Consume and pay less – a budget approach for running costs in social housing

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Abstract

Energy-efficient buildings such as passive houses have low heating costs. This would be good for low-income residents but so far, it has been associated with higher rents. But other running costs such as drinking water and electricity must be reduced significantly too so that low-income population groups are not financially overwhelmed. If the municipalities bear the costs for these tenants, the question arises as to how incentives can be set for economic use.

The "PassiveHouseSocialPlus" project shows how low rents and low ancillary costs can be combined. Different concepts for reducing running or ancillary costs were implemented and tested in two apartment buildings in Germany. In addition to passive house standard and efficient hot water preparation, the total of 42 low rent residential apartments are equipped with e.g. energy-efficient kitchen appliances, LED lighting and grey water usage for flushing toilets.

A special feature is the flat-rate billing of most ancillary costs. As a result, the residents are not subject to unforeseen expenses and billing for the landlord is simplified. Since the energy consumption for heating has been greatly reduced by the passive house standard, space and water heating is also included in the flat rate. For drinking water and household electricity structural measures reducing the consumption are only possible to a limited extent. Therefore, budgets have been agreed in the ancillary costs that are sufficient if people behave economically. If these budgets are exceeded, the tenants have to buy additional quantities. In order to inform the tenants how much of their budget is actually being used up, the consumption of water and electricity is measured and shown to the tenants over time on a display in the apartment. This is also supposed to keep the consumption low.

The utilisation and consumption of the apartments are being measured in detail. Basic results are that the heat usage is about in the calculated range and the winter room temperatures are with 22.0 °C the same as in privately financed apartments. The budgets for drinking water and electricity are only exceeded slightly. For electricity, the tenants reach nearly the best energy efficiency category. At the same time, the additional costs are around 45 % below the costs of comparable apartments.

Introduction

In addition to the requirements for climate protection and the economical use of resources, affordable living space represents a major challenge for the construction and housing industry, in Germany as well as worldwide. Most of the time, the two aspects appear to be incompatible opposing, as ambitious efficiency measures often increase construction costs. In particular, households with low incomes and recipients of support services for housing are often excluded from climate-friendly and resource-saving buildings. At the same time, there seems to be a connection between the energy standard of the buildings and the health of the residents (Steuwer et al. 2019). Poor energy standards in connection with energy poverty and the associated low room temperatures can lead to e.g. increased respiratory diseases or strokes. This means that poorer people also benefit from more energy-efficient buildings in terms of health.

At the same time, rents in Germany have generally risen steadily in recent years, which poses financial problems in particular for low-income households. But not only are the net rents rising, the running costs now also constitute a "second rent" that reduces the households' disposable income. Large parts of the population are affected – especially low-income earners, pensioners, single parents, the unemployed and families with many children. Especially in the group of unemployed people, the share of spending on housing increased from 35 % to over 47 % between 2004 and 2017 (Statistisches Bundesamt 2017). In 2019, 4.8 million households out of 41.4 million households in total received a threat to block electricity (12 %), and 298,012 connections were actually blocked. 1.0 million threats to close the gas connections were issued and 30,997 connections were actually blocked (Bundesnetzagentur 2020). Energy poverty is therefore also an important issue in Germany.

The reduction of living and ancillary costs is therefore essential for these households. If these households receive state transfer payments, minimizing the housing costs from rent and ancillary costs is also in the interests of society as a whole, since these services are borne by the municipalities and thus by the general public.

In addition to the structural provisions to reduce energy consumption and costs, information technology can inform tenants about their actual consumption and thus contribute to a further reduction in energy consumption. However, these techniques are still not widely used in German residential buildings. In the following, a project is presented in which energy-efficient building methods in social housing are combined with feedback instruments.

Building concept of the "PassiveHouseSocialPlus"

In order to provide people with difficulties in accessing the housing market with inexpensive living space, Neue Wohnraumhilfe gGmbH in Darmstadt initiated and implemented the "PassiveHouseSocialPlus" project 2018/19. This project intended to combine low rents and low running costs with modern and climate-friendly apartments in subsidized housing.

The PassiveHouseSocialPlus was implemented in Darmstadt, Germany, on a former American barracks site. On the property there was a three storey building block with three entrances for soldiers with their families. The buildings were constructed in 1955 and were generally in good condition.

For this reason, it was decided to keep two thirds of the existing building and to refurbish it energy efficient, creating 22 apartments of different sizes (see Figure 1). As a result, the manufacturing energy expenditure for the new building structure was avoided. However, barrier-free access would have been very difficult to implement. Therefore, one third of the building was demolished and replaced by a barrier-free new building, in which there are also 6 wheelchair-accessible apartments out of 20 apartments (see Figure 2). The PassiveHouseSocialPlus thus consists of two structures – a refurbished existing building and a barrier-free replacement building with a total of 42 apartments for about 132 people on 3,186 m^2 of heated living space.

SPECIAL FEATURES OF THE BUILDINGS

In order to reduce the ancillary costs in operation, concepts were implemented to increase energy efficiency in heating and hot water preparation, in electricity consumption in the apartments as well as in auxiliary energy, to reduce drinking water consumption and to minimize electricity costs. These are e.g.:

- Passive house standard of the building envelope (new building), renovation with passive house components (existing building) to reduce heating costs; the U-values of the opaque building envelope are usually between 0.10 and 0.15 W/(m^2*K), the windows have triple thermal insulation glazing (Ug = 0.50 to 0.54 W/(m^2*K)) in plastic frames (Uf = 0.94 W/(m^2*K))
- Ventilation system with heat recovery in every apartment for increasing indoor air quality and reducing ventilation heat losses
- Home stations for drinking water preparation at the usable temperature level
- Improved thermal insulation of the distribution pipes to minimize distribution heat losses (twice the insulation thickness compared to the minimum legal requirements)
- Pre-installed, energy-efficient kitchen appliances to reduce household electricity consumption (A++ and A+++)

Figure 1. West view of the refurbished old building.

Figure 2. South-west view of the new building.

- Energy-efficient LED lighting in all rooms
- Energy-efficient system technology (lift, pumps, LED lighting – some with presence detectors – in stairwells and basements)
- Water saving taps to reduce drinking water consumption
- Gray water system for the treatment of slightly polluted wastewater for flushing toilets to reduce drinking water consumption
- Photovoltaic system with battery storage to reduce also electricity costs

A green roof under a photovoltaic system was installed to ensure better summer comfort in the neighborhood and a delayed rainwater drainage. The rainwater is also seeped into the property.

BUILDING TECHNOLOGY

The two buildings of the PassiveHouseSocialPlus have a common district heating connection in the basement of the existing building as well as 2×2 buffer storage tanks, each with a volume of 1.5 m^3, for buffering peak loads during domestic hot water preparation and reducing the commissioned district heating power, which means that ancillary costs for the residents can be reduced. The maximum output was limited to 60 kW, so that a heat output for heating and domestic hot water preparation of a maximum of 17.5 W/m^2 is available. The local supplier guarantees a quite low primary energy factor of 0.5 kWh_{pe}/kWh_{final} for district heating.

Each apartment has its own ventilation device with heat recovery, that can be set in four steps by the tenants. The building envelope was very well sealed against air leaks in order to minimize heat losses. In the airtightness test according to DIN EN 13829, the new building achieved a n_{50} value of 0.24 1/h, the existing building achieved a value of 0.52 1/h in mean. Thus, the maximum value for passive houses of 0.6 1/h was undercut in all building parts.

The refurbished existing building has an east-west oriented PV system with 40.9 kW_p (monocrystalline modules) on the extensively greened flat roof, the new building has 43.3 kW_p. There is also a lithium-ion storage system with a net storage capacity of 17.5 kWh in the existing building and 43.8 kWh in the new building.

To reduce the consumption of drinking water, the buildings have a common grey water treatment plant. For this purpose, slightly polluted wastewater from showers/bathtubs and hand basins in the bathroom is collected separately and fed to the grey water treatment plant. Wastewater from the kitchen was not used for the grey water system because of the higher fat loads to be expected there. The grey water system is located in the basement of the existing building and consists of a filter for the grey water, a treatment tank with biological cleaning and a storage tank for treated process water. The treated process water is used exclusively for flushing toilets; the toilets are supplied with a separate water installation for this purpose. If the amount of process water is insufficient, drinking water is fed into the storage tank.

The apartments in both buildings were completed and let in the course of 2019.

Flat rate of running costs

An important aim was to minimize the running costs, which are above all consumption-related costs for heat, electricity, drinking water and sewage as well as other housing costs such as e.g. basic internet services. For this purpose, an investigation was carried out in advance to examine the possibilities of reducing different types of running costs (Großklos et. al 2018). In addition, it was considered which types of running costs can be billed at a flat rate to simplify administration.

RUNNING COSTS

The heat supply for heating and domestic hot water preparation has a large share of the ancillary costs. The consumption for heating was reduced very strongly due to the low heat need of 13.0 kWh/(m^2*y) for both buildings in average. Since the energy need for heating is below the threshold for usage-bound billing set in Germany the flat-rate billing was legally permitted, also for domestic hot water preparation. Some housing companies have already reported good experiences with this concept (EH+ 24 2016). The total consumption costs for heat are therefore billed based on square meters – for the first year of operation the cost of heat supply is €0.53/(m^2*month). Structural measures to reduce energy consumption are difficult when it comes to domestic hot water usage. At least all fittings were equipped with water-saving taps to reduce the volume flow. However, the hot water volume is measured and considered in the budget for drinking water (see below).

The consumption of drinking water and thus the costs are expected to be reduced by three measures:

- Through the water-saving taps.
- By replacing drinking water with treated grey water for flushing toilets.
- A budget that is calculated for the remaining drinking water, depending on the number of persons in the household, which is adequate if the people behave economically and which is considered in the flat-rate for operating. If the budget is exceeded, additional credit for drinking water must be purchased. The intention is to motivate for economical handling of resources.

Household electricity, which in Germany is usually not billed by the landlord but by the supplier, is also included in the flat-rate for running costs via a budget. The budget is based on the highest efficiency category A of the German household electricity index "Stromspiegel Germany" (Stromspiegel 2019) and should be sufficient if the people are economical. In order to reduce electricity consumption as well as electricity costs per kWh, both photovoltaic systems and electricity storage systems were installed. Since the legal hurdles for the delivery of electricity to the tenants by the landlord turned out to be too high (Behr, Großklos 2017), an energy cooperative was commissioned to operate the systems and supply the tenants. On average, the gross electricity price is 27.0 ct/kWh including the basic charge; the comparative price for the basic supply is 33.8 ct/kWh without the basic charge.

To reduce the ancillary costs for household-related services and other fixed running costs, simple maintenance work is carried out by the caretakers of the landlord (e.g. filter exchange in the ventilation systems), whereby the flat-rate ancillary costs can be further reduced. Finally, the tenants can use the WiFi, which was set up for budget accounting, within the flat-rate for ancillary costs with a limited bandwidth, so that no separate Internet connection is required.

COMPARISON OF ANCILLARY COSTS

The flat rate for the running and ancillary costs in the PassiveHouseSocialPlus in 2020 including the budgeting for tap water and basic WiFi coverage is at €1.99/(m²*month) (without electricity). In comparison, costs from the running cost table for Hesse (evaluation year 2016) of the German Tenants' Association (Deutscher Mieterbund 2018) were €2.82/(m²*month). In social housing, the local costs in Darmstadt were already €3.60/(m²*month) in 2019 (Bundesagentur für Arbeit 2021). That means the costs were about 45 % below comparable costs in the same city.

With the PassiveHouseSocialPlus, the budget for household electricity of €0.35/(m²*month) was added, so that running costs totaling €2.34/(m²*month) were incurred.

BUDGET RECORDING AND BILLING

The tenants have an overview of the current state of the budget for drinking water and household electricity and can also see a forecast for the possible purchase of electricity or water by the end of the year. This consumption is continuously recorded and summarized on a display (Figure 3) in the hallway of the apartments with forecasts for annual consumption and consumption for the last 30 days. The system was further developed for the special requirements of the PassiveHouseSocialPlus.

In each apartment, the water and electricity consumptions are measured with a high time resolution with meters and processed further with a controller. The data for the individual apartments is encrypted and sent via a central gateway in the basement of the building to the provider's central cloud server, where it is compared with the budget for each apartment and forecasts for the remaining distance to the budget are calculated.

The consumption and the forecasts are then prepared for graphic processing and sent to the display in each apartment and shown there. In addition to consumption and forecast data, messages from the landlord can also be shown on the display.

If the budget is exceeded, the budget recording and billing system could also be used to directly process the purchase of additional amounts of water or electricity. The supply can in principle also be interrupted if no additional budget is purchased. Since the tenants usually have little money and there are high legal hurdles for power shutdowns in Germany, the shutdown possibility is not used with PassiveHouseSocialPlus. Instead, the landlord advises the tenant on the purchase and offers installment payments so that the household budget is not overloaded.

The use of the budget visualization by the tenants is to be examined from a social science perspective within the research project.

Measurement results

In the framework of the research project MOBASY, in which the PassiveHousSocialPlus is one part, the consumption and usage parameters are examined in detail using measurements over a period of three years. More than 600 meters and sensors with more than 1,100 measuring points are installed. After moving into the apartments in the refurbished building in August/September 2019, measurement data has been available in the fully rented state since October 2019, which is shown below (the new building is not evaluated yet). The energy reference area "EBF" of 1,661 m² according to Passive House Planning Package (PHPP) was used for the area-related parameters.

ROOM TEMPERATURES

Each apartment was equipped with at least one temperature sensor in the living room. Temperature and humidity sensors were installed in all rooms in 7 of the 22 apartments in the existing building. The measured values were recorded every hour and then given as living area-weighted mean values.

Figure 3. Overview page for consumption of electricity and drinking water on the display in a flat.

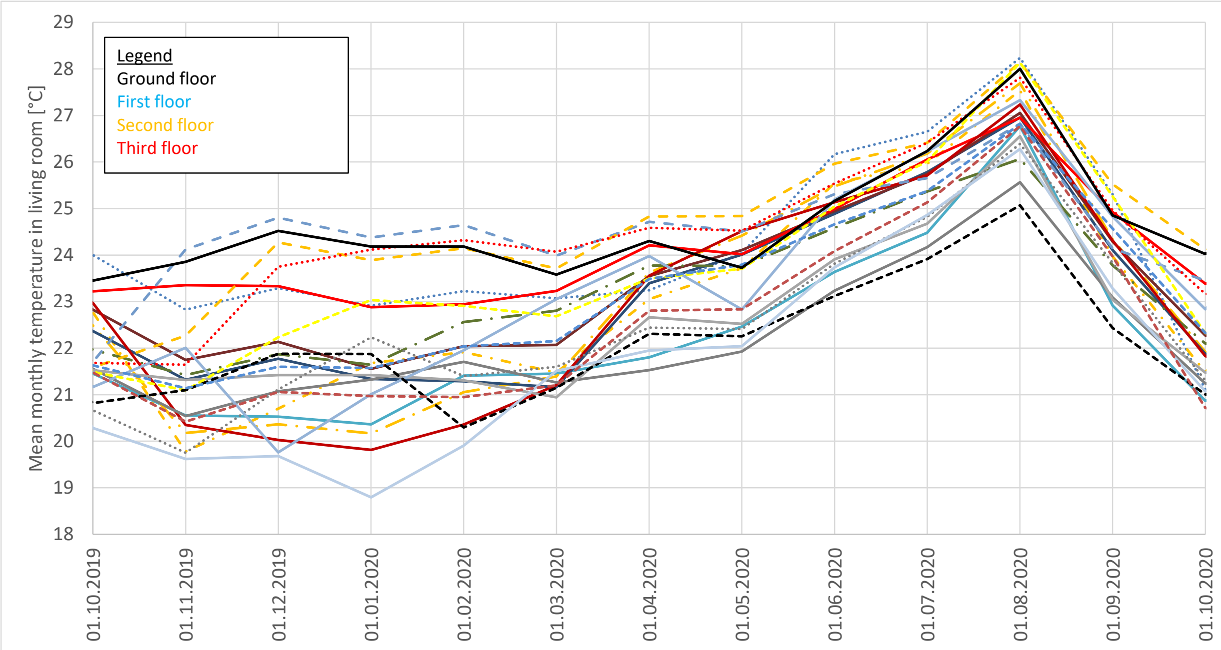


Figure 4. Course of the year of temperatures in the living room of each flat.

Figure 4 shows the course of the year of the temperatures in the living room of each flat. The floor of the apartment is indicated by the color. In winter, the living room temperatures vary between 19 °C and almost 25 °C. The mean temperature in the living rooms between October and March was 22.1 °C. In June and July, the average room temperatures were below 26 °C; in the very hot August 2020, an average of 27.1 °C was measured in the apartments. The minimum mean summer room temperature in August 2020 was 24.8 °C, the maximum value 28.2 °C.

The area-weighted values of the mean room temperatures in the existing building during the heating season from October to March was 22.0 °C, the minimum mean value for a flat was 19.8 °C, the maximum value 24.0 °C. Figure 5 shows the mean values of the measured room temperatures of the refurbished existing building (red point) and other energy-efficient apartment buildings in Germany as a function of the heating energy consumption (the uncorrected measured values are shown, for some buildings several years are included). The room temperatures in the winter half-year of buildings with a very low measured heating consumption between 10 to 30 kWh/(m²*y) are all in the range of 21.5 °C to 22.8 °C with the exception of one building. Some of the buildings have a flat-rate billing for heating costs, but most of them have a consumption-based heating billing system. With an average of the measured room temperatures of 22.0 °C, the PassiveHouseSocialPlus is therefore not conspicuous in comparison – despite subsidized housing and flat-rate billing.

ENERGY FOR HEATING AND DHW

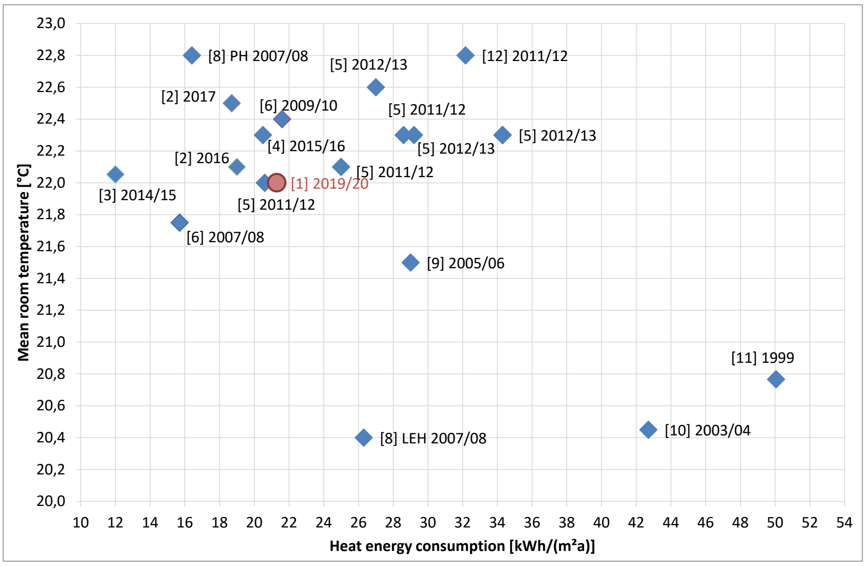
To heat the refurbished building, a total of 35,364 kWh of heat (from district heating) was consumed from October 2019 to the end of September 2020, which corresponds to a consumption value of 21.3 kWh/(m²*y). The characteristic value includes the heating consumption and the distribution losses from the outlet of the buffer tank including the old existing risers in the outer walls.

If only the usual heating period from October to the end of March is considered, the heating consumption is 19.3 kWh/(m²*y). Thus 2.0 kWh/(m²*y) were consumed in the summer half of the year, because on the one hand the heating circuits were not switched off until mid-April and on the other hand the radiators in the bathrooms can be operated all year round because of the heat supply for the home stations.

If the average room temperature measured in the heating season of 22.0 °C (see above), the actual on-site climate in the 2019/20 study period and the actual hot water consumption are taken into account in the Passive House Planning Package (PHPP), the result is an adjusted demand value of 17.1 kWh/(m²*y), of which 2.6 kWh/(m²*y) are attributable to distribution losses and 14.5 kWh/(m²*y) represent the useful energy demand for space heating. The actual electrical power consumption also influences the heating demand via the internal heat sources. If, for this reason, the actual electrical power consumption and the resulting internal heat sources are considered, the energy need for heating is 19.7 kWh/(m²*y) (of which 2.3 kWh/(m²*y) for distribution losses). The measured consumption is 1.6 kWh/(m²*y) above the adjusted demand value for the local climate and considering the actual room temperature. In view of the summer consumption of 2 kWh/(m²*y), the measured heating consumption and the adjusted demand value are corresponding very well. Nevertheless, there was also air exchange by opening of windows to a limited extent and window shading in winter, which reduced solar gains. This means that the measured value and the adjusted demand value on the one hand go well together, but there are some remaining uncertainties.

GRAY WATER USAGE

Slightly polluted wastewater is collected separately in the bathrooms and processed in the central grey water system in the basement for flushing the toilets. The system was put into operation in mid-October 2019 and only the refurbished building



No.	Name	City	Reference
[1]	PassiveHouseSocialPlus	Darmstadt	(this project)
[2]	Speicherstraße	Frankfurt	(EH+ 38 2018)
[3]	Licht + Luft	Tübingen	(EH+ 28 2016)
[4]	Cordierstraße	Frankfurt	(EH+ 24 2016)
[5]	Rotlintstraße	Frankfurt	(Großklos 2013)
[6]	Tevesstraße	Frankfurt	(Peper, Grove-Smith, Feist 2009)
[7]	Tevesstraße	Frankfurt	(Peper, Schnieders, Feist 2011)
[8]	Hoheloogstraße	Ludwigshafen	(Peper, Feist 2008]
[9]	Gartenstadt	Mannheim	(Schmidt et al. 2007)
[10]	Gördeler Straße	Karlsruhe	(EnSan-KA 2004)
[11]	Straße der Befreiung	Wittenberg	(FG Bau und Umwelt 2001)
[12]	Wißgrill	Wien	(Wißgrill)

Figure 5. Room temperature in the heating season of PHSP (in red) over heat energy consumption in comparison with other highly efficient apartment dwellings (reference areas may be different for the buildings).

was supplied until December 2019. The amount of water for flushing the toilet was in the range of 60 m³/month, but drinking water still had to be fed into the system, so that the cover ratio of toilet water consumption was between 30 and 40 %. The apartments in the new building were added from January 2020. As a result of which the water consumption for flushing toilets rose continuously to between 140 and 160 m³/month until March. The share of coverage fell to below 20 % in spring 2020 due to increasing consumption. In mid-July, another filter system was added. The cover ratio has increased as a result and was 68 % in September 2020.

If extrapolating the water consumption for toilet flushing from the values for the months March to September (period with full occupancy of the old and the new building) to one year, the consumption figure is 13.9 m³/(person*y). The average drinking water consumption for flushing toilets in Germany according to (BDEW 2020) is 12.3 m³/(person*y), the measured consumption is thus around 13 % above the national German average. Because of the corona pandemic, it must be taken into account that the tenants, especially the schoolchildren, were increasingly at home from mid-March 2020, which has an impact on consumption. However, only 8.6 m³/(person*y) of drinking water were used in the same period, the rest could be covered with treated grey water. This average cover ratio of 38 % should increase significantly in the future after the changes to the system in summer 2020.

DRINKING WATER CONSUMPTION

The drinking water consumption measured in the apartments includes both cold and warm water - the latter is heated directly in the apartment. A budget for drinking water was agreed with the tenants in the rental agreement, which was calculated depending on the number of people in the apartment: 25 m³/y for the first person, for the second person an additional 18 m³/y, for the third and fourth person 17 m³/y in addition and each additional person 15 m³/y extra. The mean drinking water consumption in Germany is about 46 m³/y. To reduce consumption, all draw-off points were equipped with water saving taps on site. The toilet flush is fed from the grey water system and is not included in the following figures.

Figure 6 shows the water budget and the actual water consumption for each apartment. The values scatter around the bisecting line. In the case of 8 apartments, the consumption is equal to or less than the flat rate, 14 apartments exceed the budget – but to different degrees. In total for the entire existing building, 1,593.9 m³ of water was used in the apartments, the total budget was 1,461 m³ and was thus exceeded by 9.1 %. However, the costs of exceeding the budget vary greatly from apartment to apartment. On average, this results in an additional purchase worth €94/y per apartment or €7.85/month, with the highest value being €18.14/month. Since the budget recording system did not go into operation until summer 2020, the tenants hardly had any feedback on their individual consumption, so that the expected consumption-limiting effect of the visualization was not yet able to take effect in this accounting year. In the case of tenants for whom the housing costs are covered by the municipality, the tenant only incurs additional organizational, but not financial, additional expenses. In these cases, too, the effects of purchasing water budgets cannot yet be estimated.

The total drinking water consumption in the apartments of 1,593.9 m³/y corresponds to a consumption of 21.0 m³/(person*y). According to (BDEW 2020), the average drinking water consumption in households in Germany without flushing the toilet is 29.2 m³/(person*y). Thus, in the PassiveHouseSocialPlus the drinking water consumption was 28 % lower.

ELECTRICITY CONSUMPTION

The apartments have already been equipped with particularly economical household appliances (A +++) by the landlord, and there is also complete lighting with LED lamps. A budget for household electricity per apartment was agreed with the rental agreement, which, depending on the occupancy, is based on the most economical efficiency class A of the household electricity index for Germany (Stromspiegel 2019): 850 kWh/y for the first person, additional 350 kWh/y for the second person and additional 300 kWh/y for each following person.

In Figure 7, the measured annual power consumption is plotted against the power budget of the respective apartment. The dotted diagonal shows where the consumption would be if it exactly corresponds to the budget. In 9 apartments the consumption is equal to or below the budget, 13 apartments exceed the budget, but usually only slightly. The sum of the household electricity consumption of the existing building is 36,489 kWh/y, the budget was set at 35,750 kWh/y – the total budget was thus exceeded by 2 %. Apartments that exceeded the budget had to buy additional contingents; the average of the apartments that exceeded the budget resulted in costs of €98/y or €8.19 per month, for the apartment with the highest additional consumption it was €20.78/month.

ELECTRICITY PRODUCTION

The photovoltaic systems on the existing building generated a total of 41,533 kWh of electricity in the period from November 2019 to September 2020, which corresponds to a generation of 23.7 kWh/(m²*y) or 963 kWh/kW_p. This value is approx. 18 % above the projected PV yield according to PHPP for the same period. Since the solar irradiation on the horizontal in the same period was 24 % above the long-term mean value of the weather station used for the yield forecast, the match is quite good, if you take the solar radiation into account.

The battery storage was installed in September 2019, but was out of service several times in the winter of 2019/20 and during 2020 it had to be disconnected from the grid several times due to the need to change cells. The storage unit was charged with a total of 3,058 kWh (this corresponds to 1.84 kWh/(m²*y)), and 2,152 kWh or 1.3 kWh/(m²*y) were withdrawn, resulting in a total storage efficiency of 70 %. This is well below the value

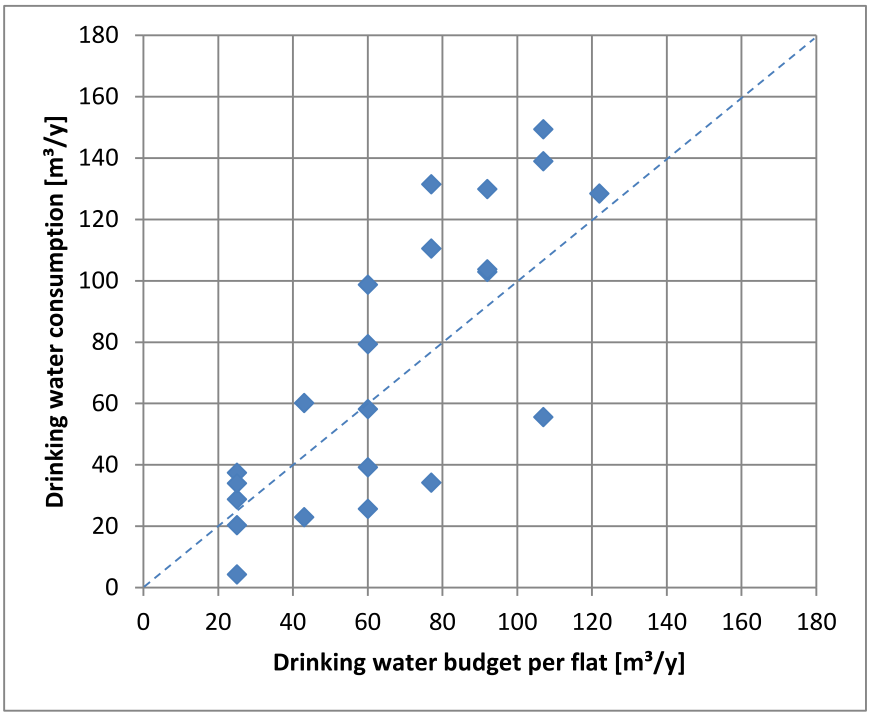


Figure 6. Drinking water consumption over budget for drinking water for each flat (annual values).

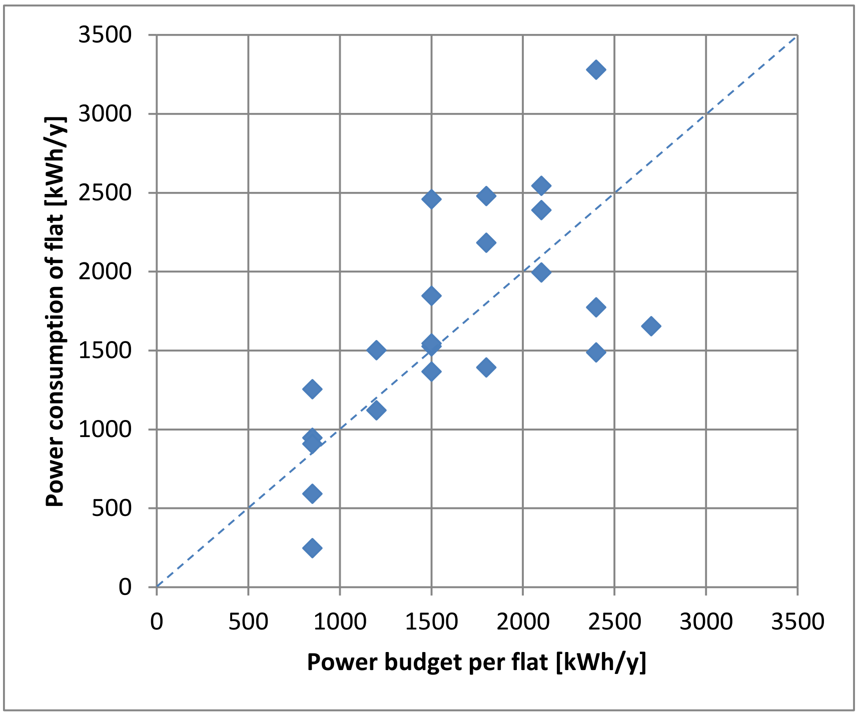


Figure 7. Power consumption over power budget of each flat (annual values).

of approx. 80 % estimated by the manufacturer. After the battery cells were replaced in October 2020, storage efficiency is expected to increase.

Of the 23.7 kWh/(m²*y) PV generation, 48 % was consumed directly in the building, the surpluses being fed into the grid. Together with the amount of energy taken from the battery, this results in self-consumption of 55.3 % for the entire period.

Higher self-consumption can hardly be expected, as the electric storage unit was designed to be very small with only approximately 18 kWh for 22 apartments for cost reasons. The degree of solar coverage for electricity consumption, i.e. the proportion of electricity consumption that can be covered by the PV system together with the battery storage, averaged 40 % in the eleven months, 50 to 60 % in summer and 10 to 20 % in (core) winter.

Construction costs

The construction costs of the new building (building envelope and systems engineering) of €1,734 €/(m² living space) are particularly low compared to the typical cost range for multi-family houses of the best national energy performance level (KfW Efficiency House 40) and are even within the cost range of new buildings according to the statutory minimum standard.

In the refurbished existing building, the costs for the ventilation system with heat recovery and roof renovation are within the expected cost range. The costs for the thermal insulation composite system, windows, heating system and basement ceiling insulation are slightly lower, and the costs for upgrading the existing heating peripherals and for basement ceiling insulation with cladding are slightly higher. The total costs for building envelope (including living space expansion) and systems engineering were €1,468/m².

The costs for the PV system were €1,234 per kW peak, whereby the elevation of the modules for the green roof increased the costs by €284. With a standard substructure, the installation costs for the PV system would have been €950/kW peak. Additionally, the battery storage in the existing building cost €1,291/kWh.

The grey water system incurred costs of €26,889 or €640 per apartment. With the actual interest rate of 0.6 %, maintenance costs of 2 % of the investment sum and a measured power consumption of 2,800 kWh/y, the coverage of the grey water system must be around 50 % in order to refinance the costs through savings, if the investor and user were identical (which is not the case here). The measured cover ratio is around 70 % after the system has been upgraded.

The total costs of budget recording and visualization were €2,953 per flat. The technology has largely been newly developed and still has considerable potential for cost savings. A significant reduction in costs is necessary for wider dissemination.

Conclusion and outlook

The measurement results show that energy-efficient refurbishment can achieve very low consumption also in social housing. Moreover, the running costs are 45 % below values of comparable tenant groups in the same city. At €6.50/m², the rents are well below the comparative rent of €10.06/m² at this location and are therefore affordable for poor people. In addition to the usual state subsidies, this was achieved through moderate construction costs of €1.487/m² for the building envelope and the system technology including PV system, battery storage and kitchen equipment (Großklos et al. 2021).

Due to the energy efficient building standard and the ventilation systems, the apartments have a comfortable temperature level and the tenants are continuously supplied with fresh air. This creates the structural prerequisites for a healthy living environment.

The results so far are largely unaffected by the consumption feedback, as this only went into operation in summer 2020. However, the consumption of electricity and drinking water is already in the range of the agreed, very economical budgets. Here, the values are to be compared with the consumption including feedback in the coming measurement periods. A tenant survey is also planned for winter 2021/22 in order to inquire about general satisfaction as well as tenants' assessments of the flat-rate billing of running costs and budgets.

In terms of power supply, the solar system together with the rather small battery storage provided approx. 40 % of the electricity consumption in the building. How big the influence of a larger battery storage is will be evaluated by surveying the roughly equal new building with more than twice the storage capacity.

The heat supply via district heating simplifies the system technology, but on the other hand there is no possibility for the building owner to influence the price and the greenhouse gas emissions per used kWh heat. For this reason, new concepts will be required in the future that also meet ambitious requirements for greenhouse gas emissions. Due to the low heat consumption, the prerequisites for the further development of the buildings towards a climate-neutral building stock have been created. However, the evaluation of the operating data for the heat and power supply also shows that there is optimization potential in these buildings too, which should be addressed in the future.

After the monitoring of these first buildings has shown good results, the next step is to disseminate and implement the ideas for reducing ancillary costs in cooperation with other landlords. In terms of the energy performance level, the conditions for this are quite good thanks to the current state subsidies. So far, however, investors hardly feel responsible for reducing the costs of drinking water or household electricity, and the legal hurdles for the supply of tenants with electricity by the landlord are also high. At this point, the legislature should also improve the legal conditions for reducing running and ancillary costs.

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