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LOW RENTS AND LOW OPERATING COSTS IN SOCIAL HOUSING – AN EXAMPLE FROM GERMANY

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Abstract. The social housing project "PassiveHouseSocialPlus" in Germany with 42 residential apartments demonstrates how low rents and low operating costs can be combined. Different concepts for reducing operating costs were implemented and tested in one refurbished and one new apartment building. High energy efficiency for heating (passive house standard) and domestic hot water preparation were complemented by efficiency measures for household electricity (e.g. pre-installed energy-efficient kitchen appliances, LED lighting) and water savings through gray water usage for flushing toilets.

Additionally, a flat rate billing scheme for most of the ancillary costs was established. Due to the overall low level of consumption, space heating and domestic hot water are also included in the flat rate with defined budgets. Displays in all apartments are informing the tenants about the used-up budget and show a forecast for the consumption of water and electricity until the end of the year.

Results from more than two years of measuring are showing a low consumption of heat, which is about in the calculated range. The budgets for drinking water and electricity are slightly exceeded on average, nevertheless, the consumption levels are significantly below average consumption in Germany. The operating costs are around 30 % below the costs of comparable apartments in the same city.

Keywords: Social housing, operating costs, flat rate, budget, monitoring results, heating, water, electricity.

1. Introduction

Affordable housing is a major challenge in the housing market, in Germany as well as worldwide. Inexpensive housing must also be combined with the requirements for climate protection and the economical use of resources. Most of the time, the two aspects seem incompatible, as ambitious efficiency measures often increase construction costs. As a result, low-income households and recipients of support services for housing have often no access to climate-friendly and resource-saving dwellings. In addition, rents in Germany have generally risen steadily in recent years, which poses financial problems for low-income households in particular. In addition to the net rents, however, the operating costs are also increasing, which today can represent a "second rent" that reduces the disposable income of the households. Large parts of the population are affected – especially the unemployed, single parents, low-income earners, pensioners and families with many children. In the group of unemployed people, the share of housing costs of the disposable income increased from 35 % to over 47 % between 2004 and 2017 [1]. For them it is essential to reduce the living and operating costs. The general public also has a great interest in reducing costs, because if state transfer payments are paid, minimizing housing costs from rent, operating and ancillary costs is also in the interest of society as a whole.

Figure 1. Refurbished old building (west view).

2. Building concept

The "Neue Wohnraumhilfe gGmbH" in Darmstadt initiated and implemented the "PassiveHouseSocialPlus" to provide people with difficulties in accessing the housing market with inexpensive living space. This project, which was implemented in 2018/19, intended a combination of low rents and low operating costs in a modern and climate-friendly subsidized housing.

The two buildings of the PassiveHouseSocialPlus were implemented on a former US-Army barracks site in Darmstadt, Germany. Two of the three building parts from 1955 were kept and refurbished to an energy efficient building standard (with 22 apartments), to minimize the manufacturing energy expenditure for a new building structure (see Figure 1). For barrier-

Figure 2. New building (view from south-west).

free access one third of the building was replaced by a barrier-free new building (20 apartments in total) with also 6 wheelchair-accessible apartments (see Figure 2). The two buildings have 42 apartments in total and 3 186 m^2 of heated living space for about 138 residents.

Concepts for reducing ancillary costs during operation were implemented in both buildings. The focus was on increasing energy efficiency in the areas of heating, domestic hot water (DHW) preparation as well as on electricity consumption in the flats and for auxiliary services. In addition, measures to reduce costs for drinking water and household electricity were implemented. These are e.g.:

- Passive house standard of the building envelope for the new building, respectively refurbishment with passive house components for the existing building to reduce heating costs; windows have triple thermal insulation glazing with a U_g-value from 0.50 to 0.54 $W/(m^2 \cdot K)$ in plastic frames ($U_f = 0.94\,W/(m^2 \cdot K)$), the U-values of the opaque building envelope are in the range of 0.10 to 0.15 $W/(m^2 \cdot K)$.
- Ventilation system with heat recovery in every apartment for increasing indoor air quality while reducing ventilation heat losses.
- Minimization of distribution heat losses through improved thermal insulation of the distribution pipes (doubled insulation thickness compared to the minimum legal requirements).
- Energy-efficient kitchen appliances (A++ and A+++) were pre-installed as well as LED lighting in all rooms to reduce household electricity consumption; energy-efficient system technology (lift, LED lighting, pumps).
- Water saving measures.

The PassiveHouseSocialPlus is heated with a common district heating connection (in the basement of the existing building). Two tanks with 3 m^3 volume in total are buffering peak loads during DHW preparation and reduce the commissioned district heating power, which reduces the ancillary costs for the tenants. The maximum rated power was limited to 60 kW (17.5 W/m^2 in total for heating and DHW preparation). A primary energy factor of 0.5 kWh_{pe}/kWh_{final} for district heating is guaranteed by the supplier.

The heating system of the refurbished building furthermore consists of the existing distribution system and the existing radiators. The DHW is supplied via home stations in each flat. The maximum flow temperature in the 4-pipe-system is 48 °C for heating and DHW. In contrast, the new building has a 2-pipe-system also feeding home stations in each flat but delivering the heat to an air supply heating and only one single radiator in the bathroom. The maximum flow temperature in the 2-pipe-system is 53 °C for DHW in summer and 58 °C for heating and DHW in winter.

Each apartment in the PassiveHouseSocialPlus has its own ventilation system with heat recovery, that allows the tenants to choose among four levels of ventilation. In order to minimize heat losses, the building envelope is sealed against air leaks very well. The new building achieved an airtightness test value according to DIN EN 13829 n_{50} of 0.24 1/h, the existing building has a mean value of 0.52 1/h. Thus, all building parts are well below the limit for passive houses of 0.6 1/h.

Both buildings have monocrystalline PV systems installed on the flat extensive green roof in an east-west orientation, the refurbished building 40.9 kW_P, the new building 43.3 kW_P. There are also lithium-ion storage systems for each dwelling with a net storage capacity of 17.5 kWh in the existing and 43.8 kWh in the new building. The power produced by the PV systems is used in the buildings first, then stored in the battery storage in case of a surplus production and, finally the remaining power is fed to the grid.

Flushing the toilet needs a lot of drinking water. To minimize this water consumption, the buildings use gray water from a gray water treatment plant in the basement. Slightly polluted waste water from showers and hand basins in the bathrooms is collected separately and fed to the shared gray water treatment plant in the basement of the existing building (wastewater from the kitchen was not used because of higher fat loads to be expected there). The gray water system consists of a filter for the gray water, a treatment tank with biological cleaning and a storage tank for the treated process water. The cleaned water is used via a separate water installation exclusively for flushing toilets. If the filling of the process water tank is to low, drinking water is fed in to ensure toilets can be operated at any time.

Both buildings were finished in 2019 and let between August and December 2019.

3. Flat rate billing

One objective of the project was to minimize the operating costs. In particular, these are the consumption-related costs for heat, electricity, drinking water and

Figure 3. Visualisation of the budget for household electricity and drinking water on a display in each apartment.

sewage. To examine the possibilities of reducing the different types of operating costs, an investigation was carried out beforehand [2]. To simplify the administration by the landlord, it was also assessed which types of operating costs can be billed at a flat rate.

Usually, the energy supply for space heating and DHW preparation forms a major part of the ancillary costs. In the PassiveHouseSocialPlus the consumption for heating was reduced to a very low level of 13.0 kWh/(m$^2 \cdot$ yr) needed for both building parts in average (at standard conditions). Because this value is below the limit value of 15 kWh/(m$^2 \cdot$ yr), which is defined in the heating costs ordinance in Germany, a flat rate billing for heating and DHW was legally permitted in contrast of a usage-bound billing. The total costs of consumption for heat are therefore calculated based on the living area of the flat, even if measures to reduce the energy consumption for DHW are difficult. However, the DHW volume is measured and considered for the available budget for drinking water.

The drinking water consumption and thus the additional costs should be reduced with the following measures: through the usage of water-saving taps, by the replacement of drinking water with treated gray water for flushing toilets and by the visualization of the remaining budget that is calculated for the drinking water. The amount of the budget depends on the number of persons in the household and should be sufficient if the tenants are frugal. The budget is included in the flat rate billing and was set at 25 m^2/yr for the first, 18 m^3/yr for the second and 17 m^3/yr for each additional person. Additional credit balance for drinking water must be purchased, if the budget is exceeded. The aim is to motivate the people to use resources economically.

Household electricity is also included in the flat rate for operating costs via a budget, which is unusual in Germany because electricity is normally billed by an energy supplier. The budget is calculated according to the lowest consumption category A of the German Household Electricity Index [3] and requires frugal behavior of the tenants. The budget is as follows: 850 kWh/yr for the first person, 350 kWh/yr for the second person and 300 kWh/yr for each additional person.

The buildings have photovoltaic systems and electricity storage in order to reduce the electricity costs per kWh. Since the legal hurdles for the landlord to supply electricity to the tenants are very high in Germany [4], a service provider (energy cooperative) was commissioned to supply the tenants.

The displays in the apartments show the consumption of the budget for water and electricity as well as a forecast up to the end of the year and historical values (Figure 3).

An additional feature is the free WiFi in the apartments, which the tenants can use with limited bandwidth within the service charge flat rate.

4. Measurement results

In the PassiveHouseSocialPlus more than 600 meters and sensors with more than 1 100 measuring points are installed to measure the consumption and usage parameters over a period of nearly three years. The following results are from the period October 2019 until September 2021 (refurbished building) and March 2020 until September 2021 (new building), respectively. The heated living space of 1 662 m^2 (refurbished building) and 1 578 m^2 (new building) were used for the area-related parameters.

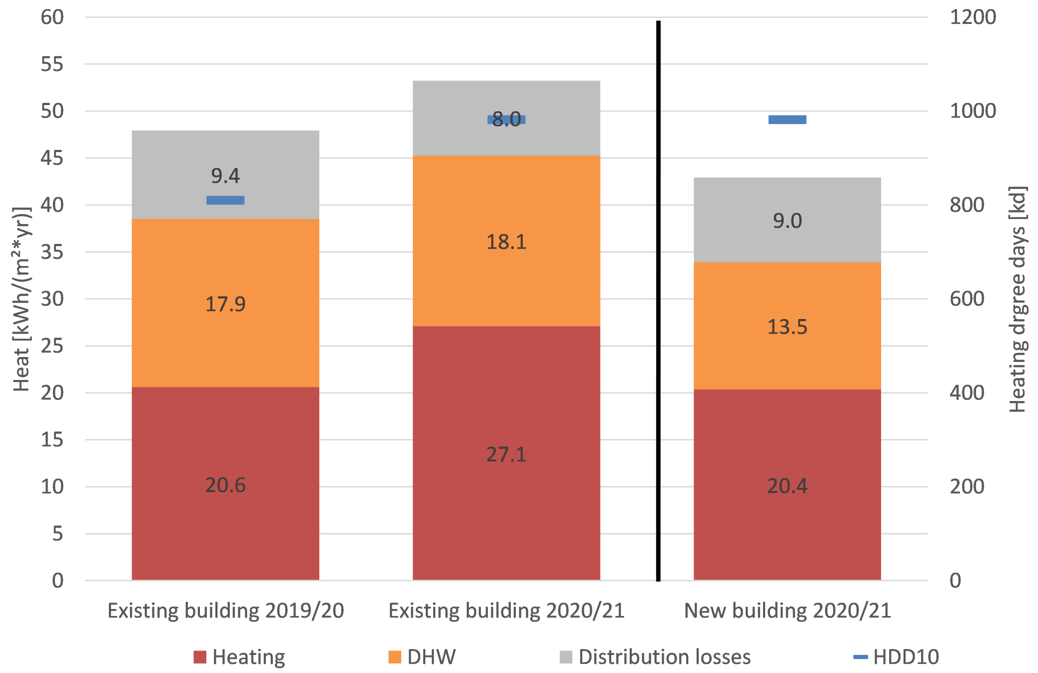

Figure 4. Heat consumption for heating, DHW and distribution losses of the refurbished (left and middle column, two heating periods) and the new building (right column, one heating period) as well as heating degree days on site.

4.1. Heating and DHW

For the first heating period the refurbished building had a heat energy consumption of 20.6 kWh/($m^2 \cdot yr$) including distribution losses between the buffer tanks and the flat (Figure 4 left). According to the PHPP, the heating demand was 19.2 kWh/($m^2 \cdot yr$) including distribution losses.

Although the values match well, the interpretation must take into account that the outside climate in 2019/20 was very mild (the heating degree days were only 810 Kd compared to a long-term average of 1018 Kd). At the same time, the average room temperature was around 22 °C, which is often measured in energy-efficient buildings. If these factors and the actual household electricity consumption (internal heat sources) are considered in the PHPP, the result is a heating requirement of 19.8 kWh/($m^2 \cdot yr$). Consumption and adjusted heating requirements therefore also go well together. In addition, a consumption of 17.9 kWh/($m^2 \cdot yr$) for hot water preparation and 9.4 kWh/($m^2 \cdot yr$) for distribution losses (only distribution for DHW and storage losses) was derived from the measuring data. These values agree very well with the planning values for an adapted outside climate. The total heat consumption reached 47.9 kWh/($m^2 \cdot yr$) in 2019/20.

In 2020/21 the consumption for heating was 27.1 kWh/($m^2 \cdot yr$) (Figure 4 middle). This increased consumption can be explained very well by the lower outside temperature (982 Kd heating degree days April until March). Due to the longer heating period, the distribution losses are somewhat lower and the hot water consumption is almost unchanged. The total heat consumption reached 53.2 kWh/($m^2 \cdot yr$).

In the new building, 20.4 kWh/($m^2 \cdot yr$) were measured for heating (Figure 4 right) in 2020/21, whereby the distribution losses are not included here. The heat consumption for DHW preparation is 13.5 kWh/($m^2 \cdot yr$), which is lower than in the existing building, but fits well with the planning values due to the lower occupancy density in the new building. The total heat consumption reached 42.9 kWh/($m^2 \cdot yr$) in the new building.

4.2. Household electricity and total power consumption

For household electricity 23.4 kWh/($m^2 \cdot yr$) where measured 2020/21 in the refurbished building and 25.9 kWh/($m^2 \cdot yr$) in the new building (Table 1). To classify the values, the smaller area per person in the buildings must be considered, which is 43 % below the average in Germany for apartment buildings. General power, e.g. for lightning of corridors, is 2.0 or 1.2 kWh/($m^2 \cdot yr$) respectively. The total power consumption is 31.9 kWh/($m^2 \cdot yr$) for the refurbished and 34.6 kWh/($m^2 \cdot yr$) for the new building.

The total budget for household electricity was 65 950 kWh/yr, the actual consumption was 79 652 kWh/yr, i.e. the budget was exceeded by 21 %. The following figures are showing for each flat the power consumption over the power budget 2020/21. If the marked rhombus is above the dashed diagonal, the flat has consumed more household electricity than provided with the budget. In the refurbished building (Figure 5) approximately as many flats are below the dashed line as are above. In mean, the consumption is 9 % above the calculated budget. 41 % of the flats are reaching electricity efficiency class A, 23 % class

	Refurbished building $[\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})]$	New building $[\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})]$
Household electricity	23.4	25.9
General power	2.0	1.2
Auxiliary power	6.5	7.5
Total	31.9	34.6

Table 1. Electricity consumption of the refurbished and the new building in July 2020 – June 2021.

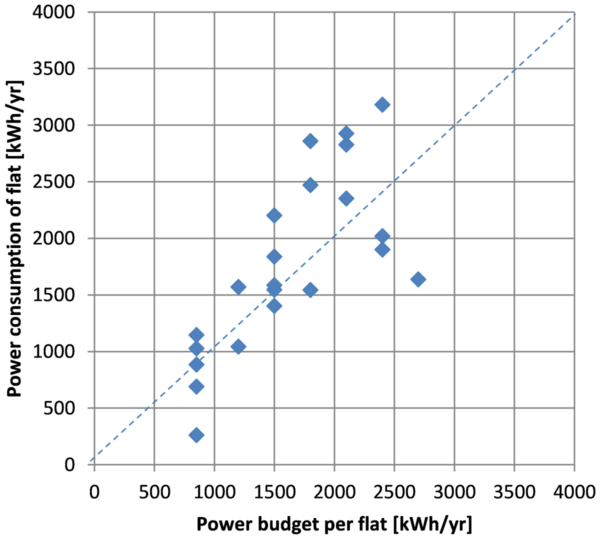

Figure 5. Power consumption per flat over power budget per flat for the refurbished building 2020/21.

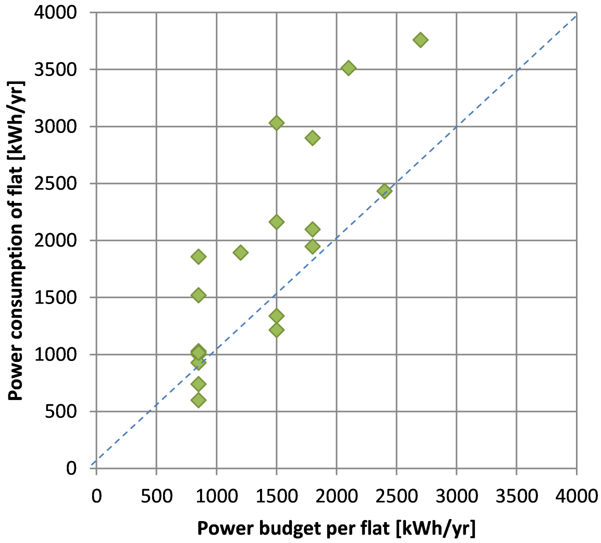

Figure 6. Power consumption per flat over power budget per flat for the new building 2020/21.

B, 32 % class C and only one flat (5 %) the class D, which represents the mean power consumption in Germany [2]. In Figure 6 (new building) the budget is exceeded by 35 % on average. There, only 20 % are reaching class A, 25 % class B, 20 % class C, 15 % class D and 10 % class E and F each. The reasons for the different adherence to the budget between refurbished and new building are not known.

4.3. Power generation

In 2020/21, a PV yield of 24.0 $\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})$ was measured in the refurbished building, which is in the same order of magnitude as household electricity consumption. Of this yield, 11.6 $\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})$ were used directly, 1.9 $\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})$ were used to charge the battery and 11.4 $\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})$ were fed into the grid (Table 2).

The PV yield in the new building was slightly higher with 25.5 $\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})$ and with 12.1 $\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})$, more electricity was consumed directly in the building. 5.2 $\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})$ were used to charge the batteries and only 9.7 $\mathrm{kWh}/(\mathrm{m}^2\cdot\mathrm{yr})$ were fed into the grid. The PV yield in the new building is higher than the annual household electricity consumption.

The share of direct consumption in the refurbished building was 49 % of the PV power generation, the total self-consumption including battery storage was 56 % (Table 3). 39 % of the total electricity consumption of the existing building was covered physically by the PV system.

The efficiency of the battery storage 2020/21 was 70 % in the refurbished building and 76 % in the larger storage unit in the new building, which is below the expected value of approx. 80 %. After commissioning, a number of problems (cell charging, software) with the battery storages occurred. These were fixed during operation. From March to August 2021 the efficiency of the battery storage reached 75 % in the refurbished building and 78 % in the new building.

4.4. Drinking water

An important item in the reduction of costs was the economical use of drinking water, since the costs of 3.75 €/m^3 for drinking water including wastewater fee in Darmstadt are relevant for the ancillary costs. The total budget for drinking water in all apartments, that does not contain any water for flushing the toilet (see below), was 2 663 m^3/yr. The consumption of 2 810 m^3/yr or 20.4 $\mathrm{m}^3/(\mathrm{person}\cdot\mathrm{yr})$ in the evaluation period 2020/21 was around 5.5 % above budget. In the new building, the budget was even slightly undercut; in the refurbished building, consumption was 10 % above the budget. The average drinking water consumption in Germany is 44.9 $\mathrm{m}^3/(\mathrm{person}\cdot\mathrm{yr})$ [5] with a share of 27 % (that means 12.1 $\mathrm{m}^3/(\mathrm{person}\cdot\mathrm{yr})$)

	Refurbished building [kWh/($m^2 \cdot$ yr)]	New building [kWh/($m^2 \cdot$ yr)]
PV-power generation	24.0	25.5
of that		
• Direct consumption	11.6	12.1
• Charging of battery	1.9	5.2
• Grid supply	11.4	9.7

TABLE 2. Power generation and feed-in of the refurbished and the new building in 2020/21.

	Refurbished building	New building
Ratio of direct consumption of PV power generation	49 %	45 %
Ratio of self-consumption (incl. battery) of PV power generation	56 %	71 %
Total coverage ratio of household consumption	39 %	43 %

TABLE 3. Characteristic proportions for electricity in 2020/21.

accounted for flushing the toilet. Without this proportion, a comparative value of 32.8 m^3/(person · yr) could be calculated. This means that the apartments are below the average consumption by 38 %.

For flushing toilet 16.7 m^3/(person · yr) were measured in the two buildings in mean, the value is thus around 37 % above the national German average. Nevertheless, the drinking water consumption could be significantly reduced to 5.57 m^3/(person · yr) by the gray water system. The cover ratio has reached a mean value of 67 % from August 2020 until July 2021 which means a reduction in drinking water consumption by 54 % compared to the German mean value.

5. Rents and auxiliary costs

The construction costs for the refurbished building were 1 485 €/m^2 (including building envelope, system technology, PV system and battery storage), for the new building it was 1 763 €/m^2 and reached the originally planned amount [6]. As a result, the targeted height of rents, including public funding, could be achieved. The rents in the apartments are 6.50 €/(m^2 · month) and thus well below the comparable rent, which in this area is 10.04 €/(m^2 · month), while the best energy standard has been implemented at the same time.

The billed ancillary costs in 2020 were 1.14 € for consumption costs for heating and drinking water, 0.87 € for other ancillary costs such as property tax, building cleaning or waste disposal and 0.52 € for household electricity, which is normally not included in ancillary costs in Germany. The agreed flat rate for ancillary costs and the billed costs were in the same range in 2020, so that the landlord's expenses were covered. However, the necessary security surcharges are missing, so that the flat rate for ancillary costs (excluding household electricity) had to be increased from 2.10 €/(m^2 · month) at the start of the rental to 2.50 €/(m^2 · month). Nevertheless, the ancillary costs are still well below the comparative value of 3.59 €/(m^2 · month) in social housing in the same city for 2016 [2].

6. Conclusions

In the social housing sector, 22 apartments were created in a highly efficient refurbished building and 20 in a new building meeting the passive house standard. A special feature of the project is the flat rate for ancillary costs and the budget for drinking water and household electricity, which are also included in the flat rate. The household's consumption and the remaining range of the budget are shown on a display in each apartment.

The measurement results show that the heating consumption is very low, despite flat rate billing, and is only slightly above the expected values if the actual room temperatures and outdoor climate are taken into account.

The total heat consumption for heating, DHW preparation and distribution losses is between 45 and 51 kWh/(m^2 · yr) and therefore also quite low – especially when the high density of people in the apartments is considered.

Household electricity and drinking water consumption are slightly higher than the budgets agreed. Nevertheless, 81 % of households use less electricity than the average in Germany and only 10 % are above the average. The PV systems provide about as much electricity over the year as is consumed in the households in total. Physically, 39 resp. 43 % of the electricity consumption of the buildings could be covered with solar energy. Drinking water consumption is 38 % below the average consumption in Germany. For toilet flushing the average drinking water consumption was 54 % lower than the mean value in Germany, despite high individual consumption and due to the gray water treatment and reuse.

The results of the monitoring are predominantly positive and a significant reduction in ancillary costs could be achieved, even if there is still room for improvements. The presented concepts should now be widely applied. In the case of consumption feedback, further comparisons between the use of displays and inexpensive online access would be useful.

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