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The Alte Schäfflerei at Benediktbeuern Monastery – Conjunction of Architectural Conservation and Energy Performance Improvement in a Historic Buildings

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Abstract. This paper gives an introduction into the research and measures of monument conservation and energy performance improvement of the Alte Schäfflerei (Old Cooperage) in the monastery of Benediktbeuern in upper Bavaria, Germany. The works started in 2010 when a contract was made between the Monastery and the Fraunhofer Gesellschaft to establish the "Fraunhofer Centre for Conservation and Energy Performance of Historic Buildings". Both, resource and energy efficiency are approaches that are in the focus of the research. Moreover, all measures should comply with monument preservation rules and respect the original substance. The calculation of the impact of different energy saving measures like the improvement of the historic windows, internal and external wall insulation, attic and floor insulation as well as the use of renewable energies from the central power station of the monastery on the overall energy demand is presented.

Keywords – Listed building, DIN V 18599, energy performance, architectural conservation

1. Introduction

1.1. Research for energy efficiency in historic buildings with priority of building preservation

The „Alte Schäfflerei" (i.e. Old Cooperage, Fig. 1) at Benediktbeuern Monastery from the second half of the 18th century belongs to the former craftsmen court of the monastery and is an ideal place for research on building conservation and energy performance. The central aspect of the Fraunhofer Centre is the close interaction of practical heritage preservation, science and monument preservation as well as the critical examination of new, innovative materials and technologies for historical buildings.
Refurbishment and energetic improvements of historic buildings often means danger of loss of original constructions and historic building substance. These so called primary documents (Fig. 2, right) can tell us about the use history of the building, the taste of a certain time or about ancient building technology. Also historic windows, decorated plaster or ancient wooden floors form fascinating aesthetic elements and they constitute heritage values, which we want to keep for future generations. Therefore it is the aim of all research and demonstration activities at the Fraunhofer Centre for Conservation and Energy Performance of Historic Buildings to explore how it is possible to preserve historical building components and at the same time improve the building in a sustainable and durable way.

Currently research is focusing on historic windows. The Alte Schäfflerei features a very diverse assortment of windows. Due to its former use as a craftsmen workshop these windows from 19th to 20th century are not very elaborate but rather simple constructions with single glazing. Nevertheless, they form the aesthetic appearance of the facades and of the interior rooms and so contribute considerably to the overall perception of the historic building. All existing windows were kept, repaired and improved energetically (for details see [5]), either with an additional plane to enhance the window to a box-type or by exchanging the single glazing with insulation glass.

Figure 1. Since 2010 the historic building of the Alte Schäfflerei functions as a place of research on building preservation and energy refurbishment measures.

In recent years also several different measures for thermal insulation of the building envelope were implemented and monitored. As one of the first measures, the floor of the northern part of the building and of the new entry hall was renewed and insulated by a 30 cm thick layer of broken foam glass that also prevents capillary transport from the ground. Recovered historic floor bricks were stored and reused in the entry hallway. The ceiling to the attic which was originally open was closed and insulated in a project supported by the German Federal Environmental Foundation DBU using 6 different insulation materials. Ecological materials like wood fiber mats, cocos fiber mats, hemp fiber mats, cellulose fiber filling and also conventional materials like mineral wool, perlite filling, are implemented and monitored. At the same time an energy efficient mechanical ventilation system was installed which recovers heat and also moisture from exhaust air.

Much effort was put in the question on how to install internal wall insulation without destroying historical evidence like plasters of painted surfaces from earlier use phases of the building (Fig.2, right). In historic houses often many layers of paint are preserved, many of them colorful and bright. Removal of the original plaster or fixing internal wall insulation onto it with glue mortar would ultimately destroy these layers from the past. In a research project funded by the German Federal Ministry for Economic Affairs and Energy BMWi different ways of reversible internal wall insulation were developed and monitored [7]. Three main solutions were further developed: (a) internal wall insulation with a layer made of a special reversible mortar and a volatile binder, (b) reversible dry-wall constructions using Japanese paper as a protection for the historic surfaces and (c) insulating glass as internal wall insulation as a window into history showing delicate decorations and earlier changes to the buildings layout [6]. Different insulation materials are built in for the internal wall insulation: renewable materials like typha board, cellulose fibre filling and reed mats; conventional materials like capillary active mineral board, mineral wool, perlite filling and bricks filled with perlite; novel high insulation materials made of aerogels of different manufacturer as plasters and boards. Overall 11 different solution are implemented and monitored.

The first research project, which was funded by the German Federal Ministry for Economic Affairs and Energy BMWi between 2008 and 2014, explored successfully possibilities for installing low temperature wall heating systems in historic buildings, an optimized radiator and the so called Temperierung heating system to avoid damages from moisture on cold walls and corners [4; 5].

Figure 2. Reversible internal wall insulation on the upper floor of the Alte Schäfflerei. The insulation glass in front of the wall presents evidence from earlier use phases of the building (right picture). Next to it on the right Aerogel plaster was applied as internal wall insulation with a reversible mortar to protect the original surface.

2. Methods

Energy improvements of existing or historic buildings can be approached in many ways. Sometimes heritage regulations will allow only certain measures and exclude others. Also questions of monetary amortisation and ecological aspects play an important role. An assessment of the different refurbishment options on the overall energetic performance of the Alte Schäfflerei is conducted according to DIN V 18599 (2018) [1] with software ZUB Helena Ultra v7.67 [2] in order to calculated the overall energetic balance of the historic building. The result of the calculation is the energy demand expressed as (1) use energy demand, (2) end energy demand and (3) primary energy demand. The energy demand includes in this study heating, airing, domestic hot water and lighting so far applicable. According to DIN V 18599 the use energy demand is the energy needed to sustain indoor air temperature >19 °C. The calculated end energy demand contains the plant losses or in other terms the efficiency of implemented technical devices of the heating system for example. The primary energy demand is calculated with a factor which relates to the type of energy source used, given in DIN V 18599, and is multiplied with the end energy demand.

2.1.1. Building model and variants

To get information on improvement of energetic performance for different refurbishment options, relative comparisons of improvements are performed. One main problem to deal with is to develop a model according to DIN V 18599 which is applicable for the different building conditions or stages of refurbishment. Since this study is based on real building conditions over the entire age of the building some simplifications and assumptions for the building construction and usage of the building have to be made. The calculation of the energetic performance enables us to estimate the hypothetic overall energy performance in former times and the energy savings due to energetic refurbishment of the building.

To compare the building before and after refurbishment it is necessary to introduce a hypothetic but realistic model of the building and a possible historic use scenario. This is implemented for the upper floor which was partly not separated with a ceiling to the attic before renovation. Since with the renovation, which started in 2010, some additional changes in the layout of building have been made, an introduction of several building zones is necessary. Therefore we first calculate a hypothetical "unrenovated" use with a one zonal model where the whole building would be heated to an indoor temperature < 17 °C. In reality during the historic period the building was used as a storage for wood and a barrel making workshop and probably was completely unheated except for a few places in the working spaces. The hypothetical "unrenovated" model is used as a baseline which shows how the building would perform in its original state compared to today use with more or less the same boundary conditions. For all other calculations we switch to a multi-zone model with several zones for calculation (see Fig. 3). In the 1950ies after a major change happened to the building layout and a new building use started with indoor temperature >19 °C. The multi zone model is retained only with minor deviation for the complete comparative study from the 1950ies building use named “past decades” to “today” and to simulate a planned future state of the building with full refurbishment of all building components called “next step”. The energy performance of these different refurbishment measures is calculated and presented for all Variants listed in table 1.

Table 1. Refurbishment Variants for energy performance calculation models to compare primary energy demand, end energy demand and use energy demand of the Alte Schäfflerei.

No.	model	Heat supply system	Building components	Additional changes
0	hypothetic “unrenovated” (1-zone)	Coal stove	Hypothetic ceiling towards attic added	
1	hypothetic „past decades“ 1950ies (multi-zone)	Oil stove	see above	
2	hypothetic “today” Var. 1 (partly renovated, fossils)	Oil stove	windows, insulated ceiling; partly: walls, ground floor,	
3	hypothetic “today” Var. 2 (renewable heat supply)	renewable	see above	
4	“today”	renewable	see above	+ mechanic ventilation
5	“next step” Var. 1	renewable	see above	+ LED lighting
6	“next step” Var. 2	renewable	all components renovated	+ blower door test

In the course of a refurbishment since the 1950ies, the ceiling of the upper floor was thermally improved and also the heat supply changed from decentralised oil stoves to central heating supplied by a local heating power plant mainly running with renewable fuels. Therefore we used a second hypothetic model “past decades” Variant 1 with partly renovation of the building components but still with decentralised oil stove heating. The impact of renewable fuel is taken into account in model “past decades” Variant 2. The primary energy factor for heating with coal or oil stove is 1.1 and is switched in “past decades” Variant 2 for local heating power plant with renewables to 0.2.

The necessary air ventilation rate for hygiene air condition is considered for every model according to the usage profile for each zone. The model “today” describes the building at the state of refurbishment as it is currently. Onwards model “today” an additional mechanical ventilation is implemented which is ventilating the main part of the upper floor with a show room (floor area 195 m², air volume 622 m³) and ensures a ventilation rate of ca. 1.8 h^{-1}. This effects only in a small lift of the energy demand because of heat recovery with recovery factor of 0.95. In future refurbishment measures it is planned initially to switch to lightning with LED (“next step” Var. 1) and later to enhance all building components energetically to the current level (“next step” Var. 2).

2.1.2. Building components, Building and HVAC

Since the Alte Schäfflerei today demonstrates different refurbishment solutions e.g. on windows restoration and improvement, internal and external wall insulation, etc., several different values on thermal performance of same building components exist. Therefore the different renovation measures for certain building components are partly simplified and implemented with summarized mean values based on real renovation measures for same building components or components with same thickness (masonry) respectively. Examples of U-values before and after renovation are given in table 2. The building has a net floor area A_{NFG} of 659.2 m², a net volume of 2187.4 m³ and a total building envelope area of 1.347.5 m² (figure 2). In total 920.1 m² (68 %) of the building envelope is thermally improved.

Table 2. Examples of U-values of building components before and after energetic renovation.

Building component	U-value bevor renovation [W/m²K]	U-value after renovation [W/m²K]	Share of improved components out of total surface area of component [%]
Masonry	1.05 (upper floor)	0.34	47
windows (average)	4.30	1,58	100
Ceiling to attic	0.98	0.18	100
Ground floor	3.43	0.12	53

With partly renovation of the building slight changes have been made in the building envelope on doors to the outside, windows and minor configuration of some rooms onwards from "past decades" variant 1. This leads to minor but neglectable changes in the energetic overall balance. According to DIN V 18599-2 a lumped sum surcharge of 0.1 W/m²K on the U-Values of whole heat transmission area is calculated due to thermal bridging since only thermal bridges of windows are currently available but not for all other thermal bridges.

Figure 3. Multi zonal model of the ground floor (left) and cross section of the Alte Schäfflerei (right) with boundary of heated space (red line).

The heating system with conventional hydronic heating radiators (upper floor, partly ground floor), floor heating (partly ground floor) and wall heating (partly ground floor) is implemented in the software corresponding to the built in situation. The energy supply of Benediktbeuern monastery is provided by a central heating power plant that creates up to 95 % of the energy renewable, mainly from wood chips, solar and water power. The energy is distributed within a local small district heating system, also connected to the Alte Schäfflerei. The ventilation concept relies on partly mechanical ventilation supplemented with window ventilation. There are two independent decentralized mechanical ventilation systems with heat recovery implemented. One mechanical ventilation for the exhibition room in the upper floor (above workshop of ground floor) and one ventilation system for the sanitary zone (ground floor). Both systems are implemented with heat recovery factor of 0.95 according to the technical specifications. In the exhibition room with 621 m³ air volume a ventilation rate of almost 1.8 h^{-1} can be maintained with mechanical ventilation.

3. Energy performance improvements through different refurbishment measures

Within the model "unrenovated" use only the energy demand for heating is calculated. From model "past decades" onwards, the energy demand for lighting is calculated and from model "past decades" variant 2 on, with changing to renewable heating, domestic hot water is included.

With renovation of the complete windows and partly the building components of the building envelope the level of air tightness improves. According to DIN V 18599 an air infiltration rate n_{inf} bevor renovation (model “past decades”) of 0.65 h^{-1} and after renovation (onwards model “past decades” Variant 1) n_{inf} of 0.39 h^{-1} is calculated. With complete renovation (“next step” Variant 2) and test of airtightness with blower door test the infiltration rate can be reduced down to n_{inf} of 0.13 h^{-1}. This leads to significant lower heat losses caused by air infiltration.

Table 3. Results of primary, end and use energy demand of the building Alte Schäfflerei.

No.	model	specific end energy [kWh/m²a]	specific primary energy [kWh/m²a]	end energy demand [MWh/a]	primary energy demand [MWh/a]
0	hypothetic “unrenovated”	525	599	186.507	209.167
1	hypothetic „past decades“	315	378	207.777	248.883
2	“past decade” Var. 1 (partly renovated)	186	243	122.331	160.228
3	“past decade” Var. 2 (renewable heat)	192	146	126.603	96.074
4	“today” (+mech. ventilation)	212	151	139.995	99.250
5	“next step” Var. 1 (+LED lighting)	205	96	134.913	63.019
6	“next step” Var. 2 (completely renovated)	148	84	97.280	55.373

The model hypothetic “unrenovated” use cannot completely be compared to the other models because of a changed zonal model with different net floor area. The starting model for comparison is the hypothetic model “past decades” with an end energy demand of ca. 208 MWh/a. The partly energetic refurbishment (with all windows renovated) decreases (model “past decades” variant 1) the end energy by 41 % to ca. 122 MWh/a. With changing the heat supply system to renewable fuel and to centralized heating the end energy demand rises slightly with model “past decades” Variant 2. In opposite the primary energy demand drops from 160 MWh/a to 96 MWh/a. Introducing the mechanical ventilation in model “today” leads to a slight increase in end and primary energy demand, see table 3. Within “next step” Variant 1 is planned to replace the lighting with LED lighting. This results in a small decrease of end energy demand but in a big drop in primary energy demand from 99 MWh/a to 63 MWh/a (36 %).

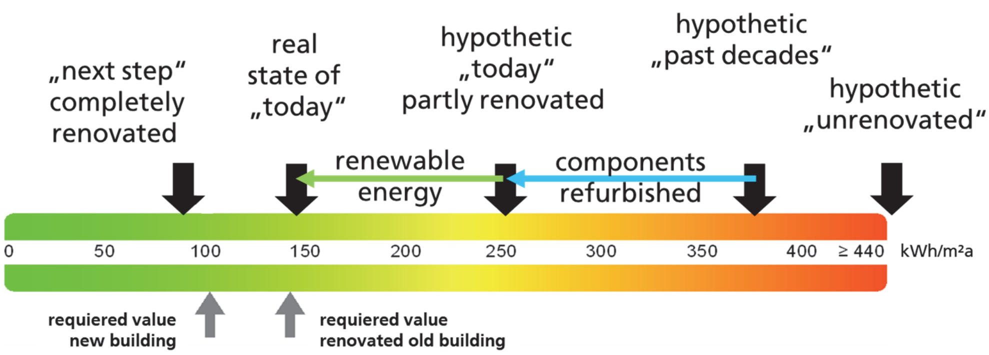

Figure 4. Energy performance certificate according to DIN V 18599 with specific primary energy demand for the calculated main refurbishment variants.

The electric energy for lighting also heats the rooms as a side effect. A decreasing electric energy demand for LED lighting results in an increase of heating energy demand but with a much lower primary energy factor for renewable fuels compared to electricity. With energetic refurbishment of all building components and additional test of air tightness of the building the end energy demand can be reduced by ca. 38 MWh/a (28 %) to 97 MWh/a. Due to the very low primary energy factor of renewable fuels the primary energy demand decreases only to 55 MWh/a. Overall drops the end energy demand of the hypothetic model "past decades" by 110.5 MWh/a. The reduction of primary energy demand is even much higher with 193.5 MWh/a. With the calculated savings of end energy the monetary savings can be calculated. Assumed energy costs of 6 Cent/kWh would result in savings of 6630 EUR/a.

Table 4. Infiltration rate and heat loss factors for the different models of the building Alte Schäfflerei.

No.	model	ACH infiltration [h^{-1}]	heat loss factor infiltration $H_{V,inf}$ [W/K]	heat loss factor transm. H_T [W/K]
0	hypothetic "unrenovated"	0.59	459	1587
1	hypothetic „past decades"	0.65	481	1610
2	"past decade" Var. 1 (partly renovated)	0.39	289	909
3	"past decade" Var. 2 (renewable heat)	0.39	289	909
4	"today" (+mech. ventilation)	0.39	289	909
5	"next step" Var. 1 (+LED lighting)	0.39	289	909
6	"next step" Var. 2 (completely renovated)	0.13	96	500

The calculated specific primary energy demand of the main variants is shown in figure 4. The specific primary energy demand of the model "unrenovated" use is due to the altered model not completely comparable to the other models. Starting with the hypothetic model "past decades" the thermally improvement of most parts of the building lowers the specific primary energy demand considerable from 378 kWh/m²a to 243 kWh/m²a ("past decades", partly renovated). Changing the heat supply to renewable fuel has also a great impact and lowers the primary energy demand further to 151 kWh/m²a to the current state "today". The "next step" will be to change lighting to LED and thermal improvement of all remaining building components. This will lead to further improvements in primary energy demand to 84 kWh/m²a which outmatch the requirements of the reference model for new buildings of DIN V 18599.

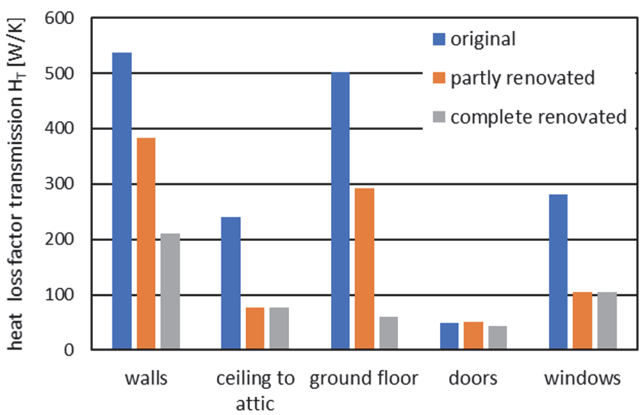

Figure 5. Comparison of heat transmission losses by building components for the models hypothetic "past decades" (original), "today" (partly renovated) and "next step" (completely renovated).

The energetic improvements are also expressed in changes in heat loss coefficient by transmission H_T for the building envelope and by air exchange caused by infiltration $H_{V,inv}$, see table 4. Additionally the calculated air change Rate per hour ACH for infiltration is registered. Within the steps of energetic refurbishment of the building components the air tightness of the envelope improves. A more detailed view of the heat transmission losses H_T is given in figure 5 for the different types of building components. Further improvements are mostly possible on walls and insulation of the ground floor as well as for the roof of the smaller northern part of the Alte Schäfflerei in a possible "next step" of the energetic refurbishment.

4. Summary and Outlook

The monitoring of energy performance of the Alte Schäfflerei as well as the calculations show that considerable energy savings can be reached with measures respecting the integrity of the existing building fabric and components like the historic windows. In the case of the Alte Schäfflerei, the improvement of building envelope and components leads to an energy reduction of approximately one third compared to similar a hypothetic use of the same unrenovated building zones, which are now partly renovated. About the same savings in terms of primary energy demand are obtained by changing the energy source from fossil energy to renewable, which shows the large potential in CO2 saving for historic buildings with this particular measure. Of the remaining ca.150 kWh/m²a again ca. 50 kWh/m²a can be deducted by changing lighting from light bulbs to LED light. All further steps for renovating the building like insulating the eastern façade and the walls of the ground floor of the main building, etc., will only lead to a minor further reduction in terms of primary energy demand because of very low primary energy factor of 0.2 which is relevant because of the renewable energy used to heat the building. But it is the end energy, which has to be provided for the building's use and which is to pay for at the end of the day. This end energy demand can be lowered further by about 28 % by a complete renovation of all so far not refurbished building components. Additionally, the complete renovation of all remaining building components will improve thermal comfort and healthiness due to higher surface temperatures of thermally refurbished building components, which help to avoid problems of mould growth which are often common in historic houses. Still, respect for the historic evidence and for heritage values will guide all further measures in the Alte Schäfflerei.

References

[1] DIN V 18599: Energetische Bewertung von Gebäuden - Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung. Beuth-Verlag 2018.

[2] ZUB System GmbH. https://www.zub-systems.de/de/produkte/helena

[3] Kilian, R.; Bichlmair, S.; Krus, M.: Evaluation of different wall heating systems in historic monuments – aspects of energy and conservation. In: Journal of Architectural Conservation 2018, Vol. 24, No. 1, p. 19-26. Taylor & Francis Group 2018.

[4] Bichlmair S.: Die Temperierung und die Erhaltung von Gebäuden in traditioneller Bauweise - Wirkung auf Raumklima und Baukonstruktion. Dissertation 2020. Technische Universität München. Fraunhofer Verlag.

[5] Bichlmair, S.; Krus, M; Kilian, R.; Merktle D.: Energetic refurbishment of the historic windows of the listed heritage building Alte Schäfflerei and its influence on the overall energy balance. SBE21 Heritage Conference 2021, Bolzano, Italy.

[6] Bichlmair, S.; Krus, M; Kilian, R.: Innendämmung mit Durchblick. Energetische Sanierung und Sichtbarkeit Historischer Oberflächen. IBP-Mitteilung 560. Fraunhofer-Institut für Bauphysik IBP. 2018.

[7] Krus, M.; Kilian, R.; Pfundstein, B.: "Comparison of Different Systems for Internal Wall Insulation with Reversible Application for Historic Buildings". Proceedings of the International Conference on Energy Efficiency and Comfort of Historic Buildings. Bruxelles 2016