The influence of near zero energy buildings on the future Danish energy system

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Abstract

Buildings consume a large proportion of primary energy in Europe in the form of electricity, heating, cooling and gas. In response to this, the concept of near Zero Energy Buildings (nZEB) has been developed. These buildings have very low energy demands, integrate renewable energy, and to increase energy efficiency they utilise smart technologies. nZEBs aim to increase energy efficiency from a demand-side user perspective. For example, the building is more energy efficient by having a well-insulated envelope, and the user reduces energy consumption through better user-behaviour, or with different smart technologies. This leads to a reduced end-use energy demand and carbon emissions. When looking at buildings within the entire energy system, there are also energy efficiency gains to be achieved on the supply-side. For example, within a district heating system, heat pumps can be installed. If an energy system becomes more efficient on the supply-side, then the question is how much energy needs to be saved on the demand-side, for instance by nZEBs. The purpose of this paper is to analyse and understand the implications from building nZEBs within an energy system that is a) transitioning to 100 % renewable energy, and b) has substantially improved supply-side energy efficiency. A case study from Denmark is used to understand the outcome for the energy system when nZEBs are built in this context. The analysis looks at the total system energy savings, costs and resource consumption. Based on the results from the study, the paper finishes with some basic policy recommendations around nZEBs in Denmark and Europe.

Introduction

Buildings consume a large proportion of the primary energy demand in cities in Europe. Subsequently most carbon emissions that arise from cities are from buildings. Around 40 % of the primary energy of buildings is for space and hot water heating (European Parliament 2016). To improve energy efficiency, the penetration of renewable energy and to reduce carbon emissions, today numerous city initiatives focus on the building sector (especially for heating).

The recast of the EU Directive on Energy Performance of Buildings (EPBD) specifies that by the end of 2020 all new buildings should be near Zero Energy Buildings (nZEBs) (European Commission 2010). The deadline for building nZEBs in Europe is 2018 for public buildings and 2020 for all other residential and non-residential buildings. nZEBs aim to lower the energy consumption and carbon emissions of the building stock thus lowering the impact of the city and country (Kylili and Fokaides 2015).

According to the EPBD, the definition of a nZEB is a "building with very high energy performance where the nearly zero or low amount of energy required should be extensively covered by renewable sources produced on-site or nearby" (European Commission 2010). Thus, nZEBs combine energy efficient building design with renewable technologies, for example solar PV, to allow for the efficient use of energy, as well as renewable energy generation (Torcellini and D.B. Crawley 2006).

Numerous studies have focused on nZEBs and their usefulness for improving energy efficiency. This has been on a building level (Pikas, Thalfeldt, and Kurnitski 2014; Mohamed, A., Hasan, A., & Sirén 2014). Some studies have investigated nZEBs at community level (Lopes et al. 2016). A study investigated the influence of local renewable generation from nZEBs on the wider energy system (Lund, Marszal, and Heiselberg 2011). However, despite these research efforts, to the knowledge of the authors, there has not been any investigation into the energy efficiency gains from nZEBs in an energy system that is transitioning to 100 % renewable energy.

Thus, the aim of this paper is to demonstrate the role and influence of nZEBs in the Danish energy system as it transitions to 100 % renewable energy by 2050. An investigation is done on the implications from building nZEBs in this context. The implications on the system include: the change in the total energy consumption, the resource consumption (biomass), the socio-economic costs, and the impact on the energy supply.

nZEBs AS DEFINED IN DENMARK

In Article 9 of the EPBD (BPIE 2015), all Member States are required to make a national nZEB definition and promote the uptake of nZEBs. Most countries have put in place in their building codes the maximum primary energy demand of future new nZEBs. In Denmark, nZEBs are defined in the Building Code 2015 (BR15). BR15 defines energy frames for nZEBs (i.e. net primary energy demand of the building[1]). Based on BR15, all new buildings built after 2015 need to meet the nZEB energy frames and there are voluntary energy frames for after 2020, which are likely to become mandatory in BR20.

The energy frame considers the end use energy demand of the building, which includes heating, domestic hot water, cooling, and electricity for operating the building. The net primary energy demand is calculated using a specified formula, which multiplies the energy used in the building with the primary energy factors for each energy carrier, e.g. electricity or district heat. If renewable energy is exported from the building to the grid then this is subtracted from the net primary energy demand.

In Denmark the energy frames for new and existing buildings are presented in Table 1 (Thomsen 2014).

The energy frames for new buildings are expected to be 0 kWh/m^{2}y in 2025.

This paper will discuss whether the energy frames required for new residential and non-residential buildings today and in the future in the Danish building code are reasonable within the Danish energy system that is transitioning to renewable energy by 2050.

CASE STUDY

This paper assesses the implications of building nZEBs in the Danish energy system as it transitions to 100 % renewable energy. In Denmark a political decision was made in 2012 to achieve 100 % renewable energy supply by 2050. In response to this goal, numerous research studies have been carried out to investigate how this could be achieved (Lund and Mathiesen 2006; Dyrelund et al. 2008; Mathiesen, Lund, and Karlsson 2009; Lund et al. 2011; Mathiesen et al. 2015; Energinet.dk 2015; Danish Energy Agency 2014). This paper utilises the most recent study to demonstrate how the country will transition to 100 % renewable energy and to assess nZEBs in this context. The study is called the "IDA Energy Vision 2050" which was done in 2015 by Aalborg University for the Danish Society of Engineers (Mathiesen et al. 2015).

In the IDA Energy Vision 2050, numerous scenarios and sensitivity analyses were made to demonstrate how Denmark could achieve 100 % renewable energy supply by 2050; cost effectively and within resource constraints. The study builds from previous studies progressing from 2006 (Lund and Mathiesen 2006), 2009 (Mathiesen, Lund, and Karlsson 2009) and 2011 (Lund et al. 2011) and thus it can be seen as a further iteration and improvement of the analysis for Denmark. For further details about the methodology, data collection and analysis please refer to the study Mathiesen et al. (2015). In this paper, the main scenario from the IDA Energy Vision 2050 is used and is referred to as the "IDA 2050 scenario".

The IDA 2050 scenario provides the energy system configuration in 2050 from which the implications of nZEBs are modelled and analysed for this paper. The scenario is described in the Methodology section below.

Methodology

The methodology is split into three main parts. The first part describes the Danish building stock that is predicted to exist in 2050, which includes the existing and new buildings. The new buildings will be nZEBs and the implications of these on the energy system are analysed in this paper. The second part describes the future 100 % renewable energy system in Denmark and some of its main components. This helps to illustrate the context in which nZEBs will be built. The third part describes the way in which the nZEBs are modelled in the context of the IDA 2050 scenario, which is done using six different scenarios.

PART 1: THE DANISH BUILDING STOCK IN THE 100 % RENEWABLE ENERGY SYSTEM

In Denmark, the building stock in 2050 is expected to include the floor space of the existing building stock today plus the floor space of new buildings added from today to 2050. In 2015, the total heated floor space for residential and non-residential (service) buildings was 358 million m^2, most of which were single-family houses. In 2015, the average heat performance of existing buildings was 132 kWh/m^2, including hot water. On average 0.25 % of the existing buildings are demolished and replaced per annum (Energi – Forsynings – og Klimaministeriet 2014). For the replaced buildings, from now to 2050, it is assumed that they are replaced with a building with improved heat demand, and this new building will reduce the average heat demand of the existing building stock.

From 2015 to 2050, new buildings will be built and added to the building stock. These new buildings will mostly be nZEBs, especially from 2020 onwards. The total expected new floor space is 113 million m^2 which is a new build rate of approximately 1 % per annum (Danish Energy Agency 2014). This increases the total heated floor space of the building stock in 2050 to 461 million m^2.

1. The mix of energy end-uses differs between countries but always the energy use of residential building lighting and appliances is excluded. However, in non-residential buildings the lighting is included.

Table 1. Energy frame (net primary energy demand) of new Danish nZEBs in the BR15 and voluntary energy frames defined for 2020 and 2025.

	New residential buildings (kWh/m²y)	New non-residential buildings (kWh/m²y)
2015	30 + 1,000 / (heated gross floor area)	41 + 1,000 / (heated gross floor area)
2020	20	25
2025	0	0

PART 2: THE 100 % RENEWABLE ENERGY SYSTEM IN DENMARK

The 100 % renewable energy system described in the IDA 2050 scenario is a radical redesign of the system that exists today. A redesign is deemed necessary in order to cost effectively transition to 100 % renewable energy and to integrate a large amount of fluctuating renewable energy. Compared to the energy system of today, it is a more complex system. It is designed to create more interactions between the different energy sectors. These interactions are shown in Figure 2.

The new system (the IDA 2050 scenario) is the most feasible way to achieve a sustainable 100 % renewable energy system in Denmark, and it will cost about the same as the system today. The system has been developed using a computer simulation model (EnergyPLAN) and expert judgement. The system is balanced on an hour-by-hour basis over one year (2050), where all energy demand and supply is matched near perfectly in each energy sector.

On the supply-side, numerous infrastructural changes are made to improve the system. This allows for improved inter-sector integration, the addition of energy storages and the creation of energy sector synergies, which leads to better energy efficiency in the system. Some important changes include:

- Integrating renewable energy, such as wind power, with heat pumps at district heating level and building level
- Utilising wind power to produce and store heat in large-scale thermal storage for district heating
- New heat sources are used in district heating such as heat from solar thermal sources, and non-conventional excess heat sources (geothermal heat, solar heat, excess industrial heat)
- Electric vehicles consume renewable electricity, rail is completely electrified, as well as some light freight
- Electrofuels (liquid and gas) are produced via electrolysis and other technologies to integrate renewable energy and to store electrical energy in areas where it is not traditionally stored (e.g. heavy transport liquid fuels)

The main changes in the energy demand and supply of the system from 2015 to 2050 are presented in Table 2. For more details about the changes see Mathiesen et al. (2015).

Overall, the primary energy demand of the energy system from 2015 to 2050 reduces, even though the electricity demand increases (Figure 3). This demonstrates a significant improvement in the energy efficiency of the system. This is due to an increase in cross-sector integration and energy storages, for example utilising wind power in district heating and reducing the use of solid fuel technologies such as power plants, CHP and boilers.

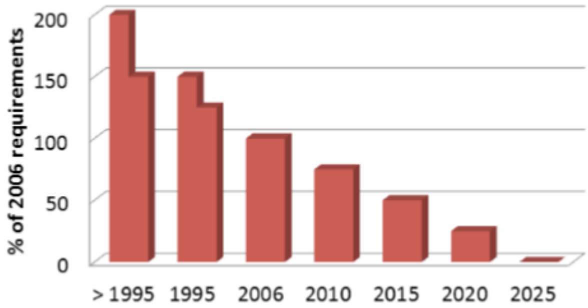

Figure 1. Energy use requirements in Danish buildings by construction year. With the reference from 2006 set at 100 % (Thomsen 2014).

BUILDING STOCK ENERGY PERFORMANCE IN THE IDA 2050 SCENARIO

In the IDA 2050 scenario, the existing building stock was assumed to be renovated to a point where the heat demand is reduced by 40 % from 2015 to 2050. Thus, the average space heat demand lowers from 132 kWh/m² to 80 kWh/m². The hot water demand remains the same (hot water uses 14 kWh/m²). These heat savings are based on future cost-effective renovation measures that could be achieved in the next 35 years (Lund et al. 2014). New policy measures would be needed to encourage these renovations.

It is estimated that for new buildings, the heat demand in Denmark in the next few years up to 2020 will on average be 56 kWh/m² (42 kWh/m² for space heating and 14 kWh/m² for hot water which remains constant from 2015 onwards). This heat demand is based on the trajectory of heat demand improvements since 2005 (Wittchen, Kragh, and Aggerholm 2016; Mathiesen et al. 2015; Lund et al. 2014). In the IDA 2050 scenario it is assumed that all new buildings are built with this heat demand from 2015 to 2050.

The average heat demand per square metre for existing buildings, new buildings and the entire building stock is shown from 2015 to 2050 in Figure 4. The heated floor space of the total building stock is also shown. The figure demonstrates that the change in the total average heat demand of the entire building stock is very closely aligned with the lowering of the average heat demand of the existing building stock. This is due to the large size of the existing building stock and its high heat demand. The new buildings make a relatively small impact on the total average heat demand.

In this paper, the heat demand of the new buildings (nZEBs) is the variable being used in the analysis. The analysis procedure is described in more detail below.

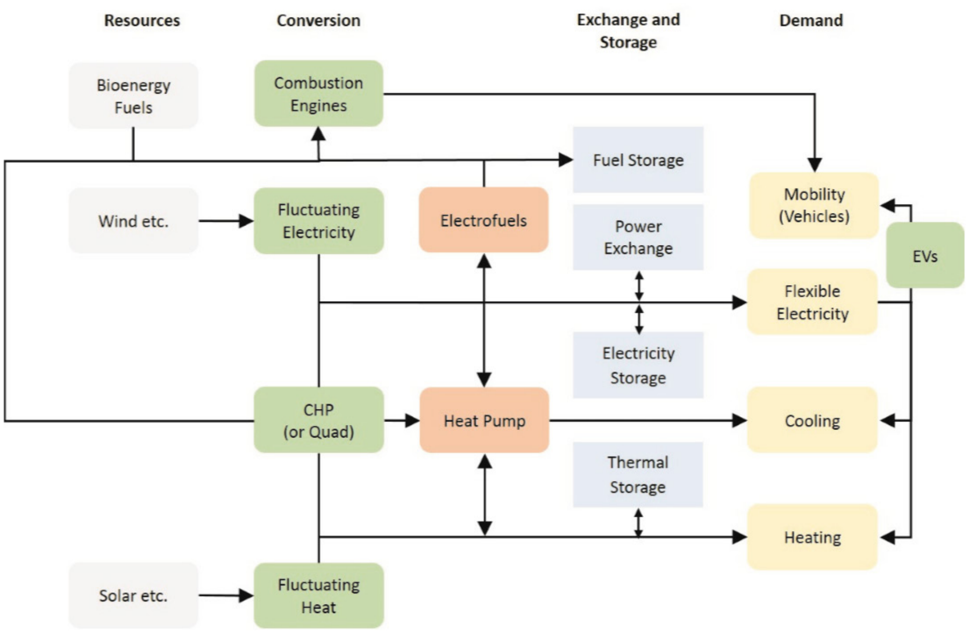

Figure 2. Simplified illustration of the energy flows (arrows) in the 100 % renewable energy scenario (IDA 2050 scenario) between resources, conversion technologies, exchange and storage and demand.

Table 2. Main energy system demand and supply changes from 2015 to 2050.

	2015	2050
Electricity demand (TWh)	34	93
Buildings heat demand (TWh)	47	35
Offshore wind production (TWh)	4.4	64
Onshore wind production (TWh)	7.2	16
Solar PV production (TWh)	0.6	6.4
Fossil fuel consumption (TWh)	155	0
CHP+PP production (TWh)	21	14
District heating supply (% of total heat demand)	53	63

PART 3: NZEBS IN THE 100 % RENEWABLE ENERGY SYSTEM IN DENMARK

In Denmark, the ambition from 2020 onwards is to set the energy frame (net primary energy demand) for new buildings at 20 kWh/m²y and 25 kWh/m²y for residential and non-residential buildings, respectively. These levels will decrease beyond 2025. To achieve the Danish energy frame requirements, the heat demand of new buildings will need to be quite low. The heat demand could be offset by producing and exporting local renewable energy, which is subtracted from the net primary energy demand of the building. However, if distributed renewable energy production is utilised, this means that the excess electricity will need to be integrated into the grid. In H. Lund, Marszal, and Heiselberg (2011) this has been shown to be problematic in a highly renewable energy system in Denmark due to the high amount of wind power. There is a regular mismatch between energy demand and supply in the system. Therefore, to avoid problematic mismatches within the energy system the production of excess electricity from the nZEBs should as low as possible. Which means the heat demand should be as low as possible to achieve this.

Therefore, in this paper, six scenarios have been devised where the heat demand of the new buildings (nZEBs) is lowered beyond 56 kWh/m² to ensure that the nZEB level of 2020 is more achievable. This paper does not focus on the calculation of the net primary energy of the nZEB. Thus, the local renewable energy production and the primary energy factors of the nZEBs are ignored. The paper considers only the end-use heat demand of the buildings (assuming lower heat demand makes it easier to achieve nZEB status) and then it investigates the implications of these lower heat demands on the 100 % renewable energy system.

Scenarios analysed for nZEBs in the 100 % renewable energy system in Denmark

Six scenarios were analysed in which the heat demand of the existing buildings (2015) and future buildings (nZEBs built from 2015 to 2050) were adjusted. The electricity demand remained the same in each scenario.

For the existing buildings, the heat demand was analysed for two heat levels:

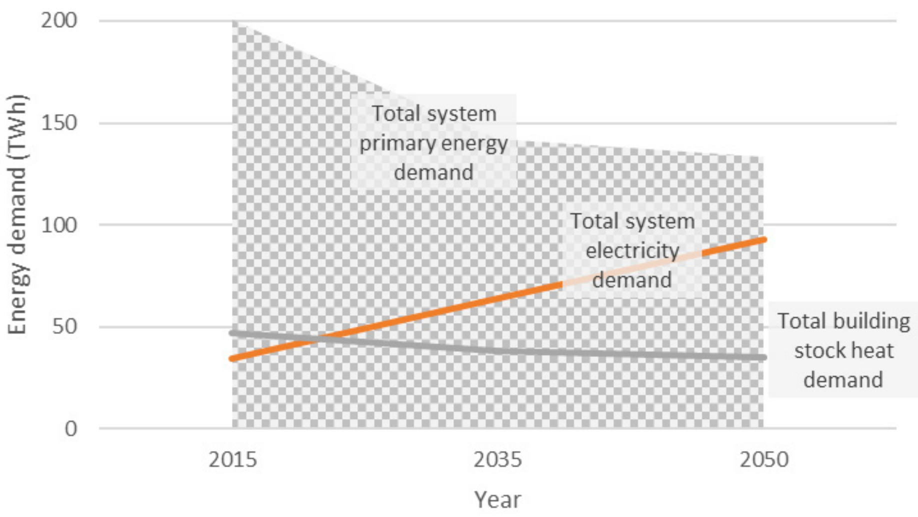

Figure 3. From 2015 to 2050, the figure shows the correlation between total system primary energy demand and the total system electricity demand as well as total building stock heat demand. System energy efficiency and synergies between the energy sectors cause the primary energy demand to decrease over time.

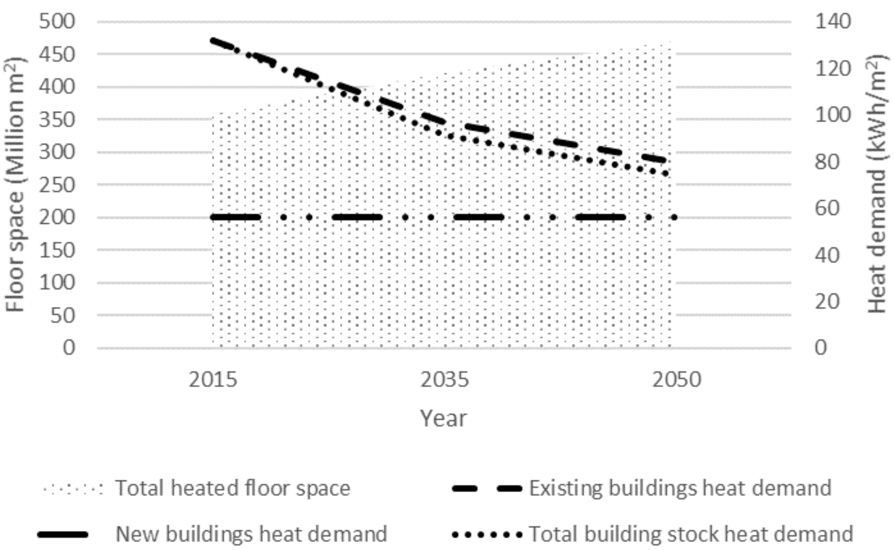

Figure 4. Total heated floor space and heat demand per square metre of existing, new and total building stock in 2015, 2035 and 2050 in Denmark.

1. No renovations are made to the existing buildings, thus they continue to consume 132 kWh/m² to 2050. This is an extreme case.
2. The heat demand in existing buildings is reduced by 40 %, decreasing to 80 kWh/m² by 2050.

For the new buildings, the scenarios for the heat demand were:

1. All new buildings are built to 2050 with heat demand of 56 kWh/m².
2. All new buildings are built to 2050 with a heat demand of 44 kWh/m².
3. All new buildings are built to 2050 with a heat demand of 36 kWh/m².

The last two scenarios make it easier for buildings to achieve nZEB status. In each scenario, all the new buildings that are built from 2015 to 2050 have on average one of these heat demand levels, i.e. in Scenario 2 all the new buildings have an average heat demand of 44 kWh/m².

Using these different levels of heat demand, six scenarios were defined. Each scenario had different average heat demands for the existing and new buildings. All the scenarios are presented in Table 3, including the total heat demands of the building stocks.

When the heat demand is adjusted for the buildings in each scenario, this means that the heat demand of the entire building stock will change and thus the capacity of the heat supply technologies needs to be adjusted in the system to meet the altered demand. The technologies that were adjusted in the scenarios include:

- Centralised boilers that supply district heat to the buildings
- The size of the district heating network
- Individual boilers in the buildings
- Individual solar thermal
- Individual heat pumps

The size of the heat units were adjusted according to the new heat demand that they need to meet. Furthermore, each of the heat supply technologies were adjusted in equal measure to one another, meaning one technology was not adjusted more than the other.

This study assumed that the same proportion of new buildings will be supplied with district heating as is the case for the existing buildings in 2050 (63 %). The remaining 37 % will have individual heating, for instance via heat pumps.

To achieve a lower heat demand, additional investment costs are required for the renovation of existing buildings and for the improvement of new buildings. The costs for renovating existing buildings and for improving new buildings were based on H Lund et al. (2014). The investment costs for existing buildings reflect investments in an increasing number of buildings, i.e. the costs are less in the beginning due to renovating older poorly performing buildings and then the costs increase after the older buildings have been renovated and newer ones start being renovated. Investment costs for new buildings are based on costs for different levels of heat demand in a new 150m^2 single-family house and these costs reflect an increased investment in *all* new buildings. For further details about the cost calculations, see H Lund et al. (2014).

The investment costs for the heat supply technologies in the energy system are based on either increasing or decreasing the costs according to the change in capacity of the heat units.

The costs are presented in the Results section in Table 4.

Analysis software: EnergyPLAN

For each scenario, the energy system needs to be balanced in terms of being able to sufficiently supply energy for each hour during the year. Therefore, an analysis of the energy system for each scenario is required, and this was done using the simulation software EnergyPLAN, which was also used for the IDA 2050 scenario. EnergyPLAN simulates the energy system on an hour-by-hour basis by integrating the different energy sectors, including electricity, heating and cooling, transport, industry and gas. The tool balances the system with support from a number of technical or market regulating strategies defined by the user. The investment, operation and maintenance costs are included for all the energy supply technologies. Further details about the tool are provided here H Lund and Department of Development and Planning Aalborg University (2015).

Using this tool, the energy system, which includes the building stock, is modelled for the year 2050. To compare the scenarios, the relevant outputs from the tool are total annualised socio-economic costs of the entire energy system (cost to society with a low discount rate, and excluding taxes, subsidies etc.) and biomass demand.

Biomass is expected to be the main solid fuel in 2050, and it will be in limited supply in Denmark and globally. Therefore it is important to understand how much biomass is needed in each scenario. In Denmark, the total available sustainable biomass (residue biomass) is expected to be approximately 45 TWh. With energy crops and algae, the potential is increased to 60 TWh (Mathiesen et al. 2015). However, a sustainable and reliable consumption would be at the lower end of this range.

The results from EnergyPLAN are utilised to compare the scenarios with one another and the results are presented below.

Results

The results for the different scenarios are presented in Table 4. The table presents the total heat supply for the building stock, the biomass demand and the total annualised socio-economic costs of the energy system. The table also presents the annualised socio-economic costs of the heat units and the renovation costs for existing buildings and improvement costs for new buildings.

To demonstrate the cost difference between the scenarios, Scenario 1 is used as a reference point for all the other scenarios.

Table 3. Existing and new building heat demands and associated building and system costs.

	Scenario 1 – Exist: 132 / New: 56	Scenario 2 – Exist: 132 / New: 36	Scenario 3 – Exist: 80 / New: 56	Scenario 4 – Exist: 80 / New: 44	Scenario 5 – Exist: 80 / New: 36	Scenario 6 – Exist: 54 / New: 56
Existing building average heat demand (kWh/m^2)	132	132	80	80	80	54
New building average heat demand (kWh/m^2)	56	36	56	44	36	56
Total heat demand of existing building stock (TWh)	47.3	47.3	28.6	28.6	28.6	19.3
Total heat demand of new building stock (TWh)	6.3	4.1	6.3	4.9	4.1	6.3
Total heat demand of entire building stock (TWh)	53.6	51.4	34.9	33.5	32.7	25.6

As shown in Table 4, all the scenarios have similar socio-economic costs compared with Scenario 1 (+/- 1 to 2 %) and this is likely within margin of error. This means that in terms of total socio-economic cost it does not make much difference to build nZEBs or not. The cost differences between the scenarios is small because when the buildings do not save energy via improving the buildings, the saved investment costs offset the additional cost of having to supply heat to the buildings. And vice-a-versa, when investments are made into improving the buildings, the saved heat demand and reduced cost of heat units offsets this additional investment.

However, the important metrics to look at are the total heat demand and biomass demand in each scenario, because the heat demand needs to be supplied somehow and the biomass demand needs to be met sustainably.

Scenario 1 and Scenario 2 have the highest heat demand of 53 TWh and 51 TWh, respectively, and this is because the existing building stock is not improved from 2015 to 2050, remaining at 132 kWh/m². Scenario 2 is a worst-case scenario because it is not expected that the heat performance of existing buildings will not improve over time. In scenario 2, the new buildings are installed with heat performance of 36 kWh/m². Although the heat performance is improved, the total heat savings are only 2 TWh compared to the heat demand of Scenario 1.

The biomass demand in Scenario 1 and Scenario 2 is 52 TWh which is very close to the upper limit of biomass potential in Denmark and this would require new bioenergy sources such as energy crops and algae or imported biomass. The sustainability of these resources is uncertain.

Scenario 3 involves renovating the existing buildings to a heat performance level of 80 kWh/m² and the new buildings are built with a heat demand of 56 kWh/m². In Scenario 3, the heat demand is reduced substantially from 53 TWh to 35 TWh. Thus Scenario 3 has the one of the lowest biomass demands of 46 TWh. This level of biomass demand is near the sustainable level of biomass consumption.

In Scenario 4 and Scenario 5, where the heat performance of new buildings decreases to 44 kWh/m² and 36 kWh/m², respectively, and the heat demand of existing buildings is 80 kWh/m², the biomass consumption does not decrease significantly with these improvements because the total heat demand decreases by only 1–2 TWh.

In Scenario 6, the heat demand of the existing building stock is decreased to its lowest level of 54 kWh/m² (60 % reduction from the original level of 132 kWh/m²) and new buildings remain at 56 kWh/m². This decreases the total heat demand to 26 TWh. Despite this, the biomass demand does not decrease much further and this is due to the configuration of the energy system.

This further reduction in heat demand actually decreases the demand for heat from renewable heat supply technologies such as large-scale heat pumps. The installed capacity of the large-scale heat pumps is not adjusted in the scenario since they are required to meet certain hours of peak heat demand during the year. This means that this extra heat saving in the building stock demands less heat from this technology even though it is able to produce this heat with its installed capacity. It also means that less wind can be utilised in the system since the heat pumps are not operating as often. There is a minimal cost saving or reduction in biomass demand from the reduced heat demand since large-scale heat pumps are powered by renewable electricity, which does not involve bio-

Table 4. Total heat demand, total energy system costs and biomass demand for each of the six scenarios in 2050.

	Scenario 1 – Exist: 132 / New: 56	Scenario 2 – Exist: 132 / New: 36	Scenario 3 – Exist: 80 / New: 56	Scenario 4 – Exist: 80 / New: 44	Scenario 5 – Exist: 80 / New: 36	Scenario 6 – Exist: 54 / New: 56
Total heat demand (TWh)	53	51	35	34	33	26
Biomass demand (TWh)	52	52	46	46	46	45
Total energy system costs (M€)	16,534	16,825	16,386	16,524	16,708	16,671
Cost difference from Scenario 1	N/A	291	-148	-10	174	137
Additional annualised cost to renovate existing buildings (M€)	0	0	1,136	1,136	1,136	2,026
Additional annualised cost to improve new buildings from base scenario (M€)	0	523	0	282	523	0
Centralised DH boilers annualised cost (M€)	173	173	100	97	97	63
Individual biomass boilers annualised cost (M€)	96	88	64	55	51	45
Individual heat pumps annualised cost (M€)	1,758	1,673	1,188	1,139	1,109	895
Individual solar thermal annualised cost (M€)	272	258	184	176	172	148
District heating network costs annualised cost (M€)	375	360	265	265	265	191

mass. Thus, it could be argued that the extra energy savings leads to a perverse negative outcome.

Discussion

This paper demonstrates the importance of the existing building stock in the future Danish energy system. In Denmark, around 90 % of the existing buildings will exist in 2050 (the annual demolition rate is low at ~0.25 %). In the future, these buildings will account for most of the total building stock and most of the heat demand. If the existing buildings are renovated sufficiently then the 100 % renewable energy system will have a sustainable biomass demand.

Even though new buildings will be added to the stock, today they are being built with a heat demand that is sufficient for the future renewable energy system. The additional heat demand of new buildings will not have significant implications for the Danish energy system and its economic and environmental impacts.

The configuration of the energy system has a major influence on the importance of nZEBs. Denmark has a highly efficient heating system caused by the 53 % share of district heating. This is expected to increase to 63 % in 2050. Furthermore, the district heating system provides opportunities for integrating more sustainable energy technologies into the system. These technologies include low-temperature district heating, heat pumps, industrial and geothermal heat, solar thermal and thermal storage. As these technologies are integrated into the system, the annualised cost for supplying heat is likely to decrease as well.

It is expected that to achieve a significant reduction in carbon emissions by 2050, all EU countries will need to transition their energy systems to renewable energy, and the local energy system configurations will need to be understood. Therefore, it is expected that each country will need to do an analysis on their national energy system. The results from these studies should be used to inform policy on nZEBs to ensure that they are implemented appropriately. As shown in this study, nZEBs have not proven to demonstrate substantial benefits to the highly renewable energy system in Denmark.

In this study, the additional costs to improve new buildings to better energy standards were based on previous research. But these costs are expected to decrease over time due to better building practices and materials, and cheaper renewable energy technologies, and it is uncertain exactly how much these buildings will cost in the future. These changes could change the results of this study. Therefore, further analysis, which investigates the different costs for new low-energy buildings, is encouraged. Furthermore, the number of new buildings assumed in this study has been estimated and this could also be different in the future. This could be investigated further.

Lastly, the primary energy factors for the energy carriers play an important role in determining whether a building achieves nZEB status or not. As the energy system integrates more renewable energy (similar to the changes shown in this paper), the primary energy factors for the energy carriers will decrease. Therefore, based on the expected changes in the energy system over time, further research should calculate new primary energy factors for the energy carriers. These new factors will have an impact on the net primary energy demand of the new buildings.

Conclusions

This paper assessed the role of nZEBs in the future 100 % renewable energy system in Denmark in 2050. The purpose was to test whether the energy frames for new buildings in the Danish building code are reasonable within a 100 % renewable energy system. This was done by analysing three different heat demand levels for new buildings built from 2015 to 2050.

The paper showed that in the highly renewable system in Denmark, new nZEBs with low heat demand do not decrease the total energy system costs or biomass demand significantly. The cost of the energy system is nearly the same as if all future buildings are built with the same heat demand in which they have today. There are only small differences in the total system cost between the different low-energy nZEB scenarios analysed in the study (+/- 1 to 2 %) and this is likely within margin of error. Furthermore, the biomass demand of the energy system is also not decreased significantly when the heat demand of new buildings is decreased.

The new building stock is already being built with a relatively low heat demand and the results in this paper indicate that the energy frames in Denmark are arbitrarily low when considering the benefit in which the new low-heat buildings will provide to the system.

To decrease the total heat demand of the system and to achieve sustainable levels of biomass consumption, investments should be made into improving the existing buildings, since most of the future energy demand will be from these buildings and most savings can be achieved here as well.

Today energy savings are essential due to the energy supply being based on fossil fuels. But in a highly renewable energy system with district energy, in some cases, the consumption of energy is beneficial compared with saving energy. The consumption of the energy actually switches from being a burden to the system to being a benefit to the system. For example, wind power can be utilised to store heat for district heating, or in heat pumps. This allows a larger capacity of wind power to be installed.

In terms of making EU policy for nZEBs in the future, the policies should focus on the necessary energy consumption level of new buildings within the context of the transitioning energy systems of each Member State. Research should consider the energy system in which nZEBs will be built, including the existing buildings and their role. The future primary energy factors for the different energy carriers should also be understood as well.

In Denmark, with its particular energy system, the building code does not need to aim for very low primary energy demands for new buildings, but rather policy should be designed to encourage energy savings in existing buildings. Overall, the benefits to the energy system from continuously improving the energy performance of new buildings should be better understood.

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