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Challenges on the way to a plus energy multifamily building: from planning to implementation

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Abstract

A climate-neutral building standard for new and existing buildings is essential for achieving climate protection targets in the residential building sector. In the BMWK-funded research project "sEnSys", a holistic energy supply concept for multi-storey residential buildings that achieve plus energy in the annual balance is being developed and implemented in a real demonstration building. The concept focuses on energy-efficient, grid-friendly and smart building technology, a predictive control strategy and cost-effective operation via suitable operator models (e.g., tenant electricity model).

Planning a plus energy building requires a holistic approach. Various aspects such as energy efficiency, the use of renewable energies, building regulations and user behavior must be taken into account. This complexity can delay or complicate implementation. When the planning is detailed, this complexity and investment costs can come to the centre of attention and cause a change in the planning that could have a negative impact on the plus energy balance. As a result, the preliminary target can be missed during implementation.

This paper shows an energetic, economic and ecological evaluation of the retrofit measures in the planning process of a demonstration building. The starting point is the preliminary planning, which moves further and further away from the initial situation as the project progresses due to changes in the building class and building technology. An assessment is made throughout of how the current planning status can be reconciled with the plus energy balance. In order to be able to make well-founded statements about energy consumption and the ecological footprint, calculations were carried out in accordance with DIN TS-12831 and DIN V 18599 and the resulting boundary conditions were used in simulations in the software TRNSYS. The economic viability of the retrofit was examined over a period of 25 years using the annuity method of depreciation.

Keywords: Multi-Storey Residential Building, Retrofit, Energy Supply Concepts, Energy and Climate Neutrality, Whole Life Carbon Emissions (WLCE);

1. Introduction

Global warming requires a significant reduction in greenhouse gas emissions across all sectors. The building sector contributes significantly to this (37%), both through operational emissions (heating, cooling, electricity consumption) and through construction and maintenance processes [1]. Increasing the renovation rate in existing buildings is one of the most effective measures for short-term emission reductions and, at the same time, an opportunity to improve comfort and life cycle quality. The renovation of multi-family dwellings is gaining importance in research [2-5]. However, there is a lack of universally applicable standard solutions, as framework conditions, building typologies and usage profiles vary.

In this context, the concept of plus-energy buildings (PEB) is gaining importance: through optimised building envelopes, efficient building services engineering, integrated renewable systems and intelligent

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operational control, energy requirements can not only be met, but exceeded [6]. A model retrofit of a multifamily building (MFB) into a PEB serves as a practical reference project that highlights feasibility, economic efficiency and obstacles, and acts as a demonstrator for further initiatives.

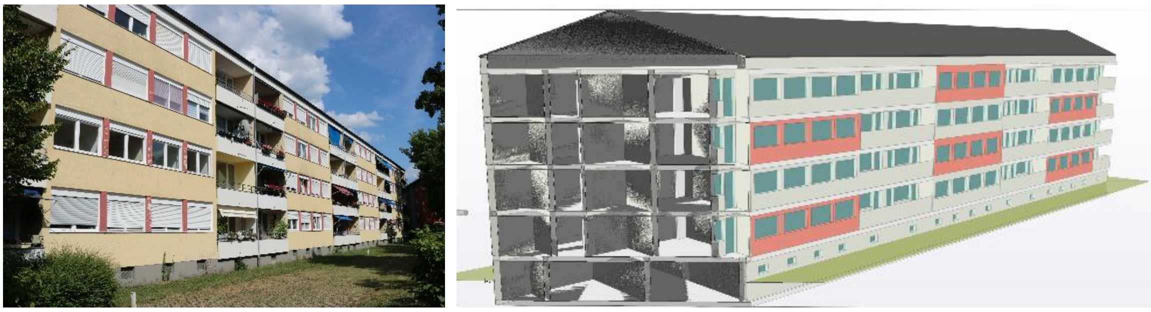
The aim of this paper is to present the planning process for a model retrofit that exemplifies how real-world conditions influence PEB status. Energy performance indicators, life cycle costs and CO_2 reduction potential are analysed in order to identify effective technical solutions (building envelope, building services, hydraulics) and barriers that stand in the way of widespread implementation.

2. Methods

This chapter describes the methodological approach underlying the planning and evaluation of the model renovation of the apartment building. The aim is to present the planning process, which maps different variants and systematically evaluates their impact on the PEB status, key performance indicators (KPI) and economic efficiency. TRNSYS 18 software is used to map the building and its technical systems. The energy-thermal simulation model is used to determine thermal and electrical consumption and to make the results of the nine planning variants comparable.

2.1. Demonstration building

The reference building is a MFB built in 1968/69, located in the city of Erlangen (Germany). The four-storey building (see Fig. 1.a) features a heated gross area of about 2600 m², 32 apartments, an annual heating demand of 180 kWh/m² and a gas condensing boiler. Erlangen has a design temperature of -13.2 °C [7,8], an average temperature of 9.8 °C and a solar yield of 1058 kWh/(m² y) [9]. The heating load of the existing building was calculated to 218 kW [8] and the annual delivered energy demand to 689 MWh [7].



a) b)

Fig. 1. (a) The reference four-storey residential building located in Erlangen, Germany. (b) IFC model as a digital twin of the reference building.

2.2. Planning process

This chapter describes the planning process for a model retrofit of an MFB and provides an example of how external conditions influence the PEB status. The approach is based on the systematic variation of key parameters such as weather/orientation, PV size, heat pump source (borehole/air), battery size, ventilation type (e.g., mechanical ventilation (MV) or window airing (WA)), radiators (rad) or floor heating (FH) and hydraulics (e.g., thermal energy storage (TES)). The starting point is the preliminary planning, which becomes increasingly distant from the initial situation as the project progresses due to changes in the building class and building technology. Factors influencing the planning process include the building owner's assessment of economic efficiency, the addition of other stakeholders such as energy planners, and changes in the framework conditions for government subsidies.

A separate planning variant is created for each variation, which is documented and evaluated in terms of PEB status, KPI and economic efficiency. Table 1 shows the specifications of the variants.

The starting point is the preliminary planning with Var1, which was initially intended to examine the possibility of implementation as a PEB. Therefore, standard weather data from DWD [9] for this climatic region (TRY13) was selected, the possible PV area was assumed to be 75% of the roof area and standard PV modules (nominal power south side: 320 W/module and north side: 150 W/module) were used, and 2400 kWh of household electricity per apartment was assumed. A battery with a nominal capacity of 100 kWh was selected. The building owner had initially planned a geothermal heat pump system and to retain the radiators (rad). The building envelope was selected to just meet the legal requirements of the efficiency house 55 (EH55), which means 55% of primary energy demand of minimum legal requirements.

Table 1. Specification of variants

Variants	Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var8	Var9
Weather	TRY13	Erlangen	Erlangen	Erlangen	Erlangen	Erlangen	Erlangen	Erlangen	Erlangen
PV in MWh	100	119	119	119	119	119	119	119	119
Building	m.l.r.*	m.l.r.	m.l.r.	m.l.r.	m.l.r.	Energy planner	Energy planner	Energy planner	Energy planner
HP source	borehole	borehole	air	air	air	air	air	air	air
Battery in kWh	100	100	100	70	140	70	70	70	70
Ventilation	MV	MV	MV	MV	MV	WA	MV	MV	MV
Heating	rad	rad	rad	rad	rad	rad	rad	FH	FH
Distribution	2 pipes	2 pipes	2 pipes	2 pipes	2 pipes	2 pipes	2 pipes	2 pipes	4 pipes
Num. of TES	1	1	1	1	1	1	1	1	2

*minimum legal requirement

Subsequently, location-specific weather data from the DWD was selected, the PV system was detailed on the basis of roof plans (nominal output: 430 W/module) and the orientation of the building was changed to a precise south-west location (Var2). For economic reasons, the building owner wanted to change the heat pump source to air (Var3). The used battery stacks (2^{nd} life batteries) offers only options of 70 kWh (Var4) or 140 kWh (Var5). In the next planning step, an energy planner was consulted, resulting in a slight change to the building envelope. However, the energy consultant decided against mechanical ventilation (MV), as the high investment costs could be avoided and EH55 requirements were still met (Var6). However, as a positive energy balance was not possible without MV, MV was added again in the next iteration step. In contrast to the heat recovery of Var1-Var5, the heat recovery was increased from 60% to 88% (Var7). In the building owner's further planning, the apartments were also to be modernised in addition to the energy-efficient retrofit. Therefore, floor heating was to be installed instead of radiators (Var8). In the final planning step, it was investigated whether the coefficient of performance of the heat pump could be improved by using a 4-pipe hydraulic system (Var9).

Due to uncertain conditions (interest rate developments, government subsidy programmes, legal requirements), the start of the renovation was repeatedly postponed and no plans were finalised by energy consultants and specialist planners. Therefore, this paper cannot yet present a final configuration or compare the simulation with measurement data from monitoring.

3. Results and Discussion

Fig. 2 shows the energy flows and consumption values for the nine variants. At the top, the PV generation and total electrical consumption as well as the negative or positive balance are shown. The first variant with less PV production and Var6 without MV have a negative balance. There is a slight increase in consumption from geothermal to air-to-water heat pumps. Window airing in Var6 shows a significant increase in consumption, resulting in a negative balance. Fig. 2 below shows the supply cover factor (SCF) and the load cover factor (LCF). The supply cover factor describes the ratio of PV and battery consumption to PV generation, while the load cover factor represents PV and battery consumption to total electrical consumption. In Var1, the SCF and LCF are quite high because a different household profile was used. In the other variants with the same household profile, good results are seen with geothermal heat pumps and large batteries with 140 kWh.

Table 2 shows the seasonal performance factor (SPF). High values are achieved when using a geothermal heat pump, as well as with FH and a hydraulic system with two separate storage tanks and 4-pipe distribution.

Fig. 3 shows the variants that were evaluated in terms of their total costs over 25 years (investment, operational cost as well as maintenance and servicing costs), primary energy consumption per year and global warming potential per year (GWP). Var6 with window airing stands out as it is significantly cheaper, but performs worse in terms of primary energy demand and GWP. The other variants are quite similar each other.

The costs range between 50 €/m²y and 60 €/m²y, primary energy between 33 kWh/m²y and 44 kWh/m²y, and GWP between 358 kgCO$_2$/m²y and 411 kgCO$_2$/m²y.

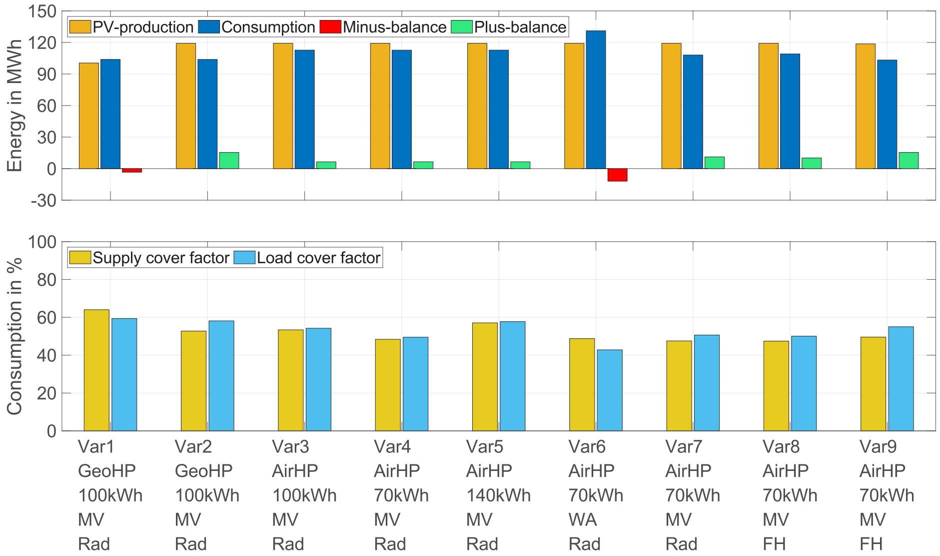


Figure 2. Energy production and consumption (top) and supply cover factor and load cover factor (bottom)

Table 2. SPF of the Variants

Variants	Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var8	Var9
SPF	3.21	3.90	2.87	2.87	2.87	2.75	2.78	2.84	3.62

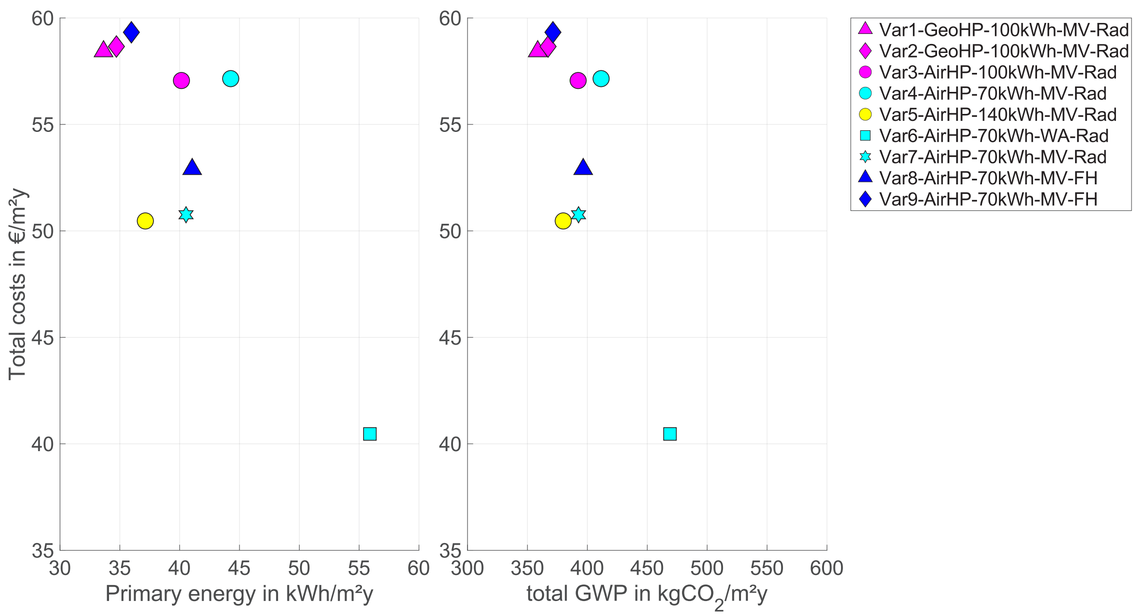


Figure 3. Total costs against the primary energy demand (left) and the total GWP (right)

4. Discussion and conclusions

This paper shows the planning process for the retrofit of an MFB. The starting point is the preliminary planning, which becomes increasingly distant from the initial situation as the project progresses due to changes in the building class and building technology. Factors influencing the planning process include the building owner's assessment of cost-effectiveness and the associated modification of components with high overall costs (e.g., geothermal heat pumps). Furthermore, other stakeholders are brought in during the planning process, such as energy planners, who neglect certain measures for achieving the PEB in order to focus on real feasibility. For example, breakthroughs during the installation of ventilation ducts in existing buildings can lead to consequential damage and costs if electrical cables that are not shown in the existing plans are damaged. Furthermore, changing conditions in government subsidies make it difficult to commit to specific components and measures during the planning phase.

Since the increase in key interest rates in 2022 [10], the rise in material prices in 2021 [11] and the increased legal requirements in the construction sector, the rate of new construction and renovation has fallen [12]. This project is also affected by this. Mainly, due to changes in the framework conditions for government subsidies, the renovation was repeatedly postponed by the building owner during the project period. As a result, no final technical planning was carried out and it has not yet been possible to simulate and evaluate a final variant. The start date for the retrofit cannot be determined either due to the framework conditions. As a result, this study was only able to examine the planning process and its impact on the PEB target.

The study shows that geothermal heat pumps and floor heating systems with separate hydraulics for hot water and heating deliver good results in terms of efficiency and LCF and make a positive contribution to the energy balance, whereas window airing is unable to achieve a positive energy balance. The size of the PV system and the use of an MV are decisive for a positive energy balance. In terms of total costs over 25 years, the variant with window airing stands out and achieves the lowest costs. Since 2nd-life batteries are used in this retrofit project, the investment costs are lower and a larger battery capacity also achieves very good results.

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