Heat and Moisture in Wooden Bearings of Monuments (continued)

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Summary

Currently, insulation has been and will in future be applied to many buildings. This proves to be a challenge for monumental or old buildings. Mostly insulation has to be applied at the interior side of a building. That is why hygro-thermal bridges are inevitable. A wooden beam end beared in the external wall is an example of such a hygro-thermal bridge. Adding interior insulation introduces a risk on mould growth and can even lead to deterioration of wood.

In this area several studies, including measurement studies, have already been performed. With the use of simulation models, the risk on deterioration of wooden beams can be analyzed in another way. A simulation model made with COMSOL multiphysics that uses the logarithmic, capillary pressure (Lpc) as moisture potential has already been developed. The theory and a single result were reported at the Comsol conference in Rotterdam 2017.
In this study we will show how the COMSOL model has used for a variant study to solve the problems introduced by insulating monumental facades..

A case study from Denmark, that included measurements of a wooden beam end beared into a massive masonry wall, has been used for this simulation study. Two variants have been simulated in COMSOL: a solution with adding active heating at the hygro-thermal bridge and a variant where only patial insulation was applied. For these variants the influence of the moisture content inside the wooden beam has been mapped and the risk on mould growth and deterioration has been analyzed.

Introduction

Applying thermal insulation to building envelopes is common for new built buildings. Old buildings built in the Netherlands before 1950, however, are mostly not applied with thermal insulation.
There is a risk of permanently damaging a monumental building when applying thermal insulation in a wrong way. Therefore, a number of studies has been performed to see whether thermal insulation can be applied without damaging the building.

These have been introduced in the former study. [Schellen 2017] and are listed in the references.
In this publication we will focus on the results and practical applications of the Comsol application.

Figure 1. Wooden beam end (bottom) as part of the internal construction (top) of a church in Beusichem. The end disintegrated and is not connected to the wall anymore

The COMSOL model was validated for a
1D and a 2D construction. The COMSOL model has been validated with measurements performed by Harrestrup, M. [2016] and was presented in Rotterdam [Schellen 2017]. The original construction consists of a masonry wall with a thickness of 2 bricks (see figure 2). The load bearing beam inside the wall has a diameter of 150x150mm. The floor beam has a height of 140mm and is surrounded by an air layer of 20mm. The cladding and the plaster are both 30mm thick.

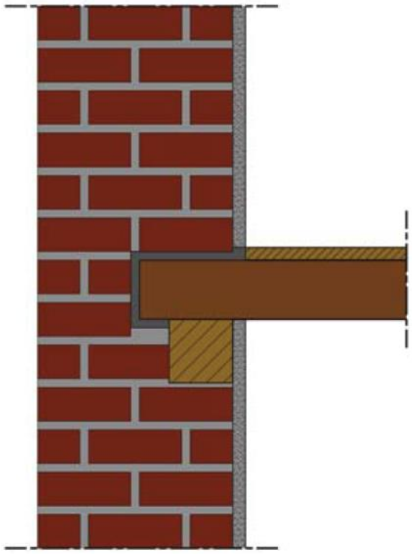

Figure 2. Danish construction used by [Harrestrup, M. 2016].

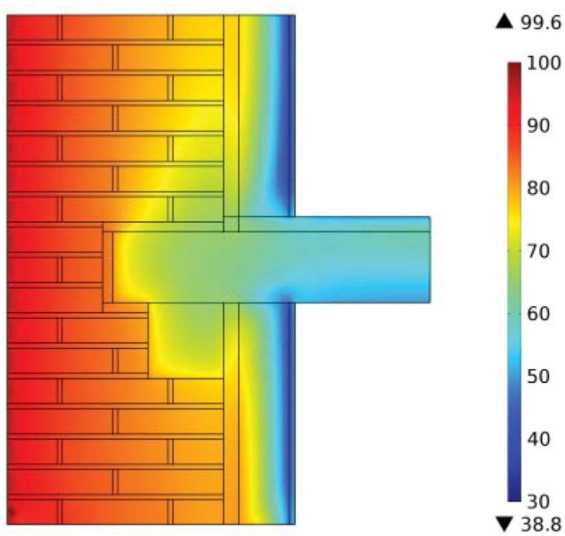

Figure 3. RH distribution within the construction during a rain event at 29-12-2012.

After applying interior insulation for both a dwelling and a museum indoor climate, the moisture content after one year of simulation is almost similar, difference <0,1% (see figure 4). In all situations calculated moisture buildup occurs.

In the summer the museum climate appears to be most critical. Highest deviation between the two different indoor climates is also found in this season.

During the summer, the indoor temperature of the museum remains 20°C while the indoor temperature of the dwelling reaches values up to 34°C, due to the absence of cooling.

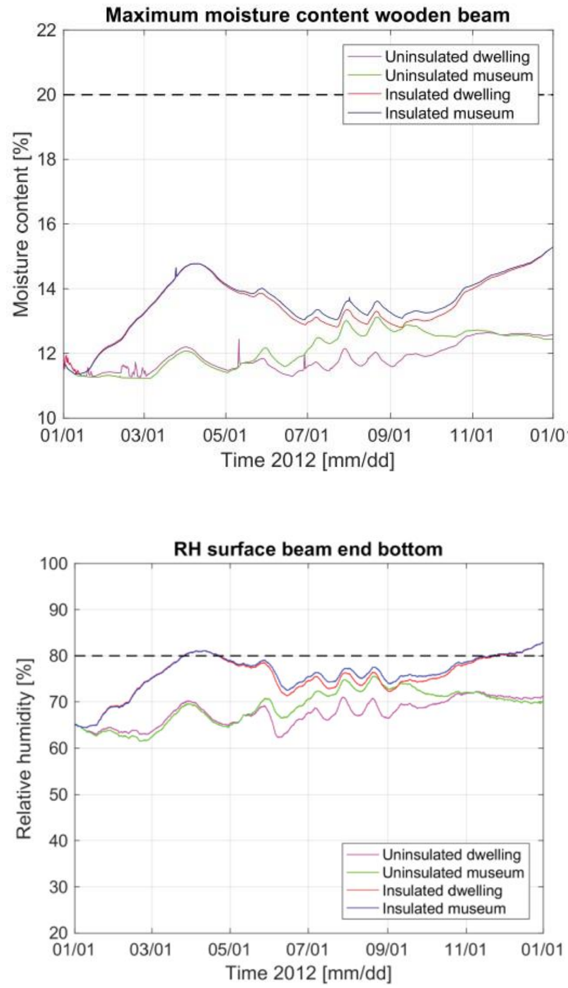

Figure 4. (top) Highest moisture content found in the wooden beam in mass percentage [%]. The uninsulated situation with dwelling (blue) and museum (red) climate is compared to the insulated situation with a dwelling (magenta) and museum (green) climate.
(bottom) RH at the surface of the wooden beam end. The uninsulated situation with a dwelling (magenta) and museum (green) indoor climate was compared to the insulated situation with dwelling (red) and museum (blue) indoor climate.

The relative humidity at the surface of the beam end shows a similar trend as the moisture content. The insulated situation shows relative humidity values higher than 80% (the threshold for mould growth). Also here the museum climate shows the highest values during summer. At the interior surface none of the simulations reach relative humidity values above 80%.

Simulation variants

The influence of changing the construction of the insulation is investigated.

The simulations are performed for the original construction (uninsulated), a fully insulated wall at the interior, an insulated wall with a gap of 200mm around the wooden beam and an insulated wall with a gap of 100mm at the connection to the floor, where active heating is applied.

The insulation thickness is 100mm. In all cases EPS insulation is applied. At the interior side of the insulation, gypsum board with a thickness of 12mm is applied. The heating is activated when the outdoor temperature drops below 10°C. With a water temperature of 35°C in the heating system, it is assumed that the air temperature near the wall and floor reaches a temperature of 30°C.

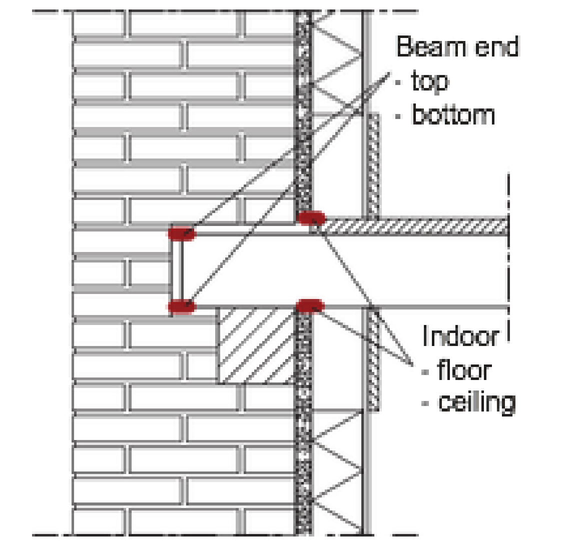

Figure 5 Position of the results for the insulated wall with 200mm insulation gap around the wooden beam.

Results

In figure 5 and 6 the analyzed positions are visualized. For the moisture content (see figure 9) the results of a change in construction already look promising when compared to the other categories. The moisture increase due to adding full insulation is halved when active heating is applied. This is also visible in figure 7, where the humidity is lower near the interior than the fully insulated construction from figure 3.The best result is achieved when a 200mm gap is applied. There the moisture content deviates < 1% from the uninsulated construction.

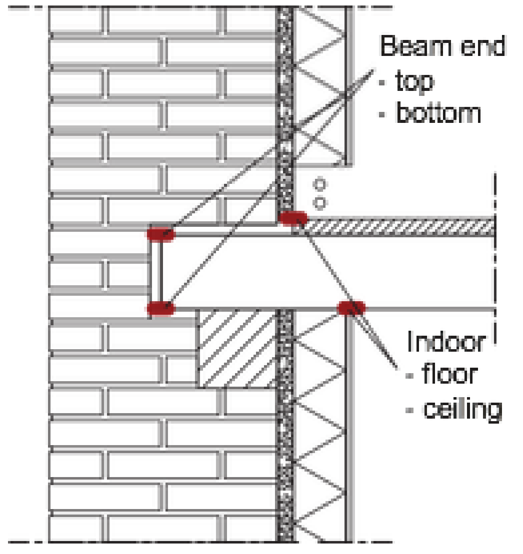

Figure 6 Position of the results for the insulated wall with active heating at the wooden beam.

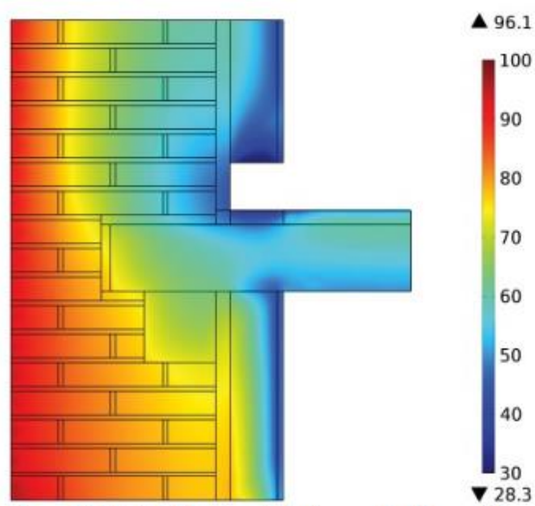

Figure 7 RH distribution within the construction and the active heating at the gap, during a rain event at 29-12-2012.

The positive effect of heating is also visible for the RH values at the surfaces. In none of the positions a RH higher than 80% has been reached. The RH shows the best improvement at the indoor surface and the top of the wooden beam end. There is also a positive effect noticeable at the bottom of the wooden beam end, however the coverage of the active heating remains limited compared to the insulation gap of 200mm.

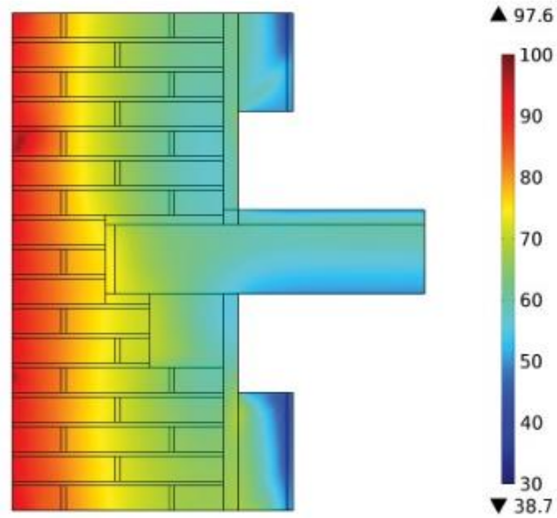

Figure 8 RH distribution within the construction and the insulation gap of 200mm, during a rain event at 29-12-2012.

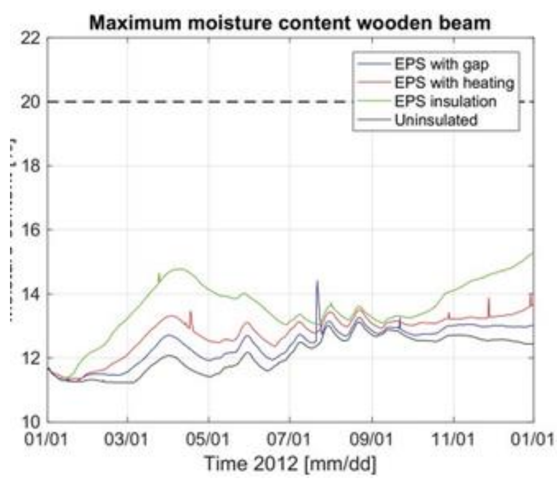

Figure 9 Highest moisture content found in the wooden beam in mass percentage [%]. The uninsulated situation (black) is compared to the fully insulated situation (green), a 200mm insulation gap (blue) and active heating (red).

For the construction with a 200mm gap at the surface of the beam end, a significant improvement has been found. However, the downside to this construction appears to be the inside surface that has higher RH values than the uninsulated wall, while the fully insulated wall with EPS caused an improvement.

Conclusions

To achieve the best results in reducing the risk at deterioration and still apply insulation at the interior, changes need to be made to the construction. Adding an active heating pipe at the corner between the wall and the floor is such an adaptation. The simulated heating pipe is able to localy increase the air temperature to 30°C. The earlier found increase of the moisture level - after one year - for a fully insulated wall with EPS, is halved when the heating pipe has been applied.

The most effective way to reduce the moisture level is to create an insulation gap of 200mm around the wooden beam. After one year only a quarter of the original increase for a fully insulated wall with EPS remains.

There is a downside to applying an insulation gap or an active heating pipe: the heat losses increase compared to a fully insulated wall. For the heating pipe solution this results in a higher energy use. For the insulation gap solution, however, this results in a lower temperature at the interior surface and therefore a higher relative humidity. The relative humidity rises above 75% but remains below the 80% threshold that is used in this research.

References

Berger, J., Chhay, M., Guernouti, S. & Woloszyn, M. (2014). Proper generalized decomposition for solving coupled heat and moisture transfer. Journal of Building Performance Simulation, DOI: 10.1080/19401493.2014.932012.

Börjesson, F. (2013). An investigation of the water vapour resistance. Chalmers University of Technology. Gothenburg, Sweden.

Delgado, J.M.P.Q., Barreira, E., Ramos, N.M.M & Freitas, V.P. (2013). Hygrothermal numerical simulation tools applied to building physics. DOI 10.1007/978-3-642-35003-0.

Gnoth, S., Jurk, K., & Strangfeld, P. (2005). Hygrothermisches Verhalten eingebetteter Holzbalkenköpfe im innnengedämmten Außenmauerwerk. Bauphysik 27, Vol. 2. pp. 117-128.

Grobbauer, M., & Ruisinger, U. (2012). Innendämmung, Holzbalkenköpfe und Kastenfenster in der Sanierung. Technische Universität Graz, Bauphysiktagung 2012. pp. 88-108. DOI: 10.3217/978-3-85125-237-8.

Guizzardi, M., Derome, D., Vonbank, R. & Carmeliet, J. (2015a). Hygrothermal behavior of a massive wall with interior insulation during wetting. Building and Environment, Vol. 89. pp. 59-71.

Hagentoft, C.E., et al. (2004). Assessment method of numerical prediction models for combined Heat, Air and Moisture transfer in building components: Benchmarks for one-dimensional cases. Journal of thermal environment & building science, Vol. 27, pp. 327-352. DOI:0.1177/1097196304042436.

Hens, H.L.S.C. (2015). Combined heat, air, moisture modelling: A look back, how, of help? Building and Environment, Vol. 91. pp. 138-151

Goesten, S. (2016). Hygrothermal simulation model: Damage as a result of insulating historical buildings. Master thesis.

Harrestrup, M. & Svendsen, S. (2016). Internal insulation applied in heritage multi-storey buildings with wooden beams embedded in solid masonry brick façades. Building and Environment, Vol. 99. pp. 59-72.

Holle, H.J. (2009). Innendämmung bei erhaltenswerten Fassaden - ein baukonstruktives Projektbeispiel. Bauphysik 31, Vol.
4. pp. 227-234. DOI: 10.1002/bapi.200910030.

Janetti, M.B., Ochs, F. & Wolfgang, F. (2012). On the conservation of mass and energy in hygrothermal numerical simulation with COMSOL multiphysics. Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28. pp. 2860-2867.

Janssen, H. (2014). Simulation effi ciency and accuracy of different moisture transfer potentials. Journal of Building Performance Simulation. Vol. 7, No. 5. pp. 379-389. DOI: 10.1080/19401493.2013.852246.

Kehl, D. (2012). Holzbalkenköpfe im Mauerwerk. Holzbau 6. pp. 20-25.

Kehl, D., Ruisinger, U., Plagge, R., & Grunewald, J. (2013). Wooden beam ends in masonry with interior insulation – A literature review and simulation on causes and assessment of decay. Proceedings of 2nd Central European Symposium on Building Physics.

Li, Q., Rao, J., & Fazio, P. (2009). Development of HAM tool for building envelope analysis. Building and Environment. Vol. 44. pp. 1065–1073.

Morelli, M., & Svendsen, S. (2012). Investigation of interior post-insulated masonry walls with wooden beam ends. Journal of building physics 36, Vol. 3. pp. 265-292. DOI: 10.1177/1744259112447928.

Portal, N.W., Schijndel, A.W.M., & Kalagasidis, A.S. (2013). The multiphysics modeling of heat and moisture induced stress and strain of historic building materials and artefacts. BUILD SIMUL. Vol. 7. pp. 217–227. DOI: 10.1007/s12273-013-0153-4.

Renato, P. (2013). Innovative approaches for the experimental determination of the liquid water conductivity and validation of a model for heat and moisture transfer in porous building materials.

Santos, G.H., Mendes, N. & Philippi, P.C. (2009). A building corner model for hygrothermal performance and mould growth risk analyses. International Journal of Heat and Mass Transfer. Vol. 52. pp. 4862–4872.

Schellen, H.L., Spierenburg, M., Schijndel, A.W.M. van. (2017). Heat and moisture in wooden bearings of monuments. Comsol conference Rotterdam 2017.

Stopp, H., Strangfeld, P., Toepel, T., & Anlauft, E. (2010). Messergebnisse und bauphysikalische Lösungsansätze zur Problematik der Holzbalkenköpfe in Außenwänden mit Innendämmung. Bauphysik 32, Vol. 2. pp. 61-72. DOI: 10.1002/bapi.201010008.

Strangfeld, P., et al. (2011). Bauphysikalisch schadensfreie Innendämmung von Außenwänden mit eingebundenen Holzbalkenköpfen. Wissenschaftstage der Hochschule Lausitz.

Uittenbosch, S. (2012). Risico van inwendige condensatie in een externe scheidingsconstructie. Eindhoven University of Technology.

Vereecken, E., & Roels, S. (2015). Capillary active interior insulation: do the advantages really offset potential disadvantages? Materials and Structures. Vol. 48. pp. 3009–3021. DOI: 10.1617/s11527-014-0373-9.

Vinha, J. (2007). Hygrothermal performance of timber-framed external walls in fi nnish climatic conditions. Tampere Universityof Technol