Hygric performance of internal insulation with light-weight autoclaved aerated concrete

Gregor A. Scheffler

Xella Technologie- und Forschungsgesellschaft, Section of Applied Research and Building Physics, Hohes Steinfeld 1, 14797 Kloster Lehnin, Germany

Abstract: The reduction of the world-wide CO_2-consumption is a key challenge for the international community as a whole. The building sector and in particular the energy consumption of buildings is one of the major contributors to this consumption. Therefore, not only the national and international legislation is challenged, but also the building industry to provide innovative and sustainable solutions for the reduction of building energy consumption.

For new buildings, standards and requirements concerning the thermal performance are already set very high. Therefore the energy-saving potential is used rather efficiently in this sector nowadays. However, a much larger energy saving potential lies in the building stock, and particularly in the group of buildings erected before 1980. For these buildings, the transmission heat losses are very high whereas an external insulation is often not applicable. Consequently, internal insulation is the only option.

Internal insulation changes the thermal performance of the outer walls significantly. This can lead to moisture problems which is the main reason why internal insulation is often seen critically.

This paper introduces an innovative and sustainable internal insulation system based on a light-weight autoclaved aerated concrete. Starting with a discussion on the advantages and disadvantages of the different internal insulation options, the benefits of diffusion-open systems are derived. The working principles of such insulation systems are explained and the particular advantages of AAC-based internal insulation – combining the good thermal properties with the excellent hygric and mechanical properties – are highlighted. Finally, the proof by calculation is compared with experience and evidence from building application.

Keywords: internal insulation, vapor diffusion, capillary activity

1. INTRODUCTION

The reduction of the building energy consumption has become one of the most important issues building professionals have to deal with. Due to its huge energy saving potential, particular focus is directed towards the existing building stock [6], [11]. Apart from more efficient energy production and the use of renewable energy sources, the upgrade of the building structure itself is most important with regard to air tightness and thermal insulation. While being generally the preferred option, an external insulation is often not applicable for older buildings due to the aesthetical and cultural value of their facades. Hence an internal insulation remains the only option to reduce the transmission heat losses of these buildings.

An internal insulation is often seen critical due to its sensitivity to vapor diffusion and interstitial condensation. The reason for this is the relation between temperature and relative humidity / vapor pressure. As a consequence of the pronounced temperature drop over the internal insulation, a vapor diffusion flow develops into the structure. There are two general options how to deal with this vapor diffusion flow: one is to prevent the wall from this vapor flow by making it vapor-tight. The other is to apply an internal insulation system which can cope with this moisture. Both options are introduced in more detail as follows.

1.1. Vapor retarding insulation

The principle of vapor retarding internal insulation systems is shown in Fig. 1. An internal insulation is applied to an existing masonry wall. In order to prevent vapor from entering the wall, a vapor barrier needs to be installed at the internal side of the insulation. The wall finishing is typically made of wall boards as e.g. gypsum fiber boards which also act as an additional protection layer for the vapor barrier.

It is apparent that the vapor diffusion resistance of the vapor barrier needs to be sufficiently high in order to prevent the structure from interstitial condensation. If such condensation occurs, it can lead to deterioration of the existing wall structure as well as of the insulation material and its thermal properties. In principle, such structures are state of the art. They, however, require particular care during installation with regard to joints, connections and penetrations. Small imperfections or leaks can lead to substantial moisture damage.

The working principle, i.e. the prevention of vapor diffusion into the structure by sealing it with a vapor retarding layer, is at the same time the big disadvantage of such insulation systems. Neither drying to the interior, nor buffering of moisture from the room air are possible if the wall has been made (almost) vapor tight. This is particularly dangerous for wall structures which need the drying potential to the interior as wooden framework or clinker / brick wall structures.

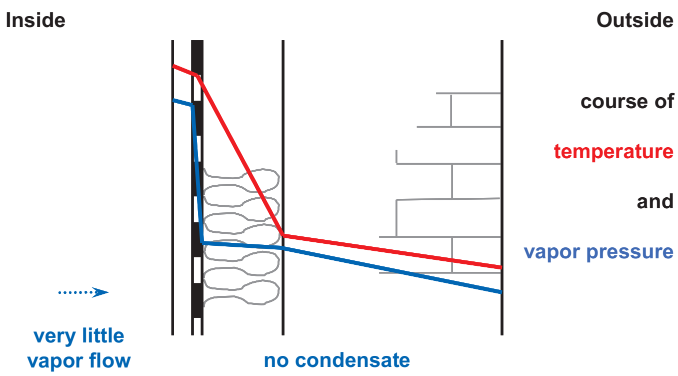

Fig. 1. Principle of vapor retarding internal insulation systems. The vapor diffusion flow is prevented by the vapor barrier. Drying to the interior is hardly possible.

1.2. Vapor open, capillary active insulation

See Fig. 2 for an illustration of the principle of vapor open, capillary active internal insulation systems. The insulation system consists of the insulation material itself and an adhesive mortar to connect it to the existing wall structure.

Capillary active insulation materials must fulfill three building physical requirements. They must have a low thermal conductivity, a high vapor permeability, and the ability to conduct moisture in liquid form already at low moisture levels. This so called capillary activity is the key property for the working principle of such systems. Vapor retarding insulation systems can either consist of one material fulfilling both tasks (vapor retarding and thermal insulating) as e.g. EPS or XPS, or of two material as e.g. mineral wool with a foil as vapor barrier. Capillary active insulation works always as a system of two materials: the insulation and the adhesive mortar. Their properties need to be concerted. The mortar should have a lower vapor permeability and a lower liquid conductivity than the insulation material. Usually it also possesses a higher thermal conductivity.

The reason for this property combination is the working principle of capillary active insulation systems. During winter, a temperature profile develops over the wall with a steep slope throughout the insulation material. The consequence is a vapor diffusion flow into the structure. If the saturation vapor pressure is reached, liquid water falls out inside the structure. Due to the higher thermal conductivity and the lower vapor permeability, the adhesive mortar ensures that the condensation layer remains inside the insulation material. The insulation absorbs this moisture and conducts it back to the inner wall surface in liquid form.

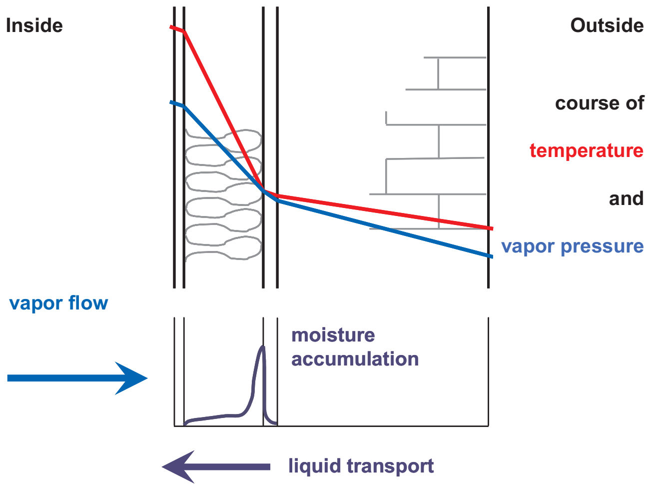

Fig. 2. Principle of vapor open, capillary active internal insulation. The vapor diffusion flow into the structure is not prevented. Accumulating moisture is absorbed by the insulation material. This moisture is transported back towards the inner wall surface in its liquid phase by capillary forces. Consequently, the moisture level is kept permanently low and the drying potential to the inside is hardly affected.

Liquid transport follows the capillary pressure gradient. Inside one material this means, that liquid transport also follows the moisture content gradient. In our case this is from the cold side of the insulation material back to the inner wall surface, see Fig. 2. Since both transport mechanisms (liquid conduction and vapor diffusion) follow different driving forces, they can proceed into different directions at the same time. After a while, a steady state develops between vapor transport in one and liquid transport in the other direction. By that, the overall moisture level inside the wall is kept low whereas the indoor climate is affected in a positive way due to moisture buffering by the vapor open structure.

1.3. Objectives

A capillary active internal insulation system has been developed on AAC basis [5]. This insulation system is particularly suitable for upgrading existing buildings which require a sensitive renovation and a drying potential to the inside.

The typical design standards for the hygrothermal building component performance [2], [4] contain only simplified calculation methods where liquid transport is neglected. Consequently, capillary active insulation systems can not be properly calculated. More advanced methods are available and standardized [12], [13], [3], but often not known to the building practice which often leads architects and engineers to hesitate proposing such systems.

This paper gives an example application of such more advanced calculation methods on capillary active internal insulation. For calculation, the DELPHIN program was used [8]. It allows to account for coupled heat and moisture transport under varying climatic conditions. The material data was determined and implemented according to [9] and [10].

2. INVESTIGATION METHOD

When applying an internal insulation, the critical details are the connections of walls, windows and ceilings. Old buildings often contain wooden floor structures. Therefore, such an old building was chosen to be investigated in our study, see Fig. 3. The school was built around 1900. The clinker facade with its characteristic structuring elements was to be preserved. Therefore, only an internal insulation could be applied for upgrading the energy performance of the building.

Fig. 3. View on the old school building. Drawing according to [1]

2.1. Structural details

The structural detail of the floor beam – wall connection is shown in Fig. 4. As thin wall structures have less thermal resistance, this detail of the 3rd floor was chosen where the upper wall is recessed compared with the lower floors. The beam end rests on a wooden bearing. It has no direct contact with the wall bricks. The air gap around it is not in contact with the interior. To the wall, 120mm internal insulation is applied. The ceiling is lowered with a acoustic ceiling panels.

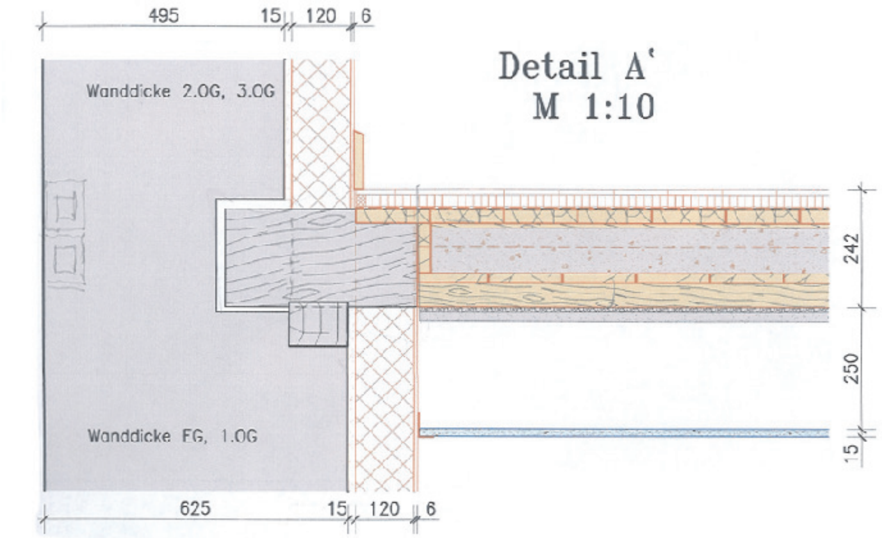

Fig. 4. Connection of wooden floor beam and wall structure. An internal insulation of 120 mm was applied consisting of the developed light-weight AAC. Drawing according to [1]

The facade is made of a 75 mm thick clinker layer. The remainder of the wall is made of normal brick masonry. The mortar joints were considered to be fully covered. For simplification, they were omitted during calculation.

A second investigated detail is a window connection shown in Fig. 5. It consists of a combination of wooden lintel and a masonry arch. A list of material properties used for calculation can be found in 0.

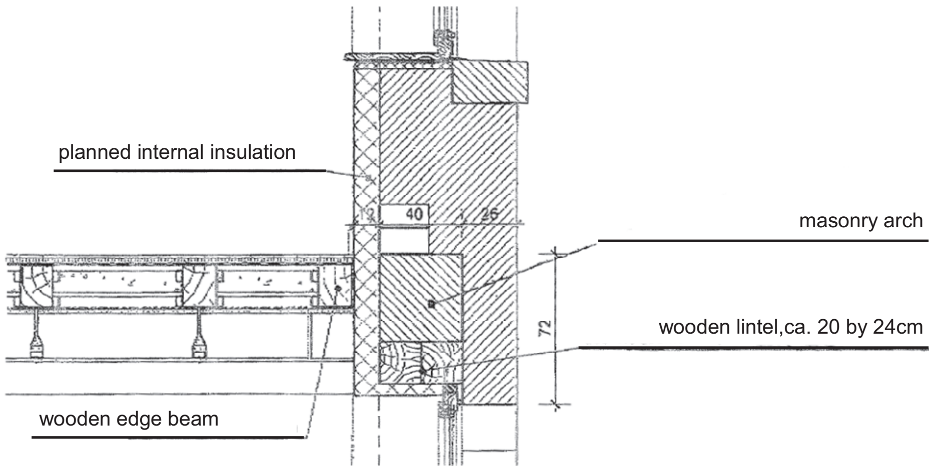

Fig. 5. Window connection with wooden lintel

Table 1. List of used materials and material properties

Material	Bulk density [kg/m³]	Thermal conductivity [W/(mK)]	Vapor diffusion resistance [–]	Water absorption coefficient [kg/(m²√s)]	Sorption moisture content [m³/m³]
clinker (old)	2100	1,0	30	0,005	0,003
brick (old)	1800	0,75	20	0,070	0,003
wooden beam (longitudinal)	530	0,13	45	0,058	0,075
wooden beam (perpendicular)	530	0,13	150	0,020	0,075
air gap (10mm)	1,3	0,067	0,7	-	-
air gap (50mm)	1,3	0,278	0,35	-	-
acoustic ceiling	300	0,10	1	-	-
adhesive for light-weight AAC insulation	830	0,15	15	0,003	0,052
light-weight AAC insulation	115	0,045	4	0,017	0,008

2.2. Evaluation criteria

The assessment was done in two steps. The first step is a one-dimensional investigation of the undisturbed wall structure with internal insulation under stationary (constant) and transient (real) climatic conditions. In case, no moisture problems occur, the two-dimensional details according to Fig. 4 and Fig. 5 are investigated in a second step.

The calculations were done according to [12], [13] and [3]. The criteria for structural failure are determined by the moisture performance in relation to the risk of mould growth and accumulation of increased water contents inside the structure. These criteria were evaluated for the stationary calculations.

For the assessment of the structural behavior under transient climatic conditions, additional requirements were set. First of these is, that there is no continuous built-up of moisture inside the structure over several years. And second is that the wooden parts inside the structure are not in danger of damage.

2.3. Climatic boundary conditions

The internal climate were assumed to follow normal conditions for offices, i.e. constant 20°C of temperature and 50% relative humidity (RH). The external climatic conditions distinguish between constant and transient conditions. For the stationary calculations, the outside conditions were set to -10°C of temperature and 80% of RH. For the transient calculations, a central German climate data set was applied, see 0.

Table 2. Climatic boundary conditions of the calculations

Boundary Conditions	Temperature [°C]	Relative Humidity [%]	Duration
Inside, constant	20	50	60d / 5..10a
Outside, constant	-10	80	60d
Outside, real climate data	Climatic data set of central Germany including hourly values of temperature, relative humidity, solar radiation, wind and rain.		5..10a

3. RESULTS AND DISCUSSION

3.1. One-dimensional calculations

In a first step, the moisture performance of the undisturbed wall structure was calculated for 60 days. We evaluated the amount of overhygroscopic moisture occurring inside the structure as well as the development of the relative humidity.

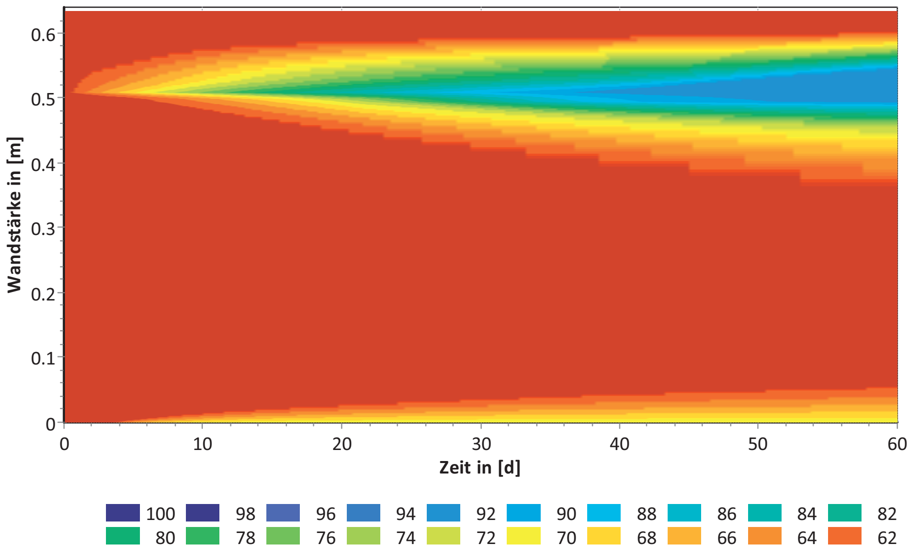

Fig. 6. Development of relative humidity versus wall structure (y-axis) and time (x-axis) for the undisturbed wall

Overhygroscopic moisture was not detected at all. The development of the RH over time is shown in Fig. 6. At the cold side of the insulation, the relative humidity reaches values of about 95%. This is normal and part of the working principle of such insulation systems. The insulation absorbs the accumulated moisture and dries out quickly during the warm season. Due to the capillary conductivity of the material, the moisture is conducted back towards the inner wall surface and the overall moisture level is kept low, see Fig. 6. The working principle is hence confirmed, this structure works well according to the standard proofing conditions.

For proofing the structure under real climatic conditions, calculations were done for five years with the boundary conditions according to 0. As result, the course of the relative humidity is plotted versus time at two positions inside the structure. One is the cold side of the insulation material and the other is the joint between outside clinker and normal brick masonry, see in Fig. 7. The reason for that is to investigate the influence of moisture from both internal and external sources.

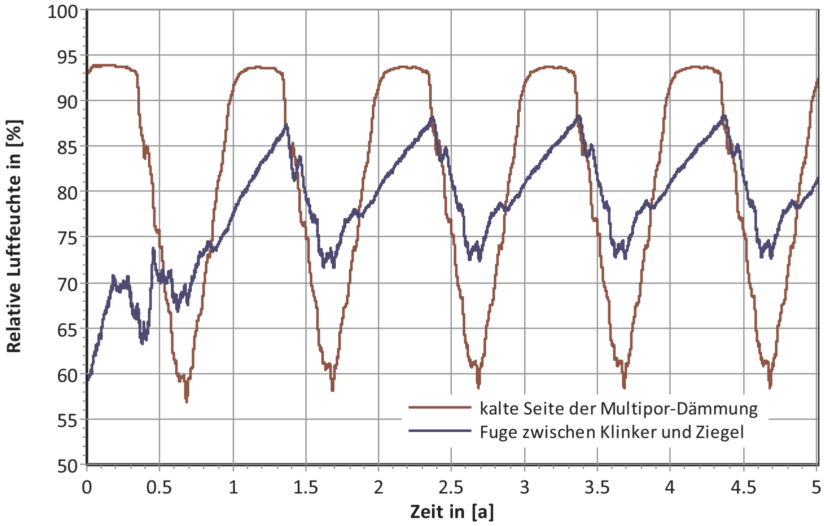

Fig. 7. Calculated course of the relative humidity at the cold side of the internal insulation

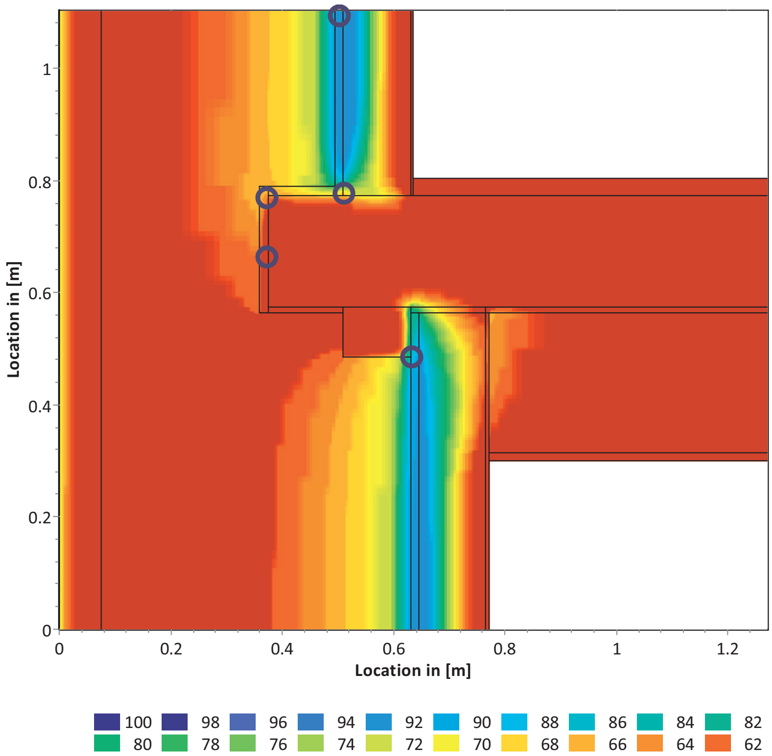

Fig. 8. RH distribution versus wooden floor-beam structure after 60 days under constant climatic conditions according to Table 2

The results show, that a quasi-stationary moisture level is reached within two years. After that, the same moisture contents are reached for every following year. The increased RH at the cold side of the insulation is normal and does not lead to problems. Here, we observe the same transport and storage behavior as already discussed for the stationary results. This principle, and particularly the drying, becomes visible here as the RH at the cold side of the insulation oscillates between 60% in summer and 94% in winter. The structure works well also under real climatic conditions.

3.2. Two-dimensional calculations

Two details were investigated according to Fig. 4 and Fig. 5. For each of them, first a calculation under constant climatic conditions was performed according to 0 for 60 days. Afterwards, the structural behavior under real climatic conditions was investigated.

Connection wall – floor beam (Fig. 4)

As result of the stationary calculations, the relative humidity after 60 days is plotted versus the structure in Fig. 8. There is no accumulation of overhygroscopic moisture inside the structure. Likewise the one-dimensional calculation results, the RH increases at the cold side of the insulation. After 60 days, it reaches about 95%. The wooden parts are not exposed to critical relative humidity. Slightly increased RH values of 86% can be noticed in the range of the wooden beam bearing. However, these are not seen critically. There is nor risk for mould and other moisture related problems to occur.

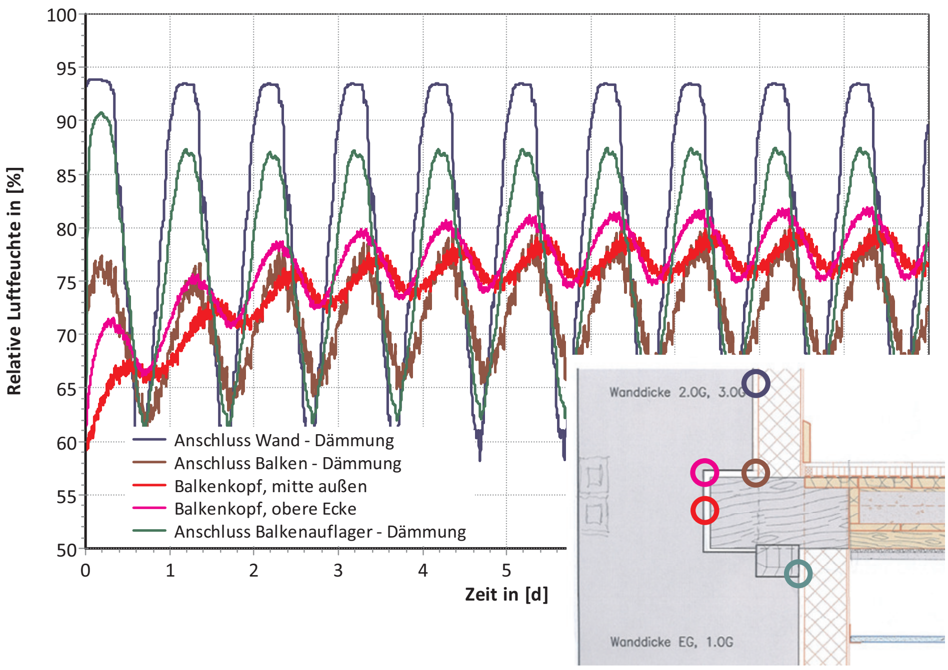

Fig. 9. Relative humidity versus 10 years of time for the wooden floor beam detail. Calculation results under real climatic conditions. The positions are indicated in the small detail in the corner

The blue circles in Fig. 8 indicate the positions for which an RH-line is plotted versus time in Fig. 9 for the calculations under real climatic conditions. For these calculations, an increased initial moisture content was assumed for the light-weight AAC insulation. The results show, that this initial moisture content dries out within the first year. The increased RH values at the connection of floor-beam and insulation which occur during the first year can not be found in the second year anymore.

The calculation results show that a quasi-stationary stage is reached after 7 to 8 years. In the range of wooden structures, the RH does not exceed values of 82%. Hence, the structure works well also under real climatic conditions. The renovation with our light-weight AAC was therefore recommended.

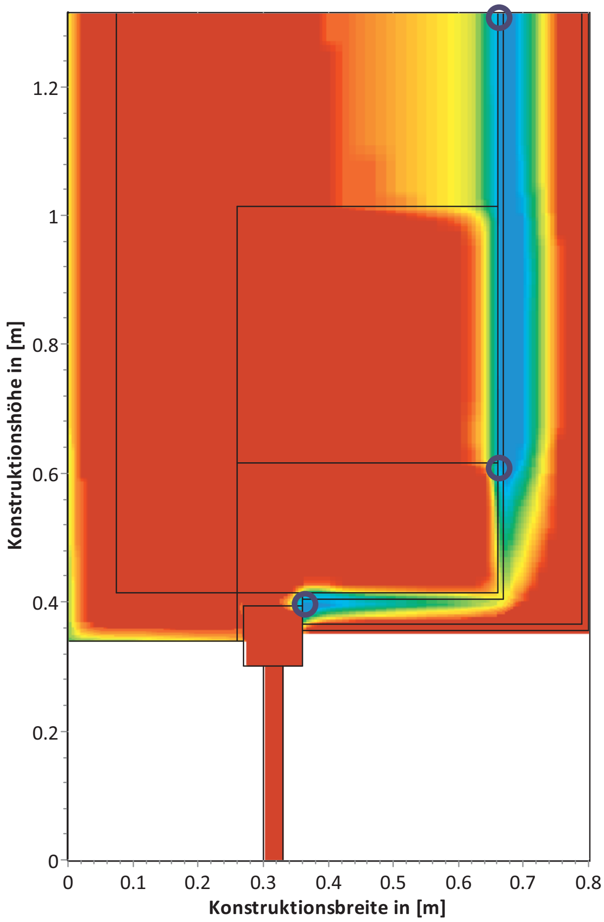

Fig. 10. RH distribution versus window detail after 60 days under constant climatic conditions according to 0.

Window connection (Fig. 5)

Fig. 10 shows the distribution of relative humidity versus structure after 60 days of calculation with constant climatic conditions. Increased RH values can be found at the cold side of the internal insulation. The maximum values reach up to 93%, in the range of the lintel up to 90%. These values are not seen critical because they are reached inside the structure, so there is no risk of mould growth. Moreover, no overhygroscopic moisture occurs and the adsorbed water can quickly dry out during the warm season.

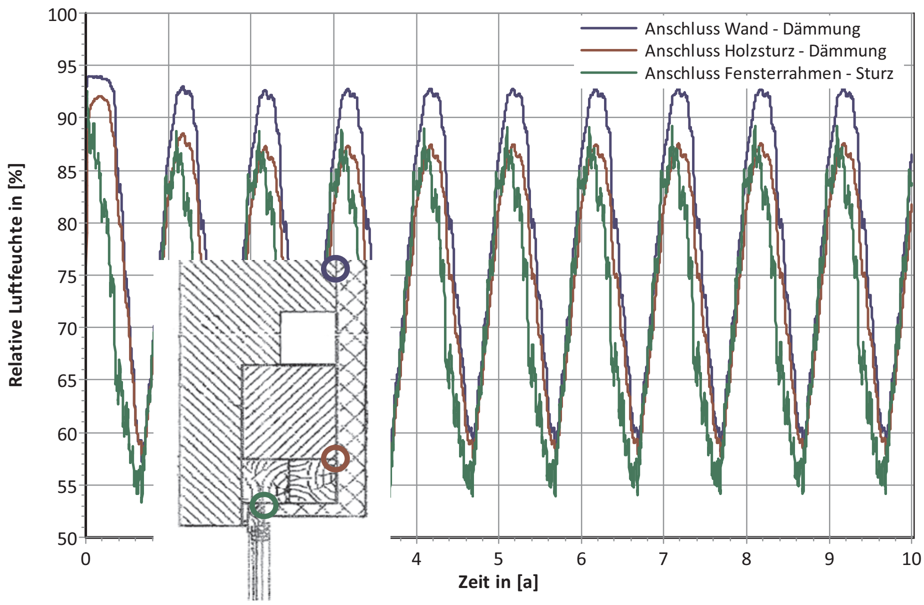

Fig. 11. Relative humidity versus 10 years of time for the window connection detail. Calculation results under real climatic conditions. The positions are indicated in the small detail

The calculation results under real climatic conditions are shown in Fig. 11 where the relative humidity is plotted versus time. The initial moisture content of the light-weight AAC insulation dries out within the first year. A quasi-stationary stage is reached within three years. An accumulation of moisture does not occur.

The RH values reached at the wooden elements during winter are below 90% and have a falling tendency over the years. Moisture problems or damage are not to be expected. Also the structural detail of the window connection is regarded as fully functional.

4. SUMMARY AND CONCLUSIONS

Energy performance upgrade of existing heritage buildings is often only possible by internal insulation. The two general systems of internal insulation were presented and discussed regarding their advantages and disadvantages. Whereas the classical system was vapor retarding, the up-to-date solution are diffusion open and capillary active systems due to their positive moisture buffer capacity and the high drying potential for the existing wall structure.

The application of such a diffusion open and capillary active insulation system made of light-weight AAC was investigated by 1D and 2D numerical heat and moisture simulation. The objective was to assess the structural moisture performance of an old school building when applying 120mm internal insulation reducing the U-value from $U_{non\text{-}insulated} = 1.11$ W/(m²K) to $U_{insulated} = 0.28$ W/(m²K)).

The 1D simulation results illustrate the working principle of our insulation system. In winter, the vapor diffusion into the structure leads to increased relative humidity at the cold side of the insulation. Overhygroscopic moisture does not occur due to the excellent moisture storage and transport properties of our material. The system proved to work also under realistic climatic conditions.

The 2D results showed that the system also works for complicated details as wooden floor beams connecting to the wall or a window connection. For the latter one, a quasi-stationary stage was reached within three years after renovation. For the wooden floor beam detail, such stages was reached within seven to eight years. In none of the calculations, critical moisture contents were observed.

It is important to notice, that the wind-driven rain protection of the structure is very important. The calculations assume an intact wind-driven rain protection of the clinker facade. The measure for that was that the structure worked also before an internal insulation was applied. It is therefore important to take into account the local climatic conditions and material properties.

One consequence of applying an internal insulation is that the drying potential of the existing wall structure is reduced. This has two reasons, one is the lower temperature of the wall during winter and the other is the added drying resistance due to the insulation material. The calculation results show that the application of a vapor open, capillary active insulation system add only little diffusion resistance to the wall and allow for a significant drying potential to the inside. Though the moisture content inside the masonry structure increases, the overall moisture level is kept below critical values. The light-weight AAC insulation material provides hence an excellent renovation solution, even for sensitive materials as wooden floor beams.

BIBLIOGRAPHY

[1] Drawings by Büro für Bauplanung K. Richter, Jägerschlösschenstraße 53, 09125 Chemnitz. Client of the renovation: City of Chemnitz.

[2] DIN 4108-03: 2001-07: Wärmeschutz und Energie-Einsparung in Gebäuden, Teil 3: Klimabedingter Feuchteschutz. Beuth-Verlag Berlin.

[3] EN 15026: 2007: Hygrothermal performance of building components and building elements – Assessment of moisture transfer by numerical simulation.

[4] ISO 13788: 2001: Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods

[5] Kreft, O., Straube, B., Schoch, T. 2011: Internal Thermal Insulation with Light Weight Autoclaved Aerated Concrete. Article submitted to the 5th International Autoclaved Aerated Concrete Conference in Bydgoszcz, September 2011, Poland.

[6] Marin C., 2007. Atlas Environment du Monde Diplomatique. La Maison écologique, Nr. 37.

[7] Morelli M., Scheffler G.A., Nielsen T.R., Svendsen S., 2010. Internal Insulation of Masonry Walls with Wooden Floor Beams in Northern Humid Climate. Buildings XI Conference, Clearwater Beach FL.

[8] Nikolai A., Fechner H., Grunewald J. Delphin – Simulation program for coupled heat, air moisture and salt transport in porous materials. Software developed at the Institute of Building Climatology at Dresden University of Technology. www.bauklimatik-dresden.de

[9] Scheffler G.A., Plagge R., 2011. Methods for moisture storage and transport property determination of autoclaved aerated concrete. Article submitted to the 5th International Autoclaved Aerated Concrete Conference in Bydgoszcz, September 2011, Poland.

[10] Scheffler G.A., 2011. Introduction of a full-range model for liquid and vapor transport properties on autoclaved aerated concrete. Article submitted to the 5th International Autoclaved Aerated Concrete Conference in Bydgoszcz, September 2011, Poland.

[11] Tommerup H., Svendsen S., 2006. Energy savings in Danish residential building stock. Energy and Buildings 38, 618-626.

[12] WTA Merkblatt 6-1-01/D: Leitfaden für hygrothermische Simulationsberechnungen. Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V., Mai 2002.

[13] WTA Merkblatt 6-2-01/D: Simulation wärme- und feuchtetechnischer Prozesse. Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V., Mai 2002.