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Energetic refurbishment of the historic windows of the listed heritage building Alte Schäfllerei and its influence on the overall energy balance

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Abstract. This study examines compatibility of monument conservation and modernization of historic windows of old buildings on the example of the Alte Schäfllerei (Old Cooperage) housing the Fraunhofer Centre for Conservation and Energy Performance of Historic Buildings at Benediktbeuern monastery. Several historic windows are extended to box-type windows and examined in detail. The calculation of the thermal bridges and the resulting U-values of the windows as well as the linear thermal bridge heat loss coefficients result in a reliable estimation of the thermal behaviour of the box-type windows. Via measurements of the surface temperature and heat fluxes on a box-type window the thermal resistance and heat transfer coefficient are estimated. The heat transfer coefficient is calculated in accordance to DIN 10077 with simple and detailed calculation and compared to the estimated calculation of simplified measurements. The energy efficiency of the whole building of the Old Cooperage is calculated in accordance to DIN V 18599 and shows the rate of heat losses of the windows compared to the overall energy demand of the building. For this purpose, the Old Cooperage is implemented with a hypothetical historic usage in DIN V 18599.

Keywords – Listed building, windows, thermal bridge, box-type window, DIN V 18599.

1. Introduction

The Alte Schäfllerei was built in 18th century as part of the Benedictine monastery in Benediktbeuern (south Bavaria, Germany). The building was originally used as a workshop and storage for beer barrels and later by the craftsman maintaining the monastery. In the 1950ies a major intervention was done to the windows. The window openings were enlarged. This state of the building envelope lasted unchanged until current refurbishment and transformation to the Fraunhofer Centre for Conservation and Energy Performance of Historic Buildings in the years 2010 to 2020. Within this major refurbishment most parts of the building components were improved. Energetic refurbishment measures comprise internal wall insulation in the upper floor, installation of an insulated ceiling as a closure of the upper floor to the roof, partly refurbished floor with crushed foam glass insulation and last but not least energetic retrofit of the different types of historic windows found in the building.

For examination and demonstration different solutions of energetic retrofit of the windows are implemented. Some of the windows are retrofitted only with thermally improved glazing instead of the existing single glass pane. The most implemented retrofit solution at the old Cooperage is an additional window with modern two pane glazing on the inside, in front of the existing single glazed windows. The positions of the new additional windows in relation to the existing ones are varied. The new windows are positioned partly in line with the inner wall surface or in front of the existing window in a distance of about 12 to 15 centimetre. In both solutions the reveals are still visible and not cladded with wood.

Four windows are extended to typical box-type windows with wooden cladding on the reveal between the existing and new casement windows. These box-type windows are on main focus of the investigations, see figure 1 and figure 2. The additional window F 1.25 is a double leaf casement with 2-pane glazing with U_g 1.3 W/m². The additional windows F 1.26 and F 1.27 are built almost identically with single leaf casement and 2-pane glazing with U_g 1.1 W/m².

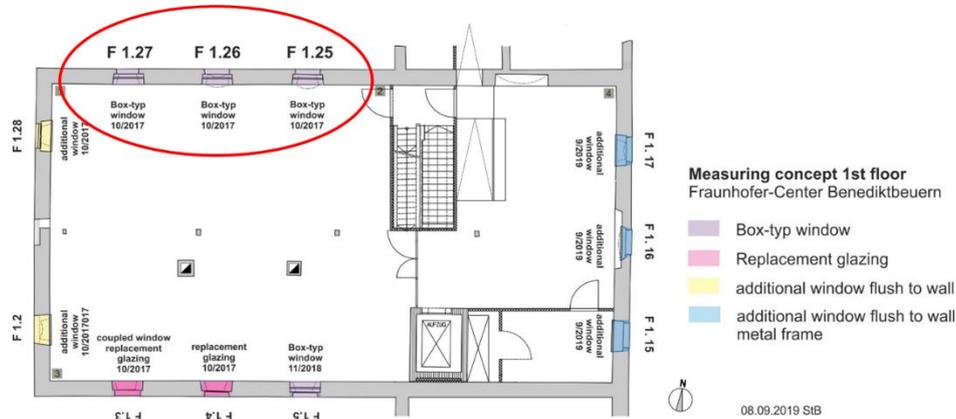


Figure 1. Ground sketch of the upper floor in the Alte Schäfflerei. The investigated box-type windows are marked with rectangles and numbered (F1.25, F1.26 and F1.27)



Figure 2. Example windows with partly different solutions of energetic renovation in the ground floor and upper floor of the Alte Schäfflerei.

2. Methods and measurement concept

Since the additional window is built with special attention to listed building regulations and to ensure an historic impression of the inside view, the framing is especially customized. This entails a very thin framing with customized fittings. The evaluation of window constructions with regard to freedom from damage (surface temperature, risk of mould, etc.) and energetic performance is carried out on the basis of known regulations [1-3] and [6], calculated with software Flixo [4]. Detailed investigations on thermal bridging, with different variants of built in situation, enables a better understanding of heat fluxes and heat transmission of typical historic constructions. With measurement of heat flux on both window levels and surface temperature on both side of the glazing (see figure 1 and 2) it is possible to

calculate the thermal resistance R at the axis of measurement, based on [7]. This simplified derived R -value is neglecting heat losses of thermal bridging of the window construction (framing) compared to hot box measurement in laboratory [9]. The related U -value of the box-type window can be calculated out of the R -value with standard boundary conditions. One of the objectives of the measurements is to evaluate the measured R respectively U -values with detailed calculation. With additional Infrared-Imaging the thermal performance will be documented.

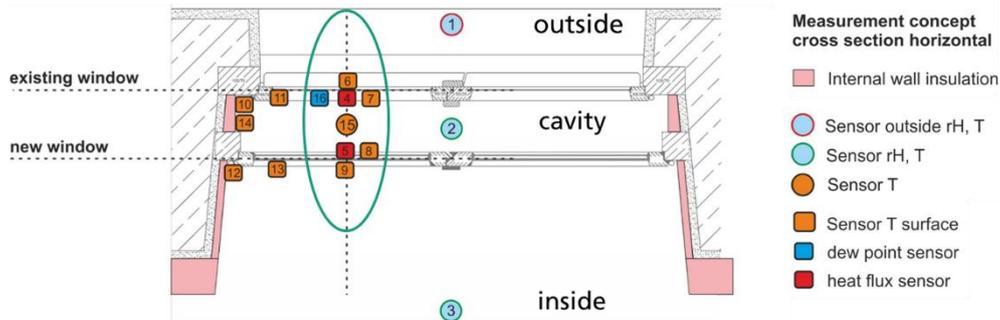


Figure 1. Measurement concept on the box-type windows on the north side of the upper floor. The sensors for measuring heat flux, air temperature in the cavity and surface temperature on the glazing are within the green oval.



Figure 2. Interior view of window F 1.27 with closed (left) and open inner window casement. A heat flow sensor can be seen in the middle of the lower right glazing.

The knowledge of the energetic performance before and after refurbishment of the windows is a necessary precondition to calculate the overall energy performance of the historic building Alte Schöfflerei due to German national code DIN V 18599 [8]. The calculation of the energetic performance of the whole building enables to estimate the energy savings due to improved window tightness which goes along with renovation of the windows. In opposition allows a focus on U -values only the calculation of heat losses of heat transmission. The energy savings due to energetic refurbishment of the windows can be calculated with examination of two variants. To compare the building before “past decades” and after refurbishment “partly renovated” it is necessary to introduce a hypothetical but realistic model of the building for a historic use of the “past decades”. This is due to the upper floor which was partly not separated to the attic with a ceiling bevor renovation.

3. Examinations and Results

3.1. Surface temperatures of inner surface of windows

The criteria of minimum surface temperatures according to [1-3] cannot be fulfilled completely with the enhanced existing windows to box-type windows. There is a risk on mould growth on framing at the sealing of the glazing to the frame with a minimum surface temperature of $11.1\text{ }^{\circ}\text{C}$ to $12.4\text{ }^{\circ}\text{C}$ instead of

the necessary minimum temperature of 12.6 °C. This is mainly due to customised very slim framing of the new windows. A major risk is between window sill and framing due to lack of thermal insulation which is a precondition for the listed building. The surface temperature in the corner between sill and frame lowers down to temperatures from 7.9 °C to 10.2 °C which is partly below dew point temperature of 9.3 °C. With thermal insulation at the sill the situation would sufficient improve the temperature level from 10.2 °C (without insulation) to temperatures above 12.6 °C without mould risk for the window F 1.26.

3.2. Heat transmission coefficient U_W

The calculated R-values are based on the measurement of heat flux and surface temperatures. The positioning of the surface temperature sensors on different window components levels enables the calculation of R-values for the new 2-pane glazing, cavity and total box-type window. The two positions of heat flux sensors on the new glazing and existing glazing show different values. The R-values calculated with heat flux sensor on the existing pane results in lower R-values of the cavity and total box-type window. This is assumed due to thermal bridging effects of the framing on the additional window which are not register by the sensor at the position on the glazing. The measured R-value of the new 2-pane glazing meet very accurate within the uncertainty the specifications of the manufacturer. R-values are calculated with the data in period from November 15, 2018 to February 15, 2019. Only periods without radiation influence are used (night hours, measured global radiation on the facade < 5 W/m²), figure 3.

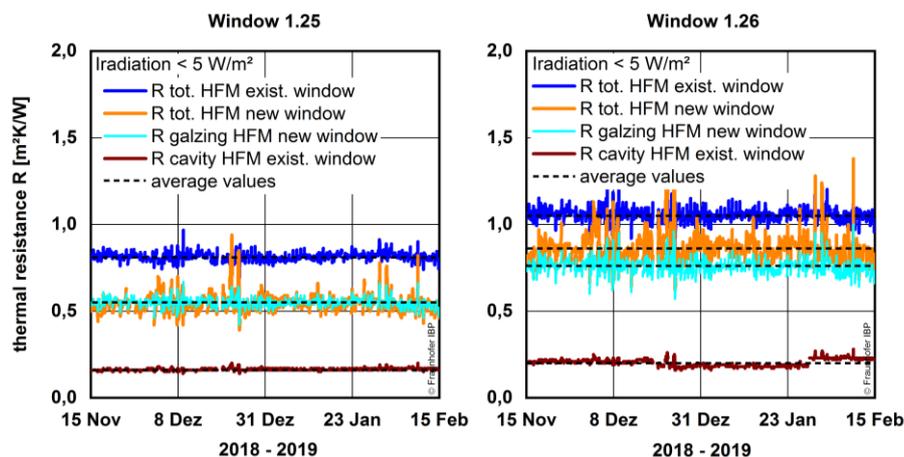


Figure 3. In situ measured thermal resistance R of the box-type window in total, new double pane glazing and cavity with different heat flux position on new and existing window for double leaf window 1.25 U_g 1.3 W/m²K (left) and for single leaf window 1.26 U_g 1.1 W/m²K (right).

To determine the thermal behaviour of the existing windows and the renovation variants carried out, the windows on the north side F 1.25, F 1.26 and F 1.27 are examined with standard boundary conditions. Since the window profiles to be investigated can only be assumed approximately according to DIN EN ISO 10077-2 [3], the resulting U_W -values are determined in the course of the thermal bridge calculation, the respective heat transfer coefficient of the window frames using the software Flixo 7, as well as the hand calculation method according to [2]. For the air layer in the space between the two window levels (cavity), a uniform thermal resistance of 0.18 m²K/W is used in the calculations. The heat transfer coefficients $U_{W,tot}$ determined for the box-type windows F 1.25, F 1.26 and F 1.27 are listed in table 1. In addition to the values calculated with the thermal bridge software, the U -values determined from the measurement of the heat flows and the U -values calculated according to DIN EN ISO 10077-1 [2] are given. The U_W values of the existing windows (outer window level) deviate slightly from each other due to the slightly different geometry of the components and window sizes. The U_g -values of the two pane glazing according to the manufacturer's specifications are also given in the table.

The U-values calculated with Flixo are slightly better for window F 1.25 with the additional double-leaf window with U_g 1.3 W/m²K than the simplified calculation according to [2]. For the other two single leaf windows with U_g 1.1 W/m²K, the more detailed calculation with the software corresponds to the simplified calculation. It is noticeable that the calculated $U_{W,tot}$ values correspond approximately to the U_g -values of the new thermal insulation glazing. The U_W -values derived from the measurements with heat flow meter on the pane of the outer (original) window result in an average U-value for window F 1.25 that lies between the calculation variants. The measurement results for windows F 1.26 and F 1.27 are slightly below the calculated values, see table 1. Calculating the U-values with results by measuring the heat flows on the inner new window pane leads to even greater deviations (not shown in table).

Table 1. U_W -values of the three box-type windows calculated with Flixo and simplified calculation according to DIN EN ISO 10077-1 as well as results of the in situ measurement $U_{W,meas}$ and U_g -values.

Heat transmission coefficient U	Window / window component	F.1.25 [W/m ² K]	F.1.26 [W/m ² K]	F.1.27 [W/m ² K]
$U_{W,e}$ (Flixo, DIN 10077)	Window outside (existing)	4,59	4,36	4,34
$U_{W,i}$ (Flixo, DIN 10077)	Window inside (new)	1,75	1,48	1,48
$U_{W,tot}$ (Flixo)	box-type window tot.	1,25	1,09	1,09
$U_{W,tot}$ (DIN 10077-1)	box-type window tot.	1,41	1,10	1,10
$U_{W,measured}$	box-type window tot.	1,34	0,94	0,95
U_g (specs. manufacturer)	double glazed pane	1,3	1,1	1,1

3.3. Thermal Bridging of built in situation

The linear thermal bridge heat losses (psi-values) over the component connections of the window to the wall are determined according to [7] for the window sill, reveal and lintel. For a comparison, the thermal bridge heat losses of the original installation situation of the existing window with and without internal wall insulation as well as the extension to a box-type window with and without internal insulation of window F 1.26 are calculated, see figure 4. The reveal and lintel are insulated but the sill is due to recommendation of Bavarian State Office for Monument Protection not insulated. The window sill is only covered with plaster. The insulation of the sill with 4 cm thick Typa [10] (λ 0.55 W/mK) would lower the psi-value for variant 4 from 0.232 W/mK to 0.004 W/mK for window 1.26.

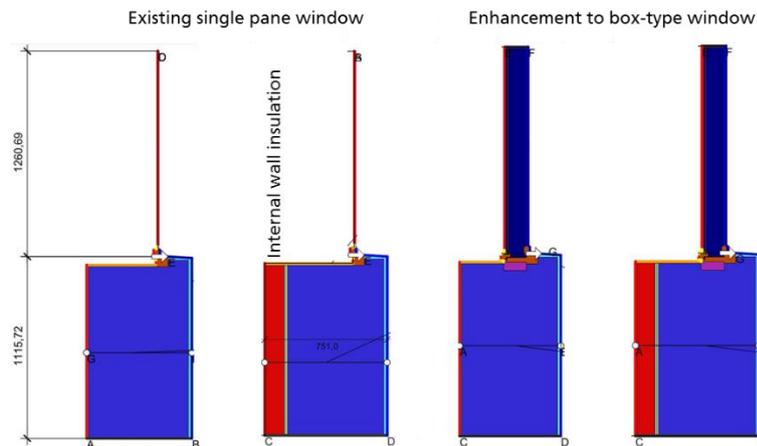


Figure 4. Cross section of the different implemented models in Flixo [4] of window F 1.26 for calculation of thermal bridge (psi-value) of the sill without thermal insulation.

The thermal bridge heat losses of the installation situation are summarised here as a thermal bridge addition ΔU_B and related to the window area and added to the $U_{W,tot}$ of the window. The result is the effective U-value $U_{W,eff}$ which takes into account the thermal bridge losses of the installation situation in relation to the window [5], see table 2.

Table 2. $U_{W,tot}$ of the window F 1.26, ΔU_B and effective U-value $U_{W,eff}$ for the original single window and with extension to a box-type window. Both cases with and without internal wall insulation.

Window F 1.26	$U_{W,tot}; U_W$ [W/m ² K]	ΔU_B [W/m ² K]	$U_{W,eff}$ [W/m ² K]
Box-type window without internal wall insulation	1,09	- 0,24	0,85
Box-type window with internal wall insulation	1,09	0,57	1,66
Existing window without internal wall insulation	4,60	4,21	8,81
Existing window with internal wall insulation	4,60	5,31	9,91

The thermal bridge surcharge ΔU_B for the installation reaches for the historic wall and original window without interior insulation ca. 4.2 W/m²K an approximately equal level as the U_W -value of the original window with ca. 4.6 W/m²K. Installing interior insulation in combination with the original window increases the thermal bridge surcharge ΔU_B to 5.3 W/m²K. This huge thermal bridging effect can be detected by IR-image on the façade, figure 5. The extension to a casement window with modern thermal insulation glass improves the thermal transmittance U_W to around 1.1 W/m²K. The thermal bridge surcharge for the installation ΔU_B becomes negative at -0.24 W/m²K without interior insulation. This reduces the effective U-value $U_{W,eff}$ of the existing window without interior insulation from 8.8 W/m²K to 0.85 W/m²K for the box-type window with two pane glazing. With the actually realised design variant as a box-type window with interior insulation, thermal bridge losses of just under 0.6 W/m²K occur and thus increase the effective U-value $U_{W,eff}$ to almost 1.7 W/m²K.

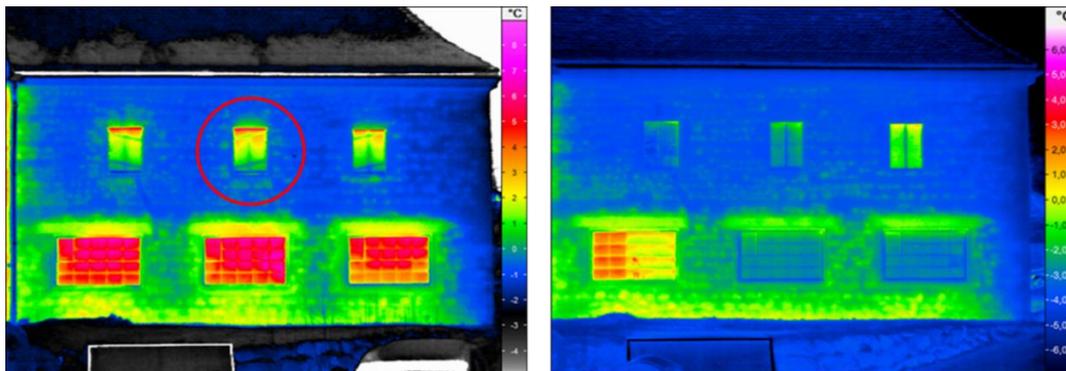


Figure 5. IR-images of the north façade of the Alte Schäfflerei with internal wall insulation in the upper floor, left IR-image with original window, right IR-image with extension to a box-type window. The additional heat fluxes caused by thermal bridging are clearly visible with elevated surface temperature around the window (left image marked with red circle on window F 1.26).

3.4. Energetic overall balance of the Alte Schäfflerei – Heat loss of windows

The calculation of the energetic overall balance is calculated according to DIN V 18599 [10] with software ZUB Helena Ultra v7.67 [11]. 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. The focus is here on the heat loss of the windows with a net area of 62.5 m², this equals to ca. 5 % of the total envelope area.

Two hypothetic models of Alte Schäfflerei are compared to get information on heat loss through windows. Bevor renovation was no separation of the upper floor to the attic. To be able to compare the usage of “past decades” a hypothetic ceiling is implemented in the model. In the course of refurbishment the ceiling in the upper floor was implemented and also the heat supply changed from decentralised oil stove to central heating supplied by a local heating plant mainly running with renewable fuels. Therefore we used a second hypothetic model “past decades, partly renovated” with partly renovation of the building components equal to the real state of refurbishment but still with decentralised oil stove heating. Since the Alte Schäfflerei demonstrates different refurbishment solutions e.g. on windows, internal and external wall insulation, etc. several different values on thermal performance of same building components exist. Therefore the different renovation measures on building components are simplified

implemented with summarized mean values based on real renovation measures. The mean heat transfer coefficient U_w of the windows before renovation is set to $4.3 \text{ W/m}^2\text{K}$ and after renovation to $1.58 \text{ W/m}^2\text{K}$ for all windows. With renovation of the windows the level of air tightness rises. Before renovation of the windows an air infiltration rate of n_{inf} of 0.65 h^{-1} and after renovation of 0.39 h^{-1} is calculated according to DIN V 18599. This leads to significant lower heat loss caused by air infiltration.

With renovation of the building slight changes have been made in the building envelope on doors to the outside, windows and configuration of some rooms. This leads to minor deviation in the energetic overall balance. For reason of comparison a surcharge of $0.1 \text{ W/m}^2\text{K}$ according to DIN V 18599-2 on thermal bridging was calculated on whole heat transmission area since only thermal bridges of windows are established. Therefore the changes in heat transmission coefficient H_T and coefficient for heat loss by ventilation H_V caused by the windows are also shown in the table 3. The end energy demand for heating includes heat transmission losses and ventilation heat losses. The share of the windows on end energy demand for heating is shown in table 4.

Table 3. Heat loss coefficient H of the windows for the two variants “past decades” and “partly renovated”.

Windows	„past decades“	„partly renovated“	Difference
Heat loss transmission coefficient H_T [W/K]	281,6	105	176,6
Heat loss ventilation coefficient H_V [W/K]	481	289	192
Heat loss coefficient $H = H_T + H_V$ [W/K]	763	394	369

Table 4. Difference of end energy demand heating of the windows for the two variants “past decades” and “partly renovated”.

End energy savings by windows	Difference end energy demand heating [kWh/a]
Difference heat transmission	15.211
Difference ventilation	18.780
Difference total end energy	34.021

The calculated specific primary energy demand with decentralized oil stove heating for both variants is shown in figure 6. Additionally marked are the savings of renovation of windows on specific primary energy demand.

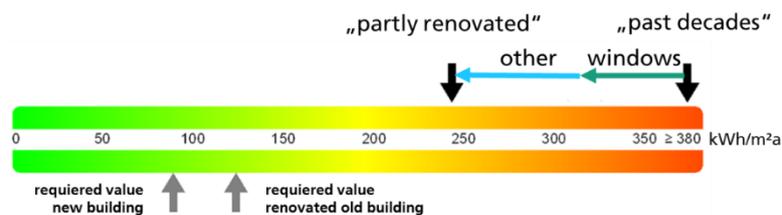


Figure 6. Energy performance certificate according to DIN V 18599 with specific primary energy demand for the two hypothetical variants and share of windows on improvement.

4. Conclusion and outlook

The customised framing of the additional windows have little disadvantage in minimal surface temperature for the examined windows due to needs of historic view. If thermal insulation on window sill, reveal and linter is possible the required surface temperatures can be almost maintained. The U -values based on measurements are depending on the position of the heat flow meter. The position on the outer window level (original window) are more reliable compared to the position on the inner window level. This is due to heat fluxes of thermal bridging on the inner window which are not captured on the heat flux meter position on the inner window level. The divergence of heat flux on the pane of the outer window level to the real overall heat flux is therefore lower. U_w -values (calculated) of the enhanced

existing window to box-type window are about the U_g -value of the new glazing for these cases. Box-type windows have a great potential for Psi-values (linear thermal transmittance) of thermal bridges nearly zero if the details are planned thoroughly and thermal insulation is possible. In opposition the existing windows show huge thermal bridging effect of the built in situation and double roughly the U_w -value of the window almost unaffected by internal wall insulation.

The potential energy savings of existing windows energetically enhanced with additional windows are sufficient. In case of the Alte Schöfflerei with improvement of U_w from 4.3 W/m²K to 1.58 W/m²K saves roughly 15.000 kWh by heat transmission per year. The savings of ventilation heat losses are even higher due to improved tightness of the building envelop which derives mainly from improvement of window tightness.

In this study the thermal performance and surface temperature are investigated. In future work the hygrothermal aspects of the cavity of the box-type windows will be investigated in more detail. Also thermal insulated glazing on the original window instead of single pane glazing will be implemented and investigated in terms of U_w -value and improvement of hygrothermal behaviour in the cavity. With additional improvement of the glazing of the original window of the already realized box type windows U-values lower than 0.85 W/m²K should be possible [12]. The Alte Schöfflerei will be completely renovated in a further step with a new heat supply with renewable fuel. This will rise the efficiency and lower the primary energy demand further considerably.

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