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## **A DANISH HEAT ATLAS FOR SUPPLY STRATEGIES AND DEMAND SIDE MANAGEMENT**

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### **ABSTRACT**

The expansion of district heating, the assessment of the impact of heat supply strategies, as well as the analysis of significant heat demand savings require sound decision support at high detail. Data is needed to continuously quantify potentials and costs of measures in the end-use and supply sectors. To improve scientific and practical knowledge regarding heat planning and the economics of future district heating, a heat atlas for Denmark has been developed at Aalborg University. The heat atlas employs a building-sharp database of physical building characteristics, which is used to calculate heat demand and possible savings. The location of each building relative to heat supply technologies is mapped and used for the assessment of supply strategies by potentials, costs and environmental impact. Both elements can furthermore be used to balance investments in supply with investments in energy savings on a local and national scale. The present paper shows examples from recent studies carried out for municipalities embarking on a strategic energy planning process. The access to and the usefulness of a heat atlas methodology is being discussed and implications for planning and the perspectives for future development are presented.

### **INTRODUCTION**

Supply strategies as well as demand side management in district heating are closely related to the spatial nature of district heating and heat demand.

#### **The spatial nature of renewable energy systems**

Whenever a change is to be implemented in the collective heat supply, such as the expansion of existing district heating (DH), the implementation of significant heat savings at demand side, or the formulation of policies and strategies that inflict major changes to heat supply, these measures require a sound data foundation for making decisions.

The spatial nature of renewable energy systems and the need to fundamentally change them with massive investments, new policies and change of behaviour requires a geographical system for data storage, retrieval and analysis of location-based information, which allows for getting answers for questions like 'where are buildings with district heating?', 'what is the heat demand within this area?' or 'how far is this area located from a nearby energy plant?' or 'who will be

able to invest?'. A possible solution for this is a geographical information system (GIS), which incorporates a spatial database, a set of methods for spatial analysis, as well as the capability of supplementing energy system data with e.g. socio-economic or planning data. As the primary focus is on heat demand and supply, this system is here called a Heat Atlas (1).

#### **Origins of heat atlases**

The concept of heat atlases is not new. The oil crisis of 1972-1973 and the UN Conference on the Human Environment (the Stockholm Conference) have triggered the interest in acting on the waste of energy resources, issues of pollution, scarcity and socio-economic risk of the energy system, which at this point was highly reliant on oil, increasingly polluting and progressively less efficient. Denmark, heavily dependent of oil, was left in a state of crisis and vulnerability: high costs of energy affected households and companies, and a negative currency balance had an impact on socio-economy (2).

The country subsequently managed to rid itself partly of their dependency of imported oil. The ministry of trade published an energy plan in 1976, aiming at nuclear power and the conversion of oil-fired power stations to coal. The heating sector was addressed by the expansion of district heating, which in the larger cities was to be based on the co-generation of heat and power. In the years after this first energy plan, regions and towns began to look into heat planning. With the Heat Supply Act of 1979 a legal basis was laid for municipalities and counties to develop heat plans (3), which prescribe the heat supply in a given area. Heat plans were to be formulated for given built-up areas, parts of towns or the like, with homogenous building mass and with similar supply opportunities, the so-called energy districts. For each energy district, there was made an account for the buildings located within, their means of heating, as well as their estimated heat demand. A predominant heat supply was defined, and for newly developed areas a collective heat supply (district heating, later also natural gas) was prescribed. District heating systems had their fuel and technology arranged by means of these heat plans. Hence, the Heat Supply Act was a rigorous and effective means to create many local monopolies for heat supply, to be utilised by publicly or cooperatively owned district heating companies. Because of its geographical nature, the heat plans required a spatial basis of information and

decision-making, the heat atlas. The early heat atlases were based on paper maps and punch-card registers, and converted into computerised planning tools with the advent of GIS in the 80s. The spatial entities were legally binding planning documents, prepared by the municipalities and collected by the Danish Energy Agency. Each year the heat plans were to be revised (4). By means of heat planning, based on spatial data and spatial zoning, district heating grew to be the most popular means of heating, which now covers 50% of the Danish heat demand. At the same time, the heat demand of the Danish building stock has remained constant. The importance of oil in covering the heat demand shrank from more than 90% in 1972 to merely 10% in 2010. This had not been possible without the combination of decentralised spatial planning of heat supply using heat atlases; the introduction of stricter building codes; as well as the general energy awareness triggered by the oil crises.

Since 1990 municipalities are not obliged to prepare specific heat plans, but may develop heat supply by means of a project-based negotiation between administration and utility. The liberalisation efforts in the energy sector further reduced interest in heat planning, and currently municipalities are left without the means to strategically plan local energy systems (5).

An increased awareness of the limitations of fossil fuels as well as recent research projects such as Heat Plan Denmark (6) have moved the subject of municipal heat supply planning to the top of the agenda, and initiatives to combine local climate strategies with local heat supply have led to the development of strategic energy planning in many Danish municipalities.

The objective of this paper is to describe the development of such heat atlases, which allow for the assessment of efficiency measures in the building mass, the expansion of district heating, and the use of renewable energy sources for existing buildings. These heat atlases are to be used for spatial analyses of the choice between these different efficiency opportunities on the pathway towards 100% renewable, sustainable energy systems. The core methods of producing a heat atlas for Denmark are being described, and several cases on the national, regional and local scales are presented.

## **METHOD**

### **Design principles for a heat atlas for Denmark**

Heat atlases represent the geographical heterogeneity of the real world and must reflect e.g. the distribution of the building stock or the distance to infrastructure. A heat atlas must therefore aim for the smallest possible geographical entity, which yields the highest available level of detail: ideally the single building. The single household is the smallest socio-economic entity to affect energy demand. It is also the broadest basis for decision making on consumption, investment in the building stock, and energy-related behaviour.

Heat atlases must furthermore allow for decisions on "how far to go", reflecting the significant difference between theoretical, technical, economic and socially or environmentally acceptable potentials of a technology. Each fraction of the potential comes at a specific cost. The heat atlas must be able to represent the marginally increasing costs of utilising a technology in a continuous way, using the marginal costs as a decision parameter. The marginal costs of a resource, however, are not the same for the whole country: potential resources are geographically distributed by density and availability and therefore different specific costs of utilisation. We consequently need a spatially continuous model, which maps fractions of the total resource base by costs, technical constraints, environmental impact or social consequences.

Heat atlases finally must provide a better basis for making energy systems analysis with computer models. This means that the heat atlas must be able to deliver consistent data on the potentials of a resource, its costs and impact. An example is the assessment of the conversion potentials of individual natural gas heating to district heat (7). To provide a reasonable figure, the less economically attractive portions of the total potential (all buildings with natural gas heating) must be excluded, e.g. by defining cut-off distances or maximal connection costs.

### **Elements of a heat atlas**

Heat atlases are potentially data intensive. They ultimately require the single building as the smallest computational and mappable unit {{68 Ravetz, Joe 2008}}. Fortunately, in Denmark there is a national system of public databases, which describe individual buildings, businesses, agriculture and the civic population using unique address and geographical locators. This greatly facilitates the development of heat atlases, which in most other countries only can be based on aggregated statistics, surveys, aerial imaging or detecting, or remote sensing in combination with spatially coarse statistics or census data. Using the national register of buildings and dwellings (BBR), it is possible to locate by address coordinates each individual building by age, use, area, heat supply and up to 60 other individual data(8). The register is updated daily. In addition, an increasing proportion of Danish buildings have been subject to energy audits in recent years, which can be used to perfect a model of the current and future heat demand. A great challenge however is the accuracy of the BBR, which is based on house owners' input. It can be observed, e.g. that the number of oil boilers is greatly overestimated, since not all house owners have reported the replacement of such by a biomass boiler or the like. Also, a higher quality level can be observed for urban areas compared to rural municipalities, which may reflect the effort made in public administration to achieve accurate registers. Another uncertainty is that the heat demand of a building still needs to be calcu-

lated using national averages of specific heat demand for types and age classes of buildings. These problems are about to be addressed though, as new legislation requires the registration of heating means and annual heat demand.

Hence comprising the best possible basis for mapping heat demand, these large scale empirical and register data need to be organised in a way, which allows access to the smallest entities (the single building) as well as its geographical relation to other phenomena such as district heating networks, energy supply units, local renewable energy sources, or plain administrative units. In other words, a heat atlas must represent the complete supply chain of primary energy to end-use heat demand. This is imperative because buildings of the same characteristics may receive district heating from different sources, or vice versa.

Another central element of a heat atlas is the ability to support spatially explicit analyses for actual locations, for spatial distributions, distance between phenomena or a spatial overlay of occurrences, all at the highest possible degree of detail.

Finally, the heat atlas must contain costs of implementing heat savings, district heating installations and utilising renewable energy. Costs can be defined as direct or marginal costs, as well as operation and investment costs, and should be associated to actual amounts or fractions of resource utilisation. This requires the link between the models that describe the energy performance of buildings with scenarios for efficiency measures and the connection to district heating grids, with economic analysis of these, for individual buildings.

#### **Technical implementation**

Technically, the heat atlas is an integrated spatial database with associated analysis tools. As software for the GIS database and analysis ESRI's ArcGIS version 10 has been chosen, which offers good analytical capabilities and data connectivity. The integrated spatial database is designed using the File Geodatabase, which allows for efficient handling of large datasets in the ArcGIS 10 environment. An open-GIS interface can be programmed, so that the Heat Atlas can be made available for project partners, e.g. by a Web-GIS.

Various thematic data are contained, such as building points, network lines, and supply or planning areas. For each of these themes there is a geometrical representation (point, line or polygon) as well as associated attribute or descriptive data. The spatial database also comprises a geographical structure by means of hierarchy (administrative or supply boundaries) or by describing vicinity or neighbourhood.

Regular updates are crucial. The updating rate depends on the budget, but yearly updates should be aimed for. The main component is the BBR extract,

which comes at a cost of 1,000 €. Other components are either available from the public domain or from the National Mapping and Cadastral Agency (9) by means of an agreement with Danish governmental institutions such as universities.

#### **USING A HEAT ATLAS FOR MUNICIPAL HEAT SUPPLY AND SAVING STRATEGIES**

Many Danish municipalities have embarked on a process of strategic energy planning. Central elements are a continuation of heat planning, typically seeking to expand DH, as well as a more recent tendency of identifying saving potentials in the built environment, a result of the energy saving agreements in many municipalities but also the supply sector. This is also of relevance for the newly agreed EU directive on energy end-use efficiency, as well as other legislation in this field. As a case the municipality of Ballerup has been used, located in the Copenhagen area.

#### **Expansion of DH systems and conversion of natural gas areas**

High natural gas prices and the desire to gain independency from fossil fuels currently drives the conversion of areas, which after the exploration of natural gas in the Danish sector of the North Sea were planned to have individual natural gas heating, to district heating. District heat emits now marginally less CO<sub>2</sub> than individual natural gas, and can most often be supplied by existing district heating networks at a lower cost to the consumer. The project "Heat Plan Denmark" described by means of a heat atlas potentials, costs and the overall feasibility and policy requirements for such a conversion at a massive scale, which could bring the share of district heating from 46% of the net end-use heat demand to 60 – 70%. The study found good feasibility of doing so, and it pointed out possible synergies between modern district heating networks and low-energy buildings (6,10).

Based on empirical cost data for the expansion of district heating, a cost model for the expansion of district heating systems into neighbouring natural gas areas was developed, separating the economically attractive potentials for new district heating from the larger technical potential (7).

For Ballerup municipality a heat atlas was developed using a BBR extract of 11,000 buildings. By means of spatial overlay analysis the attribute data of the heat atlas, such as building size, type and ownership, current heat demand and possible savings and their associated costs, heat supply and heating installation, were transferred to a topographical feature dataset that describes built-up areas of different characteristics. This built-up dataset is part of the national public topographical database FOT. The result is a description of heat demand and supply in neighbourhood- to quartier-sized areas, which can then be used to formulate heat supply

strategies on a municipal level. A major advantage is that this process relies entirely on frequently updated public data, which can automatically be converted to a heat supply map for continuous heat planning.

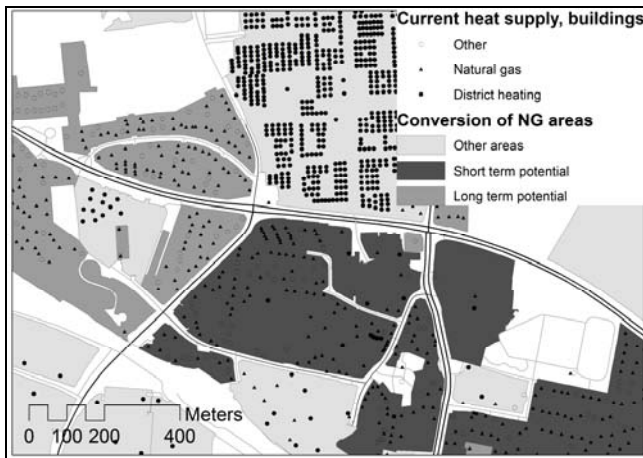


Figure 1: An example of the combination of heat atlas data and built-up areas for the identification of natural gas areas and their conversion potential on the basis of current heat supply and location.

### Extending the current DH grid

The cost of extending DH grids into areas without collective heat supply or areas currently heated with individual natural gas requires the assessment of the investment costs in order to separate the technical from an economic potential, leaving out those buildings, which are out of reach, be it because of high individual connection costs or little contribution to the supply potential. This requires a model first developed for Heat Plan Denmark (6) and described in Möller and Lund (7), which composes required investment costs for each building from transmission, distribution and connection cost components, which are calculated using spatial data such as the attributes of the single house, the built-up area it is located in, as well as the distance to the nearest existing DH infrastructure. The result is a calculation of costs for each building, which is converted into a cost-supply curve of the future DH potential, see fig. 2.

### Mapping energy end-use and saving potentials

Future energy systems based on renewable energy supply will not be feasible without significantly reducing the energy end use for heating, electricity and transport. Focusing on the heat demand, studies (11) agree on a potential of roundabout 50% reduction of the present heat demand in the Danish building mass. This requires substantial investments in the existing building mass, as new buildings, even if they were built as ultra-low energy buildings, only yield an annual saving potential in the order of 1%, depending on the building activity.

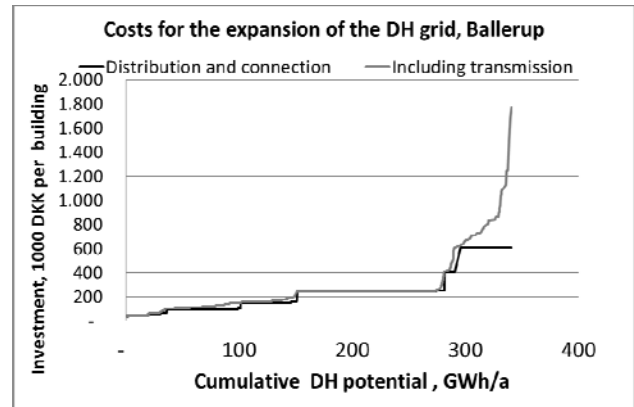


Figure 2: Investment costs required for the establishment of DH grids to all buildings not heated by DH in Ballerup municipality. The cost-supply curve allows separating buildings currently out of reach from the technical potential defined by area.

In order to map the heat savings potential in a given area, the heat atlas comprises the savings and the associated investment costs for each building by its type and age. Investments are given as direct investments, if a building was to renovated only for the sake of saving heat, or as marginal costs, which only describe the additional costs of insulation, better windows and ventilation in case the building is to be renovated anyway. The marginal costs are usually half the direct costs, depending on the building type and age.

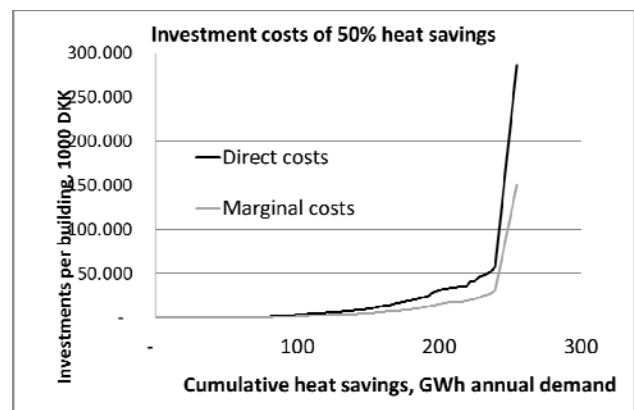


Figure 3: Cost-supply curve of 50% heat savings in the Ballerup building mass. 25% of the buildings can be retrofitted for 200,000 DKK if renovated anyway, while if accepting a sum of 500,000 DKK per building, the potential for heat savings in the municipality climbs to 30%, which is 15% of the present heat demand in the municipality.

As the heat atlas not only contains information on the head demand and the savings, but also many additional data such as building type, ownership and the location relative to the energy supply system, it is possible to assess end-use energy efficiency measures in relation to energy supply. This may allow for the differentiation of end-use measures by ownership, e.g. favouring public housing in schemes which primarily address social problems; or by heat supply, e.g. taking into

account the diversity of heat sources in the Danish district heating systems, where the actual share of fossil fuels is 0-100%. This way, some DH areas may be allowed for higher investments if using solar or geothermal energy, while allowing for less ambitious heat saving measures. This may be interesting in areas where the property values are low, and investments are more likely to be carried out in collective DH systems than in individual homes.

### **Supply strategies and demand side management**

It follows from these applications that not all energy saving potentials in the existing building mass are economically feasible in the shorter or longer term. If assuming that the potential to carry out heat savings of 50% in average is fully utilised in the municipality, this represents substantial savings also for the DH grid infrastructure and for the supply system in particular. The DH grid can be carried out using smaller dimensions, and even the temperature levels can be lower. If the problem with legionella in domestic hot water installations can be dealt with, the temperatures can be as low as 50 degrees C forward and 30 degrees C return. These low temperature levels mean that the heat losses in the DH grids can be substantially reduced, and, more importantly, the low forward temperatures allow for much higher efficiencies of heat supply units, e.g. if the heat supply is being based on large-scale heat pumps, or on organic Rankine cycle plants. Even with present technologies such as back-pressure steam turbines in waste incineration plants the electric efficiencies of such plants can be raised several per cent-points, allowing for much better utilisation of the waste resource. Hence substantial end-use savings are essential to future district heating grids, if present problems such as the tariff structures of DH, where high fixed connection prices lever few incitements for heat savings, are overcome.

### **CONCLUSIONS**

This paper addresses the issue of heat atlases for mapping heat demand and supply in energy systems, which ultimately will be based on 100% renewable energy. First, renewable energy systems are discussed in a geographical context. It is made plausible that geospatial methods are required, which map energy demand and supply geographically. The historical context and existing research in this field is presented, along with relevant parts of Danish energy planning development. The paper then elaborates on the required functionality and the elements needed to build geographically detailed heat atlases, which allow for spatially explicit analyses of future renewable energy systems. Emphasis is here on a rigorous analysis of the energy end-use savings, their potential, costs and location relative to the supply system. Finally, a range of actual applications is presented for the municipality of Ballerup and placed in the context of the general idea of this paper. The examples comprise the conversion of individual natural gas to district heating, which is assessed using a novel method of spatial analysis; then the process of extending present DH infrastructure using the heat atlas is described; next, the heat demand saving potentials are being drawn, and the economically feasible share of the heat savings is being documented. Finally, it has been discussed how end-use savings can go hand in hand with the development of DH grids and supply systems in a demand side management plus supply side planning approach.

In conclusion, there are many tasks on national, regional and local levels, where heat atlases can improve planning by the highly detailed data provided by heat atlases. The data prepared by means of heat atlases has been used for a series of research projects, and there is good potential for further research. The practical use of heat atlases has been demonstrated for several development projects on local and national levels. Further research in this field should address a better spatial integration of heat atlases, as well as the development of localised heat demand models.

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