Practical experiences with refurbishing seven apartment buildings to zero-emission level

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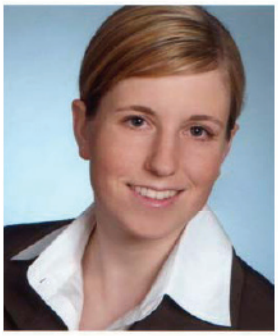

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Summary

Seven apartment dwellings have been refurbished to passive house standard with recycled and renewable materials. Additional measures have been established to reduce energy demand for heat distribution, domestic hot water, auxiliary and household electricity. With a biomass co-generation the buildings should reach a zero-emission level.
A detailed monitoring of the apartments and the installation engineering showed temperatures of about 22 °C in the apartments leading to a higher comfort level than designed. The household electricity consumption of 25.2 kWh/(m²a) fell 11 % below the designed values. The measured thermal heat consumption of 26.7 kWh/(m²a) exceeds the calculated values, originating mainly from the higher temperatures and lower internal heat gains from persons and electricity.
Experiences from the operating phase of the buildings are showing the importance of the supervision of the installation engineering to optimize the energy efficiency. In the paper different measures to improve the reliability and efficiency of installation engineering are suggested.

Keywords: retrofit, zero-emission, best practice, renewable insulation, efficient installation engineering, monitoring results

1. Introduction

Between 2008 and 2011 the ABG Frankfurt Holding (Frankfurt's largest housing company) retrofitted seven apartment dwellings built in 1956. The 61 apartments have a total reference area of approximately 3800 square metres.
The seven houses in Frankfurt, Main, Germany, are assembled in three blocks of houses with four to six storeys each. Every block of houses composes one construction stage. The apartments in the existing dwelling have 2 or 3 rooms with 50 - 65 square metres living area, the newly attached topmost storeys have 3 or 4 rooms with about 100 square metres living area.
Overall aim of the project was to reach zero-emission level for heating, domestic hot water (dhw) and auxiliary energy. Therefore additional efforts were made to reduce distribution heat losses, energy for dhw production and household electricity.
After the retrofit the dwellings reach the passive house standard. Apart from marketable certified products building insulation, including the façades, was mainly made out of renewable raw materials to reduce the cumulative energy requirements (cer). The construction elements meet the requirements of passive house standard, are designed for retrofit and for apartment dwellings with their increased requirements for fire control.
The architectural office "faktor10", Darmstadt, was responsible for design and construction management of the whole project. Structural engineering and fire protection was made by

consulting engineers “bauart Konstruktions” in Lauterbach. Both developed the façade insulations to be presented later in this paper in line with a research project for the Hessian Ministry for Environment, Energy, Agriculture and Consumer protection. Bureau Baumgartner, Mörlenbach, was responsible for installation engineering. The scientific monitoring and the energetic assessment of the project were accomplished by Institut Wohnen und Umwelt (IWU). A detailed documentation of the planning period and execution of construction can be found in [1], [2] and [3].

2. Measures

2.1 Building envelope

The buildings got an all-embracing insulation during the retrofit. It was possible to execute the basement ceiling insulation with a thickness of 26 cm under the ground floor by using cellulose insulation blown-in in the hollow space of a suspension (Fig. 1 left). The certified passive house windows were mounted in front of the existing walls and were sealed on the exterior plaster (Fig. 1 middle). From there the airtight envelope is lead over the window reveal to the inner plaster. The original roofs were dismantled and replaced by new attic floors made out of wooden light weight construction (Fig. 1 right).

Fig. 1: Hollow space of 26 cm for cellulose insulation in cellar (left), mounting of the passive house windows in front of existing wall (middle) and view of the light weight construction before closing and blowing-in the cellulose in the hollow space (40 cm)

Fig. 2: Details of the façade construction: thermally isolated sub construction with 29 cm thickness (left), horizontal separation between the floors with a fire protection panel, still without the mineral insulation plate (middle) and wood wool panels with drilled holes to blow-in the cellulose in the hollow space (right)

For exterior wall insulation a façade insulation with cellulose and a wooden construction was developed, based on the system ”lambdaplus“, modified for higher fire protection levels. Here, wallboard consoles at folded metal rails were mounted (Fig. 2 left) and anchored on the existing wall. The consoles were sloped onto the outside to reduce thermal bridge effect. A square timber at

the outer side of the console forms the underground of the following boarding of wooden planks and the wood wool panels (Fig. 2 right). Additional fleece material was put along the metal rails to form well-defined vertical hollows to blow-in the cellulose in separated sections. The windows were surrounded by OSB-panels and additional gypsum fibre panels to reinforce fire protection. An additional mineral fibre plate increases the insulation of the window frame. The separation between the floors is made with thin horizontal fire protection panels (Fig. 2 middle) and additional 5 cm thick mineral fibre insulation. The total insulation thickness is 30 cm and reaches a U-value of 0.13 $W/(m^2K)$. The construction of the façade has a total thickness of 34 cm.
Thermally separated balconies and electrically driven window shutters are completing the outside appearance of the buildings (Fig. 3).

Fig. 3: Views of two of the three construction stages

2.2 Installation engineering

To reduce ventilation heat losses controlled ventilation with heat recovery in each apartment is used (Fig. 4 left). The ducts for air distribution were placed in the bathroom and in a hollow space in the corridor.
Zero-emission or zero-energy buildings have to achieve a maximum level of efficiency in all fields of consumption. Besides the optimization of the thermal envelope a range of additional energy saving measures in heat generation, heat distribution and hot water preparation were implemented. To reduce heat losses of the distribution pipes the plumbing insulation was made 2.5 times the legally mandated thickness. Large efforts were made to reduce the energy necessary for dhw production, storage and distribution. Each block has a thermal solar system of 32 m^2 (Fig. 4 right) and two 800 litre storage basins in the cellar. To increase the solar cover ratio and to reduce heat losses for storage and dhw distribution the domestic hot water temperature is reduced to 48 °C. To ensure hygienic drinking water a chemical water treatment is installed. Additionally, water saving taps were installed in all apartments.

Fig. 4: Mechanical ventilation in the bathroom of an apartment (left), rape-seed co-generation with 11 kW_{el} and 22 kW_{th} (middle) and thermal solar system on the roof during the mounting phase (right)

Most part of the remaining thermal heat is produced with the raps-seed co-generation (about 75 %, see Fig. 4 middle). In combination with the thermal solar system more than 82 % of the remaining thermal energy are produced directly from renewable sources.
All pumps have a high efficiency level, the elevators (mounted in two of the three blocks) have a low energy design with minimized standby consumption. Furthermore all apartments were equipped with drying wardrobes, energy efficient lighting in the bathroom and the corridor and a standby switch in the living room to switch off all power consumption of the audio and video equipment.

After the retrofit a detailed monitoring of the buildings energy consumption, room temperatures and installation engineering method of operation was executed (between spring 2010 and April 2013).

3. Results

3.1 Results of the retrofit

The buildings were mainly insulated by cellulose from recycled paper in renewable wooden sub constructions which means very low cumulative energy requirements (cer) for the materials. The parts of the construction can be separated predominantly for recycling at the end of the life cycle of the house. Due to the construction concept there are no fixed temperature boundaries during the mounting of the wall insulation (e. g. freezing). Furthermore the attachment of objects at the façade is possible quite easy (e. g. light, shading). In contrast one has to account for a higher time requirement for mounting the substructure of the construction. Complex façade geometries lead to many hollows so the blow-in of the cellulose has to be done accurately to avoid individual regions without insulation. Here the quality demands are increasing. Finally the planning efforts for the construction are higher compared to an external thermal insulation composite system and the planning should be executed by qualified staff.
The 7 dwellings reach the passive house standard after the retrofit. Measurements of the air tightness of the buildings result in a mean n_{50}-value of 0.29 1/h with low scattering between the buildings, even though some of them have an elevator inside. This shows that the air tightness concept could be implemented quite well.

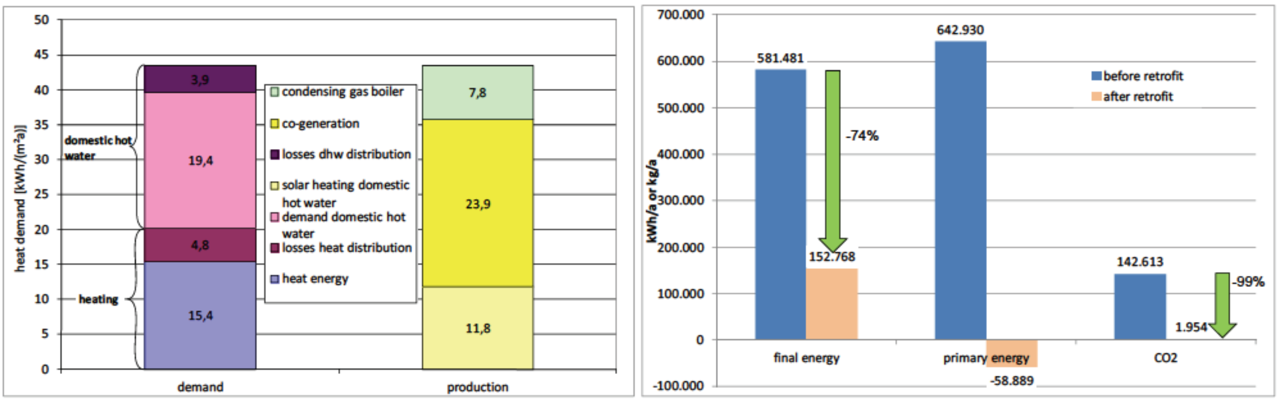

Fig. 5: Heat energy balance of the dwellings (left) and comparison before and after retrofit for final energy, primary energy and green house gas emissions (CO_2) (right)

Fig. 5 (left) shows the thermal energy balance of the buildings after retrofit. The total demand for thermal energy should reach 43.5 kWh/(m²a) including 8.7 kWh/(m²a) heat losses for storage and distribution. On the other hand the co-generation should produce 23.9 kWh/(m²a) heat (together with 11.4 kWh/(m²a) electricity). Additionally, the thermal solar system produces 11.8 kWh/(m²a) and only 7.8 kWh/(m²a) are contributed by the gas boiler.
Fig. 5 (right) compares the buildings energy and green house gases balance before (measured values) and after retrofit (demand). The final energy could be reduced by 74 % not considering the

increasing living area. As shown in the middle of the diagram the dwellings have - due to the credits from the electrical power of the co-generation supplied to the grid – a negative primary energy balance. The green house gases could be reduced by 99 % to nearly zero, so the buildings have a zero-emission level for heating, dhw and auxiliary energy.

3.2 Results of the monitoring

The mean room temperature during the heating period of the passive houses (January until March, November and December) in 2011 was 22.2°C. That means that the comfort demands / room temperatures of the tenants are quite high and clearly above the 20 °C used as standard boundary condition during the planning of the building. But high room temperatures in retrofitted apartment buildings could be found quite often. In Fig. 6 (left) the mean room temperatures during the heating period of the three construction stages of this project and six comparable retrofit projects in apartment blocks is plotted against the measured heat consumption for heating. The measured values are in the upper range but not unusually high. There is no evidence that including the costs for heating in the apartment rent (like in Rotlintstraße) increases the room temperatures significantly.

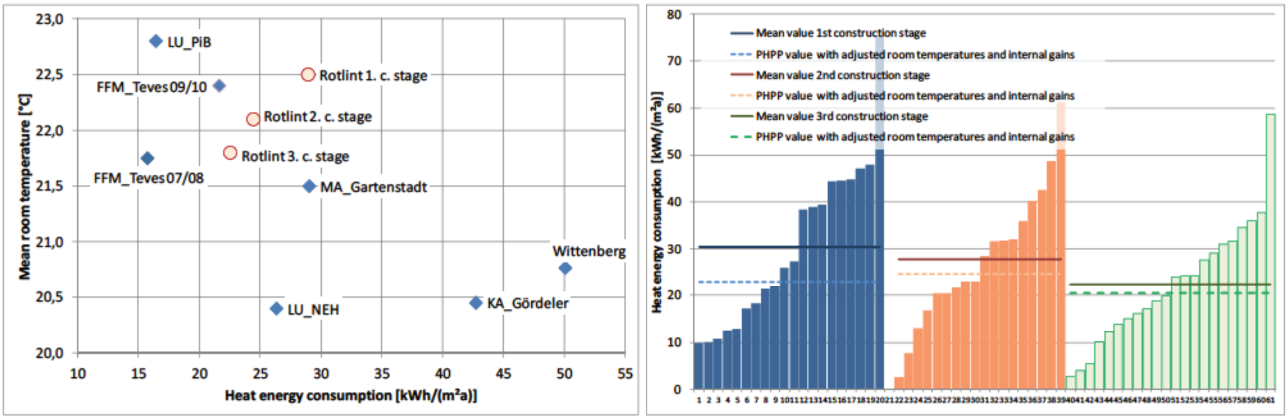

Fig. 6: Left: mean room temperature vs. heat energy consumption of seven retrofitted apartment buildings [5]-[9] (FFM_Teves with results of two different years) - results of the project at Rotlintstraße are plotted as circles; right: measured heat energy consumption of the three blocks at Rotlintstraße, ordered increasingly

The measured thermal heat consumption of the apartments is shown in Fig. 6 (right). The mean value for all apartments is 26.7 kWh/(m²a) (slightly different for the different construction stages), the calculated value was 15.4 kWh/(m²a). Taking into account the higher room temperatures and the lower internal heat sources form persons (actual occupancy of people is 40,5 m²/Person) the thermal heat demand of the second construction stage (the most disadvantageous block referring to orientation) increases from 17.5 kWh/(m²a) to 24.6 kWh/(m²a) – the measured value in 2012 was 27.8 kWh/(m²a). Accordingly the over-consumption is mainly caused by the high room temperatures and the lower internal heat gains. But further influences have been detected:

- High room temperatures
- Lower internal heat gains from persons due to people density and lower electricity consumption
- Late switching from summer by-pass to winter heat recovery of the ventilation system (partly not until January!)
- Partly summer service of the heating due to manual mode of heating control
- Usage of window shutters during daytime in winter, which reduces solar heat gains
- In some apartments increased window ventilation in the bathroom

In 2012 the household electricity consumption reached 25.2 kWh/(m²a), which is 11 % under the calculated value of 28.2 kWh/(m²a) and clearly under the measured value in other energy efficient projects, which are reaching 30 kWh/(m²a) to 33 kWh/(m²a) [4]. That result shows that a reduction in household electricity is possible when implementing efficiency measures.

3.3 Results of the operation

The installation engineering of the buildings was quite complex to control and to maintain due to one co-generation, one condensing gas boiler, three thermal solar systems and a (small) district heating between all blocks. In two of three construction stages the solar pumps failed and had to be replaced. Without the detailed monitoring the problem probably wouldn't have been detected for months. In 2011 the solar system in the block without problems reached a solar cover ratio of 55 % which is near the 61 % solar cover ratio planed in advance. Additionally, return valves had been detected which where missing or not operating in correct order causing misoperation between co-generation and boiler. These examples show the importance of a monitoring phase after initial operation of complex installation engineering.
The co-generation appeared to produce soot after four months of continuous operation, polluting the balcony of one apartment. After a longer time of research for relief a filter system for a fork truck was installed for the separation of the soot. That co-generation is essential for the on-site production of electricity and hence for the credits for zero-emission level. Since December 2012 it is operating again and now the dwellings could reach zero-emission level.
As mentioned above, the company responsible for maintaining the ventilation system and switching from summer by-pass to winter heat recovery didn't keep the appointed date for maintenance. Additionally some tenants couldn't be reached so their ventilation system couldn't use heat recovery during winter time. That increased thermal heat consumption by about 14 % or 3 kWh/(m²a). The implication is to have less sensitive systems (e.g. temperature dependant automatic switching) for future projects.

4. Discussion, conclusions

It was possible to insulate nearly the whole opaque building envelope of the seven apartment dwellings with recycled and renewable materials. This leads to low cumulative energy requirements (cer) and could be an alternative to external thermal insulation composite systems out of non degradable materials. The consequences are higher costs of about 141 €/m² area of component and higher planning and quality ensuring efforts.
The measured room temperatures are about 2 K higher than standard boundary conditions, which can be seen also in other retrofitted apartment dwellings. In consequence we would suggest for planning zero-energy or zero-emission buildings to take this circumstance into account and calculate the energy balance with the increased but realistic higher room temperature of 22 °C to reach zero-energy in reality. Maybe the approach for single family houses could be slightly lower.

The heat energy consumption is higher than calculated with standard boundary conditions, but most parts of the excess consumption are used by the tenants for increasing comfort and living space. The reduction of these remaining kilowatt hours describes the need for interventions to motivate tenants to optimize their user behaviour.

Implementing zero-/plus-energy or zero-emission houses leads to more complex installation engineering to produce electrical energy in addition to the thermal heat which increases the demand for detailed planning and surveying during at least the first years of operation. Also self control for renewable installation engineering could be increased to get better efficiencies. The acceptance test after the building process could be enlarged by the results of a total year of operation to proof not only the individual function but the interaction of all components. The example of the maintenance of the ventilation system and the heat recovery shows the importance of low maintenance concepts.
Although all reported difficulties during the project realization and operation the measured heat consumption could be reduced by more than 70 % (measured before and after retrofit), despite the increased thermal comfort in the apartments. That shows the importance of reducing the energy consumption for heating, domestic hot water, heat storage and distribution as well as auxiliary and household electricity when planning a zero-/plus-energy or zero-emission dwelling. If these

efficiency concepts are implemented with top priority a failure in installation engineering won't challenge the whole building concept. After solving the problems with the co-generation resulting from mechanical engineering (soot production) at the end of 2012 the buildings will reach a zero-emission and a plus-energy level for the mentioned categories.

5. Acknowledgment

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Free download of the IWU project reports (in German) at www.iwu.de

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