

Hydrothermal performance of wooden beam on solid masonry with capillary-active internal insulation

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Abstract. With the increasing requirements for the energy performance of buildings, there is a demand for internal insulation systems in buildings where it is not possible to apply an external insulation system for legislative reasons. Currently, there has been an upsurge in the development of diffusion-open insulation materials whose properties can compensate for the risks of damage to solid masonry walls insulated with traditional diffusion-closed internal insulation systems. The properties of diffusion-open systems are already well known. This paper focuses on the simulation of the thermal moisture behaviour of a detail of a timber beam embedment in a wall with capillary active thermal insulation in cold climatic conditions of Central Europe.

1 Introduction

In recent years, there has been an increase in energy performance requirements for buildings. One way to reduce the energy performance of a building is to improve the thermal performance of the building envelope. Typically, wall insulation is carried out by means of an external insulation system. This solution is generally considered safe and is commonly used in practice. There are a large number of historic buildings in Central Europe which can be considered as cultural heritage. In order to preserve valuable historic facades, the application of an internal insulation system is often the only way to improve the thermal performance of solid masonry walls. The application of internal insulation in historic buildings can reduce heating energy consumption by 30 % - 40 % [1]. Internal insulation systems are one of the most risky insulation methods and significantly alter the thermal and moisture behaviour of the structure.

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In a large number of historic buildings in Europe, ceilings are made up of timber beams supported on solid brickwork. The durability and performance of embedded timber elements are largely dependent on moisture. The application of an internal insulation system can expose the structure and the embedded timber elements to a significant risk of moisture damage [2-4]. These risks need to be properly assessed and the correct insulation strategy selected. The risks of damage to the ends of timber beams can be reduced by heating the timber elements, for example with heating cables or by applying materials with higher thermal conductivity [5]. Wind-driven rain is an important source of moisture in masonry.

Moisture ingress into the wall is influenced by the external finish, more specifically the ability of the render to transport moisture. High WDR loads on the perimeter load-bearing walls can lead to an increase in moisture at the ends of the timber beams, potentially damaging them [6]. Mould can develop which, amongst other things due to the release of spores, can adversely affect the indoor air quality and pose health risks to the occupants of the building. Rot leads to biological decomposition of the wood and affects its mechanical properties. Walls with internal insulation should be protected against the effects of WDR by appropriate surface treatment or other protective elements [7].

The ends of timber beams can be protected from moisture by raising their temperature, which increases the potential for drying out. A large number of studies dealing with timber beams are based on numerical simulations using 2D models. In a study [8] it was shown that the use of 2D models is appropriate in assessing the risk of moisture damage to timber beams for different types of cladding. 2D models were found to be inappropriate when evaluating the effectiveness of active heating to raise the end temperature of a timber beam. In the 2D models, the width of the timber beam is assumed to be the same as the width of the wall. In the case of the observation of the thermal and moisture behaviour of the critical detail, the 2D models show only small deviations from the 3D models in temperature and moisture content. For active heating of the end of the wooden beam, the width plays an important role. The real beam width is much smaller compared to the masonry width.

In this study, changes in the thermal moisture behaviour of the end of the timber beam at several critical points are presented as a function of the thickness of the insulation material. The modelled wall is insulated with a diffusion-open system with capillary-active calcium silicate-based thermal insulation. The model is simplified and serves as a preparation for a more detailed analysis based on experimental measurements and numerical studies. External and internal surface treatments and the effect of wind-driven rain are neglected. The exterior boundary conditions correspond to the cold European climate.

2 Metodology

The modelled wall corresponds to a typical brick wall of historical buildings in the Czech Republic. The thickness of the wall is 440 mm. A wooden beam with a height of 200 mm is placed in the masonry. The width of the wooden beam is not considered due to the simplification of the model into 2D. The length of the wooden beam is 150 mm behind the inner face of the masonry. The timber beam is placed in a 40 mm thick air pocket in both horizontal and vertical directions. The air gap around the beam

prevents direct contact between the timber and the masonry to prevent capillary transport of moisture into the timber beam.

The numerical simulation was performed using DELPHIN 6.1.5 software [9]. Four models of the wooden beam were created. The first model (reference wall) represents the situation without the application of thermal insulation. For the remaining 3 models, the application of an internal insulation system with capillary active calcium silicate based thermal insulation was considered. This thermal insulation has the ability to redistribute moisture towards the interior. The formation of a condensation plane is assumed to occur around the adhesive mortar, i.e. at the contact between the thermal insulation and the brickwork. Models with internal insulation differ in the thickness of the thermal insulation. The tested thermal insulation thicknesses are 50 mm, 100 mm and 200 mm. The adhesive mortar thickness is 10 mm. The observed critical points around the end of the timber beam (A, B, C) are shown in Figure 1. To observe the changes in temperature and humidity patterns due to the application of the insulation system at the point not affected by the curvature of the temperature and humidity field, points D, E, F were defined. In this study, only the results of points A, B, C and D are presented.

For the outer boundary conditions, climate data from the DELPHIN 6.1.5 database was used. This is the model year for the city of Kassel, Germany. The effect of the WDR has been neglected in the calculations. Indoor boundary conditions were also imported from the database in the program corresponding to the standard indoor climate according to DIN 4108-3 of 2001. The indoor temperature is 20 °C and the relative humidity is 50 %. A wall without internal insulation has a heat transfer coefficient value of approximately 1.467 W/m²K, a wall insulated with 50 mm of internal insulation has 0.548 W/m²K, a wall with 100 mm of insulation has 0.340 W/m²K and a wall with 200 mm of insulation has a heat transfer coefficient value of 0.194 W/m²K.

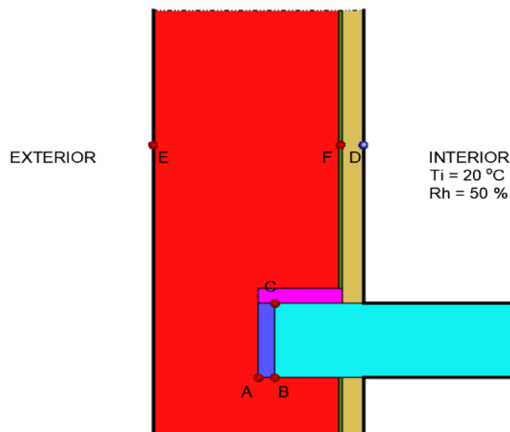


Fig. 1. Schematic representation of the computational domain for a wooden beam placed on a wall with internal insulation with the study points marked.

3 Results

3.1 Relative humidity

In the results, one year is presented for all 4 models of wooden beam placement with and without internal wall insulation. The simulation was set to 7 years to achieve a quasi-steady state. The quasi-steady state was reached after 5 years of simulation. Figures 2- 5 represent the moisture profiles of each wall without and with internal thermal insulation.

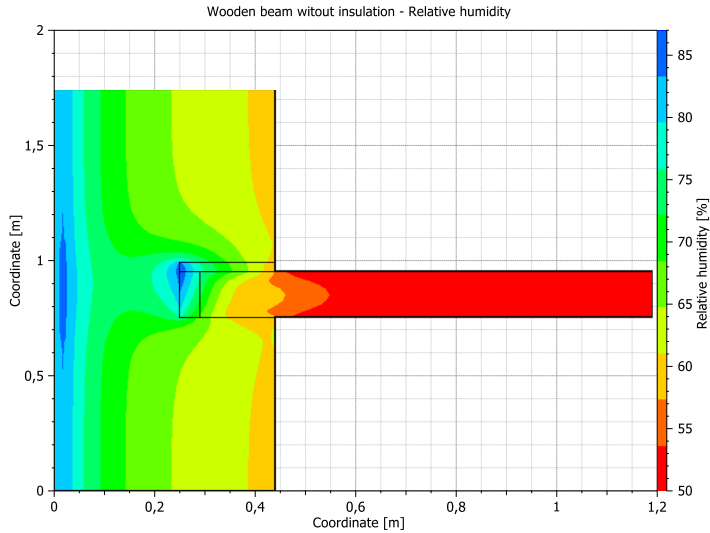


Fig. 2. Relative humidity profile of a wall with an embedded wooden beam without internal insulation.

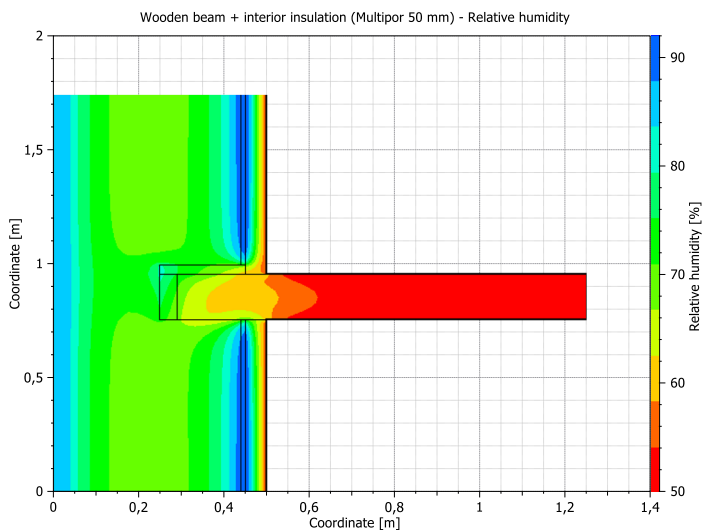


Fig. 3. Relative humidity profile of the wall with embedded wooden beam with 50 mm thick internal insulation.

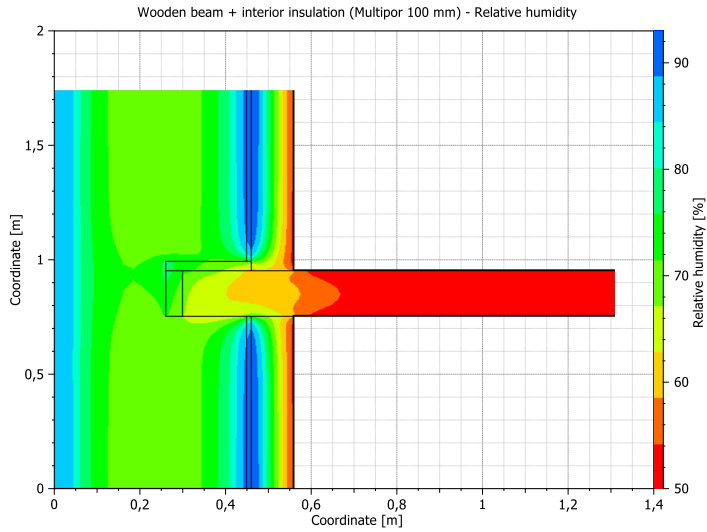


Fig. 4. Relative humidity profile of the wall with embedded wooden beam with 100 mm thick internal insulation.

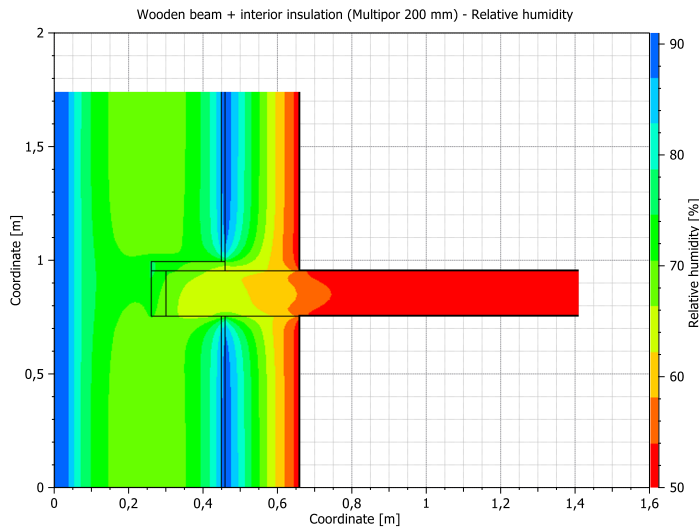


Fig. 5. Relative humidity profile of the wall with embedded wooden beam with 200 mm thick internal insulation.

Figures 3 - 5 show the changes in the moisture behaviour of the studied detail. Between the thermal insulation and the masonry wall, the formation of the assumed condensation plane can be seen. The resulting condensate should be redistributed by the capillary active thermal insulation towards the interior. Furthermore, the effect of the internal insulation on the increase of the relative humidity in the area of the external face of the masonry is evident. As the thickness of the thermal insulation

increases, the relative humidity increases, especially in the area 5 cm from the outer face of the masonry towards the interior. This increase in humidity could potentially increase the risk of damage to the external face of the masonry due to freeze-thaw cycles. The figures showing the relative humidity profiles show the effect of the reduction in relative humidity with the application of capillary active internal insulation around the timber beam.

More detailed results are presented in the following graphs. Figure 5 shows the relative humidity profile at the postulated critical point A over a period of one year. The highest relative humidity value (78.3%) was observed for the uninsulated wall. The lowest RH value (75,2 %) was observed for the wall with 200 mm thick thermal insulation. As the thickness of the thermal insulation increases, the maximum RH values at point A decrease.

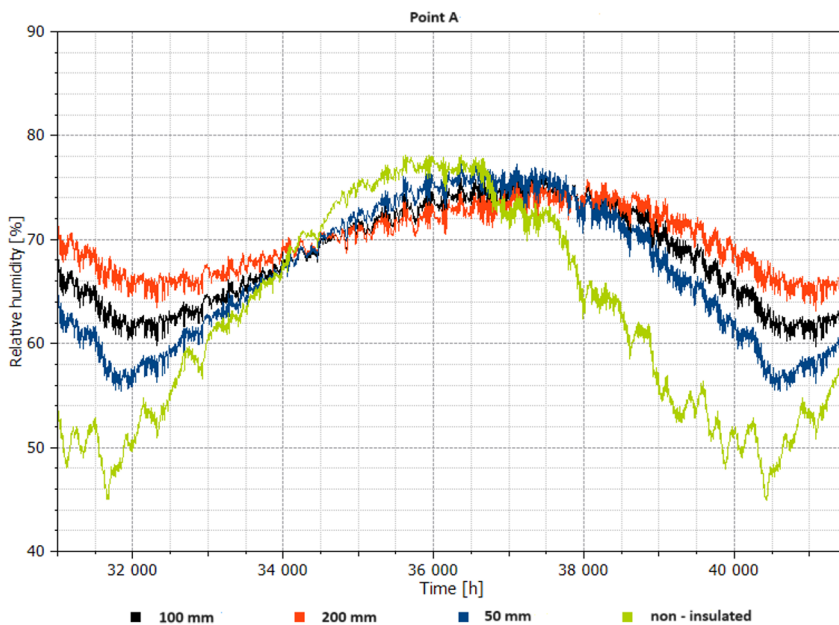


Fig. 5. Relative humidity at assessment point A for a wall without internal insulation and with internal insulation thicknesses of 50 mm, 100 mm and 200 mm.

Figure 6 shows the relative humidity at the surface of the timber beam at the point of insertion on the masonry. The lowest relative humidity value was recorded for the uninsulated wall. For the insulated walls, an increase in the maximum relative humidity value was observed at point B in all cases. The maximum RH values for the insulated walls showed little difference.

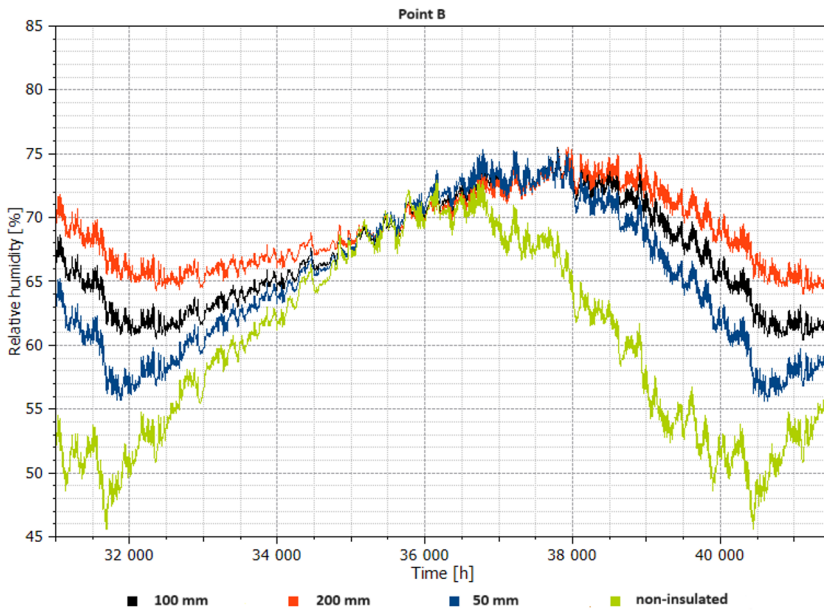


Fig. 6. Relative humidity at assessment point B for a wall without internal insulation and with internal insulation thicknesses of 50 mm, 100 mm and 200 mm.

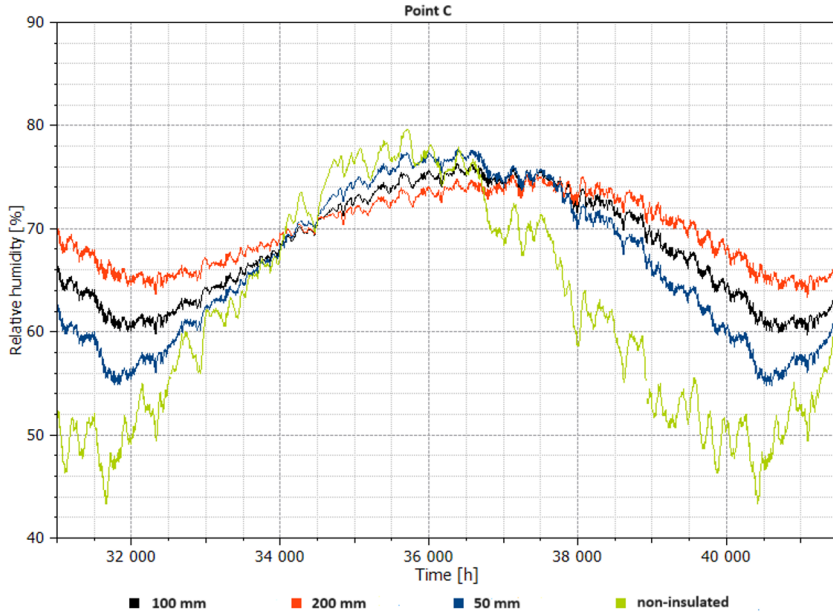


Fig. 7. Relative humidity at assessment point C for a wall without internal insulation and with internal insulation thicknesses of 50 mm, 100 mm and 200 mm.

The relative humidity at point C (Fig. 7) shows a very similar behaviour to point A. As at point A, the maximum relative humidity value decreased with increasing thickness of the thermal insulation. For the uninsulated wall, the maximum RH value was found to be close to 80%. The lowest RH value (75,01 %) was recorded for the model with 200 mm of thermal insulation thickness. Figure 8 shows the relative humidity on the inner surface of the wall.

The highest relative humidity value was recorded for the wall without thermal insulation. Despite the ability of the capillary active thermal insulation to redistribute condensed moisture into the interior, a decrease in relative humidity at the inner surface can be observed. As the thickness of the thermal insulation increases, the relative humidity at the surface decreases and shows less variation throughout the year. With increasing thickness of thermal insulation, in general, in all cases, smaller fluctuations in relative humidity can be observed over the year.

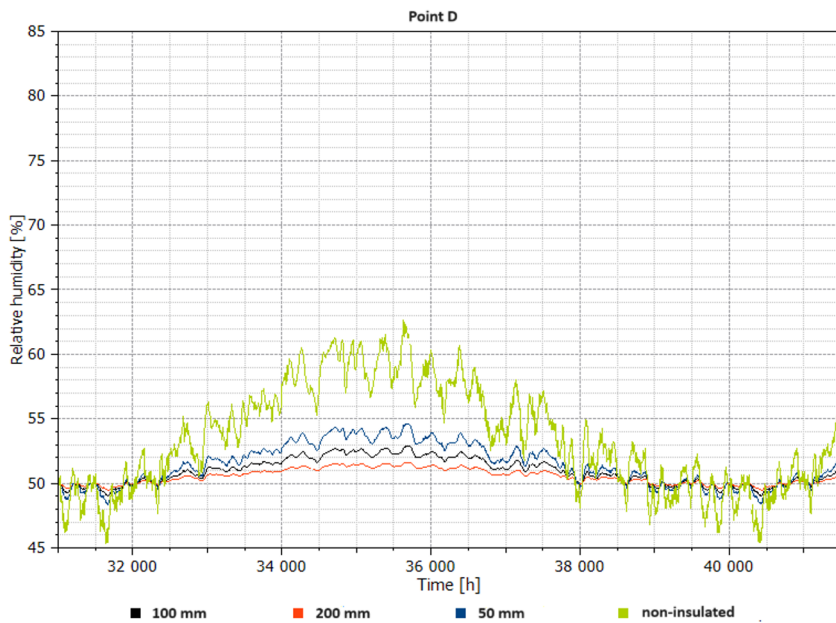


Fig. 8. Relative humidity at assessment point D for a wall without internal insulation and with internal insulation thicknesses of 50 mm, 100 mm and 200 mm.

3.1 Temperature

Figures 9 - 12 show the temperature profiles of the individual modelled walls. The temperature profiles show that the application of internal thermal insulation results in cooling of the masonry structures. The temperature isotherms are shifted towards the interior and the cooling effect of the masonry is amplified with increasing thickness of the thermal insulation.

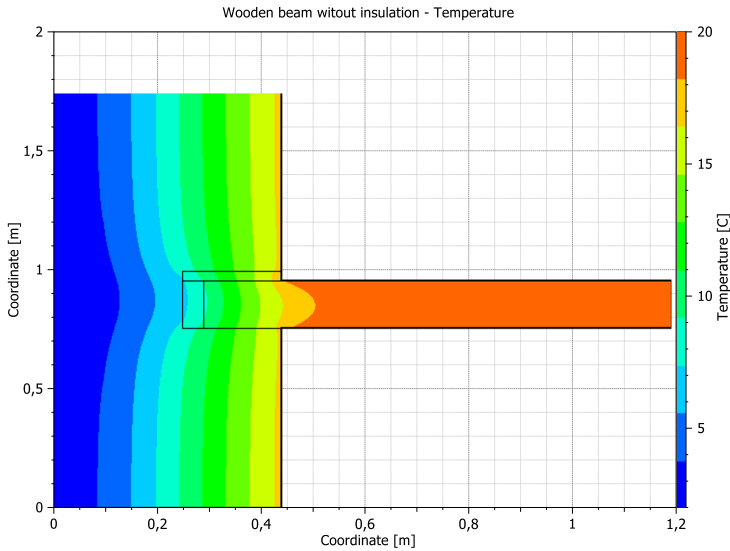


Fig. 9. Temperature profile of a wall with an embedded wooden beam without internal insulation.

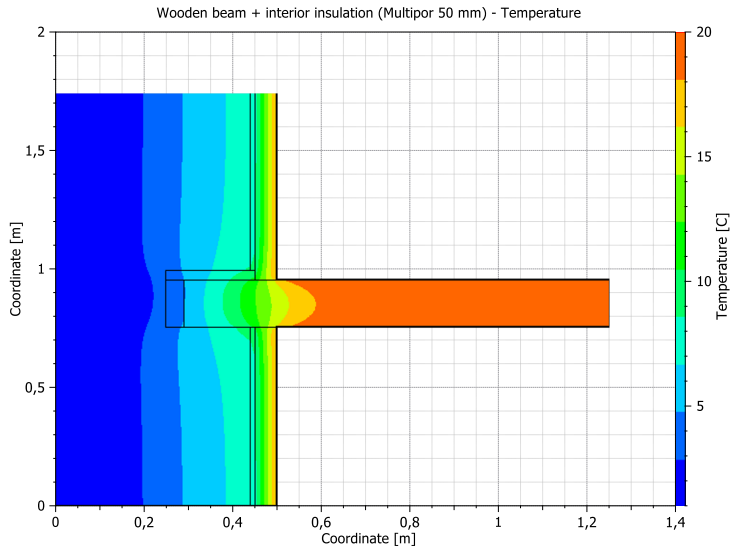


Fig. 10. Temperature profile of the wall with embedded wooden beam with 50 mm thick internal insulation.

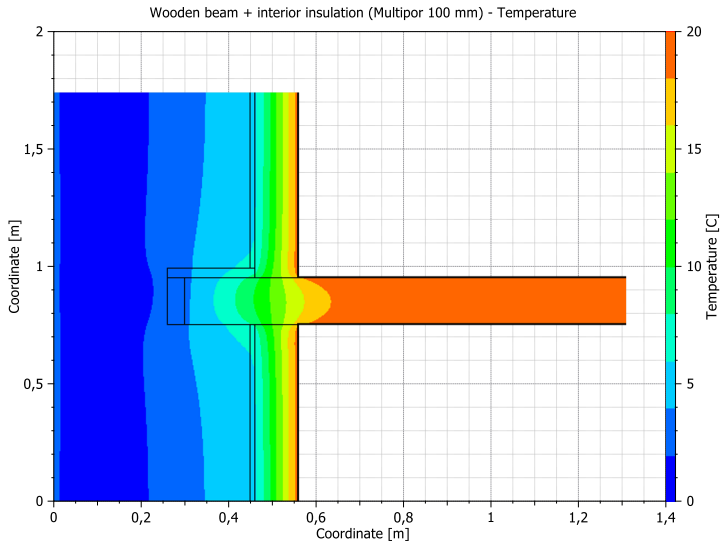


Fig. 11. Temperature profile of the wall with embedded wooden beam with 100 mm thick internal insulation.

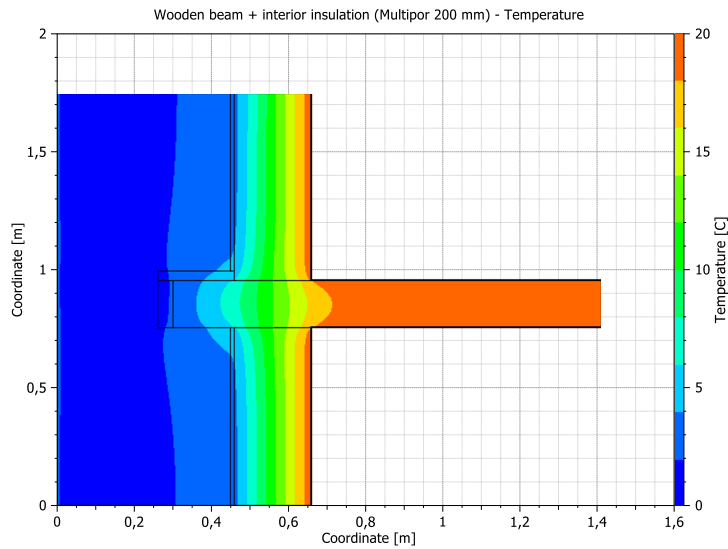


Fig. 12. Temperature profile of the wall with embedded wooden beam with 200 mm thick internal insulation.

The course of temperatures at critical points is presented in more detail in the following graphs (Figs. 13-16). Figure 13 shows the temperature trend over a period of one year at critical point A (air pocket). The application of internal insulation has resulted in a temperature drop. As the thickness of the thermal insulation increases, the temperatures at the observed location decrease. The lowest temperature was found at the wall insulated with 200 mm thick insulation, where it briefly dropped below the freezing point ($-0.31\text{ }^{\circ}\text{C}$). The highest temperature was recorded at the wall without thermal insulation ($6.08\text{ }^{\circ}\text{C}$).

The difference between the temperatures of the uninsulated wall and the wall with 200 mm of thermal insulation is almost $6.5\text{ }^{\circ}\text{C}$. The low temperature reduces the potential for drying out and increases the risks of moisture-related damage. Figures 14 and 15 show the temperature at the surface of the timber beam at the point of attachment to the masonry and at the top edge of the beam. The temperature history shows a very similar behaviour to that of point B. In neither case did the temperature drop below freezing at these points. As in point A, the lowest temperatures were found for the wall with 200 mm thick insulation, while the highest temperatures were found for the walls without thermal insulation.

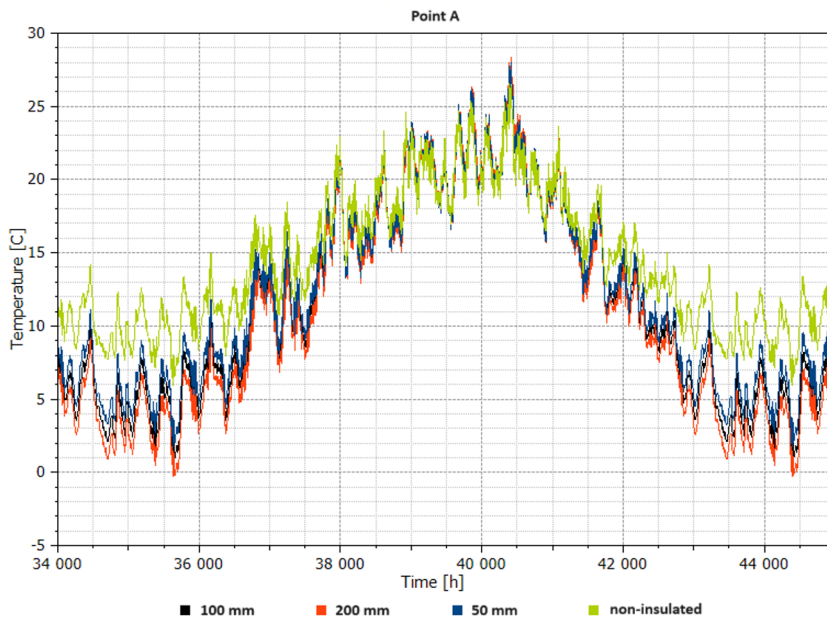


Fig. 13. Temperature at assessment point A for a wall without internal insulation and with internal insulation thicknesses of 50 mm, 100 mm and 200 mm.

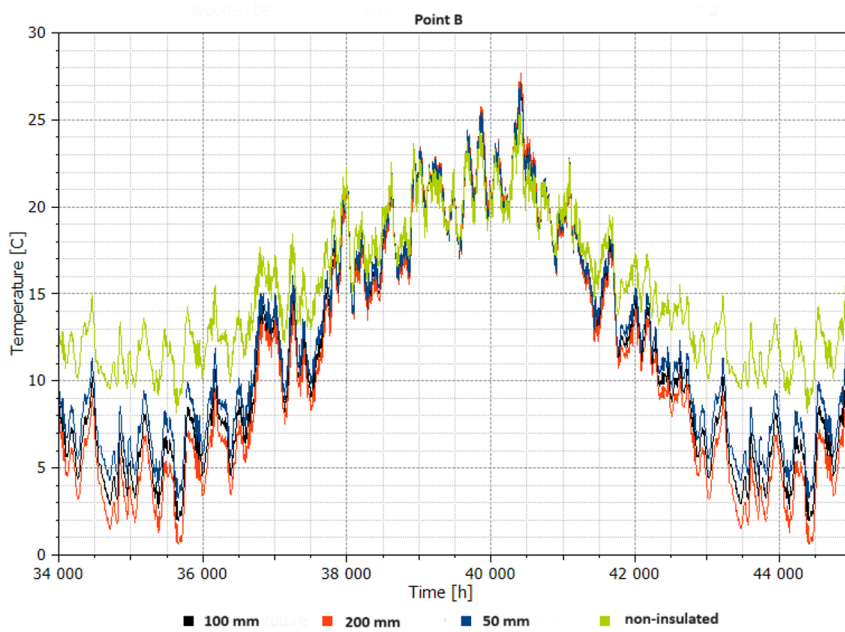


Fig. 14. Temperature at assessment point B for a wall without internal insulation and with internal insulation thicknesses of 50 mm, 100 mm and 200 mm.

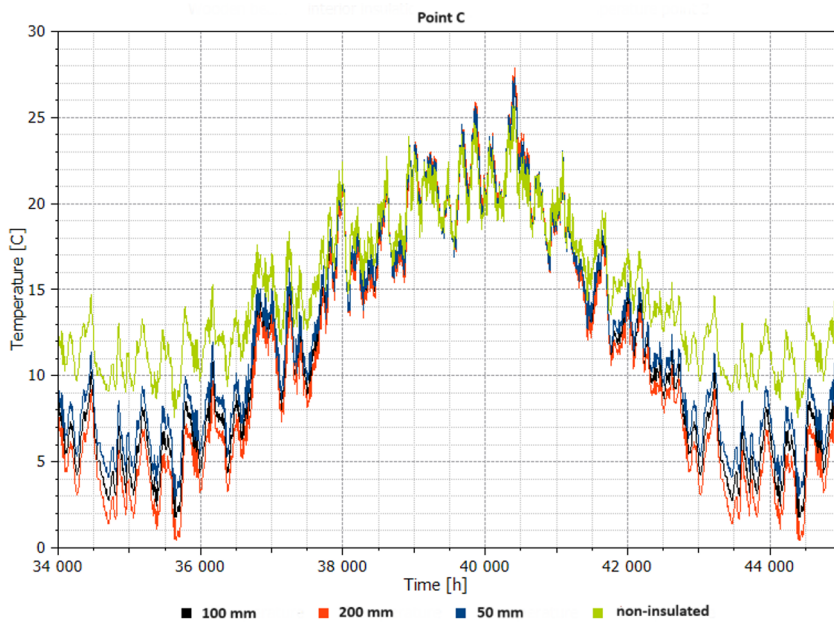


Fig. 15. Temperature at assessment point C for a wall without internal insulation and with internal insulation thicknesses of 50 mm, 100 mm and 200 mm.

Figure 16 shows the temperature evolution on the inner surface of the masonry. The application of thermal insulation has a positive effect on the internal surface temperature. The highest surface temperature was recorded for the wall with 200 mm thick thermal insulation.

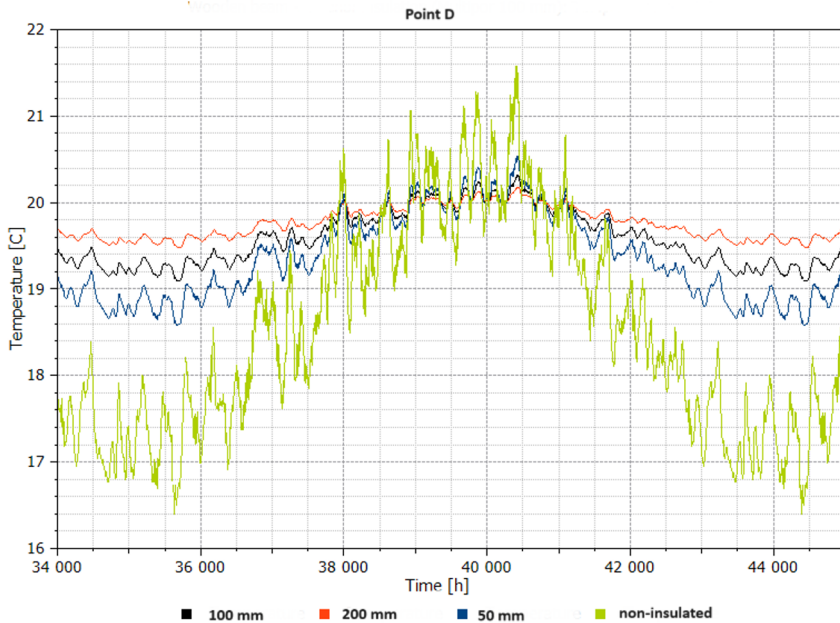


Fig. 16. Temperature at assessment point D for a wall without internal insulation and with internal insulation thicknesses of 50 mm, 100 mm and 200 mm.

4 Discussion

The application of the internal insulation changed the thermal and moisture behaviour in the wall and at the location of the wooden beam on the masonry. With the application of capillary-active thermal insulation, a slight decrease in the maximum relative humidity values was observed in the winter period in the area of the timber beam placement, except at point B (timber beam to masonry contact), where lower relative humidity values were observed for the uninsulated wall.

The application of thermal insulation can be observed to reduce the drying potential at the timber beam location. The relative humidity trend for the insulated walls shows less fluctuation during the model year than for the wall without thermal insulation. For a wall without thermal insulation, a drop in relative humidity below 46 % can be observed during the summer months, whereas for walls with thermal insulation, relative humidities range from 55 % (50 mm of thermal insulation) to almost 65 % (200 mm of thermal insulation), depending on the thickness of the thermal insulation. After the application of the internal insulation, the temperature dropped in the whole wall and at the location of the wooden beam. In one of the cases (point A, Fig. 13) the temperature dropped below freezing for a short time. With increasing thickness of the thermal insulation, the temperature drop is higher. The lowest temperatures were recorded for walls with 200 mm of thermal insulation. The

temperature difference between the wall with the highest thickness of thermal insulation and the uninsulated wall is almost 5 °C.

5 Conclusion

Based on the simulation results, a change in the thermal and moisture behaviour of the structure was observed. The application of internal insulation does not affect much the maximum relative humidity values in the area of the timber beam embedment, in some cases leading to a reduction. In the long term, it leads to higher relative humidity values in the summer period. The greatest effect of internal insulation has been observed in relation to the temperature drop. In the case of the wall without insulation and the wall with the greatest thickness of insulation, a temperature difference of almost 5 °C was observed in the winter period.

For the wall with the highest thickness of insulation, a short-term temperature drop to below freezing was observed. Low temperature combined with high relative humidity can lead to an increased risk of frost damage due to freeze-thaw cycles. In all cases, relative humidity at the location of the timber beam was observed to vary between 70 % (50 mm of thermal insulation) and 78 % (no thermal insulation) during the winter period, depending on the thickness of the thermal insulation. Humidity between 70 % and 80 % creates a risk of mould growth and development. When designing internal insulation, emphasis should be placed on the insulation strategy and on increasing the drying potential of the timber element embedded in the masonry, for example by applying heating cables or materials with higher thermal conductivity.

6 Reference

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