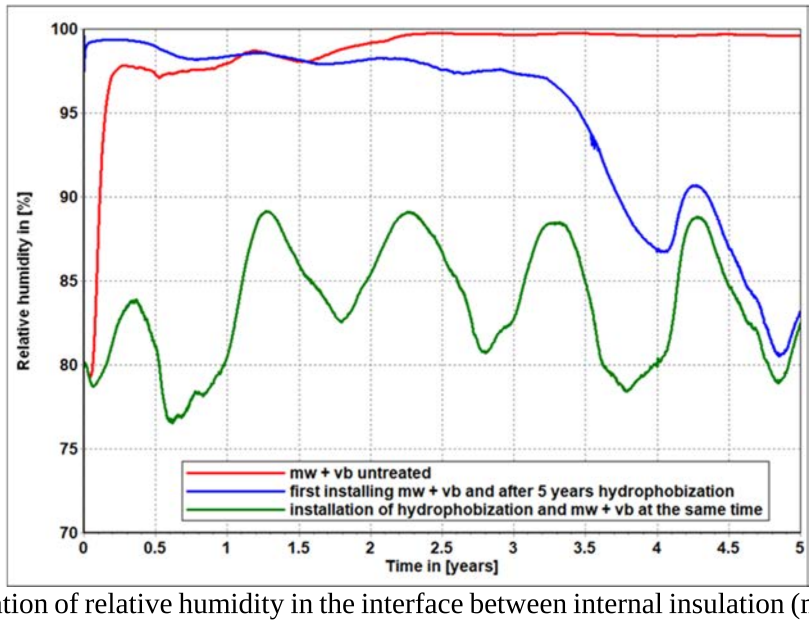

Figure 7. Simulation of relative humidity in the interface between internal insulation (mineral wool with vapour barrier) and masonry, in SW-oriented wall configurations for a five year period, when no water repellent agent is applied (red curve), then after five years being hydrophobized (blue curve), and if internal insulation and hydrophobization takes place in parallel (green curve). Concerning the blue curve, refer also to figure 6. Simulations were performed with DELPHIN software [3] with climate data for Copenhagen 2020-2024 (www.climateforculture.eu). Characteristics of an untreated and hydrophobized wall were based on [5] for the hygric properties and [4] for the hydrophobic model.

6. Conclusion

A deep renovation of a 145 year old rural building including application of internal insulation and external hydrophobization with a water repellent agent showed that it is possible to revitalise the building ensuring a suitable indoor climate. The relative humidity in the interface between the existing wall and the applied insulation is slowly decreasing, however it takes several years to get rid of the built-in moisture, when applying partly capillary active insulation to solid masonry walls in a building not being used for 20 years. Further, it was shown that a combined application of internal insulation and water repellent agent is recommended to speed up the drying process, and that the timing of the two measures is especially important in the case of a vapour-tight insulation system to promote drying of the wall.

7. References

[1] Remmers 2016 *Funcosil FC. Technical data sheet*. Germany: Löningen. Available: http://in.remmers.com/fileadmin/doc/tm/TM1_0711_IN.pdf

[2] Janssen H, Deckers D, Vereecken E, Feng C, Soulios V, Vanek A and Hansen T K 2020 *Impact of water repellent agents on hygric properties of porous building materials* (RIBuild Deliverable D2.3, www.ribuild.eu)

[3] Bauklimatik-Dresden. *DELPHIN. Simulation program for the calculation of coupled heat, moisture, air pollutant, and salt transport* Dresden: TU Dresden. Available: http://bauklimatik-dresden.de/delphin/index.php?aLa=en

[4] Soulios V, de Place Hansen E J and Peuhkuri R H 2021 *Build. Environ.* **187** 107410 https://doi.org/10.1016/j.buildenv.2020.107410

[5] Soulios V, de Place Hansen E J, Feng C and Janssen H 2020 *Build. Environ.* **176** 106843 https://doi.org/10.1016/j.buildenv.2020.106843

[6] Soulios V, de Place Hansen E J, Feng C and Janssen H 2019 MATEC Web of Conferences 282 02048 https://doi.org/10.1051/matecconf/201928202048

[7] Danish Meteorological Institute. Data on monthly, seasonal and annually weather in Denmark https://www.dmi.dk/vejrarkiv/manedens-sasonens-og-arets-vejr/tekst-kort-og-nogletal-ar/ (accessed 11 Jan 2021)

[8] Finken G R, Bjarløv S P, Peuhkuri R H 2016 *Constr Build Mater* **113** 202-214 http://dx.doi.org/10.1016/j.conbuildmat.2016.03.019

[9] Soulios V, de Place Hansen E J and Peuhkuri R H 2019 MATEC Web of Conferences 282 02049 https://doi.org/10.1051/matecconf /20192820204 9

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