OPTIMIZATION STRATEGIES FOR THE USE OF HEAT PUMPS IN EXISTING BUILDINGS AS PART OF POTENTIAL ANALYSES OF SECTOR COUPLING

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Abstract

In the transformation of the building stock in Germany, which is still predominantly heated by fossil fuels, the extensive use of heat pumps promises considerable potential for integrating renewable energies through sector coupling. The content of a research network is therefore, among other things, to develop technical solutions and the necessary planning bases for a spread of sector coupling in order to realize a maximum of emission reduction without a costly grid expansion.

For the purpose of mapping scenarios of sector coupling in the Bavarian residential building stock, the present research work investigates, on the basis of typical single-family and multi-family buildings of different construction age classes, under which system configurations heat pumps can be used efficiently in existing buildings. With the help of thermal-dynamic simulations, implementation strategies are developed, starting from the installation of the heat pump and the reduction of the supply temperatures in the heating circit of the buildings, which compensate for the resulting comfort and efficiency deficits. Combined with the goal of being able to identify the least invasive measures possible to compensate for thermal deficit, the effects of adjusting the control system, adding additional heating surfaces and replacing radiators on the under-temperature hours were quantified.

The results show that in residential buildings of the construction age class after the introduction of the Second Thermal Insulation Ordinance, control adjustments alone allow a significant reduction in the supply temperatures with only minor losses in comfort, while in older buildings this requires considerable additional measures.

Introduction

The past year has clearly demonstrated that climate change is progressing rapidly and requires decisive action to reduce greenhouse gas emissions and adapt to climate change. The restructuring of the energy system is an urgent task. The research network "Energy - Sector Coupling and Micro-Grids", or "STROM" for short, develops technical, organisational, planning and regulatory solutions, to drive this change forward quickly. The integration of electricity into the heating and mobility sectors is a necessary prerequisite for significantly increasing the share of renewable energies in these sectors.

The current research work is carried out under the sub-project 9: Structural optimization of the existing building. The objectives of the sub-project are the generation of scenarios for the long-term development of the building stock with regard to sector coupling, energy demand and emission, costs, and impact of political and legal framework. In order to achieve these objectives, a Bavaria Residential Building Stock model based on building typologies are under further development, with the particular focus to map the developments in residential buildings in the context sector coupling, and in particular the conversion of the heat supply in buildings.

The current study aims to identify the applicability of heat pumps in existing residential buildings in Bavaria, without invasive measures on the building envelope, but with only the non-invasive required measures on the heating system to achieve efficient and economical operation with consistent comfort. The simulation of the operation of heat pump and room air temperature require thermal dynamic modelling of the buildings. However, due to the large scale and limited information regarding the building geometry, it is not possible to simulate all buildings using thermal dynamic modelling in the building stock model. Therefore, thermal dynamic simulations of the heat pump systems were carried out using a typical single-family house and a multi-family house of four different construction age classes (BAK: Baualterklasse) as defined by Institut Wohnen und Umwelt (IWU), namely BAK 58-68, BAK 69-78, BAK 79-83, and BAK 84-94 (Loga et al. 2015). The findings, which indicate which buildings can be heated by heat pumps when the room air temperature remains within "certain" limits under certain required measurements and costs, are to be used as boundary conditions for the Bavaria Residential Building Stock Model. In this paper, only the results from the single-family house in presented.

Bavarian Residential Building Stock Model

The Bavarian Residential Building Stock Model is a bottom-up building physics based model. The building inventory of the whole Bavaria is compiled from various data sources original from different surveys. The foundation is the living area census 1987, where number of existing residential buildings and living area in classification of building typology, building age class and heating type were recorded at the level of district in Bavaria. The development of yearly changes of the number of building and living area from 1987 to 2021, due to new builds and demolishment of old buildings, in each classification of the buildings, were implemented based on the data obtained from special analyses commissioned at the statistical state office. The development from 2022 to future is estimated according to statistical projections on population and living area pro person.

The area of each building envelop (e.g. external wall, roof, window, ground floor) was calculated using the simplified estimation method (Loga et al., 2005) and the thermal characteristics (e.g. U-values and g-values) of the building envelop of each building type in each building age class were taken from the German Building Typology from IWU (Loga et al., 2015). With these data, the yearly heating demand of each building can be calculated using DIN V 4108-6 (2003).

In order to take into account the improvement of thermal quality of building envelop due to building refurbishment over the years, the life cycle of the building envelop of each building was simulated. For each component of the building envelop, a synthetic development plan is determined up to a selected point in time based on the technical lifespan of the individual components. Based on the normal distribution, the failure times are calculated. Energetic renovation is then determined based on the predicted failure times so that the energetic renovation rates of each component is consistent with the observed statistical data. Motivated renovations, independent of factors such as weathering but driven by the building owner's motivation, are modeled through the exponential distribution ("memoryless").

Methodology

In order to access the operation of heat pumps in building of various construction ages and the required measurements to maintain the comfort room temperature, a typical single-family house model was constructed using the thermal dynamic simulation tool IDA ICE. The thermal properties of the building envelops of the four chosen BAKs in this study were then set according to the German residentail building typology (Loga, et al., 2015). The targeted air temepatures in different rooms were used to access if the thermal comfort can be maintained in the building. These values were selected so that the operative room temperture meets the requirements of the standard for heating load calcualtion (DIN V 4108-6). Necessary countermeausres were then introduced in the modelling when the thermal comfort in the building cannot be maintained. The effects of theses measures were then anlalysed and quantified.

Thermal dynamic building model

The geometry of the typical single-family house was taken from a study by Klauß (2010), where syntheic model buildings were derived from statistcal data and data from real buildings. The building type “single-family house_small” was chosen (Figure 3).

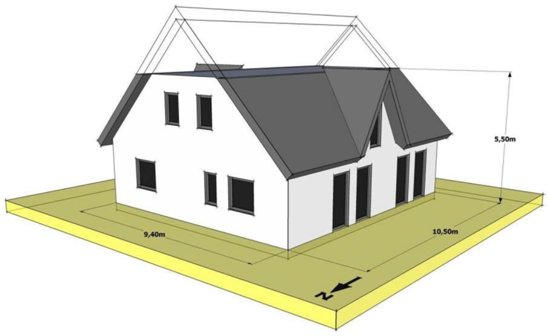

Figure 3: "Single-family house_small" - view north-west (illustration from (Klauß, 2010))

The simulated building has a usable area of 162m², which has been divided into three zones for the simulation (Figure 4).

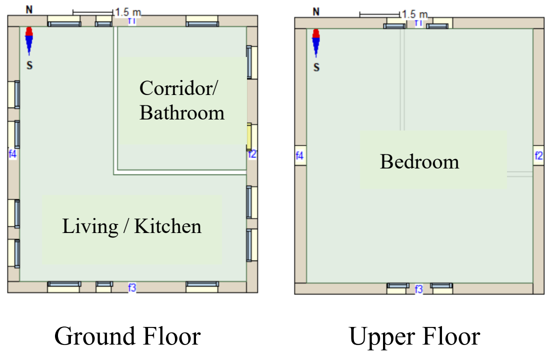

Figure 4: Floor plan of the building model in IDA ICE.

These are intended to represent three typical usage areas of a single-family house. The first floor contains a living/kitchen area on around two thirds of the area (54m²) and a zone representing the corridor and bathroom areas on around one third of the area (26m²). These areas were grouped together as they can be considered to have a lower, constant room temperature. The upper floor includes a zone as a sleeping area (82m²). The usable area would be somewhat smaller than a real single-family house due to the interior walls. For reasons of computing capacity and speed, it was decided here to divide the building only into "usage zones" and not into rooms. In principle, zone results are decisive for quantifying the comfort deficits, room simulation would also have been sufficient, however, in order to be able to quantify efficiency gains and costs for measures in the building stock model, the whole building was considered.

The orientation of the building was also taken from (Klauß, 2010). As can be seen in Figure 8, the gable ends of the building face north and south. The thermal bridge coefficient was assumed to be 0.1 W/m².K for all calculated building models. This corresponds, for example, to the assumptions from (Loga et al., 2015). Here, a thermal bridge allowance of 0.1 W/m².K was also assumed for all pre-1995 BAK. As it cannot be assumed that mechanical ventilation systems are present in existing single-family homes in the BAK under consideration, a constant air exchange rate of $n=0.7\ h^{-1}$ was assumed. This value is based on the specification for buildings not tested for tightness from DIN V 4108-6 (2003).

In addition to the heating energy requirement, the energy requirement for hot water heating is also included in this analysis. This is set at 20 kWh/m²a. It is distributed over the course of the day using a schedule that reflects living in a detached house.

The test reference year (TRY) for the Regensburg30 location was selected as the weather data set for this study. Test reference years represent the typical weather pattern over a year in the corresponding region in hourly averages. They are based on measurement series of weather data between 1995 and 2012. By averaging and interpolating over this period, these data sets are particularly suitable for mapping a typical weather pattern as part of a dynamic thermal building simulation, as they do not contain any extreme weather events.

Building envelop and heating distribution system

The compositions and thermal transmittance coefficients (U-values) and of each component of the building envelop for the four BAKs are specified in (Loga et al., 2015) (Table 1). These values were adopted for the simulation models. There are some

probable changes made to the buildings since the construction, for example, window replacement after aprrox. 25 years and insulation of the top storey ceiling, which have been taken into acount. This consideration is also suggested by the building sample from (Günther et al., 2020). Here, too, almost all of the buildings are no longer in the state of construction. Looking at the BAK buildings covered in this study, the windows have already been replaced in over 50% of the buildings built between 1958 and 1994. For this reason, the simulation models in this work are also created with windows that have already been modernized. In order to determine the heat transfer coefficient of the modernized window, a usage period of around 30 years was applied to the average year of construction of each BAK treated. A typical heat transfer coefficient for this period was therefore selected for the modernized windows.

Similarly, the design procedures and design temperatures of the radiators have also changed over the years (Table 2).

Table 2 Radiator design temperatures in four selected BAKs

Radiator design temperature supply/return [°C]			
BAK 58-68	**BAK 69-78**	**BAK 79-83**	**BAK 84-94**
90/70	70/55	70/55	55/45

This was primarily a matter of adapting to existing technologies and saving energy. Until around the early-1970s, for example, in correspondence to the standard applicable at that time, radiators were designed for 90/70°C . With the introduction of low-temperature boilers, 70/55°C was the recommended design temperature until the mid-1980s. It was later reduced further to 55/45°C for the use of condensing boiler technology (from around 1985) (Schramek,

Table 1: Composition and U-values for building envelops in four selected BAKs

	BAK 58-68		**BAK 69-78**		**BAK 79-83**		**BAK 84-94**	
	Composit.	**U-value [W/m².K]**	**Composit.**	**U-value [W/m².K]**	**Composit.**	**U-value [W/m².K]**	**Composit.**	**U-value [W/m².K]**
Roof	Pitched with 5 cm insulation	0.8	Flat with 6cm insulation	0.5	Pitched with 8 cm insulation	0.5	Pitched with 12 cm insulation	0.4
External Wall	Perforated bricks	1.2	lightweight perforated bricks	1	lightweight perforated bricks	0.8	Aerated concrete blocks	0.5
Window	Double-glazing	1.5	Double-glazing	1.2	Double-glazing	1.2	Triple-glazing	1
Ground Floor	Concrete with 1 cm insulation	1.6	Reinforced concrete with 2 cm insulation	1	Reinforced concrete with 4 cm insulation	0.8	Reinforced concrete with 6 cm insulation	0.6

2011). Accordingly, the radiators were also sized with these design temperatures in the simulation models for the individual BAK, in accordance with DIN EN 12831, whereby the individual zones of the simulations were considered as rooms within a building. In commonal practise, the radiators were oversized by 15% compared to the standard heating load. This oversizing represents an existing potential for optimization within the existing system, for example through hydraulic balancing (Wapler et al., 2018).

Heat pump model

For the initial simulations, a standard inverter-controlled air-to-water heat pump with a buffer tank is modelled for supplying space heating and domestic hot water, with a supply temperature of 55 $°C$. This supply temperature is chosen because the flow temperature must be set as high as possible, especially with older BAKs, in order to maintain the desired room temperatures with the existing radiators. In addition, 55°C is often the upper limit of the technical performance of standard heat pumps. The required hot water temperature is set at 55°C. The space heating flow temperature is adjusted to the weather via an outdoor temperature-controlled heating curve. In this study high-temperature heat pumps are not considered, as the coefficient of performance (COP) is significantly lower and a correspondingly higher electrical energy requirement is incurred.

For comparison purposes, a simulation is also carried out for each BAK with an ideal heat generator and ideal radiators in the zones. This makes it possible to easily identify any comfort or efficiency deficits in the simulations with the existing radiators and heat pump and to take appropriate optimization measures in the next step. It also serves as a comparative position for the annual heating energy requirement and is also used below to validate the simulation model.

Target temperature, limit temperature und under-temperature hour

The target temperature is the room air temperature, which was selected so that the operative room temperature meets the requirements of the standard for calculating the heating load of different zones. The limit tempeature is set at 1 K belowed the target temperature of each zone accordingly (Table 3). A under-temperatur hour is counted if room air temperautre is bellow the the limit temperature. With the tolerance range of 1K, a small comfort deficit compared to the target temperature is already permitted here. However, with this actually low deficit, it can be assumed that most residents of a single-family house will tolerate it for a few hours a year. In any case, the negative temperature peaks usually occur at night and therefore have hardly any influence on the perception of comfort in the living space.

Table 3: Target and limit temperature of living room and bed room

Living Room		Bed Room	
Target Temp. [°C]	Limit Temp. [°C]	Target Temp. [°C]	Limit Temp. [°C]
21.0	20.0	20.0	19.0

Procedure to assess the comfort deficits and necessary countermeasures

Step 1: Analysing what room temperature is reached in the buildings when a heat pump is installed with a supply temperature of 55 °C and when the supply tempeature is lowed to 45 °C. This step includes quantification of the deviations in the initial situation by visualising the under-temperature degree hours.

Step 2: Implementation of measures

- Measure 1: retrofitting of PI heating controllers for more efficient control of radiators or general control optimization of the heating system, which primarily involves adjusting the heating curve

- Measure 2: partial or complete replacement of old raditors to more efficient new low temperature radiators

- Measure 3: installation of additional heating surfaces in or on walls, ceilings and floors

Simulation Results

The results of a simple validation of the building models of the four BAKs are firstly presented. The annaul heating demand of the building models constructed in IDA ICE are compared to the values from the static monthly balance calculation in accordance with DIN V 4108-6. This is followed by the results from the initial simulations of the heat pumps, where the quantification of the deviaitons in the initial situation are presented by visulasing the unter temperature hours. Finally, the improvement of the thermal comfort, or more specifically the under-temperature hours, due to the implementation of the measurements are demonstrated.

Validation

For the validation of the building models, an comparisons of the annual heating demand calculated by the dynamic models in IDA ICE and by the static monthly balance method in accordance with DIN 4108-6 have been carried out. For a like-to-like comparison, the room temperature in the dynamic models were adjusted to 19 °C, the same as the room temperature set in the static monthly balance method. It should be noted that in the later part of the analysis, the simulations of the heat demands in dynamic models were again carried out with the previously defined room temperatures (Table 3) in order to maintain comparability with the all simulation variants.

Table 4 shows the annual heat demand for the various BAKs from the thermal-dynamic simulation and according to the static calculation method in accordance with DIN V 4108-6. The statically determined annual heating energy requirements are very consistently around 16% higher than the dynamically calculated ones. It is known from the literature that the deviation between statically and dynamically determined annual heating energy requirements is between 15 and 20% (Leindecker et al., 2014; Sumereder, 2013). These deviations result primarily from the consideration of the building's own storage masses within the thermal-dynamic simulation. The data shown here is within this range. It can therefore be assumed that the simulation boundary conditions applied here lead to reliable and consistent results.

Table 4: Comparison of the annual heat demand of the IDA ICE model with the DIN V 4108-6 method

BAK	Annual Heat Demand [kWh/a]		Deviation [%]
	IDA ICE	DIN V 4108-6	
58-68	34,358	41,204	16.6
69-78	29,921	35,625	16.0
79-83	27,238	32,590	16.4
84-94	22,064	26,244	15.9

Results of initial simulations

A general look at the summarized simulation results (Table 4) clearly shows that the specified room temperatures cannot be maintained in the older two of the BAKs under consideration. This results in a large number of under-temperature hours, and in the case of BAK 58-68 covers nearly the entire heating period. These occur because the maximum heat output of the radiators is considerably reduced by reducing the flow temperature, specially in BAK 58-68, as the difference between the design and operating flow temperature of the radiator is greatest here. The reduction in flow temperature from 90°C to 55°C results in a reduction in peak output of around 59%. As a result, the radiators are no longer able to cover the room heating load. What is also noticeable is that in the two older BAKs, the annual heating energy requirement of the "55" and "45" variant is significantly lower than that of the "ideal" variant. This is also due to the reduced output of the radiators as a result of the flow temperature reduction. The heat transfer system cannot transfer the required amount of heat to the room.

On contrast, at a flow temperature of 55°C , the average room air temperature in both living room and bedroom in BAK 84-94 can be maintained at 20°C throughout the year, and even the target room air temperature of 21°C in the living room is only undershot in a few exceptional cases. In this simulation variant, there are no under-temperature hours for both zones (Table 4).

Figure 5 and Figure 6 figures show the temperature differences between the limite temperature and the room air temeprature of the living room, over the simulated period of one year, under the two supply temperatures at 55 °C and 45 °C respectively. In contrast to purely counting the under-temperature hours, the under-temperature degree hours of can be be visualised in these two graphs. A under-temperature degree hour [Kh/a] is the product of the temperature falling below the target temperature and the duration of the fall below the target temperature. It therefore indicates not only the frequency but also the severity of the undershoot. In relation to Figure 5 and Figure 6, it is therefore the sum of all values below the setpoint temperature.

In the case with a supply tempeature of $55°C$, the number of undertemperature hours and the undertemperature degree hours correlate quite well. It can be clearly seen that the BAK 58-68, with an under-

Table 4: Summarized results of the initial simulations

BAK	Variant	Heat Demand [kWh/a]	Heat Pump SPF	Living Room		Bedroom	
				min. Temp. [°C]	under-Temp. Hour [h]	min. Temp. [°C]	under-Temp. Hour [h]
58-68	ideal	38,135		21	0	20	0
	55	31,387	3.1	16.2	5,557	17	3,399
	45	25,638	3.5	12.8	6,202	13.3	4,995
69-78	ideal	33,282		21	0	20	0
	55	31,896	3.1	19.3	398	18.9	3
	45	28,222	3.6	17.1	5,486	17.6	2,574
79-83	ideal	30,319		21	0	20	0
	55	29,427	3.1	19.3	179	19.6	0
	45	26,601	3.5	17.7	5,098	18.2	1,315
84-94	ideal	24,607		21	0	20	0
	55	24,759	3.1	20.1	0	20.3	0
	45	24,119	3.6	19.7	42	19.9	0

temperature frequency of 5557 h/a (Table 4) and 11198 Kh/a under-temperature degree hours, does not reach the limit room temperature in the living zone for most of the year. In contrast, the other three BACs (69-78; 79-83; 84-94) with significantly lower under-temperature frequencies (398 h/a; 179 h/a; 0 h/a) also generate lower under-temperatures in terms of intensity (82 Kh/a; 30 Kh/a; 0 Kh/a).

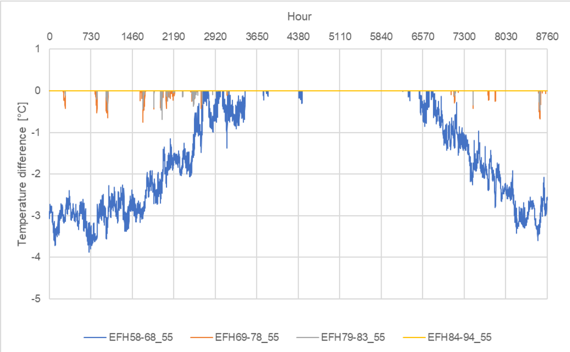

Figure 5. Yearly tempeature difference between the room air tempeature and the limit tempeature of the living room with a supply temperature of 55 °C.

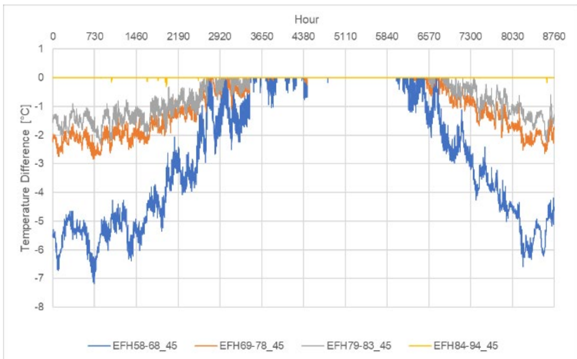

Figure 6. Yearly tempeature difference between the room air tempeature and the limit tempeature of the living room with a supply temperature of 45 °C.

The situation is different for the case with a supply temperature of 45°C. Here, in both cases, high under-temperature frequencies are achieved in the living room in the BAK 58-68 and 69-78. However, the under-temperature degree hours show that the severity of the undershoots is significantly lower in BAK 69-78. There are only 7950 Kh/a of undertemperature degree hours, whereas in the BAK 58-68 there are 22104 Kh/a of undertemperature degree hours. It can also be clearly seen in the visualisation that the deviations in BAK 69-78 are significantly lower than those in BAK 58-68, which leads to the conclusion that despite the high number of overtemperature hours, this problem can generally be solved with less refurbishment effort than in BAK 58-68.

Results of measure implementation

The summarized results of the implemented measures are presented in Table 5.

BAK 84-94

The BAK 84-94 can be converted to a heat pump without major effort and with minimal invasiveness for both supplying temperatures. The only optimization measure required here is the control-related adjustment of the heating curve. This ensures that the radiators, which are slightly undersized due to the flow temperature ranges can emit enough heat to the room to fully meet the specified comfort targets.

It is therefore possible to reduce the flow temperature to 45°C without any problems in order to also increase the overall efficiency of the heat pump system to a good level (SPF: 3.5). This efficiency can be further increased by using ground source heat pump. Here, the system described above with a system system temperature of 45°C can be increased to a SPF of 4.2.

Table 5: Summarized results of the implemented measures

BAK	Supply Temp. [°C]	Implemented Measures	SPF	
			ASHP	GSHP
84-94	55	heating curve adjustment	3.1	3.7
	45	heating curve adjustment	3.6	4.2
79-83	55	heating curve adjustment	3.1	3.7
	45	heating curve adjustment + radiators replacement (part)	3.5	4.2
		heating curve adjustment + additional panel heating (14 m^2)	3.5	4.2
69-78	55	heating curve adjustment	3.1	3.7
	45	heating curve adjustment + radiators replacement (part)	3.5	4.2
		heating curve adjustment + additional panel heating (29 m^2)	3.5	4.2
58-68	55	heating curve adjustment + radiators replacement (all)	3.1	3.7
		heating curve adjustment + additional panel heating (37 m^2)	3.1	3.7
	45	heating curve adjustment + radiators replacement (all) + additional radiators	3.5	4.2
		heating curve adjustment + additional panel heating (109 m^2)	3.5	4.2

BAK 79-83

These statements can also be applied to the BAK79-83 with minor restrictions. However, the system temperature can only be reduced to 55°C if only the heating curve is adjusted. If further reduce of supply temperautre to 45°C, it will be necessary to replace several existing radiators to heat pump radiators in the hallway and living area.

Alternatively, smaller panel heating systems (hallway: 4 m²; living room: 10 m²) can be installed. If a flow temperature of 55°C is chosen, a SPF of only 3.1 can be achieved. Replacing the radiators and consequently reducing the flow temperature to 45°C enables an increase in the SPF to 3.5. For both cases, an increase in efficiency to a SPF of 3.7 (T_{supply}=55°C) or 4.2 (T_{supply}=45°C) can also be reached through the use of a ground source heat pump.

BAK 69-78

The same applies to BAK69-78. It is possible to reduce the flow temperature to 55°C by adjusting the heating curve. To reduce the flow temperature to 45°C, however, a somewhat greater effort is required in this case. Again, replacing raditors is the preferred option, and in this case, two radiators in the living area and both radiators in the hallway need to be replaced with efficient low temperature radiators. Alternatively, additionally installed surface heating must be increased to 25 m² in the living area zone. In the hallway zone, 4 m² is still sufficient. With a reduced flow temperature of 45°C, a SPF of 3.5 can be achieved. At 55°C it is only 3.1. Here too, an increase to 3.7 or 4.2 is possible by using a ground source heat pump.

BAK 58-68

In BAK 58-68, a very high level of effort is required overall to convert the building for heat pump use. To reduce the flow temperature to 55°C, the heating curve must be adjusted and radiators replaced. All existing radiators in the building must be replaced with new heat pump radiators. If this result is also to be achieved with additional panel heating, 22 m² of ceiling heating would have to be installed in the living area alone. In the hallway zone it would be 3 m² and in the sleeping zone 12 m². By reducing the temperature to 55°C, a SPF of 3.1 (ASHP) or 3.5 (GSHP) can be achieved. If the temperature is to be reduced further to 45°C, the existing radiators must be replaced with larger radiators and two completely new radiators must also be installed in the bedroom zone. Alternatively, 50 m² of ceiling heating would have to be installed in the sleeping zone, 9 m² in the hallway zone and 50 m² in the living zone in addition to the existing heat transfer system. At this system temperature, a SPF of 3.5 (ASHP) and 4.2 (GSHP) can then be achieved.

In general, it must be said here that the effort required to maintain the old heat transfer system does not make sense for any of the variants in BAK 58-68. Since an additional surface heating system as large as the floor area of the actual zone would have to be installed to reduce the system temperature to 45°C in the residential zone, it must be noted from a technical point of view that the efficiency gain achieved is disproportionate to the effort required. Although a reduction to 55°C is technically feasible, the resulting low efficiency does not justify the expense of the conversion.

Conclusion and outlook

In this paper, thermal-dynamic building simulation was used to investigate whether heat transfer systems in existing single-family homes of various construction ages can continue to be operated when converted to heat pumps without prior façade renovation. Furthermore, various strategies were shown as to how this can be achieved using building and control technology. To this end, the results from the building simulations were examined with regard to comfort and efficiency deficits in order to subsequently develop optimization strategies for the operation of the heat pump system based on the knowledge gained. Finally, the strategies developed were also examined in terms of costs in order to include both technical and economic criteria in the development of the optimization strategy.

In general, it can be stated that the under-temperature degree hours are a very good measure of how much and by what means the heat transfer system needs to be changed. It can be assumed that with a small number of under-temperature degree hours, the comfort deficits can be eliminated by smaller additional heating surfaces, selective radiator replacement or control adjustments. A further finding from the comparison of the under-temperature degree hours is that the design temperatures of the existing heating system are a decisive factor in determining whether operation with a heat pump at low system temperatures is feasible.

The results show that it is possible for the majority of existing buildings of the investigated building age classes to be operated with a heat pump without renovating the building envelope. However, the effort involved in upgrading and modifying the existing heat transfer system increases significantly for older buildings. While in BAK 84-94 the existing heat transfer system can continue to be operated with a high flow temperature of 55°C as well as with the reduced flow temperature of 45°C without structural changes, from BAK 79-83 structural changes or additional measures must be carried out by additionally installing panel heating systems in order to be able to operate the heat pump at an efficient flow temperature of 45°C. At 55°C, it is sufficient to adapt the system to the new flow temperature. At 55°C, it is sufficient to adjust the heating curve in the medium temperature range (0°C-10°C), which was also carried out in the BAK 84-94.

In the BAK 69-78, the comfort targets could also be achieved at 55°C flow temperature by adjusting the heating curve. The air-to-water heat pump used achieved a COP of approx. 3.1 at a flow temperature of 55°C. If the system temperature is reduced to 45°C, the efficiency can be increased and the COP rises to approx. 3.6. It can be concluded that an air-to-water heat pump can be operated in the BAK 69-78 and 79-83 without any structural changes to the existing heat transfer system. However, the efficiency here tends to be in the lower range. It is only really efficient when the system temperature is reduced to 45°C. This can only be achieved in BAK 84-94 without structural changes to the existing heat transfer system.

In general, it should be noted that without retrofitting the building envelop, the buildings still have a very high annual heating demand. Although the installation of a heat pump system significantly reduces the final energy requirement and therefore also CO_2 emissions, this is still significantly higher compared to a building whose façade has been refurbished in accordance with GEG. If these solutions were scaled up to the entire building stock, the electricity requirement for heat pumps is far too high to be covered by the current German electricity grid. Not only capacity problems due to a lack of grid expansion play a role here, but the renewable electricity that would be needed to make the switch to heat pump systems sensible and sustainable in the first place is not yet available in sufficient quantities. In order to counteract this problem and to create a comparative value of how the buildings considered here compare to the GEG variant, a PV system was designed for each variant, which compensates for the difference in final energy demand between the variant considered here and the GEG variant. The size of the PV system thus directly reflects the size of the difference to the GEG variant. The use of PV electricity proved to be the economically better alternative for all variants.

In conclusion, it remains to be said that the majority of the optimization variants considered here cannot be implemented in reality in a meaningful way. Although it is technically possible to operate buildings from all the BAK considered with a heat pump at individual building level without renovating the façade, the costs for older buildings are very high and the benefits are low due to the persistently high annual heating energy requirement. This is because this immense demand for renewably generated electricity could not currently be met at the level of the entire building stock. The strategy for refurbishing the building stock must therefore continue to focus on reducing heating energy requirements. To this end, optimized considerations for the refurbishment of the the heating system, as well as building envelope, must increasingly continue in the future.

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