Stepwise refurbishment towards nZEB of a rented out flat in a historic building in Bozen/Italy

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The building, its history and use

The building located in the old town of Bozen dates from the end of 1920ies and was constructed by the Italian railway company for their workers who could buy the flats in the 1960, resulting in a multiownership (condominio with 35 units). The building is not formally listed, shows however numerous characteristics and elements worthy to be preserved.

Figure 1: view of the building from the courtyard (left) and its position at the border of the historic city centre of Bozen/Bolzano and surrounded by buildings protected as ensembles [Bozen 2006] (right)

Until 2005 the flat had barely been changed and not even joined the central heating system installed in the building in the 1960ies. In 2010 an autonomous gas heating has been added.

1st step: window refurbishment in 2017

When today's owners took over the flat in 2017, as a first step they refurbished the windows: the box-type windows with "Wolfsrachen" could be improved to reach an overall U_W of 1.05 W/m²K by repairing the distorted original wooden frame and exchanging the glazing of the inner layer with double glazing (reaming the original frame and adding a wooden batten).

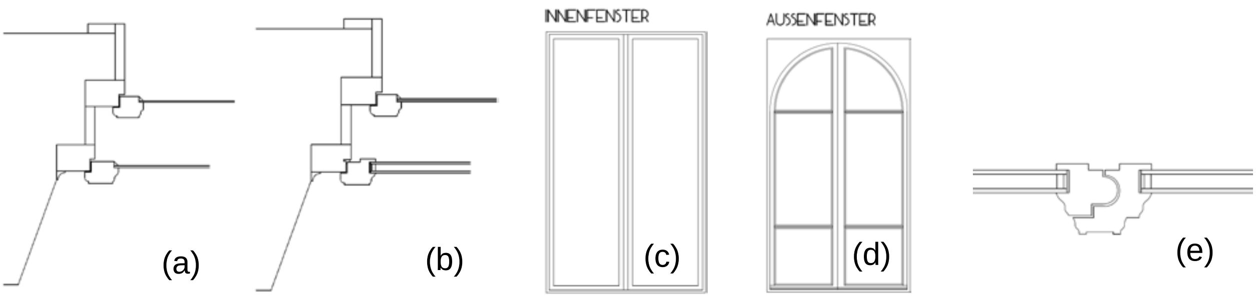

Figure 2: Section of the box type window (a) before and (b) after retrofit, (c) elevation of the inner window and (d) of the outer window, and (e) "Wolfsrachen"

An issue was the tightness to driving rain of the outer window, which could not guaranteed by the window fitter: the owners accepted a historic solution, i.e. adding a wooden batten in the box to collect the water. After five years the windows are still in perfect shape, which shows that either driving rain tightness was better than expected or the tenant had no problem at all drying the collected water with a cloth. Finally, also the wooden shutters as important element for summer comfort in Bozen Climate, have been repaired.

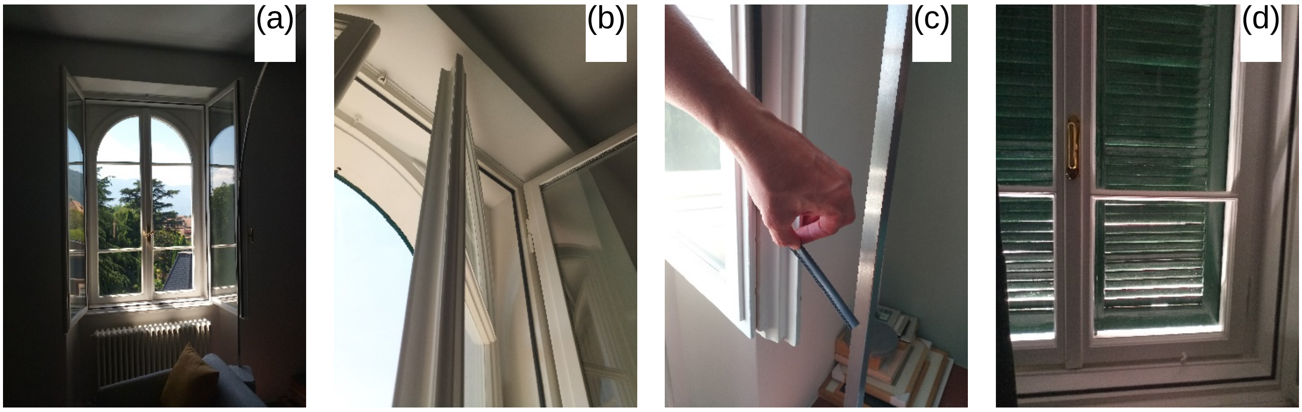

Figure 3: (a) window in the living room, (b) "Wolfsrachen", (c) sealing milled into the Wolfrachen and (d) closed shutters still letting some light in, as typical solution for summer comfort in Bozen/Bolzano

The U-values of both the original and refurbished windows were determined following EN 10077-1 for calculation U_w from U_g and U_f and combining the two window layers and EN 10077-2 for the calculation of U_f with numerical method. The energy balance is after retrofit in most cases near zero or even negative and the overall savings amount to around 750 kWh/a. The calculation is documented in [Richter 20219].

		East	South		West		TOTAL
		box	box	single	box	single	
A_w	m²	4,76	2,4	2	2,4	1,33	
A_g	m²	2,56	1,3	1,2	1,3	0,76	
$U_{w,old}$	W/m²K	2,1	2,1	4,32	2,1	4	
losses (old)	kWh/a	723	362	625	362	385	**2457**
g_{old}	-	0,76	0,76	0,87	0,76	0,87	
gains (old)	kWh/a	469	357	383	235	160	**1604**
balance (old)	**kWh/a**	**254**	**5**	**242**	**127**	**225**	**853**
$U_{w, retrofitted}$	W/m²K	1,05	1,05	1,32	1,05	1,47	
$U_{w, installed}$	W/m²K	1,25	1,25	1,88	1,25	2,51	
losses (retrofit)	kWh/a	424	212	264	212	231	**1345**
$g_{retrofitted}$	-	0,56	0,56	0,64	0,56	0,64	
gains (retrofit)	kWh/a	372	282	303	186	126	**1269**
balance (retrofit)	**kWh/a**	**52,5**	**-70**	**-39**	**26**	**105**	**76**
saving	**kWh/a**	**202**	**75**	**281**	**101**	**120**	**777**

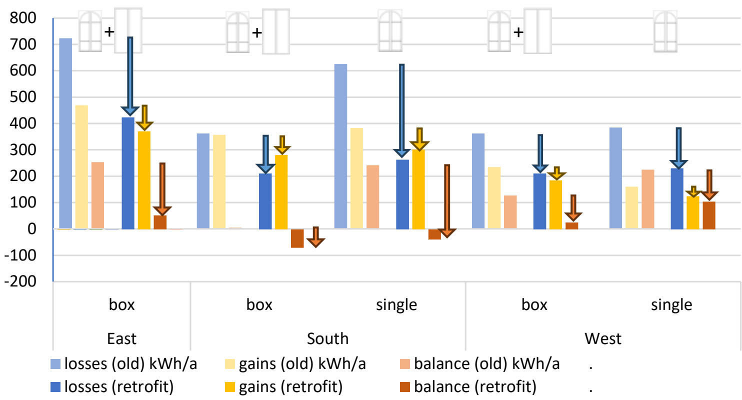

Figure 4: energy balance of old and retrofitted windows – two windows where not box-type: a South window (in the kitchen) and the west faced window in the bath room

A Blower Door test of a sample window resulted with 3,5 m³/(h m²) at 100 Pa in class 3 according EN 12207. For class 4 a value of max 3 m³/(h m²) would have been needed.

2nd step: ventilation system and insulation of walls and ceiling in 2023

Since several attempts to convince the multiownership to energetically refurbish the building as a whole were not successful, with a change of tenant the owners decided to take the chance and do the next step in energetically improving the flat: 60 cm thick full brick walls were insulated internally with 16 cm of wood fibre insulation, resulting in a U-value of 0.2 W/m²K and the ceiling towards the attic was insulated with 20 cm, with a U-value of 0.16 W/m²K. The selection of insulation material and thickness was guided by hygrothermal simulation and the decision for wood fibre was finally also due is carbon sink/storage capacity.

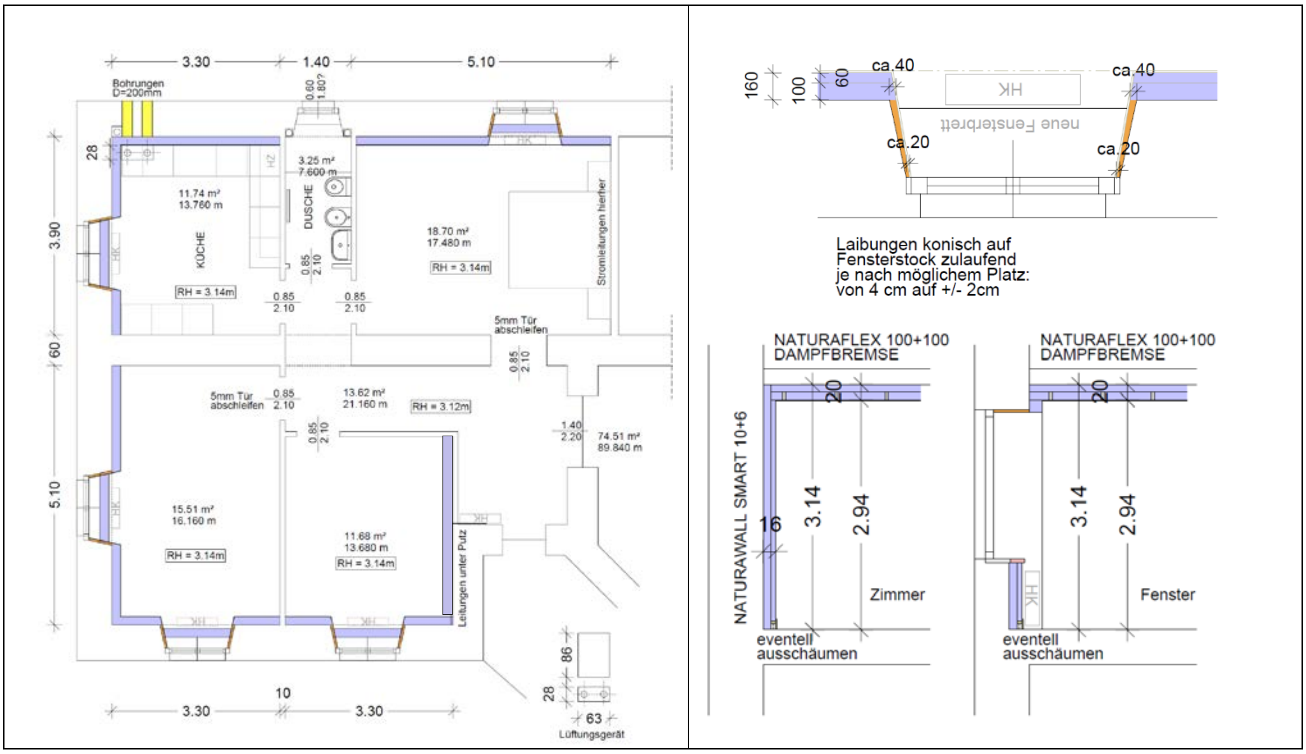

Figure 5: Floor plan and details

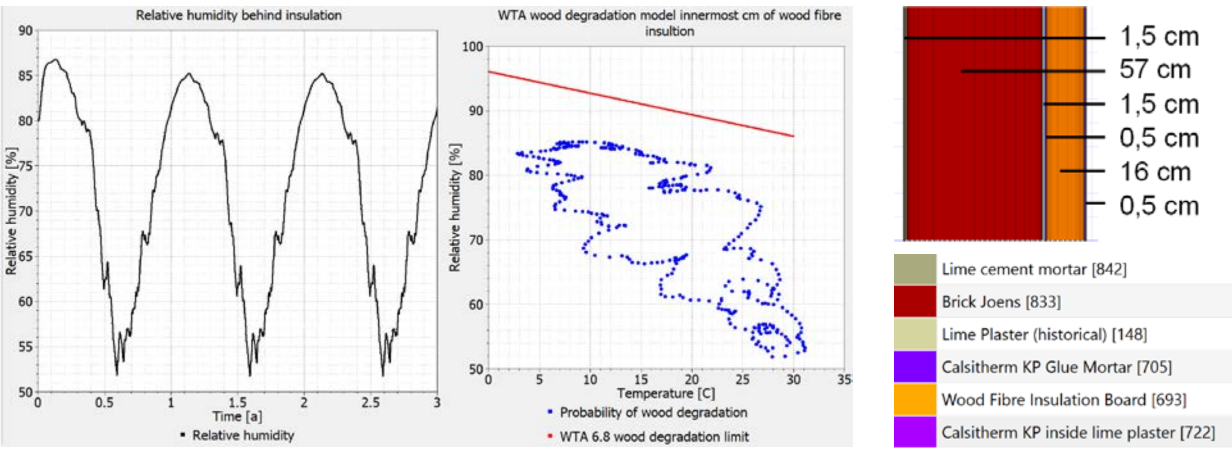

Figure 6: Hygrothermal verification of the 16 cm wood fibre insulation with delphin. Outdoor conditions Bozen, indoor conditions according EN 15026 with increased moisture load (+5%) according WTA 6.2 (the ventilation system will guarantee even less risky indoor conditions).

All thermal bridges have been calculated with [Delphin] or [Thermcalc] and are reported in Table 1. They are partly negative due to exterior surface reference. f_{Rsi} for the interior walls touching outer walls is 0,714 resp. 0,777 (minimum value in Bozen/Bolzano would be 0,587), mould risk is thus excluded. The other thermal bridges are not critical, since the flats next to it and below it are not refurbished. Most critical might be the upper corner in the flat below, but also there f_{Rsi} is still 0,72.

thermal bridges			
description	Length [m]	Ψ [W/mK]	losses [W/K]
windows	33,1	0,077	2,5
window (kitchen)	4,0	0,18	0,7
(thick) interior to outer wall	3,0	0,267	0,8
(thin) interior to outer wall	15,0	0,094	1,4
floor edge	32,0	0,160	5,1
(thick) interior to ceiling	10,0	0,180	3,6
(thin) interior to ceiling	20,0	0,100	4,0
corner	10,5	-0,270	-2,8
ceiling edge (outside)	26,1	-0,230	-6,0
ceiling edge (neighbour)	3,9	-0,010	0,04
ceiling edge (stairs and loggia)	8,0	-0,235	-1,9
bridges to staircase and loggia	3,0	0,181	0,5
bridge bathroom (window)	1,9	0,783	1,5
bridge bathroom (reveal)	0,9	1,011	0,9
Total			**6,6**

losses		
description	value	unit
windows	14,5	[W/K]
exterior walls	18,0	[W/K]
ceiling	9,1	[W/K]
to stairs and loggia	15,0	[W/K]
thermal bridges	6,6	[W/K]
ventilation	8,9	[W/K]
total conductance	**72.1**	**[W/K]**
transmission	4’519	[kWh/a]
ventilation	639	[kWh/a]
interior gains	1’485	[kWh/a]
solar gains	1’558	[kWh/a]
utilisation factor	88	[%]
total demand	**2’469**	**[kWh/a]**
total demand per m²	**29**	**[kWh/m²a]**

Table 1: thermal bridges (left) and losses as well as energy balance (right).

Additionally, the flat was equipped with a ventilation system with heat recovery (Drexel und Weiß, aerosilent bianco, 89%) – further reducing the potentially remaining risk of moisture damage potentially induced by the interior insulation. With these measures and assuming a $n_{50} \leq 1$ thanks to the refurbished windows, the expected heating demand results in 2’469 kWh/a and respectively 29 kWh/m²a corresponding to a KlimaHaus A level. The calculation with [PHPP] results with 32 kWh/m²a in a very similar value.

The about thirteen year old gas heating system was not changed as this stage, resulting in a calculated final energy demand of 3’359 kWh/a for heating (with a total efficiency for heat generation and distribution of 74%, due also to the oversizing) and 1’714 kWh/a for DHW. In terms of carbon emissions this leads to 17 kg CO_{2eq}/m²a for heating (50%), DHW (25%), illumination (11%) and auxiliary energy demand (14%).

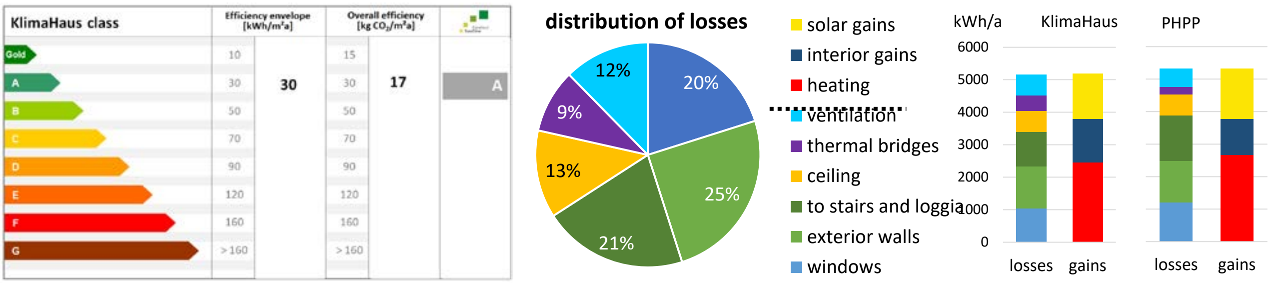

Figure 7: KlimaHaus class reched (left), distribution of losses (middle) and energy balance for both KlimaHaus and PHPP calculation (right)

To verify the calculated values the heating system was switched on for one week in January 2024 (with thermostats to reach ~16°C) and the readings on the gas meter showed a consumption of 12,65 m³ and respectively 126,5 kWh over 147 h. Weather data of the resulting days were taken from the local weather station: average T_e was 4.6°C, resulting with a T_i of 16°C in a ΔT=11,4K and 147 h in 1676 Kh. Multiplied with the 72,1 W/K from Table 1 this results in transmission losses of 120,8 kWh. Distributing the irradiation on the horizontal plane of 5,1 kWh/m² to the different orientations and multiplying this with the glazed areas and g-values results in solar gains of 25,6 kWh, which are weighted with the utilization factor of 88% and subtracted from the above losses. The heating demand of 98,3 kWh is divided by the efficiency of the heating system of 74% resulting in an expected final energy demand from calculation of 133,7 kWh – and the measured value actually being 7% below this.

PHPP allows also estimate summer comfort: without appropriate night ventilation, overheating time would rise to 22%. With night ventilation it decreases to below 1%. Assuming a climate change scenario with +1,5 K, would result in 33% overheating without night ventilation, 3,3% with cross ventilation (one window open each side) and 2% (two windows open on each side). Heating demand in winter will decrease from the 32 kWh/m^2a to 27 kWh/m^2a.

Next step: PV planned for 2024

A PV plant is in planning phase and will be installed in 2024. Since the part of the roof envisaged for the installation is in rather prominent, visible position, both geometric and colour integration are decision criteria for the modules to be chosen. It should be possible to install a total of 3.5 kWp on the roof, which will produce 4’300 kWh_{el}/a (KlimaHaus calculation, PV-GIS would result in 4’517 kWh). Considering the self-consumption of 784 kWh for lighting and auxiliary energy the KlimaHaus value for the carbon emissions decreases to 1’065 kg CO_{2eq}/a corresponding to 12 kg CO_{2eq}/m^2a and with this KlimaHaus class Gold.

On a yearly balance and considering grid feed-in, net zero emissions will nearly be reached: even if 1’200 kWh_{el} might be needed by other appliances, the fed in 2’315 kWh_{el}/a would result in 1’065 kg CO_{2eq}/a saved (with the conversion factor of 0,46 kg CO_{2eq}/kWh_{el}.

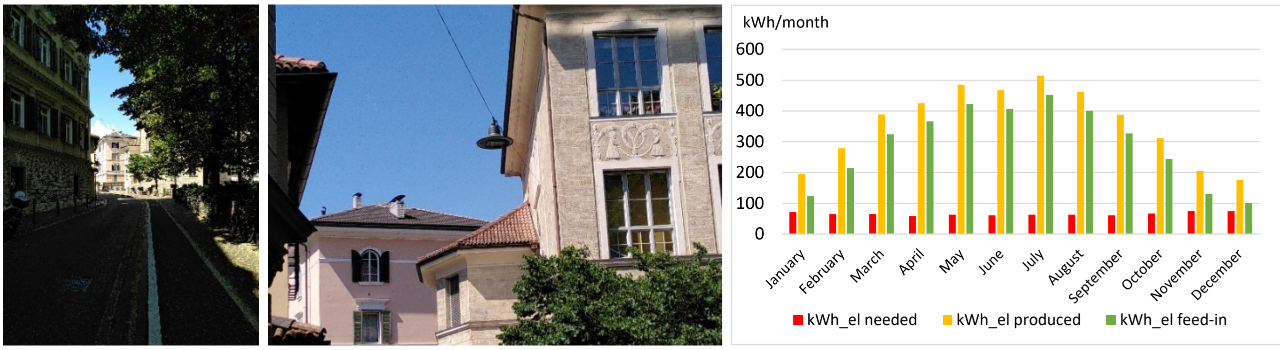

Figure 8: view of the roof from the street and envisaged PV tiles allowing to match colour and triangular shape (left and middle) and chart showing electricity and potential electricity from PV.

Final step: heating system

The last, still open step, will be to get rid of the gas boiler: chances are good to connect the building to the district heating system. This will (emission factor of the district heating 29,86 g CO_{2eq}/kWh) reduce CO_2 emissions from the 12 kg CO_{2eq}/m^2a to 1,5 kg CO_{2eq}/m^2a.

If connection to the district heating will not be possible before the end of life of the gas boiler, the installation of a heat pump will be the alternative. The calculation with KlimaHaus (e.g. Clivet SPHERA EVO 2.0/190) results in an average COP of 3.2 for heating and 3,4 for DHW and with these in an electricity demand of 1’301 kWh_{el}. KlimaHaus assumes monthly balancing of PV production and electricity needs and expects therefore a self-consumption of 1’629 kWh_{el}, 2’227 kWh_{el} to be fed into the grid and 443 kWh_{el} to be bought from the grid. These result in carbon emissions of 204 kg CO_{2eq}/a resp. 2,4 kg CO_{2eq}/m^2a.

Considerations of the owners and conclusions

The first step of refurbishing the windows was financially speaking the less interesting: the cost of 17'000,-€ divided by savings of 22'500 kWh over 30 years results in about 0,76 €/kWh$_{saved}$. Windows could however not be left as they were – and just installing new windows would not have costed so much less. With tax reduction of 65% over 10 years the net present value (calculated with interest rate of 5%) of the investment was around 8'500,- €

The second step had an overall cost of 64'800,-€ - which include all associated costs as e.g. also the carpenter taking out and reinstalling the kitchen to make space for the interior insulation, the shifting of the radiators and tubes towards the inside, security coordination of the construction works, architect, adapting cadastre values and final cleaning. With expected savings of 429'000 kWh over 30 years, this corresponds to 0,15 €/kWh$_{saved}$. With 50% tax reduction over 10 years the net present value amounts to 39'800,-€. To get this investment back over 20 resp. 30 years the rent has to be increased by 165,-€/month resp. 110,-€/month. On the other hand side, at least part of the investment can be considered anyway needed maintenance and value increase.

From the tenants point of view, gas costs go down from 130,-€/month (with the gas price of some years ago) to 28,-€/months or rather from 295,-€/month to 64,-€/month for the gas price experienced in winter 2022/23. Besides the better comfort and indoor air quality, the refurbishment thus results in much more security with regards to gas price changes: ~400,-€ overcost over a winter now compared to ~2'000,-€ before the energy retrofit.

As final remark: The reduction of net living area due to interior insulation is 4,2 m² i.e. 5%. The rooms were big enough not to suffer– and the overall amount is less than expected.

Acknowledgement

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[ThermCalc] https://www.solar-computer.de simulation with ThermCalc K13 Version 5.30.01

[KlimaHaus] Agentur für Energie Südtirol – KlimaHaus. ProCasaClima2022 Version 1.1.20

[PHPP] Passivhaus Institut, Passivhausprojektierungspaket, PHPP Version 9.7