Future Green Buildings

A Key to Cost-Effective Sustainable Energy Systems

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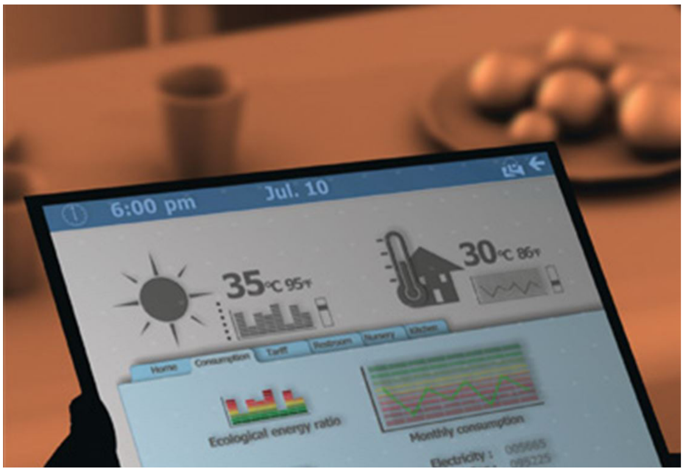

RENOVERING PÅ DAGSORDENEN

AALBORG UNIVERSITY
DENMARK

Future Green Buildings
– A key to Cost-Effective Sustainable Energy Systems

Danish title: Fremtidens byggeri - Nøglen til et omkostningseffektivt og bæredygtigt energisystem

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Bygherreforeningen
Foreningen af Rådgivende Ingeniører - FRI
Dansk Byggeri
Arkitektforeningen
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- **Bygherreforeningen (Danish Association of Construction Clients – DACC)**
- **Foreningen af Rådgivende Ingeniører - FRI (Danish Association of Consulting Engineers)**
- **Dansk Byggeri (The Danish Construction Association)**
- **Arkitektforeningen (Danish Association of Architects)**
- **Danske Arkitektvirksomheder (Danish Association of Architectural Firms)**
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Foreword

There is an increasing understanding in the public debate, as well as in the buildings and energy sector, that the times in which savings, heating, cooling, electricity, transport and gas could be seen as separate parts of energy system are over. In renewable energy systems, sectors need to be integrated. The understanding of the roles of the individual technologies is crucial. Buildings play a central role on the demand side in the future energy system. On the one hand future green buildings cannot be seen alone, on the other hand the renewable energy system cannot be looked upon without considering buildings and their users. This report aims to provide a direction for the development of buildings in and towards cost-effective renewable energy systems. The role of buildings needs to be understood better: How far should we go with savings? What is the role of flexible demand or storage at the building level? To what extent should on-site renewable energy production be the solution?

The partnership ”Renovering på dagsordenen” (Renovation on the Agenda) represents a very wide range of organisations and companies within the building sector in Denmark. The partnership has an interest in providing a better understanding of how future green buildings should perform in renewable energy systems. Long-term investments are made continuously on the demand and production side in the energy system. Buildings should not only function today, but also contribute to cost-efficient solutions and existing buildings will play a major role in the future.

This report “Future Green Buildings – A key to cost-effective sustainable energy systems” is supplemented by a short Danish summary titled: “Fremtidens byggeri – Nøglen til et omkostningseffektivt og bæredygtigt energisystem”. The report is prepared by researchers from The Sustainable Energy Planning Group at the Department of Development and Planning at Aalborg University. The project was carried out in the period from February to May 2016. The report can be downloaded from www.vbn.aau.dk.

A workshop with key participants from “Renovering på dagsordenen”, Aalborg University – Department of Development and Planning, and Aalborg University – Danish Building Research Institute (SBi) was carried out as part of the process in March 2016. The participants were: Thomas Uhd, Bygherreforeningen; Graves K. Simonsen, Bygherreforeningen; Annette Blegvad, Arkitektforeningen; Peter Andreas Sattrup, Danske Arkitektvirksomheder; Michael H. Nielsen, Dansk Byggeri; Pernille Hagedorn-Rasmussen, IDA; Henrik Garver, FRI; Søren Aggerholm, SBi; Per Heiselberg, AAU; Kirsten Gram-Hanssen, SBi; Henrik Lund, AAU; Jens Stissing Jensen, AAU; Brian Vad Mathiesen, AAU.

While Denmark is well on the way to having renewable based electricity and heating sectors, a number of challenges still exist within energy storage, transport and the integration of the energy sectors. The aim here has been to collect state-of-the-art knowledge about the role of buildings in this context, present the technical possibilities that are available and to inspire short-term decision-making based on this.

On behalf of the authors, Brian Vad Mathiesen, May 2016

Executive Summary

Similar to today, efficient buildings are essential for an affordable Danish energy supply in 2050. The purpose of this report is to describe the contribution and role of the building sector in a 100% renewable energy future, as well as the transitions that are necessary in the building sector to support this change. The report builds on a literature review encompassing more than 50 reports and research papers over the last 10 years and more than two decades of knowledge about the interactions between different components of the energy sector. The review has been focused on aspects such as cost-effective solutions from an energy system integration perspective, heat savings, electricity savings, and user behavioural aspects as well as energy storage and household level flexibility.

Many reports on green or sustainable buildings focus only on savings levels and disregard the cost of renewable energy production. Some reports focus on building level on-site renewable energy production, optimising storage for passive houses, or net-zero emission buildings. In an integrated energy system, the question is, how far should we go with savings? What is the role of flexible demand or storage at the building level? And to what extent should on-site renewable energy production be the solution?

Stakeholders associated with the buildings sector need to support such a transition because the use of buildings, renovation and expansion should facilitate an increasingly lower electricity and heat demand, while also enabling cost-effective and flexible systems to supply energy to the building.

The key to understanding the future role of existing and new buildings is to understand the changes around buildings in the next 34 years in the energy system. A number of reports have looked at scenarios towards 2050, including the Danish TSO, Energinet.dk (2015) and The Danish Energy Agency (2013). Research on identifying a balanced approach to supply side and demand side measures from a system perspective has been conducted in a number of analyses since 2006[1]. The latest report using system level knowledge and research is the IDA Energy Vision 2050 (IDA-Danish Society of Engineers)[2]. In this report we take this vision for Denmark as the point of departure, however similar developments for the energy system and role of buildings can be found in other reports. Other countries in a similar transition process may find the recommendations and results useful.

The IDA Energy Vision 2050 concludes that 100% renewable energy in 2050 is technically possible and economically feasible. This transition can also be done cost-effectively and with a sustainable use of biomass by using a Smart Energy System approach. This approach entails using synergies in savings, energy efficiency, interactions between sectors and with an integrated use of storage as well as existing infrastructures. The contribution of the building sector is essential to establish smart energy infrastructures and a 100% renewable Denmark. If done, the overall transition towards 2050 can create 50,000 jobs/year domestically within a wide range of skills, from carpenters to wind power

[1] *Ingeniørforeningens Energiplan 2030 – baggrundsrapport*; Lund H, Mathiesen B V. Ingeniørforeningen i Danmark, IDA, 2006. *Varmeplan Danmark*; Dyrelund A, Lund H, Möller B, Mathiesen B V, Fafner K, et al. Aalborg University, 2008. *Varmeplan Danmark 2010*; Dyrelund A, Fafner K, Ulbjerg F, Knudsen S, Lund H, Mathiesen B V, Hvelplund F, et al. Aalborg University, 2010. *IDA´s klimaplan 2050 – Baggrundsrapport*; Mathiesen B V, Lund H, Karlsson K. Ingeniørforeningen i Danmark, IDA, 2009. *Coherent Energy and Environmental System Analysis (CEESA)*; Lund H, Hvelplund F, Mathiesen B V, Østergaard PA, Christensen P, Connolly D, et al. Aalborg University, 2011. *Heat Saving Strategies in Sustainable Smart Energy System*; Lund H, Thellufsen J Z, Aggerholm S, Wittchen K, Nielsen S, Mathiesen B V, Möller B. Aalborg University, 2014.

[2] *IDA's Energy Vision 2050 : A Smart Energy System strategy for 100% renewable Denmark*; Mathiesen B V, Lund H, Hansen K, Ridjan I, Djørup S R, Nielsen S, Sorknæs P, Thellufsen J Z, Grundahl L, Lund R Søgaard, Drysdale D, Connolly D, Østergaard P A. Aalborg University, 2015.

engineers. In addition, there is a significant potential for jobs from increased technology export as well as the side effects of lower emissions and lower Danish health costs.

Today, buildings account for around 41% percent of the total end-use energy demand in Denmark (see Figure 1). This constitutes mainly heating, hot water and electricity demands in appliances and cooling. With such a large use of resources in buildings, reductions in electricity and heat demands as well as changes in the energy supply are essential for a cost-effective future 100% renewable energy system. Recommendations to conduct energy savings and support behavioural changes in the operation of buildings go hand in hand with supply level recommendations. District heating should be expanded further to replace individual boilers and new supply systems with lower temperature district heating from solar thermal, large-scale heat pumps, geothermal, waste incineration, and biogas. should be supported. Outside district heating areas, efficient ground-source heat pumps supplemented with solar thermal can be recommended.

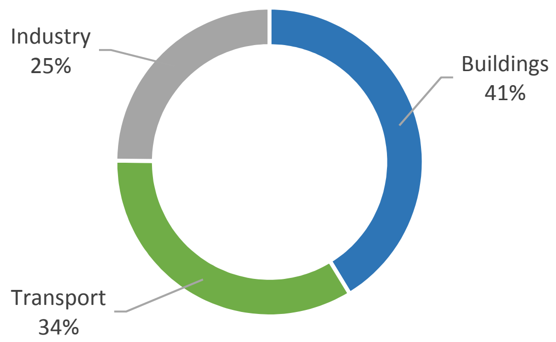


Figure 1: Breakdown of the total end-use energy demand between different sectors in Denmark

Currently, we have very strict energy performance levels for new buildings from 2015 and 2020. This however does not solve the problem we need to address in the building stock in general, because savings and low energy use in new buildings cannot reduce energy demands to a level sufficient for the energy system, and focus on new building seems to take focus away from existing buildings and the importance of electricity and heat savings there. In addition, the performance levels are strict and shaped so that they promote the installation of on-site energy production units to offset energy consumption. This means that production units are installed on buildings which may not always be cost-effective and beneficial to renewable energy on the larger scale. Additionally, it isolates the buildings from the system and makes cooperation between neighbours more difficult regarding heat supply for example. Photovoltaic (PV) should be promoted and is highly needed for electricity production on the system level. This however must not result in lower building insulation levels and it must not result in a promotion of household level batteries to shift their production from one hour to another. Both lower levels of insulation and suboptimal integration of storage can be extremely expensive.

Three separate perspectives have been identified as key for the building sector in a 100% renewable energy system. Firstly, greater energy efficiency in the whole stock is crucial to enable a renewable, flexible energy system, especially in existing buildings. Secondly, the operation and user-behaviour of people in buildings is a crucial element to achieve savings in

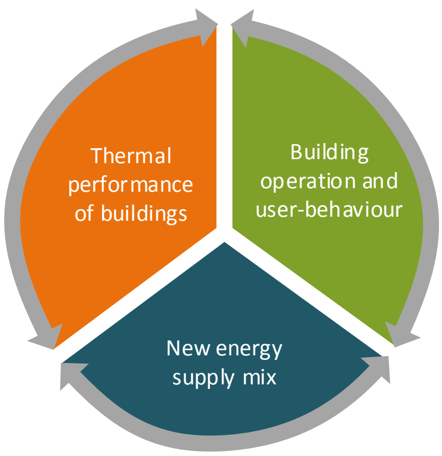


Figure 2: Three perspectives key to the role of buildings in future cost-effective sustainable energy systems

heat and electricity demands over time. The third is the supply mix of energy, where buildings have an important role in opening up possibilities for more efficient use of renewable energy and more flexible energy sources in infrastructure and storages in other parts of the energy system.

While these three points are separate elements for cost-effective green buildings of the future, they are closely and inseparably intertwined, to the point that the one is impossible without the other. In many cases parallel developments are required in order to unlock the potential contribution that buildings can have in a renewable energy future.

Thermal performance of buildings

An important point of departure for understanding the role the Danish building stock is that newly built houses only play a relatively small role due to the long lifetime of existing buildings. Only approximately 1-1.5% of the housing stock is newly built each year, most of which represents growth in the housing stock rather than replacement. Most of the buildings that are important in terms of saving energy from today to 2050 have already been built. A strategy for increasing the technical energy efficiency of the building stock must therefore have the existing building stock as its primary target.

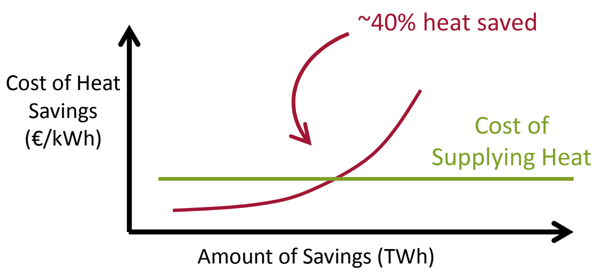


Figure 3: Simplified diagram which shows that energy renovations should only be invested in until the point in which the cost of supplying heat to the building is cheaper than further renovations. In the Danish building stock ~40 of heat demand per square metre should be saved in existing buildings

The most important contribution of the building stock is efficiency improvements and energy savings concerning the use of heating, cooling and electricity in the buildings. Energy saving strategies should be preferred as long as the marginal cost of realising these energy savings is lower than the marginal cost of increasing the renewable production, both with regard to electricity and heat (see Figure 3). In the IDA Energy Vision 2050, the recommended magnitude of heat savings in existing buildings should reach an average of approximately 80 kWh/m²/year depending on type and age, compared to an average of 132 kWh/m²/year in 2015[3]. This ensures that all houses can be renovated to a point of efficiency that makes sense for the type of building at hand, rather than focusing on investments towards integrated renewables in one building, which are typically not cost-effective from a system point of view. Given the gains necessary to bring the entire building stock to at least 80 kWh/m²/year, a broad, long term strategy taking into account the entire building stock is necessary. If heat savings are not achieved to the level suggested here, the primary energy supply in the system may increase by 16 TWh/year (58 PJ) and the costs may increase by approximately 2 billion DKK/year. Moreover, the heat savings in the buildings are important for the system, since they pave the way for low-temperature heating supplies. These are essential for both future district heating solutions as well as individual heap pumps.

Within the building sector, the focus should be on renovating pre-1980 buildings, which do not perform nearly as well as buildings built under more stringent Building Codes. Implementing heat savings on their own is in general so costly that from a socio-economic point of view, this cannot be

[3] The kWh/m² includes space heating and use of hot water, but excludes electricity consumption as well as onsite energy production such as solar thermal or PV.

recommended. It is essential that heat savings in existing buildings is implemented together with general renovation and refurbishment. Since the frequency of general refurbishment activities is 20-50 years it is critical that energy savings are systematically addressed in relation to all refurbishment activities. Otherwise, the cost of achieving demand savings is excessive and a renewable energy system by 2050 is most likely more costly.

In terms of actions required and the challenge to reach the target - which from an economic point of view is cost-effective - even going halfway is extremely ambitious. It is unlikely to happen without serious initiatives and a strong policy framework. Since 1980, the building stock's final energy consumption per square metre for space heating and hot water has decreased by approximately 35% in the past 35 years, while the total floor space increased by approximately 40%. The ambition for the next 34 years should be to accelerate reductions in the final energy consumption of the building stock. For the building stock that exists today this means that approximately 40% savings can be recommended for space heating (including hot water).

Although new buildings pose a smaller challenge overall, it is key that recommendations are made which facilitate savings to a level at which supply with renewable energy becomes cheaper. In the IDA Energy Vision 2050 it is recommended that heat demands in new buildings reach a level of ~55 kWh/m^2.

Figure 4: Operation of the buildings should account for technology, user knowledge, habits, and norms (meanings)

Building operation and user-behaviour

User practices have a decisive influence on the actual use of energy in buildings, so a change in buildings' energy demand though new technical installations will have to include changing the way that people interact with and use buildings. For example, 1) the 'pre-bound effect': residents in dwellings with a low technical energy standard may keep a relatively low indoor temperature, or they only keep part of their house heated; and 2) the 'rebound effects': residents in dwellings with a high technical energy standard may develop less energy efficient practices.

Energy efficiency cannot be seen merely as a technical exercise. Technological changes such as insulation, smart meters, thermostats, on-site energy production etc. must be accompanied by behaviour altering measures that will actually result in lower energy consumption in the operation phase. This can include smart meters and other behavioural considerations around building users' knowledge, habits and norms (meanings)[4].

In terms of the overall flexibility of the system and ability to integrate intermittent renewable energy sources, both system level flexibility and flexible demand and storage in buildings are considered. System flexibility, based on the aggregation of demand and integration between sectors as described in the IDA Energy Vision 2050 and Smart Energy System concept, is cheaper to achieve than flexibility and storage at the building level. While passive storage of heat in the buildings may be used cost-effectively, the potential is limited. It is more important to have low energy use in the operation of the buildings - and a shift from boilers to heat pumps or district heating - than to focus on flexibility on the building level. While flexible demand of electricity and heat may contribute to reducing peaks for production plants, savings can reduce peaks more consistently in the operation phase. Flexibility

[4] Gram-Hanssen K. Housing in a sustainable consumption perspective. In: Reisch LA, Thøgersen J, editors. Handb. Res. Sustain. Consum., Cheltenham, Massachusetts: Edward Elgar Publishing; 2015, p. 178–91

and storage should focus on the integration of the electricity, heat, cooling and transport sectors. Sending price signals via the electricity market to homes is an expensive and inefficient way of providing flexibility looking at the challenge in the overall system transformation. Electrification of district heat, transport and production of hydrogen by means of electrolysis can provide more cost-effective flexibility services and storage than single buildings.

The risk of promoting batteries on the household level is high - which is problematic - if careful consideration is not put into regulation of PV, electricity levies and the buildings codes. The economic costs of storage of electricity in batteries with the purpose of bringing electricity back onto the grid is very high due to two reasons. Firstly, electricity may be stored in the building when electricity demands elsewhere are high and being met by fossil fuel power plants, hence not actually stopping power plants. Secondly, using electricity at night from batteries decreases the use of electricity from the grid at times when other renewables may be abundant, demands are low in general and prices are low. In addition, battery storage in itself is an extremely expensive form of storage, with electricity storage being costlier by a factor of 100 compared to thermal storage, and more than a factor of 1000 compared to gas and liquid fuel storages.

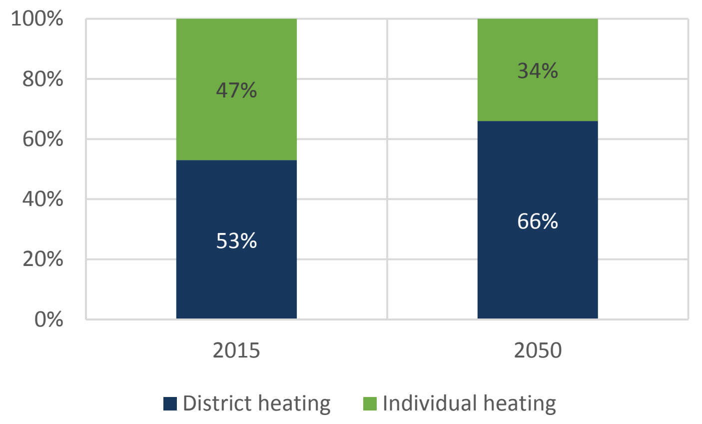


Figure 5: Proportion of total heat supply split between individual heating and district heating

Efficiency and heat, cooling and electricity savings is more important than for buildings to have energy storage or balancing capacity. Buildings' largest contribution to a 100% renewable energy system is through efficiency; by lowering the total energy needed, by lowering the peak energy needed, and in the case of thermal energy by lowering the temperature at which heat is required through more efficient buildings, and increasing the retention of heat in the building envelope. Building regulations, tariffs, and innovative smart developments should be focused on reducing energy consumption, enabling low temperature district heating, and on peak shaving through passive heat storage.

New energy supply mix

Understanding the energy supply-side of buildings is crucial for making effective decisions on energy use in buildings. Technologies such as large-scale heat pumps for district heating, low temperature district heating, large heat storages and ground source heat pumps actively help integrate renewable energy into the energy system cost-effectively. These supply side options go hand in hand with efficiency measures in the operation of buildings. In the IDA Energy Vision 2050 these infrastructures represent the link

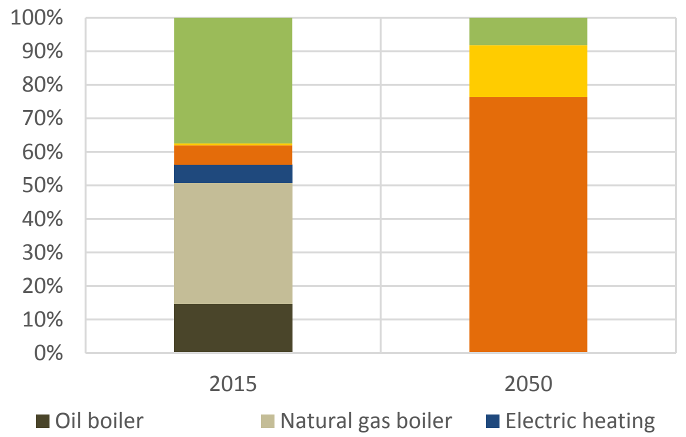


Figure 6: Breakdown of heat supply technologies within buildings

between the thermal (heating and cooling) and electricity sectors that underpin the Smart Energy System, and the system flexibility in the storage options provided. The more efficient the building stock is, the more synergies and benefits can be created for the overall system, which may consist of three times the amount of wind power we have today. It is feasible that the electricity mix may have more than 80% fluctuating renewable energy sources in 2050.

District heating coverage should be increased also to new buildings depending on local costs and local conditions (Figure 5). Cost-efficiency is associated with replacing boilers with district heating and ground source heat pumps. The use of biomass boilers should not be promoted; however, some installations will be present (Figure 6). Lower temperature demands in the buildings increase the efficiency in all these supply options.

Where feasible, solar thermal should be installed to supplement ground source heat pumps or biomass boilers. PV is an important part of the future energy system. PV should be promoted with a balanced scheme so cost-optimal installations are installed which in some cases are on buildings, in others on fields. To ensure the renovation of existing buildings and new buildings is achieved sufficiently, the demands for the building insulation level and the installation of solar thermal or PV should not be mixed in the regulatory and policy framework.

Key points & recommendations

Thermal performance of buildings

- In the future, the same as today, buildings will be responsible for a large proportion of heating, cooling and electricity demand in the energy system. However, in the future, the energy system must consume less to achieve the 100% renewable goal, meaning that it is **essential that the building stock is part of the energy transition** through energy savings. Overall existing buildings should reduce their total space heating energy consumption by around 40% between today and 2050 (including hot water). The total electricity demand from the building stock should remain at the same level as today, even with more buildings and electric heat pumps. This means electricity savings should still be promoted in new appliances. Energy efficiency and energy savings in the building stock will lower the total amount of energy required, increase retention of heat in the building envelope, lower the peak energy demand levels, and lower the temperature level required from heat supply technologies. This is very important for the overall performance of the system.

- Between 1-1.5% of the building stock is newly built yearly. Most of these buildings represent a growth in the building stock rather than replacement, which is only around 0.25% per year. In total it is expected that new building floor space will increase by around 25-30% from today until 2050. The buildings built today are required to be highly energy efficient according to the BR15. This means that for the building stock as such, **it is less important to place focus on new buildings to save energy in the future energy system**, since very little renovation activities will need to be done until 2050 for these buildings.

- Around 90% of the building stock existing today will exist in 2050. Therefore, **energy savings need to be made in the existing building stock**. To have a cost-effective energy system it is a prerequisite that existing buildings reduce total heating energy consumption by around 40% between today and 2050. This means the average heat demand per square metre for the existing building stock should be reduced by around 1.5% per year until 2050. In the last 15-20 years the average heat demand per square metre has been decreasing at around 0.8-1% per year. This means that an increase in renovation rates for existing buildings is necessary. If this is not achieved by 2050, the need for biomass may exceed the available biomass in Denmark or more wind turbines and PV may be required. This will eventually lead to risks related to energy security of supply and certainly higher costs of the energy system.

- **Renovations should be targeted at the worst performing buildings first.** A detailed list of buildings to be renovated has not been provided in this report. However, based on this assertion, most renovation activities in existing buildings should be done in buildings built prior to 1980, especially for older buildings such as individual detached houses built in the early 20th century.

- There is a very specific and limited window of opportunity to implement energy renovations in existing buildings. It is essential that **energy renovations are done when renovations are already being carried out** on specific parts of the building, for example, roofs and windows. This is because it is not cost-effective to do energy renovations by themselves. Certain policy measures would likely be needed to encourage this activity.

Building operation and user-behaviour

- Heating and electricity savings will likely not be achieved if only technical energy renovations are carried out in the building stock. It is necessary to **consider and address connecting technical energy renovations and operation (smart meters) to user behaviour in the building.** Electricity savings are mostly achieved through improved building operation and user-behaviour.

- Heating and electricity savings should be achieved with improved operation of the building (i.e. via smart meters, better appliances, thermostats etc.) and consumer behaviour. **Behaviour and user operation is key to the performance of buildings**, to the extent that end use of energy in identical buildings may vary by a factor of three. The pre-bound and rebound effects mean that even if buildings are renovated, the energy savings are not guaranteed. To address this appropriately when installing energy renovations and other technologies such as smart meters (that provide different information to the user or system operator), it is essential that three factors are considered: user knowledge, habits and norms (meanings). If these factors are addressed in isolation, not addressed, or not addressed together the chances of achieving heat and electricity savings are likely to be reduced.

- To optimise the potential of user-behaviour and operation of the building, it is important that the **operation of the buildings is according to the needs of the energy system**, and not optimised to the needs of the individual building. This is because the energy system in the future will be highly integrated, and for the energy system to operate properly it will depend heavily on the appropriate operation of the buildings. This means that buildings should not operate in isolation from the rest of the energy system or be optimised on its own.

- **Buildings should not be prioritised as a source of flexibility in the energy system** since the flexibility can be provided by cheaper means and more efficient technologies in other parts of the system, for example large-scale heat pumps, electrolysers, and large-scale thermal storage. Smart meters or flexibility in using e.g. heat pumps or regulation the heat demands have a potential to make contributions to reduce peaks for power plants and in production of district heating. The potential for integrating large quantities of renewable energy by using this flexibility is limited.

- There is **limited room for building level flexibility**, **building level energy storage and using integrated energy supply as a way to offset building level energy consumption (nZEBs).** Flexibility and energy storage services can be achieved more cost-effectively and with more success at the system level rather than the building level. Studies demonstrate that investment in passive heat storage is a cost-effective way of providing flexibility, but investments in heat accumulation tanks and batteries on the household level are not cost-effective. Energy savings in buildings are more important than building level flexibility.

New energy supply mix

- The flexibility required to integrate fluctuating renewables is realised by integrating the thermal, power and transport sectors towards 2050. The improved efficiency in the building stock will help create synergies between these sectors in the wider energy system, by allowing more integration between the thermal and power sectors. With increasing fluctuations in the electricity supply caused by wind power and PV, this calls for solutions to increase the flexibility of the system. **Buildings can contribute to a Smart Energy System by enabling a new interplay with energy supply technologies that maximise the synergies in the system, such as (low-temperature) district heating and in some buildings district cooling in dense areas, and individual heat pumps in less dense (rural) areas.** By utilising these two technologies this means that more benefits can be achieved at the system level by integrating more renewable energy technologies and cheaper energy storage technologies.

- **Individual micro-CHP options or biomass boilers do not seem to be desirable,** neither in terms of fuel efficiency nor from an economic point of view. Biomass boilers however will be used to some extent in the future although biomass can be allocated better to other purposes than heating and used more efficiently.

- It is cost-effective for the energy system to **increase the share of district heating from around half of the heat supply today to around two thirds in 2050**. This is based on analysis that used GIS mapping to determine the costs of installing new pipelines and district heating infrastructures as well as energy system analyses. Moreover, the expansion of district heating will help utilise heat production from waste incineration and industrial excess heat production, geothermal heating, biogas production (supply of heat), and solid biomass such as straw.

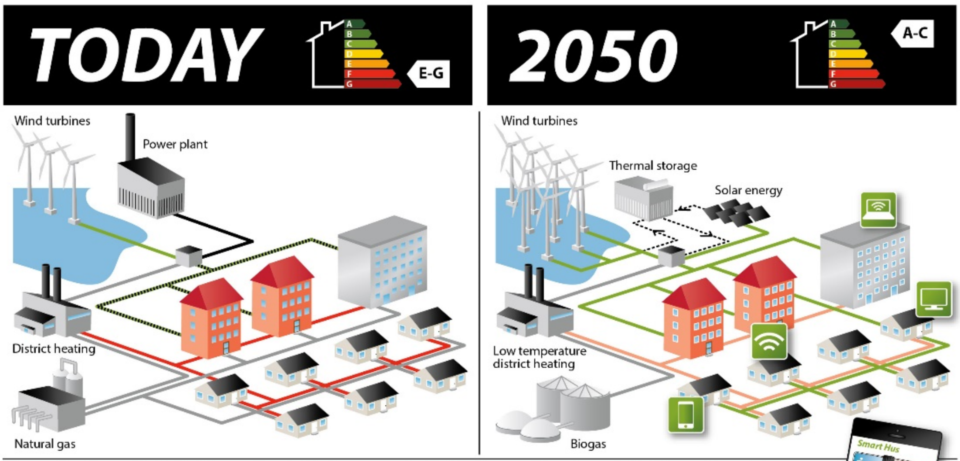
- Coupled with increased district heating and heat savings in buildings, the temperature of the **heat supplied to the buildings can be gradually decreased towards 2050** to save primary energy demand but also to enable integration of new renewable energies, excess heat from industry, large-scale heat pumps and energy storages at the system level. It is uncertain how the buildings will need to be upgraded to receive lower temperature district heat since this research is ongoing, but it is likely that most radiators installed today will be sufficient in the future. Smart meters could facilitate good solutions and help monitor changes in the operation of the building.

- **Individual heat pumps seem to be the most cost-effective alternative to district heating for buildings too far from district heating grid**. This is because heat pumps provide external benefits to the energy system through high energy efficiency, by electricity consumption, and by having some level of flexibility. They are the individual heating alternative that fits best into a cost-effective 100% renewable energy supply, also because they place the least pressure on the amounts of biomass and wind required in the system. Ground-source heat pumps should be promoted as the COP is higher than air-air heat pumps during the colder winters. On-site solar thermal heat production units should be installed on buildings to assist heat production units such as heat pumps or biomass boilers.

- It is important that **energy efficiency and building integrated energy production are regulated independent from each other** in order to avoid that for example the installation of PV, solar thermal or individual heat pumps will lead to less renovation levels and decreased energy performance in the building.

- The future energy system will have a higher share of PV, with at least 5000 MW capacity installed, however it is **important that PVs (and other electricity producing units) are installed where it is**

most cost-effective and appropriate for the energy system. It is not necessary to install solar PV on all buildings, and it can be inefficient to install solar PV on buildings in order to offset in-building energy consumption (for example in nZEBs). All electric energy production units should remain connected to the grid and interact with the system. In addition, on-site electricity storage should be avoided since this is not beneficial to the system and leads to higher energy system costs.



The green transition requires that buildings are integrated into the energy system. Significant energy efficiency is essential. Buildings must be ready for new energy sources. And smart technical solutions will ensure optimal operation and good user behavior.

Thermal performance of buildings	Level of heat demand in existing buildings	Low, medium and high	Low
	Level of heat demand in new buildings	Very low	Very low
Building operation and user-behaviour	Level of appliance electricity demand	Medium	Low
	Level of heat pump electricity demand	Low	Medium
	Energy-efficient user practices	Limited	Medium
	Building level flexible demand	None	Very limited
	On-site electricity production and own-use	Very limited	Very limited
	On-site electricity storage	None	Very limited
New energy supply mix	Level of district heating coverage	High	Very high
	Low temperature district heating	None	High
	Large scale heat pumps	Low	High
	Individual heat pumps	Low	High
	Individual boilers	High	Low

Figure 7: Three key perspectives in which the Danish building stock will be more involved in the future energy system