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Published in:
Energy

Link to article, DOI:
[10.1016/j.energy.2016.04.046](https://doi.org/10.1016/j.energy.2016.04.046)

Publication date:
2016

Document Version
Peer reviewed version

[Link back to DTU Orbit](#)

Citation (APA):

Petrovic, S., & Karlsson, K. B. (2016). Ringkøbing-Skjern energy atlas for analysis of heat saving potentials in building stock. *Energy*, 110, 166–177. DOI: 10.1016/j.energy.2016.04.046

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Ringkøbing-Skjern energy atlas for analysis of heat saving potentials in building stock

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Abstract

Ringkøbing-Skjern municipality aims to be 100% self-sufficient in renewable energy supply starting from 2020. It is expected that the building sector will contribute by reducing energy demand by 25-50%.

Technical, economic, environmental and geographical aspects need to be considered when analysing such drastic change of municipality's energy system. For that purpose, GIS-based Ringkøbing-Skjern Energy Atlas has been developed. The present paper utilises Ringkøbing-Skjern Energy Atlas together with the Heating Model to calculate potentials and costs of heat saving measures.

The results show that the reduction of heating demand by 25% and 35% can be achieved at the annuitized full cost lower than 1.7 and 2 DKK/kWh, respectively. The results also show that significant heat saving potential lies in farmhouses and detached houses as well as in buildings built before 1950. Over 75% of very cheap heat saving potential can be harvested by insulating floors, while majority of heat saving potential cheaper than 2 DKK/kWh can be utilised by insulating floors and installing mechanical ventilation systems. After heat savings and heat supply options are compared from a private-economic perspective, it is concluded that heat savings should be directed towards buildings supplied by oil boilers, natural gas boilers and ground-source heat pumps.

Keywords: Energy atlas, GIS, heat demand, heat savings, energy conservation, energy planning

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1. Introduction

Ringkøbing-Skjern is Denmark's largest municipality, with an area of around 1500 km² and a population of around 57000 inhabitants [1]. It is located in the western part of Central Denmark Region and its western part has access to the North Sea. Its energy sector went through a drastic transformation towards renewable energy in the last 8 years - its renewable energy share increased from 21 % in 2007 to 56 % in 2015. The municipality plans to continue in the same direction and reach the goal of being 100 % self-sufficient in renewable energy supply in 2020. To achieve this goal, the municipality adopted energy strategy "Energy 2020" in 2011. The strategy outlined five fields in which the progress should be made [2]:

- The wind power should contribute to the goal with 25-30 % by producing twice the current electricity consumption in the municipality.
- As the country's geographically largest municipality, Ringkøbing-Skjern have significant biomass and agricultural resources. The production of bioenergy from materials originating from animals and plants should contribute with 15-25 %.
- Other energy sources such as solar thermal, geothermal, fjord thermal, photovoltaic, wave energy and other renewable energy sources including combinations of energy sources and energy storages should contribute with an additional 10-25 %.
- Transportation sector should contribute with 5-15%. Hydrogen vehicles and hydrogen refuelling stations currently exist in the municipality. Public and private transport should be converted to new fuels such as electricity, hydrogen and biofuels. Cargo transport should partly be converted from main roads to the sea.
- Finally, building sector should add additional 10-20% by reducing the energy demand. The plan is to build energy efficient or even plus-energy buildings and perform energy savings in existing buildings. Since the existing buildings are using around 40 % of energy in the municipality, the energy consumption in existing buildings should be reduced by 25-50 % to be able to contribute with 10-20% to the overall objective.

The political goals put in front of the building sector are optimistic and cannot be reached with a nominal renovation, construction and demolition rates. Let's assume that "Business-as-usual" heat savings rate of 0.7 %/year from Ref. [3] is the nominal heat savings rate. Let's also assume that energy inefficient buildings (annual heating demand of over 200 kWh/m²) are replaced with new ones (with an annual heating demand of around 36 kWh/m²) with a nominal rate of 0.25 %/year [4]. As a result of the assumptions, from 2011 to 2020, existing heating demand will be reduced by around 9 %. To get in the range of 25-50 %, the cumulative effect of energy renovation, construction and demolition needs to be increased three times. From a technical point of view this is achievable, but heat savings in buildings have a social dimension as well. Several initiatives have been made in order to promote and support energy savings in buildings:

- A web tool is launched to give the first estimate about potentials and costs of energy savings [5]. Another website which gives advices and best practises about how to save energy in summer houses is launched as well [6].
- In a cooperation with a private company the municipality offers free energy checks to residents under "No cure, no pay" model. This means that the municipality only pays for the energy checks if the renovations of buildings are actually performed. As a result of this initiative, 178 residential buildings have been visited by energy consultants in 2012. 100 residential buildings implemented energy saving measures. The most popular energy saving measures were: insulation of ceilings, replacement of windows, installation of PVs, insulation of pipes and replacing/refurbishing of heating systems.

- The municipality has committed to reduce energy consumption in municipality's own buildings by 20 % in the period 2011-2014.
- The municipality is promoting energy action plans for companies. The goal was to increase the number of companies with an energy action plan by 10 percent points in the period 2011-2014.
- Villages Lyne and Sdr. Vium are chosen to be "energy villages". Their goal is to be self-sufficient in renewable energy supply by the end of 2016. In 2013, 76% of the buildings in Lyne and Sdr. Vium have been visited by an energy consultant and 56% has initiated energy saving measures. The average investment was around 25000 DKK (Danish Kroner) per building, while the average worth of energy savings amounted to 7000 DKK per building.
- From 2011 new houses are only allowed to be built according to BR15 standard for low energy houses. Since 1 January 2016 this standard is minimum requirement for all new buildings in Denmark [7].

To change the energy system as drastically as it is defined in the municipality's energy strategy "Energy 2020" and to do so in less than ten years requires making of complex decisions. These decisions should take several aspects of the transition into account: technical, economic, environmental, social acceptance, etc. and thus require highly detailed decision support system. Geographical data are essential in describing each of these fields. For example, waste potentials are high in cities and towns, manure potentials are high in farming areas, average wind speeds are high in coastal areas, etc. The most important geographical aspect for the present paper is that cost-effectiveness of heat saving measures depends on the position relative to existing district heating and natural gas grids. To account for the "geographical dimension" of the municipality's energy transition Ringkøbing-Skjern Energy Atlas¹ is developed. The data about energy supply and demand, transmission and distribution infrastructure, energy resources, societal and other energy data have been geographically referenced and combined with the tools built in ArcGIS software [8], as presented in Figure 1.

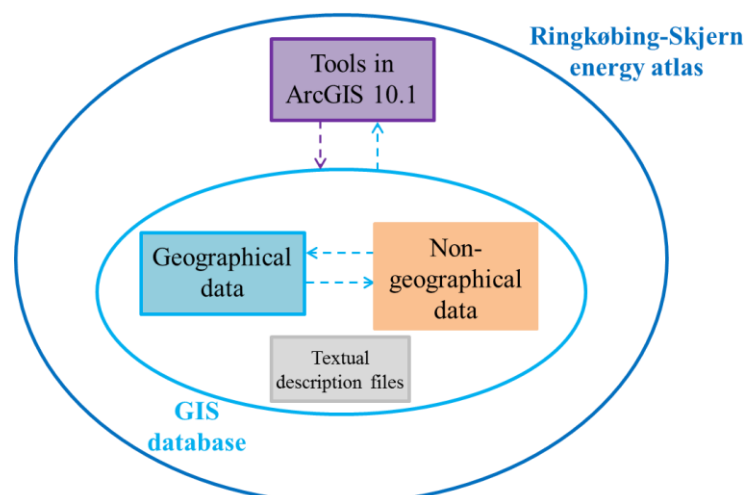


Figure 1 Graphical illustration of RKSKEA [9]

¹ Due to its long name Ringkøbing-Skjern Energy Atlas will be denoted the acronym RKSKEA throughout the paper.

The RKSK EA's GIS database is characterized by high level of details, usually defined by spatial coordinates, technical and historical data. For example, spatial coordinates are known for every building, along with its use, its heated area, construction year, heating source, etc. and in some cases measured heat consumption. Three possible application areas of RKSK EA were presented in Ref. [9]: expansion of district heating networks, finding locations for installation of wind turbines and calculation of potentials and costs of heat saving measures. The last one will be elaborated in details in the present paper. For the detailed description of RKSK EA, Ref. [9] should be consulted.

Heat savings were analysed in several studies in the past, but most often on the national scale. In few cases the scale was either very local (building or group of buildings) or city/municipal. On a very local level, Morelli et al. [10] have used a multi-storey building built in Copenhagen in 1896 as a case-study to analyse three types of energy retrofit measures. They have concluded that the heat saving measures can reduce the energy consumption by 68 %, but it is difficult to attain a “nearly-zero” energy building without using renewable energy sources. The economic aspects were not considered within that study.

Tommerup and Svendsen [11] have investigated potentials for space heating savings in the Danish residential building stock and have concluded that the profitable heat saving potential in years 2020 and 2050 is 30 and 80 % of the space heating demand in 2005, respectively. Technical potentials and associated costs of heat savings until 2050 have been documented in two reports by SBI (Danish Buildings Research Institute) [3, 12]. After analysing three renovation scenarios, potential for reduction of heating demand was estimated to be between 52 and 73 % of the existing heating demand [12]. Seventeen less ambitious scenarios were analysed in [3]; when compared to heat demand in 2011, maximal reduction of heat demand of 47 % is reported. The energy saving potential in buildings of the public sector was analysed in [13] and energy saving potential of 74% of energy consumption in 2006 was reported. Heat saving potential in the Danish building stock of around 75 % of existing heating demand is reported in Ref [14], but it is stated that complete energy system analysis should be undertaken in order to find a cost-optimal share of heat saving measures. A linear optimisation model of the Danish power and heat sectors, Balmorel, was used in Refs. [15, 16] for analysis of the cost-optimal share of heat saving measures in 2025 and 2050, respectively. The reductions of 11 and 12-17 % of projected heat demands in 2025 and 2050, respectively, are found to be optimal. These savings correspond 13 and 16-22 % of existing heating demand.

In Ref. [17] it is presented how Danish heat atlas can be utilised to calculate potentials and costs of heat saving measures, approximate them and feed them into energy system models. Heat saving programmes in the existing building stock and prioritising of heat saving measures in areas with CO₂-intensive heat sources were identified as possible applications of Danish heat atlas in Ref. [18].

One of the rare studies on heat savings at the local level was performed by Sperling and Möller for the city of Frederikshavn [19]. They have created very detailed heat atlas and adjusted it to local conditions, which is very similar to the approach in this article. On the other hand, they have predefined a reasonable heat demand reduction level of 20 % over the analysed period and did not analyse heat savings in more details but performed energy system analysis using EnePLAN model [20]. Instead, the present study analyses heat saving potentials and costs in more details – their geographical distribution, distribution on building types and components of the building envelope. Since residential buildings are responsible for 85 % of the heating demand in buildings in Ringkøbing-Skjern municipality, the present paper focuses on heat savings in the residential building stock.

2. RKSK EA and Heating Model

This section will present the part of RKSK EA utilised in the present analysis, introduce the model for calculation of net heat demand, potentials and costs of heat saving measures (called the Heating Model) and show how they work together. RKSK EA is used to store and pre-process the data about residential building stock before feeding the data into the Heating Model. The Heating Model is first utilised to calculate the existing heating demand². After that, the potentials and costs of heat saving measures are calculated and returned back to RKSK EA to geographically represent results.

2.1 Representation of residential buildings in RKSK EA

The residential building stock in RKSK EA is characterized by geographical and non-geographical data. The geographical data are spatial coordinates which provide the information on "where the buildings are". The non-geographical data include use of buildings, their worth, sizes of different areas, types of water and energy supply systems, materials used for envelope, weighted average u-values and f-values³, ventilation and infiltration rates, etc. and thus describe buildings in more details. In the present paper, each building is characterized by the construction period, use, type of heating supply and heated area. The geographical data are extracted from the BBR⁴ database [21], while non-geographical data are extracted from the BBR database and reports containing statistical data from the Energy Labelling Scheme [3, 12, 22]. The non-geographical data are utilised to aggregate the buildings into groups before feeding the data into the Heating model. The residential building stock is aggregated into 72 groups according to construction period and use. Total heated area for each of these groups is presented in Figure 2. This aggregation is chosen because the statistical (weighted average u-values and f-values) and empirical data (indoor temperature before renovation, ventilation and infiltration rates, etc.) about the Danish building stock are available at this level [3, 12, 22]. The validity of using national heat atlases on a local level was summarized by Möller and Nielsen [23]. They have reported very good match between calculated and measured heating demands for a city of Aalborg and significant mismatches for some small district heating systems in Central Denmark Region. Irregular updating of public registers and the fact that socio-economic, demographical and behavioural aspects are not included in national heat atlases are identified as the reasons for the mismatch. They have reported small mismatches for building types large in number (such as single-family houses) and greater diversity and high errors for building types fewer in numbers, such as public institutions and industries. They have also confirmed that the heat atlases based on heat demand calculations can never replicate the heat demand in individual buildings.

After the existing heating demand, potentials and costs of heat saving measures are calculated and adjusted with the local conditions in the Heating Model, the geographical data are utilised to link the results with the 1 km² Danish Square Grid and thus spatially represent the results.

² If not specified otherwise, heating demand is the sum of demand for space heating and domestic hot water.

³ f-value for a specific element of building's envelope (wall, window, etc.) is the ratio between area of that element and heated area of building.

⁴ BBR (in Danish "Bygnings- og Boligregistret") is an acronym for the Danish Register of Buildings and Dwellings.

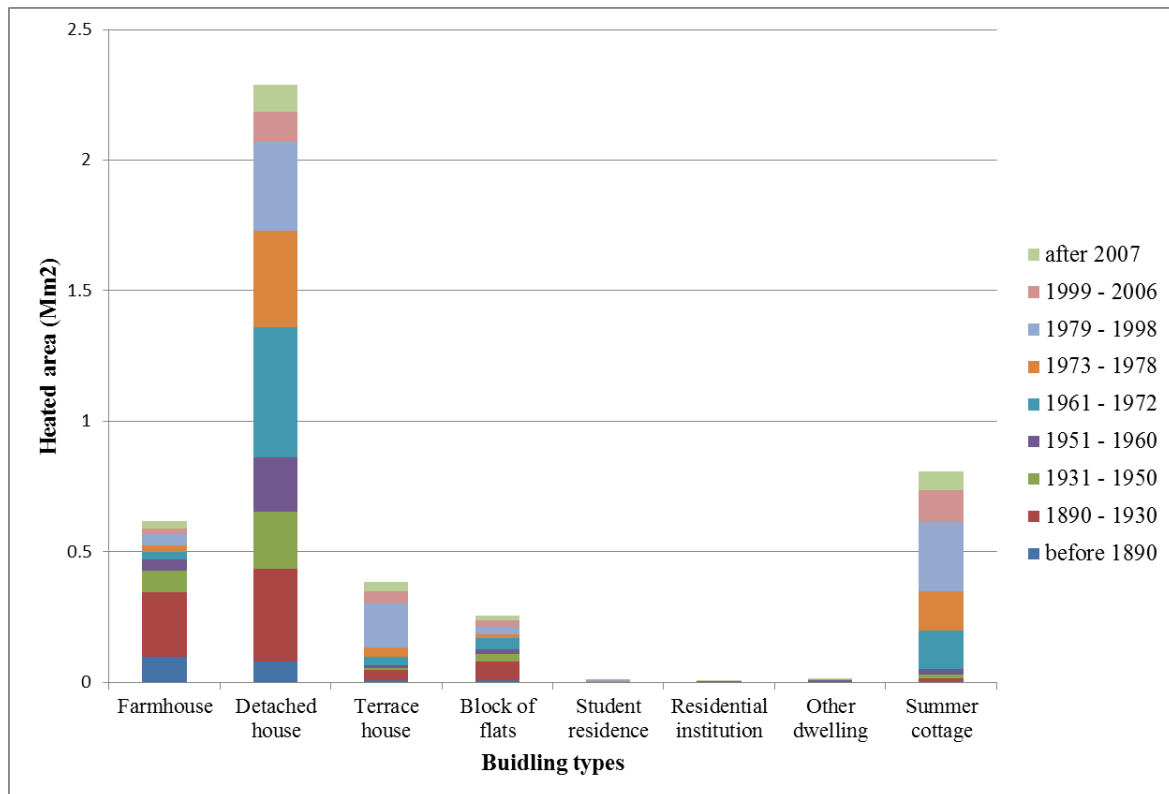


Figure 2 Heated area of residential buildings in Ringkøbing-Skjern municipality

2.2 The Heating Model

The Heating Model is a heat loss model which has several functions, as presented in Figure 3:

1. Calculating existing demand for space heating and domestic hot water and adjusting it to statistics and/or local conditions.
2. Calculating potentials and costs of heat saving measures.
3. Approximating potentials and costs of heat saving measures and feeding them into one of energy system models.
4. Making projections of future heating demand based on the assumptions regarding renovation, construction and demolition rates.
5. Visualizing and geographically representing results in GIS-based tools such as RKSK EA.

In Figure 3 the user inputs are put into the green shapes, results into the red, data inputs into the black and data manipulation procedures in the blue ones. The workflow of the model is as follows:

- The total heated areas, physical characteristics (weighted average u-values and f-values, ventilation and infiltration rates, etc. originating from [3, 12, 22]), population data [1], and user inputs are inputted for each of the building groups.
- Specific demand for space heating and domestic hot water (kWh/m²) is calculated for each building group, aggregated and compared with statistics. If the match with the statistics is initially not achieved, user inputs are changed until the satisfactory match with the statistics is achieved.
- Several renovation levels are assumed for the components of buildings' envelopes – floors, walls, roofs, windows and ventilation systems, as presented in Table 1. The heat saving potential for each renovation level is calculated as a difference between current heating demand and heating demand after the assumed renovation. The marginal and full

costs of heat saving measures are collected from SBI's reports [3, 12, 22]. The marginal costs represent costs of heat saving measures if they are done after the end of the lifetime of a specific component. The full costs represent costs of heat savings if they are done with the sole purpose of saving heat. The costs are annuitized with 4 % discount rate over the lifetimes of different components of building envelope (20 years for ventilation systems, 25 years for windows, 35 years for roofs and 40 years for floors and walls).

- For each component of buildings' envelopes, the most cost-effective heat saving measure (i.e. the lowest amount of DKK⁵ per saved kWh) is chosen out of heat saving measures assumed in Table 1. These costs (in DKK/kWh) and associated potentials (in kWh) are aggregated and ordered from the least to the most expensive. In this way heat saving curves are obtained.
- On one hand these results can be visualized in a GIS-based tool such as RKSK EA. On the other hand, these curves can be approximated and used as inputs to energy system models, as presented in [17].
- If the construction, demolition and renovation rates are assumed, the Heating Model provides projections of the future heating demand.

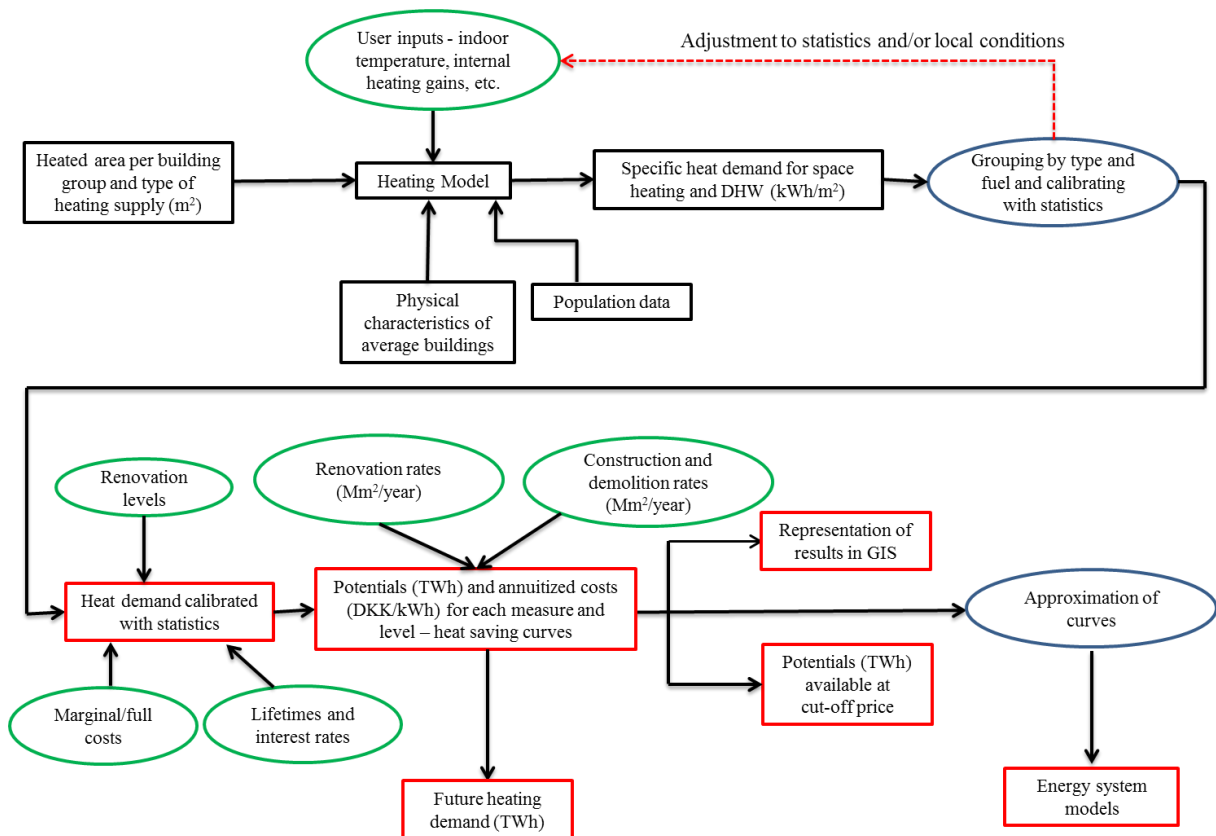


Figure 3 Inputs, outputs and flows in Heating Model

⁵ DKK denotes Danish Kroner throughout the paper. 1 DKK=0.134 EUR

Table 1 Assumed heat saving measures for component of building envelope

Component of building envelope	Heat saving measure
Wall	Adding insulation – 100 mm
	Adding insulation – 200 mm
	Adding insulation – 300 mm
Roof	Adding insulation – 100 mm
	Adding insulation – 200 mm
	Adding insulation – 300 mm
Floor	Adding insulation – 50 mm
	Adding insulation – 100 mm
	Adding insulation – 150 mm
Window	Installing A+ windows
	Installing A windows
	Installing B windows
	Installing C windows
Ventilation	Installing ventilation systems with heat recovery

2.3 RSKK EA and the Heating Model

In the present analysis the Heating Model is not used to produce inputs for energy system models or to make projections of the future heating demand in Ringkøbing-Skjern. The procedure how RSKK EA and the Heating Model work together is illustrated in Figure 4: RSKK is used to store the data about residential building stock, pre-process them and feed them into the Heating Model. The Heating model is then calibrated to the local conditions. After that, the potentials and costs of heat saving measures are calculated. At the end, these results are sent back to RSKK EA and visualized within the 1km² Danish square grid.

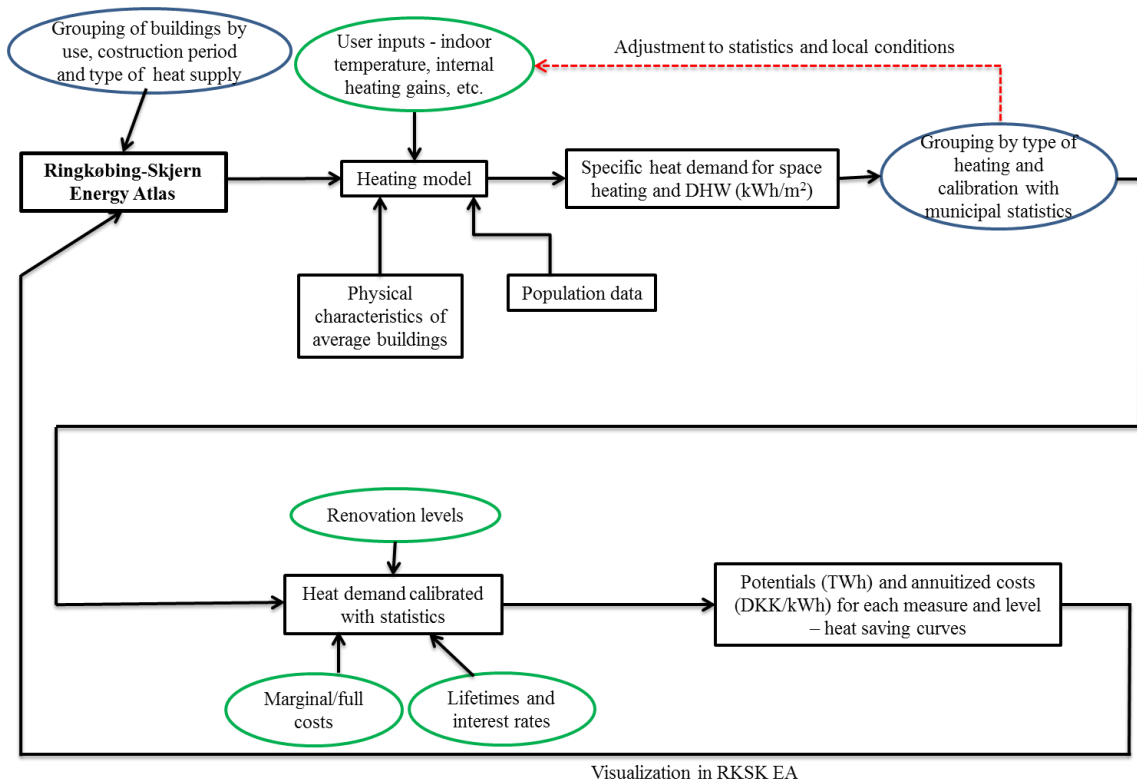


Figure 4 Heating Model and Ringkøbing-Skjern Energy Atlas working together

3. Results and discussion

Initially, the Heating Model was calibrated with the Danish Energy Statistics. This means that the user inputs were adjusted in a way that the net heating demand (calculated by the Heating Model) matches the net heat demand in the Danish Energy Statistics [24] for each building group and type of heat supply. When the data about residential building stock in Ringkøbing-Skjern are inputted into the Heating Model two aspects are observed. First, there is a very good match between the total heating demand calculated by the Heating Model and the Ringkøbing-Skjern energy statistics [25] – 1.83 PJ compared to 1.91 PJ or only 4.3 % lower. Second, when the calculated heating demands are compared separately for each type of heat supply, moderate differences were observed for district heating and natural gas (5 and 7 %, respectively) while significant differences were observed for oil (75 %), renewable energy (-50 %) and electricity (100 %). The mismatch in oil and renewable energy is due to relatively large utilization of biomass in the municipality compared to the Danish average. The mismatch in electricity consumption for heating is due to large number of summer cottages, compared to the Danish average, in which direct electric heating is often used.

To be able to accurately represent the heating demand in Ringkøbing-Skjern's residential building stock, the Heating Model is adjusted to local conditions:

- Instead of national averages, local average monthly outdoor temperatures are used [26]. The outdoor temperatures affect the space heating demands.
- Instead of national averages, local population data are used [1]. The number of people per m^2 of heated area affects demand for domestic hot water.
- By changing the user inputs, the calculated heating demand is calibrated to match the Ringkøbing-Skjern energy statistics [25].

The calculated heating demands before and after the adjustments to local conditions are presented in Figure 5.

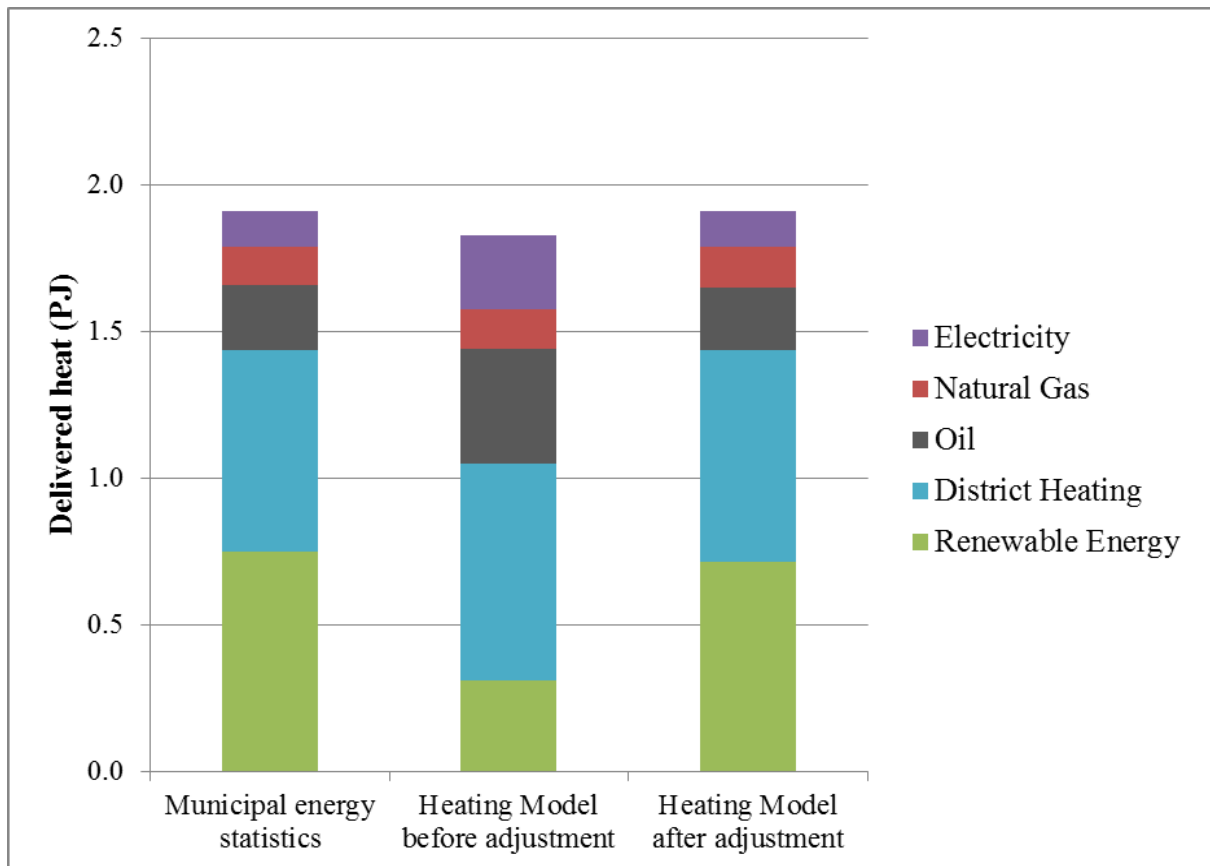


Figure 5 Comparison of calculated heating demands before and after adjustment with local statistics

Even though the match between the Heating Model and the statistics is achieved for every type of heat supply on the municipal level, the comparison between measured and calculated heat demands is done for eight district heating systems as presented in Figure 6. For the remaining four district heating system present in the municipality, the consumption data are not available. Two conclusions can be made based on the comparison presented in Figure 6. First, generally good match between measured and calculated data is achieved - for four out of eight district heating systems the relative error is within the range (-9 %, + 7 %), while for seven out of eight the relative error is within the range (-14 %, +17 %). There are several possible explanations for the big relative mismatch in case of Troldhede district heating system – large number of unoccupied buildings, use of supplementary heating sources (wood stoves, electrical heating, solar heating, etc.), etc. Second, the relative error is smaller for bigger district heating systems and bigger for smaller district heating systems.

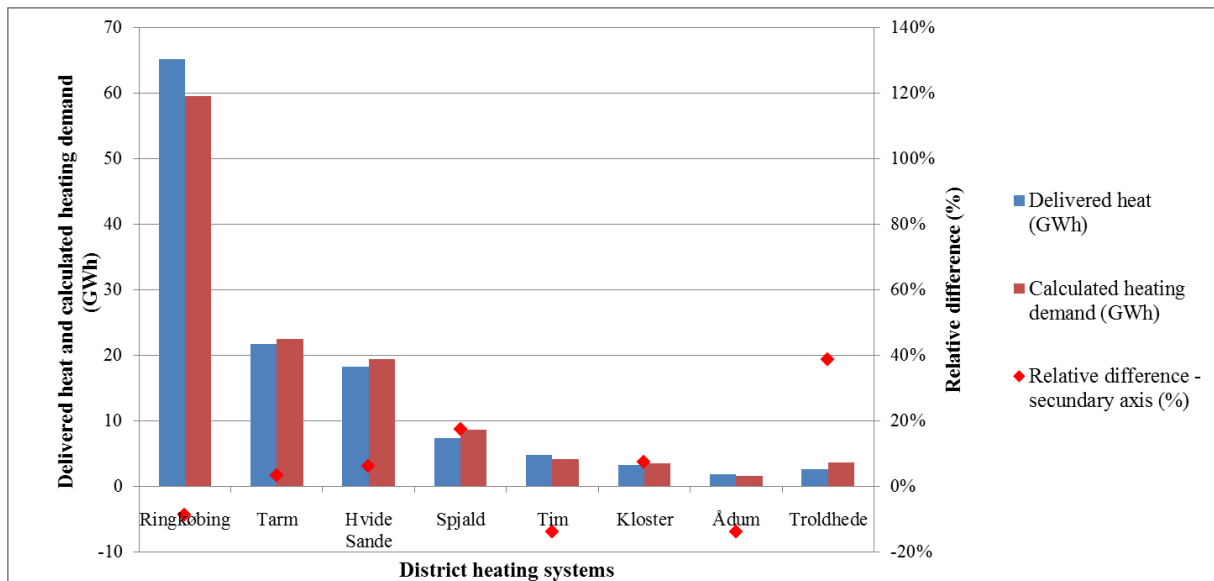


Figure 6 Comparison between calculated heating demands and delivered heat for eight district heating systems

3.1 Potentials and socio-economic costs of heat saving measures

Figure 7 presents the calculated potentials and annuitized socio-economic investment costs of heat saving measures in Ringkøbing-Skjern municipality. The costs are shown separately for marginal and full prices, as well as before and after adjustment to local conditions. To put the heat saving potentials into the context, the lines which are showing 25 % and 50 % of existing heating demand are also presented in Figure 7. It is clear that the adjustment to local conditions does not make important difference between the curves, which could lead to the conclusion that the adjustment to local conditions is not very relevant. On the other hand, there are two reasons why this is necessary. First, the adjustment is affecting heat saving potentials for certain types of heat supplies, such as oil boilers. When seeking self-sufficiency in renewable energy supply, this makes an important difference. Second, buildings in Ringkøbing-Skjern are good representatives of net heating demand of average Danish buildings resulting in smaller difference between adjusted and non-adjusted curves. However, in some other parts of the country, the difference might be more significant.

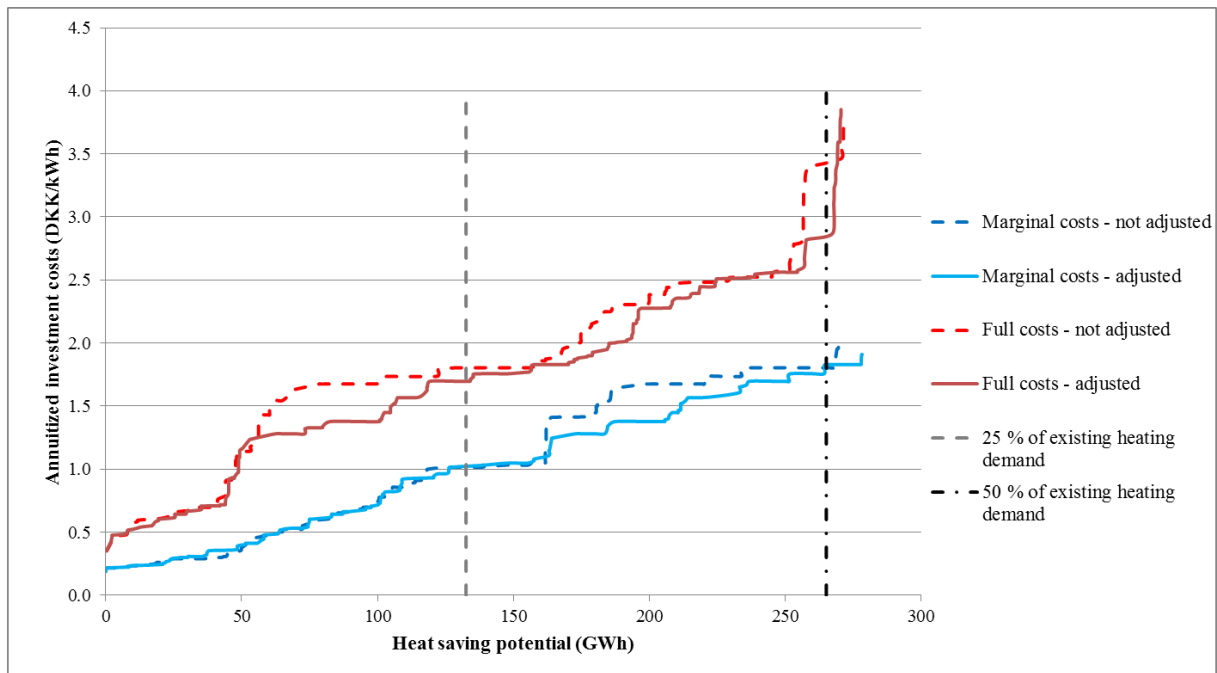


Figure 7 Potentials and annuitized socio-economic costs of heat saving measures before and after adjustment to local conditions

Even though the curves which are presented in Figure 7 give a good idea about the aggregated potentials and associated investment costs in the municipality, there are several questions which can't be answered based solely on these curves: "Where is the potential located?", "Which types of building constitute the potential?", "Which components of the buildings' envelopes mostly contribute to the potential?"

To answer these questions the curves presented in Figure 7 are disaggregated, sent back to RSK EA, spatially referenced to 1km² Danish Square Grid and presented in Figure 8 and Figure 10. Due to simplicity and short time frame for performing heat savings in Ringkøbing-Skjern, only the adjusted full cost curve is used onwards. The heat saving potentials with annuitized full investment costs lower than $0.7 \frac{DKK}{kWh}$ and $2 \frac{DKK}{kWh}$ are presented in Figures 8, 9, 10 and 11, respectively.

In case when the cut-off costs are set to $0.7 \frac{DKK}{kWh}$, the following results are observed:

- The average investment costs are $0.57 \frac{DKK}{kWh}$. The average investment costs give an indication about how big are investment costs which are lower than the cut-off costs. For example, marginal and full costs presented in Figure 7 have different average costs at the same cut-off costs. The average investment costs can also be used for comparison with the heat supply alternatives.
- Total heat saving potential amounts to around 35 TWh or 6.7 % of existing heating demand in the municipality. Even though the heat saving potential of 6.7 % is way below the political goal of 25-50 % reduction of energy demand, it is cheaper than heat supply alternatives (the price of district heating supply in Ringkøbing-Skjern ranges from 0.5 to $1 \frac{DKK}{kWh}$ without VAT and the connection costs [27]).
- From the geographical perspective, the highest potentials for heat savings per unit of area are located in the centres of towns Ringkøbing and Skjern. At the same time, these are the biggest towns in the municipality.

- More than 75 % of heat saving potential can be utilised by insulating floors.
- 89 % of the potential comes from farmhouses and detached houses even though they are responsible for only 66 % of total heated area. The farmhouses themselves are responsible for 42 % of the heat saving potential and for 14 % of heated area.
- Buildings built between 1890 and 1930 and between 1931 and 1950 are responsible for 70 % of heat saving potential and only 25 % of heated area.

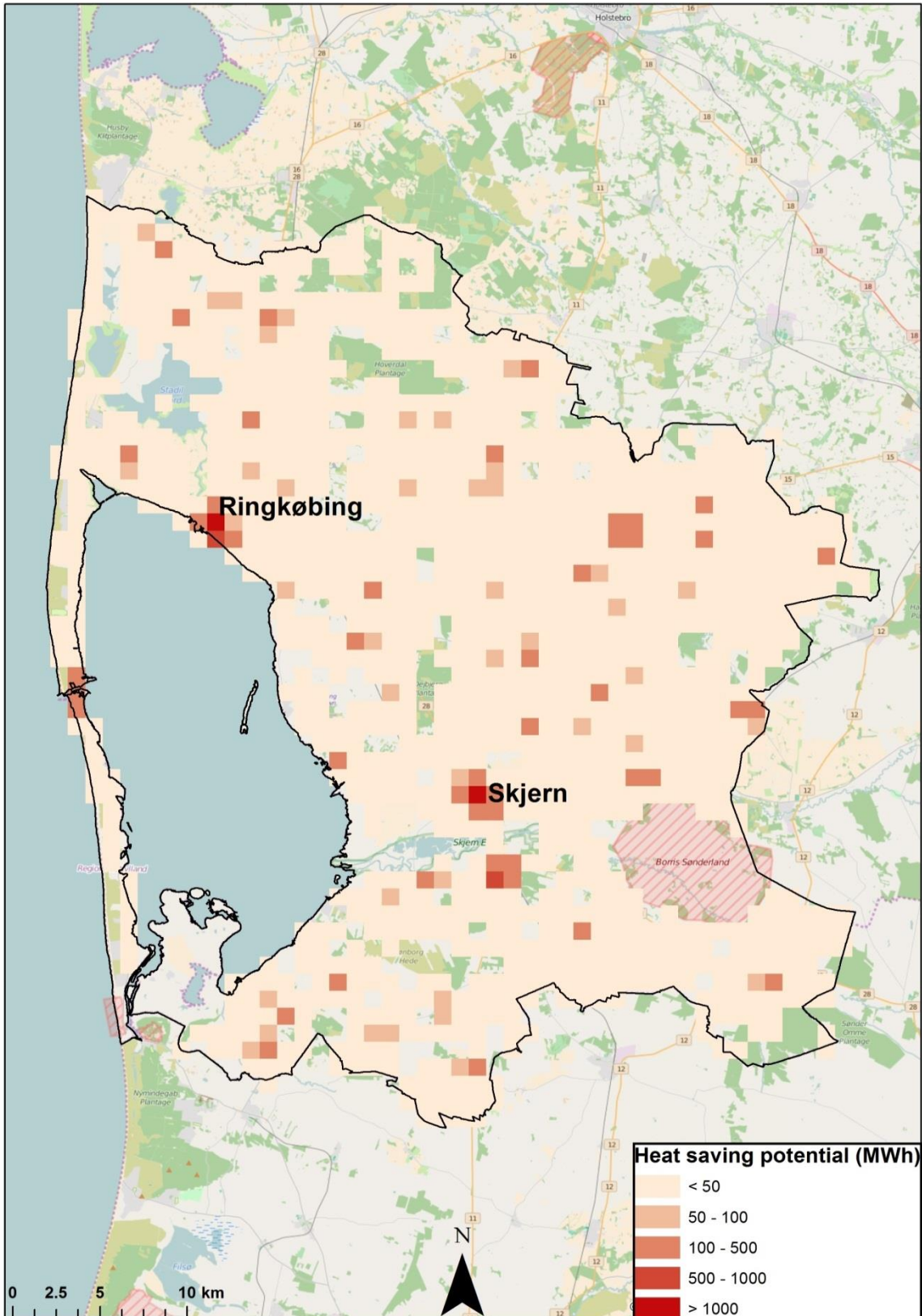


Figure 8 Heat saving potentials with annuitized full investment costs lower than $0.7 \frac{DKK}{kWh}$ specified according to geographical location

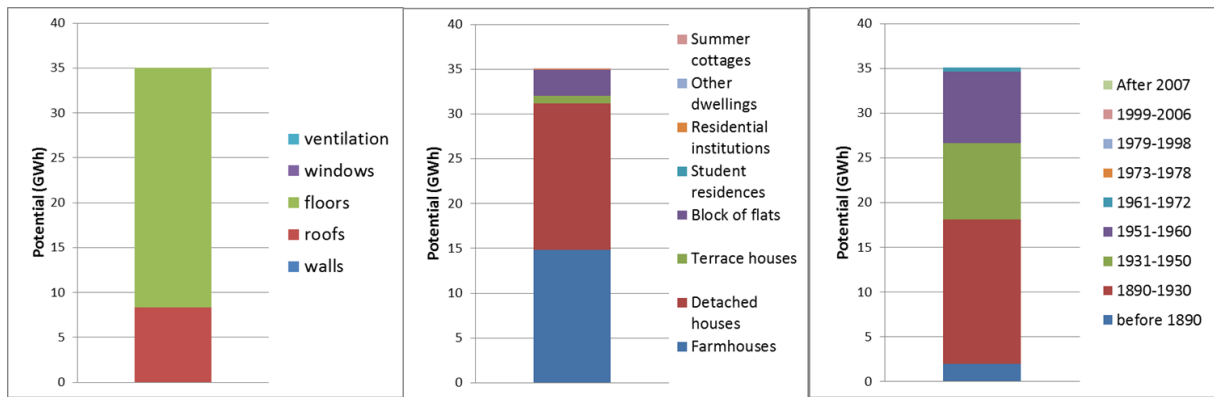


Figure 9 Heat saving potentials with annuitized full investment costs lower than $0.7 \frac{DKK}{kWh}$ specified according to components of buildings' envelopes, construction periods and use of buildings

In case when the cut-off costs are set to $2 \frac{DKK}{kWh}$, the following results are observed:

- The average investment costs are $1.33 \frac{DKK}{kWh}$.
- Total heat saving potential amounts to around 185.2 TWh or 35 % of existing heating demand in the municipality.
- From the geographical perspective heat saving potential is located in most populated towns, such as Ringkøbing, Skjern, Tarm, Videbæk and Hvide Sande; the remaining part of heat saving potential is scattered around the municipality.
- 70 % of heat saving potential can be achieved by insulating floors and installing mechanical ventilation systems with heat recovery.
- 83 % of the potential comes from farmhouses and detached house even though they are responsible for only 66 % of total heated area. Farmhouses themselves are responsible for 24 % of the heat saving potential and for 14 % of heated area.
- Buildings built between 1890 and 1930 and between 1931 and 1950 are responsible for 43 % of heat saving potential and only 25 % of heated area.

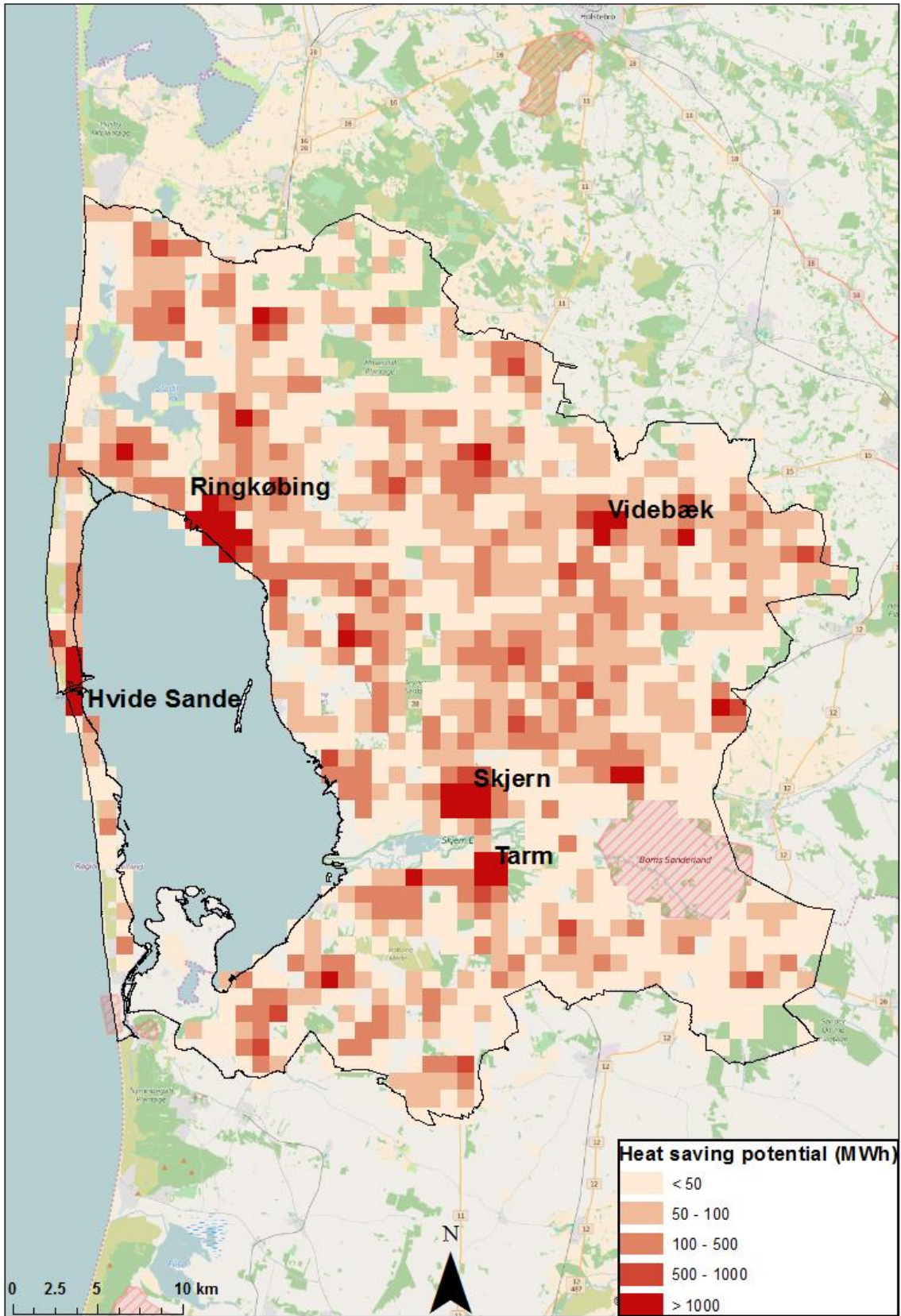


Figure 10 Heat saving potentials with annuitized full investment costs lower than $2 \frac{DKK}{kWh}$ specified according to geographical location

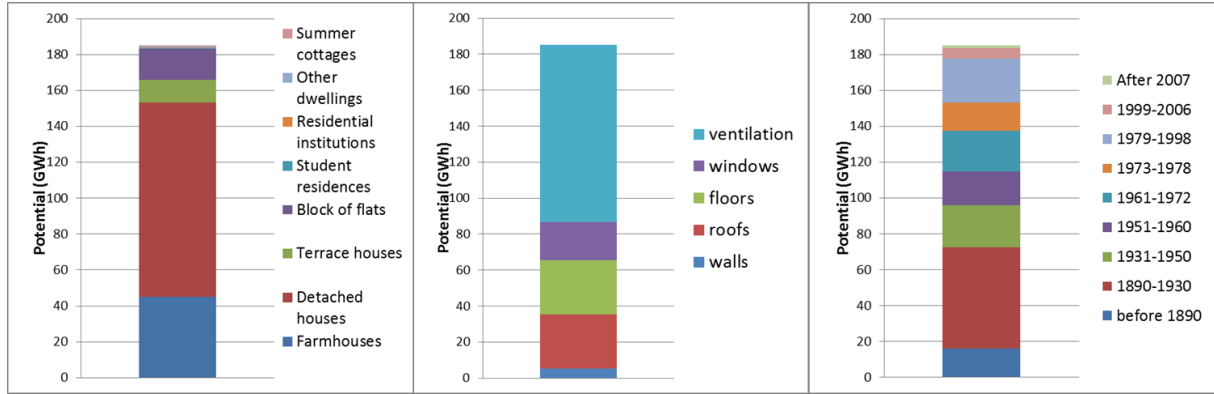


Figure 11 Heat saving potentials with annuitized full investment costs lower than $2 \frac{DKK}{kWh}$ specified according to components of buildings' envelopes, construction periods and use of buildings

3.2 Comparison of heat saving measures with heat supply options from private-economic perspective

After the potentials and socio-economic investment costs of heat savings are calculated, geographically referenced and related to groups of buildings and components of building envelope, the next step is to compare them with costs of heat supply. The comparison is done from the private-economic perspective. The private-economic costs of heat saving measures are calculated by adding VAT on top of the socio-economic costs. The private-economic costs of heat supply options are calculated using the following equation:

$$C = C_{INV} + C_{FIX\ O\&M} + C_{VAR\ O\&M} + C_F \cdot k_F, \quad (1)$$

where the used symbols have the following meaning:

C – total private-economic costs of supplying one unit of heat ($\frac{DKK}{kWh}$).

C_{INV} – annuitized private-economic investment costs of heat supply options. In case of district heating, investment costs are the costs of heat exchangers and connecting pipes. The costs are annuitized with 4 % interest rate over technical lifetimes of technologies (22 years for natural gas boiler and 20 years for other technologies).

$C_{FIX\ O\&M}$ - annual private-economic fixed operation and maintenance (O&M) costs of heat supply options. In case of district heating, payments not related to the amount of consumed heat are included in the fixed O&M costs.

$C_{VAR\ O\&M}$ – annual private-economic variable O&M costs of heat supply options.

C_F – annual private-economic fuel costs in year 2015.

k_F – increase in average private-economic fuel costs in period 2015 – 2035 relative to costs in 2015. k_F is calculated from [28].

Investment, fixed and variable O&M costs and lifetimes for individual heating technologies are obtained from the Technology Catalogue for Energy Plants [29]. The costs of connecting to district heating are based on the official price lists by Ringkøbing and Tarm district heating companies [30, 31]. The private-economic fuel costs in 2015, parameter k_F and conversion efficiencies are listed in the Table 2. The private-economic calculations are done for four illustrative building groups. The results are presented in Table 3.

Table 2 Conversion efficiencies, fuel prices and fuel price increase coefficient k_F

Technology	Fuel	Price in 2015	Reference	k_F	Conversion efficiency [29]
Oil boiler	Oil	7600 $\frac{DKK}{1000 l}$	[32]	1.62	100%
Natural gas boiler	Natural gas	6.5 $\frac{DKK}{m^3}$	[33]	1.24	102%
Wood pellet boiler	Wood pellets	2125 $\frac{DKK}{t}$	[34]	1.06	80%
Ground source heat pump	Electricity	1.7 $\frac{DKK}{kWh}$	[35]	1.49	330%
District heating – Ringkøbing	District heat	0.36 $\frac{DKK}{kWh}$	[30]	1.3	98%
District heating – Tarm	District heat	0.34 $\frac{DKK}{kWh}$	[31]	1.3	98%
District heating – Other networks	District heat	0.75 $\frac{DKK}{kWh}$	[27, 30]	1.3	98%

Table 3 Private-economic costs of heat supply and heat savings

	Detached house 1890-1930	Terrace house 1979-1998	Detached house 1951-1960	Farmhouse 1890-1930
Oil boiler	1.69	2.06	1.72	1.66
Wood pellet boiler	0.95	1.31	0.98	0.93
Natural gas boiler	1.07	1.39	1.10	1.04
District heating - Ringkøbing	0.75	0.90	0.77	0.74
District heating - Tarm	0.86	1.14	0.89	0.84
District heating - Other networks	1.09	1.20	1.10	1.08
Ground-source heat pump	1.36	1.97	1.42	1.32
20 % reduction - full costs	1.00	2.20	0.85	0.88
30 % reduction - full costs	1.24	2.21	1.22	1.12
50 % reduction - full costs	1.78	2.44	1.71	1.62

Several results can be observed from Table 3:

- In all analysed building types reduction of heating demand by 20 % is more expensive than district heating in Ringkøbing and Tarm. In three out of four analysed building types the reduction of heating demand by 20 % is cheaper than the average district heating price in the rest of the municipality.
- In around sixty years old detached houses, the reduction of heat demand by 20 % is competitive with district heating in Ringkøbing and Tarm and less expensive than the other heat supply options. The reduction by 30 % is in the same price range with natural gas boilers and wood pellet boilers. Larger reductions than 30 % are not competitive.
- The costs of reduction of heating demand in the farmhouses from beginning of 20th century by 20 % is very similar with the price of district heating in Ringkøbing and Tarm and cheaper than the other heat supply options. However, farmhouses are located far away from existing district heating areas and thus the connection to district heating does not represent a realistic option. The reduction of heating demand by 30 % is similar with the price of heat from wood pellet boilers.
- In all building types except in terrace houses built between 1979 and 1998 the reduction of heating demand by 30 % is cheaper, while the reduction by 50 % is comparable with the cost of supply from oil boilers and ground-source heat pumps.

4. Conclusions

To assess how realistic the municipality's plans regarding heat savings are, RKSKEA was used together with the Heating Model. RKSKEA was used to store and pre-process the data about residential building stock before feeding the data into the Heating Model. The Heating Model was first utilised to calculate the existing heating demand and adjust it with local conditions. After that, the potentials and costs of heat saving measures were calculated and sent back to Ringkøbing-Skjern Energy Atlas to be geographically represented.

Before the present study, the Heating Model was calibrated with the Danish Energy Statistics. The heating demand calculated in the Heating Model was only 4.3 % lower than the heating demand stated in the Ringkøbing-Skjern's energy statistics. Based on that, it can be concluded that in terms of net heating demand residential buildings in Ringkøbing-Skjern are good representatives of the average Danish building stock.

The potentials and full socio-economic costs of heat saving measures were calculated in the Heating Model. The results show that reduction of existing heating demand by 25 % can be achieved for full socio-economic costs lower than $1.7 \frac{DKK}{kWh}$ (average price of $1.18 \frac{DKK}{kWh}$), while half of existing heating demand can be reduced for less than $2.85 \frac{DKK}{kWh}$ (average price of $1.64 \frac{DKK}{kWh}$).

Geographically, the largest concentrations of cheap heat savings (annuitized investment costs lower than $0.7 \frac{DKK}{kWh}$) are observed in two biggest towns, Ringkøbing and Skjern. More than 75 % of cheap heat saving potential can be achieved through insulation of floors. If building uses are analysed, cheap heat saving potential can be utilised in farmhouses and detached houses; if construction periods are analysed, buildings built before 1950 constitute the largest share of cheap heat saving potential.

From the geographical perspective, heat saving potential equal to 35% of existing heating demand (annuitized full investment costs lower than $2 \frac{DKK}{kWh}$) is mostly located in towns, such as Ringkøbing, Skjern, Tarm, Videbæk and Hvide Sande; the remaining part of heat saving potential is scattered around the municipality. If heat saving potentials are split according to components of building envelopes, over 70 % can be utilised by insulation of floors and

installation of mechanical ventilation systems with heat recovery. In the same manner as for cheap heat savings, farmhouses and detached houses and buildings built before 1950 constitute biggest part of heat saving potential.

After the costs of heat saving measures have been compared with heat supply technologies from the private-economic perspective, several general recommendations can be made:

- Heat saving measures are not competitive with the heat supply options in the buildings constructed after 1979. As a result of that, the remaining three recommendations refer exclusively to buildings constructed before 1979.
- Reductions of heating demand by heat saving measures of 30-50 % should be done in buildings supplied by oil boilers and ground-source heat pumps, while savings of 20-30 % should be done in buildings supplied by natural gas boilers.
- From a purely private-economic perspective, the cost of heat from wood pellet boilers in buildings older than 40 years is similar to the costs of reduction of heating demand by 20-30 %. However, the unexpected rise of wood pellet prices can greatly increase the price of heat from wood pellet boilers. On the other hand, the price of heat savings cannot be affected by a rise in fuel prices.
- Heat savings larger than 20 % should not be directed towards buildings supplied by district heating in largest towns, Ringkøbing, Skejrn and Tarm. The reduction of heating demand by 20-30 % can be advised in smaller district heating areas.

"Energy 2020" states that energy demand in buildings should be reduced by 25-50 % in order to contribute with 10-20 % to the overall objective, but it doesn't provide the split between electricity and heat savings. Heat savings were analysed within the present paper. The reduction of heating demand in building stock by 50 % is technically possible, but cannot be backed-up by private-economic calculations. The reduction of heating demand in building stock by 25 % in 9 years is somewhat optimistic but seems achievable even when private-economic perspective is considered. The reduction of energy demand by 25 % in 9 years can be achieved a bit easier. Heat saving measures can reduce heating demand by 20-25 %, while construction of new and demolition of existing buildings can reduce heating demand by another 2.5-3 %. Since the heat demand makes up 81 % of energy demand, heat savings, construction and demolition are reducing the energy demand by 20-24 %. To achieve the reduction of energy demand of 25 %, the remaining 1-5 % can be achieved through electricity savings.

RKSK EA proved to be useful tool storing and pre-processing the data about residential building stock and visualizing the results from the Heating Model. The Heating Model proved to be flexible enough to be able to adjust to local conditions in Ringkøbing-Skjern and useful when it comes to calculating potentials and costs of heat saving measures. It is also proven within the scope of the present paper that they can work well together.

5. Room for improvements and future work

Even though RKSK EA and Heating Model proved to work well together and produce useful outputs, there are some aspects which should be addressed in the future:

- All buildings in the municipality are considered to be occupied and thus in the Heating Model they constitute the heating demand and heat saving potential. More realistic representation of the building stock will be achieved by including information about unoccupied buildings; this refers to both actual unoccupied buildings and part-time

unoccupied buildings. According to Statistics Denmark, there are 8.5 % of unoccupied buildings (corresponding to 6-6.5 % of total heated area) currently in Ringkøbing-Skjern [36]. Around 50 % of these buildings are actual unoccupied buildings, while temporarily unoccupied buildings due to relocation, secondary residences and buildings erected after the start of a year constitute the remaining part.

- The heat delivered to every building is known for eight district heating systems. The measured heat consumption for all buildings should be added to RKSK EA. From 2011 all companies providing district heating, heating oil or natural gas are required to report end-user consumption to BBR. However, the consumption of biomass, which is important fuel in Ringkøbing-Skjern, is not reported.
- It is shown that in some cases reduction of heating demand by 20-30 % is the best solution from the private-economic perspective. The question which seeks an answer is whether the owners can afford it. The common understanding is that energy inefficient buildings usually have low market value and low equity. Thus, the amount of money which can be loaned through property mortgage loans is also lower. Because of that, heat savings might be unaffordable for some building owners.
- Installation costs of heat savings and individual heat supply technologies are based on national averages; the local costs should be included. However, this factor is not expected to play an important role in the final price of heating.

Acknowledgment

The work presented in this paper is a result of the research activities of the Strategic Research Centre for 4th Generation District Heating (4DH), which has received funding from The Innovation Fund Denmark.

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