The role of energy efficient buildings in the EUs future power system

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4 Key messages

A highly energy efficient building stock, realised by deep renovation and efficient new buildings, brings multiple benefits for demand reduction, but also increases efficiency on the supply side.

Energy efficient buildings, under the expected electrification of the heat sector can reduce electricity demand and peak loads by 57 GW (equalling current total electricity production capacity of the Netherlands and Austria) .

An energy efficient building stock offers higher flexibility for electricity supply, as efficient buildings have the ability to keep the desired room temperature stable over a longer period, also when the heating system is turned off.

There is significant potential for CAPEX gains- 89-153 billion EURO of CAPEX reduction could be conceived in the power sector by 2050.

1. A highly energy efficient building stock, realised by deep renovation and efficient new buildings, brings multiple benefits such as reduced GHG emissions, reduced dependence from (fossil) fuel imports[1], job creation triggered by investments specifically in building renovation[2], reduction of fuel poverty, and increased comfort. Next to these recognised benefits, efficiency on the demand side, materialised in a highly performing building stock, also has the potential to reduce costs and increase efficiency on the supply side, thus supporting a resilient future energy system.

2. Energy efficient buildings, under the expected electrification of the heat sector, reduce electricity demand and peak loads. Energy efficient buildings, typically optimising the envelope insulation and performance of equipment, indeed need and consume less energy. This translates into a reduction of the system peaks, and thereby a reduction in needed investments in generation and grid infrastructure. It leads to a reduction in the amount of energy that needs to be generated and transported, thereby reducing system operational costs and losses. In a high efficiency scenario[3], 57 GW in peak load can be saved compared to a low efficiency scenario by the year 2050, which equals the current total electricity production capacity (renewable and non-renewable) of Austria and the Netherlands combined.

3. An energy efficient building stock offers higher flexibility for electricity supply. Highly efficient and well insulated buildings have a higher capability to shift heating operation in time, as those buildings have the ability to keep the desired room temperature stable over a longer period, also when the heating system is turned off. This increased flexibility can be translated into a reduction of the peak demand and to a reduction of the electricity system losses, while maintaining thermal comfort for its occupants. The impact of energy efficiency on the flexibility of the power systems leads to an additional reduction in peak load of the EU power system of around 12 GW (respectively up to approx. 60 GW when considering national/regional boundaries).

4. Clear financial benefits through investment savings. The potential reduction of peak loads and increased flexibility, considering a high efficiency scenario, translates into 89-153 billion EURO of CAPEX reduction in the power sector until 2050. Those additional savings in peak load capacities and grid infrastructure, usually not taken into account or neglected in cost/benefit analysis, should be part of the estimation of the economics of energy efficiency in buildings including deep renovation strategies.

[1] Deep renovation of buildings - An effective way to decrease Europe's energy import dependency, Ecofys for EURIMA, 2014 [2].
[2] Renovation tracks for Europe up to 2050; building renovation in Europe - what are the choices?, EURIMA, 2012 [3].
[3] High energy efficiency ambition level: ~ 53% reduction of useful energy demand for space heating by 2050 compared to 2012 including new buildings (cf. Chapter 3.1).

1 Executive summary

The recognition of the importance of energy efficiency is based on its proven benefits, specifically in the building sector, to reduce energy demand and thus final energy use.
This delivers direct impacts such as the reduction of related energy costs and greenhouse gas emissions[4]. Additionally, energy efficiency achieves further benefits, such as reduced independence from (fossil) fuel imports[5], job creation triggered by investments specifically in building renovation[6], a reduction in fuel poverty, and increased comfort.

Beyond these benefits efficiency of buildings energy use also has the potential to reduce costs and increase efficiency on the supply side.
More specifically this study looks into the impact of high efficient buildings on the power system. The reason for this choice is the expected electrification of the heat sector by the growth of electric heat pumps to supply heating (and cooling) energy to the EUs building stock. This is a foreseeable trend as the power sector has a large potential for integration of renewable energy and heat pumps can effectively convert electricity to useable heat.
As a consequence, a significant increase in the electricity demand is expected due to the installation of heat pumps. This will require significant investments in electricity production capacities and a respective strengthening of the grid. These investments can be reduced by energy efficiency measures that lead to a decrease in the energy demand of buildings.

Highly efficient buildings are thereby beneficial for the power systems in two ways:

1. *Reduction of energy demand from buildings*: energy efficient buildings need and consume less energy and therefore reduce the dimension of demand. This translates into a reduction of the system peak and a respective reduction in the generation and grid infrastructure investments. Furthermore, it leads to a reduction in the amount of energy that needs to be generated and transported and ultimately to a reduction of the system operational costs and the related losses.

2. *Higher flexibility:* the flexibility of heat demand refers to the ability of shifting the operation of heat pumps without affecting the temperature comfort levels inside the building [7]. Typically, highly efficient buildings have a higher capability to shift heating operation in time, as a highly insulated building envelope has the ability to keep the desired room temperature stable over a longer period, also when the heating system is turned off. This increased flexibility can translate into a reduction of the peak demand and to a reduction of the system losses by the reduction of marginal losses.

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[4] Cost effective climate protection in the EU building stock, Ecofys for EURIMA, 2005 [1].
[5] Deep renovation of buildings - An effective way to decrease Europe's energy import dependency, Ecofys for EURIMA, 2014 [2].
[6] Renovation tracks for Europe up to 2050; building renovation in Europe - what are the choices?, EURIMA, 2012 [3].

Measures such as energy efficiency on the demand side, which affect the three key characteristics of heat demand, i.e. dimension, pattern and flexibility, will therefore have positive impacts on the power system.
The aim of this study is to describe and quantify these effects in more detail and to assess the additional benefit of a highly energy efficient buildings on the future electricity system of the EU.

The assessment revealed (by comparing the situation in 2050 under a high efficiency and a low efficiency scenario) that a highly energy efficient building stock, via reduction of peak loads of electric heat pumps and the ability to shift space heating demand in time (as highly efficiency building envelopes can keep the desired room temperature stable for a longer period when the energy supply is interrupted) have the ability to significantly reduce necessary peak capacities and avoid distribution losses.

The following table summarized the effect of energy efficient buildings on the electricity grid.

Table 1: Summary of the full impact of demand side reduction of buildings through energy efficiency on the EU power system demand and its flexibility until 2050

	Impact from reduced electricity demand for electric heat pumps of high efficient buildings		Impact from increased flexibility of running heat pumps in high efficient buildings	
Reduction in peak load	57 GW (9%)	43-50 billion EURO in electricity generation CAPEX[7]	12 GW (2%)	9-11 billion EURO in electricity generation CAPEX
		26 billion EURO in grid CAPEX		6 billion EURO in grid CAPEX
Reduction in power losses	12 TWh/a (5%)	1 billion EURO per year in Grid OPEX[8]	< 1 bln EURO	< 1 bln EURO

The reduction in peak load from reduced electricity demand for electric heat pumps due to high efficiency buildings of 57 GW is significant and matches the current total electricity production capacity (renewable and non-renewable) of Austria and the Netherlands combined.

The impact of energy efficiency on the flexibility of the power systems leads to an additional reduction in peak load of the EU power system of around 12 GW. This represents a lower boundary of the effects, as grid operators actually have to balance demand and supply not at EU level but on national/regional boundaries (with less options to balance), which results in higher peak load savings from the gained flexibilities. In a case study on the German residential market, the impact of

[7] CAPEX: capital expenditure that a business incurs as a result of investments
[8] OPEX: operational expenditure that a business incurs as a result of performing its normal business

flexibilities was found to be 5 times higher than assuming balancing of demand and supply on EU level. Considering this would locate the effect of increased flexibility from high efficient buildings in Europe in the area of 60 GW and therewith be in the same order of magnitude as the reduction in peak load from reduced energy demand.

Additionally, the stronger fluctuation of the growing share of renewable electricity production will further increase the need for flexibilities on the demand side.

In financial terms, the total CAPEX savings in 2050 are 73 billion EURO (Impact from reduced electricity demand for electric heat pumps of high efficient buildings) plus an additional 16 billion EURO (Impact from increased flexibility of running heat pumps in highly efficient buildings) equalling a total CAPEX reduction of 89 billion EURO in 2050 (and up to 153 billion EURO if considering more national/regional boundaries). Reduction in power losses would be around 1 billion EURO in 2050. Comparing this with investment costs under the study renovation tracks for Europe [3], the resulting 89-153 billion EURO of CAPEX reduction are in a range of approx. 3-5 % of the total necessary additional investments for demand reduction measures when following a high efficiency instead of a low efficiency scenario. Those additional savings in peak load capacities and grid infrastructure are usually not taken into account or neglected in cost/benefit analysis, resulting in an underestimation of the positive economics of a more ambitious insulation of the EU building stock.

As a consequence of the above, highly energy efficient buildings (i.e. new buildings and in deep retrofits) do not only show benefits at the building level but can also deliver benefits at electricity system level, thus supporting a resilient future energy system.

2 Background and aim of the study

With the building sector being responsible for 40% of energy consumption and 36% of CO_2 emissions of the EU, the future development of the sector will be of crucial importance and will be decisive in achieving or missing EU energy and climate targets. End of 2014 the EU member states have committed - in addition to the 2020 20/20/20 targets - to reduce the domestic 2030 greenhouse gas emissions by at least 40% compared to 1990. The European Council endorsed a share of at least 27% as a binding EU target for renewable energy and as an indicative target for energy savings by 2030. The Roadmap for a low carbon economy sets as plans for the building sector CO_2 savings of 88-91% by 2050 compared to 1990 [4]. Furthermore the 2030 policy framework aims to make the European Union's economy and energy system more competitive, secure and sustainable. The EUs communication on the Energy Union, published in early 2015, thereby specifically declares energy efficiency to rank first ("Energy efficiency first: fundamentally rethinking energy efficiency and treating it as an energy source in its own right so that it can compete on equal terms with generation capacity"[9]). Thereby the EC has recognized the building sector as one of the sectors with a huge energy efficiency potential, although this has not yet been translated into clear objectives.

The recognition of the importance of energy efficiency is based on the proven benefits of energy efficiency, specifically in the building sector, to reduce energy demand and thus final energy use. This delivers direct impacts such as the reduction of related energy costs and greenhouse gas emissions[10]. Additionally, energy efficiency achieves further benefits, such as reduced independence from (fossil) fuel imports[11], job creation triggered by investments specifically in building renovation[12] and reduction of fuel poverty and increased comfort.

Beyond these benefits efficiency of buildings energy use also has the potential to reduce costs and increase efficiency on the supply side.
More specifically this study looks into the impact of high efficient buildings on the electricity grid. The reason for this choice is the assumed significant growth of electric heat pumps to supply heating (and cooling) energy to the EUs building stock. This is a foreseeable trend as the power sector has a large potential for integration of renewable energy and heat pumps can effectively convert electricity to useable heat. As a consequence, also the required amount of electricity for heat pumps is likely to raise significantly along with the increase number of systems in the future.
This will require more investments in electricity production capacities and strengthening of the grid, unless energy efficiency on the demand side of buildings reduces these needs.

Highly efficient buildings are thereby beneficial for the power systems in two ways:

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[9] European Commission - Press release, 25.02.2015

[10] Cost effective climate protection in the EU building stock, Ecofys for EURIMA, 2005 [1].

[11] Deep renovation of buildings - An effective way to decrease Europe's energy import dependency, Ecofys for EURIMA, 2014 [2].

[12] Renovation tracks for Europe up to 2050; building renovation in Europe - what are the choices?, EURIMA, 2012 [3].

1. *Reduction of energy demand from buildings*: energy efficient buildings consume less energy and therefore reduce the dimension of demand. This translates into a reduction of the system peak and a respective reduction in the generation and grid infrastructure investments. Furthermore, it leads to a reduction in the amount of energy that needs to be generated and transported and ultimately to a reduction of the system operational costs and the related losses.

2. *Higher flexibility:* the flexibility of heat demand refers to the ability of shifting the operation of heat pumps without affecting the temperature comfort levels inside the building [7]. Typically, high efficient buildings have a higher capability to shift heating operation in time, as a highly insulated building envelope has the ability to keep the desired room temperature stable over a longer period, also when the heating system is turned off. This increased flexibility can translate into a reduction of the peak demand and to a reduction of the system losses by the reduction of marginal losses.

The aim of the study is to describe and quantify these effects in more detail to assess the additional benefit of a highly energy efficient buildings on the future electricity system of the EU.

3 Impact of energy efficient buildings on the power system

3.1 Impact of energy efficient buildings on energy demand and load curves

High energy efficiency in new buildings, but specifically in renovation can substantially cut down energy needs in the buildings sector.

The study “Renovation tracks for Europe until 2050 – building renovation in Europe – what are the choices” revealed that ambitious new buildings (nearly zero energy buildings) and a deep renovation of the existing stock can save 80% of the final energy use for space heating by 2050, compared to 2012.

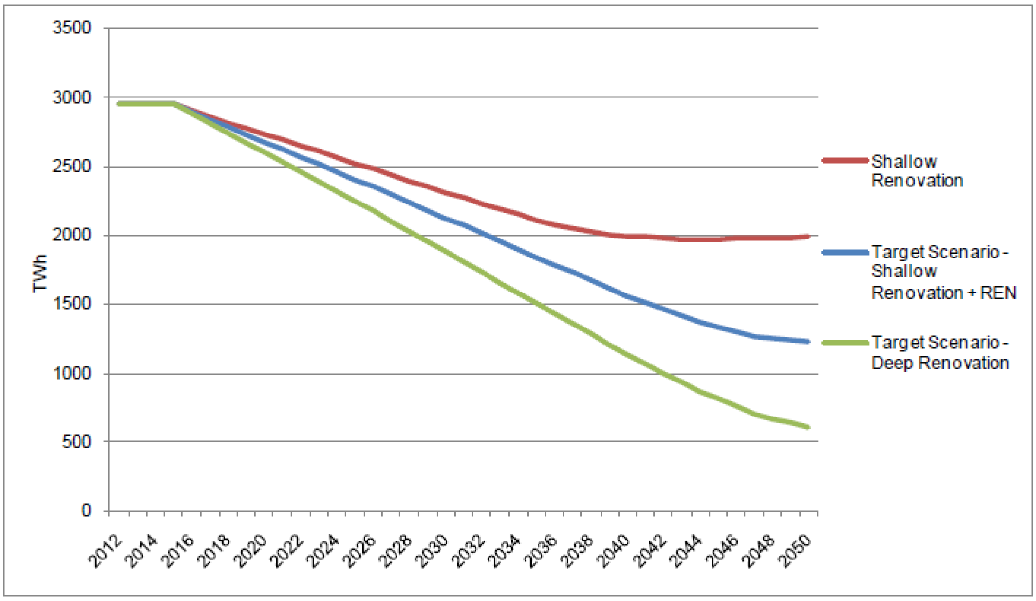


Figure 1 Final energy for space heating EU27 [TWh] without new buildings [3]

This is achieved by a combination of

- significantly reduced space heating demand (energy need in the rooms of a building to be supplied by a heating system) in renovated buildings in Europe by an average of approx. 70% and new buildings showing an average space heating demand of only 20-25 kWh/m²a and
- improved efficiency of supply systems.

Focusing on the contribution of energy efficiency on the demand side, savings of 53%[13] of the energy demand compared to 2012 are achieved by energy efficiency on the demand side (improved energy efficiency of the building envelope and implementation of ventilation systems with heat recovery) in the deep renovation scenario, cutting in half the energy needed in buildings today despite the whole stock growing by 2050 by around 45%.

On the other hand, a development with so called shallow renovations (only partial renovations taking place at low ambition level) and moderate instead of high ambition level for buildings would only lead to a reduction in space heating demand of 8% in 2050 compared to 2012.

To show the impact and role of energy efficiency on the future electricity grid, we developed two scenarios for the situation in 2050, with different ambition levels related to energy efficiency and thereafter describe the different effects on the electricity system in 2050.
The two scenarios are characterized as described in Table 2.

Table 2 Brief description of renovation tracks scenarios

Scenario	Description
Low efficiency scenario	Low energy efficiency ambition level (~ 8% reduction of useful energy demand for space heating by 2050 compared to 2012, including new buildings[14]). The low efficiency scenario reflects in renovation the shallow renovation track of the study “renovation tracks for Europe” and a moderate ambition level in new buildings[15]
High efficiency scenario	High energy efficiency ambition level (~ 53% reduction of useful energy demand for space heating by 2050 compared to 2012 including new buildings). The high efficiency scenario reflects for renovations and new buildings the deep renovation track of the study “renovation tracks for Europe.

Further explanation on background and assumptions for the two scenarios can be found in the study renovation tracks for Europe until 2050.

[13] The above mentioned numbers refer to useful energy whereas the “Renovation tracks for Europe up to 2050” study considers final energy.
[14] In the framework of this study, new buildings in the shallow renovation paths are assumed to show a moderate ambition level (while showing an ambitious level in the renovation tracks study).
[15] Reflecting an average useful heat demand of approx. 40 kWh/m²a

Despite substantial cuts on energy demand, the remaining energy needs of buildings still need to be covered mainly by renewable energy to reach the targeted -90% CO_2-emission reduction in the building sector as defined in the European roadmap for a low carbon economy [4]. Since the electricity sector has a high potential for renewable energy and the building sector provides the necessary technology to convert renewable electricity into useful heat (and cooling), i.e. by electric heat pumps, various studies point towards a considerable increase of electric heat pumps to cover the space heating demand of Europe in the future, e.g. Heat Pump Implementation Scenarios until 2030 [5].

In this study we assume 65% of the energy need for space heating in 2050 will be covered by electric heat pumps (40% air-water heat pumps, 25% ground water heat pumps). To translate the annual energy need of the buildings in the EU in 2050 according to the two scenarios into load curves for space heating (and subsequently load curves for electricity driving heat pumps) heat profiles of Germany were applied to the EU27 building stock. This clearly represents a simplification, however, the German case with its moderate climate conditions and central position in the EU is assumed to be reasonably representative within this scoping study.

3.1.1 Low efficiency scenario

In the low efficiency scenario a reduction of energy demand for space heating (energy needed in the rooms, excluding supply system efficiencies) from 2,560 TWh for 2012 to 2,356 TWh for 2050 useful energy demand is assumed, i.e. a decrease of 8% compared to 2012. Additionally, insulation has an effect on cooling demand [6]. In this study however the focus is put on space heating.

Figure 2 illustrates the load profile of demand for electricity of heat pumps for the shallow renovation scenario. The peak load can be found at around 163 GW. The overall useful energy provided by heat pumps is 1,530 TWh. This translates into 340 TWh of electricity use.
We thereby assume (on the background of ongoing research and development in the heat pump markets) an average COP of heat pumps used for space heating in 2050 of 4.5.

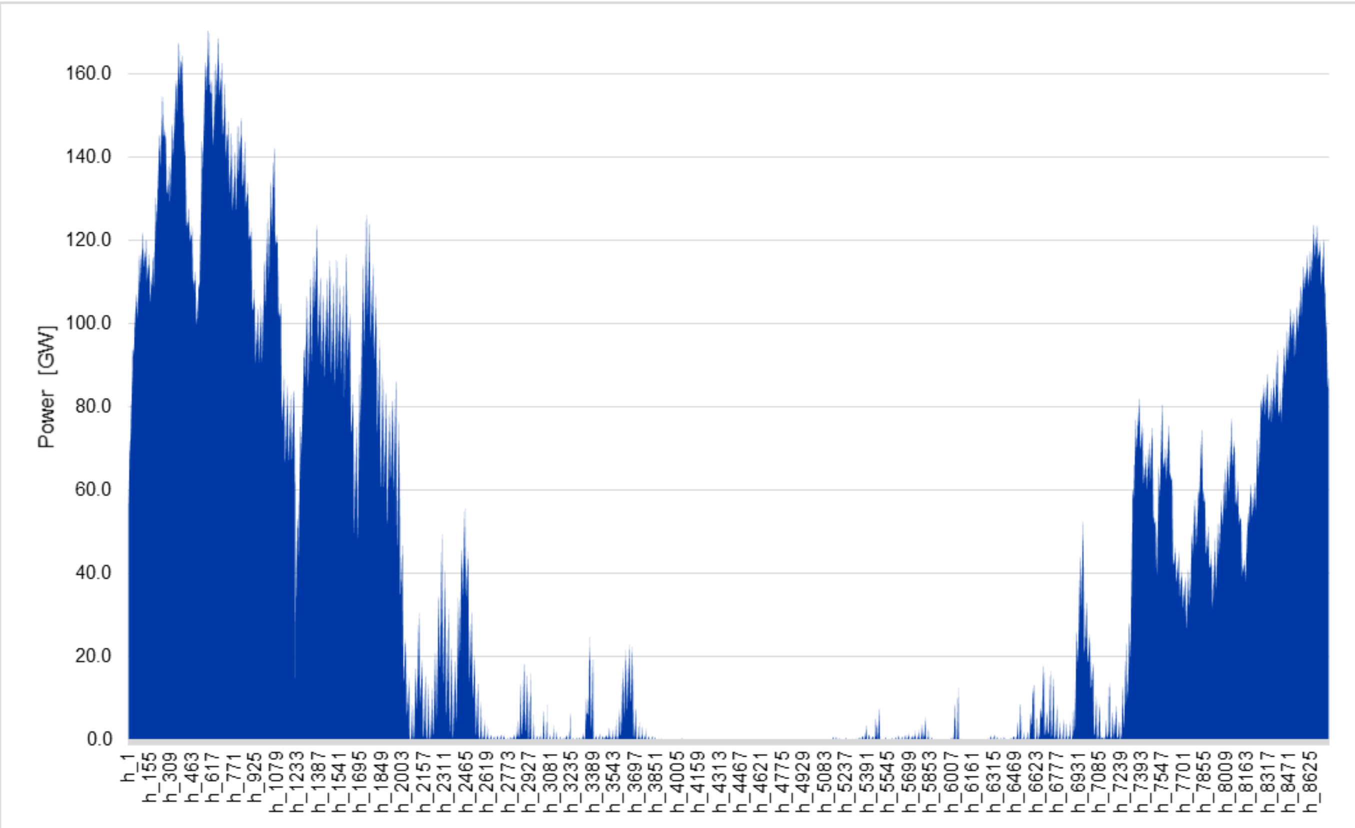


Figure 2 Hourly load profile of demand for electricity of heat pumps in the EU – Shallow renovation

3.1.2 High efficiency scenario

In the high efficiency scenario, high ambition in energy efficiency leads to a reduction of useful energy demand from 2,560 TWh for 2012 to 1,211 TWh for 2050, representing a reduction of 53% compared to 2012.

The peak load in this scenario can be found at around 100 GW as shown in Figure 3. The total energy demand provided by heat pumps is 787 TWh; assuming again an average COP of 4.5[16] of the heat pumps for space heating in 2050 the electrical demand, is 175 TWh.

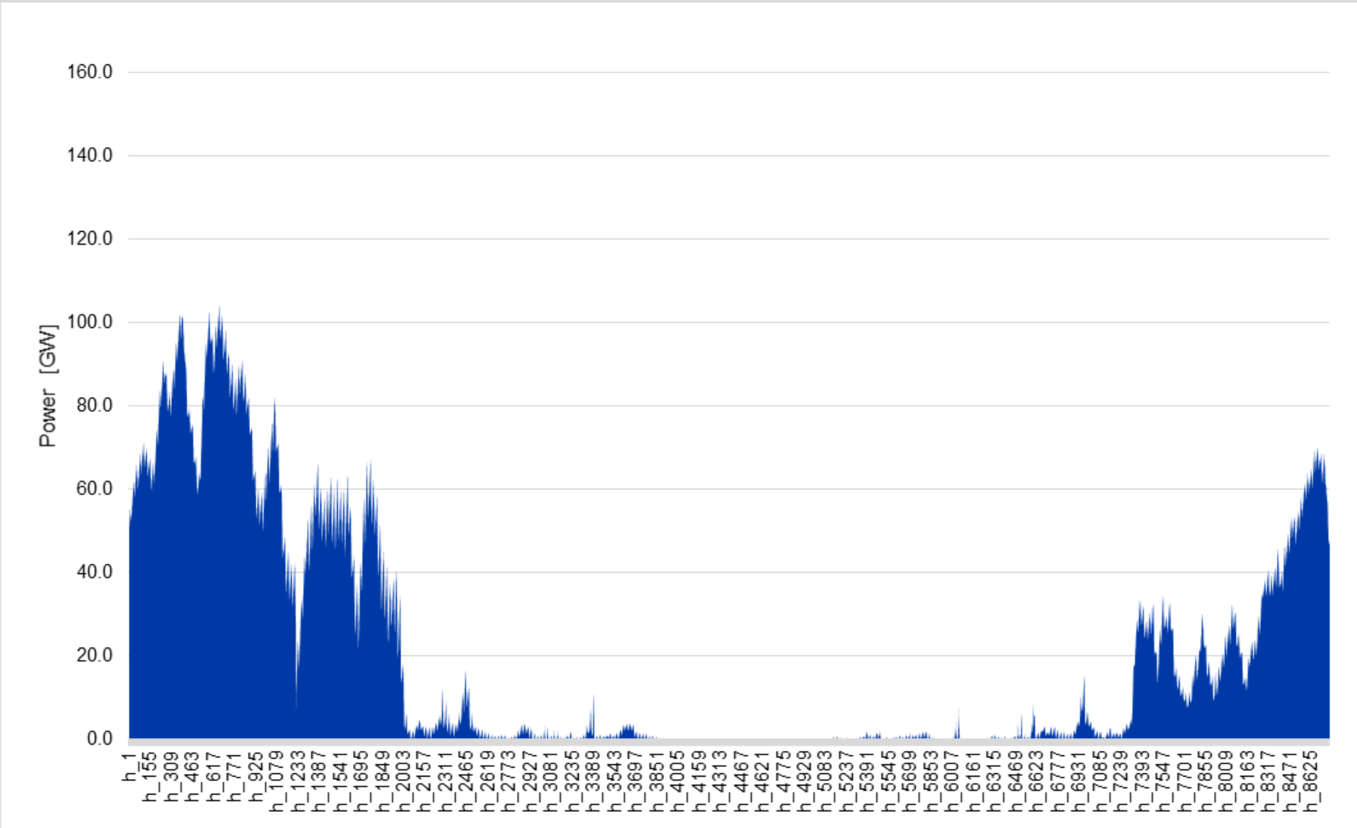


Figure 3 Hourly load profile of demand for electricity of heat pumps in the EU – Deep renovation

From the graphs it becomes visible, that energy efficiency on the demand side can not only substantially cut energy needs for space heating and related electricity use for heat pumps (savings of 165 TWh in 2050 of the high efficiency versus the low efficiency scenario), but can also significantly reduce related peak loads in electricity use in the future energy system in 2050 from around 160 GW (low efficiency scenario) to 100 GW (high efficiency scenario).

[16] low energy buildings offer the possibility to use lower system temperature which support in the case of heat pumps to achieve higher COPs compared to heat pumps in less efficient buildings. However for air-water heat pumps, high efficient buildings shorten the heating period to the times with lowest outside temperatures, which leads to lower COPs or air-water heat pumps at these times. As an average, we therefore assumed the COPs of heat pumps (mix of air- water and ground water heat pumps) to be the same in both scenarios.

Info box:

The future of the electricity grid

The policy targets set at the EC climate action plans for moving to a low carbon economy impose practically a full decarbonisation of the European power sector. [4]

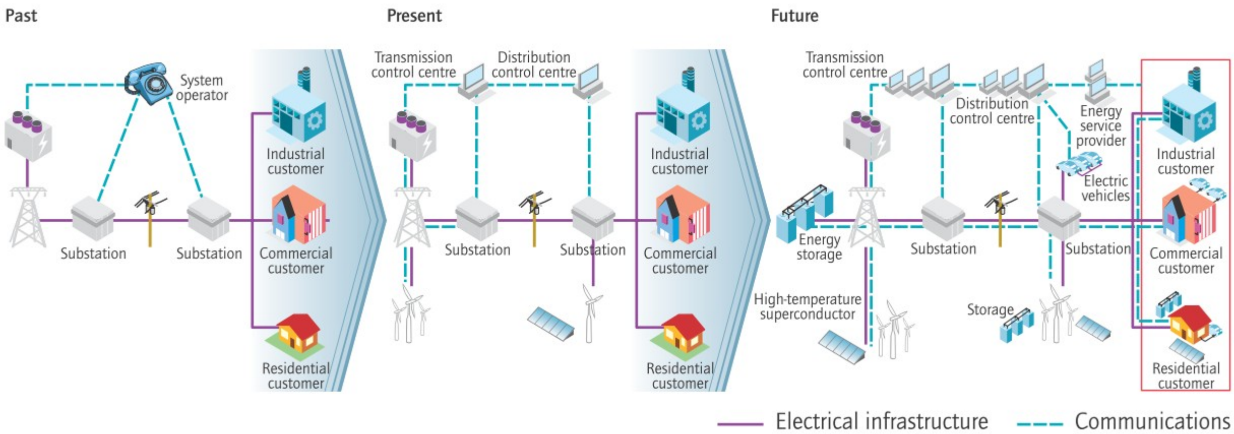


Figure 4 The transformation of power systems: from centralised to decentralised

This implies a radical transformation of the power systems to a demand-centric, decentralisation paradigm, affecting all system levels. These changes can be summarised as follows:

- *Generation*: traditionally electricity was centrally produced in controllable large-scale power plants that were situated far from demand, connected to the high voltage transmission grids. In future power systems, large shares of electricity should be produced by small to medium scale and variable renewable power plants, situated in all system levels, and mainly in the distribution grids close to demand and in buildings, on the so called 'behind the meter'. Therefore, there is a shift towards decentralisation and non-controllability of generation.

- *Grids*: traditionally grids were designed for uni-directional power flows, i.e. to transport energy from generation in transmission systems to the loads in the far end of distribution grids. The integration of distributed generation changes this paradigm and grids should be able to support bi-directional flows, from local systems where local generation exceeds demand. This new paradigm is referred to as Smart grids.

- *Demand*: demand undergoes the most radical transformation, in two key aspects:
    - *New demand:* a demand increase is expected due to the electrification of the transport and heat sector. The massive dimension of this increase creates concerns on the investments needed in grid infrastructure to support this development.
    - *Flexibility:* traditionally demand was considered passive and had no active role in the management of the power system. In the future, the flexibility in demand should be explored i.e. the ability to reduce/increase according to power system signals, in order to compensate the non-controllable supply.

The investment dimension in grid infrastructure in order to enable this transition is immense. The European Commission Energy Roadmap 2050 estimates investments requirements in transmission and distribution grids to sum up to over bn 270 € and bn 1245 € respectively in 2050 in their High Energy Efficiency scenario[17] [6].

In the following we will focus on how the electrification of the space heating sector affects the power system and will discuss positive cross-sector impacts due to high efficient buildings.

Electrification of heat sector: what about the power system?

Increasing the electricity demand (as foreseeable for the building sectors heat supply) affects the whole power system value chain and has traditionally been the key driver behind the power system development and investment decisions. The dimension of needed investments depend on four distinct characteristics of demand, namely demand dimension, location, pattern and flexibility. In addition to the before mentioned dimensions the way of supply (e.g. renewable, fossil) has an impact on the whole power system value chain and investment.

In this respect, the electrification of heat sector has the following aspects:

- *Dimension*: An electrification of the buildings sectors heat supply will lead to additional electricity demand. Electrification scenarios already involve the adoption of technologies such as heat pumps [7]. However, an assessment of the impact of energy efficiency on such an electrification scenario to the EU system load is generally missing in related literature.
- *Location:* buildings are connected at low voltage levels of the system. In this respect, the demand increase will present the same locational patterns as the current electricity demand from buildings.
- *Pattern:* the temporal pattern of the electrical heat demand defines the coincidence to existing peaks and therefore the contribution of this new demand to the increase of the peak demand.
- *Flexibility:* strongly linked to the temporal pattern, this characteristic relates to the ability of the heat demand be changed and shifted in time, so it does not coincide with system peaks.

[17] This scenario assumes the highest penetration of heat pumps and electric vehicles compared to other scenarios [6]

In order to assess the impact of energy efficiency on the demand side of buildings on the power system, it is important to look at the dimension, pattern and flexibility potential of heat demand. Based on these characteristics, the impacts to the power system can be classified in two key categories:

1. *Generation and grid infrastructure investments:* the dimensioning of the needed infrastructure to supply raising electricity demand to run heat pumps in the building sector is defined based on the expected new demand peak. This peak increase can be translated in needed generation peaking capacity and in needed investments in transmission and distribution grids.
2. *Operational costs:* typically 4-15% of electrical energy is lost in the transmission of electricity of several member states in the E.U[18], with the highest share (70%-85%) being lost in distribution grids (medium and low voltage, close to industrial and residential customers) [8]. Increasing buildings electricity demand will lead to an increase of the energy losses in the electricity grids. Since losses are a quadratic function of the network loading, the dimension of this increase depends on how much the new demand increases the peak load of the system. In particular, if the new demand appears at peak hours, the relative effect of losses will be increased with respect to off-peak hours[19]. [9]

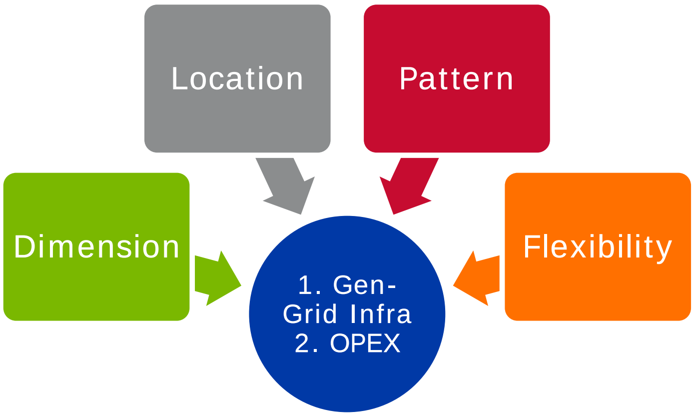


Figure 5 Key characteristics for the assessment of the impacts from the electrification of the heat sector.

Measures such as energy efficiency on the demand side, that affect the three key characteristics of heat demand, i.e. dimension, pattern and flexibility will therefore have positive impacts to the power system.

[18] This range corresponds to the following countries: Austria, Czech Republic, Denmark, Finland, France, Greece, Hungary, Italy, Luxembourg, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden and United Kingdom.

[19] Because losses grow quadratically with load, the marginal losses (losses during peak hours) are much greater than the average losses. As discussed in [9], a rule of thumb is that marginal losses are about 1.5 times average losses.

3.2 Impact of energy efficient buildings on the power system: methodology

Highly efficient buildings are beneficial for the power systems in two ways:

1. *Reduction of energy demand from buildings*: energy efficient buildings consume less energy, therefore reduce the dimension of demand. This translates into a reduction of the system peak, thus a reduction to the generation and grid infrastructure investments. Furthermore, it leads to a reduction of the amount of energy that needs to be generated and transported, thus to a reduction of the system operational costs and of the related losses.

2. *Higher flexibility*: the flexibility of heat demand refers to the ability of shifting the operation of heat pumps without affecting the temperature comfort levels inside the building [7]. Typically, high efficient buildings have a higher capability to shift heating operation in time, as a highly insulated building envelope has the ability to keep the desired room temperature stable over a longer period, also when the heating system is turned off. This increased flexibility can translate into a reduction of the peak demand and to a reduction of the system losses by the reduction of marginal losses.

In order to investigate the impact of energy efficiency in buildings to the EU power system we analysed the impact of electrical heat demand from buildings to the electricity demand in EU. Key scenario parameters and methodological points on our approach are the following:

- *EU system load:* We start from a detailed electricity demand for Europe for the industrial, commercial and residential sector. We obtained this based on scaling the hourly vertical load data at country level[20], obtained from the ENTSOE database [10], by the relative shares of industrial, commercial and residential consumption to final electricity consumption in each country. The hourly temporal resolution allows to investigate the impacts of heat load pattern and flexibility to the system. We use the 2014 dataset as a benchmark[21] and investigate the effects of heat demand increase due to the large scale heat sector electrification scenarios presented in chapter 3.1.
- *EU electricity heat demand scenarios:* We use the heat demand time series for two buildings energy efficiency scenarios (low and high efficiency scenario) on hourly temporal resolution. We deduct the load curve of heat pumps electricity demand by dividing the estimated space heating demand of all buildings by an average COP of 4.5. This demand is then added to the EU system load in order to assess the impact of the heat sector electrification.

[20] This analysis involves all members of the EU in 2014. We do not consider Norway and Switzerland.
[21] This is assuming a constant demand due to efficiency gains in the power system, in line with the assumptions of most studies.

- *Heat demand flexibility:* We analyse the effect of the flexibility of the heat demand by simulating the peak shifting potential under the two energy efficiency scenarios. To investigate this effect, we assessed the time span, in which the room temperature for an average building drops for more than 0.25 °C below the desired room temperature, when the heating system is turned off. The results showed that heat pumps in average buildings reflecting the low efficiency scenario (new and renovated buildings) can be turned off for 45 minutes while in average buildings that reflect the high efficiency scenario, heat pumps can be turned off for 120 minutes. In our simulations where therefore allow shifting of heat pump operation for 1 hour in the case of the low efficiency scenario and 2 hours for the high efficiency scenario. We thereby assume the allowed deviation from the desired room temperature by 0.25 °C to be a conservative estimate that fully respects the highest comfort needs. Several utilities, e.g. in Germany or Switzerland, already offer such tariffs with up to 2 hours of allowed interruption of heat pumps. Such tariffs are typically used for newly built low energy houses.
- In all cases we investigate the difference between the low and high efficiency scenario and estimate the peak reduction and reduction of system losses due to the increased buildings energy efficiency. This difference reveals the gains to the system by the adoption of a high efficiency strategy for the building stock.

The approach has obvious limitation since it does not take into account the detailed network and power park characteristics. However, it can provide a first assessment of the magnitude of expected effects. A more detailed simulation of the electrification of the heat sector to the European power system should be performed as a next stage, focusing on a detailed quantification of the costs and benefits of such a strategy.

3.3 Results

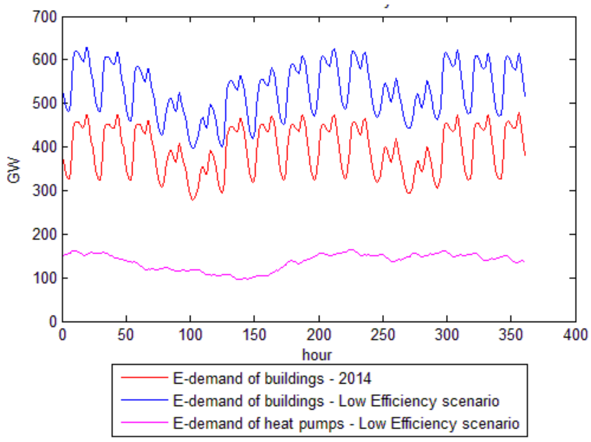
3.3.1 Impact of lower electricity demand of energy efficient buildings on the EU power system

Figure 6: Increase of heat demand from buildings to the EU system load: Time series for 2 weeks in January showing the respective patterns (left) and load duration curves showing the total impact (right) (left) shows the increase on the total EU system load due to the electrification of the heat sector, in the form of time series. As can be seen, the aggregate operation of heat pumps does not present high temporal fluctuations, therefor no radical changes in the demand patterns are observed.
The global results presented in Figure 6: Increase of heat demand from buildings to the EU system load: Time series for 2 weeks in January showing the respective patterns (left) and load duration curves showing the total impact (right) (right) are as follows:

- Low efficiency scenario: the building sectors electricity consumption (heating/cooling, lighting and appliances for residential and non-residential buildings) of the EU increases by approx. 11% (from 3070 TWh to 3415 TWh) and the system peak by 31% (from 480 GW to 630 GW).
- High efficiency scenario: the building sectors electricity consumption of the EU increases only by approx. 6% (from 3070 TWh to 3250 TWh) and the system peak by 20% (from 480 GW to 573 GW).

Comparing the two scenarios reveals that higher efficiency in buildings leads to a reduction of the peak load by 9% (57 GW) and to a reduction of 4.8% (165 TWh) on the energy generated and transported.

This is a considerable impact, as the 57 GW of avoided peak load until 2050 represent e.g. the complete current electricity production capacity (renewable and non-renewable) of Austria and the Netherlands together.



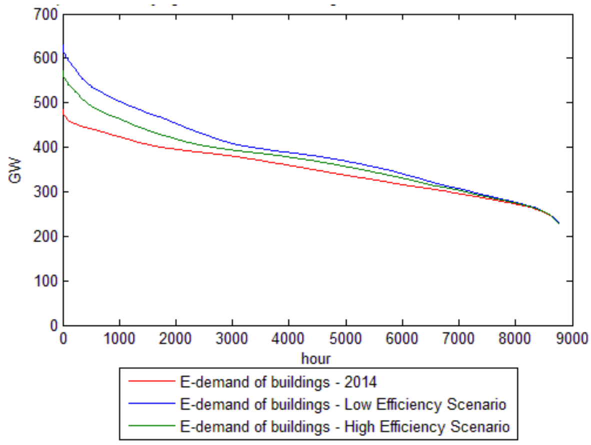


Figure 6: Increase of heat demand from buildings to the EU system load: Time series for 2 weeks in January showing the respective patterns (left) and load duration curves showing the total impact (right)

This reduction of peak load translates into a reduction in investment and operation costs in generation, transmission and distribution. A rough estimation of these benefits is as follows:

- *Generation Investments*: To supply peak load, the lowest-cost and secure solution existing today for grid operators is to rely on gas open cycle plants. The potential of future cost and performance of those plants have been assessed in [11] through industry participation workshops. The findings show an estimated CAPEX in 2050 of gas plants varying between600-700 €/kW. The generation capacity to supply the peak is estimated by the addition of the respective losses to the peak load. As discussed in [9], efficiency measures that lead to peak reduction have a magnified positive impact due to reduction of marginal losses. This leads to an increase of avoided generation capacity by 25%. Including this impact leads to respective generation CAPEX savings in the power system equivalent to generation CAPEX savings bn 43 – 50 €.
- *Grid Investments:* According to the World Energy Investment Outlook of 2014, the breakdown of grid investments for the European Union between 2014-2035 show a share of increasing demand to the capital cost of transmission and distribution networks of 12% and 20% respectively. Assuming that these shares remain the same in 2050, we estimate that the total investment costs in grids driven by demand increase will reach cumulatively bn 282 € in 2050[22]. A reduction of 9% of peak load owing to highly efficient, well insulated buildings would leads to savings of bn 3 € in transmission grids and bn 23 € in distribution grids .

[22] In the EC study [6] this number is driven by the penetration of electric vehicles and heat pumps. However, the final energy consumption in the High Energy Efficiency scenario results to 3200 TWh with the transport sector responsible for 20% of the share. Since our High Efficiency scenario resulted in a final energy consumption of 3250 TWh, we can assume a similar impact. In that sense, we estimate that equipping two-third of the building stock of the EU with heat pump would require bn 282 € of investment in the transmission and distribution grids.

Furthermore, the reduction of 165 TWh of energy generated and transmitted translates in estimated operational savings of:

- *OPEX in grids:* Power losses in the transmission and distribution grids of the E.U in the last 10 years have varied between 7% and 6.7% [12]. Scenario studies in references [13] [14] assume for 2050 power losses levels of 7.5% and in reference [15] power losses of 6%. Assuming an average range of 7%, an additional 12 TWh of energy in the EU is saved in the high efficiency scenario. Reference [13] evaluates two 2050 European scenarios where Europe meets its ambitious carbon target with a reduction of 95% compared to the 1990 emission levels[23]. The study finds that in 2050 the average cost of generation increase from 74.5 €/MWh (today) to 85 €/MWh. Hence saving 12 TWh of power losses in the grid corresponds to approx. bn 1 € per year of operation. The direct savings of the reduction of 165 TWh in operation costs in 2050 corresponds (at 85 €/MWh) to 14 bln €.

3.3.2 Impact of higher flexibility of energy efficient buildings on the EU power system

Figure 3 illustrates the daily load shape of the highest peak during the year in both scenarios. As discussed, by exploring the heat pump demand flexibility potential, we allow load shifting actions of one hour for the Low Efficiency scenario, and of two hours for the High Efficiency renovation scenario. The strategy is to shift load such that the peak load and the load variability is reduced, assuming that grid operators are allowed to control the heat pumps of the buildings such that they can minimize their system capital and operation costs.[24]

The results show that load shifts of 2 hours are much more effective in reducing the system peaks. Results prove that the impact of load shifting is greatly increased for a high efficient building stock as the peak load of the system is reduced by 13 GW in the High Efficiency scenario whereas it decreased by 1 GW in the Low Efficiency scenario. Figure 4 proves that point by illustrating the highest loaded 100 hours during the year for each scenario when heat pumps are not controlled (blue curve) and controlled (red curve).

[23] Conventional generation share decrease from 75% in 2008 to 7% in 2050 and RES share increase from 25% to 93%. CO_2 price increase from 10€/Mwh to 80€/MWh. Oil prices decreases by 50% and Gas, Coal and Nuclear prices are assumed fairly constant.

[24] Such operation is practiced today in Switzerland over 100,000 heat pumps installed where grid operators are allowed to turn them off three times per day (non-consecutives), each time up to 2 hours maximum [20]

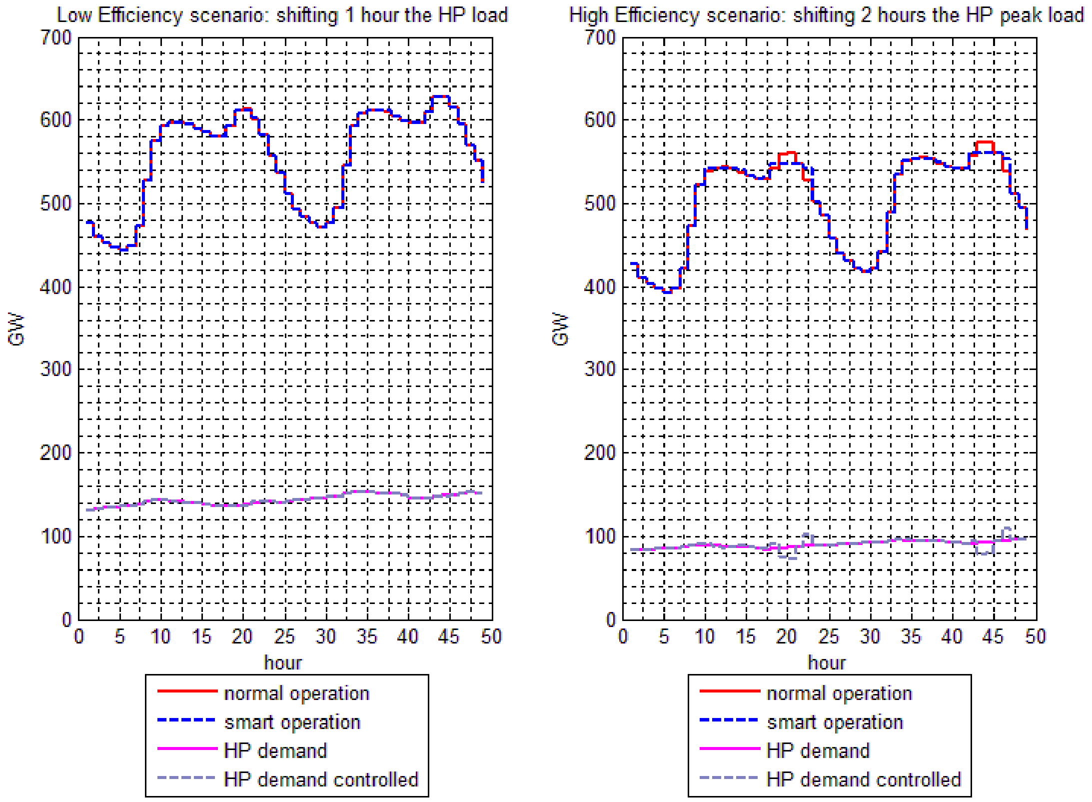


Figure 7: Daily load shape of the estimated EU electricity demand of buildings and the heat pump electricity consumption: Low Efficiency scenario with the option of shifting heat pump consumption by one hour (left) – High Efficiency scenario with the option of shifting heat pump consumption by two hours (right)

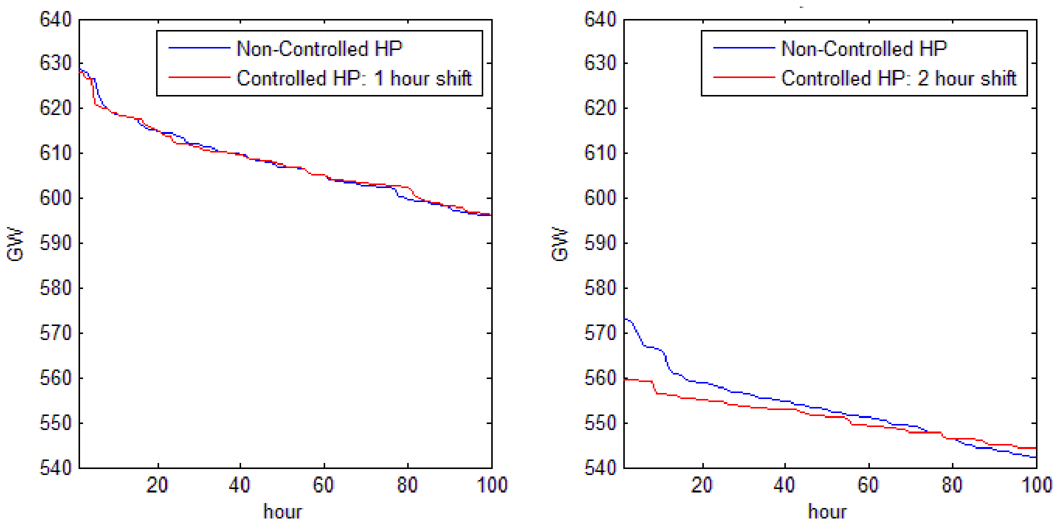


Figure 8 Load duration curve of each scenario showing the total impact of each heat demand flexibility option on the EU power system

Similarly to our quantification in the first case study, a rough estimation of reducing the peak load by 12 GW (2% from original peak of 630 GW) owing to a higher flexible heat demand as a result of high efficient buildings leads to:

- *Saved generation Investments*: bn 9 – 11 € avoided investments in gas peaking plants
- *Saved grid Investments*: bn 5 € avoided investments in distribution grids and bn 0.7 € in transmission grids

In this case study we have looked at the aggregated load demand of all buildings (industrial, residential and commercial) in the EU, which illustrates the impact of high efficient buildings on the flexibility of heat demand at a very high level, using current electricity demand patterns.
The lower the power system and the building load demand are aggregated, the higher the value of insulating buildings. The next case study focuses only on residential buildings in Germany.

3.3.3 Case study: Impact of the energy efficiency scenario on a country level: the case of residential houses in Germany

The scenarios on energy demand for space heating in this case study are comparable to the ones used for the assessment at EU level. Again, we consider that 65% of the heat demand in buildings in 2050 is supplied by heat pumps in 2050 and compare the impact of energy efficiency in the two scenarios.

To obtain a representative load curve of the aggregated residential houses of Germany, we scaled up the standard residential household load profile[25] to the total residential household consumption in the country (126 TWh in 2014 according to [16]). Figure 5 shows that the impact of controlling heat pumps is higher than in the previous case study as more heat pump load can be shifted to reduce the peak load due to the increased variability of the residential load curve on a country level.

[25] The standard household load profile in Germany is published by the German Association of Energy and Water and is available online for download at http://www.ewe-netz.de/strom/1988.php

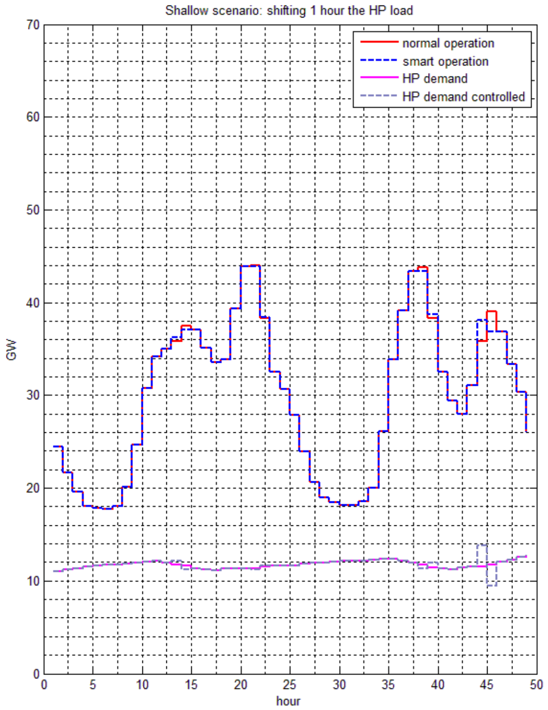


Figure 9 Daily load shape of the estimated residential buildings demand of Germany and the heat pump electricity consumption: Low Efficiency scenario with the option of shifting heat pump consumption by one hour (left) – High Efficiency scenario with the option of shifting heat pump consumption by two hours (right)

Figure 6 illustrates the impact of controlling heat pumps over the whole year with respect to each efficiency building scenario.

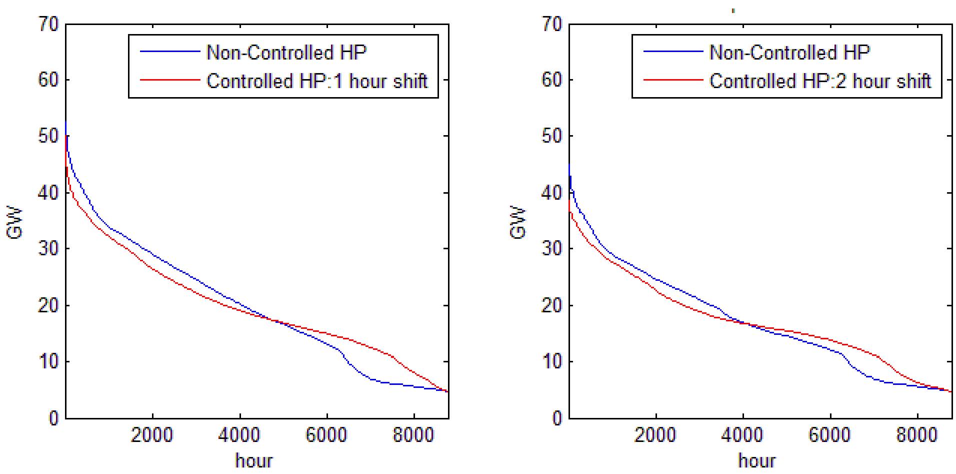


Figure 10 Load duration curve of each scenario showing the total impact of each heat demand flexibility option on the German power system. (Left) low efficiency scenario. (Right) high efficiency scenario.

Comparing now the two building efficiency scenario, the results show:

- 1 hour shift: Peak load in the system decreased by 4% (2GW)
- 2 hour shift: Peak load is reduced by 16% (7GW)

The case study proves that the impact of insulation on the flexibility of the power system is higher the lower the power system and building demand are aggregated as more heat pump load can be shifted to reduce peak load.

The value of power system flexibility offered by high efficient buildings in the assessed case of the residential building stock in Germany increased by 10%, as an additional 5 GW of peak power could be shifted in time. On a EU scale, the added value was increased by 2%.

In that sense, the results of case study 2 proves to be a lower end of the added value of energy efficiency to the flexibility of the EU power system as the results proved to be five times higher when analysed on a country level and a single building sector. For an accurate estimation, detailed country assessment needs to be conducted taking into account the peculiarities of different heat demand of buildings between north and southern countries and the different residential load curves per country.

3.3.4 Overview: impact of energy efficient buildings on the power system

Comparing the situation in 2050 for the high and low efficiency scenario, high energy efficiency leads to a reduction of peak load of 57 GW of energy generation of 165 TWh/y and on power losses of 12 TWh/y. This translates into monetary savings of bn 69 to 76 € in generation and grid infrastructure capital costs and grid yearly operational savings of bn 1 €).

Furthermore, we investigated the role of heat demand flexibility in enhancing those savings, since high efficient buildings have twice the capability to shift heating operation in time without affecting the temperature comfort levels inside the building. Results show that on a system level perspective, if all heat pumps were controlled with the objective to reduce peak level demand, high energy efficiency allows for additional reduction of 12 GW peak can be achieved. In total, demand flexibility through energy efficiency saves additionally bn 15-17 € in capital costs.

The following table summarizes the results of the study.

Table 2: Summary of the impact of demand side reduction of buildings through energy efficiency on the EU power system demand and its flexibility

	Impact from reduced electricity demand for electric heat pumps of high efficient buildings		Impact from increased flexibility of running heat pumps in high efficient buildings	
Reduction in peak load	57 GW (9%)	43-50 billion EURO in electricity generation CAPEX	12 GW (2%)	9-11 billion EURO in electricity generation CAPEX
		26 billion EURO in grid CAPEX		6 billion EURO in grid CAPEX
Reduction in power losses	12 TWh/a (5%)	1 billion EURO per year in Grid OPEX	< 1 bln EURO	< 1 bln EURO

The reduction in peak load from reduced electricity demand for electric heat pumps of high efficient buildings of 57 GW is significant and matches the complete current electricity production capacity (renewable and non-renewable) of Austria and the Netherlands together.

The impact of energy efficiency on the flexibility of the power systems leads to an additional reduction in peak load of the EU power system of around 12 GW. This represents a lower boundary of the effects, as grid operators actually have to balance demand and supply not at EU level but smaller national/regional boundaries (with less options to balance) which results in higher peak load savings from the gained flexibilities.
As described in the case study in chapter 3.3.3. the impact of flexibilities in this case was found to be 5 times higher than assuming balancing of demand and supply on EU level.
Considering this would locate the effect of increased flexibility from high efficient buildings in Europe in the area of 60 GW and therewith be in the same order of magnitude as the reduction in peak load from reduced energy demand. For an accurate estimation, detailed country assessment would need to be conducted taking into account national circumstances.
Additionally, the stronger fluctuation of the growing share of renewable electricity production will further increase the need for flexibilities on the demand side.

In financial terms, the total CAPEX savings in 2050 are 73 billion EURO (impact from reduced electricity demand for electric heat pumps of high efficient buildings) plus an additional 16 billion EURO (impact from increased flexibility of running heat pumps in high efficient buildings) equalling a total CAPEX reduction of 89 billion EURO in 2050 (153 billion EURO if considering more national/regional boundaries). Reduction in power losses would be around 1 billion EURO in 2050. Comparing this with investment costs under the study renovation tracks for Europe [3], the resulting 89-153 billion EURO of CAPEX reduction are in a range of approx. 3-5 % of the total necessary additional investments for demand reduction measures, when following a high efficiency instead of a low efficiency scenario. Those additional savings in peak load capacities and grid infrastructure are usually not taken into account or neglected in cost/benefit analysis, resulting in an underestimation of the positive economics of a more ambitious insulation of the EU building stock.

4 Conclusions and outlook

The assessment shows, that high efficient buildings can, under the hypothesis of an increasing electrification of the building sectors heat supply, not only significantly cut the electricity demand, but also related distribution losses and necessary investments in additional peak capacities and grid infrastructure.

Furthermore, energy efficient buildings make the power system more flexible. Energy efficient buildings with a highly efficient building envelope, either new buildings or after deep renovation, have an increased flexibility potential through their capability to shift heating operation in time without affecting the thermal comfort levels inside the building. High energy efficiency on the demand side, leading to considerable reduction in the heat demand in buildings, can thus also reduce costs in grid infrastructure and in power system operational costs.
On the flexibility, the assessment at European level represents clearly a conservative estimate. Moving towards country level reveals a significant increase of saving potentials from increased flexibility and should be a topic of further research.

As a consequence of the above, highly energy efficient buildings (for new buildings and in deep retrofits) do not only show benefits at building level but can also deliver benefits at electricity system level, thus supporting a resilient future energy system.

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