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Comprehensive energy renovation of two Danish heritage buildings within IEA SHC Task 59

Jørgen Rose^{1,2}, Kirsten Engelund Thomsen¹

¹ Department of the Built Environment, Aalborg University, A C Meyers Vænge 15, DK-2450 Copenhagen SV, Denmark

² Corresponding author, jro@build.aau.dk

Abstract. Historic and heritage buildings present a significant challenge when it comes to reducing energy consumption to mitigate climate change. These buildings need careful renovation and increasing their energy efficiency is often associated with a high level of complexity, since consideration for heritage values can often reduce and impede possibilities and sometimes even rule out certain improvements completely. Despite these issues, many such renovation projects have already been carried out, and therefore the IEA SHC Task 59 project (Renovating Historic Buildings Towards Zero Energy) in cooperation with Interreg Alpine Space ATLAS has developed a tool for sharing these best-practice examples – the HiBERAtlas (Historical Building Energy Retrofit Atlas). The Internet platform serves as a best-practice database of both individual energy efficiency measures and whole-building renovation projects. This paper presents two of the Danish projects featured in HiBERAtlas. The first project, Ryesgade 30, is a Copenhagen apartment building with a preservation worthy period brick façade. The second project is the Osram Building, a listed Copenhagen office building from 1959 with a protected façade, which today acts as a culture centre. Both renovation projects achieved significant energy savings and consequently CO₂-emission reductions, and the indoor climate in both buildings have also improved significantly.

Keywords – Historic buildings; energy renovation; energy savings; HiBERAtlas; IEA Task 59; best-practice database; indoor climate.

1. Introduction

The European building stock accounts for approx. 40% of the total energy consumption in Europe [1]. In order to reduce this and thereby mitigate climate change, there is a need for significantly increasing the energy efficiency of the existing building stock. In this respect, historic and cultural heritage buildings are special. They need careful renovation and restoration and increasing their energy efficiency is often associated with a high level of complexity, since consideration for heritage values can often reduce and impede possibilities and sometimes even rule out certain improvements completely. Lidelöw et al did a literature review on energy efficiency measures for heritage buildings which clearly underlines this fact [2].

Despite these issues, many renovation projects related to heritage buildings have already been carried out and therefore it makes sense to promote some of the best-practice examples that can serve as inspiration for e.g. architects, building owners etc. To this end, the IEA SHC Task 59 project (Renovating Historic Buildings Towards Zero Energy) [3] and Interreg Alpine Space ATLAS [4] jointly developed a tool for sharing best-practice examples – the HiBERAtlas (Historical Building Energy Retrofit Atlas) [5]. The Internet platform can be used for sharing best-practice examples of both individual energy efficiency measures and whole-building renovation projects.

This paper presents two of the Danish projects featured in HiBERAtlas.

Ryesgade 30, a Copenhagen apartment building with a preservation worthy period brick façade which featured internal insulation of facades and external insulation of gable, new energy efficient windows, central mechanical ventilation with heat recovery, roof insulation, roof-installed photovoltaic system and establishing new attractive penthouse apartments with roof terraces overlooking Copenhagen city. Due to the building's status as worthy of preservation, the renovation could not change the appearance of the facade. However, the municipality accepted that windows were replaced with new and energy efficient replicas of the old windows. A test apartment had demonstrated that this solution was the cheapest and most energy-efficient.

The Osram Building, a listed Copenhagen office building from 1959 with a protected façade which featured insulation of the thermal envelope using alternative methods, energy saving lighting systems, solar thermal collectors, new energy efficient windows, improved use of daylighting and automatically controlled natural ventilation. Today the building acts as a culture centre. The renovation of the Osram Building was part of a strategic cooperation with a number of Danish enterprises for the purpose of mutual profiling on climate-friendly buildings and should therefore present a spearhead for possibilities and methods of renovating old industrial and commercial buildings worth preserving. In order to achieve this, high ambitions were necessary.

Both renovation projects achieved significant energy savings and consequently CO₂-emission reductions. The indoor climate in both buildings have also improved significantly; for the Osram Building natural ventilation provides fresh air and helps to avoid high indoor temperatures while new roof windows provide increased daylighting levels. In Ryesgade, the new windows and insulation of the façade have improved airtightness and thereby removed draught and risks of condensation while the new mechanical ventilation system provides fresh air.

2. Renovation projects description

2.1. Ryesgade 30

Ryesgade 30 is a very well-documented renovation case. It was part of a research-project lead by the Technical University of Denmark and the renovation won the 2013 “RENOVER-prisen”, an award given to extraordinary renovation projects. For these reasons most of the information given in this paper have already been published in papers, reports etc., however most of it in Danish [6 – 8].

Ryesgade 30 is a multi-storey apartment building located in Copenhagen Denmark. It was built in 1896 and has six floors with 32 apartments divided in three different stairwells (block A, B and C) and a total heated area of 2 760 m². On the ground floor the building has commercial premises. The building has an unheated basement and an unheated attic. Ryesgade 30 has a heritage value corresponding to Class 4 in the SAVE classification system [9], which means that the façade of the building cannot be changed (the period masonry with horizontal cornices and bands are protected). Figure 1 shows the façade of the building and figure 2 shows a horizontal cross section of the apartment layout.



Figure 1. Façade of Ryesgade 30 after renovation including new roof and penthouse apartments. Ground floor has commercial premises.

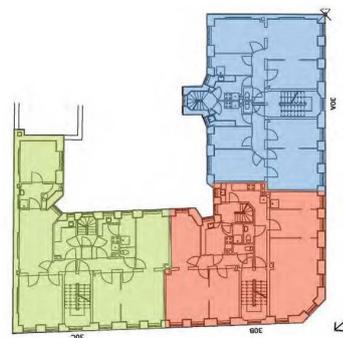


Figure 2. Horizontal cross section showing the apartment layout of the building. Blue is stairwell A, red is stairwell B and green is stairwell C.

Before the renovation exterior walls were solid brick masonry with a thickness varying from 350-710 mm (1½ - 3 bricks). Windows had one pane of glass in a wooden frame, were very energy-inefficient and also gave rise to cold draughts in the apartments. The horizontal division above the basement was uninsulated and the roof had 50 mm insulation. The building is heated by district heating and had natural ventilation through leaks in the building envelope and opening of windows.

As mentioned, the Ryesgade 30 renovation was part of a research project, and therefore several different solutions were investigated regarding possible energy improvements. All pre-renovation measurements and tests are described in detail in [7].

For the façade, internal insulation was tested in one apartment. This test involved measuring temperature and relative humidity behind the insulation and at two beam ends and measuring temperature behind insulation in window reveals. These tests showed, that internal insulation was a viable solution and suggested that 40 mm insulation could be added to the walls and 20 mm to the reveals and therefore this was chosen as the solution for the building.

For the windows four different solutions were tested; three different variations of renovating the existing windows and one solution where windows were replaced with new replicas. The conclusion was, that the new replicas had the best energy performance while also being the cheapest solution and the Municipality of Copenhagen approved this choice for the full renovation.

For the ventilation, decentral balanced mechanical ventilation with heat recovery was tested in one apartment. Unfortunately, the test gave no unequivocal answers. However, all apartments were fitted with mechanical ventilation with heat recovery, but different systems were used in each stairwell; Stairwell A: traditional central system; Stairwell B: central demand controlled system; Stairwell C: decentral system. This way the three systems could be compared through detailed measurements.

For the floor over basement 100 mm insulation was added from beneath and for the part of the masonry wall acting as fire protection (gable) 200 mm mineral wool was added to the outside. And finally, on the roof photovoltaic panels were added. The photovoltaic system is expected to produce 8 950 kWh per year, covering more or less the electricity consumption of the new ventilation systems.

In addition to the energy improvements, a series of general improvements were carried out during the renovation. New kitchens and bathrooms were installed and all facades, basement and stairwells were renovated. All installations were replaced except parts of the heating system. Four new penthouse apartments with individual roof terraces were added to the top of the building, which increased the heated floor area to 3 310 m² and significantly increased the value of the building.

The energy improvements of Ryesgade 30 are summed up in table 1.

Table 1. Energy improvements in Ryesgade 30.

Construction	U-value (W/m ² K]	
	Before	After
Brick wall (mean)	1.40	0.37
Windows	4.20	0.89
Floor over basement	1.50	0.30
Roof	0.52	0.15
System		
Ventilation	Natural	Mechanical with heat recovery
Photovoltaics	None	80 m ²

2.2. The Osram Building

The Osram Building was built in 1953 as an industrial building. It was the first prefabricated house in Copenhagen. Built as an office and warehouse for Nordisk Glødelampe Industri A/S. As a part of Neighbourhood Development Project in a former semi industrial area of Copenhagen, the City of Copenhagen initiated an energy renovation of the cultural centre “OSRAM”. The facade of the building is listed. The building was renovated in 2009.

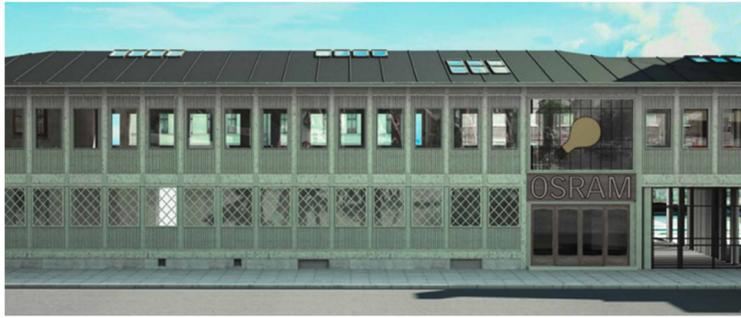


Figure 3. Façade facing the main street after renovation



Figure 4. Façade facing inside after renovation

The objectives of the renovation was:

- To energy renovate a former industrial building, now in use as Culture Centre by utilizing daylight, and combining mechanical and natural ventilation to improve the indoor climate.
- To minimise energy consumption by improving the thermal envelope and utilizing energy saving lighting.
- The target was to minimize the resources required (and the CO₂-emissions) both during construction and upkeep.

Table 2 shows the U-values before and after renovation of the Osram Building.

Construction	U-value (W/m ² K]	
	Before	After
Roof	0.20 – 0.30	0.20 – 0.30
Deck above the gate	3.90	0.09
Walls	1.65 – 3.73	0.09
Windows	2.70 – 5.90	1.20
Doors	1.00 – 5.20	1.00 – 1.50
Slab floor and basement deck	0.57 – 2.37	0.57 – 2.37

Before the renovation the roof insulation was performed with mineral granules later supplemented with batts to a total thickness of 150 mm. The center of the roof had a footbridge with extra 100 mm insulation. The deck above the gate (to the right of the entrance) 120 mm concrete and 380 mm's insulation was added on the outside.

The walls were a mix of prefabricated concrete elements, concrete columns and uninsulated brick walls and 380 mm's insulation was added on the inside. The lower part of the back façade was insulated on the outside.

The windows in the building ranged from single glass windows with different levels of sashes to standard windows with two layers of glass. The main entrance door had a single layer of glass. The two other entrance doors to the building were relatively new. All windows were replaced by low energy windows with thin frames except for the façade windows on the ground floor. Here a floor-to-ceiling glazing was added on the inside to preserve the expression of the façade. Skylights were installed in the roof.

Before renovation half of the ground floor was a deck construction facing ground. It consisted of 120 mm concrete on 120 mm cinder. The remaining part faces the partially heated basement and consisted of 200 mm reinforced concrete. No insulation was added to the slab/deck. 100 mm insulation was added to the outside of the foundation to reduce thermal bridge effects.

The original heating system was based on district heating using steam supply. The heat distribution system was a single pipe system. The new heating system is based on district heating using hot water

supply. The heat distribution system is a two pipe system and thermostat valves have been added to all radiators.

In addition to the existing windows the renovated building has an added 24 m² of roof windows, 16 roof windows of 0.66 m x 1.40 m and 12 roof windows 0.66 m x 1.18 m, to increase the amount of daylighting in the building. In the stairwell the horizontal division was removed to allow for the daylight from the roof windows to penetrate all the way to the ground floor.



Figure 5. Façade facing garden before renovation



Figure 6. Façade facing garden after renovation

The original ventilation system was a simple mechanical exhaust system where air was removed from toilets and kitchens. In the renovated building mechanical ventilation with heat recovery was installed and this was supplemented by natural ventilation via the roof windows. The natural ventilation through the roof windows is controlled by electric motors based on the indoor climate. Solar heating was added to the building to supplement the district heating using hot water supply. Furthermore, decorative LED lighting has been added to the window sills in the original façade windows of the building, making it possible to set the scene for any arrangement in the building as a cultural centre.

3. Calculated and measured energy savings

3.1. Ryesgade 30

The data given in the following was taken from [6].

For Ryesgade 30 the heat consumption before the renovation was measured as 155.5 kWh/m² per year (average for 2007-2009). This was compared to the results of an IDA ICE [10] simulation model, which predicted the consumption as 151.6 kWh/m² per year based on an indoor temperature of 20 °C.

After the renovation the consumption was measured as 83.0 kWh/m² (September 2013 to September 2014) and during the same period the photovoltaic system produced approx. 11 000 kWh, corresponding to 3.3 kWh/m² per year. The electricity production was approx. 20% higher than expected. The IDA ICE model had predicted a heat consumption of 60.6 kWh/m² per year, so the actual consumption was significantly higher than expected. Figure 7 shows results of measurements and calculations.

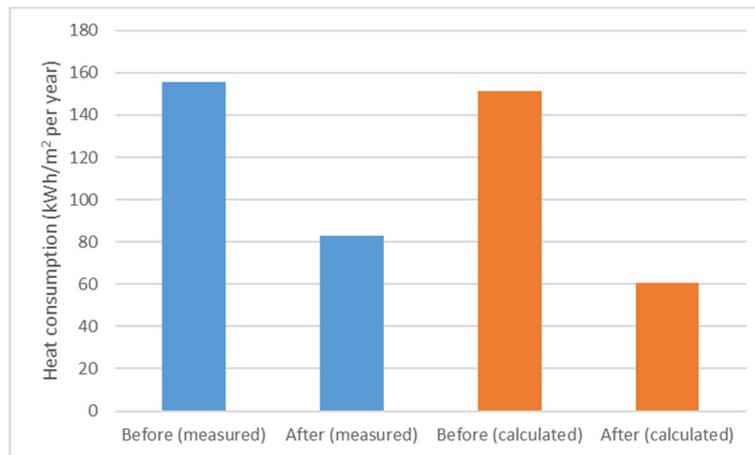


Figure 7. Measured and calculated heat consumption before and after renovation of Ryesgade 30.

One of the main reasons for not achieving the expected savings in heat consumption was the fact that the indoor temperature after the renovation was significantly higher than what is usually used in these types of calculations. The temperature was measured during the heating season of 2013-2014 in blocks A and B (20 different sensors in total) and the result showed an average indoor temperature of 22.5 °C.

If the IDA ICE calculation model is revised to take into account the actual indoor temperature, the expected heat consumption increases from 60.6 to 77.3 kWh/m² per year.

Another possible explanation for the difference between measured and calculated heat consumption is the infiltration and ventilation of the building. In the calculations it is assumed that the heat recovery rate is 85% in average and that the infiltration is very low, i.e. 0.05 l/s per m². Parametric calculations with the calculation model shows that in particular an underestimation of the infiltration rate can influence the heat consumption, and since the opening of windows and doors is part of the infiltration, this parameter is heavily dependent on user behaviour.

For Ryesgade 30 unfortunately no detailed economic data is readily available. However, in a test apartment approximate prices were calculated as: windows €4 665, ventilation system €5 900, internal insulation €6 660, consultancy, labour etc. €5 240, i.e. totalling approx. €22 465 per apartment. This does not cover the cost of external insulation of the gable, new penthouse apartments and photovoltaics.

3.2. The Osram Building

The primary energy (including the primary energy factors) was calculated as 288 kWh/m² pr. year before renovation and 153 kWh/m² pr. year after, i.e. a total reduction of 47%. The electricity consumption before renovation is 45 kWh/m² pr. year and after renovation 40 kWh/m² pr. year. The heating consumption is decreased from 158 to 37 kWh/m² pr. year and the domestic hot water from 18 to 16 kWh/m² pr. year.

The energy savings for the building is 9 500 and 181 000 kWh per year for electricity and heating respectively. The savings from the façade insulation and the windows account for 150 000 kWh per year and the rest are from the heating- and lighting systems, the controls and the solar panels.

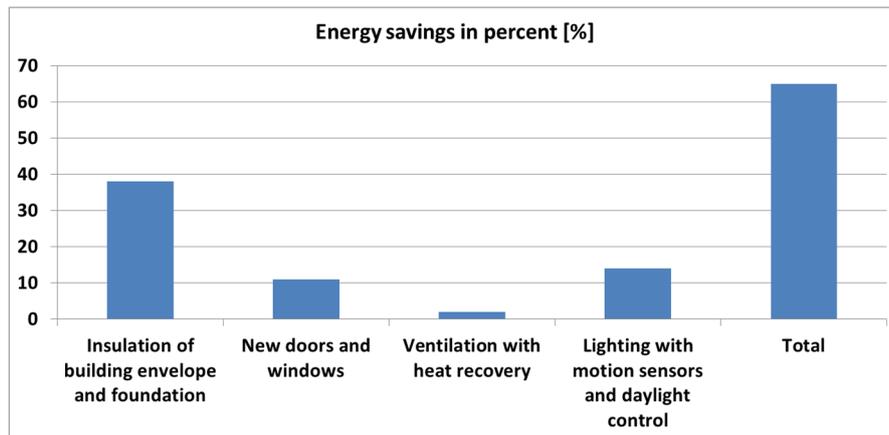


Figure 8. Energy savings in percent divided in the different parts of the renovation.

The Osram Building was renovated in 2009, so the prices etc. are from this time. The total investment for the renovation project was approximately €564 000 of which €212 000 were directly aimed at energy reductions. The expected total savings per year was €13 000, i.e. resulting in a simple payback time for the entire project of approximately 18 years. This should result in CO₂-reductions of approximately 29 tons per year.

4. Lessons learned

4.1. Ryesgade 30

The residents of Ryesgade 30 are generally very satisfied with the renovation and are in particular experiencing major comfort improvements. Areas within the apartments that previously could not be used due to cold and draughts can now be fully utilized.

Another important lesson learned from the Ryesgade 30 project – and from a number of other renovation projects – is, that individual user behavior is reflected in achieved energy savings. The Ryesgade project clearly demonstrates that there are still major challenges in getting residents in newly renovated homes to use the homes appropriately in relation to energy consumption.

Finally, it is also worth noting that the Ryesgade project is also a clear-cut example of the so-called rebound effect. Before the renovation, it is expensive to heat the apartments so residents maintain a temperature close to 20 °C on average, but after the renovation where the heat demand is significantly reduced, the indoor temperature is increased and part of the energy savings are converted to comfort.

4.2. The Osram Building

The indoor climate in the Osram Building was improved significantly by the renovation process. Daylighting levels in the building were raised by introducing roof windows that would both help raise daylight levels on the first floor and on the ground floor.

The indoor air quality has also improved significantly by the introduction of a combined mechanical and natural ventilation system. The mechanical system has heat recovery and ventilate the building during winter. When indoor temperatures or CO₂-levels in the building get too high, the automatic natural ventilation will be initiated (opening of roof windows). Furthermore, the lighting systems in the building have also been improved with motion sensors and automatic control, so that the electric lighting is dependent on daylight levels in the building.

The insulation of the building envelope along with the installation of new windows increased the thermal comfort in the building. The increase in airtightness and the removal of cold surfaces (windows and walls) have helped to remove draught and general discomfort in the building. Another important aspect of the building renovation is the improved lay-out of the building and the flexibility with which the building can now be used. The improved indoor climate has also helped to make the entire building area useable.

5. Conclusion

This paper has documented two Danish renovation projects where buildings with heritage significance have undergone major renovation. Both buildings had protected facades which restricted the possibilities of the renovations. However, both cases demonstrate that it is possible to achieve significant reductions in energy consumption and improve indoor climate in historic buildings.

For Ryesgade 30 the new photovoltaic system produces electricity that more or less covers the electricity use of the new ventilation systems, and therefore the electricity use before and after renovation are approx. the same. This case demonstrated that quite often expected reductions in heat consumption was not fulfilled. Originally calculations pointed to expected savings of approx. 56%, but it turned out that savings were a little below 50%. The main reason for this was, that residents exchanged some of the savings for improved comfort, i.e. by increasing the indoor temperature. This is also known as the rebound effect.

In the Osram Building an innovative solution was used for insulating the façade of the building where a combination of internal insulation and a floor-to-ceiling layer of glass was added. This meant that the measure is not readily visible from the outside, but the insulation of the façade is a significant improvement to particularly the indoor climate in the building, since it has removed drafts. The electricity consumption is reduced by 11%, primarily due to replacing existing lighting systems with motion sensors and daylight controls and the heat consumption is reduced by 77% as a result of an overall insulation of the thermal envelope and new windows.

The two Danish projects only had minor restrictions regarding possible renovation measures, but still demonstrate how careful planning, detailed analysis and innovative strategies can lead to very successful renovation projects where reduction of energy use and improvement of indoor climate go hand-in-hand.

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