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Heat Mismatch of future Net Zero Energy Buildings within district heating areas in Denmark

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ABSTRACT

The long-term goal for Denmark is to develop an energy system solely based on renewable energy sources (RES) in 2050. To reach this goal energy savings in buildings are essential. Therefore, a focus on energy efficient measures in buildings and net zero energy buildings (NZEBs) have increased. NZEBs are characterized by having a greatly reduced energy demand that on an annual basis can be balanced out by an equivalent generation of energy from RES.

Most buildings in Denmark are connected electricity grids and around half to district heating (DH) systems. Connecting buildings to larger energy systems enables them to send or receive energy from these systems. This is beneficial for NZEBs because even though they have an annual net exchange of zero, there is a temporal mismatch in regard to the energy consumption of buildings and the production from the renewable energy units added to them. In other words, situations occur where the renewable energy units produces more energy than the building consumes. If the building was not connected to a grid, the energy produced would have to be either stored or unused. By connecting the building to a grid it is possible to sell the energy to the grid instead of wasting the energy. The objective in this paper is find how large an area of NZEBs is to be built within DH areas and how the heat mismatch of NZEBs influence different types of Danish DH systems.

In the analyses nine different scenarios are analyzed. The examination is from a technical perspective, looking into how the overall heat production within DH areas is affected by the NZEBs excess heat production from solar thermal collectors. The resource consumption, primarily biomass, is used as an overall indicator of the effect on the DH system.

The main findings are that the heat mismatch in general is positive in DH systems, decreasing the production from CHPs and boilers and thereby fuel consumption. This however, is not the case in systems where the heat demand in summer months is covered by solar thermal already. By adding seasonal heat storages to the DH systems, the situation can be prevented.

INTRODUCTION

In recent years the focus on energy efficient measures in buildings and net zero energy buildings (NZEB) has increased, leading to many different definitions of the term [1]. There is not a general definition of what characterizes NZEBs which gives some difficulties when using this name. However, to give a common understanding of the NZEB concept as it is used in this article, the following definition is used:

> *"NZEBs are buildings which have a greatly reduced energy demand that on an annual basis can be balanced out by an equivalent generation of energy from renewable energy sources (RES). Also NZEBs are connected to other energy infrastructure like electricity grids or district heating (DH) networks* [2]*."*

By using this definition NZEBs are not seen as autonomous buildings supplying themselves at all times during the year. Instead they are buildings connected to the existing energy infrastructure, having a reduced energy demand supplemented by RES, producing as much energy as they consume annually. Figure 1 shows a two-step overall approach for reaching the net zero energy balance.

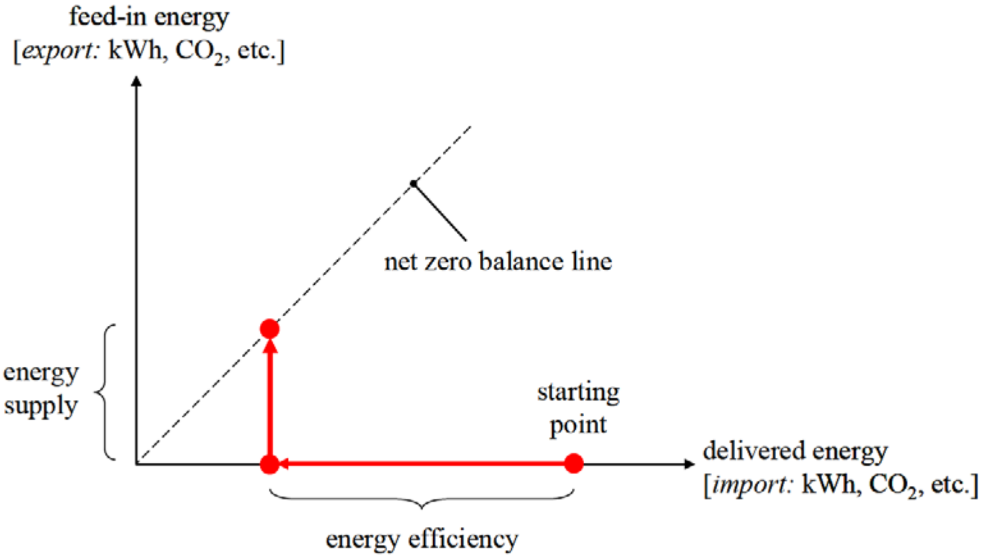

Fig. 1. Net Zero Balance of a NZEB [3]

The first step is to make an energy efficient building with a low energy demand. Thereafter, energy supply is added to achieve the net zero energy balance [3]. Hence the net zero balance is reached annually NZEBs sometimes produce more than they consume, and at other times it is the opposite. As Lund states in [4] there is from an overall energy system point of view a mismatch between the hourly production and consumption in NZEBs. Even though these have an annual net exchange of zero, the mismatch affects the overall energy system in different ways, depending on the technologies used in the NZEBs and the technologies used in the rest of the energy system. As mismatches can be both positive and negative, Lund tries to quantify this by proposing different factors for buildings with photovoltaics and for buildings with small scale wind power. Lunds article focuses on the electricity mismatch, but if NZEBs are connected to DH grids, these may also be affected by the excess heat production from NZEBs.

In 2009 the total net heat demand in Denmark was 204 PJ out of this 129 PJ was supplied by DH [5]. A 77.2% share of the heat within DH areas was produced on cogeneration heat and power plants (CHPs) [5]. The resources used within DH in 2009 were: 45.8% RE, 28.5% natural gas, 20.5% coal and 5.1% oil [5]. DH has advantages and disadvantages compared to individual alternatives. DH makes it possible to utilize waste heat from industries and waste incineration. It is a more flexible energy source which can utilize a variety of different energy sources e.g. geothermal heat. But most important is it that DH combined with CHPs can utilize waste heat from electricity production. The significant disadvantages of DH are the grid loss of heat and the large investment costs. In general the grid loss is around 20% for DH in Denmark [5]. Due to the disadvantages there are limits to where DH can be used.

Since such a large share of the Danish heat demand is supplied by district heating it is reasonable to analyze the effect that implementing the NZEB concept is going to have on these systems. As described previously the NZEB definition makes it possible for NZEBs to connect to DH grids and thereby export excess heat production to these areas. These effects have not yet been quantified and depend very much on the location and the specific DH system that the NZEBs are connected to. An important aspect in this regard is that new buildings within DH areas are not obligated to connect to the DH grids. However, in this article the goal is not to quantify the share of NZEBs connected to future DH areas. The main purpose with the article is to find the effect on the heat production in DH grids if all new single-family buildings within DH areas are built as NZEBs and connected to the DH grid. By connecting all new single-family buildings, it is possible to find the maximal effect on the DH systems.

OBJECTIVE

The objectives of the article are:

1. To assess in which types of DH areas that future single-family NZEBs is to be built, the heat demand of these NZEBs and the heat demand of the existing buildings.
2. To examine the heat mismatch of NZEBs in different typical Danish DH systems in regard to a future 2050 context.

METHODOLOGY AND TOOLS

To reach the first objective, the method used is making a prognosis of the development within the Danish building stock, with a focus on buildings within DH areas. This is done by using the Danish building register to look into the historic development, and assuming a similar future development in building construction. The building register is also used to find out how large a share of buildings is within DH in the present system. Since it has not been possible to find out how many square meters of buildings that have been removed every year, all of the existing buildings are assumed to exist in 2050. To compensate for this, the approach has been not to include other building types than single-family houses in the prognosis for new buildings. Since removal of buildings has a smaller percentage share of the total built area than construction of new, and the new buildings have a lower heat demand, these two approach each other when looking at heat demands.

To reach the second objective the method is using the heat demands found in the first objective to simulate three different sizes of typical district heating systems. By making energy systems analyses of these systems in regard to implementing solar thermal production and storages the size of the mismatches are examined.

In the article two main tools have been used, the first is a geographical information system tool called a heat atlas and the second is an energy system modeling software named energyPRO, both are described briefly in the following sections.

Heat Atlas

An essential tool used in this article is the heat atlas developed by Bernd Möller. The methodology was initially used in the Reveille project [6] and later on in relation to Heat Plan Denmark 2008 [7] where the methodology was used the first time in combination with geographical information system (GIS) modelling. Later it has also been described in scientific articles [8] and [9]. The methodology consists of four components:

1. National data from the Danish Building Register (BBR) on building level.
2. Heat consumption models based on building period, type and usage.
3. Model for calculating the costs for connecting building to existing or new DH-networks.
4. A geographical database for heat planning based on the municipal heat plans.

The outcome of the model is a spatial database with heat demand and supply for each building that can be used for various analyses linked to geographic structure of the heating system [10]. In this article the heat atlas is used to find out how many of the current buildings are located within district heating areas, and what their heat demand is. It is also used to find out how many single-family houses that historically have been built within different types of DH areas. This is used to make a prognosis of how large the area of future NZEBs within DH areas is going to be. The area of NZEBs is used further on to find the heat demand for NZEBs within DH areas.

EnergyPRO

EnergyPRO is an energy modeling software developed by EMD international which is a Danish Engineering Consultancy [11]. EnergyPRO is used for techno-economic analyses of different energy projects. In this article version 4.1.1.111 of energyPRO has been used. The model is specifically good for optimizing CHP plants and DH systems with multiple energy producers. The model can be operated to calculate in 10 minute steps, but for the modeling in this article 1 hour steps are used. Normally energyPRO is used to model concrete energy projects, but for the analyses in this article it has been used in a different manner. The reasons for choosing energyPRO are the ability to model storages, CHPs, solar thermal and connect different DH areas. The last is very useful when the goal is to see the interaction between NZEBs and a DH system. With energyPRO it is possible to model the heat demand from a group of NZEBs with solar thermal production and connect this to a DH grid and see the effects.

GEGRAPHICAL AREA AND HEAT DEMAND

In this section the geographical boundaries for the analysis are established by finding the DH areas and dividing them into six overall categories. This is based on GIS analyses with data from the Danish building register and the annual energy producer count from the Danish Energy Agency. The expected floor area and heat demand for new NZEBs in 2050 is assumed by looking at the historic development within the building mass geography. Afterwards the heat atlas methodology is used to find both the built area and the heat demand of the existing buildings within the DH areas.

The DH area types

In Denmark there are around 415 different DH networks, this make it necessary to categorize similar areas, to get an overview. Out of many ways to categorize DH areas, the most appropriate depends on the areas examined. In Denmark the production method within DH areas is to a far extend combined heat and power (CHP) plants and to some extend boiler production. CHP plants can be divided into the larger central and smaller decentralized units. Currently the registered fuel types amounts to 19 different [12] and within most DH areas more than one type is used. This depends on how many different types of production units are connected. It has been chosen to divide the areas by primary fuel used. To distinct between central CHP and decentralized CHP the DH areas with a total electricity capacity of 100 MW or more are chosen as central areas, everything between 100 and 0 is decentralized CHP and everything without electricity generation capacity is boiler areas. Since there is not any official measure for classifying central CHP plants, the division at a 100 MW has been to approximate the amount of units generally considered as central in Denmark. The division gives 12 central CHP areas, 276 decentralized CHP areas and 137 boiler areas. In Table 1 the fuel consumption in 2008 for each area type is shown. To simplify the overview five categories of fuels have been made. The first two is coal and natural gas. The third called "waste" includes both waste heat from industrial processes and waste incineration plants. The fourth category called "biomass" includes biogas, straw, biomass waste, wood chips, wood pellets, bio-oil and solar thermal. The fifth category named "other" includes fuel oil, gasoil and waste oil.

Table 1. Fuel consumption in DH areas in 2008 based on [12]

TWh/year	Coal	Natural gas	Waste	Biomass	Other
Central CHP	42.8	9.4	6.1	4.0	2.8
Decentralized CHP	0.8	9.9	5.6	3.5	0.4
Boiler	-	0.1	0.2	2.5	0.0

As shown in Table 1 coal amount to around 70% of the total fuel consumption within central CHP areas. Within decentralized CHP areas the most common fuel is natural gas, but since there are large amounts of waste and renewables, mainly biomass, these are also used for categorizing decentralized CHPs. Even though there only are a few of these, decentralized Coal CHP areas are also included due to methodological reasons. For the boiler areas around 90% use biomass. This gives the six different categories of DH areas listed below:

1.	Central CHP:	12 areas
2.	Decentralized CHP – Coal:	3 areas
3.	Decentralized CHP – Natural Gas:	221 areas
4.	Decentralized CHP – Waste:	13 areas
5.	Decentralized CHP – Biomass:	39 areas
6.	Boiler:	137 areas

Because the DH type by means of the heat atlas is known for each individual building, the categorization makes it possible to examine the buildings stock within each type of DH area.

Single-family houses built within DH from 1980-2009

Since the objective is to look into 2050 or 39 years into the future, it is important to make prognoses of how large an area of buildings will be built during this period. This can be done by looking at the historic development. As most building construction in Denmark is single-family houses, these are seen as the main building type for new NZEBs. Figure 2 shows the development within single-family houses from 1940 to 2008.

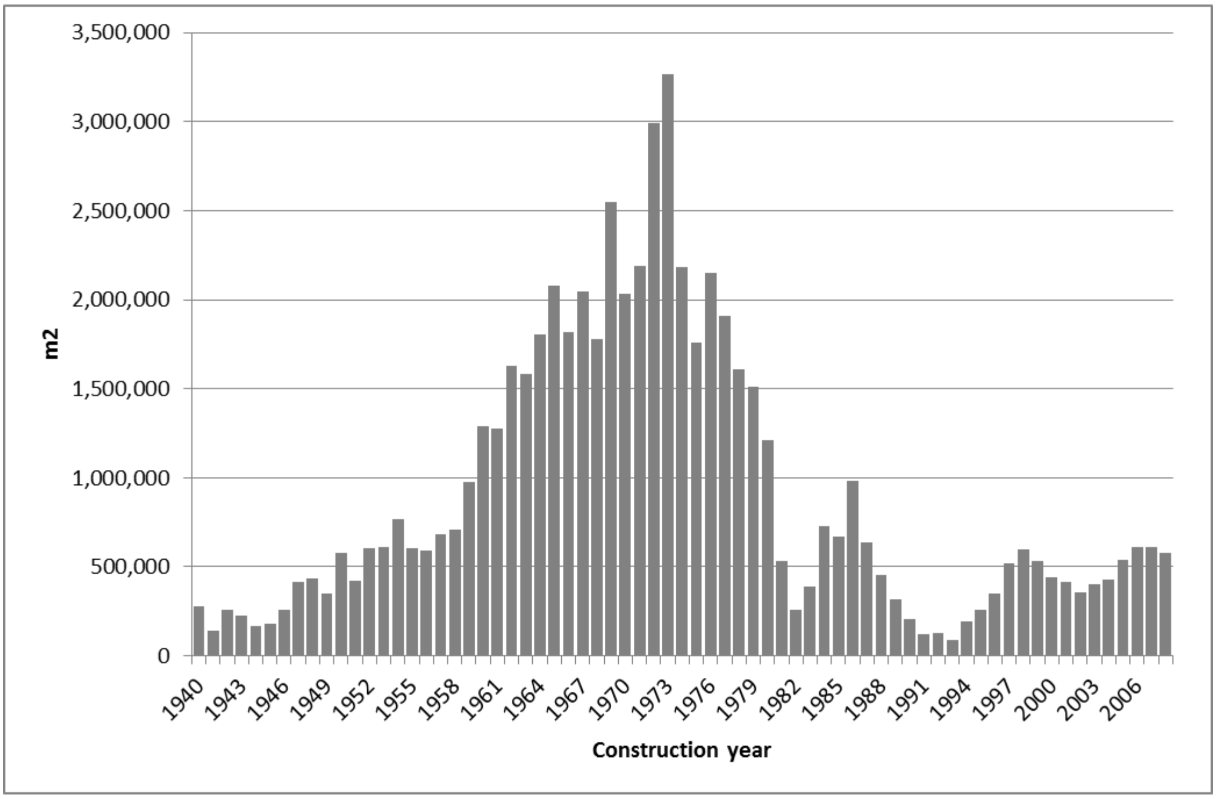

Fig. 2. Single-family houses built from 1940 to 2008 (data from the Danish building register)

Figure 2 show that from the beginning of the 1960s until around 1980, the construction of single family houses was much higher both afterwards and in the prior time period. The reasons behind this large increase in construction of single-family houses were both an increase in wealth and people moving outside the cities. Nothing within recent year's development points at a similar increase in construction as seen in 1960-1980. Within the period from 1980-2008 there are large variations, where 1982-1988 was higher than 1989-1996, and 1997-2008 higher again. To include these variations the average construction from 1980 to 2008 is used as the prognoses for the next 39 years.

From 1980 to 2009 57,323,345 m^2 single-family houses have been built in Denmark, out of this 38,448,970 m^2 were inside DH areas. To find out in which type of DH area these have been built, they are divided into the six categories of DH, this is shown in Figure 3.

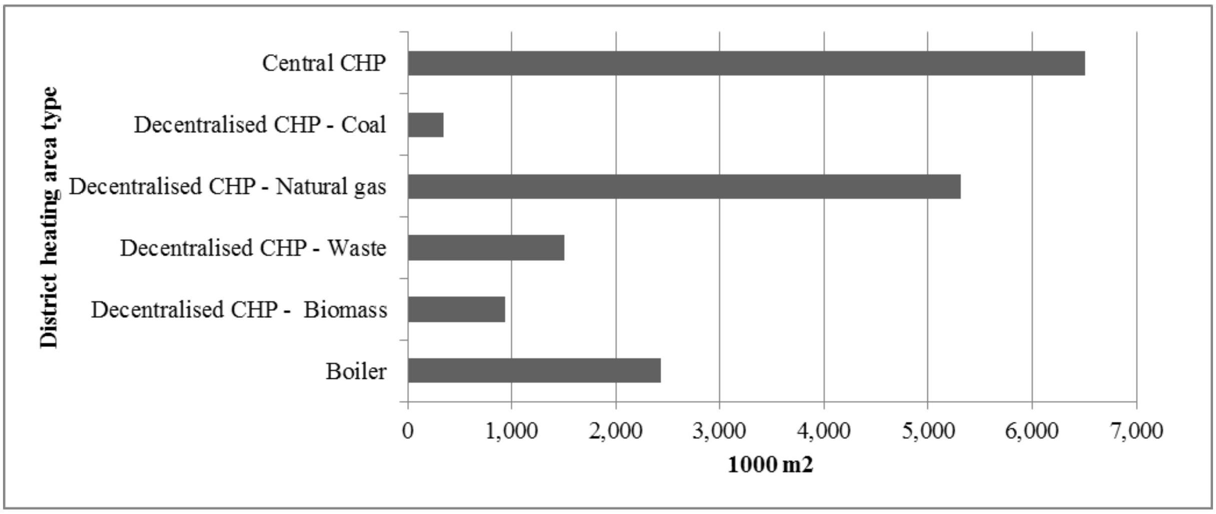

Fig. 3. Area of single-family houses built from 1980 to 2009 within five types of DH areas

Figure 3 shows that most single-family houses have been built in relation to DH areas with central CHPs and almost as large an area within DH areas with decentralized CHPs utilizing natural gas for heat production. Assuming that the construction until 2050 follows the same pattern as the last 29 years the heat demand of new NZEBs are found in the following section.

Net Zero Energy single-family houses

For the new NZEBs the annual domestic hot water demand is assumed to be 18.3 kWh/m^2 and space heating is assumed to be 15 kWh/m^2 which gives a total annual heat demand of 33.3 kWh/m^2 [13]. Based on the 33.3 kWh/m^2 the total net heat demand for new NZEB buildings is found and divided into categories of DH, this is shown in Table 2.

Table. 2. Heat demand for NZEB single-family houses based on 33.3 kWh/m^2

Area type	1000 m^2	Heat demand (MWh/year)
Central CHP	8,750,790	291,401
Decentralized CHP - Coal	457,214	15,225
Decentralized CHP - Natural gas	7,149,176	238,068
Decentralized CHP - Waste	2,032,585	67,685
Decentralized CHP - Biomass	1,253,514	41,742
Boiler	3,269,791	108,884
Sum	22,913,070	763,005

With the assumption that future construction follows the same pattern as previous 29 years, most of the new NZEBs will be constructed within central CHP areas. Almost the same share will be constructed within decentralized CHP areas presently using natural gas. The third largest heat demand will be within the boiler areas and the remaining part is built within decentralized CHP areas using coal, waste or biomass.

Existing buildings within DH areas

For the existing buildings within DH areas, all building types are included to give the total heat demand in the areas. The existing buildings are assumed to be able to reduce the space heat demand with 50% compared to the present situation according to [14,15]. Table 3 shows the total heat demand for all areas including a 50% heat reduction from the present situation.

Table. 3. Square meters and heat demand of existing buildings with a 50 % heat reduction

Area type	Area 1000 m^2	Heat demand MWh/year
Central CHP	156,149	13,134,027
Decentralized CHP - Coal	5,738	483,625
Decentralized CHP - Natural gas	58,717	4,686,486
Decentralized CHP - Waste	25,240	2,125,879
De centralized CHP - Biomass	9,935	781,781
Boiler	22,561	1,786,813
Sum	278,340	22,998,610

Compared to the area of the new NZEBs, the existing buildings is by far a larger area and heat demand, which also implies that improving the existing building stock is very important when the aim is a fossil free society. Including all building types also show that more than half of the total heat demand is within central CHP areas.

When summarizing the heat demand for NZEBs with the rest and adding a grid loss it gives a total net heat demand of 23.76 TWh, this heat demand is close to the predictions in the 2050 Climate Plan made by the Danish Engineering Association suggesting 26.55 TWh [16] and the 25 TWh in Heat Plan Denmark 2010 [15], both of which includes a 50% space heat demand reduction.

Size of the typical DH areas within each category

To analyze the effects of new NZEBs in DH areas, a typical system is established for each DH type. This typical system is based on average annual heat demands which are shown in Table 4.

Table 4. Average heat demands in DH areas for 2050 including 15% grid loss

Average heat demands	Existing MWh/year	NZEBs MWh/year	Sum MWh/year
Central CHP	1,258,678	24,283	1,282,961
Decentralized CHP - Coal	185,389	5,075	190,465
Decentralized CHP - Natural gas	24,387	1,077	25,464
Decentralized CHP - Waste	188,059	5,207	193,265
Decentralized CHP - Biomass	23,053	1,070	24,123
Boiler	14,999	795	15,794

These average heat demands are used as a basis for the scenarios used in the analyses. The choice to look at typical systems based on average values is discussed later in the discussion section. The next section describes the preconditions and inputs used for the energyPRO modeling.

PRECODITIONS AND MODEL INPUTS

All the inputs in this section, regarding heat demands, are based on the typical DH areas defined in Table 4. As a general choice for the 2050 DH system, the systems are modeled as energy systems with biomass fueled CHPs and/or boilers as their heat supply. In some scenarios these units are the main heat supply during the year, while in other scenarios solar thermal production has a large share of the annual production. In the last scenarios CHPs and boilers can be seen as backup in the summer season, and the main heat supply during winter. Other possible heat production units is not included e.g. geothermal heat, waste heat and heat pumps are possible candidates for heat production in future DH areas. The heating value used for biomass is 14.50 GJ/ton, which is the same value as for straw which is in between wood chips with a heating value of 10.05 GJ/ton and wood pellets with a heating value of 17.5 GJ/ton [17].

Hourly heat demand

According to the energyPRO section, the model is set to operate on hourly basis for a one year period. To model the hourly heat demands, aggregated demands for both district heating and NZEBs are used. The optimal hourly distribution would be measured data on building level for all the different areas. But since this kind of data is not available, the hourly distribution used instead is an adjusted version of the one used in Heat Plan Denmark 2010 [15]. Figure 4 shows the hourly heat distribution over a year for the existing buildings and how it is modified to a new distribution with lower space heat demand.

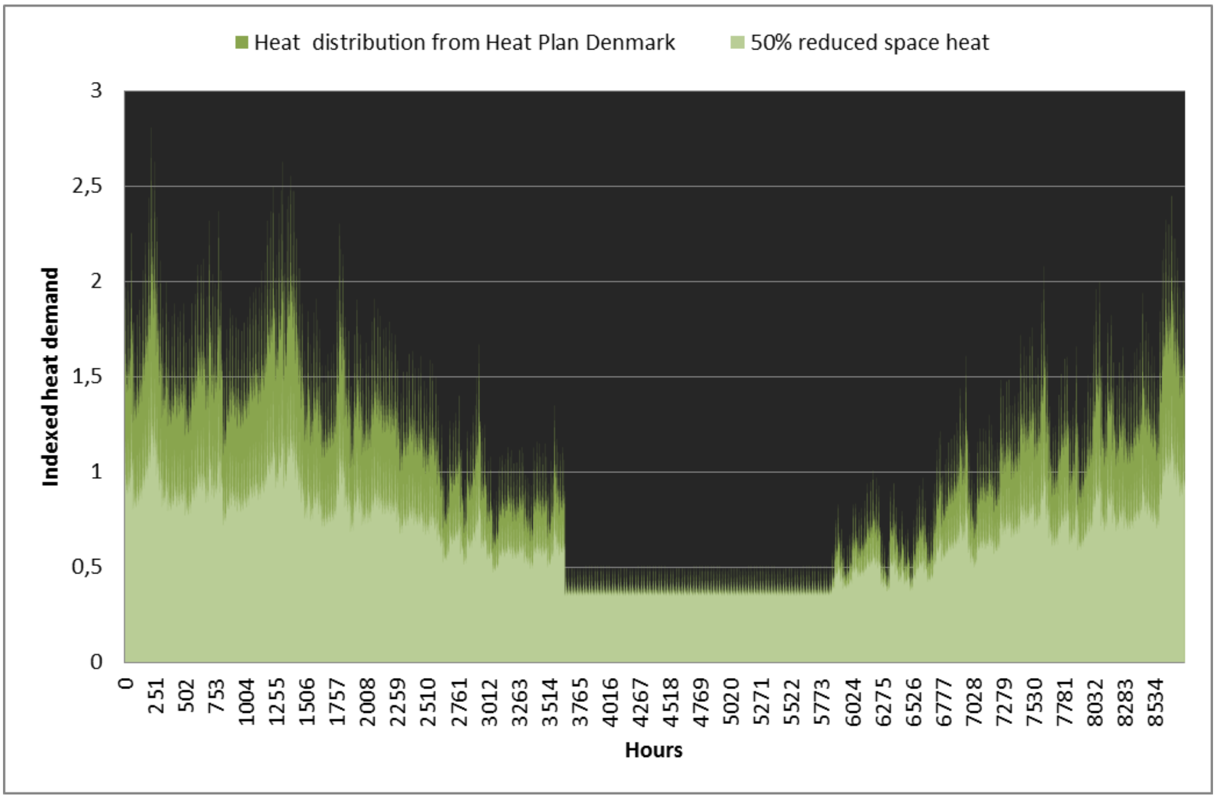

Fig. 4. Heat distribution used for heat demands within DH areas

The hourly heat demand distribution is modified in such a way that the hot water demand is not reduced, while the space heat is reduced by 50%. The hourly heat distribution for NZEBs is created in a similar way, by modifying the heat distribution for individual houses used in Heat Plan Denmark, by reducing space heat demand with 70%. The indexed hourly distributions are used together with the heat demands in Table 4, to create the actual heat demand distributions for each DH area to be used in energyPRO.

Solar thermal

There are two ways of utilizing solar thermal production in DH areas. The first is an individual solution, where solar panels are added to the roof of buildings and the excess heat is exported to the DH grid. The second solution is the collective centralized model, where solar panels are placed together on a field of land. The individual solution has the benefit of using roofs of buildings instead of land which could be used for other purposes. The collective solution has the benefit of being less investment intensive per square meter and being able to cover a larger share of the annual heat demand by using seasonal storages.

From the existing larger collective solar thermal plants in Denmark the average annual heat production is found to be 476 kWh/m^2 [18]. This average production is used to find the needed aperture area of solar collectors for each DH area type. By dividing the heat demands in Table 4 with 0.476 MWh/m^2 the needed areas for solar collectors are found. For NZEBs the area needed for producing 100% of the annual heat demand is found, while for the collective solar thermal it is only dimensioned to cover 50% of the annual heat demand. The areas needed are shown in Table 5.

Table. 5. Square meters of solar thermal capacity for NZEBs and DH

Area type	NZEB Area, m^2	Collective Aperture area, m^2	Collective Gross area, m^2
Central CHP	51,016	1,347,648	2,964,826
Decentralized CHP - Coal	10,662	200,068	440,149
Decentralized CHP - Natural gas	2,263	26,748	58,845
Decentralized CHP - Waste	10,938	203,010	446,621
Decentralized CHP - Biomass	2,249	25,339	55,746
Boiler	1,670	16,590	36,498

The first column shows the needed aperture area for collectors able to produce a 100% of the annual NZEB heat demand. The second column shows the area needed to produce enough heat to cover 50% of the heat demand in the DH areas including NZEB demand. The largest planned solar collector in Denmark is in the town of Dronninglund and will be 35,000 m^2 of aperture area [15]. From table 5 it is possible to see that area within the central CHP for covering 50% of the heat demand is unrealistically large. The decentralized CHPs with coal or waste are also large but more realistic. The last column shows the gross area used for collective solar panels which is 2.2 times the aperture area of the collectors.

To model the production from solar thermal, technical data for the collector type is needed the data used is shown in Table 6.

Table. 6. Solar thermal collector data from [19]

Input	Unit	Number
Latitude (UTM)	Degree	55
Inclination of solar collector	Degree	40
Start efficiency (η_0)		0.815
Loss coefficient (k0)	W/(m^2 °C)	2.205
Loss coefficient (k1)	W/(m^2 °C)^2	0.0135
Coefficient		4.000
Collector temperature (average)	°C	65

These data are linked to the type of solar collector chosen, the same is used for all scenarios. The inclination of solar collectors is based on an average of the existing collective solar thermal collectors in Denmark, which vary between 33 and 45 in inclination [18]. The hourly solar radiation and the temperatures outside determine the production from solar collectors, monthly averages of both are shown in Figure 5.

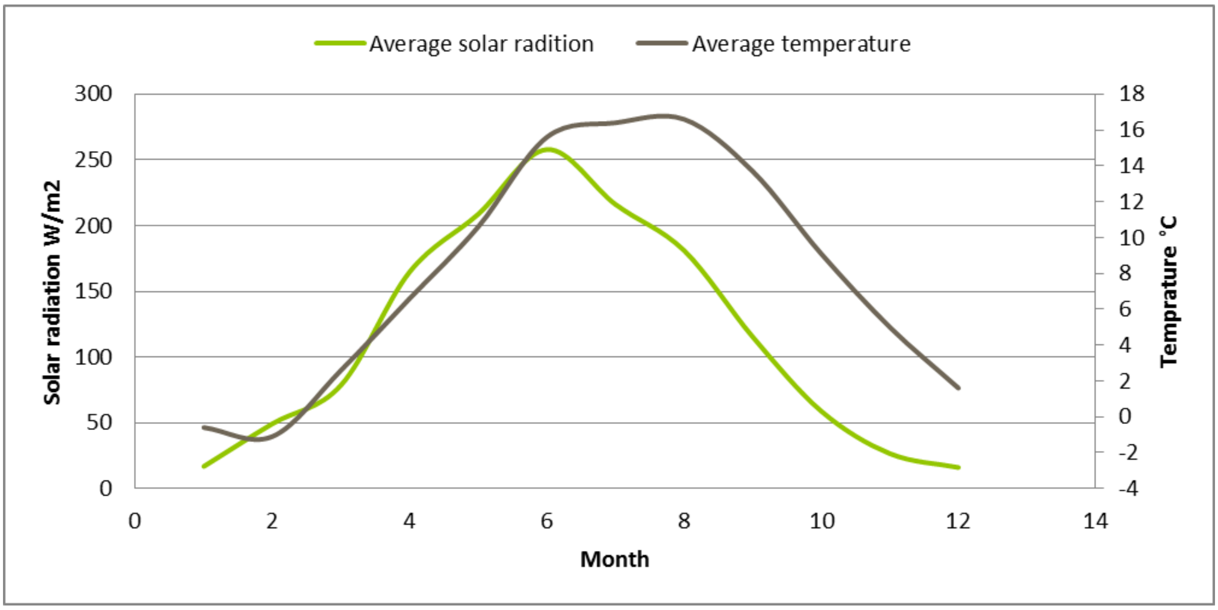

Fig. 5. Average monthly solar radiation and temperature in Denmark

Figure 5 show that solar radiation and temperature almost follows the same pattern, with high radiation and temperature in summer months. If the hourly values were shown these would show that the solar radiation only occur during daytime. It is also interesseting to observe how the temperature decrease is delayed compared to the solar radiation, this results in autumn months with low solar radiation and low heat demand, compared to spring months with a similar low solar radiation.

Thermal storage

There are different types of heat storages in DH systems, most are used for short-term storage within days. However, in Heat Plan Denmark 2010 different types of seasonal storage are described. These long-term storages make it possible to save heat from summer to winter months which is very useful in combination with solar thermal. The first type presented is a traditional heat storage tank which is an insulated steel tank. The steel tank works well, but is very expensive to establish and is also hard to fit into the landscape. An alternative to this is called pond storage, which basically is a big hole in the ground with a cover on top [2]. Other types of seasonal storages exist e.g. in Germany where also borehole and aquifer thermal energy storages are in operation [20]. There is clear production benefits of economy of scale linked to the size of storages. With a storage temperature of 80 degree Celsius, a small heat storage of 0.1 m^3 has a temperature loss of 1 K every two hours where a storage of 75.000 m^3 loses 1 K every 220 hours [2].

In the modeling only short-term storage and seasonal pond storage is used. To find the storage sizes 0.2 m^3/m^2 of solar panels is used for short-term storage and for long-term storage 2.5

m^3/m^2 of solar collectors, both following the assumptions from [2]. These assumptions result in the storage sizes shown in Table 7.

Table. 7. Total storage size for each DH area in m^3

Area type	Short-term storage m^3	Long-term storage m^3
Central CHP	10,203.13	3,369,120
Decentralized CHP - Coal	2,132	500,169
Decentralized CHP - Natural gas	453	66,870
Decentralized CHP - Waste	2,188	507,524
Decentralized CHP - Biomass	450	63,348
Boiler	334	41,475

The short-term storages are within limits of the present sizes used for heat storages, since the largest short-term storage in Denmark according to [2] is around 75,000 m^3. The largest long-term solar thermal storage in Denmark is around 70,000 m^3 and therefore in this case the storage needed in central CHP areas is seen as unrealistic. For decentralized CHP areas with heat from coal and waste, the storage size needed is more than 6 times as large as the present storages. Measured by today's standards these would be quite large storages, but are still modeled to give an idea about the potentials. The rest of the DH area types should be able to establish long-term storages in combination with solar collectors.

For both types of storages temperature of 90°C in top and 50°C in bottom is used. For short-term storage the ambient temperature follows the temperatures shown in Figure 5. To calculate the heat loss from the two types of storages different factors are used for short-term or long-term storages. Short-term storages are modeled as insulated steel tanks with an insulation thickness of 300 mm are used and a thermal conductivity of 0.0370 W/m°C. The seasonal storage is harder to model in energyPRO since it in reality uses the ground as insulation, but energyPRO needs both a thermal conductivity and an insulation thickness to model heat storages. So instead of modeling without heat loss for seasonal storage, assumptions are made. The thermal conductivity for the pond storage is assumed to be higher than the steel tank 2 W/m°C and a 5 m insulation thickness is used. Also an ambient temperature of 8°C is used, since the most of the storage is underground, which is more stable during the year compared to the ambient air temperature.

Boiler and CHPs

For the boilers the capacity is set to cover the peak hour demand added 20% and these have a heat efficiency of 90%. For CHPs the capacity is set to cover 95% of the annual heat demand, and has an electric efficiency of 46.6% and a heat efficiency of 41% [21].

THE SCENARIOS

Table 8 shows the different scenarios which are modeled in the article, to be able to examine the mismatch of excess heat from NZEBs on different sizes of DH areas.

Table 8. Scenarios used for the modeling. LTS=Long-term storage

	Boiler	Small Decentralized CHP	Large Decentralized CHP
	A1	B1	C1
Solar thermal	A2	B2	C2
Solar thermal + LTS	A3	B3	C3

Only 3 different sizes of areas are used, where in table 3 there were 6 different types. This reduction is due to natural gas areas being almost the same size as biomass areas, both of these are modeled as small decentralized CHP areas. The boiler areas are kept and the larger decentralized areas are also modeled. The decentralized waste CHP areas and the central CHP areas are excluded from the analyses. The reason for this is that in the waste areas, solar thermal would only reduce heat from waste production which would be incinerated anyway. The reason for excluding central CHP areas is that these areas are so large that they would need vast areas of land for solar thermal collectors and storage. Also these areas usually are more complicated using multiple producers, types of energy sources etc. Within these areas solar thermal production from NZEBs is not expected to have a large effect on the DH system, unless there are large amounts of waste heat or geothermal heat in the system during summer months.

RESULTS

The first thing to observe is if the NZEBs are within the definition of producing as much as they import on an annual basis, this is shown in Figure 6.

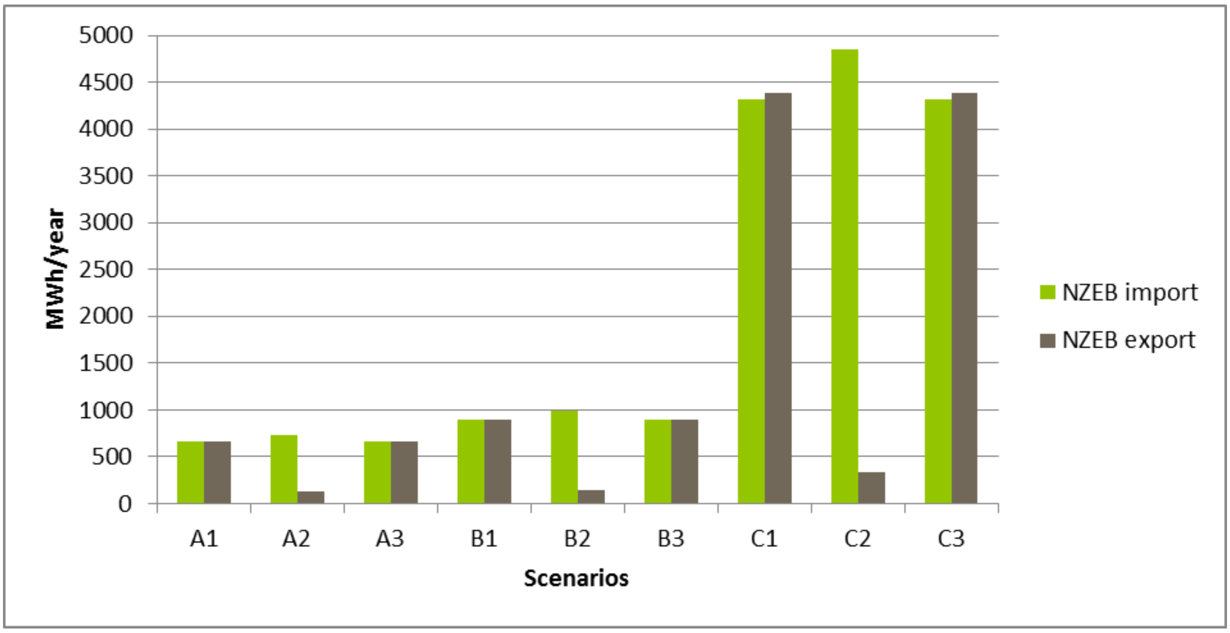

Fig. 6. Heat import/export for NZEBs in each scenario

Scenario A2, B2 and C2 are the only ones not exporting more than they import from the DH grid. This does not mean that they do not have as much solar thermal production as in the rest of the scenarios, but shows that because of the already implemented collective solar thermal collectors and no long-term storage, there is not any need in the DH systems for the excess production from NZEBs. So all the scenarios lives up to the NZEB definition, but all the 2nd scenarios produce heat which is not needed in the DH grid. A3, B3 and C3 however, show that implementing a seasonal storage would make it possible to use the excess production from NZEBs. So there are two factors to look at when determining if the excess production of NZEBs are useful in the system. The first is how large a share of production can be substituted with solar thermal and the second is how large storages are in the system. When examining the share of production replaceable by NZEB excess production, it could be difficult in other systems if there are large shares of geothermal heat or waste heat in the systems.

To look into the whole system, and not only the relationship between NZEBs and DH, the heat production in all scenarios is shown in Figure 7.

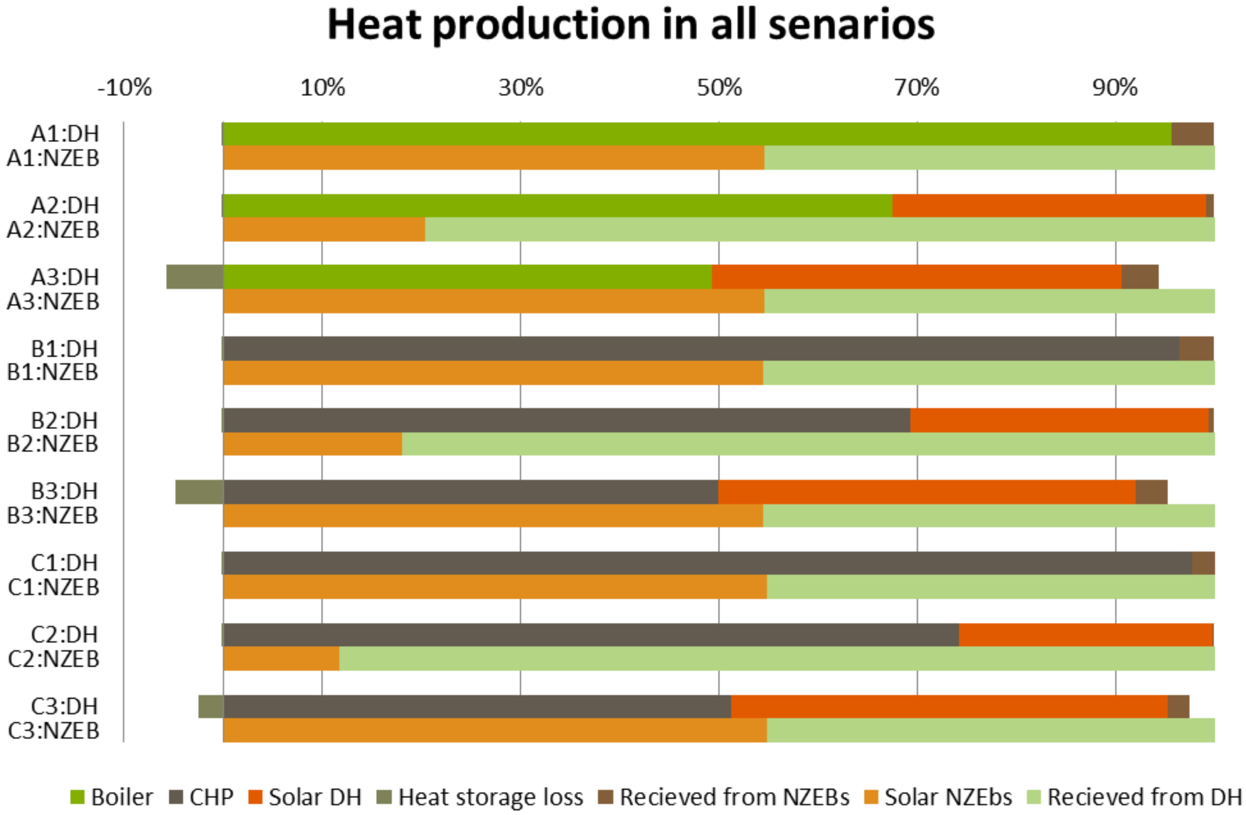

Fig. 7. Heat production in all scenarios shown as percentage of total

The figure shows the heat production in both DH and for NZEBs, to make all scenarios comparable the figure shows the percentage share of heat production instead of the specific values. A1 shows a case where 95% of the DH demand is covered by boilers and the remaining share is the excess solar production from NZEBs. The NZEBs get a bit more than 50% of their heat from solar production. In A2 where collective solar thermal collectors are added to DH, shows another situation. Here the collective collectors produce around a third of the DH demand, meaning that a smaller share of the heat production from NZEBs can be utilized in the DH area. The NZEBs also gets a part of this collective solar production, showing that their own solar production is not needed in this system. The third case A3, where a seasonal storage is added shows that more of the solar energy can be used in the system, saving boiler production. Half of the annual production in the DH area and NZEBs comes from solar energy. Noticeable is it that with the long-term storage, a storage heat loss arises. The loss however decreases when the storage increases in size, since the heat loss is relative to the surface area of the tank. The actual amount of heat loss should not be taken literally, hence there are assumptions regarding this to make it possible to model, which are not a hundred percent accurate. But to show that the relative heat loss decreases with increasing storage size, it is fine.

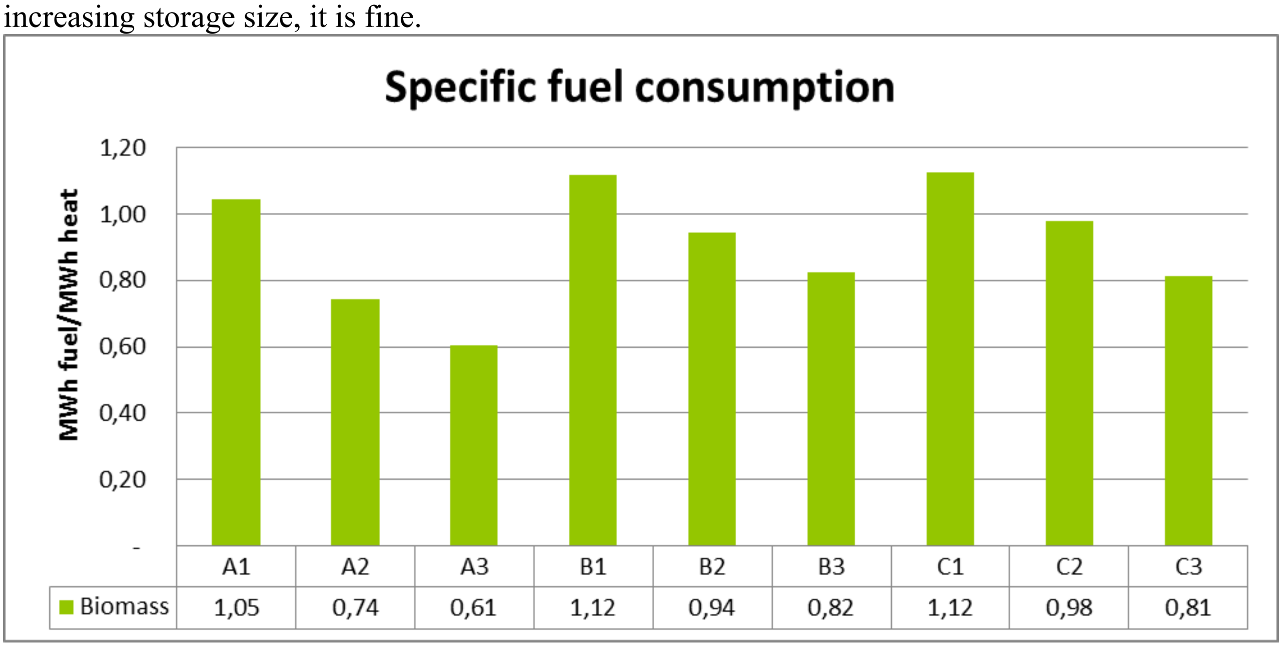

Fig. 8. Specific fuel consumption in all scenarios

Figure 8 shows the specific fuel consumption. It is clear that the biomass consumpotion decreases when adding solar thermal production and decreases even futher when adding a seasonal storage. From A1 to A3 about 40% reduction in is reached, while from B1 to B3 and C1 to C3 the fuel consumption is reduced 30%. The reason that the B and C scenarios reducition is smaller, is because these produce electricity aswell.

Another result is the content of the seasonal storage in all three scenarios from April to December, this is shown in Figure 9.

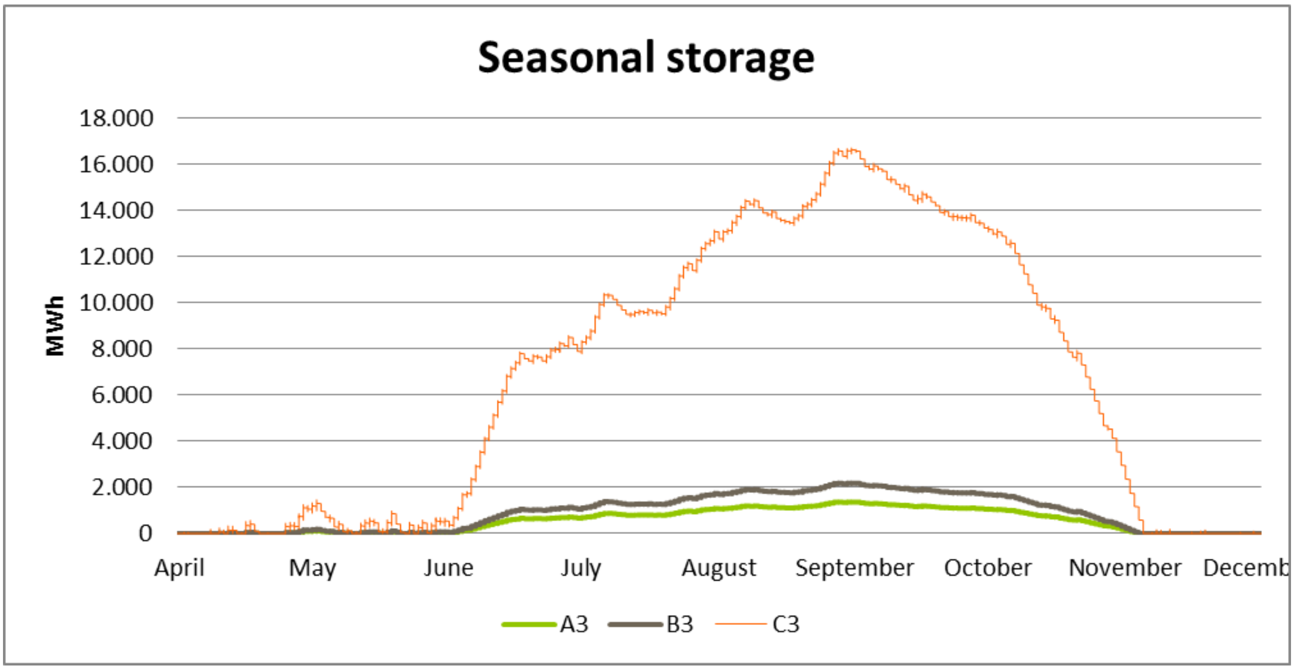

Fig. 9. Content in seasonal storage from April to December in all scenarios

In Figure 9 the storages in all scenarios starts being filled in the beginning of June and is first emptied in the beginning of November. In this period or half the year, heat is supplied solely by solar thermal collectors, which gives a large saving in fuels for boiler or CHP production. The reason that the seasonal storage is emptied before winter is the way the system is simulated, where the heat demand as first priority is covered by solar thermal production or stored thermal heat and then the biomass units run as backup units. In reality the heat could be saved longer. Depending on fuel prices, electricity prices and related factors the CHPs could in some cases produce to the heat storage, which they are not allowed to in this simulation.

DISCUSSION

There are many assumptions leading to the results in this article. The first assumption is that the amount of single-family houses to be built in the next 39 years follows the same construction rate as from 1980 to 2008. This assumption is from the author's perspective seen as reasonable, since it incorporates time periods with low building activity but also periods with high building activity, but it is also in the line with the 2050 forecasts in both Heat Plan Denmark and the Danish Engineering Society's climate plan. The timespan used, prevents the prognosis from making to optimistic or too pessimistic predictions. Another assumption is not including removal of old buildings and addition of other buildings types than single-family houses.

The method used for dividing DH into categories is also important. In this article the size of the DH area and the primary fuel is used for the categorization. The primary fuel is based on the annual consumption for each area, meaning that in some cases that the primary fuel can be only 51% of the fuel consumption. This means that, in theory some areas classified as coal, could get 49% of their heat from e.g. waste incineration plants. Also it is a question of how relevant the fuel consumption in the present system 2008 is for categorizing future energy system, which will change fuels during the next 39 years. The main idea about the category is to show what is used today, and where it is reasonable to place NZEBs with solar thermal heating. E.g. that the areas using waste does not need solar thermal production unless the waste can be stored. Most important in the categorization is the division in different sizes of DH areas, which also is the main difference in the scenarios.

Another assumption is the choice of modeling typical systems instead of concrete, actual systems. This choice is mainly based on making it manageable to model the systems. The optimal solution would be to model each DH area separately, this approach would however take a lot of resources to carry out. Therefore, a future study could be to make analyses of more specific places, to see how NZEBs is going to affect these future DH systems.

In future energy systems solar thermal is not the only renewable resource which will be used in DH areas, but also other technologies like heat pumps and geothermal production will come into play. The analysis could be improved by making more scenarios including these technologies. This however, would be have to be carried out in combination with a more general analysis for the whole country, since it depends a lot on how much wind production is in the system. Geothermal production is very site-specific and can mainly be used in larger DH areas.

Another aspect that should be addressed is the whole economic part, since both large scale solar thermal and seasonal storages are large investments. This part would be useful when examining more concrete projects, to not only show environmental but also economic results. Economy has not been included in this article, since it needs even more assumptions about future fuel prices, future electricity prices, investment prices and so on.

CONCLUSION

The goal with this article is to find out how the heat mismatch from NZEBs affects the heat production in different types of DH areas in Denmark. The first step to reach this goal, has been to make a prognosis of how much of the built area in 2050 is to be built as single-family NZEBs and how large an area the existing building mass consist of. After finding these areas the heat demands were found for both NZEBs and the existing buildings. This first step is a very important part of the analysis, since it quantifies the heat demands and the geographic placement of NZEBs. Further on all the areas has been grouped into different types of DH areas, by size of the area and primary fuel used. An important assumption in this regard, is that all new buildings within DH areas are assumed to connect to DH grids. In reality the buildings are not obligated to be connected, but the assumption is important when examining the possible maximal effect of NZEBs in relation to future DH grids.

The second step in the analysis has been to define typical DH sizes for each DH group within Denmark. Within these typical systems the ones where it was reasonable to add solar thermal production were chosen. This gave three different types of systems, where the main difference is the heat demand in the systems being 15,731, 25,362 and 192,499 MWh/year. In each of these systems biomass have been used as the fuel in boilers and CHPs, to simulate how DH systems may be in 2050. Also to make scenarios of different future system, 3 different setups are made. The first having only solar thermal on the roof of NZEBs, the second adding a collective solar thermal collector to the DH areas and the third adding seasonal heat storage to the DH areas.

The results show two things. If the DH system does not have a large amount of solar thermal production in their system, the NZEBs excess production is very useful in the DH systems, because they reduce the biomass consumption in the DH areas. Even though biomass is considered a RES, it still has the disadvantage of having a cost per unit, which changes over time. Since biomass is a resource which can be expected to be used increasingly, the reduction is positive for the DH areas. The second result is that adding NZEBs to DH systems, where collective solar thermal already covers the heat demand during summer, requires seasonal storage to increasing the share of usable solar thermal production from NZEBs.

The next step after this article will be to analyze more different energy system, including heat pumps, waste heat from incineration or industry, as well as geothermal heat. Also concrete analyses on actual heating systems can help strengthening the conclusions.

KEY WORDS

Mismatch, district heating, net zero energy, buildings, renewable energy, solar thermal, Denmark

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