EVALUATION OF DIFFERENT ENERGY-EFFICIENT REFURBISHMENTS

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ABSTRACT

In Germany, three-quarters of all existing buildings were built before 1979 and have mostly only been minimally retrofitted. Despite numerous policy incentives the annual retrofitting quota remains at a low 1.1%. In refurbished buildings often predicted energy consumption is lower than the real energy consumption: this phenomenon is known in literature as energy performance gap. The occupants’ behaviour is considered to be the main cause for it. To validate the efficiency of advanced energy efficient retrofitting, three residential buildings built in South Germany in the 1950s were retrofitted and monitored, to qualitative and quantitative evaluate the energy performance gap. The refurbishment included structural as well as engineering system aspects. Seven different retrofit designs were implemented. A high time resolution monitoring system provides information about the occupants’ behaviour, the technical functioning of the engineering systems and allowing faults’ detection.

Initial results from the field test support the findings by other research institutes that occupants who were in badly insulated buildings prior to the retrofits behave much more economically and energy aware than those in energy efficient buildings.

Further evaluation of the energy consumption levels shows clear discrepancies between the buildings retrofitted with different layouts. Two of the seven retrofit layouts consume less heating energy than expected while the other layouts need more heating energy than expected. The different occupants’ behaviour regarding the floor heating seems to be the driver of this discrepancy. For all retrofit layouts, hot water consumption as well as the distribution and storage losses remains almost constant throughout the year. While the consumption of domestic hot water, measured at apartment level, is very similar for all the retrofit layouts, huge differences are identified for the distribution losses.

Keywords: renovation, field test, energy saving ordinance, user behaviour, rebound effect

INTRODUCTION

About 40% of final energy consumption in Germany accounts for households. About 70% of the buildings in Germany were built before 1979 and therefore before the first heat insulation ordinance [1]. The potential of this sector in terms of primary energy savings is correspondingly high. Therefore, the adopted "Aktionsprogramm Klimaschutz" (Action Program Save the Climate) of the federal government focuses on the renovation of buildings. In conjunction with the "Nationaler Aktionsplan Energieeffizienz" (NAPE, National action plan for energy efficiency) the energy efficiency in buildings is regarded as an important basic point to achieve climate change targets by 2020 [2]. To exploit the potential in the building sector, the federal government provides incentives to implement energy efficiency measures in order to double the annual rate of renovation of narrow 1.1% to 2% [1]. The analysis of various central and decentralized domestic hot water systems, heating and ventilation systems, in terms of energy consumption and user behaviour, after an extensive renovation process is the focus of the here presented ongoing research project.

METHOD

In the study area three blocks from the 1950/60th were refurbished. Each block has three entrances with five floors. Over the five floors 10 apartments are located built specular to the stairs. The roof and the cellar of the buildings are not heated. For the comparison of different renovation strategies, seven retrofit layouts are implemented (see *figure 1* left). While block 1 has only one retrofit layout for all entrances, one layout per entrance is implemented for block 2 and 3.

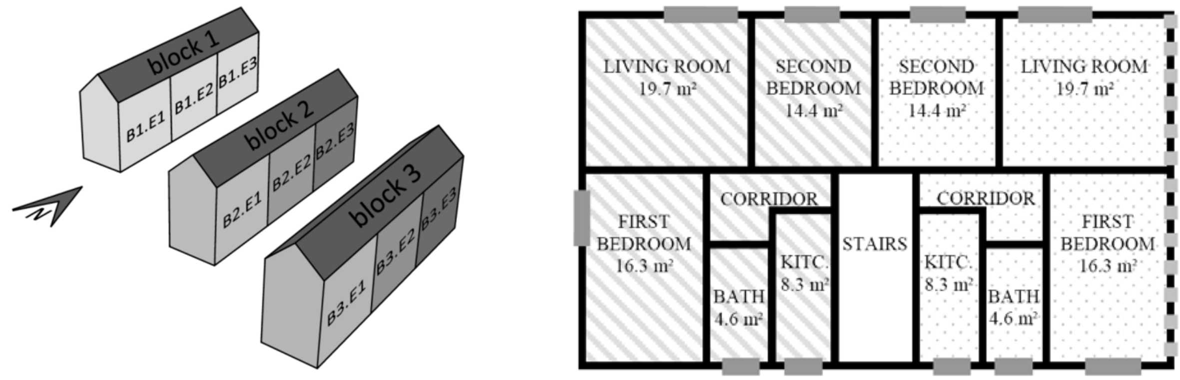

Figure 1: Overview of the situation and different refurbishments plus qualitative layout of one floor of the first building of each block (KITC. is the Kitchen)

For block 1 the external wall is equipped with 16 cm thermal insulation (thermal conductivity 035 means WLG 035), plastic windows with double glazing ($U_w = 1.3$ W/(m²K)), an insulation (WLG 035) of the top floor ceiling (16 cm) and the basement ceiling (7 cm). Block 1 is connected to the district heating network (primary energy factor 0.49 [3]). The domestic hot water is produced centralized (with circulation). Exhaust ventilation has been built as following: moist-controlled slots for fresh air supply are installed in the window frame. The exhaust air is extracted in kitchen and bathroom.

In block 2 (E1 to E3) a retrofit layout per block entrance was realized. The building construction refurbishment for B2.E1 and B2.E3 do not differ from each other. B2.E2 has passive house windows with a triple-insulating glazing, thereby resulting an u-value of 0.8 W/(m²K) for the window (so called “passive house windows”). The outer walls are provided with 16 cm insulation (WLG 022), the top floor ceiling is covered with 16 cm and the basement ceiling with 8 cm of insulation (WLG 024). District heating is also planned for the heating of the block 2. B2.E1 disposes of radiators with decentralized heating pumps. The domestic hot water is provided by decentralized fresh water stations. B2.E1 has also decentralized window ventilation systems with heat recovery. For kitchen and bathroom an air exhaust system is provided, and opening slots are installed on the windows’ frames. For B2.E2 a central hot water system with buffer storage is installed. The needed fresh air is done through central exhaust ventilation system in kitchen and bathroom. The decentralized supply air comes over the window frame slots. The rooms are heated via compact radiators with small heating pump installed in each radiator. In B2.E3 floor heating was provided for the rooms. The domestic hot water production and ventilation does not change compared to B2.E2 except for the manufacturers' of the installed products.

The constructional renovation for B3 has the same average U-value of 0.165 W/(m²K) as for B2. The redevelopment is based on the renovation of the exterior walls of a sandwich construction with vacuum insulation panels (WLG 008). The top floor ceiling and the basement ceiling are retrofitted as in B2. B3.E1 and B3.E2 have passive house windows and B3.E3 standard double glazing windows. For B3 different heat pump systems are used. In B3.E1 and B3.E2 heat pumps with CO_2 probes are installed. In B3.E3 an air source heat pump in combination with an exhaust air heat pump is used. In B3.E1 a floor heating, in B3.E2 an air heating and in B3.E3 a ceiling heating deliver the heat to the rooms. The necessary exchange of air in B3.E1 is generated by centralized ventilation with heat recovery devices installed in each apartment. For B3.E2 the ventilation is done in combination with the air heater. In B3.E3 demand-controlled supply air elements in the window frames, in combination with exhaust elements in kitchen and bath, supply the rooms with the necessary exchange of air. The domestic hot water is produced locally via freshwater stations (produced by different manufactures) for each entrance. [4, 5]

To verify the real achieved energy savings, a high-resolution monitoring system for rooms, apartments and engineering system has been installed. The monitoring includes the recording of the indoor air quality, indoor air temperature, relative humidity, window position and daylight in each room of block 2 and block 3. The energy flows of the installed engineering system (heating, domestic hot water, ventilation) from generation, storage and distribution are recorded. The monitoring system collect the data with an interval of one minute, for a total of ca. 6 million data point collected each day.

RESULTS

Study of thermal offsets inside the building and across the thermal envelope

With each amendment of the energy-saving ordinance [6] more stringent requirements for thermal insulation of buildings are demanded. In the case of a building renovation, the maximum heat transfer coefficient of the outer walls is fixed at 0.24 W/(m²K). Generally the internal walls of two adjacent apartments do not get any insulation. This raises the question whether the heat losses or gains of an apartment for the neighbouring apartment will have a significant impact on the total heating requirement of each apartment. For the analysis of the thermal offset within and across the thermal envelope a dynamically computing program language Modelica® is used to generate the buildings' dynamic models.

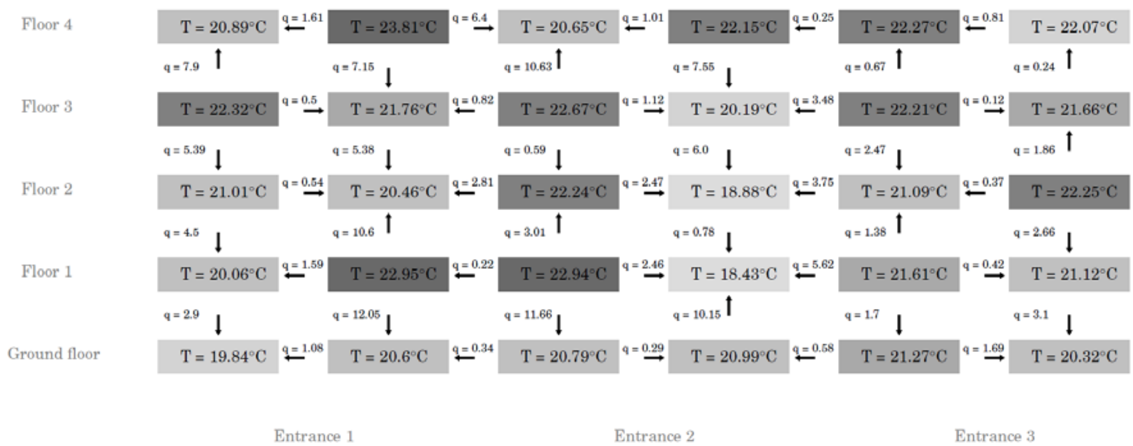

Figure 2: Heat transfers between the apartments in block 2

Due to the temperature difference of two adjacent apartments (or between apartment and other confining zones such as the staircase, the cellar or the roof) a heat shift can occur inside the thermal envelope of a building. In *figure 2* the level and direction of the transmitted heat between the apartments, for the heating season, is shown for one of the blocks (to guarantee the privacy of the tenants the block number and the year of the heating season are omitted).

The apartments are represented by colored rectangles. The color of the rectangle is determined by the measured average interior room temperature during the heating period. Dark gray stands for high, medium gray for medium and light gray for low average indoor temperatures. The black arrows indicate the heat-flow in kWh per square meter of living space and its corresponding direction.

Due to the larger transfer surface, at approximately same temperature difference, the heat flows transmitted between the different floors are larger than between the two adjacent apartments on the same floor. It is noticeable that, as expected, there are apartments (with relatively high indoor temperature) that only lose their heat, giving this to the neighbors. At the same time some apartments (low indoor temperature) collect the heat of all the neighboring apartments. In *figure 2* the heat shifts between the apartments and the staircase are not shown. The staircase is parameterized in the simulations with a constant temperature of 17 °C. In this way, the temperature of the housing space is always higher than the selected temperature of the staircase: Due to this temperature gradient, the staircase collects the heat from all the apartments.

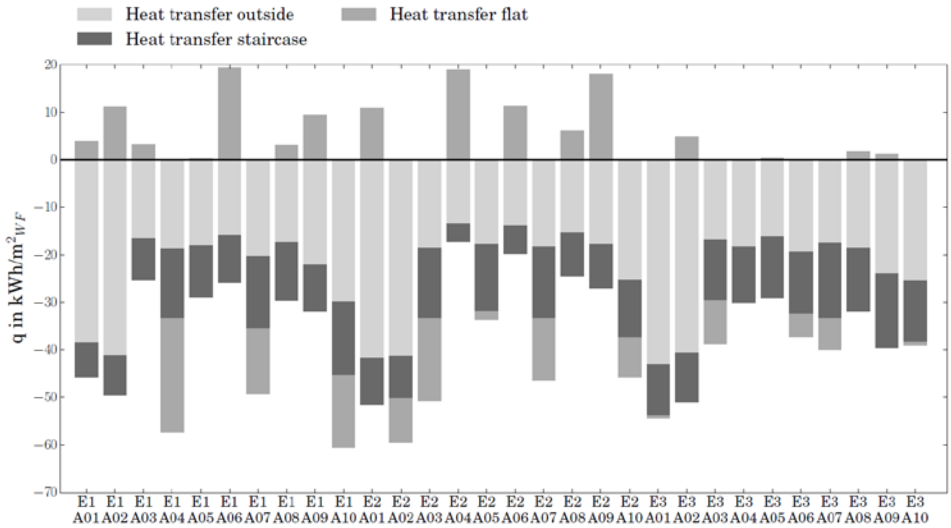

Figure 3: Comparison of the heat transmission per apartment based on the living space for block 2

In *figure 3* the specific heat shifts in $kWh/m^2_{floor\ space}$ per apartment, compared to the living space, are covered for B2. The light gray bars indicate the heat transmitted over the external surfaces; the medium gray columns show the heat transmitted to the neighboring apartments and the dark gray columns indicates the heat transmission to the staircase. In comparison with the other apartments an increased heat loss to the ground floor (A01 and A02) and to the roof (A09 and A10) is evident. The reason for this is the larger heat-transferring surface to the outside. The heat shift over the walls to the neighboring apartment is not equally distributed. Some users will benefit significantly from the heating characteristics of adjacent apartments, while other users have high losses to their neighbors. In some cases, the thermal displacements to neighboring dwellings are negligible.

The analysis of the thermal shift within the building shows that the heat gains by the neighboring dwellings may compensate partially the losses by transmission to the outside and into the staircase. On the other hand, the heat shifts to neighboring apartments can make up more than 40% of the total transmission heat loss of each apartment. It can be then concluded that the heating behavior of the adjacent dwelling and the associated heat shift within the building have a high influence on the heat demand of each apartment.

Comparison between expected and observed consumption

In the comparison of expected and observed consumption, the measured raw data cannot be directly used because the expected consumption has been identified using a standard weather data set. The observed consumption should therefore first be weather adjusted. Weather adjustment means that the proportion of heat consumption dependent on the weather is multiplied by a climate correction factor. Recognized method are described in the VDI 2067 [7] and VDI 3807 [8] and could be used for the determination of these climate correction factors. The difference between the average outdoor air temperature and average room temperature forms the basis for the determination of heating days. Heating days number those days when the heating temperature limit is below 15 °C. The normative procedure provides a good opportunity for the comparability of the consumption of buildings in different locations.

But in reality it is to known that in addition to the temperatures inside and outside, the solar radiation has a big influence on the consumption. Therefore, for this work, instead of adjusting the consumption energy figures, the expected energy figures have been calculated with real, observed weather patterns including not only the outdoor temperature, but also the solar radiation. The expected consumption values have been calculated for each monitored year, and the expected and observed consumption energy figures are compared with each other. A tool for the "weather adjustment of expected consumption data" has been therefore developed at the institute.

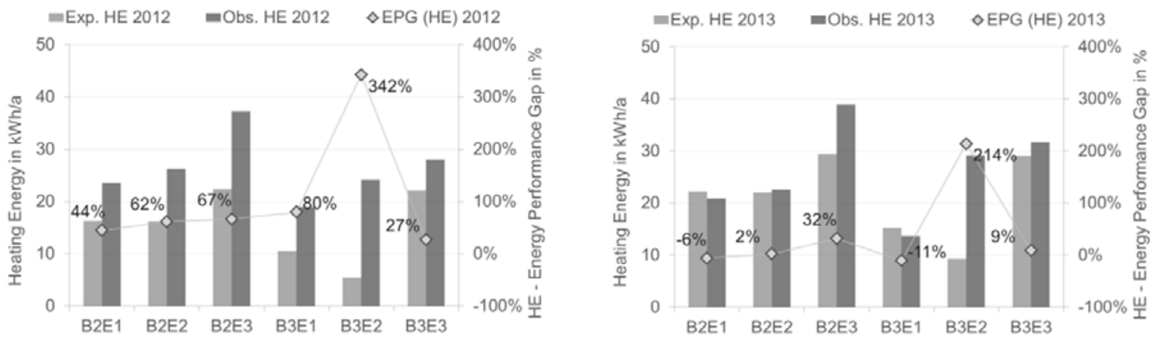

Figure 4: Energy performance gap, related to the heating energy, of block 2 and block 3, in the year 2012 (left) and 2013 (right)

Figure 4 shows the comparison of the expected heating consumption (light gray) and the observed heating consumption (dark-gray) for the years 2012 and 2013. In all cases a discrepancy between the expected and observed consumption data is revealed. The Energy Performance Gap (EPG), which is plotted on the right scale, between observed and expected consumption and the expected consumption (is defined in equation (1).

$$EPG = \frac{(Q_{obs} - Q_{exp})}{Q_{exp}} \qquad (1)$$

The values shown in *figure 4* reflect only the heating energy [9]. The comparison of this value illustrates the user behavior (heating and ventilation) without taking into account the resulting losses for transport, storage and conversion. The EPG varies between 27% and 342% for B3.E1 and B3.E2 in 2012, and between -11% and 214% for B3.E1 and B3.E2 in 2013. In 2013 there are significantly lower values than in 2012. The repeated explanation about the use of the engineering system for the tenants at the beginning of the heating season and the accompanying interviews and surveys counts to the reasons for these results. As part of the study the correct use of the heating and ventilation system and the basic features of the ventilation are mediated to the tenants. In spite of the educational explanation the gap between consumption and demand values is still too large. A reason for this gap could be that the tenants do not use as expected the mechanical ventilation system with heat recovery.

CONCLUSION

Future analyses will show whether the trends described here will be confirmed or a further reduction of consumption (especially for block 3) is possible through training courses for tenants and continuous maintenance of the engineering systems.

The presented research project offers the possibility of a systematic and scientific basis for the analysis of different renovation strategies. For evaluation and detailed consumption data of the residential building over several heating periods are available. Despite the not fully achieved conservation objectives it can be shown that an energy efficiency of buildings can reduce greenhouse gas emissions, energy consumption and, consequently, contributes to the energy costs.

ACKNOWLEDGEMENTS

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