D3.1 – Analysis of Network Layouts in Selected Urban Contexts

Fifth generation, low temperature, high exergy district heating and cooling networks

FLEXYNETS

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Table of Content

1 Introduction

The objective of the analysis described in this report is to identify the optimum layout of the district heating and cooling (DHC) network in the built environment. In other words, ‘What would be a suitable path for the network through a town?’ While the focus is on the low temperature FLEXYNETS concept, a comparison with ‘traditional’ district heating is also carried out.

It should be noted, that the analysis does not include detailed hydraulic aspects, since the purpose is to analyse and compare the layout of the network in a bigger perspective. More detailed hydraulic calculations of the FLEXYNETS concept are carried out in other tasks of the project, where some of the cases within this deliverable will be used as input cases. In this way, the analysis in this report can be seen as a pre-study of the layout of the network.

The report consists of two ‘subtasks’. First, an analysis of different settlement typologies for which the DHC networks are to be considered. A range of town sizes (small, medium and large) including different types of settlements are analysed to create reference scenarios for further analyses of the FLEXYNETS concept (also beyond this report). Secondly, different network options are investigated – in terms of geographical layout as well as thermal and financial properties – in order to provide recommendations for the layout of such FLEXYNETS networks.

2 Subtask 1 – Reference Towns

Different town sizes as well as different settlement typologies within the towns are investigated in order to consider how the heating and cooling demand is influenced by both size of the town and the typical use of the urban areas. The purpose of the reference town analysis is to create a list of possible environments in which the FLEXYNETS concepts can be simulated. The overall goal of the reference town analysis is to identify some basis conditions for the feasibility of the FLEXYNETS concept by analysing different layout of the network.

Each settlement typology (i.e. specific type of urban area) and the associated properties (such as heat demand density) can be used separately to investigate the FLEXYNETS concept in different contexts. Alternatively complete 'synthetic towns' can be generated by combining typical (average) settlement typology values for towns of similar sizes (e.g. how much of the town area each typology covers).

A comprehensive analysis of reference towns has been carried out based on extensive Danish references and databases. The used methodology is explained in the following sections and a more thorough explanation of the complete methodology approach is described in a background report[1]. Reference towns from countries in other parts of Europe are subsequently analysed in a likewise manner for comparison purposes.

2.1 Categorization of Reference Towns

The town sizes have been categorised in four different groups since big cities can have significant deviations compared to 'large towns':

Small towns: maximum 20,000 inhabitants and not smaller than app. 5,000 inhabitants

Medium towns: more than 20,000 inhabitants, but smaller than 'large towns'

Large towns: more than 100,000 inhabitants

Big cities: more than 1 million inhabitants

In section 2.2 the analysis from Denmark is elaborated. One of the tasks in the analysis has been to divide the reference towns into settlement typologies. This allows for a more detailed analysis of the FLEXYNETS concept since the typology affects the layout and feasibility of the network (compared to average values for an entire town). Four main categories were identified:

1. Residential
2. Public and Institutions
3. Commercial
4. Other

The methodology includes 10 different settlement typologies. This is due to the fact that some of the main categories comprise significant varieties. 'Residential' contains several different heat demand densities depending on the size and location of the buildings.

The typologies are described further in Table 1 and in the paragraphs following the table.

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[1] 'WP3_D3.1_part1_20160705_FLEXYNETS-Settlement-typologies-reference-towns'. Interested readers may ask the authors for this background report.

Table 1 – Overview of the FLEXYNETS Settlement Typologies.

Main categories	Typology	Description
Residential	FL ST 1	Villages
	FL ST 2	Single-family houses
	FL ST 3	Multifamily houses, small and large
	FL ST 4	Residential block development (possibly incl. shops/offices)
	FL ST 5	Row development, high-rise for residential
	FL ST 6	Shopping streets and centres partially mixed with residential
Public	FL ST 7	Public institutions (education, health, etc.)
Commercial and industry	FL ST 8	Light industry (business and commercial areas)
	FL ST 9	Heavy industry
Other	FL ST 10	Miscellaneous (recreational, nature, churches etc.)

2.1.1 Residential

There are six settlement typologies in the residential category. Since areas for shopping purposes are often mixed with/in residential buildings, this category also contains typologies including shopping centres.

FL ST 1 represents village areas with very low plot ratio[2], approx. 0-20 %. These residential areas represent rural villages, small town areas and leisure houses. This typology is also used in medium and large towns to describe areas with low plot ratios.

FL ST 2 represents single-family houses in the chosen town examples.

FL ST 3 is a merge of the typologies for multifamily houses, to include both small multifamily houses and larger multifamily houses.

FL ST 4 represents block development, where the purpose can be both residential for block multifamily buildings and some multi-use of the block buildings, e.g. shops and offices mixed with residential. Block developments can be buildings that are partially or completely built together, and the buildings typically have at least two stores.

[2] The plot ratio is obtained by dividing the gross floor area of a building by the considered ground area within which the building is erected.

FL ST 5 represents row development and high-rise buildings for residential purposes. As in FL ST 4, the buildings can have multiple functions, and can be a mix of offices, shops and residential. The plot ratio is at least 70 %. In Denmark, these types of buildings can be found through the municipality planning by specific use, categorized as 'storey buildings'.

The typology can be described as row development or cluster development for large multi-family buildings and high-rise residential buildings. The building typology may be located close to the town centre or in the outskirts of the town.

FL ST 6 represents areas allocated (mainly/partially) for shopping purposes e.g. big or small shopping centres (and/or some offices) with or without a residential share. Areas for shopping streets and shopping centres etc. are often required to maintain a certain percentage of residential area within the buildings and/or general area. Therefore, the residential share is not constant in this typology.

Even though the building heights may be lower than in FL ST 5, the plot ratio can be higher, e.g. from 80 % and above, since the buildings may be more densely located. This typology often represents 'downtown'. Since historical old buildings have shown sometimes to be located in between newer buildings and therefore cannot be separated in individual areas, these may also be included as part of this typology.

2.1.2 Public (Institutions)

FL ST 7 represents all public institutions such as hospitals, schools, town halls and other public workplaces and offices. These buildings are possible to sort out by the specific use in the municipality planning in Denmark. In other countries, there might be municipality planning or local planning available. Alternatively a manual check e.g. on google maps can be used to locate these buildings areas.

2.1.3 Commercial and Industry

FL ST 8 is the category for light industry and business, including industrial office buildings. These areas may also include some shopping centres outside residential areas. The plot ratio varies significantly from light industrial areas to areas with office and commercial use only.

FL ST 9 represents heavy industry, which means industries with a high demand for heating and/or cooling. This category is for companies with their own boiler facility for production purposes and for instance warehouses with a high cooling demand. The data does not include the demands for all the industrial processes, which means that the heat demand in this typology does not deviate significantly from the others typologies.

2.1.4 Other

FL ST 10 is the category representing recreational areas, e.g. parks, and other facilities with very little or no demand within the town or city boundary. Many different buildings and areas are included in this category, ranging from sports facilities such as a tennis courts, to marina and camping areas, as well as areas for technical facilities. Though this should not be the main target for establishing the FLEXYNETS concept, it still may be feasible to include some single buildings from FL ST 10 if FLEXYNETS is applied in adjacent typologies.

2.2 Reference Towns in Denmark – Heat Demand

A range of different town examples have been analysed ranging from small towns to large city. By splitting each town in different settlement typologies each with its own characteristics, it is possible also to consider the relevance of applying the FLEXYNETS concept only on a selected part of the town area.

The main sources for the analysis of the Danish reference towns are:

- The Heat Atlas for heat demand and data on building level for all buildings in Denmark
- The Danish Statistic for no. of inhabitants[3]
- Municipality planning for town boundary, area and classification of typologies

In the work of the Danish reference towns, the following towns and cities have been used in the analysis:

Table 2 – Danish reference town categories with representative examples incl. no. of inhabitants and town area.

Town	Inhabitants	Town area [km^2]
Nibe	5,143	2.9
Hadsund	4,913	4.1
Thisted	13,198	8.3
Average, small towns	7,751	5.1
Sønderborg	27,419	13.3
Fredericia	43,400	32.4
Randers	61,664	32.0
Roskilde	49,297	21.7
Horsens	56,536	27.9
Average, medium towns	47,663	25.5
Aalborg	132,578	60.5
Odense	173,814	78.9
Aarhus	261,570	97.7
Average, large towns	189,231	81.1
Copenhagen	1,141,694	259.6
Average, big cities	1,141,694	259.6

An example of a medium sized reference town is Sønderborg, which is a middle size town with almost 27,500 inhabitants. The town is located in the southern part of Denmark. The division of typologies within Sønderborg is seen in Figure 1.

[3] www.dst.dk

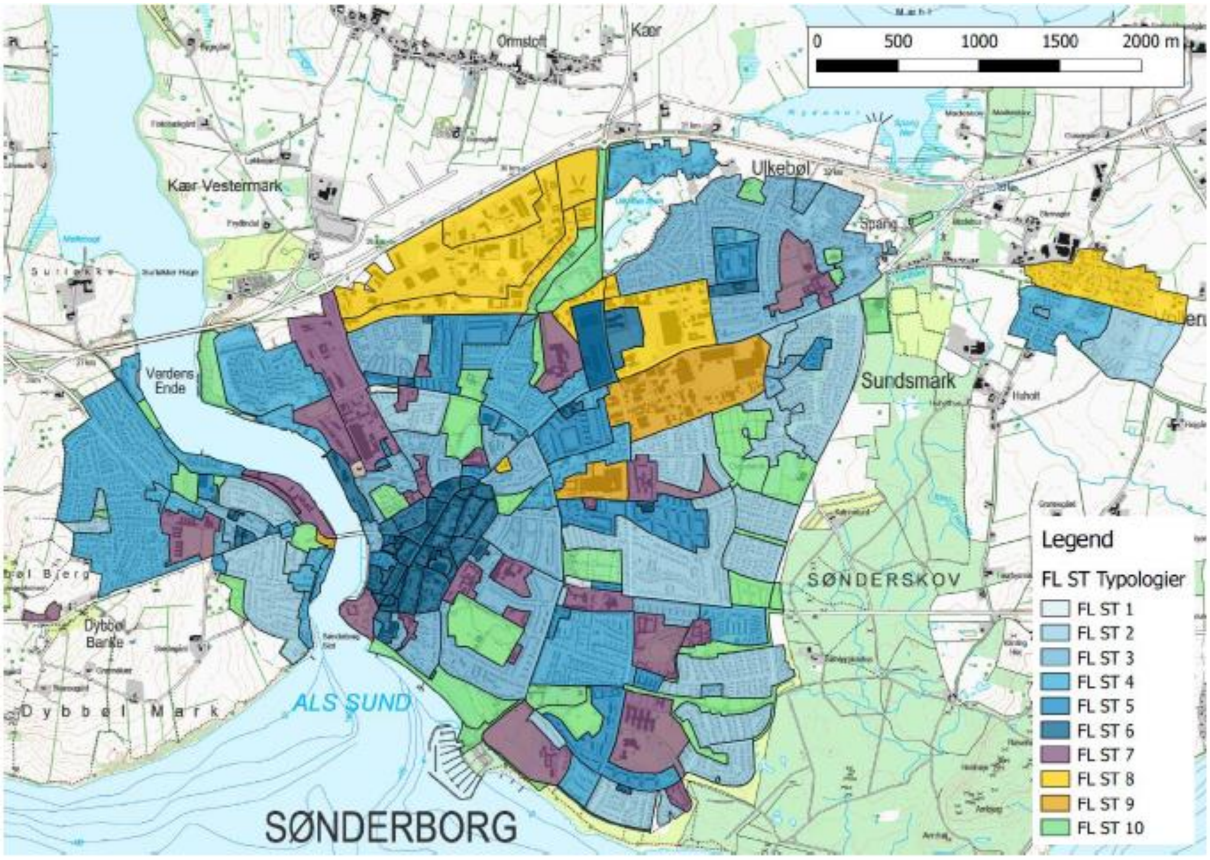


Figure 1 – The town of Sønderborg divided into the 10 settlement typologies in the FLEXYNETS project.
(Source: Background map from Geodatastyrelsen; typologies by PlanEnergi.)

2.2.1 List of Data

From the Heat Atlas and the building register in Denmark the following main data can be found together with data on type of heat supply, year of construction, cadastral number, etc.:

- Settlement use – e.g. through municipality planning/maps
- No. of floor levels
- Heated area of buildings in m^2
- Ground area of typology/quarter in km^2
- Heat demand of buildings or area
- Cooling demand of buildings or area

For Danish towns the heat demand on building level is known due to the Heat Atlas database, which contains data on heating installations (i.e. fuel type and demand), and building data from the building register in Denmark. The data on building level is summarised within each typology area.

2.2.2 Results on Heat Demand in Danish Reference Towns

By using the described method, the division into different settlement areas within the town has been made 'semi-automatic'. This way it has been possible to base the analysis on a range of town examples. The main results are described in the following sections as average values for the three categories small, medium and large towns. Denmark only has one city that falls under the 'big city' category, Copenhagen. The analysis for Copenhagen is a bit different from the rest of the towns (due to the data availability) and is therefore handled in a section on its own.

2.2.3 Average Annual Heat Demand per km² Ground Area

In Figure 2 the average annual heat demand in GWh/km² is seen for each typology provided for small, medium and large towns respectively. Note that the area in km² refers to the ground area of the town (not building floor space) unless otherwise stated. The values are weighted according to area. This means that if one town only has one small entry for (i.e. one minor example of) a certain typology, then it does not count as much in the final average as another town which has a lot and/or larger entries for the same typology.

It is seen that the first four typologies (representing different types of low density residential areas) are somewhat similar just as typologies for high density residential areas (FL ST 5 and FL ST 6) are comparable. The same applies to the two 'industry-typologies', FL ST 8 and FL ST 9.

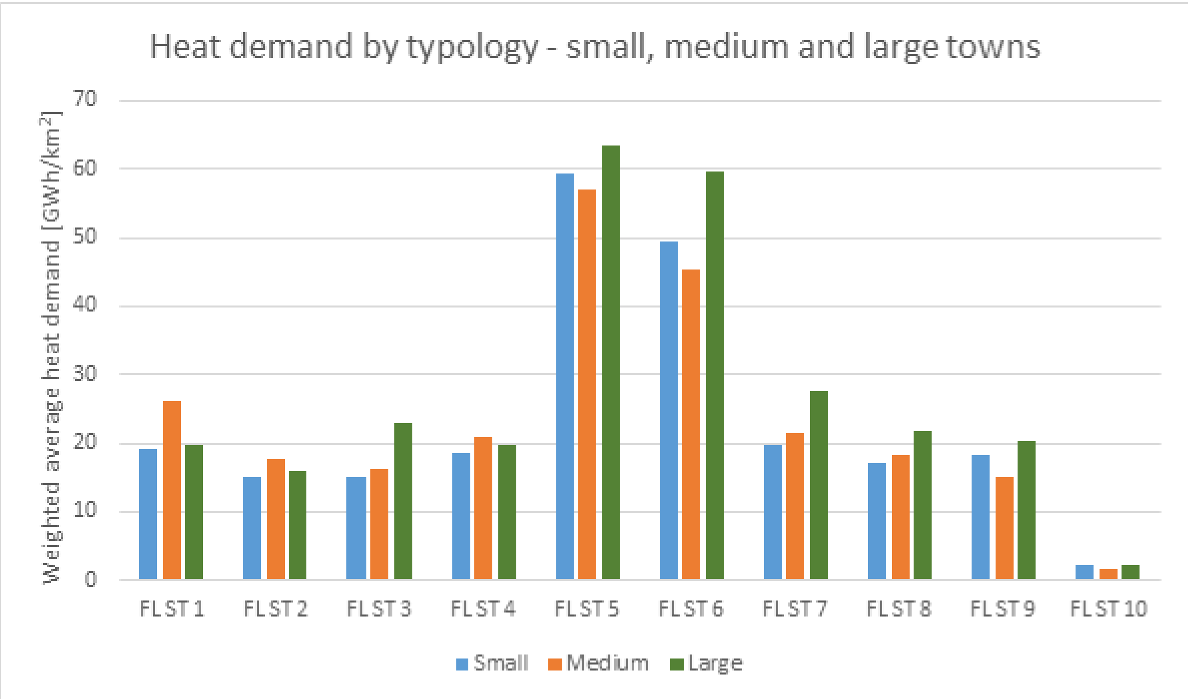


Figure 2 – Average annual heat demand per km² by typology for small, medium and large towns.

Figure 3 is created by merging the typologies representing similar values and similar categories to give a simpler typology categorisation than in Figure 2. In general, it is seen that the *density* of these simplified typology categories increases somewhat as the town size increases (i.e. the heat demand per km² increases). This may be due to four factors:

- Single-family households typically have smaller gardens when the town is big.
- 'High-rise buildings' are constructed higher for large towns.
- Large towns often include older buildings.

- The definition of an areas typology code may differ from municipality to municipality. (For smaller towns the lower limit for an area to be defined as 'high density residential' may be lower.)

Due to the limited specific data for big cities, the categories 'Residential' and 'Industry' can only be split up for small, medium and large towns.

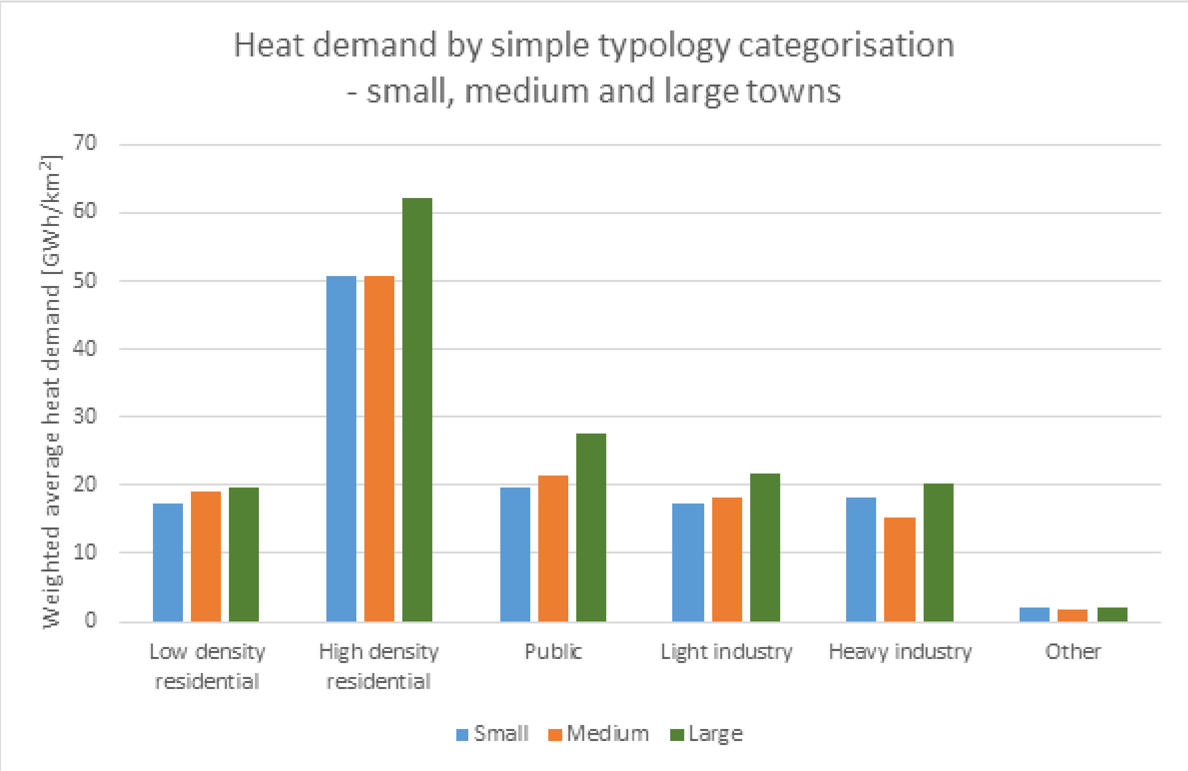


Figure 3 – Average annual heat demand per km² for small, medium and large towns with simplified typology categorisation.

2.2.4 Demand Distribution by Typology

Even though the values for 'low density residential' is small compared to 'high density residential' in Figure 3, the total demands depend on the actual area of the given typology. Figure 4 shows the share of the simplified typology categories for small, medium and large towns.

Combining Figure 3 and Figure 4 with a given town's size can then be used to estimate the demand for each (simplified) typology category in the town.

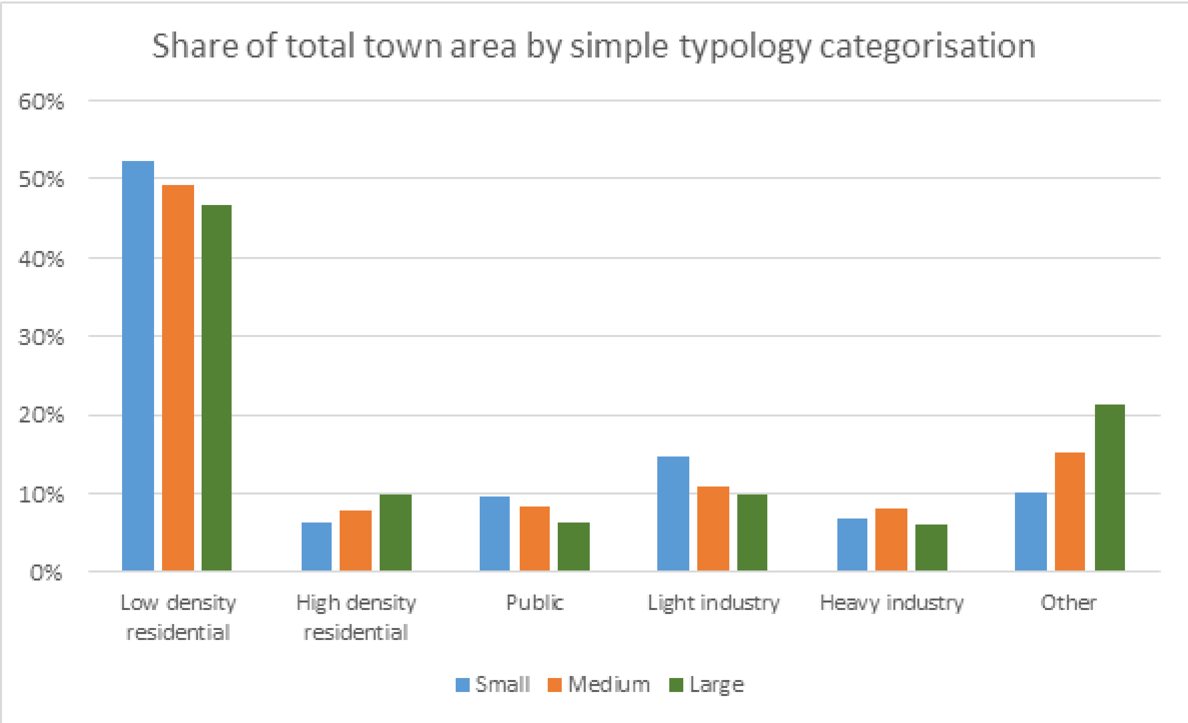


Figure 4 – Distribution of town area by (simplified) typology categorization (i.e. some are merged) for each town size.

Figure 5 shows how much of the total demand each typology represents. When grouping typologies in the same way as done in Figure 3 by using colours representing this simplified categorisation, it can be seen that even though the specific typology shares differ significantly, there are clear similarities when it comes to the share of each category (colour).

It is seen that even though FL ST 1 is somewhat higher for medium size towns in Figure 2 compared to the other town sizes, this does not affect the total result much since FL ST1 only corresponds to a small share of the total demand for medium size towns.

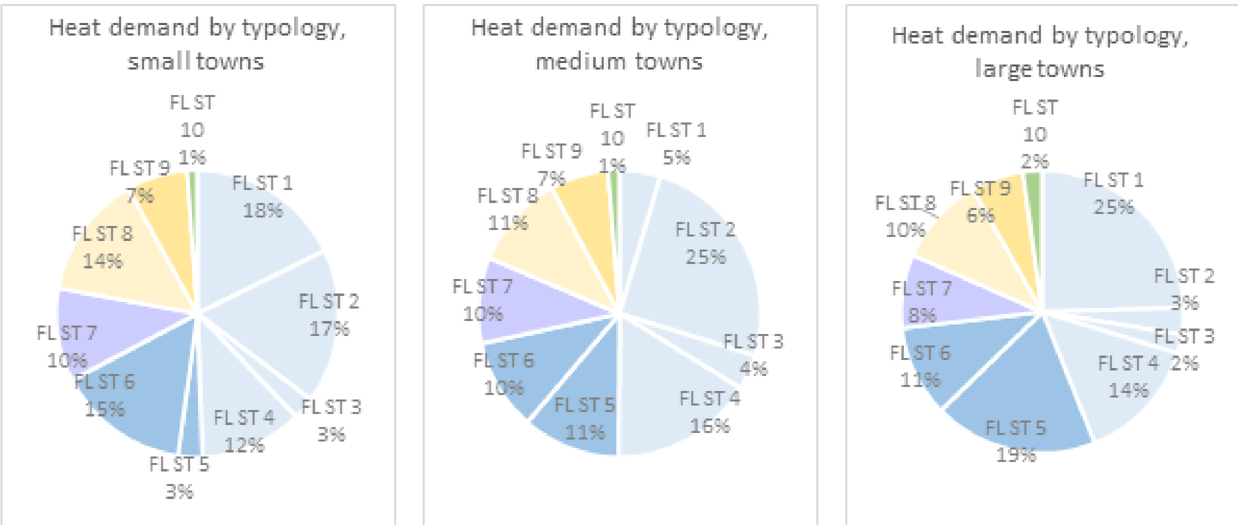


Figure 5 – Heat demand distribution by settlement typology for small, medium and large towns.

Another way to display the similarities between the typologies in the different town sizes is seen in Figure 6. This way it is possible to determine how significant the tendency is towards higher density when the town size increases. Similarly, it is possible to determine the trends regarding the share of each demand category, as the town size increases.

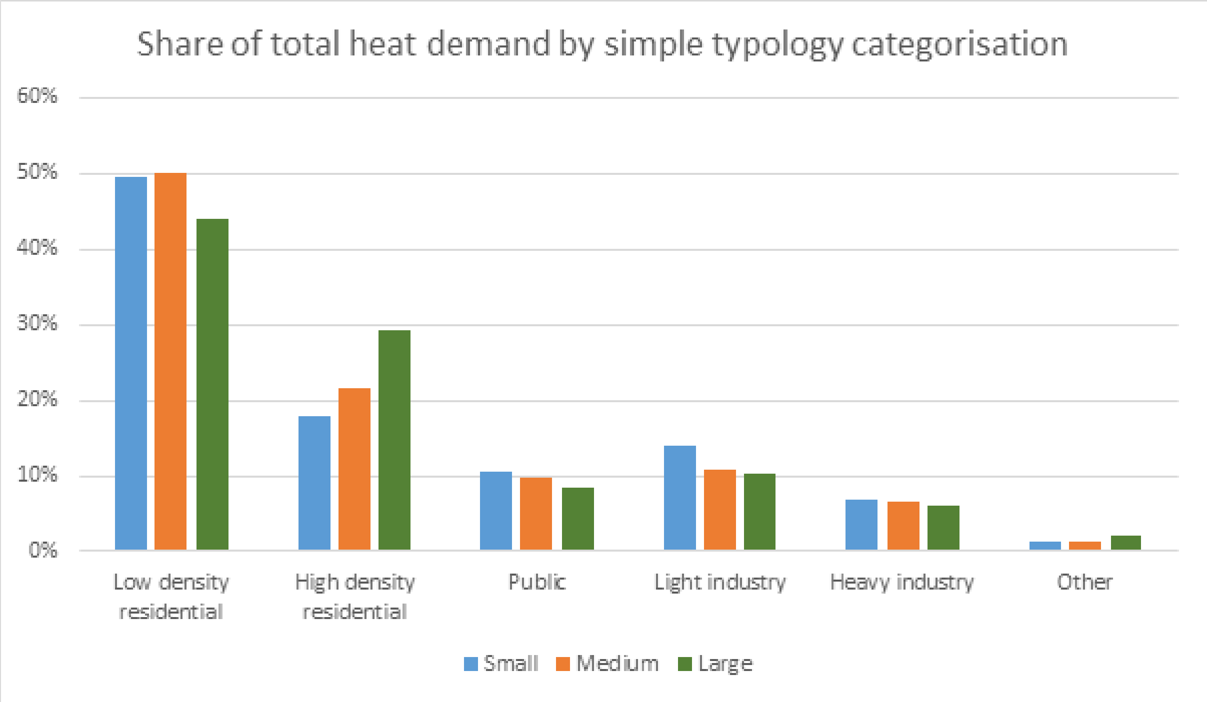


Figure 6 – Total heat demand distribution for each town size for a simplified typology distribution (i.e. some are merged).

2.2.5 Big Cities Compared to the Other Categories

Since the data for big cities is not available in equally high resolution (especially residential and industry), it is not possible to include the category of big cities in the same format as Figure 2 and Figure 3. In general the number of entries for big cities is limited (since Copenhagen is the sole big city in Denmark), which results in some uncertainty. However the trend towards increasing heat demands per km^2 as the town size increases clearly also applies for big cities (and even seems to be significantly higher for residential and industry).

An explanation for this could be that a big city border is often not where the countryside starts, but an urban area involving lower building density such as suburbs. This means that in the big city data the lower density residential areas (which are often seen in the outskirts of a town) are cut off by the city border, although the areas exist – only further away from the city centre and belonging to a suburb town/municipality. This could explain why the heat demand density for the category 'residential' results in a higher number than the averages for the other town sizes. However, the trend may mainly be affected by the fact that bigger cities can generally be expected to be denser, and that the population difference is quite big between the categories 'large towns' and 'big city'.

Figure 7 shows the share of the heat demand typologies for big cities. When looking only at categories (not typologies) and comparing with Figure 5, similar trends are seen. This is also indicated in the columns of Figure 8.

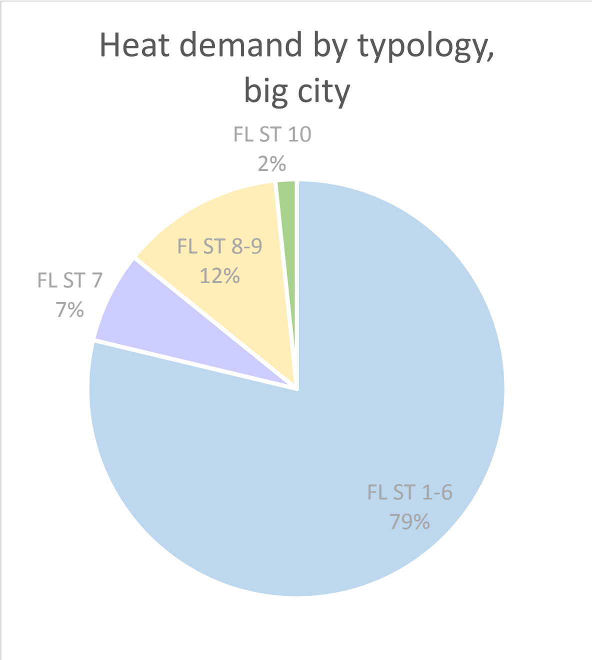


Figure 7 – Distribution of big cities' total heat demand by typology.

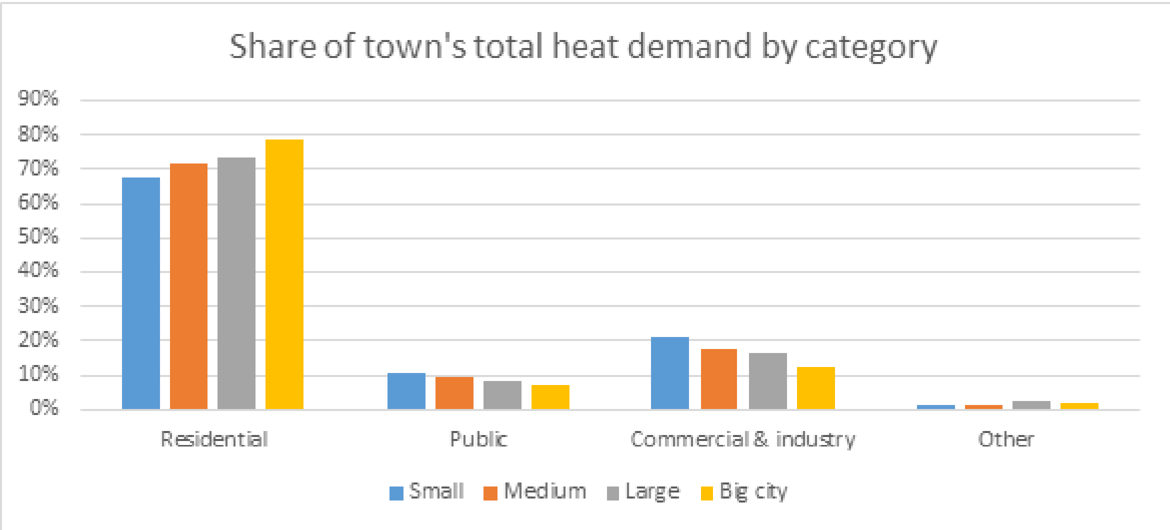


Figure 8 – Total heat demand distribution for each town size in the four main demand categories.

2.2.6 Conclusions for Heat Demand in Denmark

The following points are observed for the heat demand in the chosen reference towns in Denmark:

- The share of each settlement typology in the total heat demands is very similar regardless of whether it is a city or a large, medium or small town. Figure 8 shows that the most significant demand, around 70 %, is in the residential areas, less than 10 % of the demand is in public buildings, 15-20 % in business, commercial and industry areas, and very little demand in the 'other' areas.

- There are differences between town sizes when it comes to the share of each specific residential typology, but this can be evened out by merging some of the residential typologies, since the four 'low density residential' typologies have similar heat demands per km^2 ground area.
- Not only does the *share* of dense residential areas grow, as the town's size increases, but the *density* of these typologies also increases somewhat.
- The uncertainty increases with the ambition for the level of detail since towns are not exactly alike in reality. Any real town will therefore deviate from average values.

To include also other types of towns than the Danish examples, examples from other countries have been investigated as well. It has not been possible to use the same methodology as for the Danish towns, so for each town the used methodology is described.

2.3 Reference Town in Germany: Ludwigsburg

Ludwigsburg has about 92,000 inhabitants and is located in the southwest of Germany. Ludwigsburg has a dense historical city centre with an old building stock, out of which many buildings are under cultural heritage management. The fact that Ludwigsburg used to be the capital of the Kingdom of Baden-Württemberg during the 18th century can be seen throughout the city and its structures. During the 20th century, some smaller villages (e.g. Ludwigsburg-Grünbühl, Ludwigsburg-Oßweil and Ludwigsburg-Hoheneck) were also included to the city of Ludwigsburg, so that in some parts, former historic village centres exist. Hence, there are clearly some differences compared to the Danish examples.

Figure 9 – Location of Ludwigsburg in Germany. (Source: map by NordNordWest under Creative Commons by-sa-3.0 de licence)

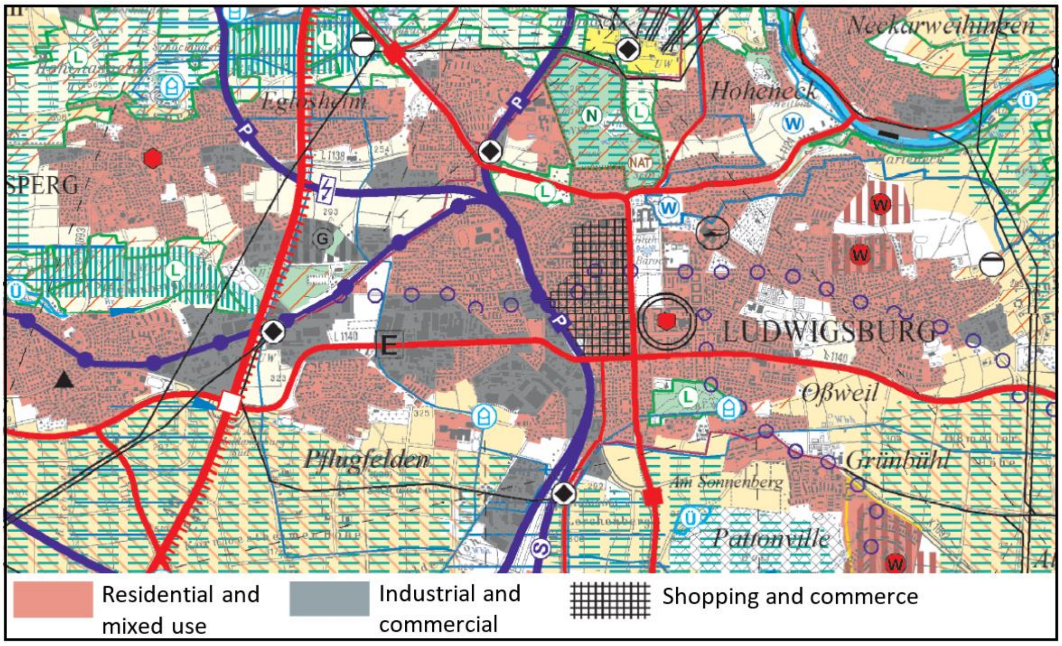


Figure 10 – Regional plan Ludwigsburg. (Source: Verband Region Stuttgart.)

Today, Ludwigsburg is representative for the economically strong region of Stuttgart, including many retail trade and service companies as well as manufacturing companies, often as part of the automotive industries supply chain.

2.3.1 Approach

For the classification approach according to the typology proposed earlier within this document, different data sources were available. These included 3D building and cadastre data (building usage and age). Unfortunately, this information was not sufficient to conduct a block/quarter-wise grouping according to the proposed typology. Because of this, a manual approach was chosen using Google Earth Pro were a 3D city model for Ludwigsburg is available. There the building typology on a block/quarter level (number of storeys, plot density, row housing yes/no, etc.) was determined visually. This approach was time consuming but feasible. Thereby the distinction between single and multifamily houses is partly difficult. Public buildings and non-residential buildings were also determined in that way. Especially for those buildings, detailed information about the usage (e.g. schools, hospitals, wholesale, industry, etc.) can be found with Google Earth and Google Maps.

With that procedure, different zones according to the specific typology were created as polygons (see Figure 11). For further processing, those polygons were exported as *.KML files containing the geocoordinates and additional information. These coordinates were further processed and then imported into the SimStadt environment, a tool that calculates heat demand based on CityGML and cadastre data.

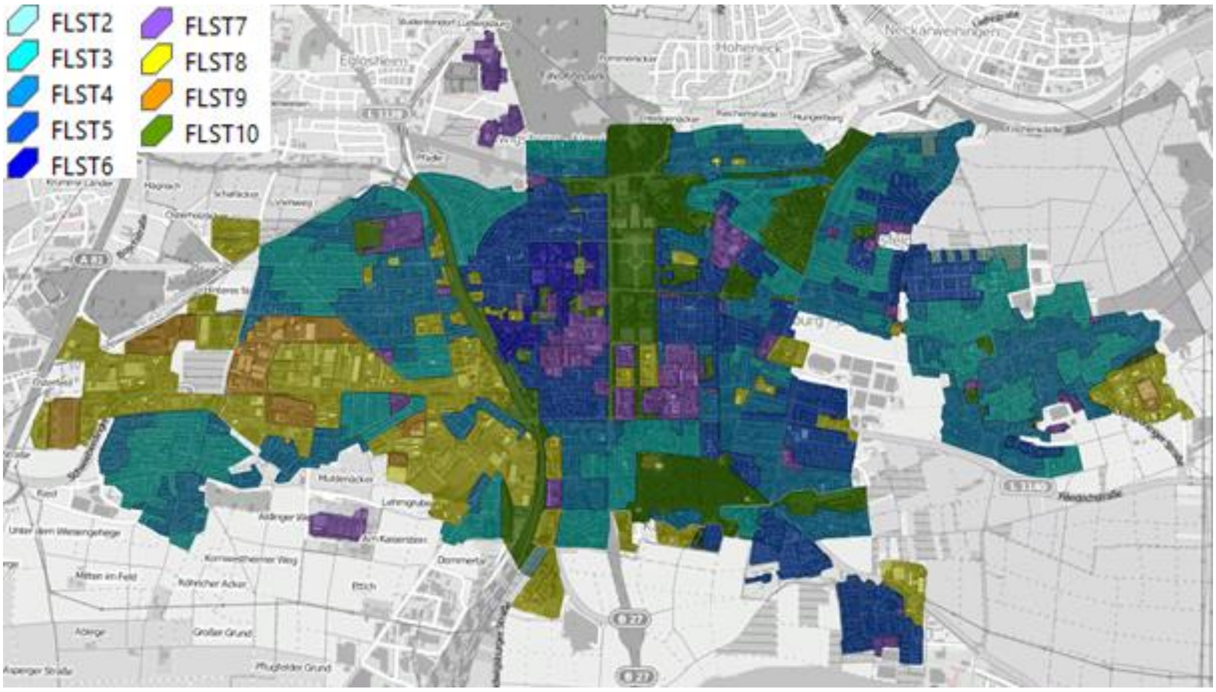


Figure 11 – Different zones of Ludwigsburg according to building typology. Source: OpenStreetMap.

2.3.2 Heat Demand Calculation Utilizing SimStadt

3D-building models can be generated by using a number of techniques including aerial stereo photo, laser-scanning-data, ground plot data or digital terrain information (see Figure 12). For the heat demand calculation of buildings, in particular the building model of CityGML (www.citygml.org) is relevant.

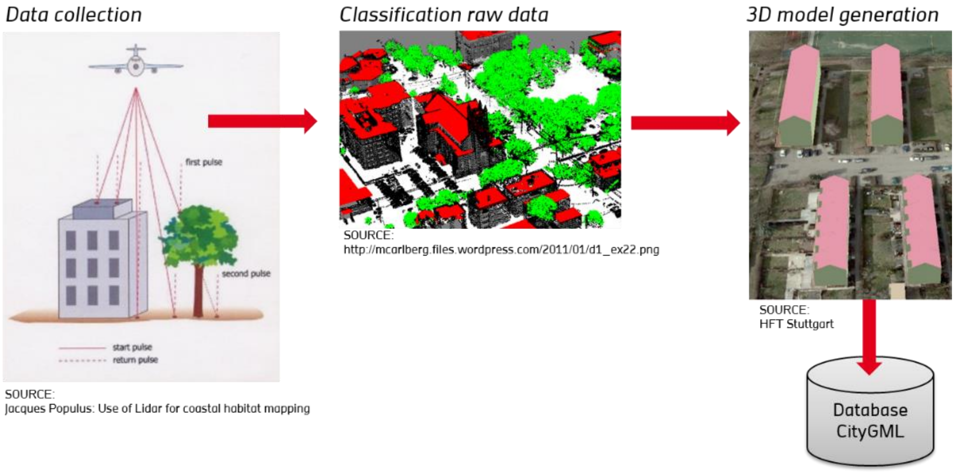


Figure 12 – Data Processing Steps.

Thereby different levels of detail can be available (e.g. LoD1, LoD2, LoD3, or LoD4 – see Figure 13). LoD1 correlates to the CityGML standard. LoD2 adds the roof form to the building level, LoD3 adds the positioning of the front windows and LoD4 incorporates the modelling of the indoor space. In general, this depends on the availability of technical data for the building in question. The minimum data, which must be provided, are the age and the type of use of the buildings. LoD1-models for Germany, for instance, are available since 2013. A complete availability of 3D-models in LoD2 for Germany is scheduled until 2018.

Calculations can be improved by adding information about number of floors, type of building (this can be done by an automatic, geometric analysis), year of refurbishment (or current thermic state), ratio of window surface related to whole frontage and insulation (type and thickness as well as further information about the attic floor and basement).

Based on CityGML Data, the thermal envelope can be determined. CityGML, compared to other 3D vector formats, is standard using information from a flexible, general purpose model. In addition, geometry and appearance information are integrated. The goal of CityGML is to define the characteristics, basic nature and relations of a 3D city model.

The heat transmission coefficients can be determined based on the usage, age and type of building, based on benchmarking data libraries using building typology classifications (see Figure 14).

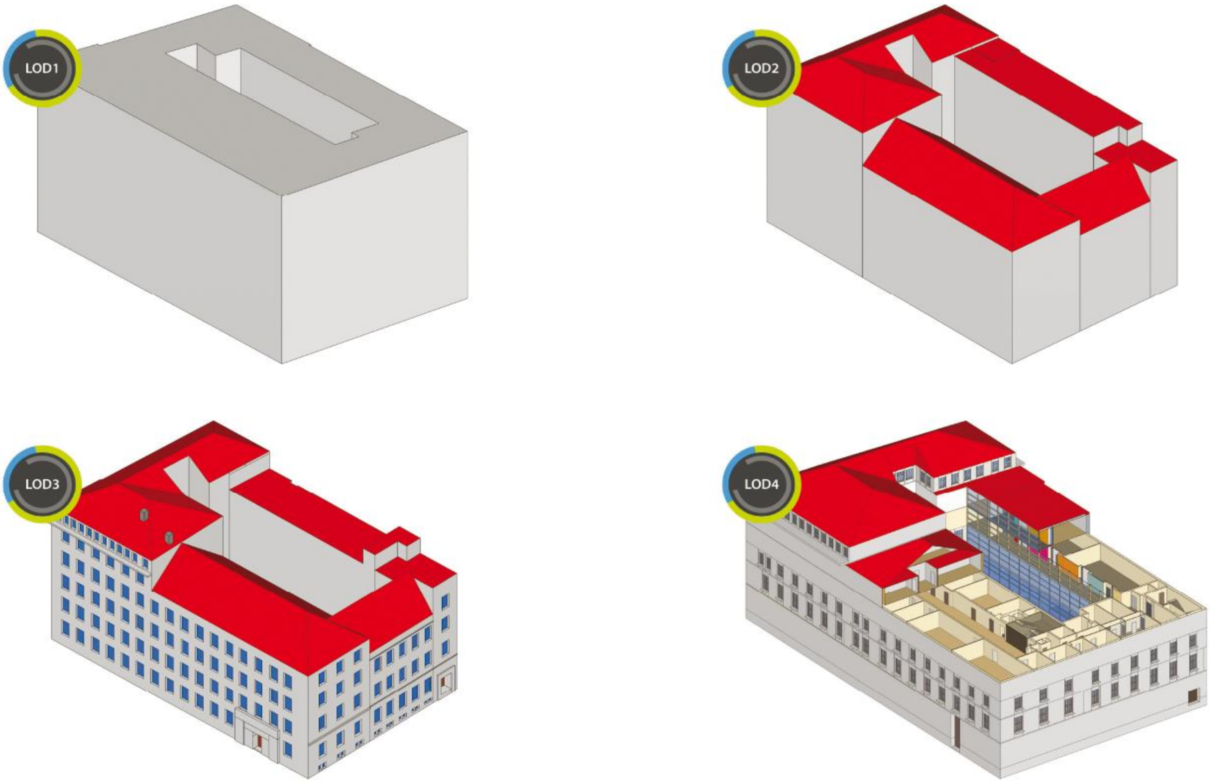


Figure 13 – Different LoD levels of 3D CityGML data.

	Before 1860	1860 – 1918	1919 – 1948	1949 – 1957	1958 – 1968	1969 – 1978	1979 – 1983	1984 – 1994	1995 – 2001	2002 – 2014
Single Family House	Umean ~ 1,9 Qsh ~ 200 – 250	Umean ~ 1,5 Qsh ~ 200 – 250	Umean ~ 1,4 Qsh ~ 200	Umean ~ 1,1 Qsh ~ 200	Umean ~ 1,1 Qsh ~ 150 – 200	Umean ~ 1,0 Qsh ~ 150 – 200	Umean ~ 0,9 Qsh ~ 100 – 150	Umean ~ 0,7 Qsh ~ 100 – 150	Umean ~ 0,5 Qsh ~ 50 – 100	Umean ~ 0,45 Qsh ~ 50 – 100
Terrasse / Row House		Umean ~ 1,3 Qsh ~ 200	Umean ~ 1,3 Qsh ~ 150 – 200	Umean ~ 1,3 Qsh ~ 150 – 200	Umean ~ 1,2 Qsh ~ 150	Umean ~ 1,1 Qsh ~ 150	Umean ~ 0,7 Qsh ~ 100 – 150	Umean ~ 0,7 Qsh ~ 100	Umean ~ 0,4 Qsh ~ 50 – 100	Umean ~ 0,35 Qsh ~ 50 – 100
Multi-Family House	Umean ~ 2,0 Qsh ~ 200 – 250	Umean ~ 1,8 Qsh ~ 200	Umean ~ 1,6 Qsh ~ 200	Umean ~ 1,4 Qsh ~ 200	Umean ~ 1,4 Qsh ~ 150 – 200	Umean ~ 0,9 Qsh ~ 150	Umean ~ 0,9 Qsh ~ 100	Umean ~ 0,8 Qsh ~ 100	Umean ~ 0,4 Qsh ~ 50 – 100	Umean ~ 0,4 Qsh ~ 50
Big Multi-Family House		Umean ~ 2,0 Qsh ~ 150 – 200	Umean ~ 1,4 Qsh ~ 150 – 200	Umean ~ 1,5 Qsh ~ 150 – 200	Umean ~ 1,4 Qsh ~ 150 – 200	Umean ~ 1,5 Qsh ~ 150	Umean ~ 1,1 Qsh ~ 100 – 150	Umean ~ 1,0 Qsh ~ 100		
High Tower					Umean ~ 1,7 Qsh ~ 100 – 150	Umean ~ 1,2 Qsh ~ 100 – 150	Umean ~ 1,3 Qsh ~ 100			

Umean: Mean U-value in W/m².K; Qsh : Average specific space heating demand in kWh /m².yr in Germany

Figure 14 – Building Typologies. (Source: SimStadt documentation.)

To calculate the heat demand for every building, compliant to the monthly balance method (DIN 18599), either default values from the building physics and usage library or corrected heat transmission coefficient and the air renewal rate are used in SimStadt (www.simstadt.eu) and the simulation software INSEL 8 (www.insel.eu). Meteorological data for 15 climate zones in Germany

(DIN V 4108-6, appendix A) containing the mean outside temperature and solar radiation, depending on orientation, are used. Example results for the calculation carried out regarding Ludwigsburg are shown in Figure 15.

Figure 15 – Ludwigsburg 3D Map of heat demand.

2.3.3 Results

In Figure 16 and Table 3, the specific heat demand and the plot area according to building typology are shown. Thereby the specific heat demand in general is higher than in the Danish example. One reason for this might be the different heat demand calculation method (U-values are determined by building typologies, then the annual heat demand is calculated per building according to German Norm 18599) and differences in the building age and refurbishment status.

Table 3 - Specific heat demand and plot ratio of different typologies in Ludwigsburg

	FLST2	FLST3	FLST4	FLST5	FLST6	FLST7	FLST8	FLST9	FLST10
Heat demand GWh/km²a	24.1	60.7	54.3	72.3	152.9	45.7	33.5	6.7	10.3
Plot Ratio	0.12	0.32	0.23	0.48	1.18	0.27	0.23	0.04	0.06
Number of buildings	39	1,538	1,518	1,109	68	257	638	14	61
Area [km²]	0.1	2.3	2.5	1.7	0.2	0.7	1.9	0.4	1.7

Especially the typology FLST6 in Ludwigsburg is atypical, because the city centre with many shopping facilities is located in the middle of the historic city with mainly very old (250-300 years) and seldom refurbished buildings. This leads to a very high heat demand.

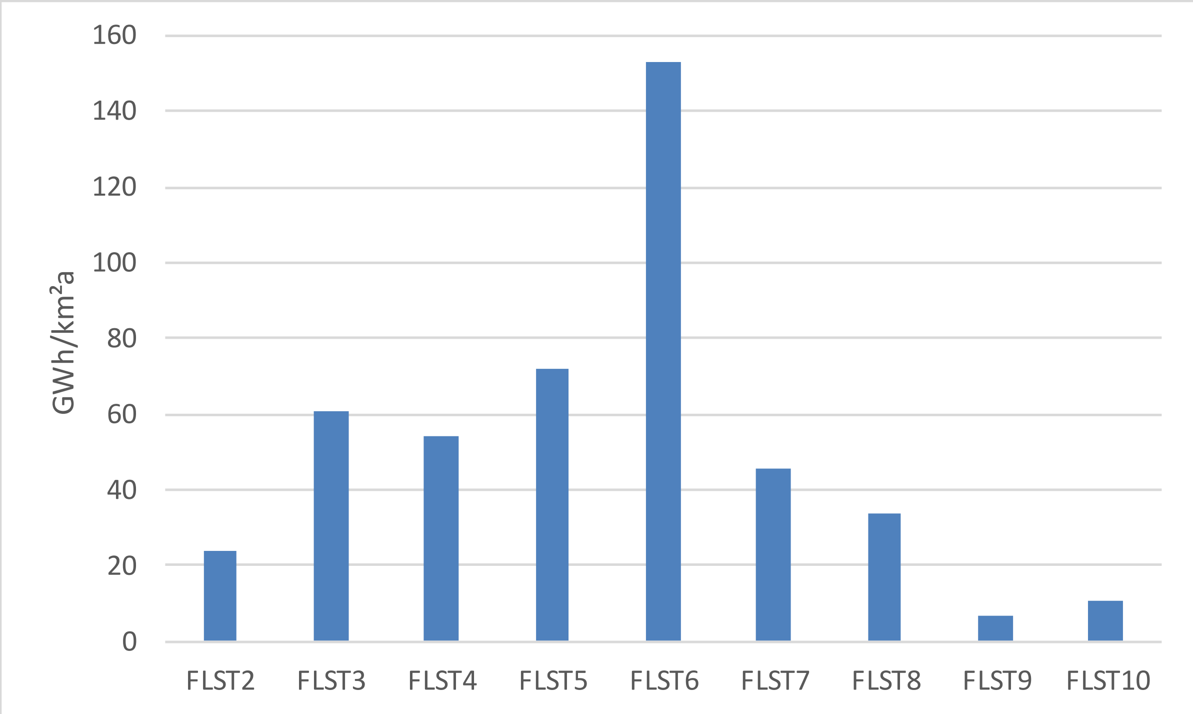


Figure 16 – Specific heat demand of different typologies in Ludwigsburg.

Figure 17 shows, that more than half of the area covered by buildings of the typologies FLST 3 – FLST 5 (multifamily houses, block development and row development /high rise buildings).

For FLST9 there was hardly any source data for the heat demand calculation available regarding industrial buildings. This is why only such a small number of buildings were taken into account (see Table 3). The real number of existing industrial buildings is significantly higher.

For FLST10 there were problems to exactly define the areas. The calculation program tended to include adjacent buildings. Therefore, only one representative area was included in the results.

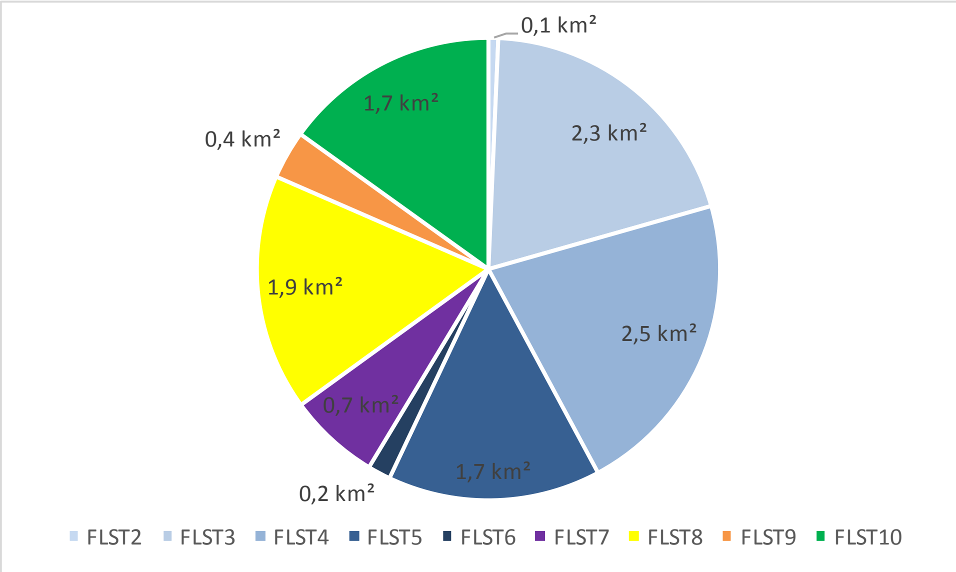


Figure 17 – Area of each typology (Ludwigsburg)

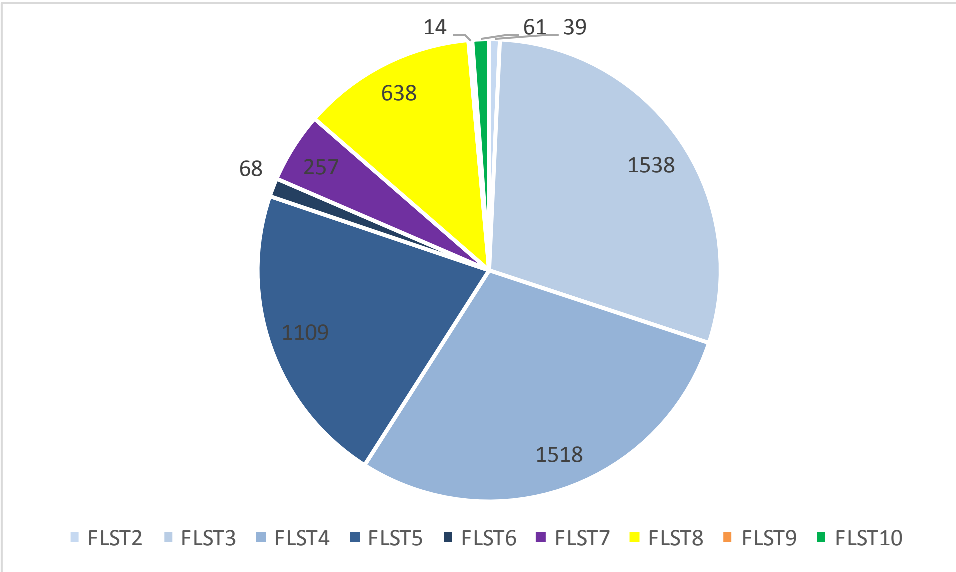


Figure 18 – Number of buildings per typology (Ludwigsburg).

2.4 Reference Town in Italy: Bolzano

Another example included to consider different circumstances than typical Danish conditions, is Bolzano. Bolzano is a located in the northern part of Italy. It is a medium-large size city, according to the German population size classes standard.

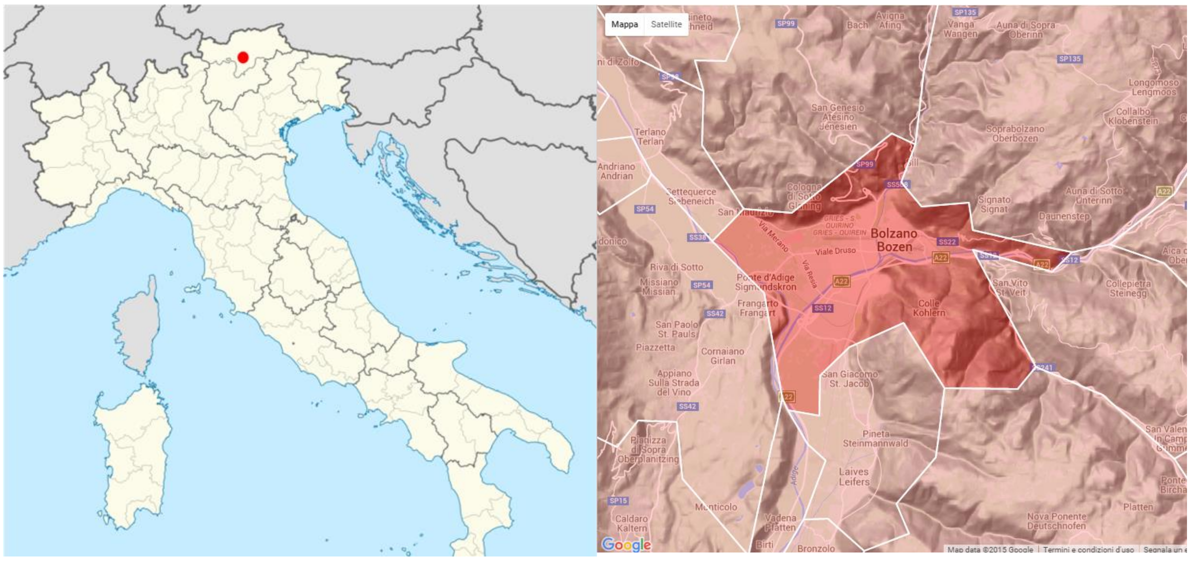


Figure 19 – Location of Bolzano in Italy and contour of Bolzano municipality.

Some reference data for the city are the following:

- Population: Approx. 106,000 by January 2016
- Population density: Approx. 2,000 inhabitants/km^2 by January 2016
- Municipality area: 52.29 km^2
- Elevation: 232-262 m
- Heating degree days (HDD): 2561.4 @ 18 °C, 2090.9 @ 16 °C[4]
- Cooling degree days (CDD): 183.2 @ 24 °C, 102.3 @ 26 °C[4]
- Heat demand: 1,350 GWh/year (thermal energy Bolzano)

2.4.1 District Heating in Bolzano

The heat of the DH of Bolzano is mostly produced by the waste incinerator of the town. Moreover, the DH power station includes a small CHP plant and a small PV plant located on the station roof. The DH network currently has a length of 20 km, which is planned to be extended in a near future. The DH network supplies heat to about 3,500 dwellings and 100 companies. A small part of the heat is used in summer for cooling through and absorption chiller.

Yearly energy consumption:	approx. 60,000 MWh
Connected power:	approx. 80 MW
Maximum requested power:	about 33 MW

[4] Source: degreedays.net.

Natural gas boiler power:	32 MW
CHP power:	3.7 MW
Incinerator maximum power (currently not fully exploited):	32.5 MW
PV plant power:	13.2 kW

At present, a large storage tank (about 6,000 m^3) is close to be commissioned. It will allow a better exploitation of the waste-to-heat facility and pave the way towards the extension of the network.

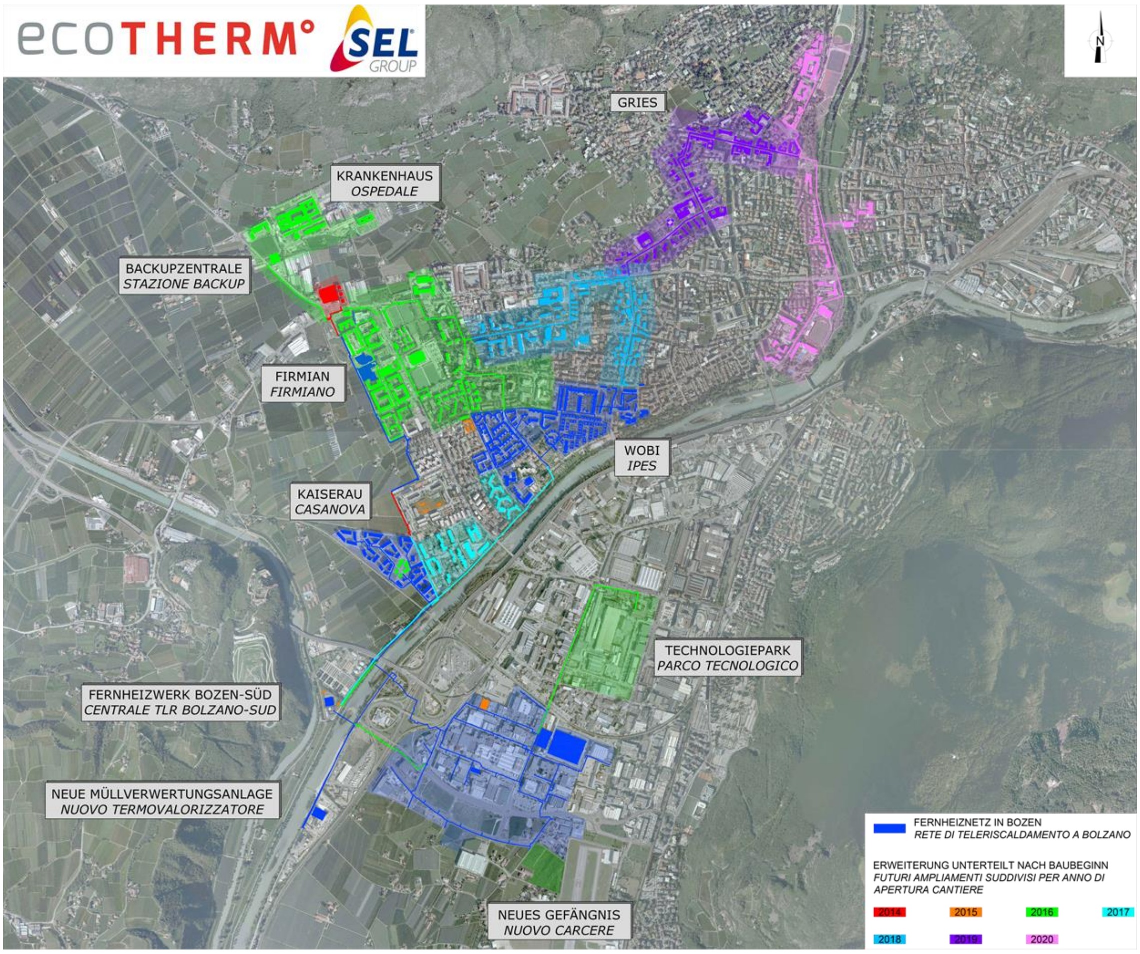


Figure 20 – Map of Bolzano DH network.

2.4.2 Market Strategy for District Heating

According to the data provided by Alperia (the company owning and managing the DH in Bolzano), as long as the network expands, they will be able to reduce the price of the supply for the end customers.

Alperia provided a document where they compare the different costs of heating according to the different fuel/technology and affirm that DH is 40 % cheaper than diesel and 20 % cheaper than natural gas.

2.4.3 Approach

The town of Bolzano was analysed to get energy consumptions and to test the settlement typology classification developed in the FLEXYNETS project.

For the case of Italy, a heat atlas similar to the Danish one is not available. However, for the specific case of Bolzano, EURAC has a good amount of detailed data available, thanks to previous research projects. Therefore, a twofold approach was attempted: on one hand, a zoning approach was used, trying to recover the settlement typologies of FLEXYNETS, on the other hand detailed data for buildings (at least for a large part of the town) were used.

2.4.4 Zoning Approach

Zoning was carried out according to the municipality plan. The urban plan of the town is freely available on the municipality website. This plan distinguishes among different zones as typical for the Italian legislation. Below, a description of the most significant zones is reported:

- Zone A: historical centre. Buildings of historical, architectonic or monumental interest, including surrounding areas which can be considered integrated in this environment.
  - A1
  - A2
- Zone B: completion zone. The covered surface must not be smaller than 12.5 % (1/8) of the ground surface (i.e., plot ratio not smaller than 1/8) and the building density must be lower than 1.5 m^3/m^2. Example: SFH, 10 m side, 5 m from boundaries, 2 floors (3 m height per floor): plot ratio = 200 m^2 / 400 m^2 = 50 %, density = 600 m^3 / 400 m^2 = 1.5 m^3/m^2. For Bolzano:
  - B1: max 4 m^3/m^2 (exception for a limited zone: 4.6), max building coverage ratio[5] 35 %, max building height 23 m, min distance from boundary 5 m.
  - B2: max 4 m^3/m^2 (exceptions exist), max building coverage ratio 35 %, max building height 17 m, min distance from boundary 5 m.
  - B3: max 3.5 m^3/m^2 (exceptions exist), max building coverage ratio 35 %, max building height 14 m, min distance from boundary 5 m.
  - B4: max 3 m^3/m^2, max building coverage ratio 35 %, max building height 14 m, min distance from boundary 5 m.
  - B5: max 2.5 m^3/m^2 (restriction for limited zone: 2), max building coverage ratio 33 %, max building height 10.5 m, min distance from boundary 5 m.
  - B6: max 1.5 m^3/m^2, max building coverage ratio 33 %, max building height 10.5 m, min distance from boundary 5 m.
  - B7: max 5 m^3/m^2, max building coverage ratio 35 %, max building height 17.5 m, min distance from boundary 5 m.
  - B8, B9, special cases.
- Zone C: expansion zone. Zones where buildings can be built, but are not yet present:
  - C1: max 4 m^3/m^2, max building coverage ratio 40 %, max building height 23 m, min distance from boundary 5 m.

[5] Building coverage ratio (BCR): similar to plot ratio, but calculated as the ratio between the building 'footprint' area (instead of the total floor area) and the ground area.

- C2: max 3.5 m^3/m^2, max plot ratio 40 %, max building height 23 m, min distance from boundary 5 m.
- C3: max 3 m^3/m^2, max plot ratio 40 %, max building height 23 m, min distance from boundary 5 m.
- C4: max 2.5 m^3/m^2, max plot ratio 33 %, max building height 10.5 m, min distance from boundary 5 m.

- Zone D: industrial zone.
    - D1-D3.
- Zone E: agricultural/rural zones.
- Zone F: zones devoted to installations of general interest.

A loose correspondence between these zones and the FLEXYNETS settlement typologies can be identified. Some typologies can be readily identified:

- A1-A2, historical city centre / FLST 6, inner city
- D1-D3, industrial zone / FLST 8, light industry and business, FLST 9, heavy industry
- E, rural zones, F, zones of general interest / FLST 7, institutions, FLST 10, other areas

However, for a large part of the residential zones the correspondence is not straightforward. The residential stock, apart from the city centre and the case of villages, is subdivided into 4 typologies:

- FL ST 2, Single Family houses (plot ratio: 25-35 %)
- FL ST 3, Multi-family houses, small and large (plot ratio: 40-45 %)
- FL ST 4, Block development (plot ratio: 50-65 %)
- FL ST 5, Row development, high rise for residential (plot ratio: 70+ %)

In order to identify a more detailed correspondence, the analysis was restricted to a limited part of the city, were the building data were available (see below). Visually looking into googlemaps for this part, no significant zones with single-family houses were identified in Bolzano. Therefore, for the considered part of the city, the zones B and C were categorized in the typologies FLST3, FLST4, or FLST5 according to visual inspection. The majority of the available zones were then classified as FLST3 (multi-family houses), with a limited zone as FLST4 (block development, corresponding to a recent set of large and densely packed buildings). A more detailed analysis could identify different building types, but no evident homogenous zones are present. Therefore, in a DHC perspective, it does not seem useful to carry out a further distinction.

Hence, from the urban plan, the town was subdivided into polygons corresponding to roughly homogenous zones. Note that in the urban plan only maximum building parameters (e.g., maximum volume or plot ratio) are specified, not actual ones. From this point of view, no huge difference appears between the various B and C zones or subzones. In general, the C zones correspond to more recent buildings or to zones still to be completely built. This has of course consequences from the energetic point of view, but it can hardly be accommodated with the FLEXYNETS typology classification.

The obtained macro-zones are reported in Figure 21, with their description reported in Table 4. The correspondence with the FLEXYNETS typology was fixed only for the zones where detailed building data were available, i.e., the 9 macro-zones labelled from 0 to 8.

Table 4 – Macro-zones selected for the town of Bolzano.

Zone	Area [m^2]	Description	FLST
0	181,695	Expansion zone, C2	FLST 3, multi family houses
1	35,296	Industrial zone, D1	FLST 8, light industry and business
2	2,878,758	Completion zone, B1-B6	FLST 3, multi family houses
3	574,476	Expansion zone, C1-C3	FLST 3, multi family houses
4	260,514	Expansion zone, C2	FLST 3, multi family houses
5	674,418	Completion zone, B1-B4	FLST 3, multi family houses
6	129,079	Historical centre, A2	FLST 6, inner city
7	33,952	Recreational area	FLST 10, other areas
8	182,207	Expansion zone, C1-C3	FLST 4, block development
9	527,853	Completion zone, B1-B5	(no building data, not analysed)
10	33,935	Completion zone, B5	(no building data, not analysed)
11	642,213	Historical centre, A1-A2	(no building data, not analysed)
12	7,619	Completion zone, B3	(no building data, not analysed)
13	237,932	Industrial zone, D1-D2	(no building data, not analysed)
14	20,915	Completion zone, B2, B4	(no building data, not analysed)
15	2,983,171	Industrial zone, D1-D3	(no building data, not analysed)

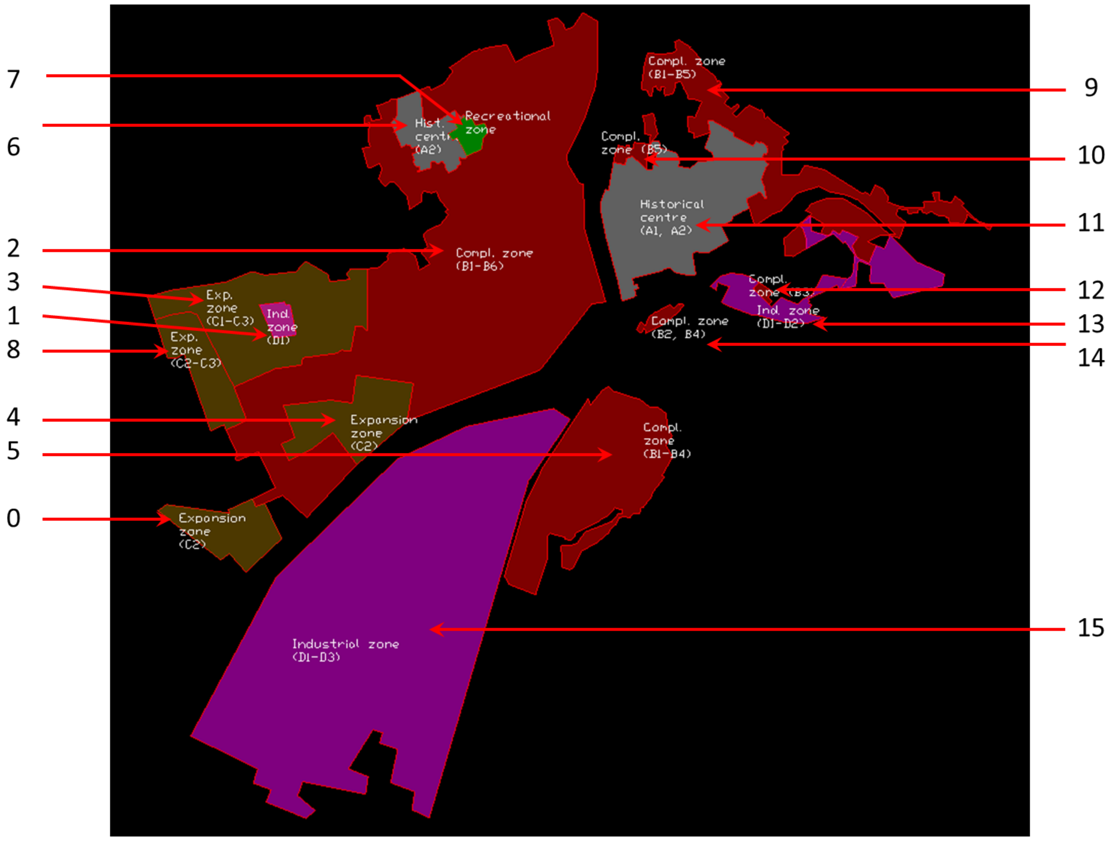


Figure 21 – Macro-zoning obtained for Bolzano. Different macro-zones are distinguished by colour. Grey: city center (zones A1-A2). Red: residential zones B. Brown: residential zones C. Purple: industrial zones D. Green: recreational area.

2.4.5 Detailed Analysis from Individual Building Data

Concerning the analysed zones, detailed information was available. Most of the used information comes from the Sinfonia EU project. For example, Table 5 reports some typical parameters (volume and ratio between external surface and volume) grouped by building age and type.

Concerning the distribution of buildings with different age within the city, one finds that the larger is the distance from the city centre, the more recent are the buildings, as it could be expected and in accordance with the urban plan. This is described in Table 7, where a coloured map shows the building age distribution. The heat demand of the analysed zones was previously calculated within the Sinfonia project. For each building in a given zone, the following parameters are available:

- Volume
- Area
- Perimeter
- Height
- Surface/volume ratio (external surface: lateral area plus twice the base area)
- Number of floors (calculated from building height assuming a standard floor height of 3.2 m)
- Total surface (living surface)
- Heated surface
- Number of flats
- Annual energy consumption

Table 5 – Building types for the analysed zones in Bolzano.

		Building types			
		Single/two-family house	Small multi-family house	Big multi-family house	Apartment block
Construction period	Class 1: Until 1918	429 – 865 m^3 S/V = 0.66 – 1.02	1053 – 3426 m^3 S/V = 0.41 – 0.67	3477 – 16363 m^3 S/V = 0.32 – 0.52	-
	Class 2: From 1918 to 1945	120 – 856 m^3 S/V = 0.64 – 1.93	875 – 3367 m^3 S/V = 0.41 – 0.70	3444 – 34137 m^3 S/V = 0.41 – 0.70	3470 – 46416 m^3 S/V = 0.22 - 0.44
	Class 3: From 1946 to 1960	305 – 843 m^3 S/V = 0.64 – 1.06	872 – 3411 m^3 S/V = 0.40 – 0.81	3441 – 29077 m^3 S/V = 0.30 – 0.60	3108 – 40248 m^3 S/V = 0.25 – 0.56
	Class 4: From 1961 to 1970	451 – 824 m^3 S/V = 0.67– 0.84	871 – 3398 m^3 S/V = 0.41 – 0.70	3463 – 26122 m^3 S/V = 0.24 – 0.53	1928 – 30724 m^3 S/V = 0.24 – 0.52
	Class 5: From 1971 to 1980	214 – 859 m^3 S/V = 0.66 – 1.61	877 – 3366 m^3 S/V = 0.42 – 0.97	3435 – 96240 m^3 S/V = 0.24 – 0.62	4394 – 34065 m^3 S/V = 0.22 – 0.42
	Class 6: From 1981 to 1990	160 – 822 m^3 S/V = 0.66 – 1.21	942 – 3378 m^3 S/V = 0.48 – 1.45	429 – 28138 m^3 S/V = 0.26 – 1.04	4041 – 64441 m^3 S/V = 0.20 – 0.42
	Class 7: From 1991 to 2005	356 – 822 m^3 S/V = 0.64 – 1.11	881 – 3334 m^3 S/V = 0.40 – 0.88	3509 – 30461 m^3 S/V = 0.30 – 0.55	2219 – 27760 m^3 S/V = 0.27 - 0.53
	Class 9: After 2006	382– 842 m^3 S/V = 0.65 – 0.98	1015– 3425 m^3 S/V = 0.42 – 1.09	3454 – 61990 m^3 S/V = 0.22 - 0.85	3623 – 76228 m^3 S/V = 0.25 - 0.41

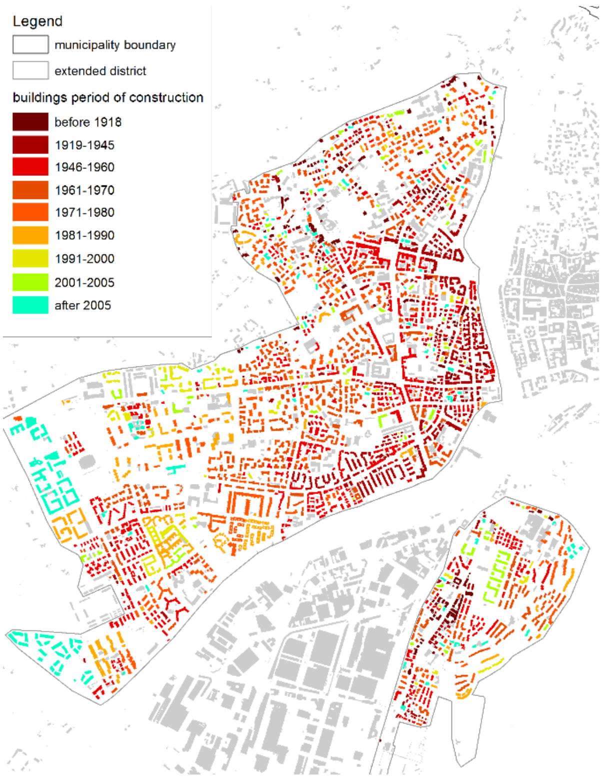
2.4.6 Results

Putting the different information together, the following results were obtained.

Table 6 – Specific heat demand and plot ratio of different typologies in Bolzano.

	FLST2	FLST3	FLST4	FLST5	FLST6	FLST7	FLST8	FLST9	FLST10
Heat demand GWh/km²a	-	94	81	-	39	-	80	-	3.4
Plot Ratio	-	0.91	1.07	-	0.41	-	0.93	-	0.04
Number of buildings	-	2129	27	-	38	-	17	-	2
Area [km²]	-	4.570	0.182	-	0.129	-	0.0353	-	0.034

Table 7 – Urban development of Bolzano – Age Classes.



For **Age Class 1**, one has about 600,000 m^3. The main building typology is the small multi-family houses, while there are no building blocks. Buildings are quite compact (S/V average around 0.56).

For **Age Class 2**, it is estimated around 2 millions of cubic meters of new constructions. In the residential quarter San Quirino and in the area of Firenze and Torino roads we can find average-dimension buildings, mainly multi-family houses, with an average S/V accounting for 0.52. The area of Viale Libertà is mainly composed by high-rise rationalist buildings, with building blocks and S/V around 0.33.

For **Age Class 3**, the overall building volume is around 3.3 million m^3, with an average dimension of a single building of 5,400 m^3. The main typology is the building block (around 62 % of the built volume) with an S/V ratio around 0.36. The features of **Age Class 4** are similar, with a built volume around 3.5 million m^3, while the average building dimension is higher (around 7600 m^3). The main building typology is the building block whose S/V is around 0.35.

During **Age Class 5**, the volume realized is around 2 million m^3. The main building typology is building blocks (around 52 %), while multi-family buildings accounts for 43 % of the volume.

During **Age Class 6** the overall volume is around 1.2 million m^3, and the main building typology is big multi-family houses, accounting for 58 % of the overall volume, while the building blocks accounts for 33 %.

For **Age Classes 7, 8, 9** the main typologies are building blocks and big multi-family houses, with an average volume of the constructions around 6,600 m^3 for Age Class 6 and 8, while a higher value was observed for Age Class 7, around 10,000 m^3.

2.5 Reference Town in Spain: Seville

Seville has been selected as a reference in Spain. Some relevant data of Seville are given below:

- Country, autonomous community (territorial role): Spain, Andalusia (capital).
- Geographical coordinates and elevation: 37°22’38’’N, 5°59’13’’W, 7 m.
- Urban area, district planning: 140 km^2. Total of districts: 11 (D01-Casco Antiguo, D02-Macarena, D03-Nervión, D04-Cerro-Amate, D05-Sur, D06-Triana, D07-Norte, D08-San Pablo-Santa Justa, D09-Este-Alcosa-Torreblanca, D10-Palmera-Bellavista, D11-Los Remedios).
- Population: 703.021 (census), 1.107.000 (real estimated) inhabitants.
- Population density: 5,022/km^2 (census), 7.907/km^2 (real estimated).
- Climate: subtropical Mediterranean[6]

2.5.1 Urban Data Sources, Mapping and Characterization Procedure

Seville has been mapped and characterized from, and through, the below mentioned databases and work procedures.

2.5.2 Urban Characterization Data Sources

- Urban characterization data source: Detailed maps edited by the Seville’s council, regarding *Use of buildings, Height of buildings* and *Age of buildings*.
- Urban consultation tool: *Googlemaps (www.google.es/maps)*. Useful for the assignation of the correspondent settlement typology to each polygon in which the city has been divided, the calculation of the urban and built areas and the checking of the buildings’ height.

2.5.3 Mapping and Characterization Procedures

The used mapping edition tool is open GIS software *Scribble Maps (www.scribblemaps.com)*. A GIS file has been generated in *.KML format available to be used, through this or any other GIS software, to consult the mapping divisions and to apply the FLEXYNETS strategies.

First of all, the entire city has been divided in a total of 507 polygons designed by a code number containing the district to which it belongs and its number within the district, with a format such as ‘*DNN-nn’*, where *‘NN’* is the district code number and *‘nn’* is the polygon code number. The division criterion is based on the general use of a specific area detected through the analysis of the *Use of buildings* map, the direct knowledge of the city and its visualization by *Googlemaps (satellite view)*. The typology classification is the same used for every reference towns of the FLEXYNETS project.

Minimum, maximum and average values of building height and age have been attributed to each polygon, studying its building stock, through the analysis of the *Height of buildings* and *Age of buildings* maps and the direct visualization of the city.

The *total (‘urban’) area* of each polygon has been measured by means the GIS tool and a ‘*built ratio’ (fraction of the total area occupied by buildings)* has been estimated for each polygon considering the following approximate values: 0.0 – 0.2 – 0.4 – 0.6 – 0.8 – 1.0. The ‘*built area’* has been calculated applying these ratios to the total area of the polygons. Finally, the ‘*inhabited area’* has been calculated multiplying the ‘*built area’* by the *‘average building height’* assigned to each polygon.

[6] Köppen climate classification Csa

All these calculations have been carried out in order to facilitate the assessment of the results referred to different areas and to allow the estimation of the yearly energy demands, which are usually expressed in terms of '*energy per unit of inhabited area' [GWh/km^2 year]* (see description of demand calculation in section 2.5.5).

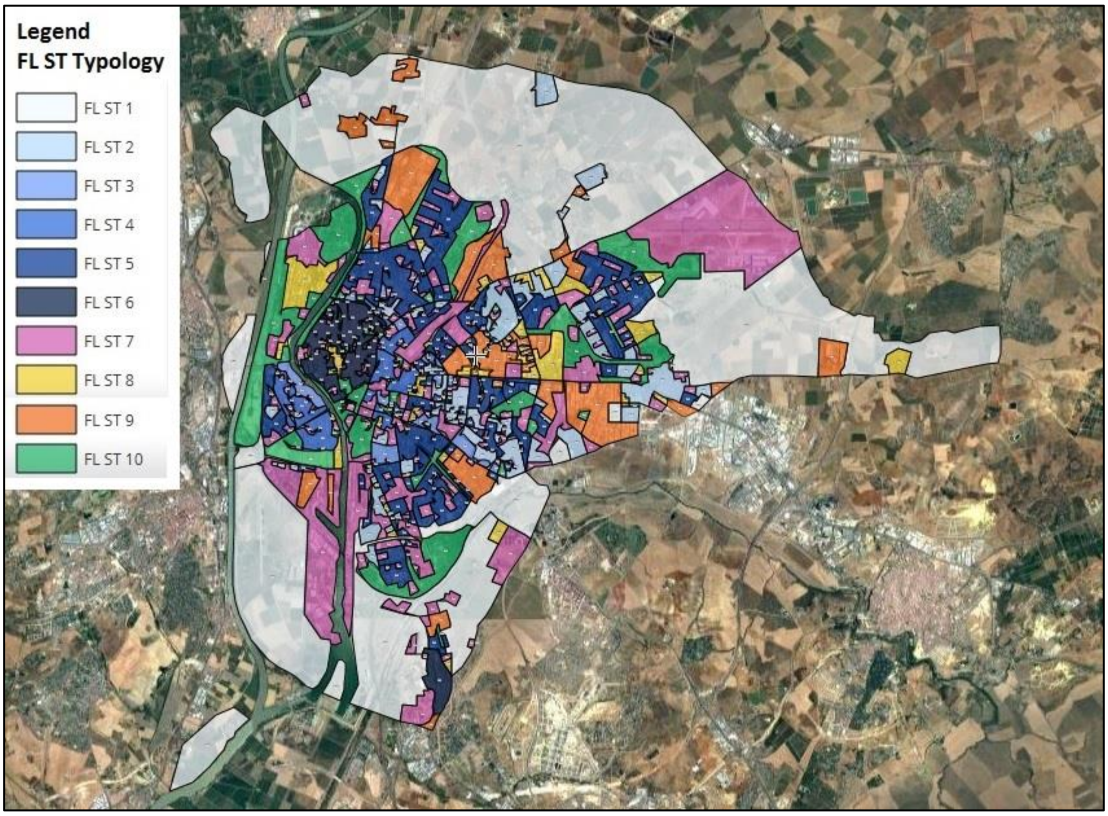


Figure 22 – Map of Seville divided into the FLEXYNETS typologies.

2.5.4 Demand Data Sources and Estimation Procedure

The heating, cooling and DHW demands have been estimated for the entire Spanish reference city with the use of the below mentioned data sources and calculation methodology.

Energy Demand Data Sources

The typical heating, cooling and DHW demands of the buildings in Seville, according with their use, have been taken from the document *'Heating and cooling energy demand and loads for building types in different countries of the EU'* of the *European Project ENTRANZE, Policies to ENforce the TRAnsition to Nearly Zero Energy buildings in the EU-27 (www.entranze.eu)*, where typical demand values of different building typologies are provided for a large number of European municipalities.

Additionally, some useful information about the evolution of the energy demand of several residential building typologies over time has been taken from the web tool of the *IEE Project TABULA, 'Typology Approach for Building Stock Energy Assessment'* (webtool.building-typology.eu).

Oher external and internal sources have been consulted in order to approach the energy demand of the reference city, such as: the Institute for Energy Saving and Diversification (IDEA), the Energy

Andalusian Agency (AAE) and the Seville's Council; as well as, internal studies and expertise of the ACCIONA INFRASTRUCTURES R&D Centre regarding the energy efficiency and renewable generation at building and urban level.

2.5.5 Energy Demand Calculation

Typical heating, cooling and DHW demands has been taken or approached, from the above mentioned data bases, to obtain an approximate yearly value per inhabited area for each FL-ST typology and building age. Relative energy values have been multiplied by the *inhabited area* in order to get global energy consumptions for the entire city and per FL-ST typology.

New relative energy demand values has been generated related to the *urban area*, aimed to obtain the spatial distribution of the energy demands throughout the city. Final results have been gathered and included in the following chapter.

2.5.6 Demand Results per Activity Sector and Building Typology

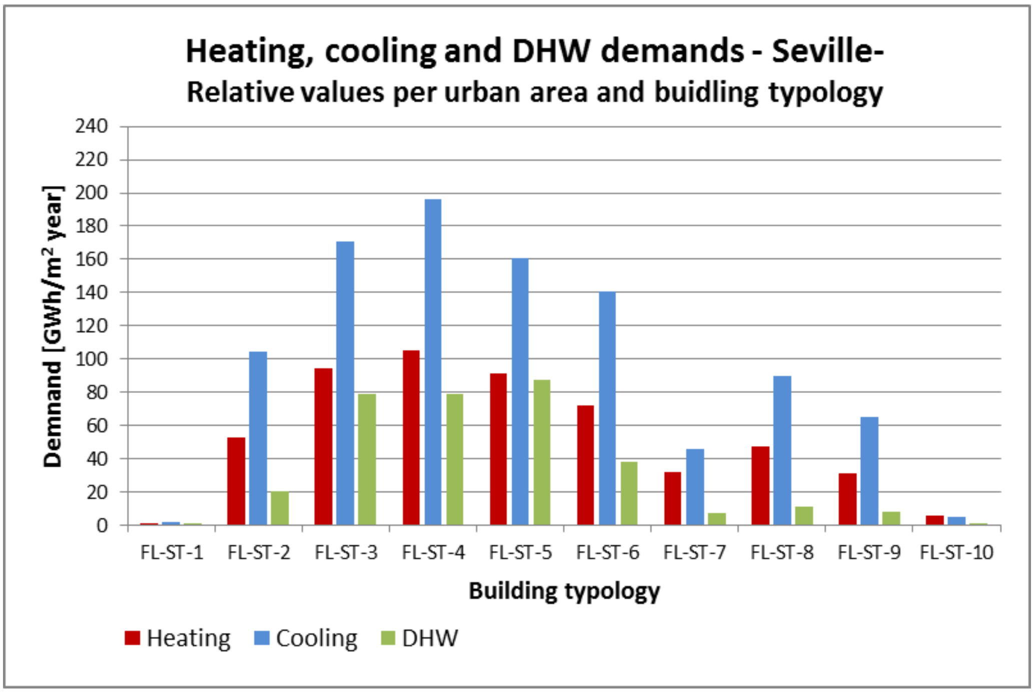


Figure 23 – Heating, cooling and DHW demand of Seville per urban area and building typology.

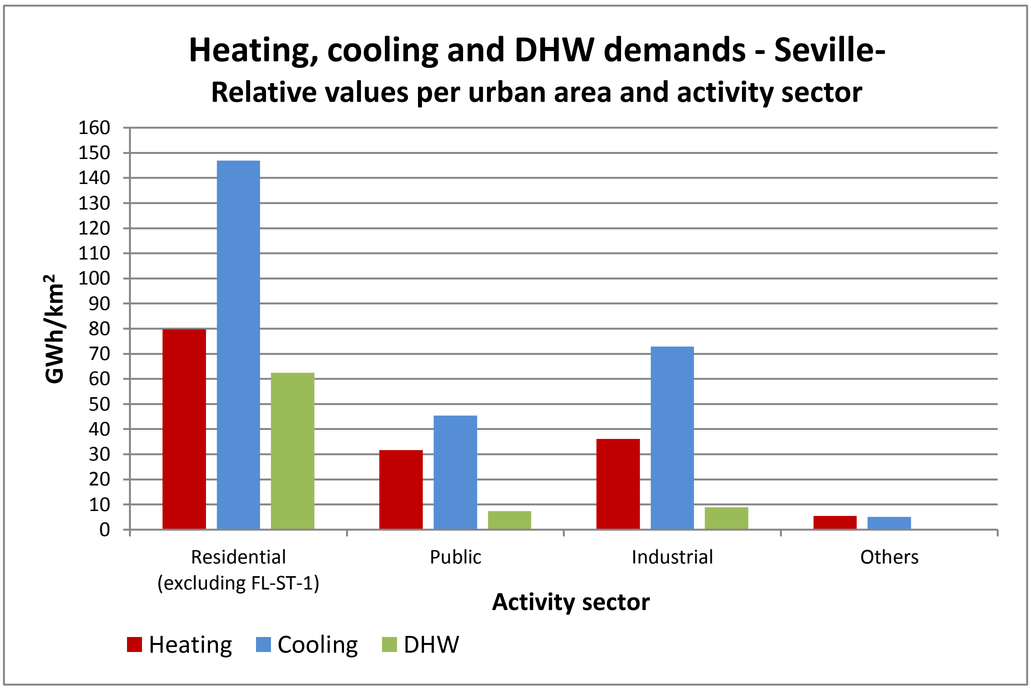


Figure 24 – Heating, cooling and DHW demand of Seville per urban area and activity sector: residential (FL-ST-2, FL-ST-3, FL-ST-4, FL-ST-5, FL-ST-6), public (FL-ST-7), industrial (FL-ST-8, FL-ST-9) and others (FL-ST-10) building typologies (FL-ST-1 typology has been excluded because of its low demand combined with a huge area, in order to not distort results)

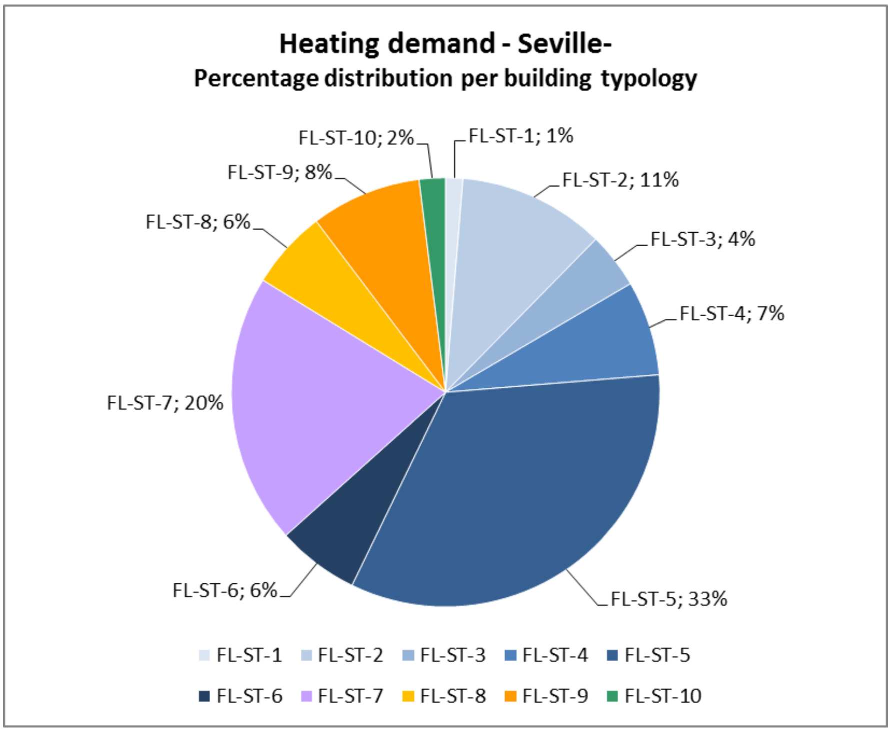


Figure 25 – Percentage distributions per building typology of the heating demand of Seville.

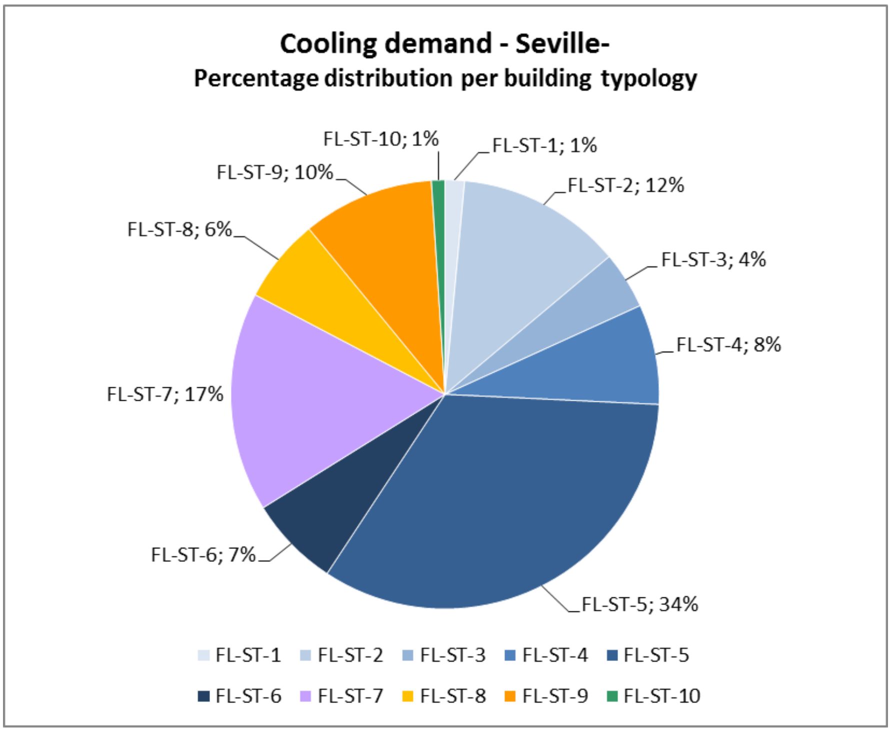


Figure 26 – Percentage distributions per building typology of the cooling demand of Seville.

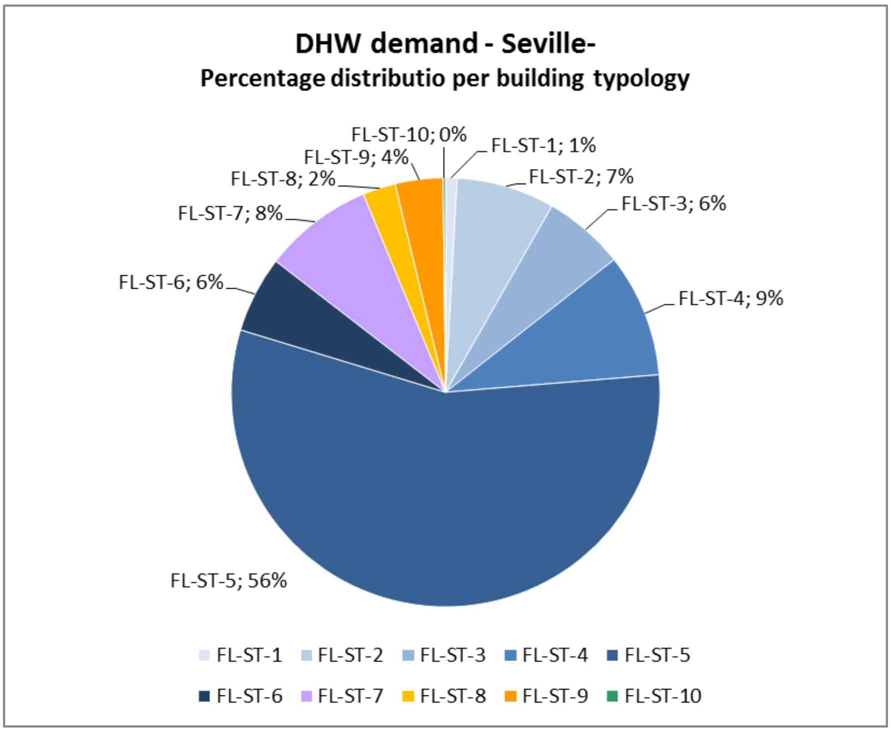


Figure 27 – Percentage distributions per building typology of the DHW demand of Seville.

2.6 Cooling Demand

In the FLEXYNETS concept, the network should be capable of supplying heating and cooling simultaneously. Therefore, it is important also to consider the cooling demand in the reference towns and in general. This section serves to describe some general considerations of the cooling demand, before a more specific estimation of the cooling demand is considered.

2.6.1 Cooling Demand in Denmark

In Denmark, a cooling study, 'Cooling Plan Denmark 2016', has been developed[7]. The main conclusion from this is that in general there is a growing need for cooling in buildings because of requirements for comfort, insulation and daylight as well as for process cooling for servers. Based on data from the BBR register and business register together with empirical figures for buildings, the cooling demand in Denmark is estimated to approximately 9,500 GWh cooling per year and 6.8 GW cooling capacity. The cooling requirements are distributed fairly evenly on comfort cooling, which occurs only in the summer months, and process cooling, which on the other hand is evenly distributed throughout the year. The cooling demand compared to the installed capacity corresponds to an average of 1,400 full load hours per year. The typical individual cooling systems are in the range of 0.5 MW cooling, while the district cooling installations typically are of 5 MW cooling or more. According to the cooling plan, there are many large-scale benefits associated with refrigeration. The price of 10 chillers of 0.5 MW cooling is roughly twice as high as the price of a single 5 MW cooling.

The applied model compares the potential cooling demand with geographic information and large scale by refrigerating, estimating where it would be economically advantageous to supply DC. It is estimated, that it would be feasible to supply nearly half of the cooling demand of 2 MW cooling with DC. The potential for construction of 2 MW cooling is estimated at 4,200 GWh cooling per year and 2.4 GW cooling capacity. An important observation is that the clusters with DH potential are mainly concentrated in the larger cities and especially in areas with industry.

District cooling potential is highest in the metropolitan area, whereas the Central Denmark Region and Region of Southern-Denmark have the greatest cooling demand. The reason for the large cooling demand in these regions is the large amount of industry. Population and building density is, however, not so great in these areas, which is why the district cooling potential is greatest in the greater area of Copenhagen and in other big cities like Aarhus, Odense and Aalborg, according to the analysis performed in the relation to the Danish 'cooling plan'.

The dual purpose of the FLEXYNETS network (i.e. heating and cooling with the same network) only comes into play, where a cooling demand is present. The future cooling potential (and potential for district cooling) found in the 'cooling plan' study shows that it can be relevant to consider the FLEXYNETS concept even for Northern European countries traditionally considered as 'colder climates'.

2.6.2 Cooling Demand in Buildings in Europe

A large project; Heat Roadmap Europe, is a project that studies the heating and cooling sector in Europe, and quantifies the effects of increased energy efficiency on both the demand and supply side in terms of energy consumption, environmental impact, and costs[8].

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[7] Dansk Fjernvarmes F&U-konto – Køleplan Danmark 2016
www.danskfjernvarme.dk/viden-om/f-u-konto-subsection/rapporter/2015-02-koeleplan-danmark-2016
[8] www.heatroadmap.eu/About.php

Based on the data collection within the project, the cooling demand in buildings is much smaller than the heat demand. This also counts for the countries in the southern part of Europe. An overview of the overall cooling demand in buildings compared to the heat demand is seen in Figure 28, while the percentage share of cooling demand in buildings compared to heat demand in buildings per country is seen in Figure 29[9].

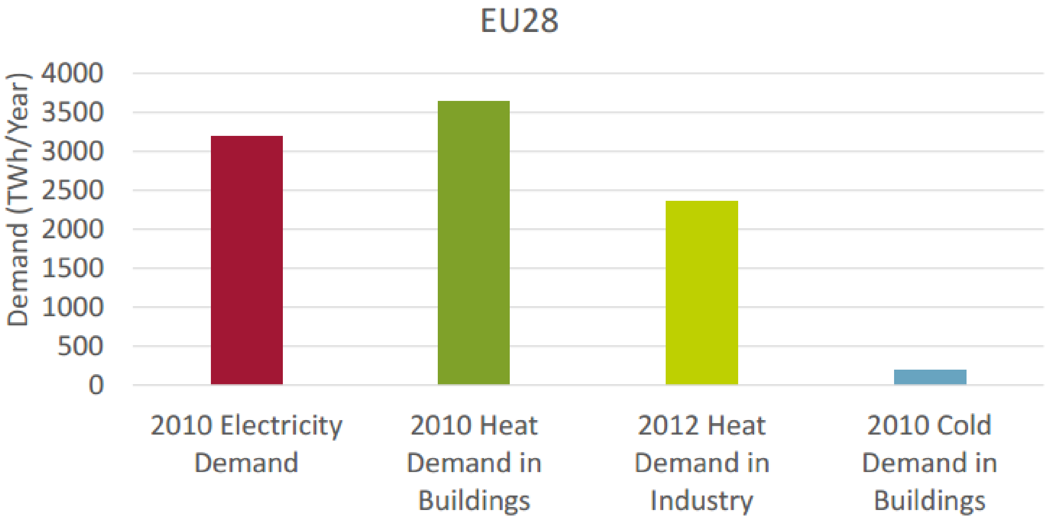

Figure 28 – Overall heat demand in the 28 EU countries compared to overall cooling demand in buildings.[9]

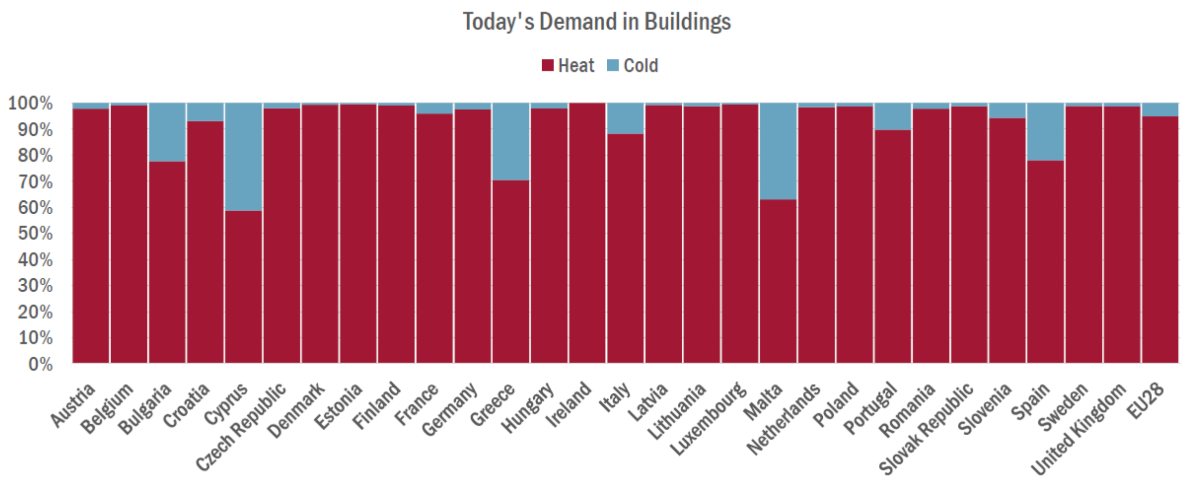

Figure 29 – Share of cooling and heat demand in buildings.[9]

A comparison of the cooling demand compared to the heat demand is more thoroughly described in section 2.7.8 concerning validation of the heating and cooling trends found based on the Danish reference towns.

As mentioned in the previous sections on cooling, no specific database similar to the Heat Atlas exists for the cooling demand in Denmark. What also needs to be considered is that the cooling demand seems to be significantly lower than the heat demand, especially for countries in the northern part of

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[9] Figures from David Connolly: 'Heat Roadmap Europe: Moving from European to Member State Heating and Cooling strategies' www.4dh.eu/images/eventlist/events/2016_conference/Plenary_2_David_Connolly.pdf

Europe. Therefore data from the iNSPiRe project has been used to estimate the cooling demand in the Danish reference towns. The iNSPiRe project and how the data is used is further described in the following.

2.6.3 Specific Cooling Demand (iNSPiRe Project)

To estimate the cooling demand in the typologies set up by the FLEXYNETS consortium, the iNSPiRe project has been used. This project will be described in the following based on text from www.inspirefp7.eu and modified to this purpose.

The iNSPiRe project is a four-year long, EC-funded project with the objective to tackle the problem of high-energy consumption by producing systematic renovation packages that can be applied to residential and tertiary buildings. These renovation packages aim to reduce the primary energy consumption of a building to lower than 50 kWh/m^2/year. A requirement is that the packages need to be suitable to a variety of climates while ensuring optimum comfort for the building users.

The project consists of a range of different work packages. Some of them include analysing and assessing the building's loads and architectural features as well as energy generation and distribution solutions, others focus on monitoring of energy management and standardizing systematic renovation packages.

The first stage of iNSPiRe is the analysis of building stock across Europe. By looking at these buildings holistically, taking in all aspects of the structure and energy distribution, iNSPiRE will use these templates to consider renovation procedures with a large replication potential.

The data from the first stage lays the foundations of iNSPiRE with an assessment and a categorisation of building stock, both residential and tertiary, across the European Union. This classification process takes into account: the age of the buildings; structural characteristics and ownership; energy usage including electricity, heating, users' patterns and comfort requirements; RES availability and building regulations. This profiling process will lead to the identification of seven primary types of target buildings. These target buildings will be the ones that have the greatest requirement for refurbishment packages.

The results from the described work on the building stock have been used to estimate the cooling demand for the reference towns in Denmark. The data from the work in the iNSPiRe project can be found at inspirefp7.eu/retrofit-solutions-database

The use of the data for analysing the Danish reference towns is described in the next section.

2.7 Cooling Demand - Reference Towns in Denmark

The building and office stock has been analysed in great detail in the iNSPiRe project, for instance by dividing the building classifications into construction age. The level of detail exceeds the scope of the analyses of the reference towns with regard to the FLEXYNETS concept. Here the scope is to estimate the feasibility and layout of networks in a town or in different typologies within a town. Therefore the estimated heat demand of the specific areas is used, rather than detailed data on the individual heat demand for each building.

To estimate the cooling data, the average numbers from the reference buildings in the iNSPiRe project has therefore been used. The analysis has been performed for cooling demand at set temperature **at 24 and 26 °C**. Denmark is placed in the Northern Continental group. For this, the following data shown in Table 8 has been identified.

Table 8 – Cooling demand for countries in the Northern Continental group. SFH = single family house, MFH = multi family house, OFF = office. (Source: iNSPiRe.)

Climate	Type of building	Indoor air set temperature (°C)	Type of load	Demand (kWh/m2y)
Northern Continental	SFH - average - all types - all ages	24	cooling	9
Northern Continental	small MFH - average - all types - all ages	24	cooling	10
Northern Continental	large MFH - average - all types - all ages	24	cooling	10
Northern Continental	OFF1 - average - all types - all ages	24	cooling	29
Northern Continental	OFF2 - average - all types - all ages	24	cooling	25
Northern Continental	SFH - average - all types - all ages	26	cooling	3
Northern Continental	small MFH - average - all types - all ages	26	cooling	3
Northern Continental	large MFH - average - all types - all ages	26	cooling	4
Northern Continental	OFF1 - average - all types - all ages	26	cooling	19
Northern Continental	OFF2 - average - all types - all ages	26	cooling	17

The following table, Table 9, shows how the classifications of the building stock in the iNSPiRe project has been matched with the FLEXYNETS typologies. Areas with villages and single family houses are assumed to correspond to the single family house classification in iNSPiRe. Multifamily houses – small and large – are assumed to correspond to an average of the small and large multifamily house data in the iNSPiRe. Residential blocks, high rise and mixed areas, are assumed to correspond to the large multifamily classification in iNSPiRe. The typologies for public buildings are considered to correspond to the office1 classification in iNSPiRe while the light industry typology is considered to correspond to the iNSPiRe classification office2.

The office1 classification has a slightly lower cooling demand than the office2 classification. The deviation between public and light business has been chosen based on the analysis on reference towns and the heat demand. Areas classified within the public typology tend to have a slightly higher heat demand than areas within the light industry typology. The same tendency is assumed to apply for the analysis on cooling demand.

Table 9 – Assumed correspondence between FLEXYNETS typologies and iNSPiRe building classifications.

Flexynets typologies			**Inspire classification**	**Demand**	**Set temp.**	
					24	26
Residential	FL ST 1	Villages	SFH	kWh/m2y	9	3
	FL ST 2	SFH	SFH	kWh/m2y	9	3
	FL ST 3	MFH small and large	MFH - ave.	kWh/m2y	10	4
	FL ST 4	Block	MFH - large	kWh/m2y	10	4
	FL ST 5	Row, high rise	MFH - large	kWh/m2y	10	4
	FL ST 6	Mixed	MFH - large	kWh/m2y	10	4
Public	FL ST 7	Institutions etc.	OFF1	kWh/m2y	29	19
Light industry	FL ST 8	Business, commercial	OFF2	kWh/m2y	25	17
Heavy industry	FL ST 9	Heavy	n/a	kWh/m2y	0	0
Other	FL ST 10	Misc.	n/a	kWh/m2y	0	0

2.7.1 Results for Cooling Demand @24

The results from the analysis of the cooling demand based on iNSPiRe data are given in this section for a reference temperature of 24 °C (defining when cooling is required). When referring to this reference temperature, the term '@24' is used.

2.7.2 Average Annual Cooling Demand per km² Ground Area @24

In Figure 30 the average annual cooling demand in GWh/km² is seen for each typology provided for small, medium and large towns respectively. As for the heat demand, the values are weighted according to area.

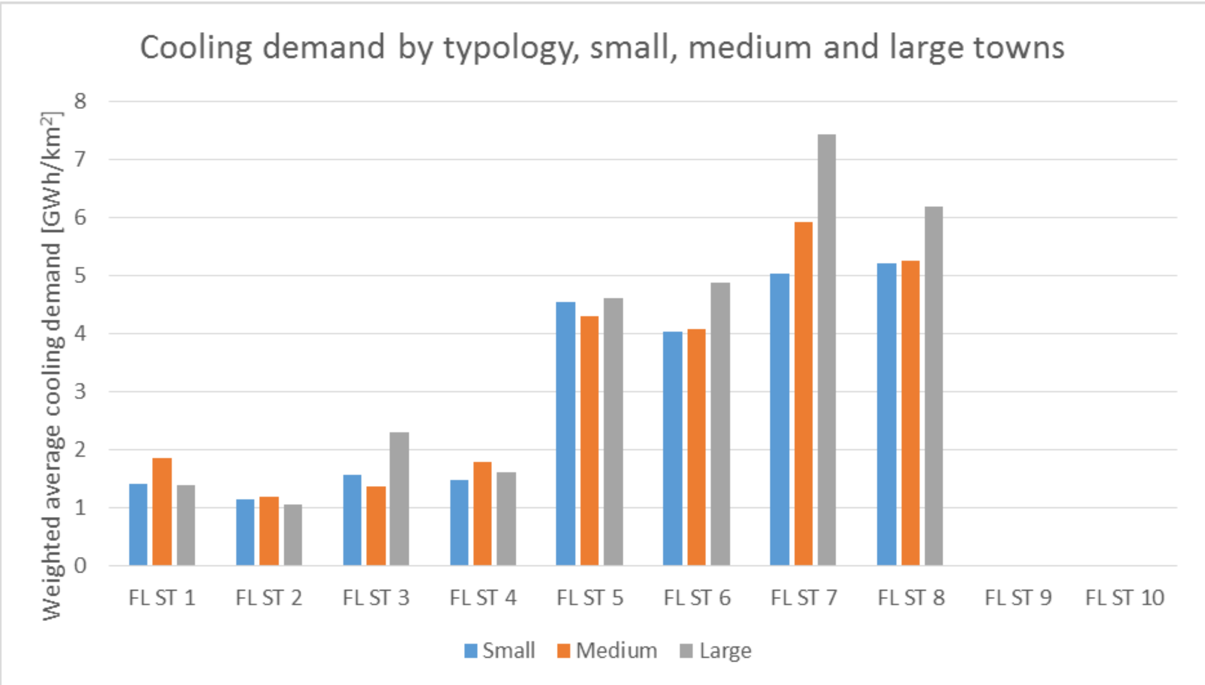

Figure 30 – Average annual cooling demand per km² @24 by typology for small, medium and large towns.

As for the heat demand, the tendency for the first four typologies (representing different types of low density residential areas) is somewhat similar and all have rather low demands per km^2. For the denser residential typologies of FL ST 5 and 6, the cooling demand per km^2 is more than doubled compared to FL ST 1 to 4. The heat demand for the public sector FL ST 7 and the light industry in FL ST 7 is similar to the less dense typologies. Contrary for the cooling demand, this is higher in these categories.

Figure 31 is created by merging the typologies representing similar values and similar categories to give a simpler typology categorisation than in Figure 30. The same trend as for the heat demand in general, is that the *density* of these simplified typology categories increases somewhat as the town size increases (i.e. the cooling demand per km^2 increases).

Also for this more simple division, a different trend for the cooling demand is seen, compared to the heat demand; the cooling demand density is highest for public and institutions in FL ST 7 and for light industry in FL ST 8.

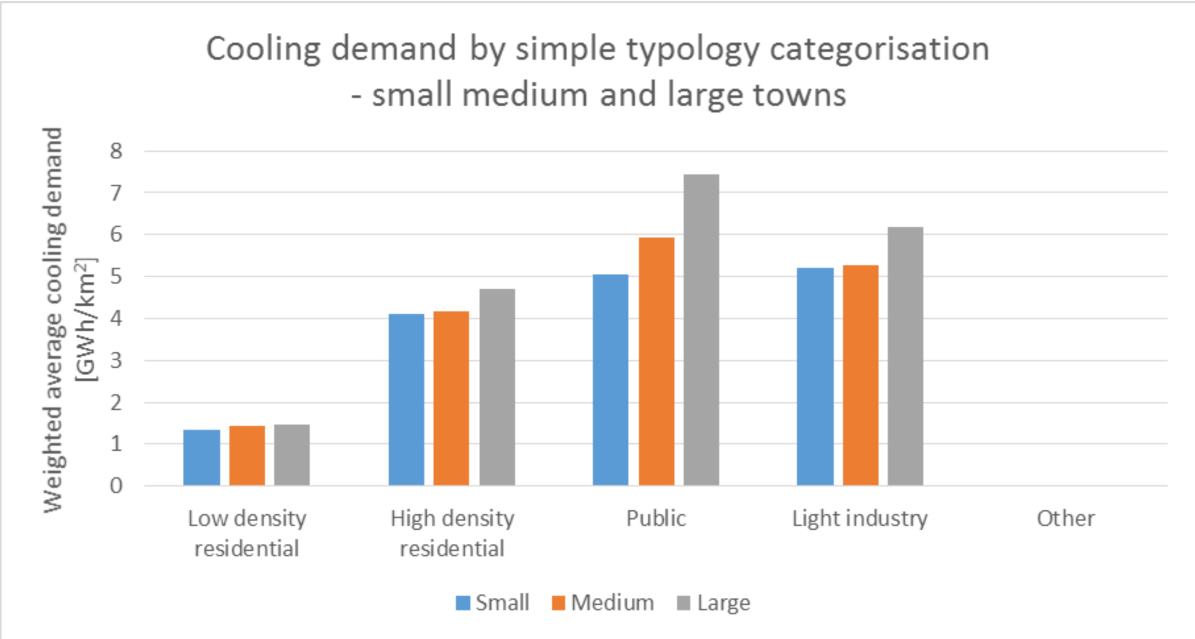

Figure 31 – Average annual heat demand per km^2 @24 for small, medium and large towns with simplified typology categorisation.

2.7.3 Demand Distribution by Typology @24

Figure 4, which is shown under the description of the heat demand, shows the share of the simplified typology categories for small, medium and large towns. The same distribution of areas applies for the cooling demand. Figure 32 shows how much of each typology represents of the total demand. When visually merging typologies (in the same way as it is done for the heat demand), it can be seen that even though the specific typology shares differ significantly, there are more clear similarities when it comes to the share of each main demand category.

The cooling demand for public, institutions and light industry has a higher share, compared to the share in the heat demand, where the public institutions together with light and heavy industry counts for 31 % in small towns and down to 24 % in large towns.

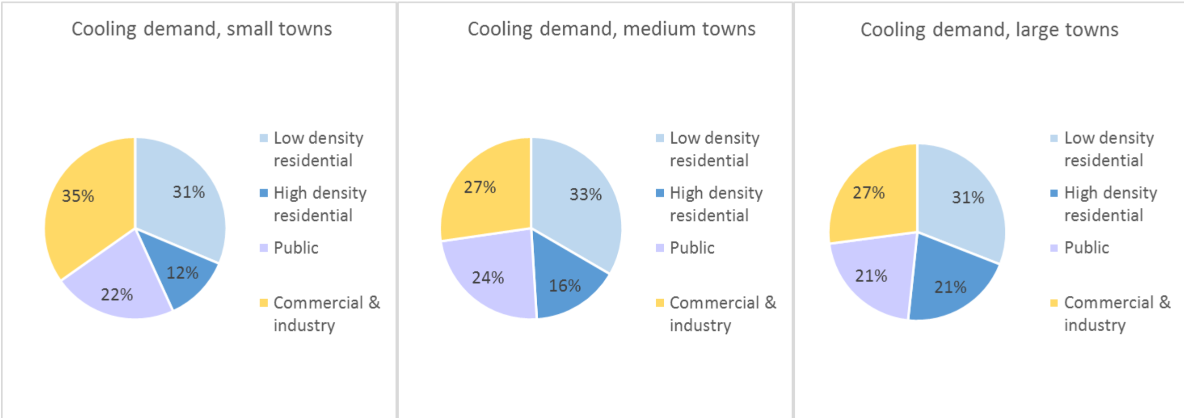

Figure 32 – Cooling demand distribution @24 by settlement typology for small, medium and large towns.

Contrary to the heat demand, the cooling demand for the public institutions and light industry are higher. The share of these two categories combined is between 48 % (large towns) and 57 % (small towns). The tendency that the share of demand decreases in the public and industry categories when the town size increases, applies for both the heating and cooling demand.

Similar to the heat demand analysis, Figure 33 is another way to display the similarities between the typologies in the different town sizes. This way it is possible to determine how significant the tendency is towards higher density when the town size increases. Similarly, it is possible to determine the trends regarding the share of each demand category, as the town size increases.

For the heat demand, the tendency was quite clear; with a high share of the low density residential buildings corresponding to 45-50 % of the total heat demand, the share decreased for high density residential buildings, and continued to decrease for public and light industry and was lowest for the heavy industry typology. This is not the tendency that is seen for the share of total cooling demand by simple typology categorisation in Figure 33; the share is more evenly distributed but is lowest in the high density residential category varying from approximately 12-20 % depending on town size.

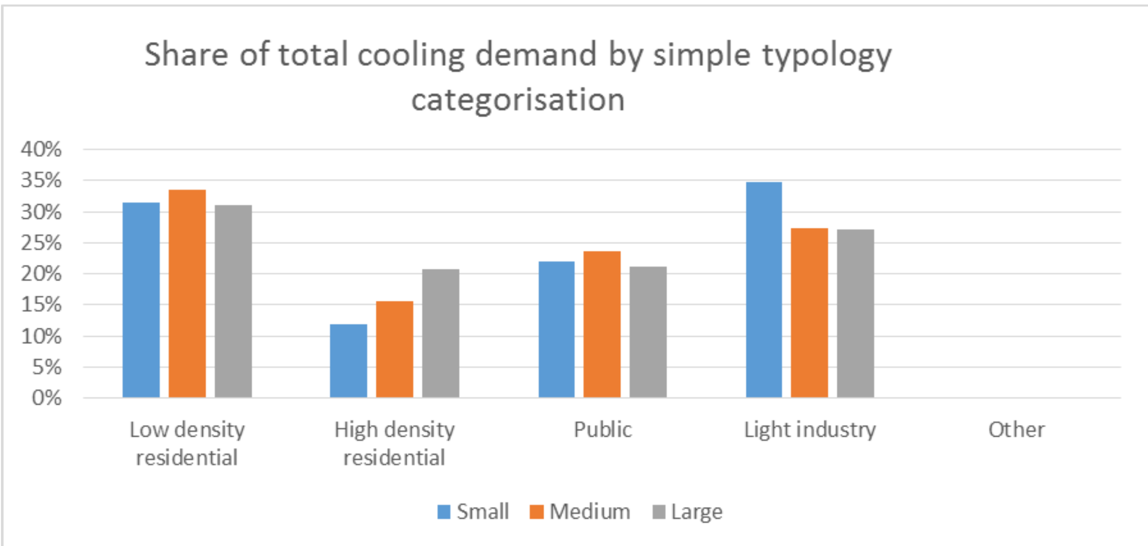

Figure 33 – Total cooling demand @24 distribution for each town size for a simplified typology distribution.

2.7.4 Results for Cooling Demand @26

Similarly to the sections above related to a reference temperature of 24 °C, the term '@26' is used in the following to refer to a set point temperature of 26 °C. The results from the analysis of the cooling demand based on iNSPiRe data are seen below. A comparison between the two set point temperatures of 24 and 26 °C is found in section 2.7.7 together with a comparison to the heat demand.

2.7.5 Average Annual Cooling Demand per km² Ground Area @26

In Figure 34 the average annual cooling demand in GWh/km² is seen for each typology provided for small, medium and large towns respectively (weighted according to area). As for the cooling demand @24 degrees and the heat demand, the tendency for the first four typologies (representing different types of low density residential areas) is somewhat similar and all have rather low demands per km².

For the denser residential typologies of FL ST 5 and 6, the cooling demand per km² is more than doubled compared to FL ST 1 to 4. The heat demand for the public sector FL ST 7 and the light industry in FL ST 8 is similar to the less dense typologies. Contrary for the cooling demand this is higher in these categories. The tendency for the cooling demand @26 degrees is the same as the tendency for the cooling demand @24 – only the cooling demand is lower.

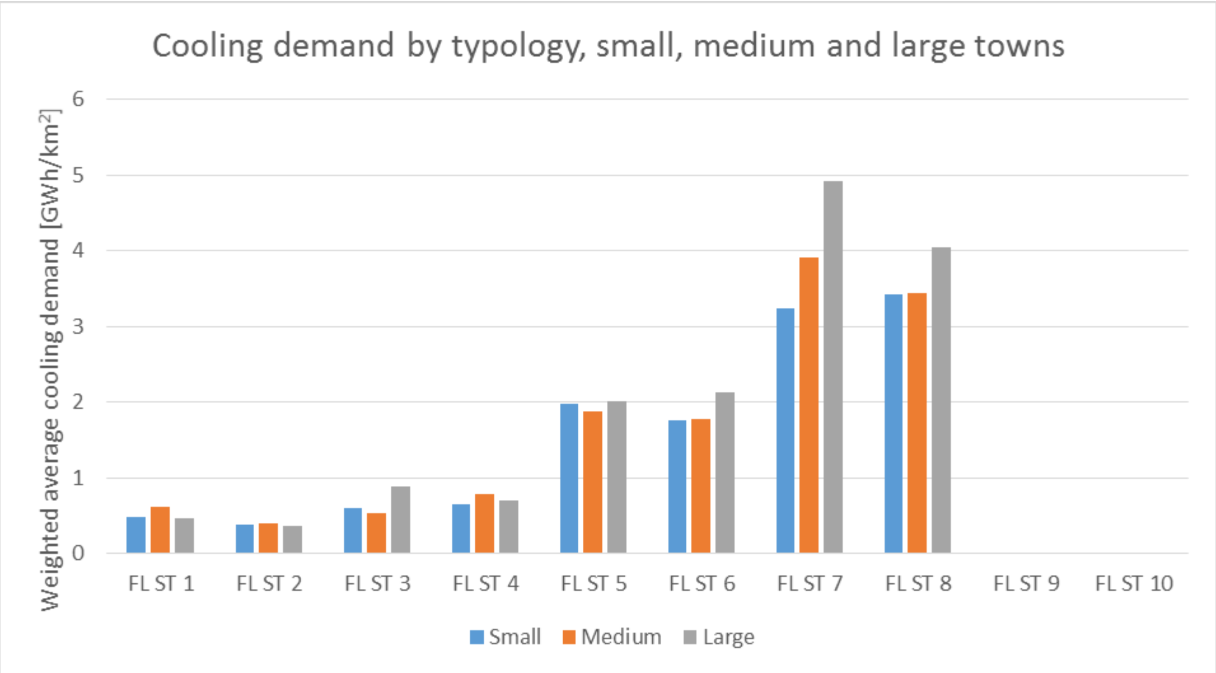

Figure 34 – Average annual cooling demand per km² @26 by typology for small, medium and large towns.

Figure 35 is created by merging the typologies representing similar values and similar categories to give a simpler typology categorisation than in Figure 34. The same trend as for the heat demand and the cooling demand @24 in general, is that the *density* of these simplified typology categories increases somewhat as the town size increases (i.e. the cooling demand per km² increases).

Also for this more simple division, a different trend for the cooling demand @26 is seen, compared to the heat demand; the cooling demand density is highest for public and institutions in FL ST 7 and for light industry in FL ST 8.

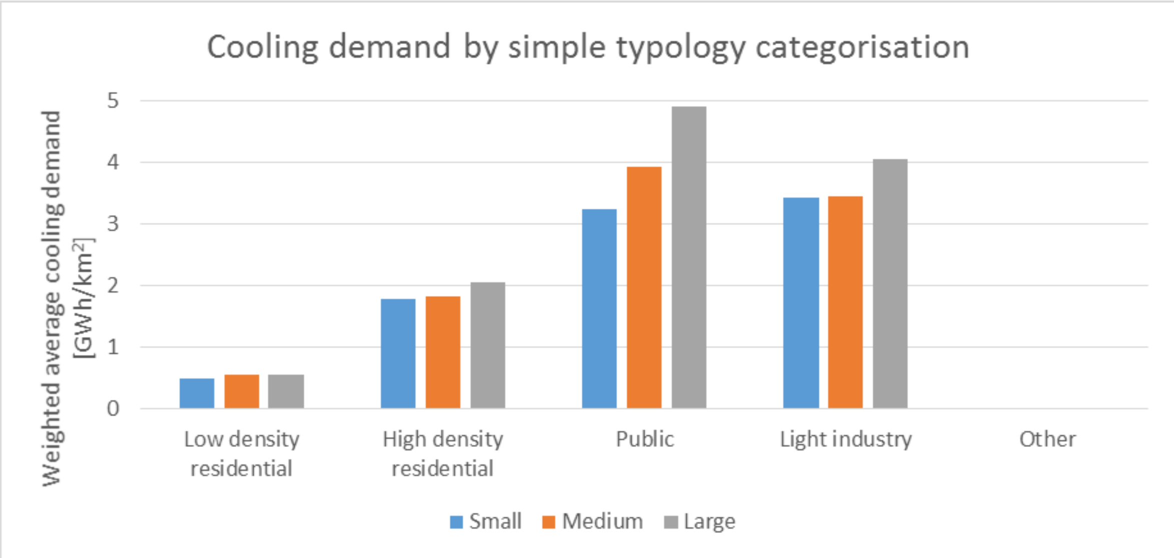

Figure 35 – Average annual heat demand per km² @26 for small, medium and large towns with simplified typology categorisation.

2.7.6 Demand Distribution by Typology @26

How much of each typology represents of the total cooling demand @26 is shown in Figure 36. The cooling demand for public, institutions and light industry has a higher share, compared to the share in the heat demand, since the public institutions together with light and heavy industry counts for 31 % in small towns and down to 24 % in large towns.

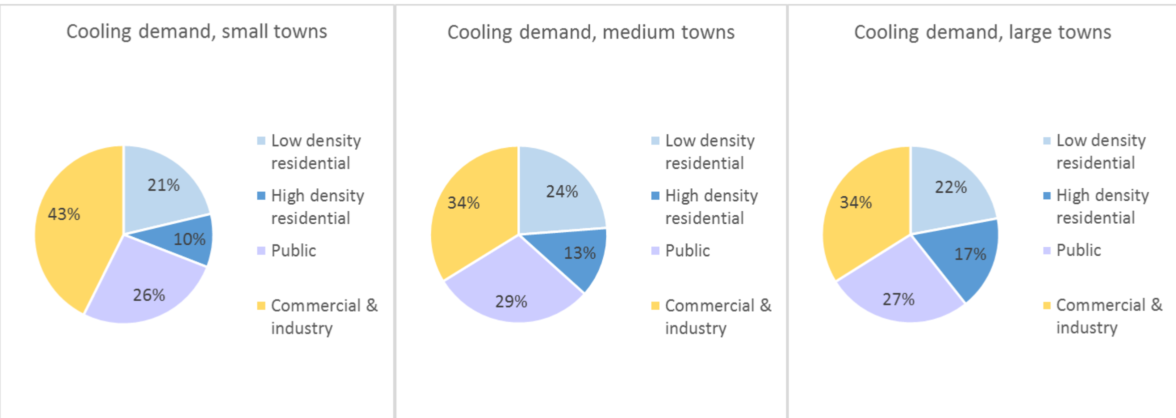

Figure 36 – Cooling demand distribution @26 by settlement typology for small, medium and large towns.

Another observation is that the cooling demand @26 has an even higher share in these categories compared to the cooling demand @24.

Similar to the heat demand analysis, Figure 33 is another way to display the similarities between the typologies in the different town sizes. This way it is possible to determine how significant the tendency is towards higher density when the town size increases. Similarly, it is possible to determine the trends regarding the share of each demand category, as the town size increases.

For the heat demand, the tendency was quite clear; with a high share of the low density residential buildings corresponding to 45-50 % of the total heat demand, the share decreased for high density residential buildings, and continued to decrease for public and light industry and was lowest for the heavy industry typology.

This is not the tendency that is seen for the share of total cooling demand by simple typology categorisation in Figure 37; the share is more evenly distributed but is lowest in the high density residential category varying from approximately 12-20 % depending on town size – i.e. the same numbers as seen for the cooling demand @24.

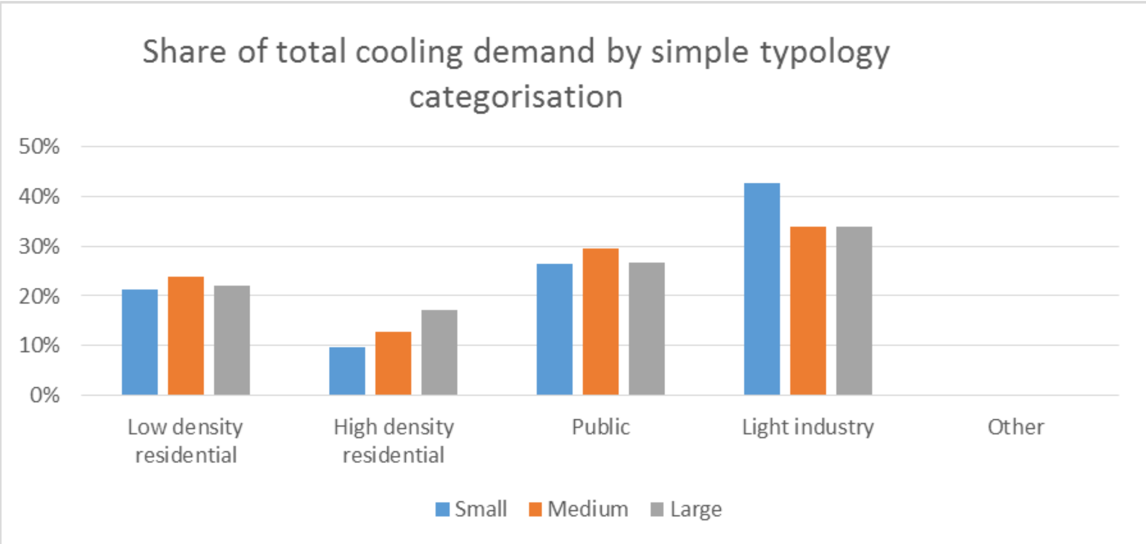

Figure 37 – Total cooling demand @26 distribution for each town size for a simplified typology distribution.

2.7.7 Conclusion on Cooling Demand

For the weighted average heating and cooling demand for each typology of small, medium and large sized towns, the average demand is found and shown in Figure 38. (Note however, that the sources are different for heating and cooling respectively.)

From the figure, it is obvious that the heat demand based on the Danish heating atlas is much higher than the calculated cooling demand based on the iNSPiRe data. The tendency shown in Figure 28 and Figure 29 on the heat demand compared to the cooling demand in EU is in that way confirmed.

It is also clear, that the cooling demand increases significantly when the set point temperature is decreased. For Denmark it has been evaluated that it is not relevant to use a set point lower than 24 °C since the estimated cooling demand based on the iNSPiRe data would be unrealistic high, compared to the estimated cooling demand in other projects, such as Heat Roadmap Europe (www.heatroadmap.eu).

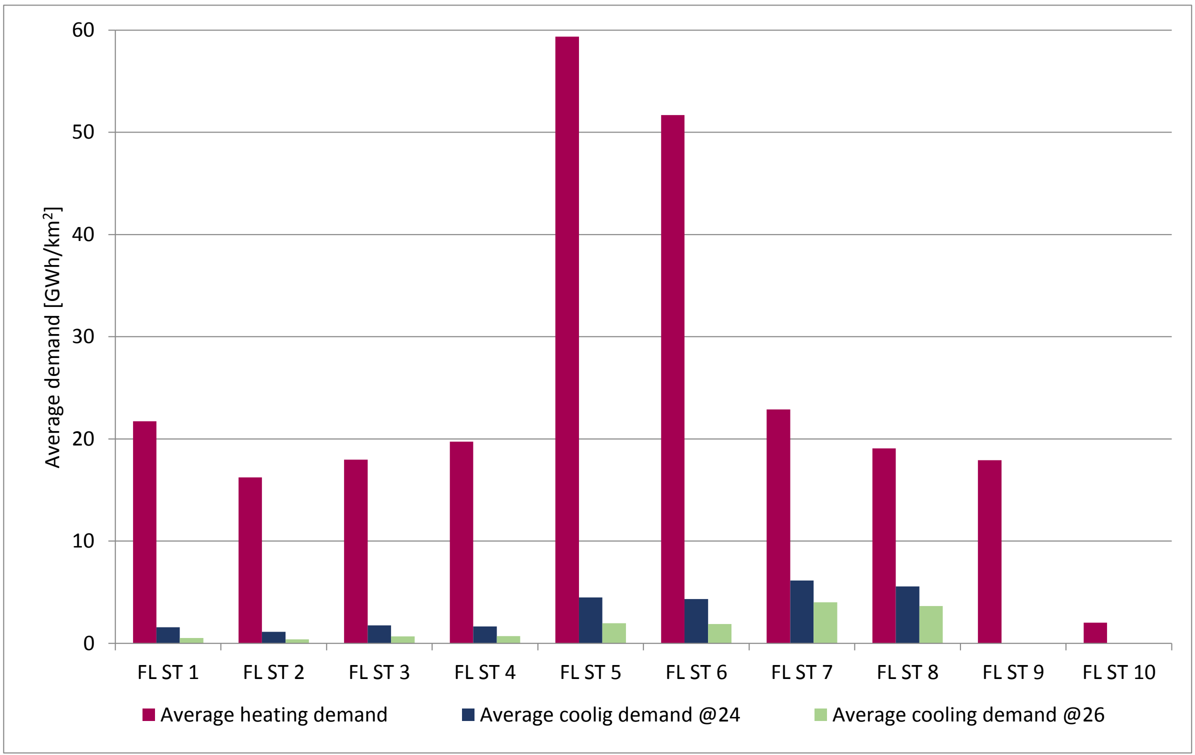

Figure 38 – Average annual heating and cooling demand per km², average by typology for small, medium and large towns.

2.7.8 Validation of Heating and Cooling Trends

Based on the Danish reference towns it was shown that the heat demand is significantly higher than the cooling demand. For Danish reference towns, the heat demand will therefore be the primary parameter for dimensioning of a FLEXYNETS grid. The trend of the heat demand being much higher than the cooling demand seems to be a general trend, as also shown in Figure 28 and Figure 29, showing the numbers used in the Heat Roadmap Europe project.

Through the work performed in relation to the reference towns a range of different projects have been identified, where different views on how to estimate the heating and cooling demand have been identified, e.g. the before mentioned Heat Roadmap Europe and the iNSPiRe projects. But also other EU projects, national references and for instance the International Energy Agency can be mentioned. Therefore a comparison of the identified trends described in this report have been compared to the work done by Associate Professor David Connolly at Aalborg University[10] in a paper describing a 'Quantitative comparison between the electricity, heating, and cooling sectors in a present and future context for Europe'. The purpose of that paper is to compare the annual and peak-hourly demand of electricity, heating, and cooling in European countries, where data is taken from a variety of different sources and combined together to illustrate the scale of consumption for each sector. In the paper, the annual energy demands are compared for all 28 EU countries, while peak hourly demands are compared for four countries that vary considerably in terms of population, climate, area, and energy supply.

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[10] Paper: Quantitative comparison between the electricity, heating, and cooling sectors in a present and future context for Europe, D. Connolly – Department of Development and Planning, Aalborg University, A.C. Meyers Vænge 15, DK-2450 Copenhagen SV, Denmark

The results based on the comparison indicate that the heat demand is currently the largest of the three sectors considered in terms of both annual and peak demands. One of the conclusions is that the heat demand is the largest annual demand in 25 of the 28 EU countries, and it has the largest peak demand in all four countries analysed.

In the paper the annual energy demand for heating, cooling and electricity in the 28 EU countries (EU28) have been identified. The data is based on information at national level for each EU28 country.

The heat demand is divided into demand for buildings and industry. It has been difficult to collect data on heating and cooling demand for industry purposes. The heat demand for the Danish reference towns are based on the Heating Atlas, which only supplies information on heat demand for room and domestic hot water. The paper indicates that a big part of the heat demand for industry will require high temperatures, which does not fit well with the supply from the FLEXYNETS project. On the other hand, this might indicate, that there is a rather large potential for utilising the excess heat in the FLEXYNETS concept and in general in DH grids (see section 2.8 on excess heat below).

When looking into the peak hourly demand for heating, cooling and electricity, the paper highlights similar trends to be observed with a larger share in the heating sector. One of the conclusions was that even in Italy, which had one of the highest proportions of annual cooling demand across all 28 EU countries the peak heat demand is nine times higher than the peak cold demand. However, it is important to notice about the figures in the paper on peak demand that these peak demands occur at different hours of the year, which can influence their impact on the energy system, which need to be considered for each individual case.

The before mentioned paper by D. Connolly also highlights that the demand in the three sectors of electricity, heating and cooling may change significantly in the future due to increased electrification, energy efficiency and demands for comfort especially in the cooling sector. A general trend towards electrification of all types of demand is mentioned in the paper together with a reduction in demand due to increased efficiency of buildings, i.e. through improvement due to additional insulation.

Therefore the paper also present an extreme future scenario, where the heat demand is reduced to 50 % and the full cooling demand for each building is met. The paper suggests that the cooling demand in Europe today may be relatively small compared to the actual potential most likely because people are willing to live with the discomfort of the warm climate in summer for a relatively short period of time.

The results from this scenario show that the heat demand only is the largest demand in three countries and the electricity demand being the most dominant. Hence a significantly change from the trends today.

If the cooling potential were met, the paper refers to a six-fold increase in the cooling demand compared to today. At the same time, the paper states, that the growth of the cooling demand in the future is uncertain, but the general perception is that the cooling demand will increase in the future as demands on comfort levels may increase in the coming decades.

2.8 Excess Heat

An important argument why lower temperatures are interesting in relation to DH is the use of excess heat from industries. In the FLEXYNETS concept, even low temperature excess heat is possible to utilize instead of wasting it to the surroundings.

In general a large potential for utilising excess heat in relation to DH has been identified. That is one of the conclusions from the Heat Roadmap Europe 2 project[11]. An overview of the excess heat potential within the EU27 countries[12] is seen in Figure 39. The 'excess heat ratio' is defined as the theoretically recoverable (i.e. potentially usable) excess heat from any given excess heat process divided by the low temperature heat demands in residential and service sector buildings.

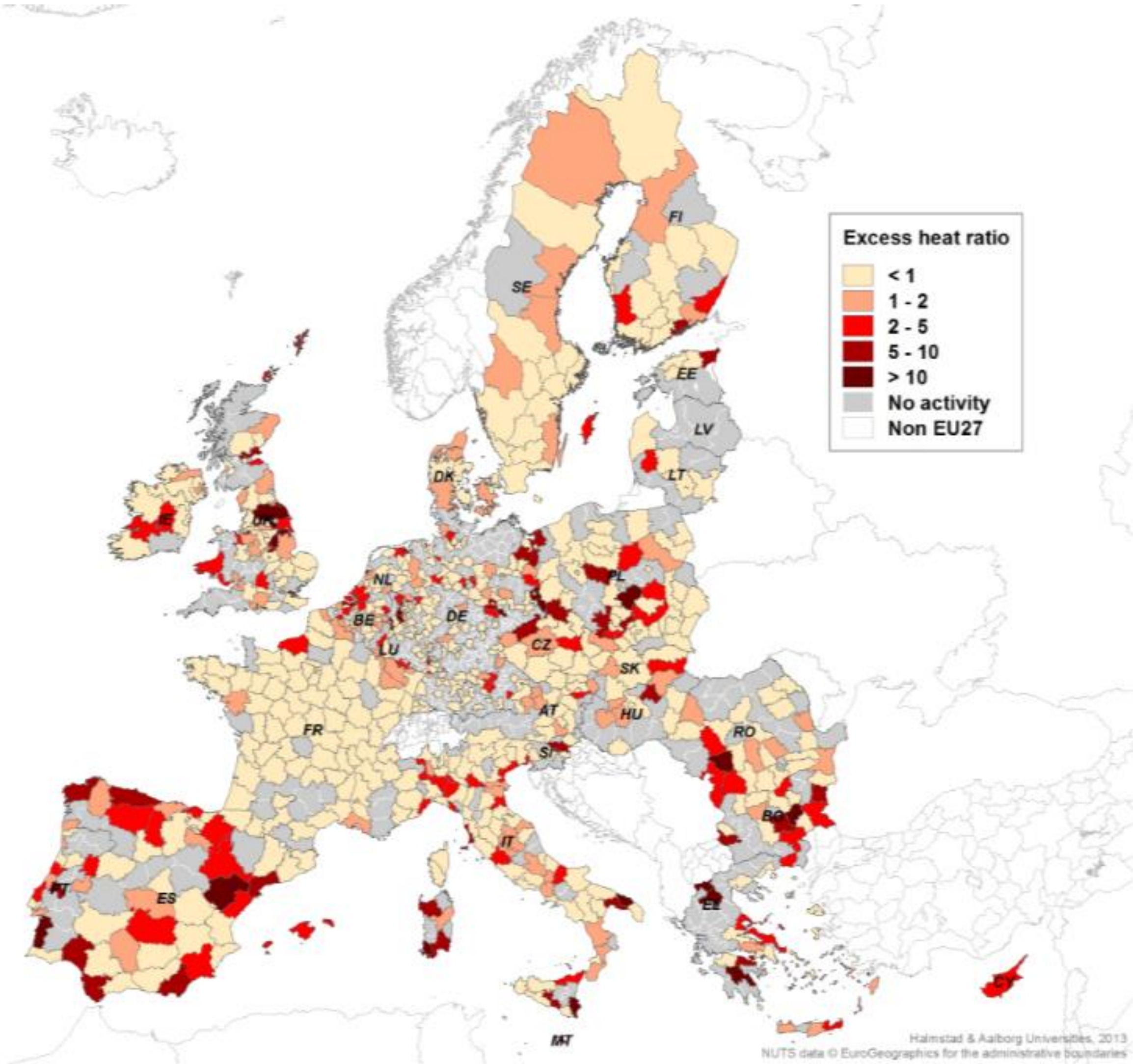

Figure 39 – Overview of excess heat ratio in EU countries (excl. Croatia). (Source: Heat Roadmap Europe 2).

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[11] Heat Roadmap Europe 2 (2013), Aalborg University, Halmstad University and PlanEnergi. vbn.aau.dk/files/77342092/Heat_Roadmap_Europe_Pre_Study_II_May_2013.pdf
The work is further partly result of the research activities of the Strategic Research Centre for 4th Generation District Heating (4DH), which has received funding from The Danish Council for Strategic Research.

[12] Developed before Croatia entered the EU.

Even though there seems to be a rather large potential, experiences show that it can be complicated to utilise waste heat; in Denmark mostly due to taxations, but also because the industries often require very short payback periods. The location of the industry can also be a barrier if transmission lines are needed. Besides this, the utility may not want to rely on a specific company for their heat supply since such a company can choose to shut down their operation due to strategic considerations internally in the company.

More information on large scale excess heat availability in Europe can be found in 'Quantifying the Excess Heat Available for District Heating in Europe, Work Package 2, Background Report 7' in the Heat Road Map Europe project[13].

Even though certain amounts of high temperature excess heat may be available at typical DH supply temperatures, there are arguments for the FLEXYNETS concept as an alternative. Lowering the temperature limit for excess heat to be utilised will increase the potential sources (in numbers and quantities), thus increasing the possible share of heat demand to be covered by excess heat. When using several sources, the security of supply is increased. In some towns, an industry could provide high temperature excess heat, but alternative solutions are preferred because of the uncertainty regarding the long term plans for the industry.

Since the availability, amount and diversity of excess heat available is different from town to town, the excess heat potential can be considered a variable when investigating the feasibility of the FLEXYNETS concept.

[13] heatroadmap.eu/resources/STRATEGO/STRATEGO%20WP2%20-%20Background%20Reports%20-%20Combined.pdf

2.9 Conclusions from Reference Towns Analyses

2.9.1 The 'Governing' Demand

In traditional DH and DC networks, the diameters for DC pipes are proportionally higher than for DH pipes, which is due to the fact that the temperature difference (ΔT) between forward and return flow is typically much lower for cooling purposes, thus requiring a higher flow to move the same amount of heat (heating/cooling). In the FLEXYNETS concept, the temperature difference for heating is lower thus making the ΔT values for heating and cooling in the DHC network more similar. This means that when the annual heat demand is much higher than the cooling demand, *heating* will be the 'governing demand', i.e. the one that the network will have to be dimensioned for (even if the main part of the cooling demand is concentrated in a shorter season).

2.9.2 Settlement Typologies and Synthetic Towns

A total of 15 different towns and cities have been analysed, each disaggregated by means of the 10 different settlement typologies. As seen from the German, Spanish and Italian examples, not only weather conditions affect the demands across towns in different regions. Typically, the insulation levels are higher in Northern European countries, which compensates somewhat for colder climates. The amount of older (non or low-level insulated buildings) also affects the demands. In addition, the height of the buildings (i.e. how many storeys a 'high rise building' typically include) has an impact, since the more storeys, the larger demand when considering the demand per km^2 of ground area. When designing DHC networks in practice, the local conditions will have to be taken into account.

This analysis serves to define the conditions in which the FLEXYNETS concepts can be tested. The different settlement typologies are used as a basis for further analysis of the FLEXYNETS concept – also beyond the scope of this report. For investigating the concepts for complete towns, the average values for the settlement typologies can be combined e.g. by multiplying share of each typology with demand density per km^2 for a certain town size to get a 'synthetic town'.

In the following analysis ('subtask 2'), the network layout is analysed by testing various configurations in different settlement typology environments.

3 Subtask 2 – Network Design

The approach in this subtask addresses the issue of locating the optimum layout for the DHC network, i.e. the path through an area, a town or a city. When designing such networks, the various possibilities for connecting heat sources and sink needs to be taken into account, since the heat supply (and cooling) to the network is not (necessarily) provided from a single source.

Below, a description of the overall methodology is provided. The following sections address some general considerations on how the temperature levels affect the design of the network. This includes considerations such as pipe dimensions and electricity for pumps.

Structure of 'subtask 2' of the report:

- Methodology description
- General considerations
- Model inputs and cases
- Outcomes

The methodology section describes the main steps in the analysis of the layout. The analysis of different layouts is performed by means of a GIS (geographical information system) based tool, using actual demand in different areas from Danish reference town examples.

A section on general considerations is provided in order to understand the general consequences in a DH(C) network, when the temperature levels are lower, while still assuming the same demand.

The main sections describe the model inputs, the cases and the outcomes of the analysis. In general, it should be kept in mind, that the analysis is performed in a steady state, meaning that it is not a hydraulic optimization tool that has been used. With the GIS tool it is however possible to calculate the pipe dimensions, lengths the heat losses, etc. Based on these calculations it is possible to estimate the costs of the grid. In this way it is possible to analyse and compare different layout scenarios in different areas. The outcomes are used to make some general conclusions on layout in different contexts.

3.1 Methodology

Different reference cases are analysed – each including a comparison of the following four scenarios to compare both the ring structure with a 'branch'/'tree' structure, and the FLEXYNETS concept with traditional DH:

a) Conventional DH – Branch structure
b) Conventional DH – Ring structure
c) FLEXYNETS concept – Branch structure
d) FLEXYNETS concept – Ring structure

The preliminary step in the analysis is to decide which pipe types that should be included, in order to determine the hydraulic parameters as well as the investment. These choices are in this analysis based on the general considerations for low temperature DH heating, which are described in further detail in section 3.2. The network is considered as a two-pipe system (i.e. one hot/warm and one cold(er) pipe).

As mentioned in section 2.9.1, here the *heat* demand defines what the dimensions should be. This is also the case for the compared conventional DH solutions. For the cooling demand, individual chillers could be assumed to supplement the conventional DH.

Analysing the network layout with the different scenarios (a, b, c, d above) is done for different town areas representing different settlement typologies. The aim is a supply of industry excess heat to the network (to some extent) and the idea is therefore, that the ring structure should reach out towards industry areas of the towns. Since the branch structure is based on one main network centre (in traditional DH representing the DH plant). To be able to supply industry excess heat to the network, at least one transmission pipe from one industry area to the network centre is necessary. (Alternatively, the investment cost could be allocated to expanding the network dimensions between the network centre and the industry supply point.)

Assuming network connections to industry areas could also represent the option of locating heat production units and/or large scale storages in such areas. Typically, there would not be space available for such installations within the town's residential areas. Reaching sources further away from the town centre opens up for even more heat supply options such as large scale solar thermal systems which often would be too 'area consuming' for the urban environments.

The ring structure network is laid out as a main ring with a certain diameter (to cope with the heat to be transferred in it) and 'branches' going from that ring in order to reach all consumers in the chosen area.

The network dimensioning is carried out by means of a GIS based tool as described in section 3.4. An important requirement for this analysis is the code for the GIS tool, in order to calculate the dimension and the length of grid between two consumer points by using preconditions corresponding to the assumed concept and chosen scenario.

A model for both conventional DH and the FLEXYNETS network is developed based on the assumptions for temperature levels in the two types of networks. The required pipe diameter for a given demand is based on dimensioning of pipes to cope with peak demand just as it is normally done in 'traditional DH schemes'. Since the electricity for the consumer heat pumps represent a share of the delivered 'end use heat', the peak demand for the network is somewhat lower in the FLEXYNETS concept compared to the traditional DH network.

The geographical inputs for the GIS tool include the location of each consumer and the streets of the town. These parameters are used to determine the distances of each pipe in the network based on actual road lengths. This avoids assumptions of a network laid out *through* existing buildings.

The Heat Atlas contains the annual heat demand of each consumer (building). This way the tool takes both the size of the consumers and their distribution along the network into account.

Supply points are included manually to define the grid starting point(s). For a traditional DH networks these represent the DH plant(s). Similarly, this point represents the starting point of the branch structure for the FLEXYNETS concept. To create the ring structure, several supply points are inserted. Each one of these represents a starting point for the network structure. The ring structure only needs small branches ('twigs') from several supply points along the ring, to reach all consumers, compared to thicker main pipes required in the centre part of the branch structure.

The principle of the methodology is shown in the flow chart in Figure 40 below. It is important to remember, that the analysis of different layouts in the built environment is assumed to take place in steady state conditions, meaning that all hydraulic parameters are fixed.

The analysis is based on the two following main assumptions setting the base for the analysis:

Type of DHC network	Pipes used	Temperature levels
Conventional DH	Series 3 pipes	78/41 °C [14]
FLEXYNETS	Series 1 pipes	25/10 °C

The parameters for chosen pipes are used to adapt the code that forms the input for the GIS tool in order to adapt it for the concept in question (FLEXYNETS/conventional DH). The input for the model and hence the code are described more in detail in section 3.4.

The overall purpose of the model is to locate the shortest grid length to supply all the consumer points from the Heat Atlas based on the actual road lengths.

The outcome includes total length of the distribution grid, the total investment costs and heat losses.

The methodology can also be used to calculate the costs per MWh heat (or cooling) delivered. For stakeholders to consider investing in this concept, feasible solutions must be presented. For the final consumer, the heat price for staying comfortable is often the key parameter. Therefore, the outcome of this analysis can prove to be a valuable tool for dissemination activities when combining the results with other investment costs as shown in the dotted box in Figure 40.

Examples of 'other costs' are the investments in heat production units which is used to calculate the annual capital costs, costs for fuel and maintenance, investments in the heat pumps at each consumer, electricity prices etc. All these costs can then be added up and compared with the demands at the consumers to get a final average cost of the energy (heating and/or cooling) delivered to the consumer in EUR/MWh.

[14] Chosen examples of hot and cold pipe temperatures for a two-pipe system. For traditional DH this corresponds to average values for Denmark, Benchmarking 2011/12.

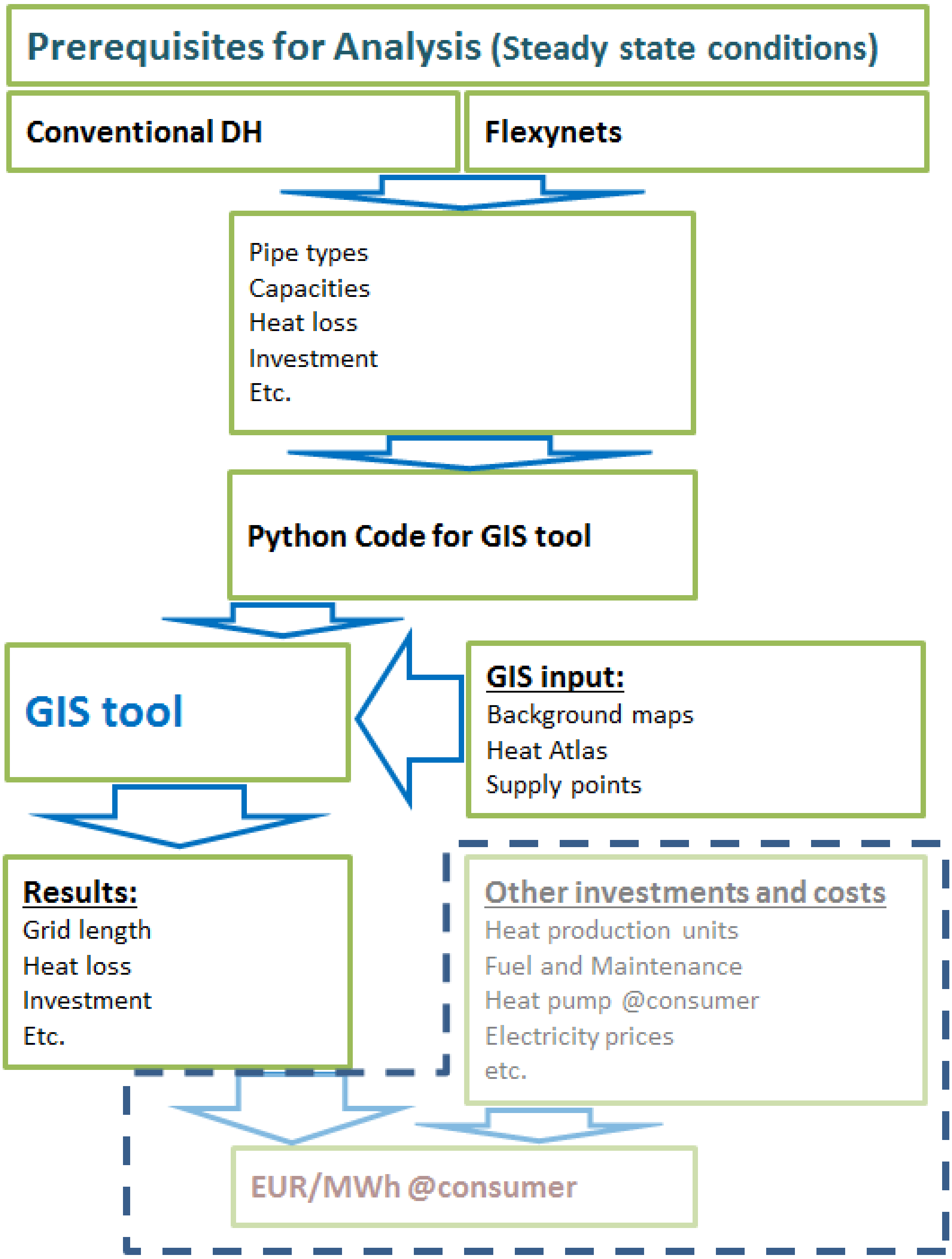

Figure 40 – Principle of the used methodology.

3.2 General Considerations

In order to distribute the heating and cooling to the customers a network is required. Due to the low temperatures it could be established as plastic (PE) pipes or as pre-insulated pipes as in 'traditional' district heating, normally using steel pipes. Considering plastic pipes in relation to the FLEXYNETS concept, the following advantages are identified for the material Polyethylene (PE):

- Low weight
- Flexible
- Corrosion resistant
- Low friction

PE pipes can be supplied with or without insulation. Steel pipes are a known technology from district heating and cooling and can be established in the same pipes as the ones used for district heating. The tubes can advantageously be established with lowest insulation class since the temperatures in the FLEXYNETS concept do not deviate much from the surrounding soil temperature. However, in this case it is still important to insulate and install alarm systems to prevent corrosion damage, which can cause premature failure of the pipes.

Some general considerations are described in the following sections, where the temperature's impact on the pipe dimension and required pumping energy is evaluated. These general considerations are included, since many parameters depend on the temperature levels in the network. It is relevant to look into the consequences of the following points for different temperature levels:

- Required diameter
- Flow rate
- Pumping energy
- Insulation materials and thicknesses

All these parameters affect the investment and the operational performance and costs of a DHC system and are therefore important to consider in the design phase. Insulation considerations are described in section 3.4. The general considerations are made by rather simple hydraulic calculations performed in Excel based on the assumptions shown in Table 10.

Table 10 – Assumptions for general considerations.

No of consumers	30	consumers			
Average peak load	15	kW	Assumed constant		
Load - Conventional DH	450	kW	Velocity	0.65	m/s
Heat pump COP	5				
Load - Low temperature DH	360	kW			
Length	30	m/consumer			
	900	m distribution grid			
Pressure loss	100	Pa/m			

The analysis is not based on a specific example but serves to show some general considerations. The considerations are shown for different temperature levels for conventional district heating and low (incl. ultra-low) temperature district heating.

3.2.1 Temperature and Pipe Dimension

The choice of temperature levels affects the required diameter and thereby the investments to fulfil the specified demand. In general, the lower the temperature difference, the larger the required dimension. To calculate the flow in m^3/s, it is used the total load, the water density (ρ), the specific heat capacity (c_p) and the temperature difference between hot and cold(er) pipe (ΔT).

In Figure 41 the pipe diameter is shown (left axis) for varying supply temperatures (horizontal axis). Since the temperature difference will not be held constant while aiming for lower and lower supply temperatures in a DH network, in this example ΔT is decreased slowly as the supply temperature decreases. The assumed ΔT can be read for each supply temperature at the right axis. The calculated required diameter is shown together with the actual pipe dimension (chosen from suppliers' available pipes on the market). The gap represents the change between 'traditional' DH and low temperature DH. The figure indicates how the pipe dimensions are affected by the choice of temperature levels.

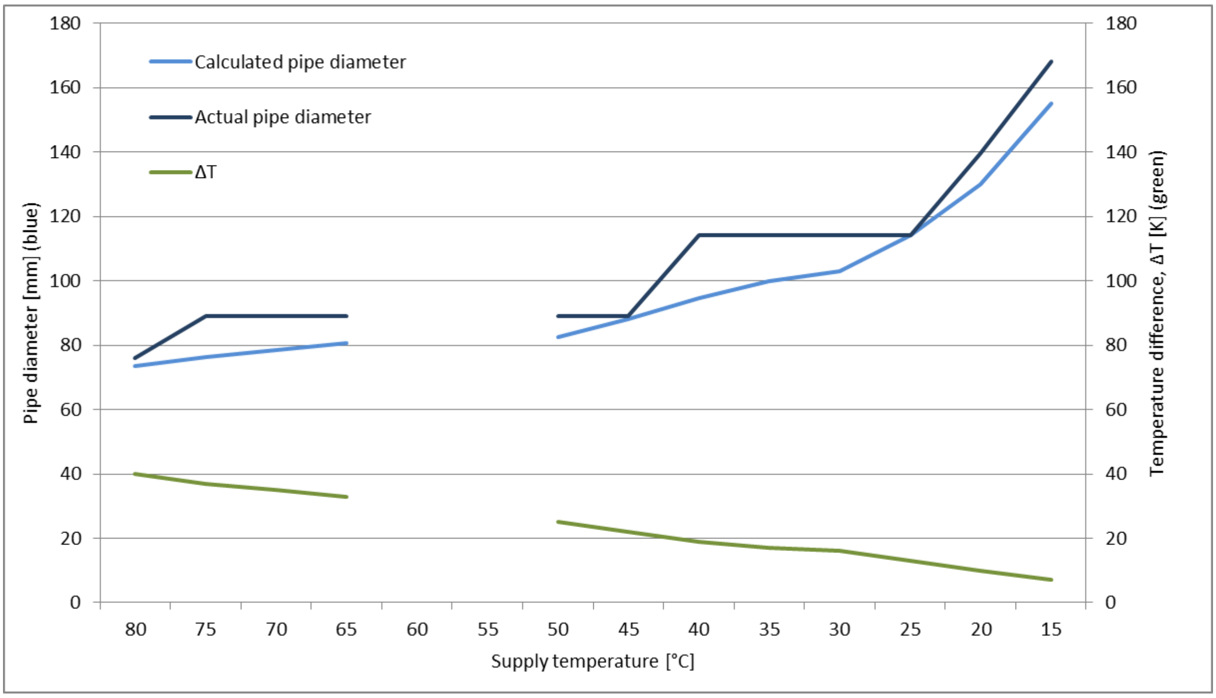

Figure 41 – Estimates of calculated pipe dimension (left axis) as function of supply temperature. Note the reversed order in the horizontal axis numbers. The assumed temperature difference is shown according to the right axis.

3.2.2 Temperature and Flow

The flow is proportional to the temperature difference ΔT. The results for this analysis and the estimated flow for the different temperature levels are seen in Figure 42, where the flow is shown according to the right axis. The figure indicates how the flow is affected by the choice of temperature levels with the same pipes as in Figure 41.

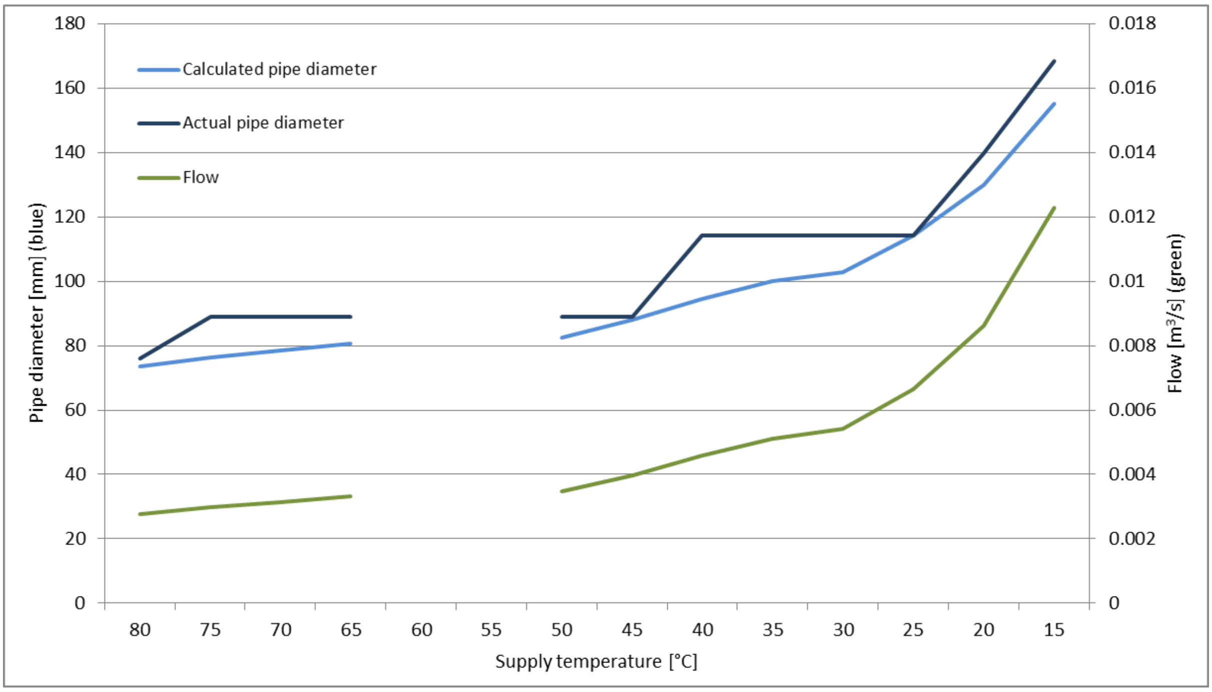

Figure 42 – Estimates of pipe dimension as function of supply temperature. The flow corresponding to the calculated diameter is shown on the right axis.

3.2.3 Temperature and Pumping Energy

The pumping capacity (P_{pump}) depends on the flow (Q) and the pressure losses (Δp) according to the following equation:

$$P_{pump} = Q \cdot \Sigma(\Delta p) \qquad [W]$$

In general, the power consumption by the pump increases proportionally to the flow and head. Hence, if the flow is doubled and the pressure loss is the same, the pumping energy is doubled. Results from this simple calculation example for each temperature level are seen in Figure 43, where the estimated required pumping capacity is seen at the right axis. The figure indicates how P_{pump} is affected by the choice of temperature levels with the same pipes as in Figure 41 and Figure 42.

Based on the simple and general considerations for the described prerequisites in the analysis above, correlations between the temperature levels and the following parameters are seen:

- Pipe dimension
- Flow
- Pump capacity

It is clear that all three parameters increase as the temperature levels decrease. The slope of the increase becomes steeper for all three parameters when the supply temperature falls below 25 °C. In a feasibility analysis and in the design phase, this should be taken into account. The two following paragraphs explain some general considerations on pipe type, pressure loss and heat loss, which should also be taken into account under the establishment of a new grid.

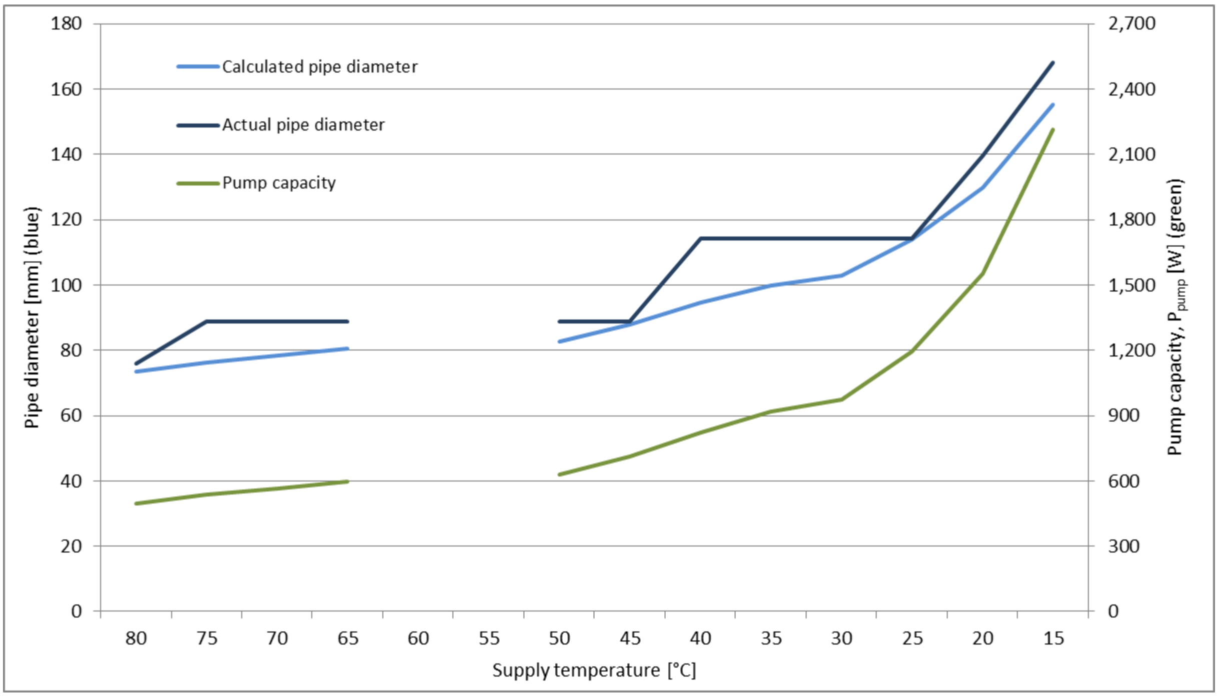

Figure 43 – Estimates of calculated pipe dimension as function of supply temperature. The estimated pumping capacity (related to calculated diameter) is shown on the right axis.

3.2.4 Pipe Type and Pressure Loss

This section relates to the previous paragraph on the energy needed for pumping. There it was shown, that the larger dimensions in general require an increased flow range. This paragraph explains how the energy loss differs depending on pipe type. In general, the energy loss in piping systems falls into two contributions:

1. Losses in straight pipes
2. Loss of individual resistors; fittings as bends, reducers, T-pieces, inlet and outlet of tanks and the like, valves, measuring instruments, heat exchangers

The total pressure loss is the sum of the two points. Point 2 is omitted in this analysis since this is assumed to be more or less the same for both plastic pipes and steel pipes, i.e. there will be the same bends, reducers, etc. When calculating the pressure loss in straight pipes, the following parameters are important:

- Flow rate [m/s]
- The pipe diameter, d [m] (alternatively, the hydraulic diameter d_h)
- The roughness, k [m]
- Kinematic viscosity, [m^2/s]
- Flow shape. It is determined whether there is laminar or turbulent flow, this is assessed using the Reynolds number Re

A distinction is made between rough turbulent flow, smooth turbulent flow and laminar flow. In assessing the flow the viscous boundary layer, which is the film layer existing at the pipe wall, is evaluated. The relationship between these parameters and the pressure loss (and thereby required pump energy) is complicated and difficult to solve analytically. Therefore, an empirical relationship for determining the pump energy is developed. Most important is the relation between the surface (roughness) and the flow. The roughness of the pipe varies for different pipe types. Some typical values are[15] (k-values in m):

Steel pipes	0.001 – 0.00015 m
Plastic pipes	0.000005 m
Cobber pipes	0.00015 – 0.0000015 m

Some rough calculations have been done by using Colebrook's formula. Calculated for one pipe of the type DN100 (pipe diameter of 114.3 mm) for a length of 10,000 m, the following results were found using an electricity price of 100 EUR/MWh:

Pipe	Roughness	Pump energy	Costs
Steel	1 mm	280 MWh/år	28.000 EUR/y
Steel	0,15 mm	170 MWh/år	17.000 EUR/y
Plastic	0,005 mm	130 MWh/år	13.000 EUR/y

In the example above, the energy for pumping and thereby also the costs are more than double for steel pipes with the highest k number compared to plastic pipes. However, if steel pipes with a low k-value are chosen, the pumping costs are much more similar to the ones of plastic pipes. For further reference in this report, steel pipes are assumed. By assuming the same type of pipes, the same source (manufacturer) of pipe prices can be used to provide prices for different steel pipe insulation classes. This way the cost of the FLEXYNETS network is more comparable with the cost of conventional DH network.

3.2.5 Pipe Type and Heat Loss

To illustrate the expected lower heat loss in the FLEXYNETS concept, a simple analysis of heat loss in the three standard classes of pre-insulated DH pipes has been carried out. The heat loss (Φ_{pipe}) has been calculated based on the following, simple equation for one pipe:

$$\Phi_{pipe} = U_{pipe} \cdot (T_{supply} - T_{ground}) \qquad [W/m]$$

where, T_{supply} is the supply temperature in °C and T_{ground} is the temperature of the ground in °C.

Some typical values of heat loss are seen in Appendix B: Heat Loss Values, which includes values for both one pipe and pairs of pipes.

The heat loss value, or the U value, is determined by the lambda value, λ. Lambda is the thermal conductivity of the insulation of pipes. This value ranges from 0.024 W/(m·K) at continuously operation to a lambda value of 0.026 W/(m·K) at discontinuous production. For comparison, the lambda value of plastic pipes with no insulation is approximately 0.35-0.40 W/(m·K). The heat loss for plastic pipes with no insulation is therefore significantly higher than in traditional DH pipes, even at the low FLEXYNETS temperature set at 25 °C forward and 10 °C in return.

An overview of the heat loss for each diameter can be seen in Appendix B. The heat loss is primarily determined by the dimension of the pipes, the thermal conductivity and the used temperatures. When comparing the heat losses for conventional DH and FLEXYNETS, it is important to be aware of the difference in capacity a given dimension is able so supply. Due to the lower temperature difference in the FLEXYNETS concept – compared to conventional DH – the pipes will in general need

[15] Typical values from Danvak (a network for technical and scientific professionals working with HVAC).

to be of a larger dimension in order to supply the same capacity. This is seen from the following table that shows the estimated capacity at the used temperature set for the analysis in Section 3.4 Model Input (i.e. 78/41 °C for conventional DH and 25/10 °C for the FLEXYNETS concept for the hot and cold pipe respectively).

Table 11 – Estimated capacities for conventional DH and FLEXYNETS based on the temperature set used in the analysis later in this report.

Pipe mm	Pipe type DN	Conventional DH Capacity in kW	FLEXYNETS Capacity in kW
33.7	25	40	16
42.4	32	77	31
48.3	40	159	65
60.3	50	288	117
76.1	65	544	221
88.9	80	830	336
114.3	100	1,610	653
139.7	125	2,763	1,120
168.3	150	4,529	1,836
219.1	200	9,140	3,705
273.0	250	16,282	6,601
323.9	300	25,993	10,538
406.4	400	47,170	19,123
508.0	500	85,042	34,476
609.6	600	136,520	55,346
711.2	700	204,340	82,840
812.8	800	289,469	117,352
914.4	900	392,893	159,281
1,016.0	1,000	516,550	209,412

To give an example, it will require a pipe of the type DN65 to supply 0.5 MW at the temperatures for conventional DH. To supply the same capacity, a larger pipe is required in the FLEXYNETS case where it would require a pipe type DN100. The exact dimension will of course depend on a detailed hydraulic analysis taking parameters such as flow and pressure conditions in to account.

The heat loss in the case of Conventional DH will be given by the pipe type DN65, corresponding to approximately 12-13 W/m, while the heat loss in the case of FLEXYNETS will be given by a DN100, corresponding to 4-5 W/m. In each case estimated based on the different temperature set for Conventional DH and FLEXYNETS.

Note also, that the heat loss depends on the fluid temperature, the temperature of the surroundings and the type of insulation with a given heat transfer coefficient. The heat loss is therefore relatively constant in steady state for the same temperatures. However, the 'temperature loss' (i.e. the drop in temperature over a given pipe distance) in a DH(C) system also depends on the flow of the fluid. At low flow rates, the temperature loss is higher than the temperature loss at higher flow rates.

The impact of the temperature loss is not expected to be significant for this analysis and is therefore not taken into account here.

3.3 Key Performance Indicators

For district heating or cooling to be competitive on the market, the generation costs and distribution costs, meaning the total costs for district heating or cooling deliveries, must be lower than the end customer costs of any individual or local alternative.

The essence of this is that the cost effectiveness of district heating and cooling systems depends on a balance between two primary parameters:

- Heat demand concentration (population and heat demand densities)
- Total network investment costs (construction costs and economic investment conditions)

Therefore, it is necessary to identify feasibility thresholds in such projects, e.g. required minimum levels of demand concentrations at given investment capacities. A general assessment of the end user costs is illustrated in Figure 44.

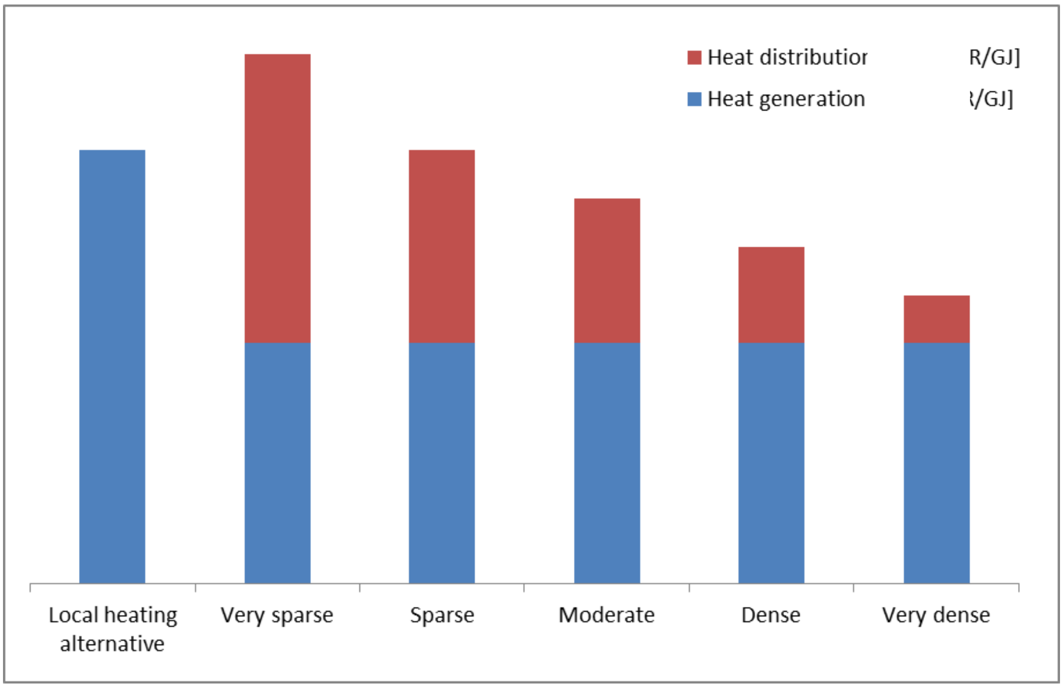

Figure 44 – General comparison of total consumer costs for a given local heating alternative and district heating. Secondary axis is omitted since the chart is only for comparison purposes.

The blue bars in Figure 44 illustrate the heat generation costs per energy quantity (e.g. EUR/MWh), and the red illustrates the distribution costs in the same unit. The figure does not show any values since the purpose is to show the general tendency. The figure is reproduced from the report 'Realise the Potential! – Cost effective and energy efficient District Heating in European Urban Areas' by Urban Persson[16].

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[16] Urban Persson, 'Realise the Potential! – Cost effective and energy efficient District Heating in European Urban Areas', 2011, p11, www.diva-portal.org/smash/get/diva2:505458/FULLTEXT02

In the book 'District Heating and Cooling' by Svend Frederiksen and Sven Werner[17], a typical threshold value which is often considered for being directly feasible district heating is 40-50 kWh/m^2 (ground area). However, it is also mentioned that in countries or regions with highly cost effective district heating, the threshold value can be as low as 20 kWh/m^2. Comparing with the figures in subtask 1, it should be noted that the values in kWh/m^2 is equal to the same values in GWh/km^2.

The threshold depends on the used technologies and fuels. A common opinion about a threshold for DH viability is 42 kWh/m^2 ground area, based on competition with fossil fuels for heating. However, a future threshold is thought to be as low as 11-22 kWh/m^2, when no fossil fuels are used for heating. This level has already been reached in Sweden and Denmark, where high taxes are applied for fossil fuels used for heating.

Another widely used performance indicator is the linear heat density. The linear heat density is described further in Appendix C.

Investments in new district heating and cooling networks will depend on mainly construction costs and pipe diameter. The cost of construction differs from high in inner city areas to lower in park areas as indicated in Figure 44.

One of the most important indicators for conventional DH heating networks has been the heat density – the perception is that a high concentration of heat demands gives low distribution capital costs and low distribution heat losses.

Other key performance indicators (KPIs) are for instance the linear heat demand, meaning the heat demand per m of network, which is in close relation to the heat density.

The used results from the analysis in this report are the final numbers on e.g. investment in the grid and the heat loss. The KPIs that is used to compare the different scenarios are:

Parameter	Unit
Linear heat density	MWh/m
Linear heat loss	MWh/m
Heat Density	MWh/km^2
Effective width	-

A structure for KPIs of district heating networks is given in the paper 'Quality indicators for district heating network'[18]. The paper focuses on how the performance of district heating network can be qualified through different indicators. These KPIs are explained further in Appendix C, together with some more detail on other KPIs as well.

17 Svend Frederiksen and Sven Werner, 'District Heating and Cooling', 2013.

18 By Pascot, Pierre-Emmanuel and Reiter, Sigrid, 2011, ISBN 9782839909068.

3.4 Model Input

The examples of preliminary network design (pipe dimensions and lengths) are based on the elaboration and adaptation of an existing software tool developed for conventional DH. Before using it in the FLEXYNETS analysis, the tool has been adapted in two new versions – one for the properties of the FLEXYNETS concept and one for the properties of conventional DH used in this report. It is important to have in mind, that the analysis is based on steady state conditions for fixed temperature levels:

Conventional DH[19]	Forward 78 °C	Return 41 °C
FLEXYNETS	Forward 25 °C	Return 10 °C
Ground	8 °C	

A ground temperature of 8 °C has been used. The ground temperature can vary from approx. 2 °C in peak winter conditions to app. 14 °C for summer months[20].

Below is described how the model calculations are carried out and how the pipe types, pipe heat loss coefficients and investment costs need to fit with the chosen concept and its predefined properties (FLEXYNETS or conventional DH) in the model.

3.4.1 GIS Software Tool for Designing Networks

The software tool is GIS based and developed for Danish towns. It determines the pipes needed to form a network where every consumer within a certain (chosen) area is connected to a node representing the heat supply (e.g. district heating plant). The user chooses the location of the node. If several nodes are inserted, the shortest route to the closest node is found. This network simulation software is chosen to help consider the optimum layout of the network, i.e. identifying the best performing solutions in terms of piping length and heat transport. Where two or more connections overlap each other, the tool calculates the size of pipe required for the merged flow.

The tool calculates total pipe diameters, length (of each diameter) and layout in the city for the lowest possible distance between the consumers and the predefined source point(s). These source points can be either a single source such as a central DH plant (as it is often seen for conventional DH) or they can be a series of nodes forming a ring structure. The network is placed along the existing road network to avoid piping through buildings. The model uses the following steps:

1. Identifies all consumers incl. their demands
2. Identifies the road network
3. Locates the shortest route from the predefined supply point(s) to the point on a road closest to each consumer
4. Defines the demand at the roads
5. Calculates the total heat demand on each route/branch
6. Calculates capacities
7. Calculates investment costs

[19] Based on average for all DH utilities in Denmark 2011-2012, Benchmarking and statistics from Danish District Heating Association.
[20] `Method for optimal design of pipes for low-energy district heating, with focus on heat losses`, Dalla Rosa A, Li H, Svendsen S.

8. Calculates heat loss

Pipe types, investments and heat loss are described in the following paragraphs.

Some drawbacks that should be noted are that the tool so far only is developed for Danish towns and cities. The software is made for a specific temperature level. Therefore, the calculations with other than the predefined temperature levels required a rewrite of the source code. This has been done in order to investigate and compare different temperature levels, i.e. FLEXYNETS temperature levels compared to temperature levels in conventional DH. The inputs for the calculation are described in the following sections concerning pipe investments and model inputs.

Another drawback is that the tool optimises for one consumer at a time. This means that the layout in some cases would be more feasible if the pipes merge together sooner than at the node. However, where two or more pipes (for different consumers) are located on top of each other, the tool automatically merges them into one bigger pipe, so the error from this is deemed negligible.

3.4.2 Pipe Types

Based on the simple and general considerations for the described prerequisites in section 3.2, there is seen a clear correlation between the temperature levels and the

- Pipe dimension
- Flow
- Pump capacity

All three parameters increase, as the temperature levels decrease (including lower temperature differences). In a design and feasibility analysis, this should be taken into account. Considering the pumping energy depending on pipe roughness, it seems that the annual costs for pumping can be acceptable using steel pipes if care is taken, that the pipes have low roughness levels. Series 1 pipes have been selected and is in this report assumed in the FLEXYNETS concept. Hence, the analysis is based on the two following main assumptions:

Conventional DH	Series 3 pipes
FLEXYNETS	Series 1 pipes

3.4.3 Pipe Investment

The investment in pipes and the work is based on two sources. The investments in the pipes are from the official price list of a well-known pipe manufacturer[21] and the other pipe related investment costs (ground work, welding etc.) are based on Swedish experiences. The total prices used in the analysis can be seen in Figure 45.

The option of using plastic pipes may make lower costs possible, but for the plastic pipes it should be noted, that these shall be pressure tight and have a diffusion barrier, which add costs to the total investment. A diffusion barrier is used to retain the cyclopentane and carbon dioxide in the insulation but also to prevent nitrogen or oxygen from soil or water from penetrating the pipes.

At the same time, the pipe materials do not represent the majority of the network investment as seen in Appendix A: Pipe Prices and Construction. More detailed information on investment in pipes and labour costs in relation to the grid can be found in the appendix.

[21] LOGSTOR price list, 2016.

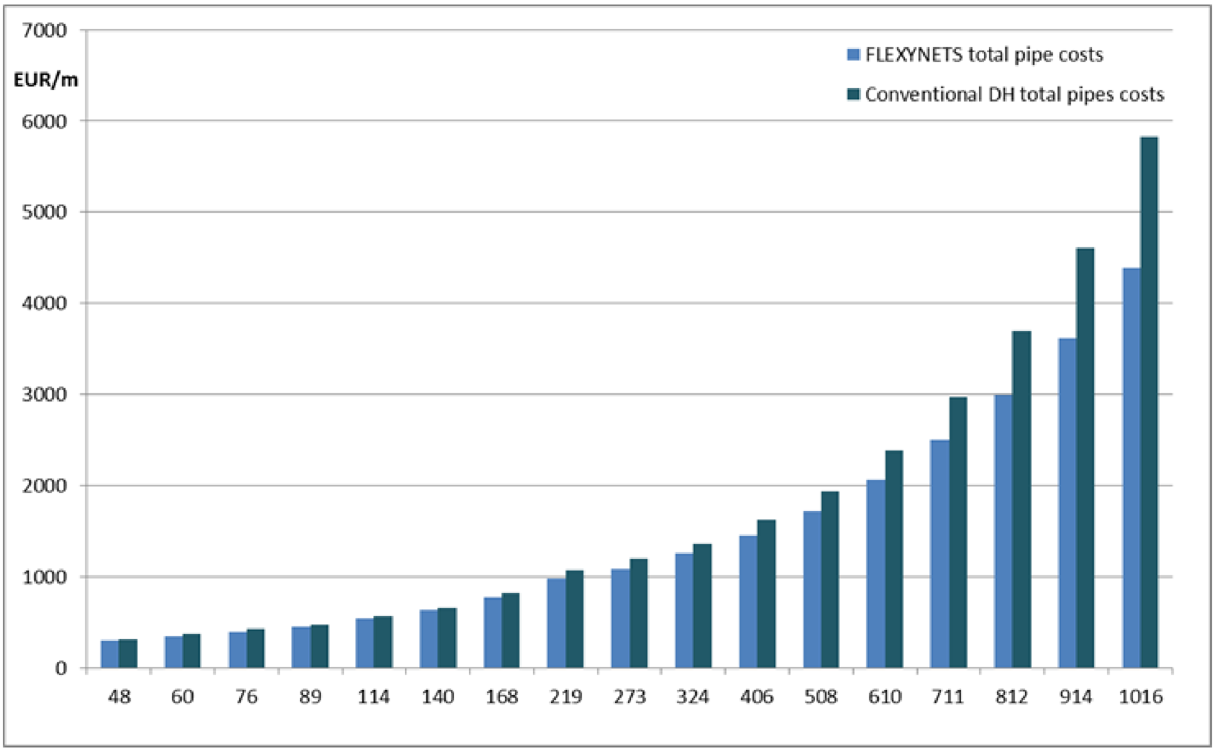

Figure 45 – Total pipe costs for FLEXYNETS and conventional DH including pipe investment and labour costs for each pipe dimension (pipe dimension in mm on the X-axis).

3.4.4 Heat Loss

The heat loss used in the calculations for the two types of pipes is seen in Appendix B. The heat loss is estimated in W per m trench length using the two different set of temperature levels for hot/cold pipe respectively, i.e. 78/41 °C for conventional DH and 25/10 °C for the FLEXYNETS concept.

3.4.5 Layers and Background Maps

For the GIS tool, background maps and layers with geographical information are needed. For this analysis, the following layers have been used:

Background maps: Visualize the contour of the area with e.g. houses

Streets: Contains information on lengths of the streets, which is transferred by the software code in order to calculate the length of the pipes

Heat Atlas: Contains information on the heat demand in Denmark. Each consumer (building) has a record containing location coordinates and the annual heat demand.

The software code is set up so that the shortest route from supply to the demands are found, based on the location and length of the streets, together with the location and demand in the records from the Heat Atlas. If the tool should be used in other countries, similar data would need to be available and an adaptation of the software would be required.

3.5 Reference Cases for Analyses

Figure 46 sums up the heat demand in GWh per km^2 ground area for reference towns in Denmark compared to the weighted average heat demand for each typology (black horizontal bars).

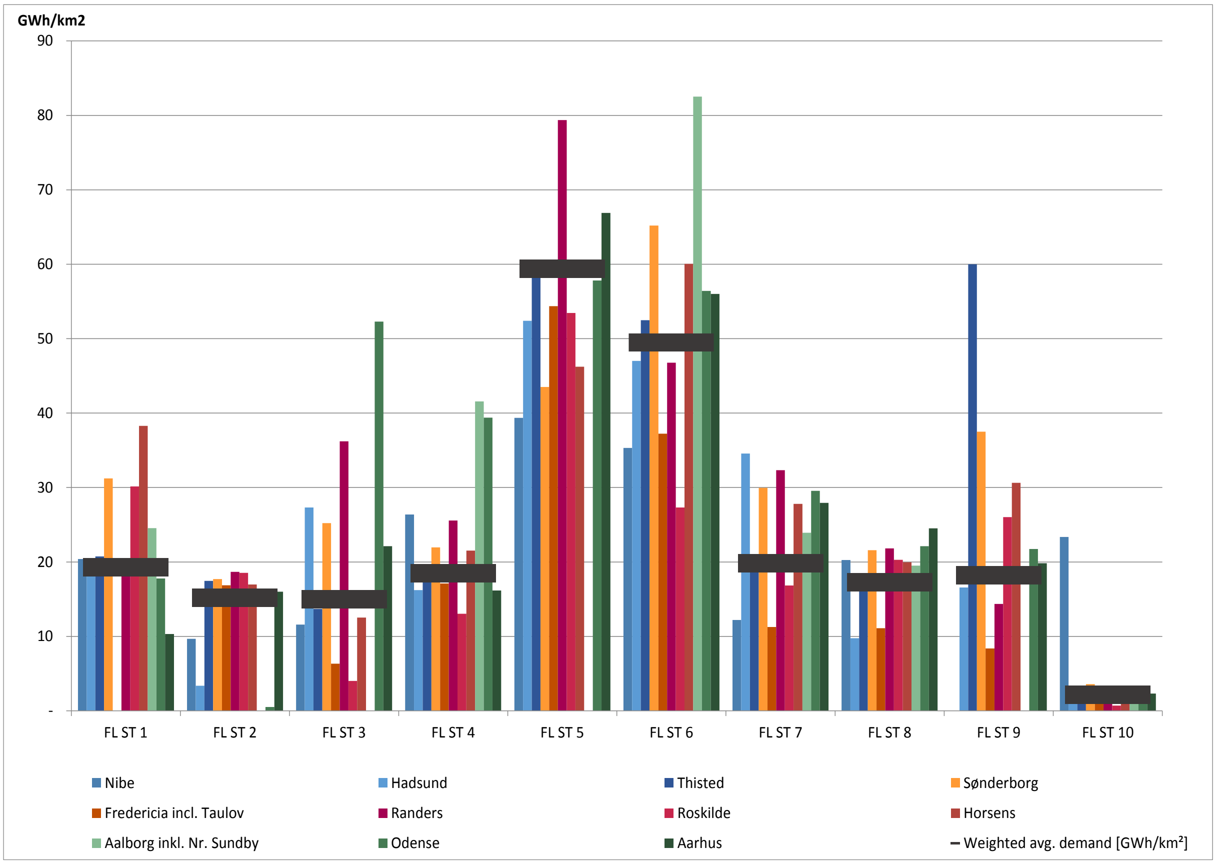

Figure 46 – Overview of heat demand in GWh/km^2 and the weighted average demand for each typology (black bars).

For the analysis in the GIS tool, two towns have been chosen: Hadsund and Aarhus.

Hadsund is in the small town category; the number of inhabitants is around 4,910 and the town area is found to be 4.1 km^2 – meaning that Hadsund has the lowest population density compared to the other small towns, with a density of around 1,200 inhabitants per km^2. Hadsund is therefore considered a case, where the FLEXYNETS concept can be analysed for sparse areas.

Aarhus is on the other hand the most populated town in the category of large towns with a population of 251,570. With an area of 97.7 km^2 the population density in Aarhus is almost 2,680 inhabitants per km^2. Aarhus is the town closest to the weighted average demand in most typologies (see Figure 46). However, by choosing a section of the main city centre, even larger demand densities than the town's average settlement typologies values can be reached.

Aarhus makes it possible both to analyse areas of uniform typologies and areas, where typologies are mixed. For the analysis, three different areas have been analysed; Hadsund, a center area in Aarhus and a mixed area in Aarhus. Each area is presented in the following sections. All results from the GIS tool analysis are gathered in Appendix F: GIS Tool Results.

3.6 Hadsund Case

As previously described, Hadsund is in the small town category with around 4,910 inhabitants and an area of 4.1 km². A map of Hadsund is seen in Figure 47, where a small overview of the town is provided in the lower right corner. The main map shows how Hadsund has been divided into the FLEXYNETS settlement typologies.

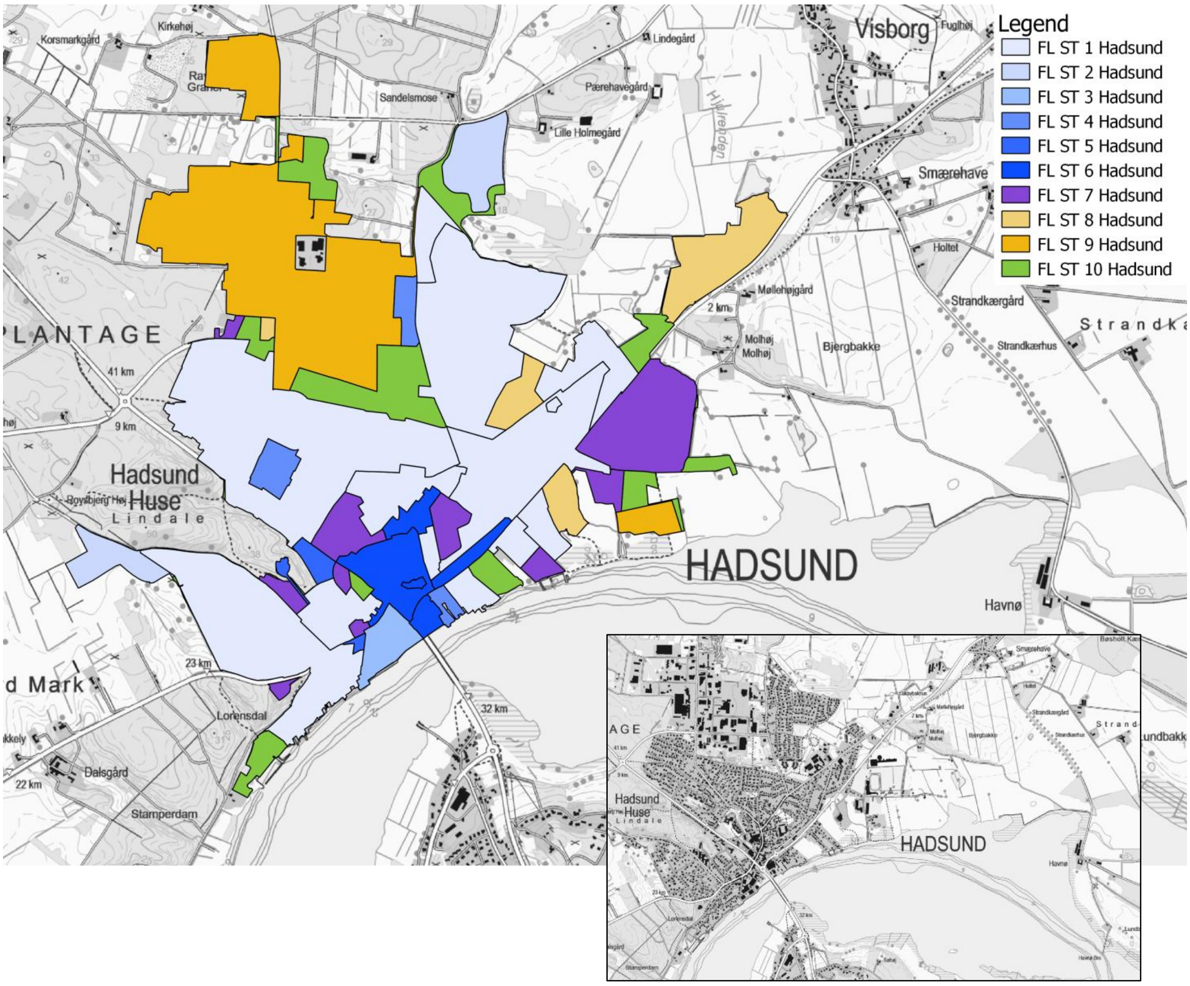

Figure 47 – Map of Hadsund including settlement typologies. (Background map from Geodatastyrelsen Denmark.)

For the analysis of Hadsund, the following four scenarios have been applied in the GIS tool:

1. Conventional DH – Branch structure
2. Conventional DH – Ring structure
3. FLEXYNETS concept – Branch structure
4. FLEXYNETS concept – Ring structure

For the branch structure, only one supply point has been placed in the centre of the town. For the ring structure, several points have been placed, where such a main ring was located along existing roads. The placement of the supply points and the main ring can be seen in Figure 48 together with the result from the GIS tool – estimating the grid structure.

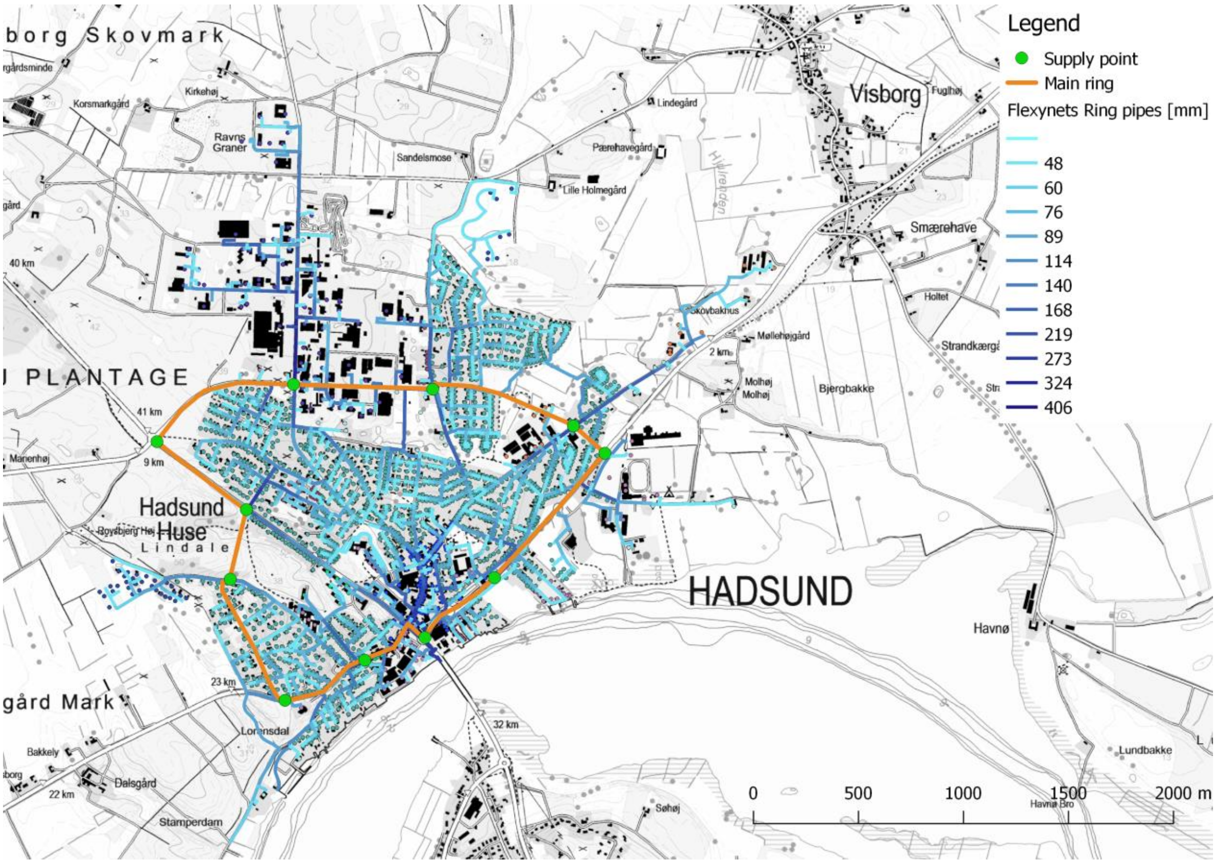

Figure 48 – Ring structure in Hadsund for FLEXYNETS temperature levels, (Background map, Geodatastyrelsen Denmark.)

The total length of the grid varies from 89 km for the branch structure to 94 km for the ring structure. The ring is in this analysis placed close to or in the outskirts of the town for different reasons; 1) in order to have connection to the industry, 2) in order to not put the pipe in yards etc., and 3) to follow already established main roads. However, the rather large geographical diameter has the consequence that the length of the ring is large, compared to the length of the transmission pipe in the branch scenarios, resulting in higher investment costs. Based on the analysis using the GIS based model, the total numbers are derived as seen in Table 12.

Table 12 – Total numbers from GIS analysis for Hadsund. All results can be seen in Appendix F: GIS Tool Results.

Case: Hadsund		**Branch Structure**		**Ring Structure**	
Small town, 4,913 inh., 4.1 km^2		**Conv. DH**	**Flexynets**	**Conv. DH**	**Flexynets**
Total Numbers					
Total length	km	88.8	88.8	93.6	93.6
Total loss	MWh/y	11,702	3,248	12,415	3,332
	%	16.6%	6.4%	17.4%	6.6%
Total heat production incl. Loss	MWh/y	70,711	50,394	71,315	50,452
Total pumping capacity	kW	216.7	454.9	411.7	771.0
Pumping energy	MWh/y	1,898	3,985	3,607	6,754
Total investment for grid	mio. EUR	35.8	39.9	40.0	43.5
	mio. EUR/MW	1.73	2.42	1.94	2.63
Performance Indicators					
Linear heat density	MWh/m y	1.0	0.8	0.9	0.7
Linear loss	MWh/m y	0.19	0.05	0.19	0.05
Heat density	MWh/km^2	14,366	11,493	14,366	11,493
Effective width	m	14.9	14.9	16.2	16.2

It is seen that the calculated heat losses in the example with the FLEXYNETS concept are reduced by almost ¾ compared to conventional DH. On the other hand pumping costs are almost doubled due to the lower ΔT. For the FLEXYNETS scenarios it is useful to recall, that the heat density is reduced due to the use of heat pumps in buildings, with an assumed COP of 5.

3.6.1 Existing DH Grid in Hadsund

For comparison, the actual DH grid in Hadsund town consists of about 80 km grid, of which 35 km are distribution pipes, 43 km service pipes and 2.4 km transmission pipe from a tilework to the plant, making it possible to utilize excess heat from the tilework. The DH grid also has an accumulation tank of 350 m³ for daily variations and a pumping station that provides operating pressure for consumers. The terrain varies in height from 0 meters at the fjord to the highest point at 49 meters. The DH grid spreads over an area of 4.2 km². An overview of the existing DH grid in Hadsund is seen on the map in Appendix D.

Some numbers for comparison to the DH grid analysed in the GIS tool have been extracted from the Danish District Heating Association's Benchmark statistics on the existing grid in Hadsund[22]:

Heat production	65,700 MWh/y
Heat sales (heat an consumer/ab grid)	52,000 MWh/y
No. of consumers	2,011 consumers
Length of distribution grid	39.5 km
Length of service pipes	43.0 km
Heat Loss	13,700 MWh/y
Heat Loss	163 MWh/km
Heat Loss	20.9 %
Linear heat density	1.7 MWh/m

The numbers in this statistics differ somewhat from the calculated results on several parameters. The heat demand used in the model is, as previously described, based on the Heat Atlas. This also means that all heat demands are included – also heat demands that typically are not included as DH potential, such as individual demands covered by biomass, natural gas boilers and heat pumps. This could also explain why the heat demand for the conventional case analysed in the GIS tool is higher than the actual heat demand given in the statistics.

Another difference is the length of the distribution grid. In the statistics, the length of the existing grid in Hadsund is stated to be 39 km, while the length is calculated to be approx. 60-61 km in the GIS tool (both numbers excluding service pipes). This can mainly be explained by the fact, that the existing DH grid does not cover a rather large part of the town in the north-western part, comparing the map of the GIS tool in Figure 48 with Figure 58 where the existing DH grid in Hadsund is shown. On the other hand, the southern part of Hadsund on the other side of the fjord is also supplied by DH heating. Together with this, the number of consumers is higher in the GIS tool, here is 2,276 demand points, while there is 2,011 consumer points in the existing DH grid in Hadsund.

[22] The numbers are from the heating season 2015/2016.

A parameter that could be added to the difference is the fact that service pipes are not included in the GIS tool. Some demands will therefore be covered by a distribution pipe along a street in the GIS results instead of a service pipe as in the actual case. I.e. the tool does not reflect the reality exactly, but can provide a good approximation taking into account the topology of the town.

The fact that the GIS tool does not include service pipes (and the heat losses in these) also explains why the heat loss is higher in the statistics compared to the model output. Since the service pipes are the same regardless of network layout, this does not affect the general conclusions when comparing layout options.

3.7 Aarhus South-West Case

An overview of Aarhus is seen in Figure 49 where the case in the south-western part (Aarhus SW) is highlighted with a red circle.

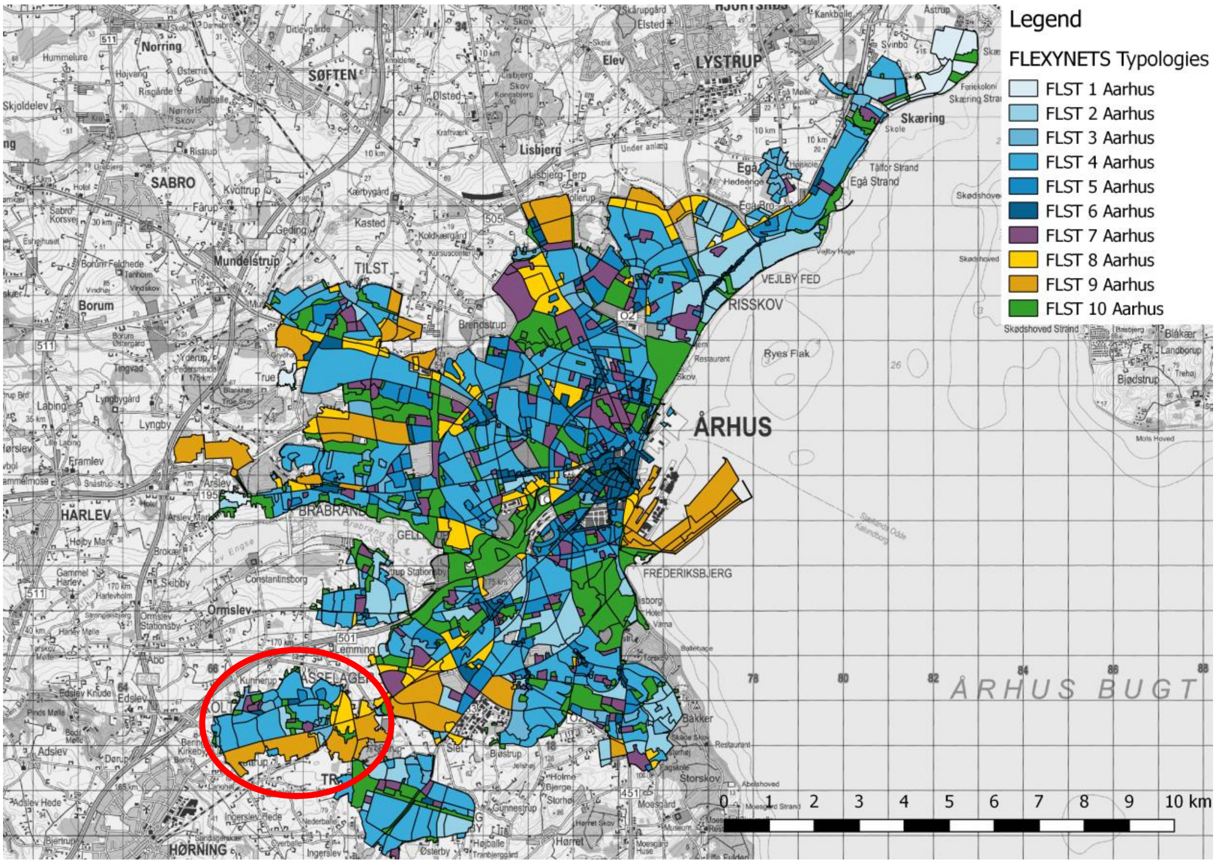

Figure 49 – Overview of Aarhus including settlement typologies. The case in the south-western part is highlighted with a red circle. (Background map from Geodatastyrelsen Denmark.)

Similar to the case of Hadsund, the different network layouts are tested in Aarhus SW. The layout for the FLEXYNETS ring scenario is seen in Figure 50. Most of the network is with small pipes (bright yellow), but closest to the ring connection points (indicated with green circles) somewhat larger pipes are seen in blue.

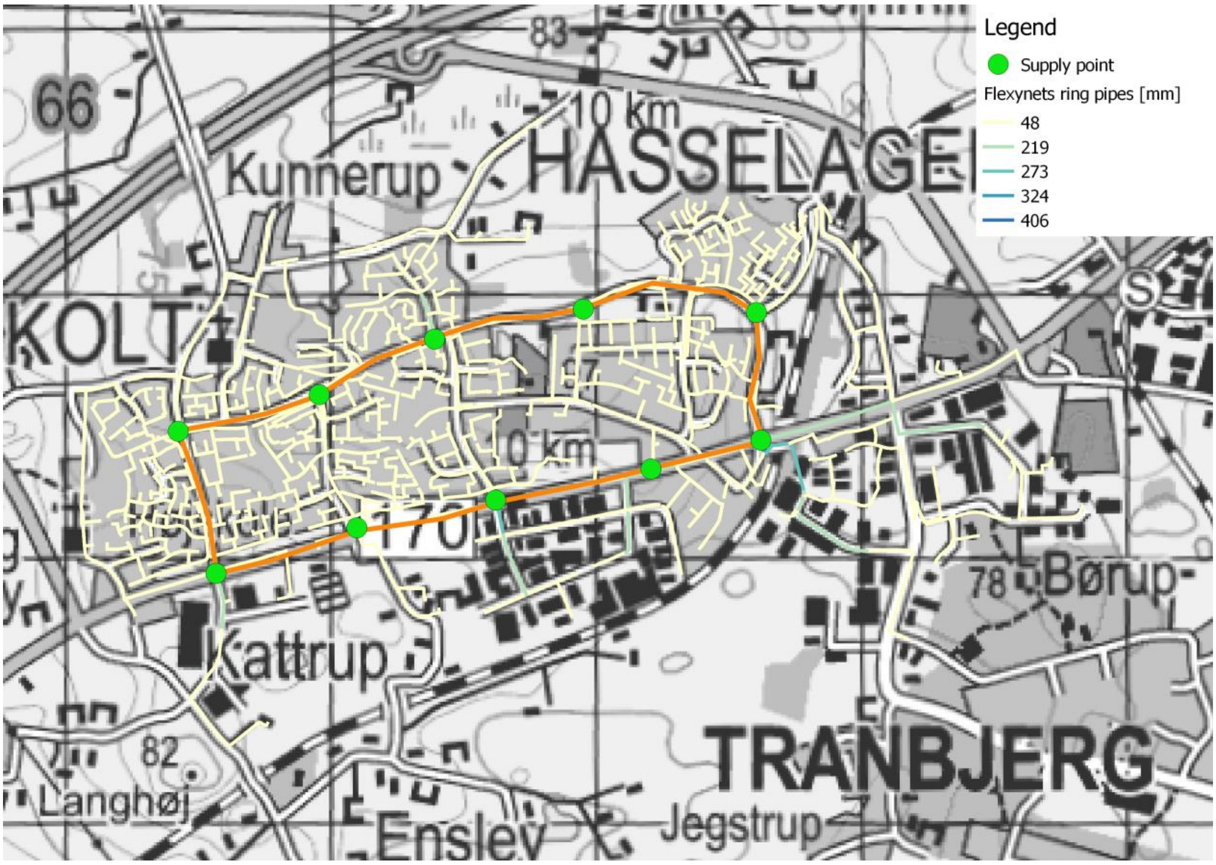

Figure 50 – Network layout example by using the GIS based tool for the case of Aarhus SW for the FLEXYNETS concept, ring structure scenario. (Background map from Geodatastyrelsen Denmark.)

Some similarities with the Hadsund case are seen when comparing Table 12 and Table 13. Again it is seen that the calculated heat losses in in the example with the FLEXYNETS concept are reduced with about ¾ compared to conventional DH. However, while the heat losses are significantly lower in the FLEXYNETS concept, some of this benefit is compensated by the additional energy use for network pumps and consumer heat pumps.

Table 13 – Total numbers from GIS analysis for Aarhus SW. All results can be seen in Appendix F: GIS Tool Results.

Case: Aarhus SW		**Branch Structure**		**Ring Structure**	
Mixed typology, 4.7 km^2		**Conv. DH**	**Flexynets**	**Conv. DH**	**Flexynets**
Total Numbers					
Total length	km	90.1	90.1	94.2	94.2
Total loss	MWh/y	10,570	2,580	12,058	3,033
	%	14.2%	4.8%	15.9%	5.6%
Total heat production incl. Loss	MWh/y	74,933	53,794	75,853	54,069
Total pumping capacity	kW	179.0	315.7	389.4	695.0
Pumping energy	MWh/y	1,568	2,766	3,411	6,088
Total investment for grid	mio. EUR	31.2	30.5	36.4	35.9
	mio. EUR/MW	1.39	1.71	1.62	2.00
Performance Indicators					
Linear heat density	MWh/m y	1.0	0.8	0.9	0.7
Linear loss	MWh/m y	0.17	0.04	0.18	0.04
Heat density	MWh/km^2	13,523	10,818	13,523	10,818
Effective width	m	13.1	13.1	14.4	14.4

3.8 Aarhus Center Case

In Figure 54 the case in Aarhus centre (Aarhus C) is highlighted with a red circle. The centre of Aarhus is typology FL ST 6 and the demand density is higher than in Hadsund and Aarhus SW.

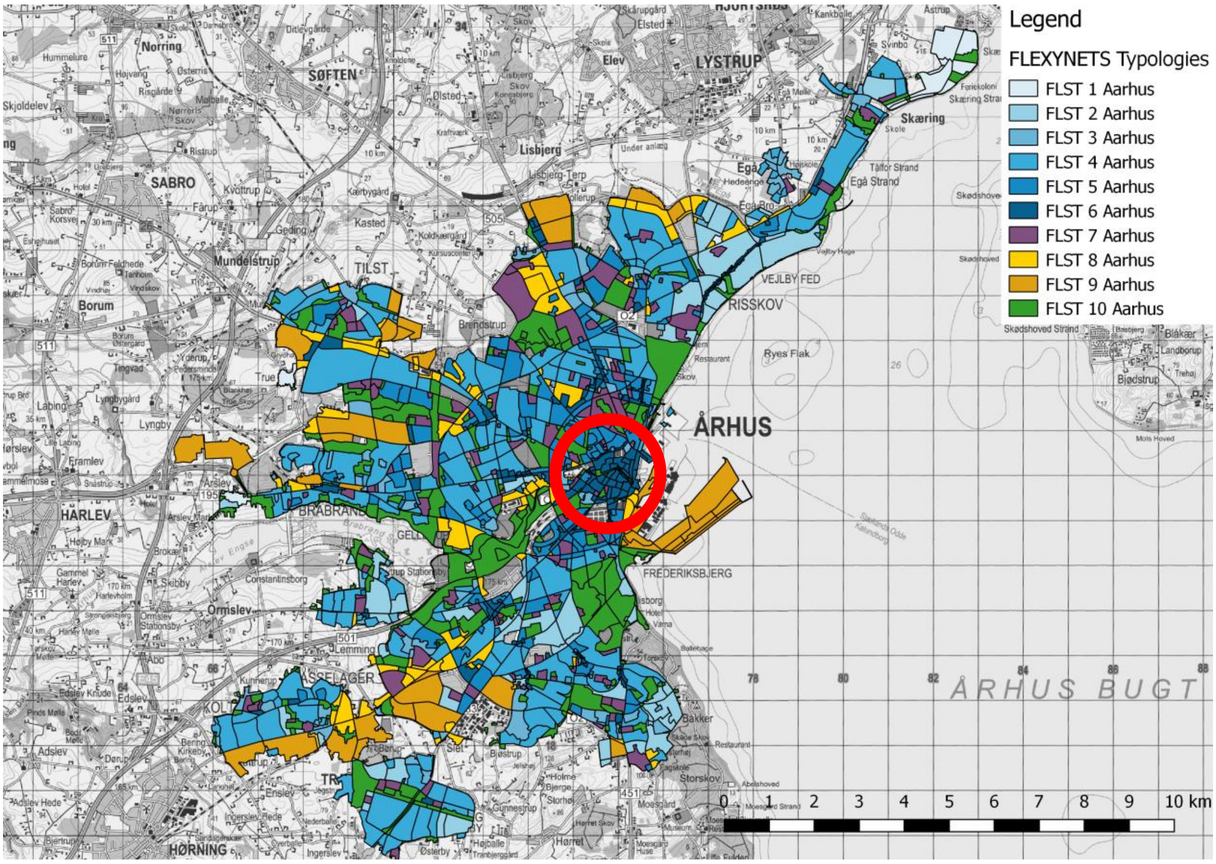

Figure 51 – Zoom of the Aarhus map with settlement typologies indicating the case in the centre highlighted with a red circle. (Background map from Geodatastyrelsen Denmark.)

In this case study, two ring structures are tested for the city centre besides the branch structure – a small and a large ring, see Figure 52. The summary of the case results is seen in Table 14. It is seen that the small ring outperforms the large ring in this example.

Table 14 – Total numbers from GIS analysis for Aarhus C. All results can be seen in Appendix F: GIS Tool Results.

Case: Aarhus C		**Branch Structure**		**Ring Structure - Small**		**Ring Structure - Large**	
FL ST 6, 0.9 km²		**Conv. DH**	**Flexynets**	**Conv. DH**	**Flexynets**	**Conv. DH**	**Flexynets**
Total Numbers							
Total length	km	37.2	37.2	36.7	36.7	37.3	37.3
Total loss	MWh/y	4,546	1,184	4,689	1,200	4,903	1,262
	%	3.2%	1.0%	3.3%	1.0%	3.5%	1.1%
Total heat production incl. Loss	MWh/y	141,129	114,761	140,825	114,647	141,039	114,709
Total pumping capacity	kW	315.3	544.7	249.7	407.2	359.0	581.2
Pumping energy	MWh/y	2,762	4,772	2,188	3,567	3,145	5,092
Total investment for grid	mio. EUR	17.7	18.0	15.4	15.4	16.9	17.0
	mio. EUR/MW	0.37	0.45	0.32	0.39	0.35	0.43
Performance Indicators							
Linear heat density	MWh/m y	7.1	5.9	6.7	5.6	7.7	6.4
Linear loss	MWh/m y	0.24	0.06	0.23	0.06	0.28	0.07
Heat density	MWh/km²	152,136	126,780	152,136	126,780	152,136	126,780
Effective width	m	21.5	21.5	22.6	22.6	19.9	19.9

The examples with the FLEXYNETS concept is seen to reduce the calculated heat losses with about ¾ compared to conventional DH, just as it is seen in the other cases. However, in absolute numbers this is not as big a saving as in the previous examples because the heat loss shares (in % of demand incl. losses) are lower in this high density area. On the other hand, the pumping costs are in the same range as in the other examples even though the total demand is much larger in this case. Hence, it seems that the importance of pumping costs in relation to the total economy of the concept is decreased when the demand density is increased.

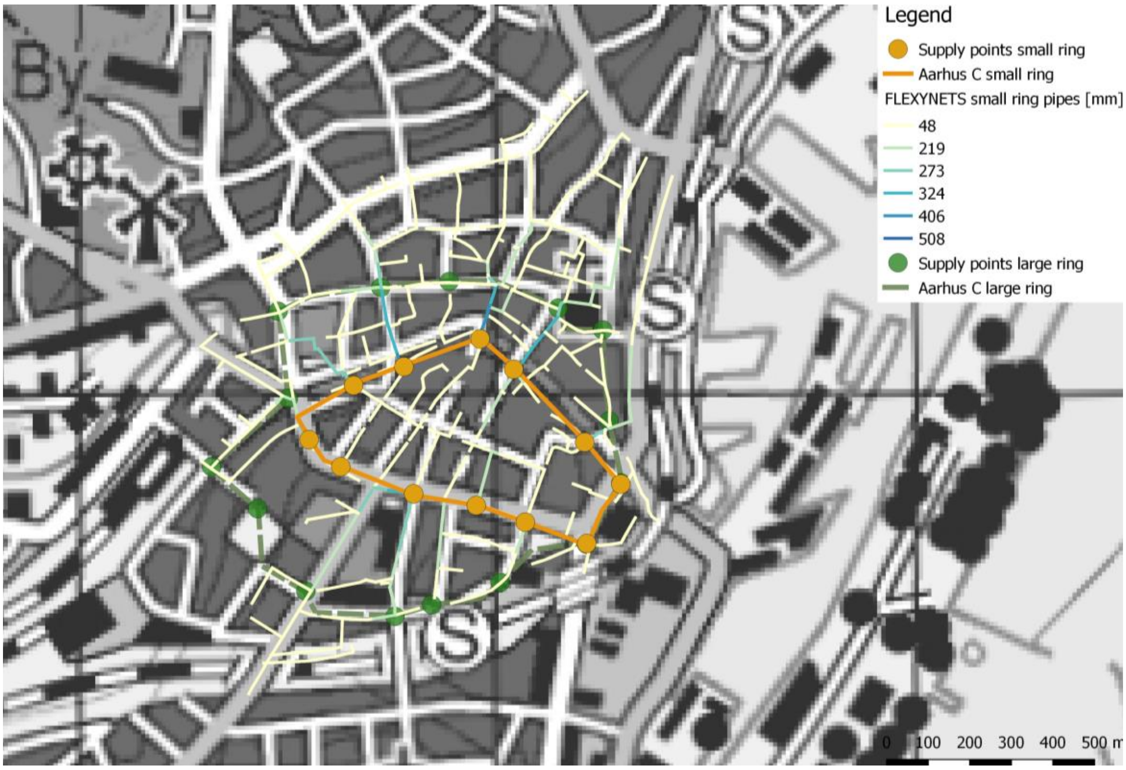

Figure 52 – Network layout example by using the GIS based tool for the case of Aarhus C for the FLEXYNETS concept, small ring structure scenario. The Large ring scenario can be seen under the small ring network for comparison of ring diameter (Background map from Geodatastyrelsen Denmark.)

In the town of Aarhus, the utility Affaldvarme Aarhus (Waste Heat Aarhus) supplies DH to more than 90 % of Aarhus municipal residents. Customers range from large housing companies to single-family houses. In addition, DH is delivered to several neighbouring municipalities.

The DH network, that consists of approximately 2,000 km main pipes, supplies every day nearly 300,000 citizens with DH. Most of the heat is purchased by the transmission company, Varmeplan Aarhus (Heat Plan Aarhus), which again purchases heat from heat producers[23].

The existing DH utility in Aarhus is utilizing some excess heat from the harbour area to the east in the city (see the industry typologies in the centre of Figure 51). Even though some excess heat is utilised, this is still only a fraction of the total heat production (approx. 350 TJ or less than 100,000 MWh in

[23] www.aarhus.dk/sitecore/content/Subsites/affaldvarmeaarhus/Home/Om-AffaldVarme-Aarhus/Organisationen/Kerneopgaver.aspx?sc_lang=da

2016) in the existing network. An overview of the existing grid and production units can be found in Appendix E.

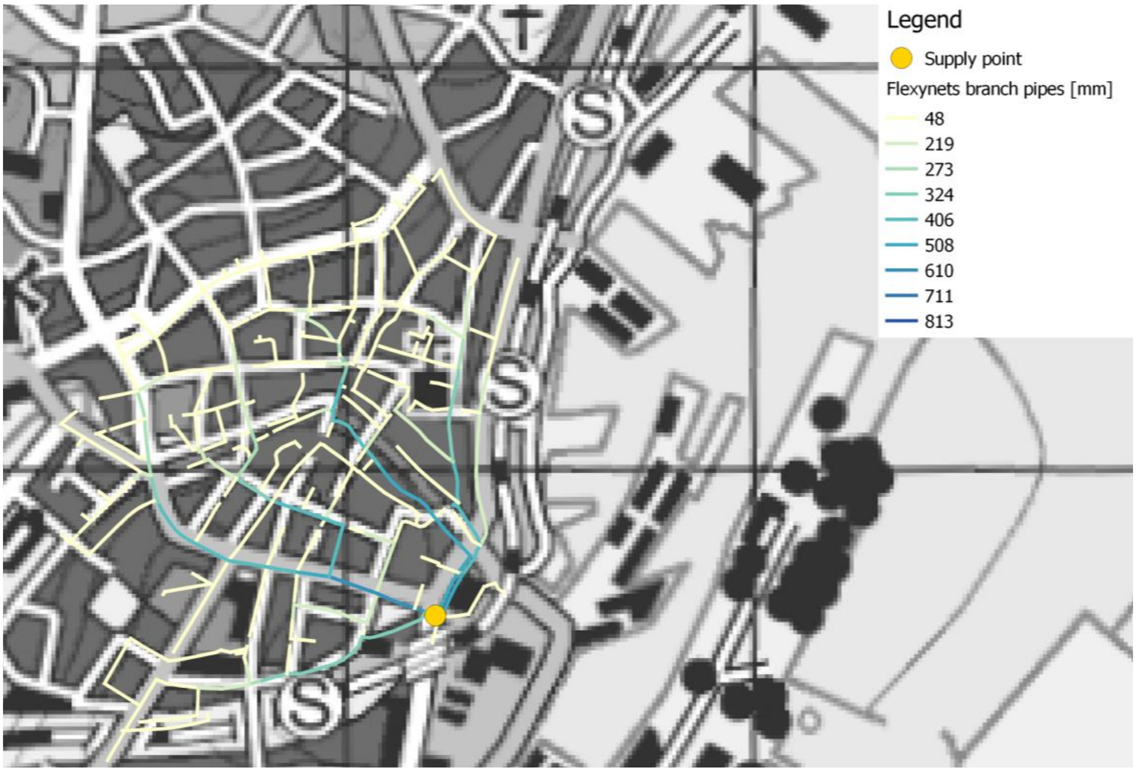

Figure 53 – Network layout example by using the GIS based tool for the case of Aarhus C for the FLEXYNETS concept, branch structure scenario. (Background map from Geodatastyrelsen Denmark.)

3.9 Conclusions for Layout

If part of the heat demand can be covered by excess heat, this supply must be connected to the network. This can be done either by means of a transmission line or by collecting excess heat from various locations through a ring structure. In other words, while a ring structure makes it possible to reach various heat sources along the ring, reaching the same sources of heat with a branch structure will require a connection from the source(s) to the 'starting point' of the network. Hence, the benefits of a ring structure will increase in case the excess heat supply is:

- Available in significant quantities
- Scattered across the town/city
- Limited in each supply point (so that one single connection is not enough)

For connecting several smaller grids, the distance between two rings will in general be shorter than connecting two main branch centre points (since the ring is further from the city centre than the branch centre). Hence, the ring structure could have a benefit in terms of scalability and connections a neighbouring network.

In addition to this, a ring structure seems to be most feasible for higher demand densities, i.e. dense urban areas.

For the analysed cases of Hadsund, Aarhus SW and the Centre of Aarhus, it does not seem optimal to locate the ring structure in the outskirts of the considered urban area. The ring should supply both 'inwards' and 'outwards' thus minimising the required pipe diameter for the network 'branches' going out (and in) from the ring while at the same time avoiding an unnecessarily big ring (geographically).

However, the ring structure will in some cases result in an additional investment costs as well as increased pumping costs, so care should be taken to identify (and quantify) the benefits of a ring structure in the specific case in question, and compare with the drawbacks before deciding the final network layout.

When establishing a DHC grid one should always consider the given circumstances. The dimensions of the pipes in the network depend strongly on the network temperatures and the maximum load.

4 Conclusions and Outlook

The reference town analysis includes a total of 15 different towns and cities, each disaggregated by means of the 10 different settlement typologies. This analysis can be used as a basis for further FLEXYNETS project analyses. The outcome is not only limited to reference town averages, but the results have been specified by settlement typology category. From specific cases it has been concluded, that there can be a significant diversity concerning the demand density, which does not only depend on latitude. Insulation levels are often higher in Northern European countries, which compensates somewhat for colder climates.

While the cooling demand is shown to be much lower than the heat demand in most of the European towns and cities, this is an area where an increase is expected in the future. Already now there is an increased focus on district cooling. The combination of heating and cooling the same network could improve feasibility of the FLEXYNETS concept.

The analysis of DHC network layout shows how a ring structure can be a suitable solution for some urban environments. The ring should not be located in the outskirts of the supply area, but between the edge and the centre of the area. The benefit of a ring is most significant when

- several heat sources are required (i.e. there is not one single excess heat supplier which can cover the entire heat demand) and
- several heat sources can be reached by the ring itself.

Reaching multiple heat sources with the ring can be a way to cover a larger fraction of the heat demand with excess heat. If for example, the alternative heat supply (e.g. boiler operation) is expensive (both in financial terms and regarding the environmental impact) compared to the available excess heat, then the investment in the ring in order to reach a larger 'excess heat fraction' may be feasible.

The benefit of the decreased network losses in the FLEXYNETS concept becomes clear when comparing with conventional DH. In the elaborated cases, and with the stated assumptions, the FLEXYNETS network heat losses are reduced with about ¾ compared to conventional DH. However, while the heat losses are significantly lower in the FLEXYNETS concept, some of this benefit is compensated by the additional energy use for network pumps and consumer heat pumps. While electricity is in general more valuable than heat, future energy system scenarios with large amounts of fluctuating wind and solar electricity production may reduce the importance of avoiding the use of electricity for heating purposes. This requires that the electricity use is controlled in a smart way facilitating the balance of demand and supply.

Local conditions will have a significant influence on the optimum solution, i.e. where the heat sources are located (how they are spread across the town area), the layout of the settlement typology/typologies etc. The analysis shows that there is not one single solution for the FLEXYNETS concept, but various trends have been identified, which can be used in the other parts of the FLEXYNETS project e.g. to evaluate the feasibility of the concept in different environments.

4.1 Outlook and Future Work

Possibilities for optimising the feasibility of the concept include the option of reducing the capacity of the pipes, if local supplies at any time can supplement the network (e.g. electric heaters in the substations or small storage tanks for peak shaving), thus making it unnecessary to dimension the network for the absolute maximum peak load.

The FLEXYNETS project also includes

- analysis of integrating energy sources and sinks with short term local storage
- evaluation of centralized and diffused storages
- detailed DHC network simulations

Analysing the behaviour of the entire FLEXYNETS system – including sensitivity analyses – will help identifying the most feasible FLEXYNETS configurations as well as the importance of for instance

- temperature levels and ΔT of the network
- location of centralised storages
- local storages for peak shaving and optimal use of heat pumps, e.g. in relation to lowest possible electricity prices

The analyses described in this report will in this way form a basis for the further work towards final FLEXYNETS conclusions and recommendations.

5 Appendix A: Pipe Prices and Construction

This appendix provides a description of the composition of the price of district heating pipes. The total costs of a DH grid consist of four main parameters:

1. Capital costs of investment
2. Cost of distribution heat losses
3. Costs of distribution pressure losses
4. Costs for service and maintenance.

In this note, only the investment costs of pipes and installation are considered.

The price of establishing district heating grids depends on several factors and the price on the pipe itself will depend on insulation class and pipe manufacturer. There is no Danish reference or collected overview of prices for investments in district heating grids, but the Swedish District Heating Association has collected experiences on pipes prices and establishment in the report that can be found on the following link:

www.svenskfjarrvarme.se/Global/Rapporter%20och%20dokument%20INTE%20Fj%C3%A4rrsyn/Ovriga_rapporter/Distribution/Kulvertkostnadskatalog_2007-1.pdf

The report divides the prices according to four types of area classification:

A. Inner City
B. Outer City areas
C. Park areas
D. Extension of existing DH areas

Based on the Swedish experiences the following general conclusions on pipe prices can be drawn.

For category A of inner city areas is in general seen the highest cost due to very high construction costs, primarily for restoration work, obstruction of pipes and traffic devices. The share for ground work of the total cost is about 50 % for the smallest pipes and up to 60 % for larger dimensions. The costs of the pipe material and pipe assembly are a relatively small part of the total costs in the smaller dimensions but can distinguish between different projects depending on parameters such as pipe type, insulation thickness and number of branches.

In category B is the total cost about 20 % less than for category A, particularly due to lower construction costs for restoration work and less obstacles.

The total cost of establishment in park and natural land is about 23 % lower than for category B and for category D, for extensions of existing grids, the lowest costs are found. Reported projects in category D are approximately 54 -72 % cheaper than category B, which is due to reuse of some existing installations. It is seen that material costs are higher than construction costs for all dimensions.

In the following, it is possible to see an overview of how the investments in the different categories are divided according to e.g. pipe material and ground work. The prices for the four examples are from a pipe type of DN 150.

In general, the denser the area, the higher is the share of investment in ground work, and the sparser the area, the lower is the costs for ground work, where by the share of the pipe costs itself increases.

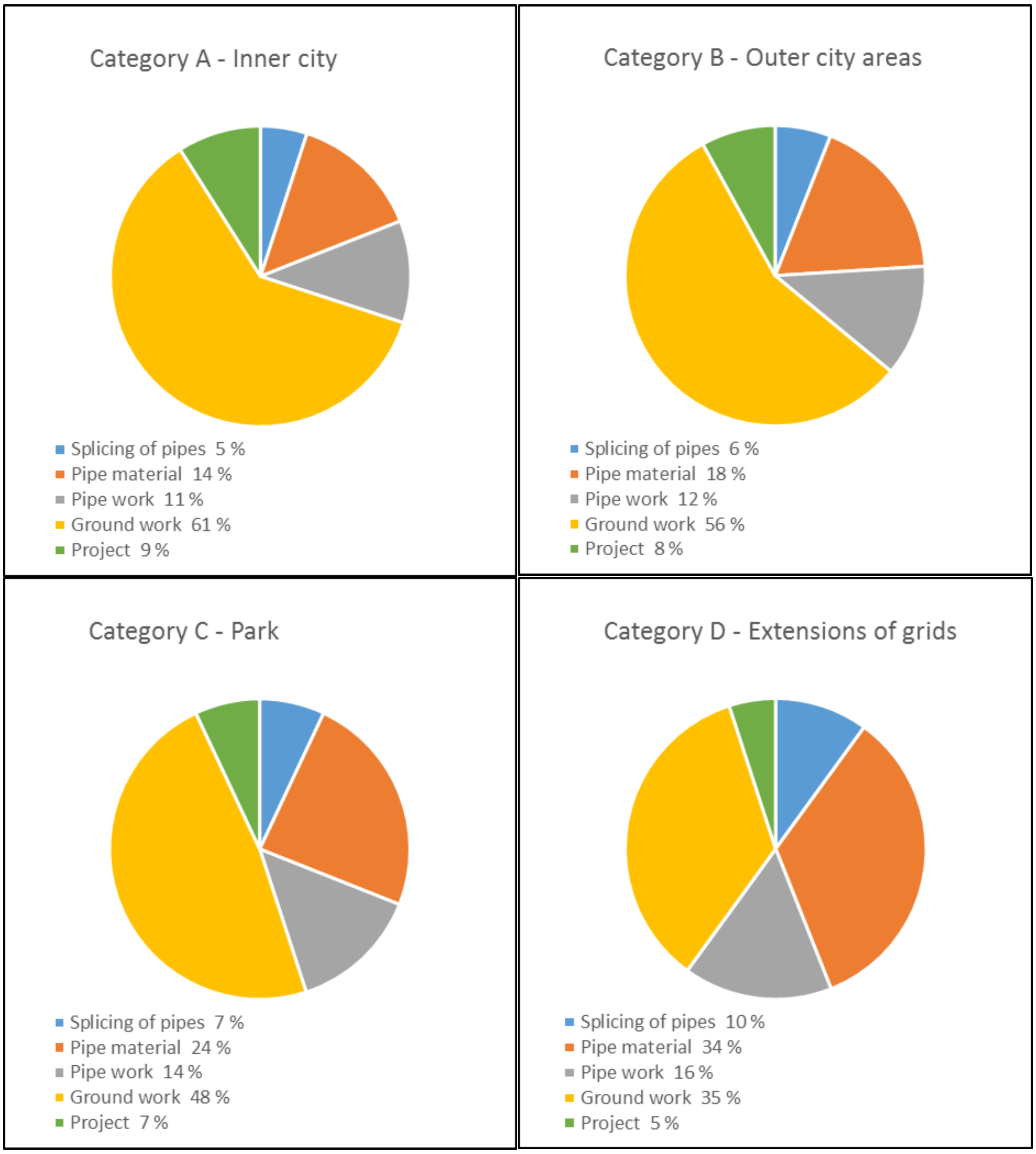

Figure 54 – Share of costs in the four categories A, B, C and D for DN 150 pipes (Reproduced from Kulvertkostnadskatalog).

The prices from the Swedish experiences reported in the catalogue are from 2007. One should be aware, that prices on pipes and the construction can vary from country to country and between different regions in one country. Therefore it can be difficult to estimate the exact price of district heating grids.

Prices for Conventional DH

In relation to the FLEXYNETS project it has been possible to collect prices from 2016 from a Danish manufacturer of DH pipes. These prices are used for the pricing on conventional DH pipes, while prices from Swedish experiences in ground work etc. are used.

Based on different insulation class and dimension the following graph applies for the Danish example, where prices are available for three insulation classes. The graph only shows the costs of the pipes and not costs for work.

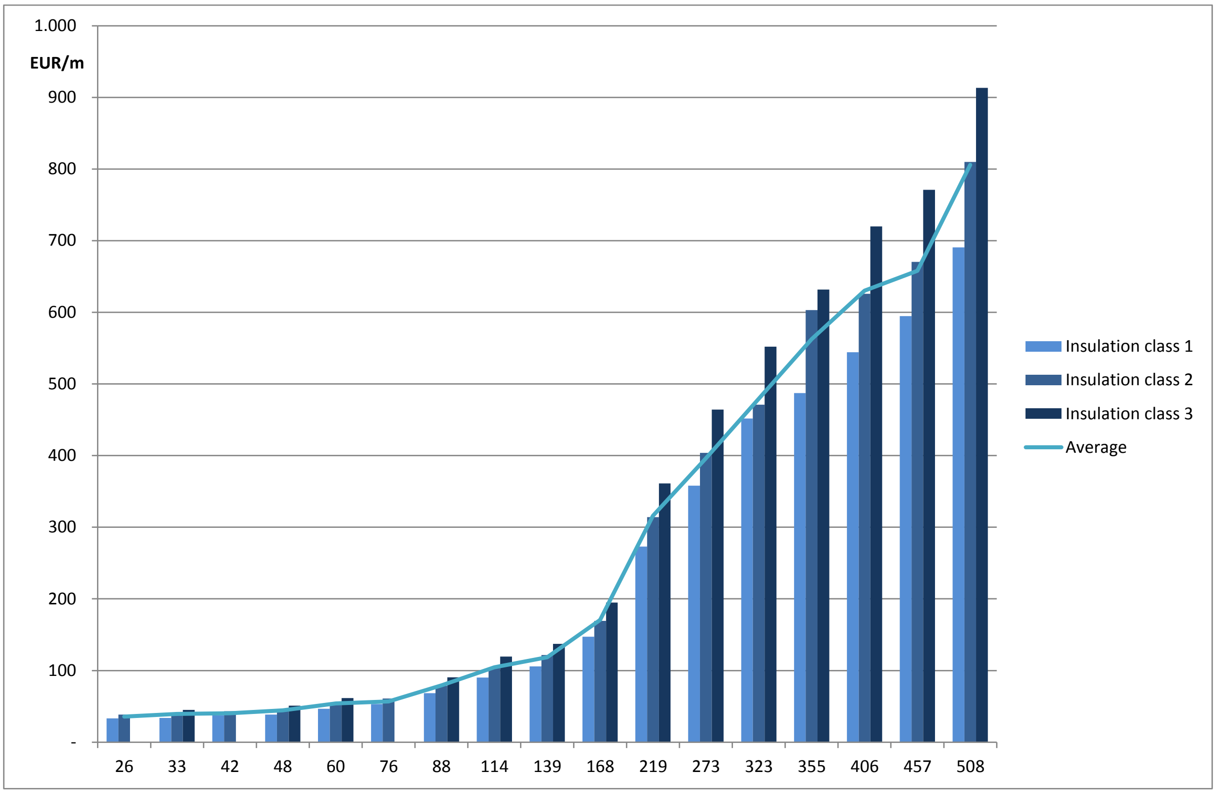

Figure 55 – Prices in conventional DH for three insulation classes, Danish pipe manufacturer – prices for pipes only in in EUR/m.

Based on the average price levels, trend lines have been applied to estimate prices of all dimensions of DH pipes.

6 Appendix B: Heat Loss Values

Some typical values of heat loss are seen in Table 15 where both values for one pipe and a pair of pipes are shown.

Table 15: Typical Values of heat loss in pre-insulated pipes and plastic pipes, PEX. (Source: Varme Ståbi, 7th edition.)

		SERIES 1			SERIES 2			SERIES 3		
Steel pipe DN	D_{s2} mm	D_{c3} mm	U_{pipe} W/(m·K)	U_{pair} W/(m·K)	D_{c3} mm	U_{pipe} W/(m·K)	U_{pair} W/(m·K)	D_{c3} mm	U_{pipe} W/(m·K)	U_{pair} W/(m·K)
15	21.3	75	0.13	0.12	90	0.11	0.11	110	0.1	0.09
20	26.9	90	0.13	0.13	110	0.11	0.11	125	0.1	0.1
25	33.7	90	0.16	0.15	110	0.13	0.13	125	0.12	0.12
32	42.4	110	0.16	0.16	125	0.14	0.14	140	0.13	0.13
40	48.3	110	0.19	0.18	125	0.16	0.16	140	0.15	0.14
50	60.3	125	0.21	0.2	140	0.18	0.18	160	0.16	0.15
65	76.1	140	0.25	0.24	160	0.21	0.2	180	0.18	0.17
80	88.9	160	0.26	0.25	180	0.22	0.21	200	0.19	0.18
100	114.3	200	0.27	0.26	225	0.23	0.22	250	0.2	0.19
125	139.7	225	0.32	0.3	250	0.26	0.25	280	0.22	0.21
150	168.3	250	0.38	0.35	280	0.3	0.28	315	0.25	0.23
200	219.1	315	0.42	0.39	355	0.32	0.3	400	0.26	0.24
250	273	400	0.4	0.37	450	0.31	0.29	500	0.25	0.25
300	323.9	450	0.46	0.43	500	0.35	0.33	560	0.28	0.27
350	355.6	500	0.45	0.42	560	0.34	0.32	630	0.27	0.26
400	406.4	560	0.47	0.44	630	0.35	0.33	670	0.31	0.3
450	457	630	0.47	0.44	670	0.4	0.38	710	0.31	0.33
500	508	670	0.55	0.51	710	0.46	0.43	800	0.34	0.33
600	610	800	0.56	0.52	900	0.4	0.38	1000	0.31	0.3
700	711	900	0.64	0.6	1000	0.45	0.43	1100	0.35	0.34
800	813	1000	0.73	0.68	1100	0.51	0.48	1200	0.4	0.38
900	914	1100	0.82	0.75	1200	0.56	0.53			
1000	1016	1200	0.91	0.83						

The heat losses for three insulation classes of pre-insulated pipes are seen in Figure 56. The estimates are based on the heat loss equation in section 3.2.5. Conventional DH temperatures (the bars in the figure) can be compared with the lower temperature level assumed for the FLEXYNETS (the line in the figure). Note however – when comparing the heat losses for conventional DH and FLEXYNETS – that there is a difference in capacity a given dimension is able so supply. Due to the lower temperature difference in the FLEXYNETS concept the pipes will in general need to be of a larger dimension in order to supply the same capacity as conventional DH.

The heat loss in W/m has been calculated using 78 °C as supply temperature for conventional DH heating using pre-insulated DH pipes. The supply temperature for the plastic pipes is set to 25 °C. A ground temperature of 8 °C has been used. The ground temperature can vary from approx. 2 °C in peak winter conditions to app. 14 °C for summer months[24].

[24] `Method for optimal design of pipes for low-energy district heating, with focus on heat losses`, Dalla Rosa A, Li H, Svendsen S.

It is evident that with conventional DH temperature levels, the heat loss is significantly lower, when using pre-insulated class 3 pipes compared to class 1 pipes. For the small dimensions, the heat loss is more similar, but for larger dimensions (above DN40), the difference is especially significant (due to the increased surface area of the larger pipes). Based on these simple calculations, it is seen how the heat loss in the FLEXYNETS concept is significantly lower than in conventional DH.

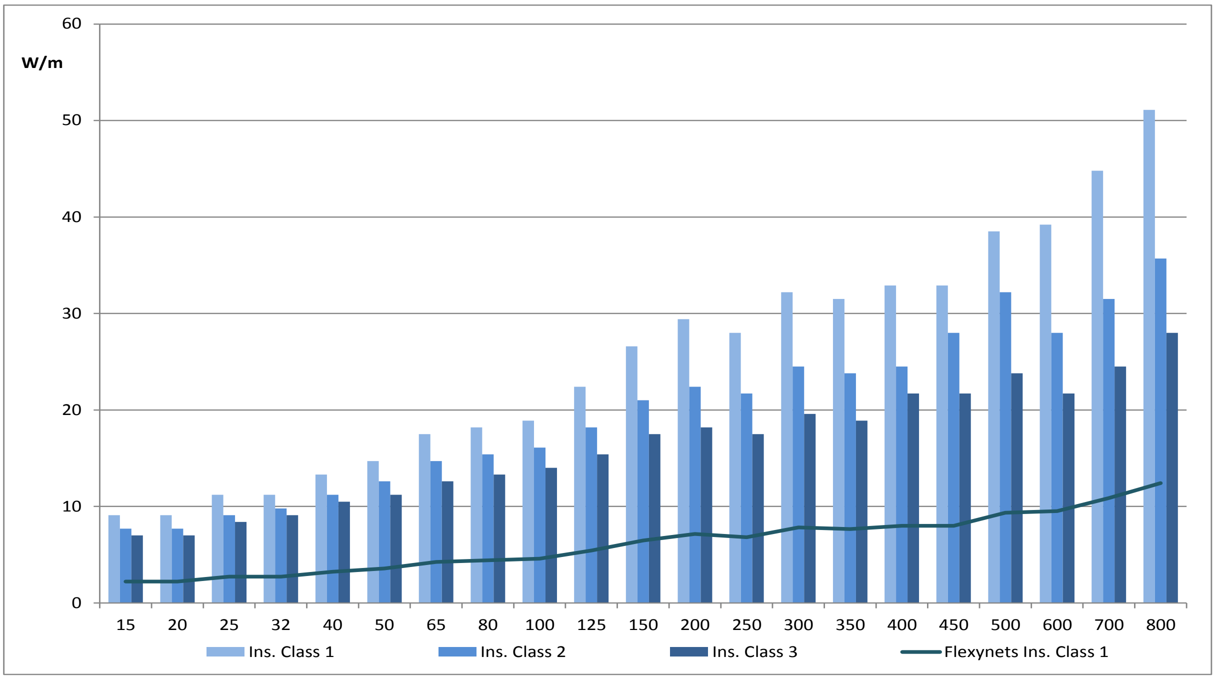

Figure 56 – Estimated heat loss for one pre-insulated pipe in W/m by using 78 °C as supply temperature for conventional DH heating using pre-insulated DH pipes. The supply temperature for the 'FLEXYNETS Insulation Class 1' pipes is set to 25 °C. The ground temperature is set to 8 °C. The development is not smooth since the insulation thickness of the pipes is not constant.

The heat loss used in the calculations for the two types of pipes is seen in Figure 57. The heat loss in this figure differs from Figure 56, since the heat loss here is estimated for a pair of pipes. Just as before, the numbers are in W per m trench length using the two different set of temperature levels for hot/cold pipe: 78/41 °C for conventional DH and 25/10 °C for the FLEXYNETS concept.

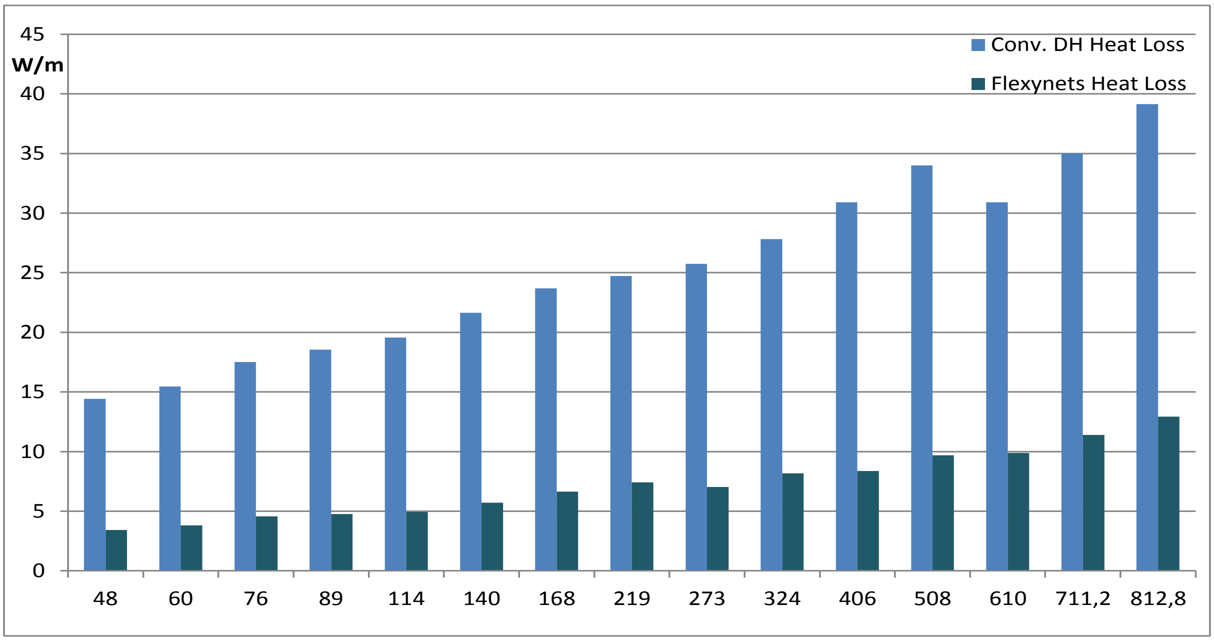

Figure 57 – Heat loss for pair of pipes in W per m trench for conventional DH and FLEXYNETS at their respective temperature levels (pipe dimension in mm on the X-axis).

7 Appendix C: Key Performance Indicators

A structure for KPIs of district heating networks is given in the paper 'Quality indicators for district heating network'[25]. The paper focuses on how the performance of district heating network can be qualified through different indicators. The paper describes four main points to consider for this purpose. These are reproduced in the following based on the text given in the paper:

First, the only energy indicator generally used is the primary energy factor (PEF), which quantifies the primary energy use of a device. However, it does not give a complete insight of the whole energy use of district heating networks. Two other parameters have to be stated for this purpose: primary energy efficiency and the energy share.

Second, district heating efficiencies are generally not taken into account unless sometimes the only amount of heat losses. A first indicator is defined to quantify networks heat losses relatively to the amount of heat delivered to customers. To take heat plant efficiencies into account, a more global indicator is defined. Its definition is close to a seasonal efficiency and it permits comparisons with other heating systems.

Third, indicators have been defined for heat plant's equipment. Their aim is to permit stakeholders to check networks management of district heating companies. Two indicators are defined: One measures subscripted power relatively to network length and the other one represent the fictitious number of plants working hours while maximum plants power was delivered all the year.

Finally, environmental efficiency is stated. This analysis can include different aspects: greenhouse gas emissions, water use and other pollutants emissions. For both design and management of district heating networks, an indicator representing CO_2 emissions appears to be the most suitable one. Expressed relatively to delivered energy, it can be seen as a sum up of previous indicators because result of bad performances increases these emissions.

In this paper, eight indicators are defined. These are:

1. The primary energy factor
2. The relative importance of losses
3. The primary energy efficiency
4. The district heating global efficiency
5. Energy share
6. Subscripted heat power by km
7. Equivalent to nominal power duration
8. CO_2 emissions

Energy (Heat) Density

The density of energy or heat is given in energy per area – it is important to notice if this is per building area or ground area. Examples could be GJ/m^2 or MWh/m^2. An example of threshold value was mentioned earlier for Swedish DH of 40-50 kWh/m^2 ground area.

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[25] By Pascot, Pierre-Emmanuel and Reiter, Sigrid, 2011, ISBN 9782839909068

Power Density

The power density is similar to the energy density, where the values are given in e.g. kW/m^2.

Linear Heat Density

Other parameters can also be used as indicators to analyse a specific area, e.g. Linear Heat density and Plot Ratio.

Linear heat density indicates the utilization of district heating in an area, i.e. the amount of heat delivered per m of pipe. The linear heat density will typically be around 0.4 MWh/m in areas with single family houses and more dense populated areas can have linear heat densities of around 1.4 MWh/m [S. Werner]. Expression of linear heat density:

$$\frac{Q_s}{L} = p \cdot \alpha \cdot q \cdot w = e \cdot q \cdot w \qquad \left[{}^{GJ}/_{(m \cdot a)}\right]$$

p = population density $[n/m^2]$ (per land area)

α = specific building space area $[m^2/n]$

q = specific heat demand $[GJ/(m^2 \cdot a)]$ (per building area)

w = effective width [m]

e = plot ratio

The effective width indicates the physical coverage of the district heating grid relative to a given land area, i.e.

w = AL / L [m]

where

AL = Total Land Area $[m^2]$

L = Total DH route length [m]

The plot ratio is a common city planning quantity that represents the fraction of total building space area in a given land area. The plot ratio is defined by

e = AB /AL = pα [-]

where

AB = Total Building Space Area $[m^2]$

Pumping Energy

The energy for pumping will vary depending on which pipe type that is used. As previously shown, the pumping energy depending on roughness is not expected to be the dominant factor in the overall economic calculations. The pumping energy is however included in the KPIs and in the further analysis, since it is also considered to be too significant to leave out.

Economic KPIs

The described KPIs for energy and load density can be used to evaluate the economic performance of grids, where for instance parameters such as investment per m and capital costs per m grid can be calculated and compared.

8 Appendix D: Existing DH Grid in Hadsund

Figure 58 – Overview of existing DH grid in Hadsund.

9 Appendix E: Existing Transmission Grid in Aarhus

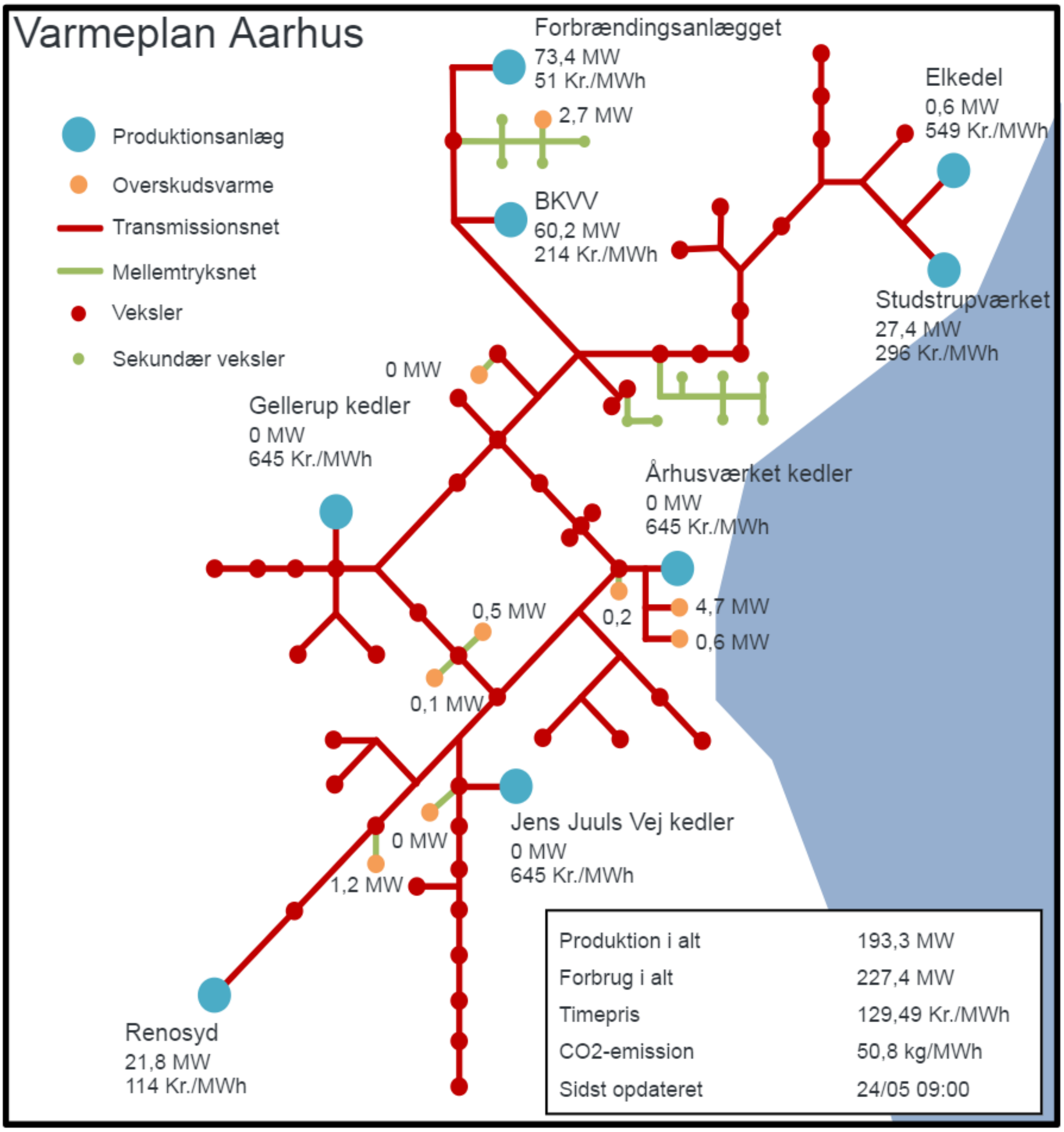

Figure 59 – Sketch of the DH transmission grid in Aarhus Heat Plan. The legend from top: Production facility, excess heat, transmission grid, medium pressure grid, (heat) exchanger, secondary exchanger (source: http://transmissionsnet.varmeplanaarhusapps.dk).

10 Appendix F: GIS Tool Results

Case: Hadsund Small town, 4,913 inh., 4.1 km²		Branch Structure Conv. DH	 Flexynets	Ring Structure Conv. DH	 Flexynets
Main Parameters					
Total heat demand ab grid/an consumer	MWh/y	58.900	47.120	58.900	47.120
Peak load (2,850 hours)	MW	21	17	21	17
Total heat cooling demand ab grid/an consume	MWh/y	3.024	2.016	3.024	2.016
Peak load (1400 hours)	MW	2	1	2	1
No of consumers	cons.	2.276	2.276	2.276	2.276
Area of typology	km^2	4,1	4,1	4,1	4,1
Distribution Grid					
Total trench length	km	61,0	61,0	60,4	60,4
Average dimension	mm	89,4	118,7	68,9	89,4
Pipe type	DN	110	125	80	110
Heat loss	MWh/y	9238	2657	8680	2436
Pumping capacity	kW	186,3	400,2	56,6	130,7
Pumping energy	MWh/y	1.632	3.506	496	1.145
Investment	mio. EUR	28,9	33,7	24,4	28,0
Main Ring for Ring Structure					
Ring length	km			5,9	5,9
Ring dimension	mm			406	508
Ring pipe type				DN400	DN500
Ring heat loss	MWh/y			1.271	305
Ring pumping capacity	kW			355	640
Ring pumping energy	MWh/y			3.111	5.609
Ring investment	mio. EUR			9,5	10,0
Ring diameter (app.)	km			1.6 - 1.9	1.6 - 1.9
Branch Transmission					
Length	km	0,5	0,5		
Dimension	mm	406	508		
Pipe type		DN400	DN500		
Heat loss	MWh/y	109	26		
Pumping capacity	kW	30	55		
Pumping energy	MWh/y	266	479		
Investment	mio. EUR	0,8	0,9		
Service Pipes					
Service pipes, 12 m per demand	km	27	27	27	27
Standard dimension	mm	26,9	26,9	33,7	33,7
Heat loss	MWh/y	2.464	591	2.464	591
Investment	mio. EUR	6,1	5,4	6,1	5,4
Total Numbers					
Total length	km	88,8	88,8	93,6	93,6
Total loss	MWh/y	11.702	3.248	12.415	3.332
	%	16,6%	6,4%	17,4%	6,6%
Total heat production incl. Loss	MWh/y	70.711	50.394	71.315	50.452
Total pumping capacity	kW	216,7	454,9	411,7	771,0
Pumping energy	MWh/y	1.898	3.985	3.607	6.754
Total investment for grid	mio. EUR	35,8	39,9	40,0	43,5
	mio. EUR/MW	1,73	2,42	1,94	2,63
Performance Indicators					
Linear heat density	MWh/m y	1,0	0,8	0,9	0,7
Linear loss	MWh/m y	0,19	0,05	0,19	0,05
Heat density	MWh/km^2	14.366	11.493	14.366	11.493
Effective width	m	14,9	14,9	16,2	16,2

Case: Aarhus SW Mixed typology, 4.7 km²		Branch Structure Conv. DH	 Flexynets	Ring Structure Conv. DH	 Flexynets
Main Parameters					
Total heat demand ab grid/an consumer	MWh/y	63.795	51.036	63.795	51.036
Peak load (2,850 hours)	MW	22	18	22	18
Total heat cooling demand ab grid/an consumer	MWh/y	7.143	5.357	7.143	5.357
Peak load (1400 hours)	MW	5	4	5	4
No of consumers	cons.	2.168	2.168	2.168	2.168
Area of typology	km^2	4,7	4,7	4,7	4,7
Distribution Grid					
Total trench length	km	62,0	62,0	62,3	62,3
Average dimension	mm	55	57	51	52
Pipe type	DN	DN50	DN50	DN50	DN50
Heat loss	MWh/y	8223	2017	8127	1974
Pumping capacity	kW	51,5	85,9	34,3	54,7
Pumping energy	MWh/y	451	752	300	479
Investment	mio. EUR	22,0	21,8	21,0	20,7
Main Ring for Ring Structure					
Ring length	km			5,9	5,9
Ring dimension	mm			406	508
Ring pipe type				DN400	DN500
Ring heat loss	MWh/y			1.584	497
Ring pumping capacity	kW			355	640
Ring pumping energy	MWh/y			3.111	5.609
Ring investment	mio. EUR			9,5	10,0
Ring diameter (app.)	km			1.6 - 1.9	1.6 - 1.9
Branch Transmission					
Length	km	2,1	2,1		
Dimension	mm	406	508		
Pipe type		DN400	DN500		
Heat loss	MWh/y	568	178		
Pumping capacity	kW	127	230		
Pumping energy	MWh/y	1117	2013		
Investment	mio. EUR	3,4	3,6		
Service Pipes					
Service pipes, 12 m per demand	km	26	26	26	26
Standard dimension	mm	26,9	26,9	33,7	33,7
Heat loss	MWh/y	2.347	563	2.347	563
Investment	mio. EUR	5,8	5,1	5,8	5,1
Total Numbers					
Total length	km	90,1	90,1	94,2	94,2
Total loss	MWh/y	10.570	2.580	12.058	3.033
	%	14,2%	4,8%	15,9%	5,6%
Total heat production incl. Loss	MWh/y	74.933	53.794	75.853	54.069
Total pumping capacity	kW	179,0	315,7	389,4	695,0
Pumping energy	MWh/y	1.568	2.766	3.411	6.088
Total investment for grid	mio. EUR	31,2	30,5	36,4	35,9
	mio. EUR/MW	1,39	1,71	1,62	2,00
Performance Indicators					
Linear heat density	MWh/m y	1,0	0,8	0,9	0,7
Linear loss	MWh/m y	0,17	0,04	0,18	0,04
Heat density	MWh/km^2	13.523	10.818	13.523	10.818
Effective width	m	13,1	13,1	14,4	14,4

Case: Aarhus C FL ST 6, 0.9 km^2		Branch Structure		Ring Structure - Small		Ring Structure - Large	
		Conv. DH	Flexynets	Conv. DH	Flexynets	Conv. DH	Flexynets
Main Parameters							
Total heat demand ab grid/an consumer	MWh/y	136,136	113,447	136,136	113,447	136,136	113,447
Peak load (2,850 hours)	MW	48	40	48	40	48	40
Total heat cooling demand ab grid/an consumer	MWh/y	11,240	7,493	11,240	7,493	11,240	7,493
Peak load (1400 hours)	MW	8	5	8	5	8	5
No of consumers	cons.	1,377	1,377	1,377	1,377	1,377	1,377
Area of typology	km^2	0.9	0.9	0.9	0.9	0.9	0.9
Distribution Grid							
Total trench length	km	19.2	19.2	18.3	18.3	17.8	17.8
Average dimension	mm	113.9	136.3	81.0	92.4	73.8	83.5
Pipe type	DN	DN100	DN125	DN80	DN100	DN65	DN80
Heat loss	MWh/y	3055	827	2626	676	2513	643
Pumping capacity	kW	151.1	281.2	39.6	69.8	28.4	50.6
Pumping energy	MWh/y	1,324	2,463	347	612	249	443
Investment	mio. EUR	11.1	11.7	8.0	8.2	7.3	7.6
Main Ring for Ring Structure							
Ring length	km			1.9	1.9	3.0	3.0
Ring dimension	mm			508	609	508	609
Ring pipe type				DN500	DN600	DN500	DN600
Ring heat loss	MWh/y			572	166	899	261
Ring pumping capacity	kW			210	337	331	531
Ring pumping energy	MWh/y			1,841	2,955	2,895	4,648
Ring investment	mio. EUR			3.7	4.0	5.9	6.2
Ring diameter (app.)	km			0.41 - 0.76	0.41 - 0.76	0.91 - 0.97	0.91 - 0.97
Branch Transmission							
Length	km	1.5	1.5				
Dimension	mm	508	609				
Pipe type		DN500	DN600				
Heat loss	MWh/y	447	130				
Pumping capacity	kW	164	264				
Pumping energy	MWh/y	1438	2309				
Investment	mio. EUR	2.9	3.1				
Service Pipes							
Service pipes, 12 m per demand	km	17	17	17	17	17	17
Standard dimension	mm	26.9	33.7	26.9	33.7	26.9	33.7
Heat loss	MWh/y	1,491	358	1,491	358	1,491	358
Investment	mio. EUR	3.7	3.3	3.7	3.3	3.7	3.3
Total Numbers							
Total length	km	37.2	37.2	36.7	36.7	37.3	37.3
Total loss	MWh/y	4,546	1,184	4,689	1,200	4,903	1,262
	%	3.2%	1.0%	3.3%	1.0%	3.5%	1.1%
Total heat production incl. Loss	MWh/y	141,129	114,761	140,825	114,647	141,039	114,709
Total pumping capacity	kW	315.3	544.7	249.7	407.2	359.0	581.2
Pumping energy	MWh/y	2,762	4,772	2,188	3,567	3,145	5,092
Total investment for grid	mio. EUR	17.7	18.0	15.4	15.4	16.9	17.0
	mio. EUR/MW	0.37	0.45	0.32	0.39	0.35	0.43
Performance Indicators							
Linear heat density	MWh/m y	7.1	5.9	6.7	5.6	7.7	6.4
Linear loss	MWh/m y	0.24	0.06	0.23	0.06	0.28	0.07
Heat density	MWh/km^2	152,136	126,780	152,136	126,780	152,136	126,780
Effective width	m	21.5	21.5	22.6	22.6	19.9	19.9