Energetic retrofit of a historic log house on the example of a "Strickbau"

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ABSTRACT

In the project 3ENCULT "Efficient Energy for EU Cultural Heritage" both, the conservation of historic buildings and climate protection are the focus of the research presented here, which is not a contradiction in terms. Energy efficient retrofit is useful for structural protection as well as for comfort reasons. Therefore, the physical behavior of a so called "Strickbau"-construction is analyzed on site, to work out feasible technologies and strategies to improve the energy efficiency of this type of historic wooden building. Beside preservation aspects, the comfort and energy standard was improved, to bring this type of Alpine building up to the high demands of the 21 st century. The main interest lies in the fields of application and analysis of new techniques for internal insulation.

Keywords

Monitoring, Internal insulation, historic wood construction, airtightness

1. History of the wood block construction in Appenzeller Land (Switzerland)

Within Europe, there are many variations of common block construction. Due to their high demand of wood they can be found mostly in regions with large forests which spread over Sweden, Finland and the European Russia to Siberia. In the Alpine region, wood block constructions are located mainly in Upper Bavaria, Austria with South Tyrol, as well as in Switzerland. "Strickbau" is the name of a wooden block construction in some parts of Switzerland, whose wooden supports (Gwettkopf) are formed by the ends of intersecting beams. Therefore, it is a linguistic variation of widespread used wooden log houses [1].

The various names of the wood block construction mainly result from the type of the corner joint (cf. Figure 1: Overview of some regional corner connections with and without wooden supports [2]). Common terms of the corner joint are "Schroten", "Wetten", "Stricken", "Gehrsatz" or even "Loftwerk". Accordingly, the block wall is known as "Strickwand", "Gwettwand" or "Schrotwand" [2]. "Stricken" and "Wetten" are especially used in Switzerland [1].

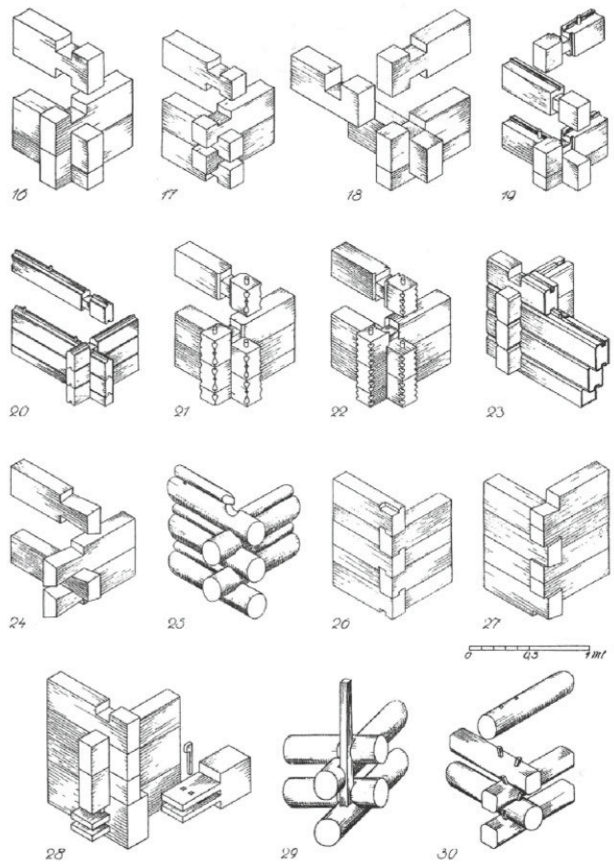

Figure 1 Overview of some regional corner connections with and without wooden supports [2].

Even within the group of Swiss log houses; there are special features which differ from canton to canton and even from region to region. Characteristic for the region of Appenzell is especially the distribution of many huge single buildings, which are often outside the village centers [3]. The Appenzeller Strickbau-technique is characterized by a sophisticated corner joint, which is marked by a dovetail-shaped combing-method with (before 18th century) or without wooden support (from 18th century).

In the 17th century, curtain grid facades of identical elements with ribbon windows, and in the parapet level integrated pulling shutters developed, so that more light could come through the window.

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Figure 2 Main facade (East) of the examined object with "Appenzeller panel"

This was necessary because of the textile production which began in the Middle Ages in the region of Appenzell, which was decentralized as a cottage industry and for which sufficient light had to be provided. Therefore the facades were designed as a paneling-casing and represent a further development of the common inside wall-casing. With the covering of the facades though, the previously exposed end grain and the wooden support of walls and corners were disguised so that the log buildings had a high durability.

The individual beams of the log walls are usually doweled to prevent position changes and the horizontal joints are filled with natural products (moo, clay, tow, etc.).

Documentation about this method of construction and detailed plans from log houses are practically non existent. The knowledge is passed down mainly by the oral tradition and by intuition, and especially by the dismantling of such buildings [3]

2. Objectives

The 3ENCULT research project is devoted to both, the preservation of historical buildings and the fulfillment of the EU climate protection goals.

In this context the energy retrofit of buildings is of high relevance, but the protection of the building and the living comfort has to be considered with the same weight. In the presented case study the physical behaviour of the so called "Strickbau" construction is analyzed. The goal is to develop appropriate technologies and methods to increase the energy efficiency for this special wood block construction.

The canton of Appenzell Ausserrhoden, followed by[3] Innerrhoden, the location of the in 3ENCULT investigated Case Study, has the highest proportion of historic residential buildings in Switzerland.

With dendrochronological investigations the oldest "Appenzeller Strick" construction is dated to 1452. For buildings that were built before 1920 [3] alone, it lists at least 8500 buildings in the canton, corresponding to a share of 33 %. Many of these buildings are classified as "Strickbau".

From the end of the 19th century, a steady decline began in inventories of the log houses. As the demand for textile products in the early 20th century decreased, the population declined sharply too,, which led to the dismantling of existing buildings in addition to the absence of new buildings [3]. The demolition of many historical log houses increased dramatically, especially in recent times, as more than 3000 buildings have been demolished since 1960 [3].

Because log construction is locally prescribed in some municipalities of Switzerland, new constructions are imitating the style, but have little in common with the original construction. So beam-and-column construction or massive type of constructions are erected and adapted only in their appearance with, for example, board panels. There are some reasons why the log construction will only carve out a niche existence in Switzerland today, due to its large consumption of wood: it is considered uneconomical, it favors strong deformation by hygro-thermal stresses and freedom of the floor plan is limited by the natural dimensions of the wood [3].

Therefore the preservation of the building stock is even more important. In the long term the preservation of historical buildings can only be assured through their continued use.

In the area of conflict between contemporary comfort and the structural characteristics of these old buildings, often inappropriate activities and interventions took place in the past which caused the irretrievable loss of many buildings.

3. Concept presentation

The examined residential building shown in Figure 2 is a two-storey Appenzeller log house. It was built in 1630 and in 1873 there were extensive renovations.

The building has a partial basement, two storeys and an attic. The ground and the first floor have approximately 45 m² of living space with a ceiling height of 1.75 m.

The aim of the investigations of this sample construction is to identify and test ways not only of improving energy efficiency according to the special requirements of conservation in existing buildings, but also ways of creating a significant improvement of the residential usability in order to increase the chances of preserving this historic kind of construction, by adjusting the conditions to modern living standards in other log constructions.

After the last tenant left, in the summer of 2011 the first investigations started. Because the log house is deconstructed at the end of the two-year study period, it was considered a unique opportunity to adapt interior insulation and find solutions and responses relating to the various issues concerning the insulation situation, thickness of insulation, requirements of steam brake or block under construction and building physical aspects. For this it was decided to conduct the inside insulation construction in a controlled way to critical limit states in order to examine the theoretical understanding for the physical behavior of buildings inside insulated wooden structures in an experimental way. Therefore an internal insulation concept that allows the detection of critical limit states in time so as not to endanger the historical construction by excessive climate stress was developed with the professionals responsible for preservation and the project partner ETH Zürich. In the context of 3ENCULT, extensive monitoring was carried out, which measured and evaluated the temperature and moisture situation under the given weather and room climate conditions in all construction areas affected by the internal insulation.

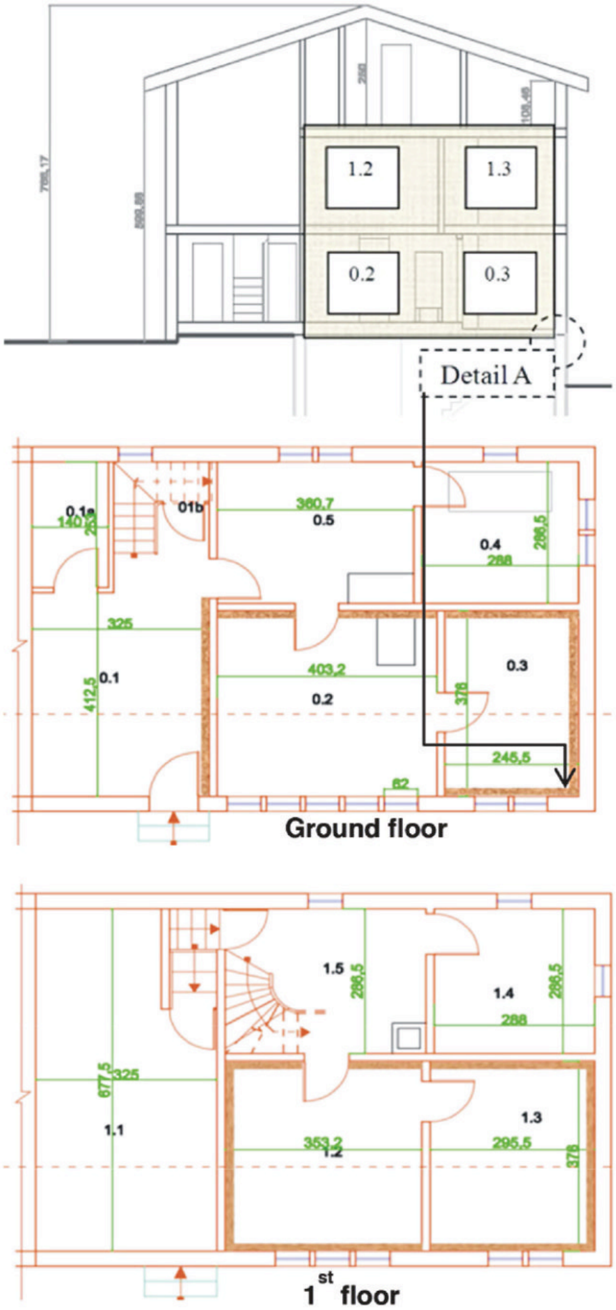


Figure 3 Building section showing the four regions of space where energetic improvement measures of walls, windows, ceilings and floors were made.

Four rooms located on the eastern window facade in the ground and the first level were included in the studies that depict an idealized building in this way. (cf. Figure 3). Due to lack of heating and opened windows, the walls to the the western and northern adjacent rooms are considered thermal loss areas, equal to the unheated attic and the basement. The walls to the east and south are described as internally insulated external components. The preservation of historical monuments and the partners of the ETH Zurich were involved in selecting type, location (indoor or outdoor), and thickness of the insulation.

The results of the studies, ongoing since 2011 and due to last, until mid-2013, will deliver an important contribution for the transfer of considerable knowledge gained from the day-to-day planning work of developing measures of energetic retrofitting of log houses in the building stock.

To simulate real usage conditions, the four subsequently insulated rooms were equipped with electrical heaters and humidifiers, to enforce critical room climate conditions during cold weather periods, as they are possible under real residential use. These cause a more or less pronounced moisture problem, for example by condensation, causing mold damage within the construction. To prevent such damage, a comprehensive monitoring system was installed accompanying the assembly of the thermal insulation, which allows the analysis of the structural behavior of the internal insulated construction under the stress of the prevailing influences of weather and climate in all rooms. In this way the artificial climate stress in this construction can be determined and evaluated.

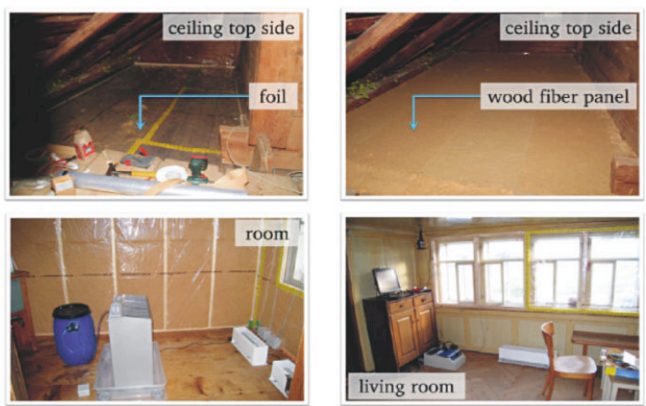
More than 200 sensors for detecting temperature and relative humidity, not only in the studied and adjacent rooms of the log house construction, but also in the section of each refurbished construction were installed, so that the near field stress of all interested and endangered construction details can be evaluated with the help of additional sensors.

Further sensors for detecting the out- and inside pressure conditions as well as the pressure condition inside the structure were used to evaluate the flow conditions, e. g. during windy weather.

3.1 Retrofitting measures

3.1.1 Internal insulation

On all external walls and walls to unheated areas, wooden claddings were built in with a distance of 40 mm from the wall. Flexible wood-fiber insulation boards with a thickness of 100 mm were installed in the compartments (cf. Figure 4: Wooden frame of squared timber (d/b = 60/40 mm), area filled with 100 mm thick wood-fiber insulation boards and fully applied steam brake slide (above). Wood dowels and compressed tape to produce the steam brake level (below). above). Subsequent to the attachment of the internal insulation a steam break was installed. All sheet joints are overlapping and sealed airtight. To incorporate the steam brake level effectively, i. e. without back flow, the joints of floor and ceiling boards were closed with custom-fit wood dowels (cf. Figure 4 below).



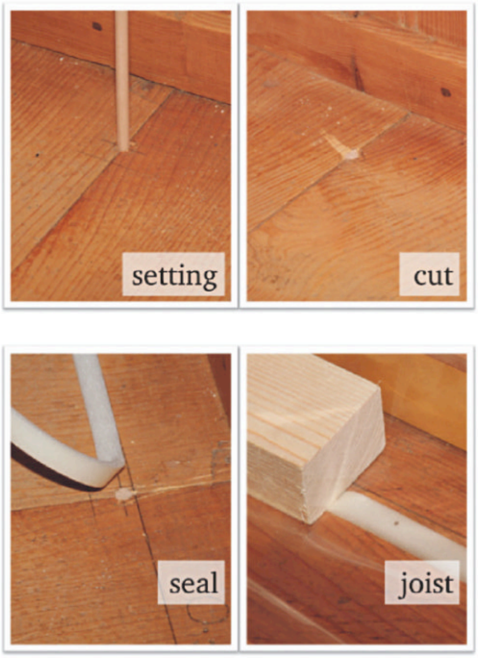


Figure 4 Wooden frame of squared timber (d/b = 60/40 mm), area filled with 100 mm thick wood-fiber insulation boards and fully applied steam brake slide (above). Wood dowels and compressed tape to produce the steam brake level (below).

To compensate for the unevenness and to avoid discontinuities, a compressed tape was pasted on the floor and the ceiling, a foil fixed above and a beam placed on this. The vertical squared timbers were cut precisely, so that the entire shell could be jammed stable without having to install a screw in the historic wooden construction.

In the attic, as well as below the ceiling of the ground floor, insulation was applied in the form of an external insulation. To establish a level of air tightness the steam brake foil at the basement and the roof was fixed full-faced between wood construction and insulation with the sheet joints bonded tightly.

3.1.2 Windows

The windows are single glazed wood frame windows and can be moved left or right overlapping. A so-called winter window exists or at least its affixing is provided for in the rooms used as lounges. This is a single glazed wood frame window, which can be attached outside using two simple turning bolts per side. Apart from a defective airtightness, the window corresponds approximately to a box-type window.

On the first floor the vapor barrier was fixed on the wooden frame level and continuously covered the windows to allow for a sufficient technical revision of these sash windows, designed as box-type windows,. On the ground floor a frame was installed on the room side of the windows, in which Plexiglas windows were inserted to simulate a thermally favorable and relatively airtight triple-glazed window situation (cf. Figure 5: Window situation in the ground level equipped with a third window level).

Figure 5 Window situation in the ground level equipped with a third window level.

4. Theoretical studies

4.1 Infrared analyses

infrared thermography was one of the analyses carried out or a weak-point test directly on the object.

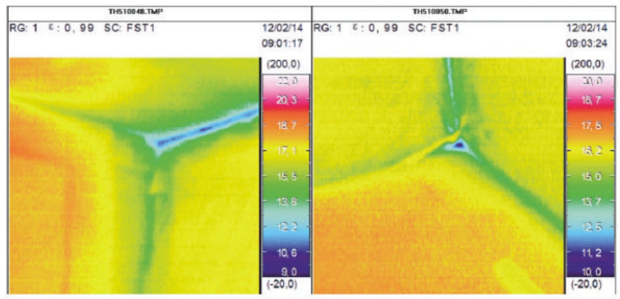


Figure 6 IR thermal imaging wall ceiling corner connection (left) and wall floor corner connector (right) with reference to the thermal bridge effects as a result of the internal insulation.

The lowest surface temperature was measured on the first floor in the lower northwest corner of the room 1.3 (approx. 9.0 °C) (cf. Figure 6 right). A similar level of temperature prevailed in the area of the thermal bridge in the upper, southwest corner of the same room (cf. Figure 6 left). The kind of installion used for the insulation was with a wood frame structure which superimposed the geometric thermal bridge with constructive thermal bridges, because of wooden beams and posts often placed in the corners or edges.

4.2 Airtightness testing

In addition to their impact on comfort (draughts), the airtightness of building envelopes plays a special role in the thermal protection because leakages cause undesired energy losses. Moreover, they can cause moisture damage in the structure by convective transport of water vapor. The airtightness was measured with the differential pressure method according to DIN EN 13289 using blower-door test. The rooms equipped with insulation and air tightness level 0.2, 0.3, 1.2 and 1.3 were examined. The rooms were considered both individually and combined floor-wise.

In a non renovated condition, air leaks around the window joints, the joints at the connection component wall and ceiling areas were located over the entire surface of the walls through knot holes and joints. Remedial maintenance could reduce the air change rate significantly between 52 % and

74 %. Only in room 0.2 was a small improvement of 17 % achieved, because no thermal improvement, and therefore no air tightness level, was applied in this room as a consequence of the historic wood paneling on the eastern wall.

4.3 Construction component behavior

4.3.1 U-Value and calculation of thermal bridges

All components of the exothermic envelope were analyzed with regard to their thermal behavior and their thermal bridges. The U-Values shown in Table 1 were calculated for each case in the original construction and refurbished state.

Table 1: Overview of the most important construction details of the analyzed log house

	Thickness [mm]	U-Value [W((m²K)]
Original state		
Exterior wall	150	0.755
Interior wall	130	0.855
Floor Ground Floor/1st Floor	65/65	1.408/1.190
Ceiling Ground Floor/1 st Floor	65/40	1.429/2.234
Doors	35	2.277
Single glazed windows	-	5.620
As before with winter windows	-	3.350
	Thickness [mm]	**U-Value [W((m²K)]**
Refurbished state		
Exterior wall	250	0.268
Interior wall	230	0.280
Floor Ground Floor/1st Fl.	165/65	0.299/1.190
Ceiling Ground Floor/1 st Fl.	65/140	1.429/0.325
Doors	35	2.277
Single glazed windows	-	5.620
As before with winter windows and PMMA-Panel	-	2.460

Moreover, all relevant geometric thermal bridges of the exothermic envelope were investigated. The consideration of the thermal bridge losses are based on the exact detection of the calculation of the linear heat transmission coefficient Ψ. The calculation of heat fluxes and surface temperatures was carried out according to DIN EN ISO 10211 in conjunction with DIN 4108-2 and DIN EN ISO 6946.

Because in the analyzed structure thermal bridges often affect each other due to their close proximity and less than the required 100 cm away from each other, all thermal bridges were considered isolated. This facilitates the assessment of the individual thermal bridges, particularly with regard to improving by energy refurbishment,.For the calculation of Ψ, necessary thermal coupling coefficient and surface temperatures were calculated using the FEM software THERM. Subtracting the U-Value and the length of the undisturbed construction element from the thermal coupling coefficient, the so-called Ψ-Value follows. The limitation of the maximum permissible error of 2.0 % is effective in part to the fineness of the generated grid. Overall, each of 17 different two-dimensional thermal bridges were mathematically analyzed and evaluated in the original as well as the refurbished state (cf. [4]).

4.3.2 Simulation of the coupled thermal-hygric construction elements behavior

To analyze the coupled heat and moisture behavior of the internal insulated construction, extensive numerical calculations were performed using the software program DELPHIN (Version 5.6.5) from TU Dresden. The indoor climate was depicted according to WTA-Sheet 6-2-01 in the form of a sinus curve, based on monthly average and expected amplitude at which a normal load of moisture was assumed. To take account of the external weather conditions, a test reference year (TRY) for the location of Appenzell was generated with the help of the software METEONORM and incorporated into the calculations.

The rainfall of 1336 l/m²a corresponds to the highest driving rain stress group III after WTA-Sheet 8-1. The exposed position of the investigated log house construction reinforces the already very high impact of rain. Accordingly weatherboards are found as a constructive rain protection already in inventory.

The geometric model of the discretized exterior construction element relating to the northeast corner is shown in Figure 7: Discretized geometry model of the northeast outer corner.

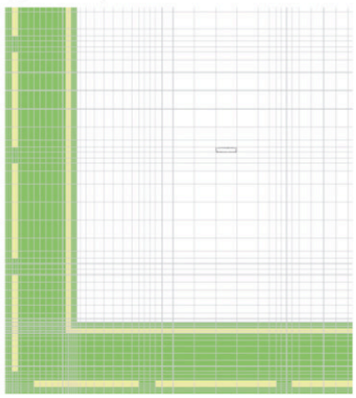


Figure 7 Discretized geometry model of the northeast outer corner.

The integral water content in the area of log wall during the year, over the entire construction cross section, is shown in Figure 8: According to [4], it could be determined generally that the calculated volumetric water content differs in the construction elements from the ground and the first floor. This was partly due to the fact, that in contrast to the ground floor, no room-side wood panels are attached. Thus, the average of water content in the ground floor is more than 4 % higher. This can be traced back to the surface temperatures of the log wall which, as a result of the additional air layer between the wood paneling and the log surface, are lower than on the 1st floor.

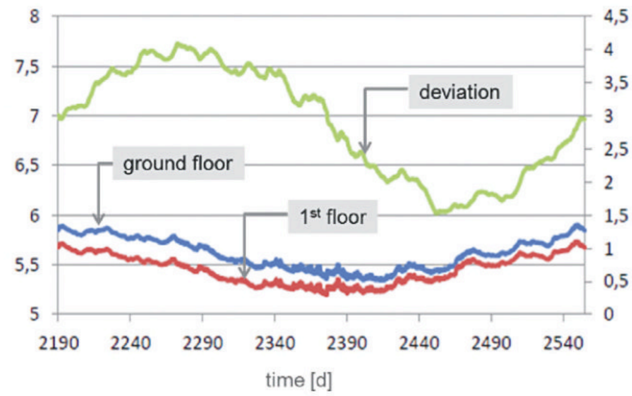


Figure 8 Comparison of the annual course of the moisture content average in the log (year 7) on the ground and 1st floor

4.4 Energy efficiency

The determination and subsequent validation of the energy demand of the investigated areas before and after the energy retrofit was done on one side with the static simulation tool PHPP (Passive House Planing Package) of the Passiv House Institut Darmstadt and simultaneously with the dynamic simulation tool IDA ICE (Indoor Climate and Energy) from EQUA. For both types of calculations the same physical properties of the construction as well as that generated with the program Meteonorm climate data were used as a basis.

In contrast to a static calculation with stationary boundary conditions, in the dynamic building simulation unsteady, i. e. more realistic, climate conditions are taken into account.

Table 2 shows the calculation results of the simulation tools. Here it is clear, that the calculation results in the original and in the refurbished state differ significantly. However, equal in both calculations is the result that with the realized measures an energy saving > 50 % can be achieved.

Table 2: Energetic evaluation with PHPP and IDA ICE.

	Original state [kWh/m²a]	Refurbished state [kWh/m²a]
PHPP	574.5	233.5
IDA ICE	337.5	111.5

5. Experimental studies

To analyze the behavior of log constructions as a result of the energetic refurbishment using internal insulation, a comprehensive monitoring concept has been implemented.

Depending on the room air conditioning and the external weather conditions, different humidity and temperature situations occur in the construction element, which can be recorded and evaluated by monitoring with a view on the exposure of the construction. (cf. Figure 9: Example of a sensor arrangement for the monitoring in the construction element (above) and the controlling system for room heating and humidification (below).).

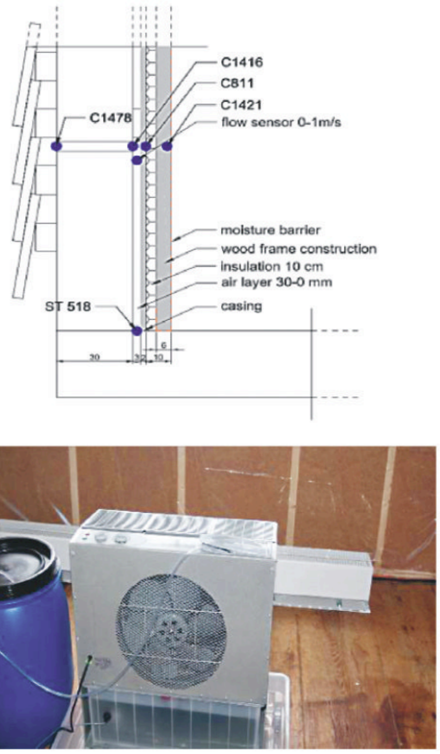


Figure 9 Example of a sensor arrangement for the monitoring in the construction element (above) and the controlling system for room heating and humidification (below).

Figure 10 shows the conditions of relative humidity inside the insulated construction during Christmas 2011 by increased room temperature (20-22 °C) and relative humidity (50-75 % RH) and the reaction in the internal insulated construction.

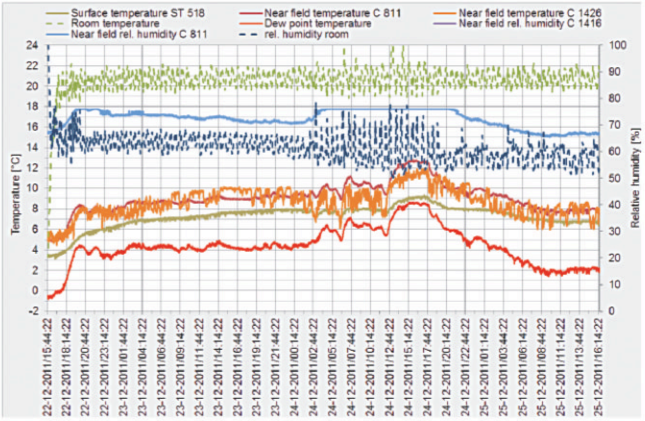


Figure 10: History of temperature and relative humidity in room 0.3 (cf. sensor position Fig. 9).

6. Conclusions

Figure 11 shows the temperature for the appropriate temperature and humidity situation in a period of a few days in the boundary layer between the insulation and the underlying wood structure.

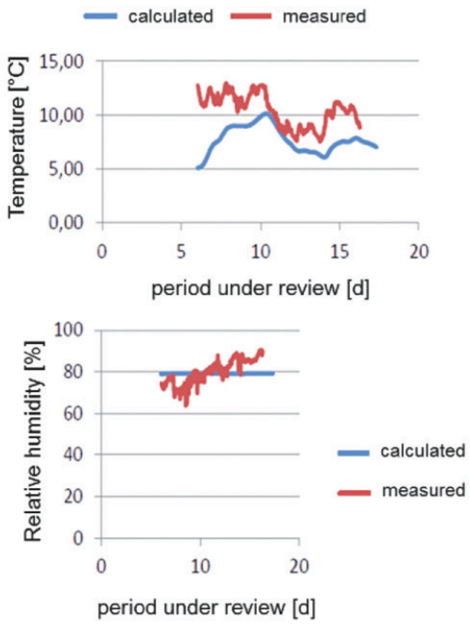


Figure 11 Comparison of calculated and measured values of temperature (above) and relative humidity (below) between internal thermal insulation and wood construction.

The comparison shows that there are varying deviations. A validation of the results will be made with the latest results of the ongoing evaluations of the measurement series in the winter period 2012/2013, when a small set of non-representative data of the previous year is available. Basically no damaging limit states were observed in the internal insulation construction.

The comparison of what was previously recognized effective on site (determined by the power consumption of the installed electric heater in a year) and the different simulation tools used to calculate energy demands, indicates that the calculated energy demand of the dynamic building simulation is more relevant to the real energy needs. (cf. Figure 12).

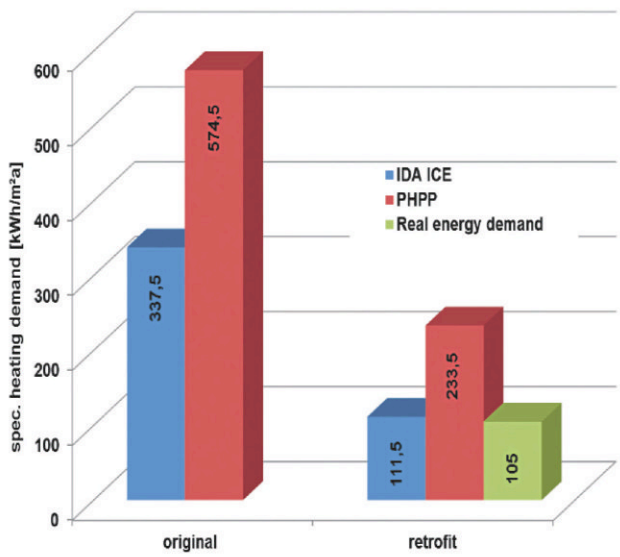


Figure 12: Comparison of the calculated and actual energy demand before and after refurbishment

However, a final evaluation of the measurements of the building's physics and biology can only be made at the end of 2013, as it requires a comprehensive evaluation of the monitoring data and a modification of the different simulation tools.

But visually no biogenic contamination of surfaces could be observed during the dismantling work of the internal insulation layers, which took place in June 2013. The results of the laboratory analyses on biogenic infestation are pending at the time of this paper.

7. Acknowledgements

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