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Thermal insulation and heat pumps - why the two belong together

Study commissioned by the Association for Insulation Systems, Plaster and Mortar e.V.

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1. Summary

Building insulation is a fundamental pillar for achieving climate protection goals in the building sector. The more decisively the heat demand of buildings is reduced, the more likely and easier the transition to renewable heating becomes. Especially in combination with heat pumps, insulated buildings offer significant advantages. If these are not utilised, the overall goal achievement is at risk. This report demonstrates the effects of ambitious building insulation on multiple levels.

In the Building

- Synergy through dual effects of thermal insulation: reducing heat demand and increasing heat pump efficiency.
- The energy price shock hardly affects insulated buildings.
- The worse a building is insulated, the more difficult it is to install a heat pump.
- Buildings can be insulated step by step so that they are prepared for the transition to the heat pump at the crucial moment.

In the Energy System

- Synergies through the dual effect of thermal insulation: reducing the required heating power and increasing storage capacity leads to a significant relief of the power grids.
- Insulated buildings are more resilient to unforeseen events.
- Thermal insulation offensive: The more ambitious the heat demand is reduced, the more realistic the transformation path for renewable energy supply becomes.

1.1. Synergies through Building Efficiency

Heat pumps can heat buildings particularly efficiently. With the use of one kilowatt-hour of electricity, they can provide three or more kilowatt-hours of heat. Therefore, they are a mainstay of decarbonisation in the building sector. In most scenarios, heat pumps will become the new standard technology. Heat pumps achieve their highest efficiency in well-insulated buildings. In uninsulated old buildings, their efficiency drops by more than a third compared to a very good building. In uninsulated buildings, more powerful and thus more expensive heat pumps are needed. However, they operate in a suboptimal condition and cannot realise their potential. Improved thermal insulation in these buildings has a dual effect: it reduces the heating energy demand of the building and enables more efficient operation of the heat pump. A leverage effect or synergy arises. A reduction in heating energy demand by 18% can result in a reduction in heating costs by 37%.

Improved thermal insulation significantly helps to mitigate the effects of the energy price increase. The prices for natural gas, heating oil, and consequently also electricity, have risen sharply in 2022 due to the Russian invasion of Ukraine. For residents of uninsulated old buildings, this results in additional costs of several thousand euros (example calculations for an apartment: €1,574, for a single-family house €2,464). They are 6 to 10 times higher than in the best building class A+ (apartment: €170, single-family house €370).

A better thermal insulation also eliminates some technical problems that can arise when installing heat pumps in existing buildings. Heat pumps work best at low flow temperatures and with high flow rates. Both are more difficult to realise the worse a building is insulated. The result is high electricity consumption by the heat pump and the heating circuit pumps. By replacing radiators, the flow temperature can be reduced. However, the underlying problem - the too high heat demand of the building - is not improved. From the point of view of the building owners, replacing radiators initially involves a lower investment than an insulation measure. From a climate protection perspective, insulation measures are indispensable in the medium term at least. Therefore, it would be more sensible to specifically carry out the appropriate insulation measures before installing the heat pump so that the heat pump can function smoothly. The radiator replacement can then be saved if necessary, and a smaller, more cost-effective heat pump can be chosen. To ensure that the building owners are not financially overwhelmed by this, they should receive targeted funding for renovation measures that prepare the house for heat pumps and other renewable energies (NT ready standard).

1.2. Synergies through Energy System Efficiency

The complete decarbonisation of buildings requires the conversion of previous fossil heating systems to decarbonised energy sources, probably electricity. Such a conversion will require large amounts of additional electricity, especially in winter. As renewable energies are not available indefinitely, the total heat demand has a significant impact on the extent and distribution in which they can be used. Many renewable energies can only be used sensibly and economically in efficient buildings. This means that the potential of renewable energies in the building sector can only be fully realised through efficiency.

The heat pump offensive is correct and leads to a climate-neutral building stock. However, when switching to heat pumps, the triangle of supply of renewable energy – system technology – thermal insulation must be balanced in all points.

Figure 1 shows the interaction between a future-oriented, efficient building envelope and the climate-politically important expansion of the electrification of building heating. Many renewable heating technologies will have to achieve an ambitious market ramp-up as part of the heat transition. According to current estimates, especially older buildings (built before 1995) are not yet prepared for efficient use of a heat pump. If there are not enough efficient buildings in stock, the growth rates of renewables cannot be achieved. However, since heating systems have a significantly shorter lifespan than the components of the building envelope, the regular renewal process for heating systems often takes place independently of a parallel renovation. For the successful implementation of the heat pump offensive, sufficient suitable buildings must be available. Efficiency measures on the envelope, however, have an advantage over renewables – both in terms of market presence and market penetration. Due to the existing capacities, they could cover a strongly growing market without problems. From an economic perspective, efficiency creates higher robustness and resilience.

By installing grid-friendly heat pumps in combination with a corresponding building envelope and on-site energy generation (solar roof obligation), grid-efficient buildings can ensure an economically sensible building operation. Buildings are transformed from consumers into flexible energy sources and storage, without losing comfort and convenience for the user.

This means:

- Buildings must be at least low-temperature ready in the first step (before installing a heat pump) to ensure technical functionality.
- In the long term, buildings must be modernised to at least the level of individual measures funding in the BEG (Federal Funding for Efficient Buildings), otherwise, energy costs will escalate and the supply of renewable energy will not be sufficient for all buildings.
- Further energy modernisation is beneficial for building owners and the power grid, but it should remain at the discretion of the homeowners (no regulatory requirement).

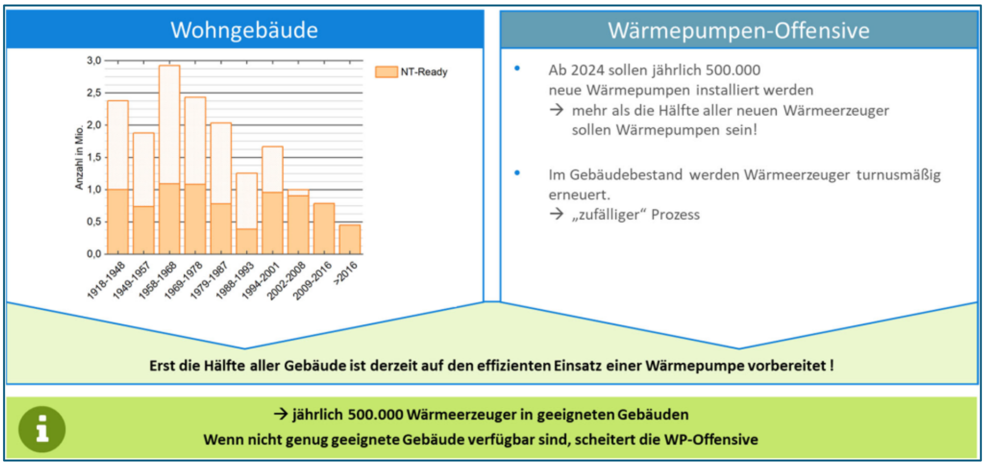

Figure 1: The number of sufficiently efficient existing buildings also determines the growth rates of renewable heating, especially for heat pumps.

The massive expansion of electric heating systems will shift the main load of electricity demand to winter. This new and changed demand will require investments in capacities as well as in the transmission and distribution infrastructure. Better structural thermal insulation reduces heating energy consumption and thus the number of necessary wind turbines and PV systems significantly.

However, not only the amount of electricity but also the question of when we need how much electricity and the interaction between grid and building is increasingly coming to the fore. The associated reduction of the necessary heating load through efficient buildings has been little considered. Especially with heat pumps, the necessary heating load determines the investment costs. The heating load also has a significant impact on the power grid. Too high peak loads can overload the local power grid. Low heating loads, which can be achieved due to system-friendly thermal insulation, guarantee grid stability. The interplay of demand flexibility and energy efficiency potential could significantly reduce the necessary additional investments.

Figure 2 illustrates how efficiency, generation, and load shifting can be combined to reduce the heating load of a building. It also shows how these coordinated mechanisms contribute to demand flexibility. A key prerequisite is that the building has a well-insulated and airtight envelope and an efficient heating and ventilation system to reduce energy demand. This is associated with lower energy costs and reduced greenhouse gas emissions. Additionally, without compromising comfort, demand shifting can moderate the demand curve of a building, i.e., energy consumption is shifted from peak times to other times to lower both costs (with time-of-day electricity tariffs) and grid load. Loads can also be shifted to ensure better utilisation of volatile electricity generation from renewable energies. In uninsulated buildings, the room temperature drops significantly below the comfort criterion within 2-3 hours, while buildings with adequate thermal insulation can bridge blocking times of up to half a day without problems. This means that the installation of grid-friendly heat pumps in combination with a corresponding building envelope and on-site energy generation (solar roof obligation) allows for grid-efficient buildings, making them economically sensible from an energy perspective.

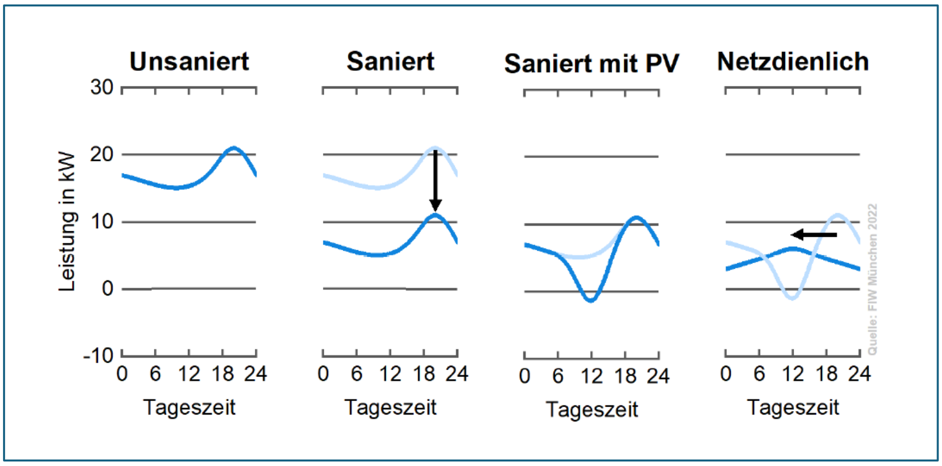

Figure 2: Interaction between the grid and the building: well-insulated buildings can shift the peaks in the heating load to the "more favourable hours".

In 2030, the building sector must emit only 67 million tonnes of greenhouse gases – 42% less than in 2021. The ambition of the climate protection goals becomes clear with scenario calculations. It shows that in the foreseeable future, there will be few alternatives in heating technology – mainly heat pumps and heating networks. However, even a very ambitious ramp-up of these two technologies will not be enough to achieve the goals for the building sector. The heat consumption must also be significantly reduced. Only in this way will it be possible to supply as many buildings as possible that are not yet heated by renewables with the still "allowed" amount of fossil fuels. The worse the thermal insulation in 2030, the fewer buildings can be heated with the remaining natural gas and heating oil, and the more heat pumps must be installed. Renovations must reach at least the thermal insulation level of individual measures in the BEG funding or better as quickly as possible. Then nearly 6 million heat pumps will suffice, as envisaged in the heat pump offensive. If the renovation requirements rise only to the level of an efficiency house 70 – as announced in the coalition agreement – we will already need 8 million heat pumps by 2030. This would require that every newly installed heat generator today be a heat pump.

Because the timing of the highest electrical load is no longer coinciding with the highest electricity production, the infrastructure expansion must be proactive and parallel to the heat pump offensive. Buildings with good thermal insulation significantly reduce electricity demand and peaks in winter. Above all, buildings that are not yet prepared for the installation of heat pumps today must be proactively energetically upgraded accordingly. Heat pumps should be installed today primarily in buildings that already have good thermal insulation. Heat pumps themselves should mandatorily be grid-friendly and equipped with control algorithms that ensure an economically sensible operation from an energy perspective (Figure 4).

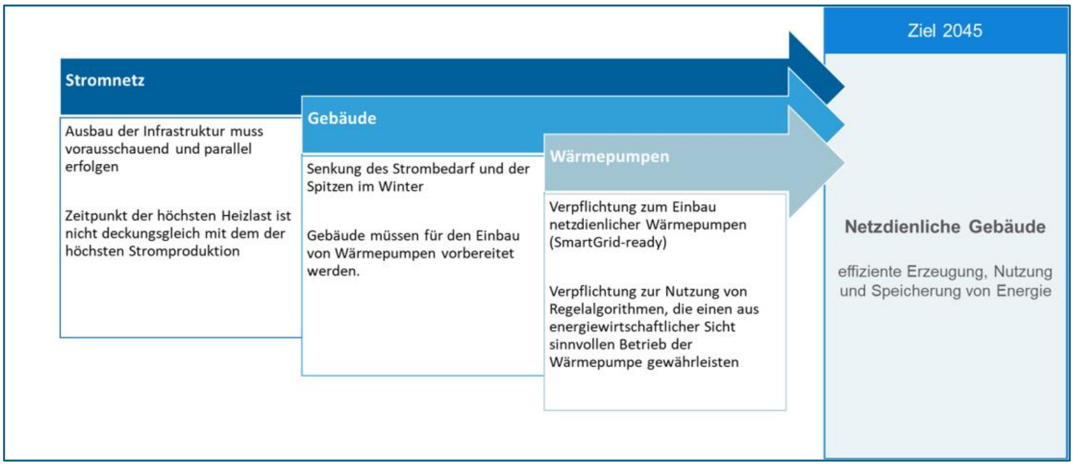

Figure 3: Target-compatible buildings require an interplay between the electricity grid, an efficient building envelope and grid-compatible heat pumps.

In summary, it can be said that the energy transition and thus the goal of a climate-neutral building stock can only be achieved if, above all, electrically heated buildings ensure efficient generation, use, and storage of renewable energies. This requires a coordinated system of a powerful power grid, efficient buildings, and grid-friendly heat pumps. Energy efficiency and demand flexibility offer both direct and indirect benefits for the building sector. The energy efficiency of buildings leads to higher user comfort with lower energy consumption. Energy efficiency strategies that target the building envelope also offer significant reserves for stabilising electrical grids and serving negative residual loads. The demand flexibility of well-insulated buildings allows shifting heating load peaks to "cheaper" hours, and the grid-friendly reduction (or increase) of room temperature and thus thermal comfort occurs much more slowly in highly insulated buildings. Even in the event of grid overload, well-insulated buildings are less vulnerable than uninsulated or poorly insulated ones.

2. Background and objectives

The necessary instruments of the federal government to achieve the goal of a climate-neutral society by 2045 are clearly and unequivocally formulated in the coalition agreement from 2021. In addition to the necessary installation of 5 - 6 million heat pumps by 2030, 15 million fully electrified passenger vehicles and 1 million public charging points are to be added in this period. Through electric cars and the electrification of buildings, electricity demand will rise significantly. The increasing dependence on electricity will place new demands on the power system. Many consumers also generate or store their electricity on-site, so power flows in the grid will increasingly go in both directions. This is likely to quickly lead to a significant, previously little-considered additional electrical load discussion.

Electric heating systems will shift the main load of electricity demand to winter. This means not only more wind turbines and PV systems for the power grid but a completely different system. The question of when we need electricity and the interaction between grid and building is increasingly coming to the fore.

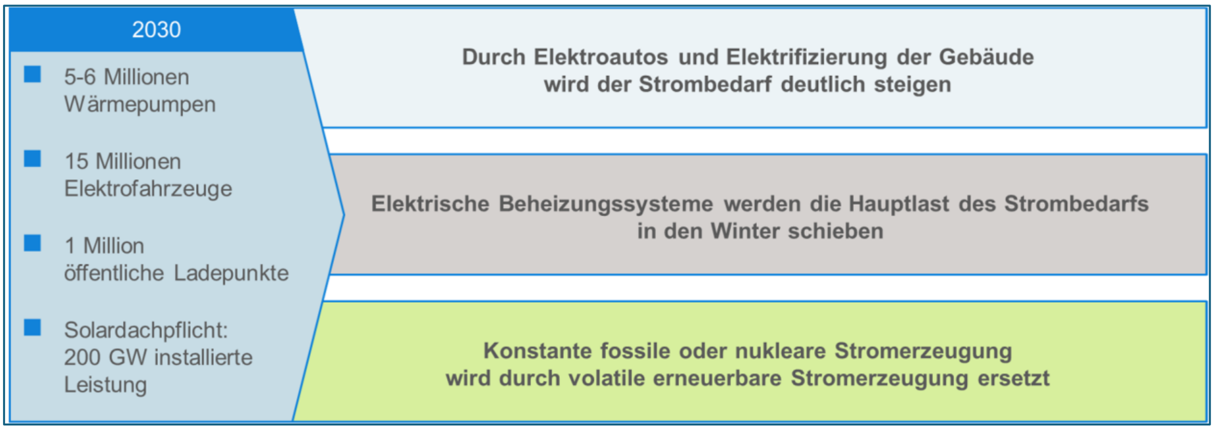

Figure 4: The political goal formulated in the 2021 coalition agreement will lead to a significantly changed electricity grid.

Buildings have the potential to significantly support the integration of renewable energy resources by balancing the fluctuations of wind and solar power generation through flexibility on the demand side.

It is undisputed that for this ambitious goal, both consumption reductions through structural thermal insulation and renewable energies on a large scale are necessary. However, there has so far been no consensus on the most cost-effective ratio of efficiency and renewable energies. It was also believed that a lack of energy efficiency could be compensated for with renewable energies and synthetic gases (power-to-gas). In an extreme form, there was talk of "insulation madness," "national insulation," and the nation of "poets and insulators."

The economic benefits of building envelope energy efficiency were extensively examined by ifeu together with Fraunhofer IEE and Consentec in a study for Agora Energiewende (ifeu et al. 2018). By coupling four models, the economic advantages of a combination of high efficiency and renewable energies were worked out: the total economic costs are lower when efficient building standards are combined with renewable energies, infrastructure costs are lower, import risks and price volatility are reduced, and national value creation is increased.

It is often overlooked that the thermal energy demand of buildings offers significant reserves for stabilising electrical grids and serving negative residual loads. The energy supply of buildings should, therefore, exploit these potentials as much as possible.

In this study, it will be shown that heat pumps and energy savings through better thermal insulation, as well as other efficiency measures (heat recovery; increasing air tightness, etc.), together achieve efficiency increases that a single technology alone could not achieve. This synergy between heat pumps and thermal insulation is crucial for the heat transition in Germany. Without it, the highly ambitious and indispensable climate protection goals cannot be achieved. To illustrate the importance of this synergy, the interaction of thermal insulation and heat pumps will be analysed at both the individual building and energy system levels.

As a consequence of this role of thermal insulation as one of the main pillars of the heat transition, the key points for a thermal insulation offensive are presented to ensure the achievement of climate protection goals in the building sector.

3. Perspective of the individual building

Heat pumps are the heat generators of the future. All current scenarios assume a strongly growing number of heat pumps in German buildings (Consentec et al. 2022, Prognos et al. 2021, BCG 2021, dena 2021a). Heat pumps will become the new standard technology – not only in new buildings but also in existing ones. The question always arises as to how well heat pumps and old buildings harmonise – especially uninsulated old buildings. Can heat pumps be installed in every building, or are there limits that make their use impossible or unattractive for the operators? This chapter examines the technical limits for the use of heat pumps and simultaneously shows solutions to overcome them.

3.1. Efficiency of Heat Pumps in Different Building Efficiency Classes

Heat pumps make use of ambient heat from the air, the ground, or other sources for heating spaces. They use electricity to "pump" the ambient heat from a low temperature to a higher temperature. Typically, heat pumps can provide 2.5 to 4.5 kilowatt-hours of heat with the use of one kilowatt-hour of electricity. The ratio of the amount of heat produced in a year to the energy used is called the seasonal performance factor (SCOPWPA). The higher it is, the more efficient and economical the heat pump operates. The seasonal performance factor can be measured if the heat pump has its own electricity meter and a heat meter. It can also be calculated in advance with some accuracy using the calculation methods of VDI 4650. In addition to the technical data of the heat pump, the conditions of the building are also considered, such as whether underfloor heating or radiators are present.

A significant influence on the seasonal performance factor of heat pumps is the flow temperature – the temperature that the heat pump provides to the house. It cannot be freely chosen but results from:

- the heat losses of the building
- and the performance of the radiators or underfloor heating.

The lower the flow temperature, the more efficiently the heat pump operates. This relationship is shown in Figure 5 with calculated values and in Figure 6 with measured values from a field test by the Fraunhofer Institute for Solar Energy Systems (ISE). The figures also show that heat pumps that use air as a heat source generally have a lower seasonal performance factor than those that use the ground. Both figures show the same trend: at higher flow temperatures, efficiency drops significantly, leading to higher costs and greenhouse gas emissions.

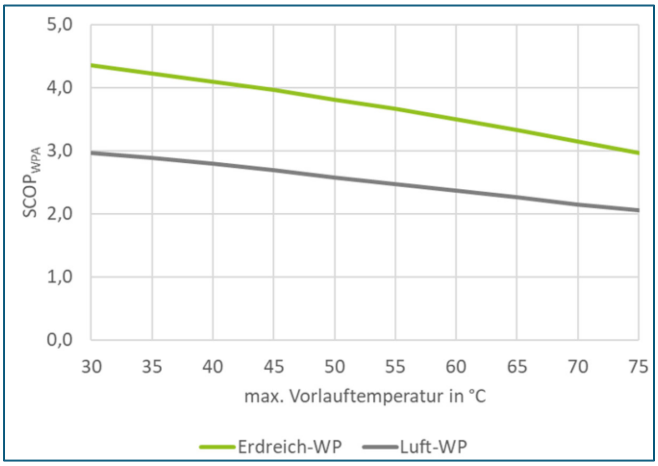

Figure 5: Annual coefficient of performance of a heat pump as a function of the flow temperature (calculated according to VDI 4650)

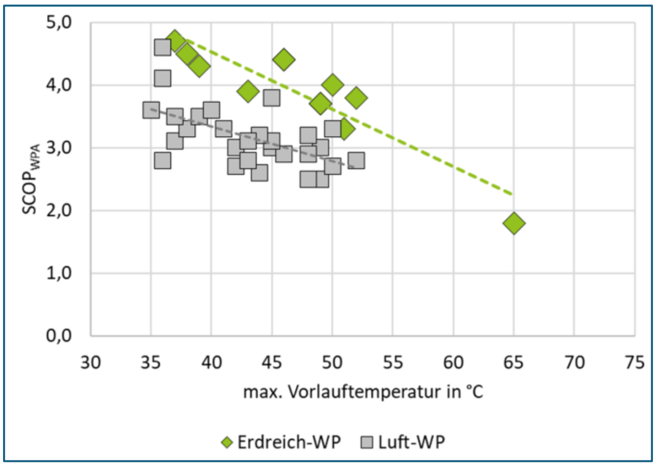

Figure 6: Annual coefficient of performance of a heat pump as a function of the flow temperature (measured values, own representation. Source: Fraunhofer ISE 2020)

The following calculation shows how the seasonal performance factor (SPF) is influenced by the efficiency class of the buildings. The calculation can only be carried out as an example since the results in a specific building depend on the respective equipment. The exact flow temperature for each individual building must be calculated for each room and can vary accordingly. Moreover, no statement can be made about whether the calculated necessary flow temperatures were actually set on the heating control system. Previously, the maxim was that the flow temperature should not be too low. For heat pumps, it must now not be too high either. The chosen type of heat pump also has a significant influence on the result. Despite the assumed simplifications, the following calculation provides a framework for the influence of the efficiency class on the seasonal performance factor. **Table 1** shows all the parameters for the calculation according to VDI 4650. The parameters are explained row by row below.

An air-source heat pump was assumed since these currently have around 87% market share (bwp 2023). The performance figures of the heat pump (COP) were not varied for the different building efficiency classes to avoid overlaying the results. Different heat pump types have different performance figures, but there is no significant correlation with the nominal heat output or efficiency class of the building.

The maximum flow temperature was simplified in steps of 5 K per efficiency class. There is no direct correlation, but the chosen temperatures can be considered quite typical for the respective efficiency class.

The heating limit temperature is the average outside temperature of a day below which the building is heated. It is influenced by the thermal insulation of a building. For old buildings, it is typically 15°C. The better the insulation standard of a building, the lower the heating limit temperature.

The standard outside temperature depends on the region where a building is located. It is the lowest outside temperature that has occurred in 20 years ten times on two consecutive days. It is defined for the regions in Germany in DIN 12831.

The correction factors for different operating conditions are read from Table 15 of VDI 4650 depending on the flow, heating limit, and standard outside temperatures.

The temperature difference at the condenser during the test bench measurement is a specification from DIN EN 14511. The temperature difference at the condenser in the specific project describes the temperature spread to which a heat pump is set in a specific building. The worse the thermal insulation of a building, the greater this temperature difference must be. With these two temperature difference values, a correction factor is read from Table 1 of VDI 4650.

Efficiency Class	A+	A	B	C	D	E	F	G	H
Heat pump performance factor at A-7/W35 εN	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67
Heat pump performance factor at A2/W35 εN	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49
Heat pump performance factor at A10/W35 εN	4.54	4.54	4.54	4.54	4.54	4.54	4.54	4.54	4.54
Maximum flow temperature TVorl,max [°C]	35	40	45	50	55	60	65	70	75
Heating limit temperature [°C]	10	10	12	12	15	15	15	15	15
Standard outside temperature ϑe [°C]	-14	-14	-14	-14	-14	-14	-14	-14	-14
Correction factor for different operating conditions, heating Fϑ1	0.135	0.145	0.136	0.148	0.135	0.143	0.157	0.173	0.190
Correction factor for different operating conditions, heating Fϑ2	0.682	0.721	0.709	0.755	0.720	0.767	0.821	0.879	0.942
Correction factor for different operating conditions, heating Fϑ3	0.162	0.170	0.241	0.253	0.349	0.381	0.402	0.426	0.450
Temperature difference at the condenser during the test bench measurement ΔϑM [K]	5	5	5	5	5	5	5	5	5
Temperature difference at the condenser in the specific project ΔϑB [K]	5	5	6	7	8	9	10	10	10
Correction factor for deviating temperature differences at the condenser FΔϑ	1.000	1.000	1.010	1.020	1.031	1.041	1.051	1.051	1.051
Seasonal performance factor for heating SCOPH	3.55	3.35	3.29	3.12	3.09	2.91	2.75	2.56	2.39
Seasonal performance factor for hot water SCOPW	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92
Monovalent operation	x	x	x						

Bivalent operation, monoenergetic parallel				x	x	x	x	x	x
Proportion of heat pump output at standard outside temperature	100%	100%	85%	70%	55%	45%	40%	35%	30%
Coverage ratio α	1	1	1	0.99	0.975	0.95	0.93	0.9	0.87
Proportion of heating energy demand	50%	70%	80%	85%	88%	90%	91%	93%	93%
Proportion of hot water energy demand	50%	30%	20%	15%	12%	10%	9%	7%	7%
Overall seasonal performance factor SCOPWPA	3.21	3.21	3.21	3.02	2.92	2.66	2.46	2.23	2.04

Table 1: Example calculation of the seasonal performance factor according to VDI 4650 for different building efficiency classes including the relevant input parameters

The annual coefficients of performance for heating operation and domestic hot water preparation are calculated using the parameters and correction factors. The value for domestic hot water preparation is independent of the the efficiency class and is therefore constant in all classes.

For efficiency classes A+, A, and B, it is assumed that the buildings can be heated solely by the heat pumps. From class C onwards, an auxiliary electric heater will kick in during cold weather. The proportion of the heat pump output at the standard outside temperature indicates how much the heat pump contributes to heat generation on particularly cold days. The remaining portion is provided by the auxiliary electric heater. The coverage ratio of the heat pump is calculated according to VDI 4650 from these values.

The seasonal performance factors for heating and hot water are weighted according to their respective proportions and combined to give the overall seasonal performance factor. Since the hot water demand is constant regardless of the efficiency class of the building, it has a high proportion of the total heat demand in well-insulated buildings. The overall seasonal performance factor of the heat pump is shown for all efficiency classes in the last row.

The results from Table 1 are graphically represented in Figure 7. The significant drop in the seasonal performance factor in the poorer efficiency classes is evident. The efficiency of the heat pump is 36% lower in the worst building class H than in class A+. This has a linear effect on greenhouse gas emissions and heating costs, which are correspondingly higher.

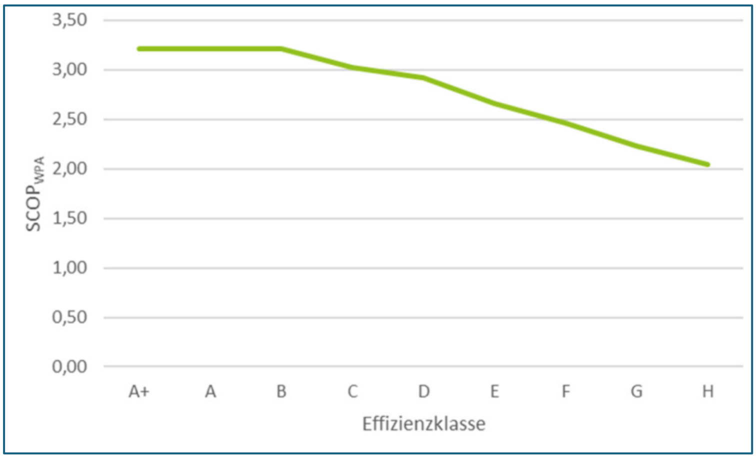

Figure 7: Exemplary annual coefficient of performance of a heat pump depending on the building efficiency class

Heat pumps can only achieve their high efficiency in well-insulated buildings. The poorer the thermal insulation of a building, the less efficient a heat pump will be as long as the heat transfer surfaces are not changed.

3.2. Impact of the Energy Price Increase in 2022 on Different Efficiency Classes

Since the Russian invasion of Ukraine in February 2022, energy prices have risen sharply. Citizens are greatly concerned about the security of supply and the affordability of their heating costs. Therefore, the federal government has supported them with two relief packages, two energy supply security ordinances (EnSikuMaV and EnSimiMaV), and the gas price cap.

In the public debate, however, the influence of thermal insulation on additional costs was hardly noticed. The following calculations show how significantly the efficiency class of a building affects the additional burden caused by the price explosion.

Figure 8 shows the monthly energy costs for a single-family house with a living area of 160 m² and an apartment with 75 m² in a multi-family house. The costs are shown for heating with a condensing boiler using natural gas and an air-source heat pump. The calculation took into account that residents of inefficient buildings behave more economically than residents of efficient buildings. To do this, the energy demand of the efficiency classes was converted into a typical energy consumption that can be expected at this energy standard. The basis for the conversion is an empirical evaluation of energy demand and consumption certificates from the Institute for Housing and Environment (IWU 2015). The annual consumption was distributed across the individual months using monthly heating degree days and multiplied by the current energy prices of the respective months (Verivox 2022a and b). The month of December was excluded because no price data was available.

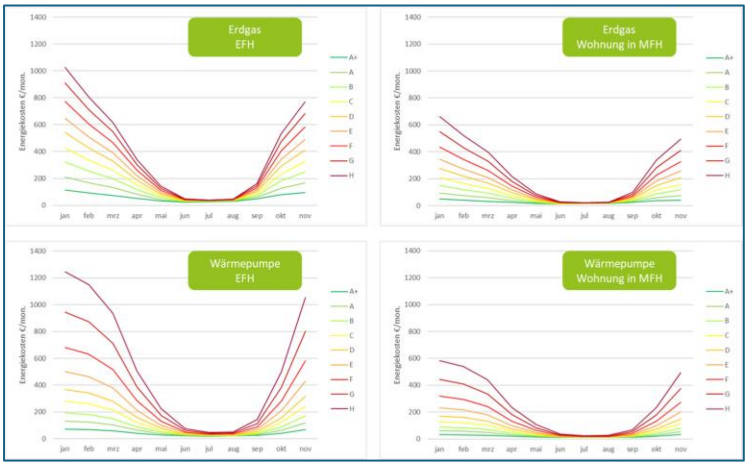

Figure 8: Energy costs for space heating and hot water by efficiency class, for different heat generators and building sizes.

The costs shown do not correspond to the heating cost advances paid by the residents but indicate the actual costs incurred in each month. It is clearly visible that high heating costs occur in the winter months, while only hot water preparation needs to be paid for in the summer. The colours represent the different building efficiency classes according to the Building Energy Act (GEG). There are large variations during the heating period. As expected, the heating costs in the poorer efficiency classes are a multiple of those in the good classes. The difference between the single-family house (left charts in Figure 8) and the apartment in the multi-family house (right charts) is primarily due to the larger living area in the single-family house.

When comparing gas heating (upper charts in Figure 8) with the heat pump (lower charts), the larger variation between the efficiency classes stands out. On closer inspection, it can be seen that the heat pump causes lower heating costs in the good efficiency classes than the gas heating, but is more expensive in the poorer efficiency classes.

This effect becomes more visible when the monthly costs are summed up to annual costs. Figure 9 shows the annual heating costs in 2022 (excluding December) compared to the average of the years 2013 to 2021. The elastic price reaction of consumers to the extremely increased prices was not taken into account. At the time of calculation, only vague evaluations were available for gas consumers and none for heat pumps.

The additional costs calculated in this way compared to the previous eight years (also excluding December) are:

- Gas Heating
  - Single-family house
    - Class A+: €370
    - Class H: €2,464
  - Apartment in a multi-family house
    - Class A+: €170
    - Class H: €1,574
- Heat Pump

- Single-family house
  - Class A+: €83
  - Class H: €849
- Apartment in a multi-family house
  - Class A+: €41
  - Class H: €401

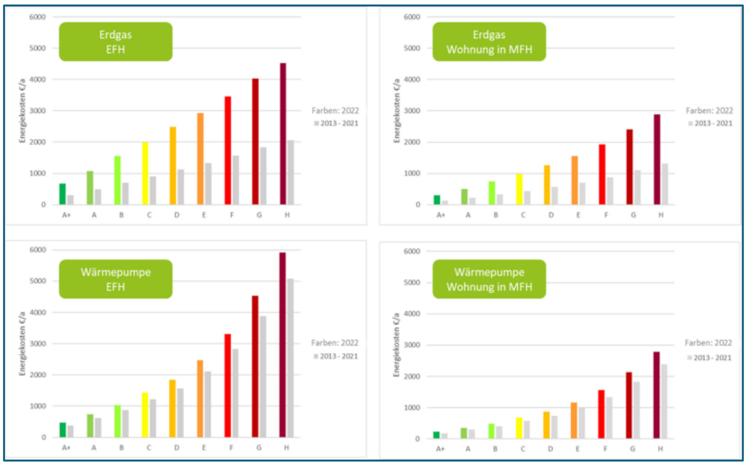

Figure 9: Heating costs by efficiency class in 2022 and before the outbreak of the Ukraine war for gas heating systems and heat pumps for a detached house and a flat (assumption for heat pumps: household tariff)

This comparison makes it clear that the additional costs due to the war in Ukraine hit residents of inefficient buildings much harder than residents of well-insulated buildings. The additional costs in the poor buildings are 6 to 10 times higher.

The differences between gas heating and heat pumps are partly due to the different price paths in 2022 for natural gas and electricity, and partly due to the different starting situations in the previous years. For the chosen framework conditions, the costs for heat pumps are somewhat higher than for gas heating (calculated with the household tariff and not with a heat pump tariff).

Figure 10 compares the heating costs of gas heating and heat pumps from the year 2022. It is particularly striking that the heating costs of the heat pump in the single-family house are lower in the better efficiency classes than with gas heating, but increase sharply in the poorer efficiency classes and overtake gas heating. This effect is caused by the lower seasonal performance factors in the poorer buildings (see Figure 7). It leads to the already higher consumption of uninsulated buildings being further exacerbated by the low efficiency of the heat pump. Even though heat pumps are generally not installed in buildings of classes G and H, this effect must still be considered in the future when 500,000 heat pumps are to be installed annually (BMWK 2022a) (see also Chapter 4.3). Positively formulated, the synergy effect of thermal insulation and heat pumps means that by reducing the heating energy demand by 18% (for example, from class G to F), heating costs are reduced by 37%.

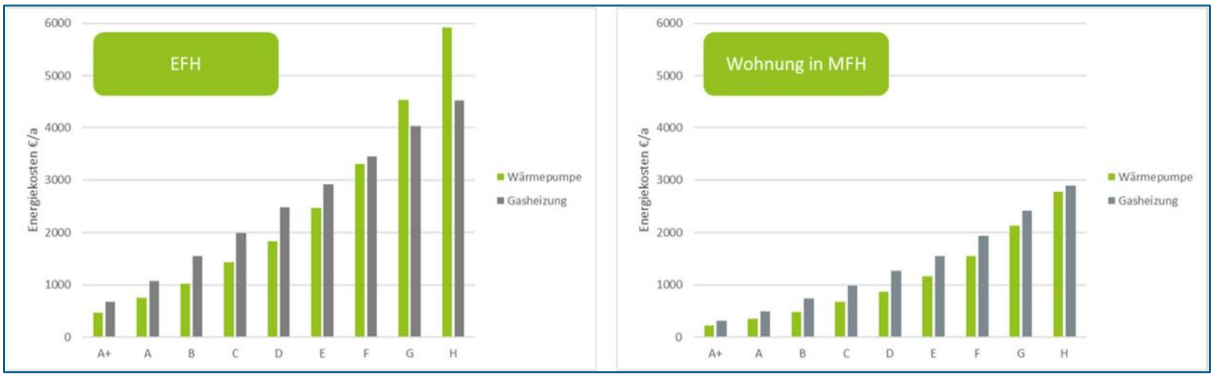

Figure 10: Comparison of heating costs for gas heating systems and heat pumps in 2022 for a detached house and a flat

3.3. Restrictions for Heat Pumps in Uninsulated Buildings

The myth that heat pumps can only be installed in new buildings and in combination with underfloor heating has been debunked. In 2020, around 50,000 heat pumps were installed in existing buildings (dena 2021b). In a field test by the Fraunhofer Institute ISE, only heat pumps in existing buildings were examined. Thirteen out of 41 systems were operated 100% with radiators. Another twelve systems were operated 50% or more with radiators (ISE 2020). The buildings were predominantly partially renovated. Figure 11 shows the thermal transmittance coefficients of the components and a building index that roughly corresponds to the specific transmission heat transfer coefficient (Ht´) in the energy performance certificate. The heating energy demand of the buildings varies widely between 40 and 130 kWh/m²a. Most buildings are roughly at the thermal protection level of the third thermal protection ordinance of 1995. However, no uninsulated old buildings from before 1978 were included in the field test.

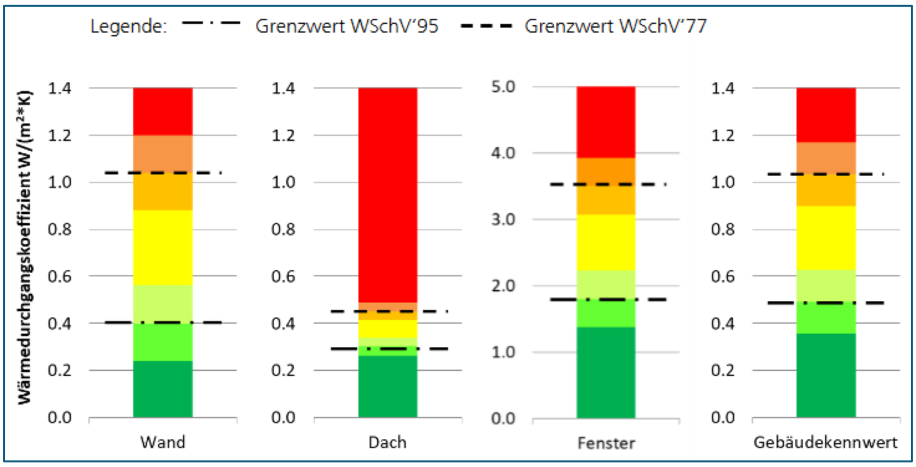

Figure 11: Thermal insulation quality of existing buildings with heat pumps that took part in the field test (source: ISE 2020)

This chapter aims to show whether there are technical obstacles to the installation of heat pumps in uninsulated old buildings. Two possible restrictions are analysed that could result from the major influence of the flow temperature on the efficiency of heat pumps:

- Can the radiators cover the given heating load?
- Can the pipework transport the required amount of heat?

For better orientation, Figure 12 shows the basic elements of a heating circuit.

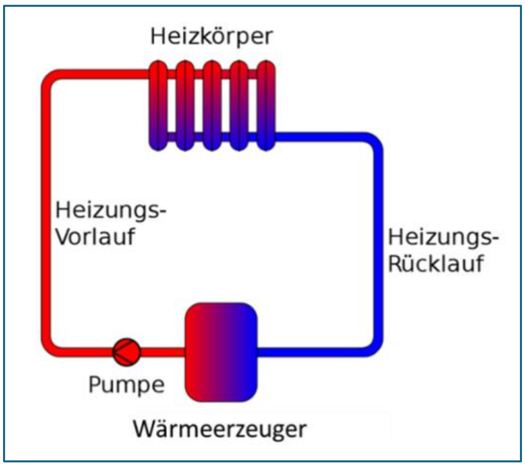

Figure 12: General diagram of a heating circuit with an explanation of terms

Influence of Thermal Insulation on Heating Load Coverage

The first potential restriction arises because the heat output of radiators decreases when the flow temperature is reduced. If the flow temperature in a heating circuit is lowered to ensure the heat pump operates with good efficiency – for example, from 70°C to 55°C – it may be that individual rooms no longer get sufficiently warm. In these rooms, the heat losses through walls, windows, or ventilation are greater than the output of the radiator. These critical rooms can be identified through calculation. Generally, it is possible to replace existing radiators with larger ones with higher output. These can be radiators of a different type (e.g., panel radiators Type 33 instead of Type 21), fan convectors, or radiators with larger dimensions, provided the spatial situation allows it. The question is whether there is a limit to the replacement of radiators that prevents the installation of a heat pump. For this, the heating output of three radiators is recorded depending on the flow temperature:

- A radiator whose output at 70°C flow temperature exceeds the heating load of the room by 120% (e.g., Type 21 in **Figure 13**),
- A radiator whose output at 70°C flow temperature exceeds the heating load of the room by 220% (e.g., Type 33 with the same external dimensions in **Figure 13**),
- A radiator whose output at 70°C flow temperature exceeds the heating load of the room by 330% (e.g., Type 33 with 50% larger dimensions in **Figure 13**).

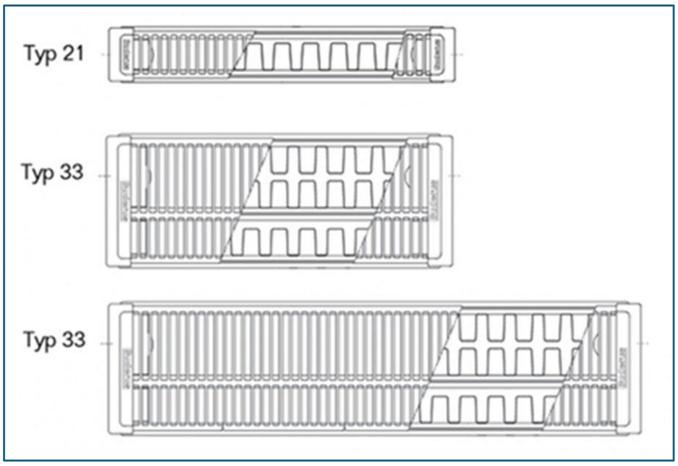

Figure 13: Examples of panel radiators: If type 21 is present as is, it can be replaced by type 33 of the same size, which increases the heating capacity to 220%, or by a type 33 that is 50% larger and increases the capacity to 330%.

Figure 14 shows that the existing radiator with 120% output (at 70°C flow) no longer covers the heating load of the room when the flow temperature is reduced to 60°C (red area). If it is replaced with a radiator with 220% output, the flow temperature can be reduced to 50°C. If it is replaced by a radiator with 330% output, the room will still be sufficiently warm even at a flow temperature of 43°C. These flow temperatures are well-suited for the operation of a heat pump.

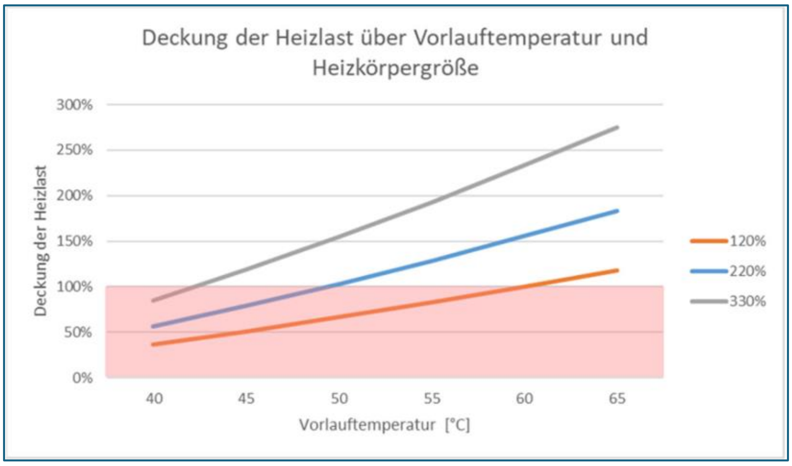

Figure 14: Covering the heating load with differently sized radiators depending on the flow temperature. In the red area, the heating load is not sufficiently covered.

However, it is questionable whether such a replacement is always possible, especially in uninsulated old buildings. Often, large radiators are already installed in such buildings to cover the high heating load. A replacement may then not be possible for space reasons. If small radiators were installed, a higher flow temperature is usually required (75 to 90°C). To sufficiently heat the rooms with flow temperatures below 55°C, very large radiators are required in this case as well, which may not fit spatially.

The technical restriction due to insufficient heat output cannot be conclusively quantified, as it strongly depends on the structural and spatial conditions in each building. The size of the radiators relative to the heating load of the rooms varies greatly even within housing units, so individual critical rooms need to be retrofitted with large radiators while other rooms can be adequately heated with the existing radiators. It is also possible to provide the required heating load on particularly cold days with additional heat generators (e.g., towel radiators or infrared heaters in bathrooms, low-emission wood stoves, etc.). However, it can be noted that the problem becomes more difficult the higher the heat demand of a building is.

Influence of Thermal Insulation on Heat Transport

Another restriction may arise from the fact that the pipelines in existing buildings are not adequately dimensioned for the operation of heat pumps. The heating circuits in existing buildings are usually designed for boilers that have a flow temperature of 70°C and a return temperature of 50°C – thus a temperature spread (difference) of 20 K. Heat pumps, on the other hand, operate with temperature spreads between 5 and 10 K. This means that at the same flow rate of the heating water, they can only transport half the output. From this relationship, it can be calculated what flow rate is necessary to transport the desired output. The required output again depends on the thermal insulation level of the building. Additionally, the flow rate is influenced by the pipe diameter. Since the calculations always refer to individual rooms, the diameter of the radiator connection pipe of an individual radiator is considered. The flow rate of the heating water in these pipes should not exceed 0.5 m/s as a guideline. Above this limit, the pressure loss increases significantly and flow noise occurs more frequently.

Figure 15 shows the flow rate of the heating water in the radiator connection pipe relative to the maximum flow rate of 0.5 m/s for different pipe diameters and different building efficiency classes. The red area indicates an exceedance of the maximum flow rate. The underlying temperature spread is 10 K. This is the recommended maximum value for heat pumps operated with radiators (bwp 2019). With a smaller temperature spread, the curves increasingly shift into the red area. The reference to the building efficiency classes on the x-axis was made by assigning the specific heating load. This reference cannot be precisely mathematically established but is based on typical guideline values. It is shown in Table 2.

Efficiency Class	Specific Heating Load [W/m²]
B	60
C	70
D	80
E	90
F	100
G	120
H	130

Table 2: Allocation of the specific heating load to the building efficiency classes

With standard (external) diameters of the radiator connection pipe of 12 to 15 mm, the maximum flow rate is exceeded. This need not be an exclusion criterion for the installation of a heat pump, as the underlying performance is based on the standard outside temperature, which by definition only rarely prevails. However, it is clear to see that this problem is significantly less virulent in the higher-efficiency classes of buildings.

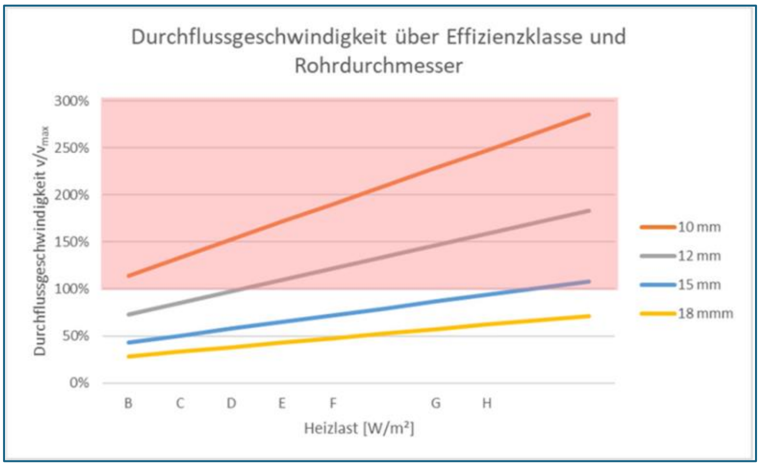

Figure 15: Flow rate of the heating water in the radiator connection pipe about the maximum flow rate for different building efficiency classes and different pipe diameters. The maximum flow rate is exceeded in the red area.

No hard mathematical limits can be derived for either of the restrictions analysed - covering the heating load and transporting the required amount of heat. Nevertheless, both studies show that technical issues need to be considered when installing heat pumps in inefficient existing buildings and that both problems become more difficult the worse the building is insulated.

No hard mathematical limits can be derived for the restrictions analysed (required heating load and required lumen flow). The worse a building is insulated, the more difficult it is to cover the heating load with lower flow temperatures. In poorly insulated buildings, it is more likely that the maximum flow rate in the pipework will be exceeded. Both problems are hardly to be expected in well-insulated buildings.

3.4. Preparing Buildings for Renewable Energy

Efficient heat pumps are important to reduce greenhouse gas emissions in the building sector and to protect residents from exploding heating costs. To increase the efficiency of heat pumps, there are two areas of action:

Increasing the performance of heating circuits by replacing radiators/installing underfloor heating or similar surface heating systems.

Reducing heat losses through insulation, sealing, and ventilation with heat recovery.

Legal Framework

The influence of these two areas of action was examined in ifeu (2021b). The extent of the influence of insulation or heating measures strongly depends on the initial condition and the geometry of the buildings. Therefore, individual planning is essential when installing a heat pump in a rather inefficient existing building. The transition to a heat pump should be embedded in an overall strategy for the building, as provided by the individual renovation roadmap (iSFP). This allows for the long-term planning and implementation of the right mix of insulation and system measures. If this is not done, there is a risk that the old heat generator will reach the end of its useful life without the building being prepared. The transition to the heat pump will then be more difficult, more expensive (as a larger heat pump will be needed), or even impossible. In ifeu (2021b), the NT-ready concept was introduced to simplify the timely preparation for renewable energy.

The pressure to act on inefficient existing buildings will continue to increase. The coalition agreement (2021) set the goal that from 2025 every newly installed heat generator should use at least 65% renewable energy. This goal was brought forward to 2024 in the second relief package (BMWK 2022b). Inefficient buildings that are not prepared in time for heating with renewable energy will likely have to resort to more expensive technologies, such as hybrid heating systems. Wood heating will foreseeably not be the solution for large parts of the German building stock, as wood will increasingly be unavailable as a fuel in the future (Consentec et al. 2022). Even though this is not currently a problem, it must be considered today given the roughly 20-year lifespan of boilers.

The heating inspection and optimisation introduced by the Federal Ministry for Economic Affairs and Energy for gas heating systems (BMWK 2022c) goes in a similar direction to the NT-ready concept. Here, lowering flow temperatures is explicitly formulated as a goal, primarily to save natural gas in light of the Ukraine war. Such a heating inspection and optimisation for owners of fossil-fuelled boilers could be used, with some adjustments, as preparation for the 65% renewable energy requirement. Insulation measures should systematically be considered as a means to achieve this goal.

Perspective of Property Owners

From the perspective of property owners, the question of whether they should prepare for a heat pump with insulation measures or radiator replacement involves several aspects:

- The investment costs for a heat pump are significantly higher than for fossil-fuel boilers, especially given the current imbalance of supply and demand. For many owners, it seems financially impossible to simultaneously invest in better insulation. Replacing a limited number of radiators is much cheaper.
- Nevertheless, a smaller heat pump could be installed if insulation is done first, saving part of the costs.
- In the long term, practically every building will need to be insulated sooner or later, considering the particularities of the facade, to meet climate targets. If insulation is done only after the heat pump is installed, the heat pump will be too powerful, usually leading to efficiency losses and higher operating costs.
- In the long term, it also becomes clear that larger radiators will no longer be needed if the building is later insulated, making them stranded assets.

Currently, the long-term benefits of building insulation are being hindered by the short-term financial burden on property owners. Funding should provide targeted solutions for this. An important step has been taken with the additional funding for the worst-performing buildings in the Federal Funding for Efficient Buildings (BEG), as it directs funds to particularly inefficient buildings. It would also be helpful to extend the funding to individual measures carried out within the framework of an individual renovation roadmap, specifically preparing for the transition to renewable energy.

Inefficient buildings must be prepared in good time for the switch to renewable energies. Good building insulation makes a significant contribution to this. Insulation contributes to a climate-neutral building in the long term; larger radiators are tranded assets in the long term.

4. Perspective of the Energy System

The complete decarbonisation of buildings requires the conversion of previous fossil heating systems to decarbonised energy sources, probably electricity. Such a conversion will require large amounts of additional electricity, especially in winter. As renewable energies are not available indefinitely, the total heat demand has a significant impact on the extent and distribution in which they can be used. The following shows how the interaction between a future-oriented, efficient building envelope and the climate-politically important expansion of the electrification of building heating can lead to a significant relief of the power grid.

4.1. Reducing the Simultaneity of Loads through Thermal Insulation

Unquestionably, a renovation with better structural thermal insulation can significantly reduce heating energy consumption. However, the associated reduction in the required heating load is rarely considered. Especially with heat pumps, the necessary heating load determines the investment costs. The heating load also has a significant impact on the power grid. Excessive peak loads can overload the local power grid. Low heating loads, achievable due to system-friendly thermal insulation, guarantee grid stability.

To investigate the interaction between heat pumps and the necessary heating load, transient thermal calculations are carried out using two model buildings (**Figure 16**) with the WUFI Plus software. These include a detached single-family house in the middle-quality segment with one residential unit. The average apartment size is approximately 146 m². The multi-family house in a closed development has balconies. The six residential units (two-per-floor layout) are classically arranged along the building axis and adjacent to a heated staircase. The model assumes a heated living area of approximately 335 m². Both residential buildings date from the 1980s and thus comply with the thermal insulation regulations that applied at the time. In this state, it is assumed that the windows installed at that time have not yet been replaced. All other external components are also still in their original condition. For direct comparison, a systemic renovation to EH 70 level is carried out.

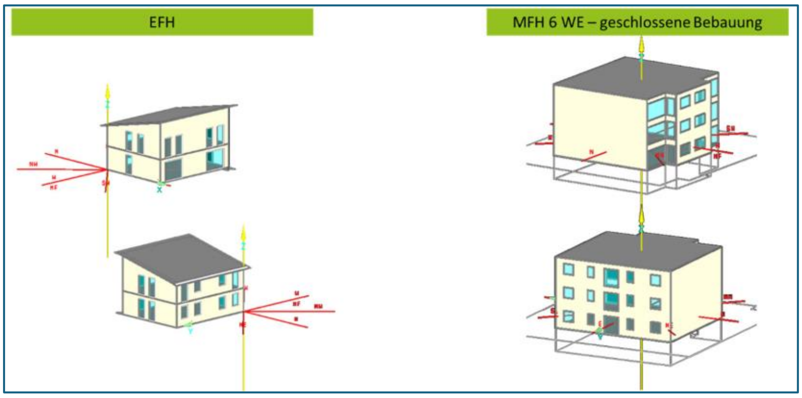

Figure 16: Selected model building

The hourly heating output required to maintain an indoor temperature of at least 20°C is compared as a function of the outdoor temperature. This direct comparison can be seen in **Figure 17**. Future-orientated, insulated buildings reduce the peak load in winter by a factor of 2 - 3 and, in addition to the energy consumption for heat, also significantly reduce the required network capacities.

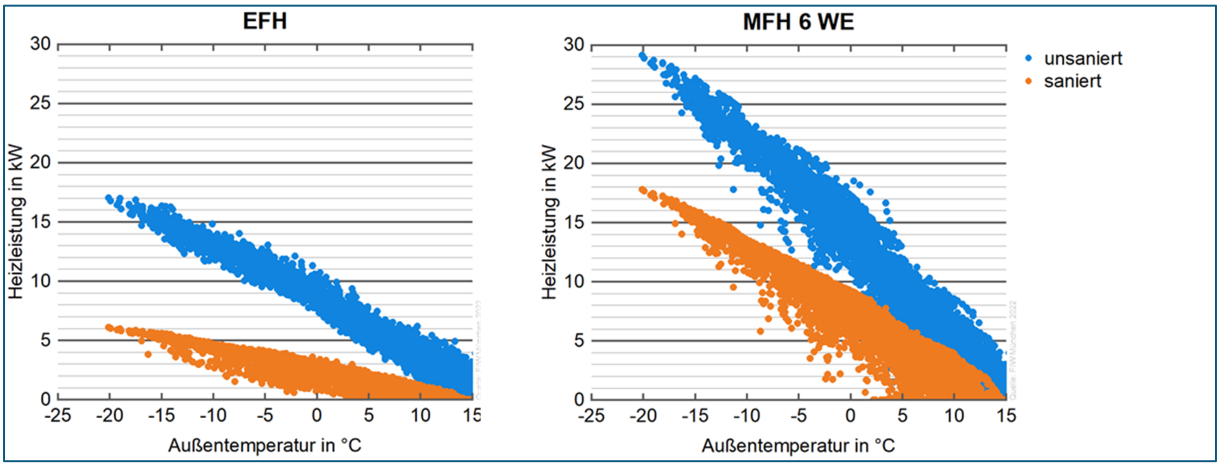

Figure 17: Heating output required to maintain a comfortable indoor temperature as a function of the outside air temperature for the two sample buildings analysed for different energy refurbishment statuses. The respective hourly heating loads are shown.

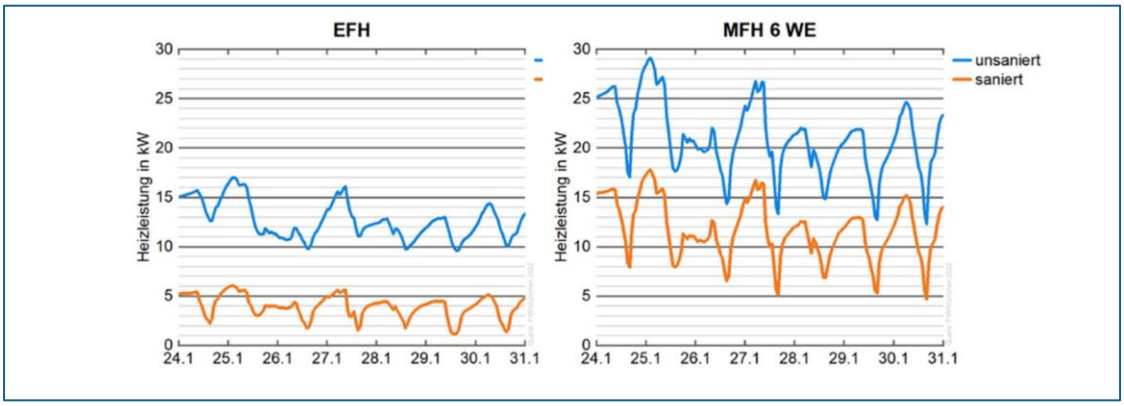

Figure 18: Heating output curve during a cold winter week in January for the two types buildings with different refurbishment statuses

Because electromobility is booming and houses are increasingly being heated with electrically operated heat pumps, electricity demand is rising – and often simultaneously in many households. This results in so-called "significant loads," especially in the evenings, which the power grids in the low-voltage grid are not designed for. A typical heat pump for an insufficiently insulated single-family house has a connection power of up to 20 kW. That doesn't sound like much at first. The problem becomes clear only when one considers that a heat pump is used continuously for several hours or even the whole day. Moreover, when residential building heating is fully electrified, such an electrical load is required simultaneously in many households. Additionally, the demand for household electricity, especially in the evenings, increases significantly, and there is the rapidly growing number of electric vehicles. **Figure 19** illustrates this aspect schematically for a renovated and unrenovated building. In addition to reducing the corresponding electrical load, well-insulated buildings can store heat for a longer time without noticeable loss of comfort, enabling a system-friendly operation, i.e., turning off the heat pump during system overloads. Future-oriented thermal insulation can reduce the peak load in winter by a factor of 2 – 3 and significantly relieve the power grid by using heat storage. The effect of load reduction through good thermal insulation becomes even more important when considering the "neighbourhood."

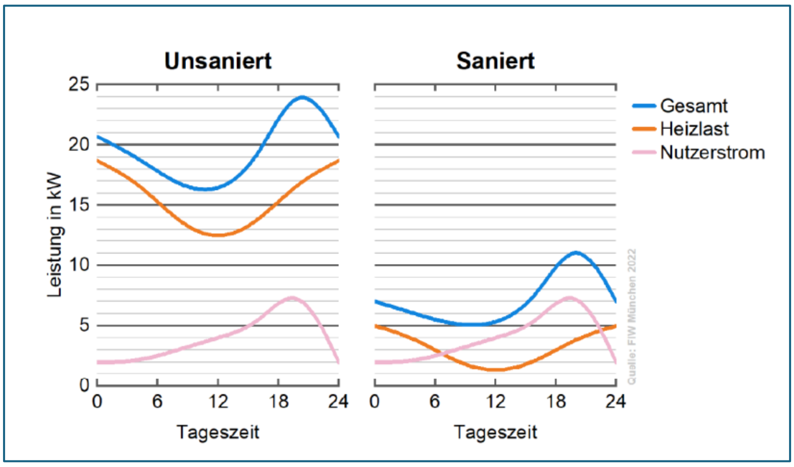

Figure 19: Schematic comparison of the daily course of the total electricity output resulting from the heating load and the user current for an unrenovated or renovated residential building.

Future-oriented insulated buildings reduce the peak load in winter by a factor of 2 - 3. This peak determines the required grid capacity!

Figure 20 shows this schematically for a neighbourhood consisting of nine buildings. If a heat pump were installed in each of these nine buildings in their unrenovated state, it would mean that the individual maximum electrical load would be 15 kW each, and in total, that would be 135 kW. The same neighbourhood, where the thermal envelope was renovated according to the current state of the art, reduces the individual load accordingly to 5 kW, or 45 kW for the entire neighbourhood. Through flexible and reactive load management, a "smart microgrid" with well-insulated buildings could further reduce the individual load. In the schematic example shown here, it becomes clear how, with appropriate thermal insulation, a requirement to install grid-friendly heat pumps (SmartGrid-ready) and mandatory use of control algorithms could ensure an energy-efficient operation of the heat pump and lead to a significant relief of the power grid.

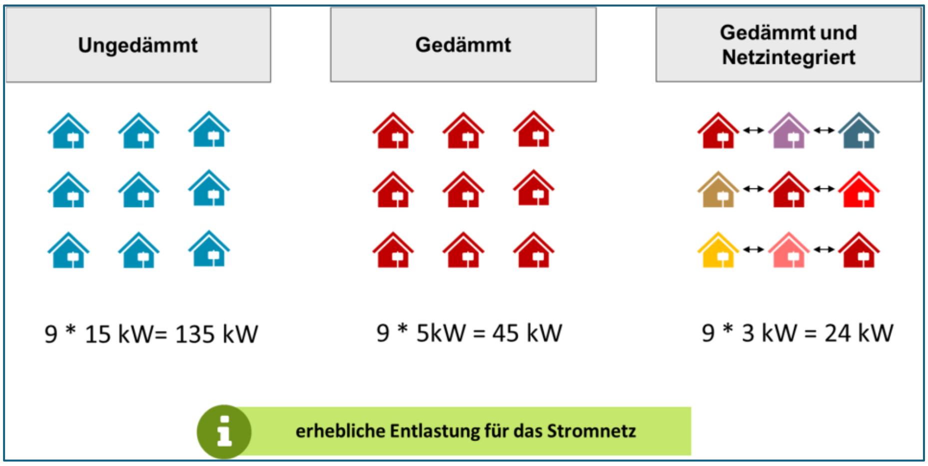

Figure 20: Grid-friendly operation of heat pumps in combination with a corresponding building envelope can significantly reduce the load on the electricity grid.

4.2. Resilience and Security during Brown-Outs

Currently, the question of a possible power outage due to system overload is being discussed. This would also mean that heating systems would no longer function. The following briefly examines the effect on room temperature during the aforementioned cold winter week for the two model buildings with different energy standards (Figure 21). In both the uninsulated single-family house and the multi-family house, the room temperature drops below 10° Celsius within half a day. After 3-4 days, the room temperature further drops to around 0° Celsius. This could, in addition to severe comfort restrictions, also have significant impacts on the frost safety of water pipes. In the energetically upgraded building, however, due to significantly reduced transmission heat losses, the room temperature drops very slowly and remains above 10°C even after almost 3-4 days. Even after a week, no critical temperatures are reached.

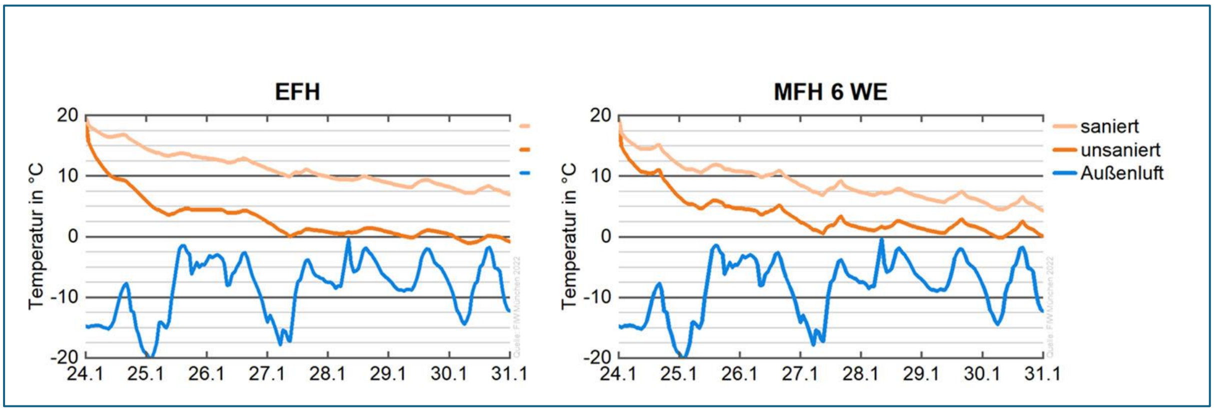

Figure 21: Development of the room temperature during a cold winter week in January for the two type of buildings with different energy standards after a heating failure.

The calculations carried out here as an example show that well-insulated buildings are less susceptible to damage in the event of an energy supply failure than uninsulated or poorly insulated buildings. The drop in room temperature and thus thermal comfort is significantly slower in well-insulated buildings. An emergency supply is also easier to organise.

4.3. Securing the Heat Pump Offensive

The heat pump offensive of the Federal Ministry for Economic Affairs and Energy aims to install 500,000 new heat pumps annually from 2024 and to have around 6 million heat pumps in the heating stock by 2030. Of the targeted 500,000 new heat pumps, at most 100,000 can be installed in new buildings, as their number is limited. This means that at least 400,000 heat pumps must be installed annually in existing buildings. Therefore, about every second new heat generator installed in existing buildings would have to be a heat pump. As explained in Chapter 3.3, the installation of heat pumps becomes more difficult the worse a building is insulated. Therefore, 400,000 buildings that are as efficient as possible must be available annually for the installation of heat pumps.

Looking at the distribution of efficiency classes in German buildings (Figure 22), it becomes clear that 30% of buildings are in the worst efficiency classes G and H. 44% are in the middle classes D to F, and only 26% are in the better classes A+ to C. Within the A+ to C classes, around 64% are new buildings constructed after 2002, whose heat generators are only just entering their first replacement cycle. Assuming a 20-year usage cycle, only about 100,000 heating renewals are expected annually in the A+ to C classes – with a slightly increasing trend in the coming years. Nevertheless, at least 200,000 heat pumps remain that must be installed annually in partially or unrenovated buildings to realise the heat pump offensive. Although the pool of these buildings is large, there are additional restrictions that prevent the installation of a heat pump, such as existing gas floor heating systems or noise issues.

Last but not least, the owners of suitable buildings must also choose a heat pump. To ensure this decision is made in favour of heat pumps, positive experiences from other users are important. Heat pumps must be associated with low costs and trouble-free operation. It is crucial to exploit the synergies between heat pumps and thermal insulation in individual construction projects.

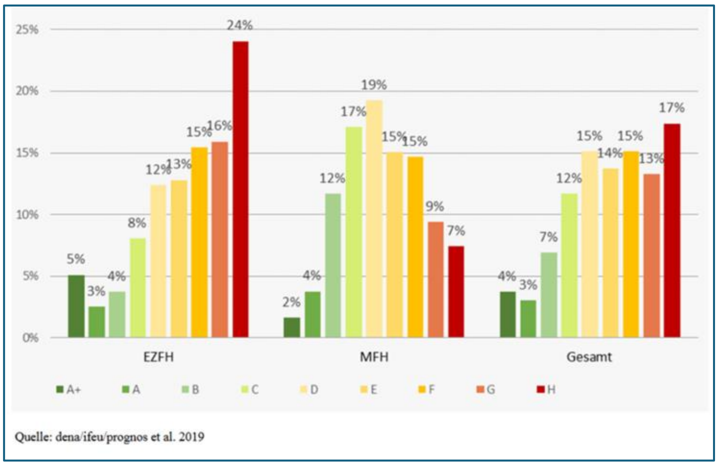

Figure 22: Frequency distribution of efficiency classes in the German residential building stock (source LTRS 2020).

If there are not enough suitable buildings available each year for the installation of a heat pump, the heat pump offensive will be slowed down. To secure the heat pump offensive, buildings in efficiency classes D to H should be specifically prepared for the switch to heat pumps. Improved efficiency is just one of many elements. However, it is particularly effective because it fundamentally ensures that a building is suitable for efficient heat pump operation.

The success of the heat pump offensive requires at least 500,000 buildings annually,

- in which the heat generator is due for replacement,
- where the builders decide on a heat pump,
- and which are technically suitable for a heat pump. This is primarily ensured through good structural thermal insulation.

4.4. Impact on Climate Protection Goals

According to the Climate Protection Act, greenhouse gas emissions in the building sector must be reduced to 67 million tonnes by 2030. This corresponds to a reduction of 44 percent compared to 2020. To achieve this goal, a mix of renewable energy and improved building efficiency will be used. How these two areas of action are balanced against each other is the subject of all current scenario calculations. In the long-term scenarios of the Federal Ministry for Economic Affairs and Energy, two scenarios were compared to better understand the influence of building efficiency (Consentec et al. 2022). Both scenarios place a strong focus on heat pumps.

In the T45-Strom scenario (abbreviation for "greenhouse gas neutrality 2045 with a high share of renewable electricity"), very ambitious insulation standards are assumed. Renovations are oriented towards the Efficiency House 55 level. This corresponds roughly to the current requirement level for individual measures in the Federal Funding for Efficient Buildings (BEG). At the same time, the renovation rate and the share of ventilation systems with heat recovery increase. Additionally, 30% of the renovations exceed the legal requirements and are oriented towards the Efficiency House 40 level. Through these measures, the useful heat consumption will decrease by 13% compared to 2020 and amount to 474 TWh by 2030.

This scenario is compared to the T45-RedEff scenario (abbreviation for "greenhouse gas neutrality 2045 with reduced efficiency"). Here, the renovation requirements are oriented towards the level of an Efficiency House 70, as provided in the coalition agreement (2021). The renovation rate and the shares of over-fulfilling the requirements and ventilation systems with heat recovery lag behind the T45-Strom scenario. Useful heat consumption will decrease by 9% to 505 TWh by 2030.

Only a few technology options are available for heat supply:

- Both scenarios assume an extremely ambitious expansion of heating networks. It is not varied between the scenarios because it cannot be further increased.
- Renewable fuels, such as synthetic hydrogen or synthetic methane (PtG), are not available to the building sector in these scenarios. Their influence was also investigated in the long-term scenarios but in two other scenarios (T45-PtG/PtL and T45-H2). They can contribute to achieving the 2030 target and mitigate the relationship between building efficiency and the number of heat pumps, but the ramp-up of these technologies must be far more ambitious than previously planned (BMWi 2020). Overall, the impact of renewable gases on achieving the 2030 target is very limited.
- Despite all known obstacles, heat pumps are the most flexible option. They can replace boilers when their useful life has expired. They are relatively independent of preconditions in infrastructure expansion and can be installed flexibly in terms of location and time where fossil boilers are regularly replaced.

To meet the sector target in 2030, 5.7 million heat pumps must be installed in the T45-Strom scenario. Among them are 0.34 million hybrid heat pumps. These are used in buildings that are not yet sufficiently prepared for the sole (monovalent) operation of a heat pump at the time of installation (see Chapter 3.4). On particularly cold days, a gas boiler will support the heat pump. The disadvantage of these hybrid heat pumps, besides the higher investment costs, is that the fuel gas will likely not be available until the end of their useful life. Through ambitious insulation of buildings, monovalent operation of heat pumps will gradually become possible, and the gas boiler will become redundant. To reach the number of 5.7 million heat pumps by 2030, at least every second newly installed heat generator must be a heat pump from 2024 onwards. This fundamental restructuring of the heating market is already provided for in the heat pump offensive of the Federal Ministry for Economic Affairs and Energy (BMWK 2022a). In the very well-insulated buildings in this scenario, the heat pumps convert electricity into heat particularly efficiently (see Chapter 3.1).

	T45-Strom	T45-RedEff
New Building Requirement	Efficiency House 40	Efficiency House 40
Renovation Requirement	Efficiency House 55	Efficiency House 70
Renovation Rate	1.95%	1.49%
Number of Heat Pumps in 2030	5.7 million	8.0 million
of which Hybrid Heat Pumps in 2030	0.34 million	0.63 million
Electricity Consumption of Heat Pumps in 2030	34.7 TWh	63.9 TWh
Total Electricity Consumption of Buildings in 2030	71.3 TWh	93.9 TWh
Installed Capacity of Heat Pumps in 2030	26.7 GW	31.1 GW
Average Performance Factor of Heat Pumps in 2030	3.0	2.8

Table 3: Effects of poorer building efficiency on the number and electricity consumption of heat pumps (own presentation based on Consentec et al. 2022)

In the T45-RedEff scenario, 8.0 million heat pumps must be installed by 2030, 0.63 million of which are hybrid heat pumps. Such a ramp-up is not considered feasible and is used here only to illustrate the impact of insufficient insulation. This extremely high number is necessary because the consumption in fossil-heated buildings decreases more slowly than in the T45-Strom scenario. This is a direct consequence of lower building efficiency. In other words, the amount of heating oil and natural gas still permitted in 2030 is only sufficient for a smaller number of buildings to avoid exceeding the sector target. **Table 3** shows the key features of the scenarios and their impact on the required number of heat pumps, their installed electrical capacity, their electricity consumption, and their efficiency (performance factor).

Figure 23 illustrates the relationship between building efficiency and the required number of heat pumps for the year 2030. A third case shows how many heat pumps would be required if no further insulation measures were implemented from 2023 onwards. In this case, the number would have to increase to 9.2 million by 2030. This number could not even be achieved if all new heat generators on the market were heat pumps by then.

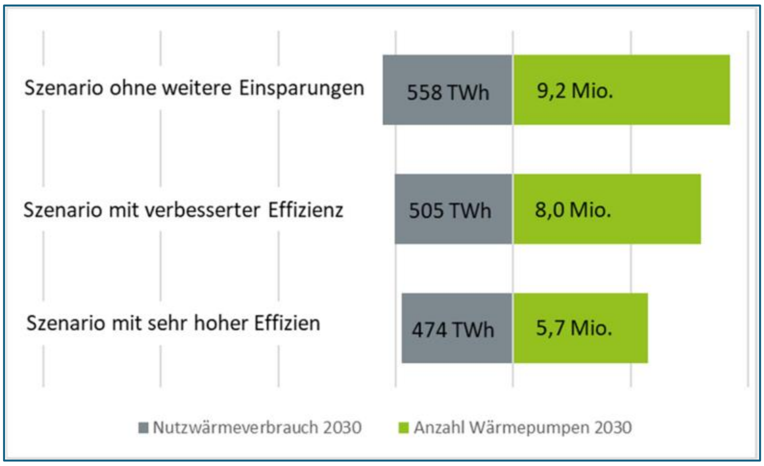

Figure 23: Building efficiency and the required number of heat pumps are in balance: the higher the heat consumption of the buildings, the more heat pumps are needed to achieve the sector target in 2030. (own illustration based on Consentec et al. 2022)

The higher the heat consumption of the buildings, the more heat pumps are needed to achieve the sector target in 2030.

4.5. Impact on the Required Expansion of Renewable Energies

This chapter also refers to the results of the long-term scenarios of the Federal Ministry for Economic Affairs and Energy, as described in Chapter 4.4 (Consentec et al. 2022). Two scenarios were calculated, both of which foresee a very high share of heat pumps. They differ in that one assumes a very high level of structural thermal insulation (T45-Strom) and the other a lower level of thermal insulation, which is still above today's level (T45-RedEff). As described in Chapter 3.1, better thermal insulation in combination with heat pumps has a dual effect: it reduces the heat demand and simultaneously increases the efficiency of the heat pump. This effect can be illustrated by comparing the two scenarios, as both have a similar number of heat pumps in 2045 (18.3 million in T45-Strom, 18.8 million in T45-RedEff). Figure 24 shows the electricity consumption for space heating, domestic hot water heating, ventilation, and auxiliary energy for the two scenarios. It increases significantly in both scenarios compared to the baseline value of 45 TWh in 2020. In 2045, it amounts to 124 TWh in T45-Strom and 169 TWh in T45-RedEff – a 37% increase.

It is occasionally argued that electricity will be renewable by 2045 and therefore will not cause any greenhouse gas emissions. In fact, the high electricity demand – also in other sectors – creates another scarcity: the areas where renewable energies are produced must be utilised to the maximum. The following figures show the potential utilisation for wind power and ground-mounted photovoltaics in the T45-Strom scenario. This means that in this scenario, almost all suitable areas must already be used to the maximum to generate the required renewable electricity. Such an ambitious expansion path is associated with risks and uncertainties. To ensure the achievement of the targets, electricity should continue to be used as efficiently as possible – even if it is renewable.

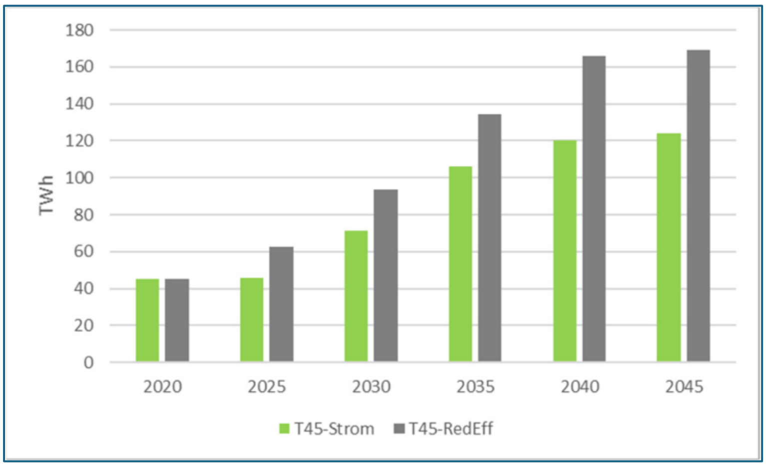

Figure 24: Electricity consumption in the building sector in the long-term scenarios T45-Electricity and T45-RedEff. (own illustration based on Consentec et al. 2022)

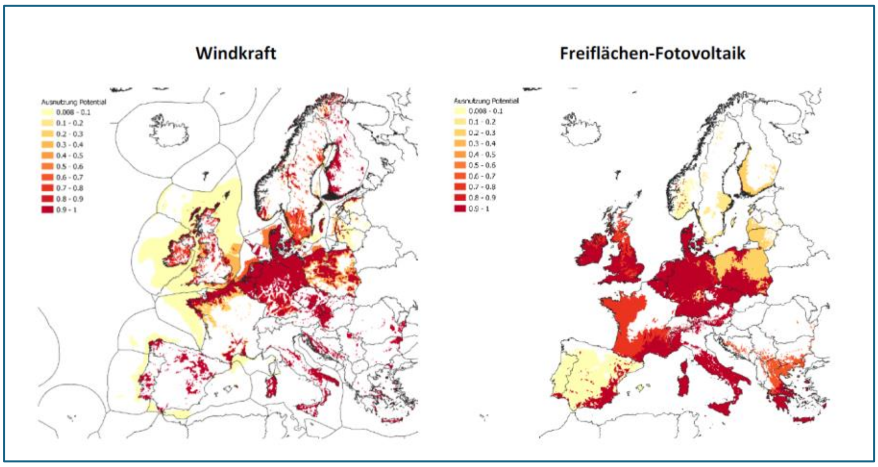

Figure 25: Utilisation of the potential for wind power (left) and ground-mounted photovoltaics (right) in Europe in the scenario T45 electricity scenario (Consentec et al. 2022)

Renewable electricity will remain a valuable and scarce commodity in the future. It must be utilised as efficiently as possible.

5. Thermal Insulation Offensive

Good thermal insulation, including building insulation, is indispensable for achieving climate protection goals in the building sector. The more decisively the heat demand is reduced, the more likely and easier the decarbonisation will be. Especially in combination with heat pumps, insulated buildings offer essential advantages without which the entire achievement of the goals would be jeopardised. This report highlights the benefits of ambitious building insulation on several levels:

In the Building

- Synergy through the dual effect of thermal insulation: reduction of heat demand and increase in heat pump efficiency.
- The energy price shock has little impact on insulated buildings.
- The worse a building is insulated, the more difficult it is to install a heat pump.
- Buildings can be insulated step by step so that they are prepared for the switch to the heat pump at the crucial moment.

In the Energy System

- Synergies through the dual effect of thermal insulation: reduction of required heating power and increase in storage capacity lead to significant relief of power grids.
- Insulated buildings are more resilient to unforeseen events.
- Thermal Insulation Offensive: The more ambitious the reduction in heat consumption, the more realistic the transformation path for the renewable energy supply becomes.

These advantages highlight the importance of building insulation for the heat transition. As a fundamental element of the building strategy, a thermal insulation offensive is therefore proposed. It would be helpful to clearly formulate the goals and communicate the importance of insulation measures. The following key points should be included in a thermal insulation offensive:

- Goal Formulation (Example): "Final energy consumption for space heating should decrease by xy% by 2030, and by xx% by 2045 compared to 2008."
- Breaking Down the Goals (Example): "To achieve this, a tripling of the annually insulated facade area is required from 2024."
- Outlining the Transformation Path (Example): "Prioritisation of buildings that should be insulated first." The following topics can be included:
    - Worst-performing buildings,
    - Buildings where the heating boiler is older than 15 years,
    - Buildings that can be insulated with little effort.
- Designing Instruments and Funding According to the Transformation Path
- Demand for and Mobilisation of Skilled Workers
    - Training, continuing education, retraining,
    - Curricula content.

- Market Potentials and Strategies to Meet Demand
- Standardisation Proposals in Legislation and Norms
- Providing a Compendium of Good Construction Practices
- Communication with the Involved Social Groups

This list is initially intended to provide a rough framework and examples of the content of the thermal insulation offensive. Each individual point requires in-depth examination and processing, which cannot be provided within the scope of this study.

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