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D4.5 Report on district heating and cooling improvements and new concepts (WP4, Task 4.3, Subtask 4.3.1)

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**
Project Duration	1st December 2016 – 30th November 2021 (60 Months)
Deliverable	D4.5 Report on district heating and cooling improvements and new concepts
Diss. Level	PU
Status	Working
	Verified by other WPs
	Final version
Due date	30/11/2019
Work Package	WP4 Demonstration in Helsinki
Lead beneficiary	HEN
Contributing beneficiary(ies)	VTT
Task description	Subtask 4.3.1: District heating and cooling improvements. Design and Development (waste heat, RES based). HEN and VTT will lead the smart integration of waste heat to the heating and cooling networks makes it possible to achieve yearly renewable share in the district heating 50-150 % of the heating demand depending on the building application. Estimation of the demand response cost value, optimisation of storage systems in district heating and cooling systems.

Date	Version	Author	Comment
21/04/2017	0.1	Kristiina Siilin (HEN)	First structure
05/05/2017	0.2	Kristiina Siilin (HEN)	Drafting the contents under each action, to be continued
14/08/2017	0.3	Mari Hukkalainen, Miika Rämä (VTT)	Added summary and results of the workshop about the status and improvements of district heating and cooling in Helsinki by HELEN and VTT on 24.05.2017.
05/09/2017	0.4	Kristiina Siilin, Anssi Juvonen, Jouni Kivirinne, Tero Korhonen (HEN)	Commenting the content made by VTT and suggesting modifications and additions. Attaching figures.
05/10/2017	0.5	Anssi Juvonen	Writing chapters 3.1, 5, 6
10/10/2017	0.6	Kristiina Siilin	Formatting and checking the whole document

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12/10/2017	0.7	Mari Hukkalainen (VTT)	Writing chapters 5.2.1 and 5.4
14/10/2017	0.8	Kristiina Siilin (HEN)	Writing the executive summary and conclusions
27/11/2017	1.0	CAR	Alignment of contents and final review
2/9/2019	1.1	Suvi Takala (HEN)	Checking the needs for updates, modifying structure of the document
15/10/2019	1.2	Sanna Käyhkö (HEN)	Drafting the contents of preliminary evaluation project in chapter 4.
21/10/2019	1.3	Miika Rämä (VTT), Esa Pursiheimo (VTT)	Adding the results of Tali area simulation model (subchapter 5.1) and heat storages optimization model (subchapter 6.1).
23/10/2019	1.4	Suvi Takala (HEN)	Updating the structure of the document. Adding subchapters 5.2.3 and 6.2. and updating the contents of subchapter 3.1.
24/10/2019	1.5	Suvi Takala (HEN)	Writing the contents of subchapter 3.2
31/10/2019	1.6	Anssi Juvonen (HEN)	Review and updates to chapter 3, reviewing chapters 5.1, 6.1.
4/11/2019	1.7	Sanna Käyhkö, Suvi Takala (HEN)	Adding contents to Chapter 4.
8/11/2019	1.8	Sanna Käyhkö, Suvi Takala (HEN)	Reviewing Chapter 4.
8/11/2019	1.9	Suvi Takala (HEN)	Writing executive summary, conclusions. Reviewing the document.
27/11/2019	2.0	Suvi Takala (HEN)	Final modifications based on project internal review by HAM.

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Abbreviations and Acronyms

Acronym	Description
B2B	Business to Business
B2C	Business to Consumer
CHC	Combined heating and cooling
CHP	Combined heat and power
COP	Coefficient of performance
CO_2	Carbon dioxide
DH	District heating
DHW	Domestic hot water
EAHP	Exhaust air heat pump
GSHP	Ground source heat pump
IoT	Internet of Things
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
PV	Photovoltaic panel
SC	Solar collector
SH	Space heating
SunZEB	A concept for an energy efficient building that recycles the solar energy from the indoor air to district heating by cooling the building with district heating.
SunZED	Solar-based Zero Energy District

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1. Executive Summary

This deliverable discusses the development and future prospects of district heating and cooling of Helen, an energy company in Finland. At first, the current state of district heating and cooling and its improvement over time are presented. After that, the future of district heating and cooling is discussed and a trend from moving from centralized energy system back to distributed system in some extent is being envisaged. The deliverable discusses research questions of mySMARTLife in the area of district heating and cooling. In addition, the deliverable discusses new investments and plans of Helen in district heating and cooling in order to reach carbon neutrality in 2035.

Furthermore, the study areas presented in this deliverable include two optimization and simulation models conducted by VTT, Technical Research Center of Finland. The Tali area optimization and simulation model by VTT is discussed in Subchapter 5.1. The model gives perspective for the possibilities of decentralized, local and renewable based production in a residential building area. According to the model, solution for building area local heat supply is a package consisting of a ground source heat pump, a heat storage and PVs. Centralized ground source heat pump added with a heat storage completes the building area system in case that DH based supply is excluded. It is also pointed out that exhaust air heat pumps and solar collectors are not feasible with current cost structure in Helsinki.

The other optimization model of VTT, heat storages optimization in Subchapter 6.1, focuses on the economical point of view and the profitability of heat storages implementation in the district heating network of Helsinki. The model indicates that the district heating system in Helsinki could still benefit from additional storage capacity; the saturation point is not yet reached. However, the profitability, i.e. annualized investment costs deducted from the profit, depends highly on the realized investment costs of the new storage system.

The Chapter 4 of the deliverable focuses on heat demand response potential in Helsinki and the Chapter 6 discusses optimization of district heating systems. In 2019, Helen started a preliminary evaluation project on production optimization and demand response potential of district heating. The objective of heat demand response study is to determine the most realistic and profitable way of deployment of demand response of district heating in Helsinki. In addition to the preliminary evaluation project, several on-going heat demand response pilots are discussed.

The current system of heating and cooling network operated by Helen meets well the goals of mySMARTLife project. Helen's network is fed with energy efficient CHP production (combined heat and power) but growing amount of heat comes from recycled waste heat sources such as sewage water and solar heat collected from buildings within district heating network. Renewables and waste heat sources including SunZEB concept, which is currently being implemented in one apartment block of Kalasatama,

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were also presented in the deliverable. Furthermore, Helen's new investment to Mustikkamaa rock cavern heat storage will enable greater system flexibility and production optimization. Several other investments and plans of Helen, including heat pumps, heat storages, bioenergy heating plants and utilization of waste heat sources, are also discussed in this deliverable. All of the new investments will contribute to the carbon neutrality targets of 2035.

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2. Introduction

2.1 Purpose and target group

The purpose of this deliverable is to report new concepts in district heating and cooling applicable in Finnish ecosystem. The deliverable introduces the current ecosystem and the strategy, which guides the development. Currently the energy production is going towards environmentally friendly energy system where the goal for Helen Ltd., an energy company in Finland, is to be carbon neutral by 2035. In this deliverable the past improvements in system efficiency and technology as well as future development with system configuration, renewable energy production and technology are covered considering city level heating network. Introduction to Helen's new investments and plans in order to reach the carbon neutrality targets are presented in Chapter 3.

The deliverable is targeted at energy providers and stakeholders responsible for planning and constructing new energy systems. This includes the energy utility companies and responsible city bureaus. The information and findings reported in this deliverable will be relevant mostly for Finnish players but other cities and countries can find some gripping surface on the results and hence this could also benefit other international stakeholders as well.

2.2 Contributions of partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable. Helen is the leading beneficiary and main responsible of the deliverable. VTT, Technical Research Center of Finland, has contributed to the research tasks of mySMARTLife. Some of the topics under this deliverable, e.g. the Tali area optimization model, were approached by holding a workshop, which was coordinated and lead by VTT. VTT interviewed Helen's experts in different fields of expertise in district heating and other heating solutions. VTT then reported the results of the workshop in the M12 version of the deliverable.

For the final version, the deliverable was complemented by VTT with the results of Tali area optimization model and heat storages optimization model. For the final version, Helen updated and complemented the contents of all chapters of the deliverable. For example, the Chapter 3 was updated, the contents of heat demand response potential and pilot projects were added to the Chapter 4. The Chapter 6 was complemented with information about new solutions to better optimize district heat production in Helsinki. The division of work and links to mySMARTLife as well as to other developments of Helen are described more in detail in the next paragraph.

The new heating concepts were studied via a simulation model of the area of Tali, which is an island area located at the end of one of Helen's main district heating pipes. The model was done under mySMARTLife

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project by VTT during 2018 and 2019. Helen and VTT held frequent meetings about the progress of the model and Helen's experts commented it throughout the process. The results of the model are discussed in Subchapter 5.1.

The deliverable also covers description of potential improvements of district heating and cooling systems for example by studying the optimization potential of heat storages, heating production and lowering the district heating feeding water temperature. In addition, heat demand response potential and pilots within mySMARTLife as well as outside mySMARTLife are discussed in Chapter 4. Furthermore, Helen's preliminary evaluation project on district heating optimization and demand response potential in Helsinki is discussed in Subchapter 4.1. The preliminary evaluation project contributes to the mySMARTLife actions of district heating and cooling, especially to the action 13 (value of heat demand reponse, estimations of potential) but also to 19 (optimization of heat storages in district heating and cooling). The Subchapter 6.1 discusses Helen's decision to acquire an expansion to the optimization system to better optimize the heat production. The acquisition of the expansion goes beyond mySMARTLife project, but the preliminary evaluation project that resulted in the decision to acquire the addition to the system is contributing to the district heating and cooling actions of Helen in mySMARTLife.

Table 1: Contribution of partners

Participant short name	Contributions
HEN	Responsible of the deliverable. Contribution to all chapters.
VTT	Contribution mainly to chapters 3.3, 3.4, 5 and 6. Contents of Tali area optimization model (5.1), Sunzeb concept (5.2) and heat storages optimization model (6.1).

2.3 Relation to other activities in the project

The following Table 2 depicts the main relationship of this deliverable to other activities and deliverables developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

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Table 2: Relation to other activities in the project

Deliverable Number	Contributions
D4.1	"*Baseline report of Helsinki demonstration area*": This deliverable provides the overall description of the baseline, including a general description of the district heating and cooling in Helsinki.
D4.2	"*Report on retrofitted actions and implemented actions new buildings including RES and storages*": SunZEB building level solutions, including planning and implementation are presented in this deliverable.
D4.23	"*New predictive and adaptive control algorithms and monitoring of performance, smart demand control system*": The deliverable focuses on providing more technical point of view into the actual operation of the systems and the needed solutions.
D4.4	*"Report on implementation and performance of innovative smart system appliances and control algorithms, BEMS and Smart control":* This deliverable reports the implementation of predictive and adaptive control algorithms described in a concept level in deliverable D4.23.

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3. Identifying district heating and cooling improvements in Helsinki

The purpose of this chapter is to give an overall description of Helen's district heating and cooling system in Helsinki. The Subchapter 3.1 introduces the current district heating and cooling system of Helen. The Subchapter 3.2 presents the planned new investments of Helen and Subchapter 3.3 identifies potential future improvements. Subchapter 3.4 compares centralized and building specific heating and cooling systems.

3.1 Introduction to district heating and cooling in Helsinki

Energy efficient tri-generation and recycling of energy form the basis of Helen's energy system. The four CHP plants were constructed between 1970 and 1990 and the peak-load and reserve power plants between 1960 and 2000. District heating also uses heat-only boilers with a high capacity for peaking and reserve. Their usage time, however, is normally very short. Heat-only-boilers are needed as the production is weather dependent and the weather changes a lot annually. The produced CHP heat amounts to around 5,000-6,000 GWh annually and covers over 90 % of the total heat production. The fuel efficiency of 90 % is among the best in the world and the production system as a whole is designed to work optimally in Finnish weather conditions. The Annex 1 presents an overview table of Helen's district heating and cooling production plants. The Annex 2 presents existing heat and cooling storages as well as Helen's plans to invest in new heat storages in Helsinki.

In 2018, Helen produced 6,700 gigawatt-hours of electricity, 7,200 gigawatt-hours of heat and 190 gigawatt-hours of cooling. Helen's energy efficient district heating covers today over 90 % of the heat demand in Helsinki. The connection capacity of the DH network is over 3,400 MW with over 15,500 customer connections and approximately 197,000,000 cubic meters are heated by district heating. The length of the district heating network in Helsinki totals over 1,380 kilometers, expanding by 15-20 kilometers annually. The flow temperature is changing according to the outdoor temperature and it is also optimized. A typical flow temperature of district heating is ca 90 °C and return temperature ca 45 °C. For the district cooling, the flow temperature is ca 8 °C and return temperature ca 16 °C. The whole district heating system is designed to meet the city's heating demand in -26 °C outdoor temperature. The map of Helen's district heating and cooling network is presented in Figure 1.

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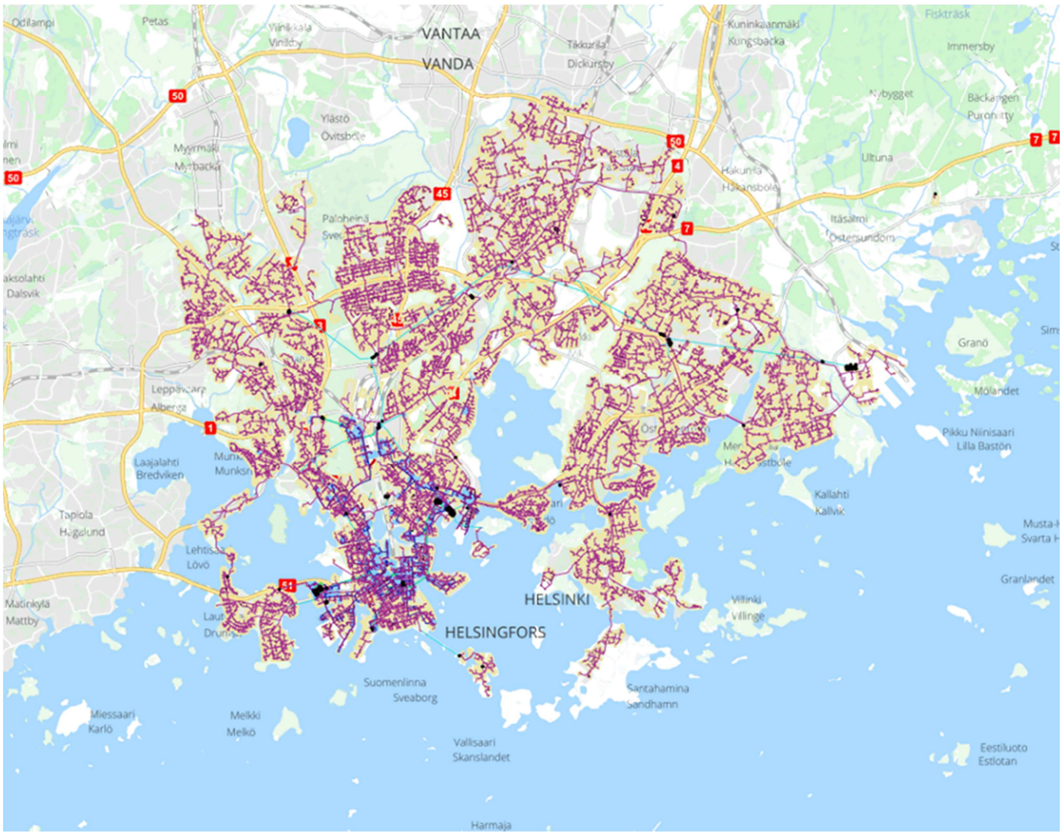

Figure 1: The map of Helen's district heating (red) and district cooling (blue) network. The black dots represent Helen's production units. Figure: Helen Ltd.

The origin of Helen's district heating and cooling for year 2018 are presented in Figure 2 below in order to give an overview of the production of district heating and cooling in Helsinki.

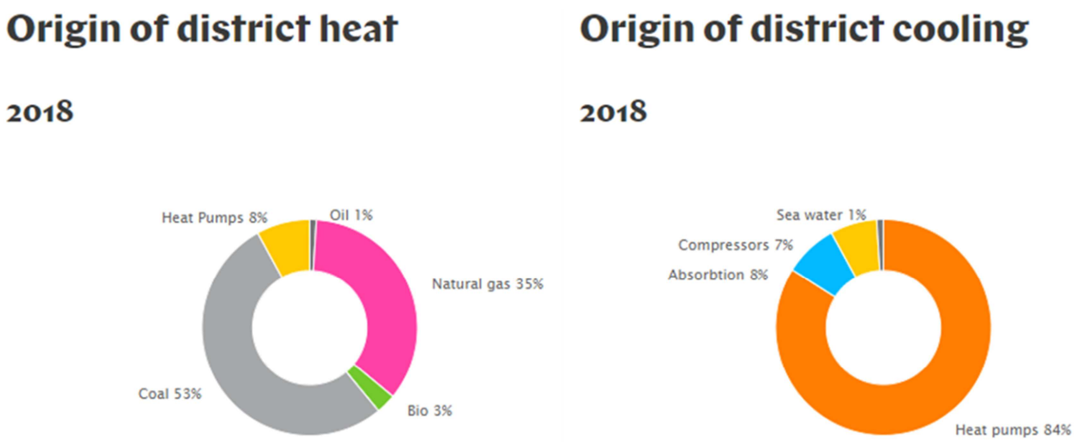

Figure 2: Origin of district heating and cooling of Helen in 2018. Source: Webpage of Helen Ltd. (Helen 2019a)

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Specific carbon dioxide emissions of energy sold by Helen were 158 g/kWh (in 2018) for heating and 72 g/kWh (in 2018) for cooling (Helen 2019b). The renewable district heat sold by Helen was produced by wood pellets (89 %) and by biogas (11 %) in 2018 and the specific carbon-dioxide emissions of renewable district heat are 0 g/kWh (Helen 2019c). For more information about CO_2 emissions see Annex 3.

As the cooling demand grows and Helen's district cooling network expands, the role of CHC (combined heating and cooling) becomes more important. In a way, Helen is in a transition from CHP production towards CHC system. Heat pumps and energy recycling will play a key role in Helen's future energy system. Example of this is Katri Vala heat pump plant, which covered 8 % of Helen's heat production in 2018. Katri Vala heat pump was constructed in 2006 and its heating capacity is 105 MW and cooling capacity is 70 MW. Katrvi Vala heat pump plant will be expanded with a new heat pump starting operations in 2021. The district heat output of the new heat pump will be 18 MW and cooling output 12 MW.

Helen's district cooling covers today the entire Helsinki inner city, and is expanding into new areas every year. The annual growth since the early 2000s has been 15 to 20 MW. In Helsinki, district cooling is used in various types of real estates including shopping malls, hotels, office buildings, public premises, residential properties and data centers. District cooling is used for recovering heat from buildings where heat would otherwise be wasted. In a way buildings act as huge solar thermal collectors. On warm summer days, half of the district heating in Helsinki is produced with recovered waste heat.

In 2016 about 79 % of district cooling was produced in Katri Vala heat pump plants and in 2018 the value was about 85 %. Today, Helen also offers cooling solutions as a service with real estate installed heat pump. This outsourced cooling solution works in principle the same way as the bigger industrial-scale heat pumps, such as Helen's Katri Vala heat pump plant. Cooling is produced in customers' premises and heat is condensed to the district heating network.

Helen's two heat accumulators and two cooling accumulators improve energy efficiency and flexibility in the production (Annex 2 presents more information about heat and cooling accumulators). These accumulators contribute the optimization of the whole energy system. Heat or cooling energy is charged in the night and used during the day when the demand hits its peak. Along with working as means for demand response, these storages maximize the reliability and guarantee of delivery of heating and cooling.

Helen aims to further improve the efficiency of energy production and distribution. In accordance with the national energy efficiency agreements, Helen undertook to increase the efficiency of energy use by 5 per cent by 2016 in comparison with the 2005 levels and to promote improved efficiency in customers' energy use by 9 per cent by 2016. Helen has also joined the new energy efficiency agreement for 2017–2025 and will develop especially the production and distribution solutions of district heat and district cooling systems to improve energy efficiency.

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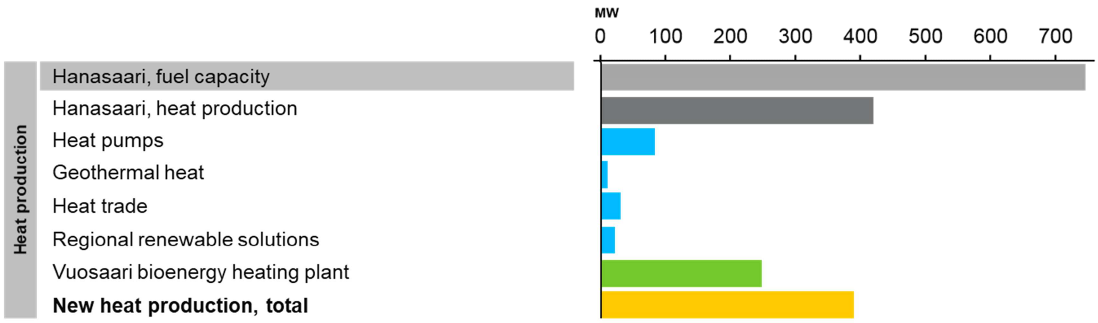
The most significant strategic policy with respect to the development of Helen's energy production structure is long-term target of carbon neutrality by the year 2035. The target is in line with the target of the City of Helsinki and Carbon Neutral Helsinki 2035 plans as well as with the national targets of Finland. Guidelines have also been set for Helen in the decision of the Helsinki City Council in December 2015 to decommission the Hanasaari CHP plant in 2024 and to replace its production with renewable energy. The national climate and energy strategy as well as the EU level energy policy impact also the emissions reduction targets of Helsinki.

Helen has published a strategy to contribute to the decommissioning of Hanasaari coal plant. Helen will replace the heat production of Hanasaari CHP coal power plant mainly with separate heat production utilizing bioenergy, heat trading and heat storages. Moreover, Helen is taking and has taken actions towards utilizing waste heat sources e.g. via heat pumps, investigating possibilities of geothermal heat, developing heat trading with other energy companies, utilizing regional RES and bioenergy. The replacement plan of the heat production of Hanasaari CHP coal power plant is presented in the Table 3.

Table 3: The heat production of Hanasaari power plant will be replaced by bioenergy, heat pumps and heat storages



District heating and cooling play an important role in Helen's mission for a CO_2-neutral future. Future energy planning is done in interaction with customers and citizens. Helen aims to make progressive investments to reduce emissions and increase renewable energy and to make use of all the opportunities offered by new technologies.

Helen's steps towards carbon neutrality can be divided to three phases:

1) Carbon dioxide emissions -40% from the level of 1990, renewables to 25% and halve the use of coal by 2025
2) Phase out of coal in 2029
3) Carbon neutral energy production by 2035

The energy system in Helsinki is flexible and provides an excellent basis for various renewable energy solutions. The heating and cooling networks are independent of the fuel used. In addition to increased use

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of biofuels, Helen is investigating, for example, extensive utilization of heat pumps, solar heat and geothermal heat. In addition to the development of production, Helen is also evaluating the possibilities of demand response, distributed generation and energy savings.

Helen has continued to the planning of an extensive investment program. In the first stage, Finland's largest pellet heating plant has been built in Salmisaari, Helsinki to replace oil, coal and natural gas use. The fuel capacity of the pellet heating plant is about 100 MW and its district heat output is about 92 MW. The pellet heating plant was completed in winter 2018. The investment will reduce carbon dioxide emissions by about 58,000 tons per year.

Helen also decided to build a large heating and cooling plant in the cooling center located under the Esplanade Park in Helsinki. Its production started in spring 2018. The investment included two industrial-scale heat pumps producing cooling and heating (2x7.5 MW cooling, 2x11 MW heating). The investment reduces Helen's carbon dioxide emissions by an estimated 20,000 tonnes per year.

3.2 New investments in heating and cooling production and heat storages

This chapter describes planned new investments of Helen to further improve the existing disctrict heating and cooling production and storage systems in Helsinki. Helen is planning new heat pumps, new heat storages as well as bio energy heating plants.

3.2.1 Expansion of Katri Vala heat pump

Helen has further continued the investments in the recycling of excess heat by building a new heat pump to complement the underground heating and cooling plant located in a rock cavern excavated under the Katri Vala Park in the district of Sörnäinen in Helsinki. To be commissioned in 2021, the new heat pump will be built in the world's largest heating and cooling plant owned by Helen Ltd. and located under the Katri Vala Park. The plant already has five large heat pumps, and it has been possible to raise their production volume each year by developing the production process.

In 2017, the plant produced more heat than ever before, a total of 570,000 MWh. Due to the new heat pump, it will be possible to increase the plant's production volume by as much as 200,000 MWh, i.e. by almost 30 %. With the new pump, heat will be recovered from the heat of purified savage wastewater that has already been utilized, which will significantly improve the efficiency of recycling thermal energy. (Helen 2018a)

The district heat output of the new heat pump is 18 MW and cooling output 12 MW. The investment will raise the thermal output of the Katri Vala heating and cooling plant to a total of 123 MW and cooling output to a total of 82 MW. The new investment will reduce Helen's carbon dioxide emissions by about 65,000

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tonnes per year and 130,000 MWh more excess heat will be recovered each year. This will also reduce the thermal load conducted into the Baltic Sea by the same amount. (Helen 2018a)

3.2.2 New large-scale heat storage to the old oil caverns of Mustikkamaa

In addition to the new investments of heat pumps, Helen has decided to invest to a large-scale heat storage system, which will be built in old oil caverns in Mustikkamaa, Helsinki (Figure 3). The new heat storage will be the largest heat storage facility in Finland. The construction work started in 2019 and the heat storage facility will be completed for production use in 2021.

Figure 3: Mustikkamaa rock cavern in Helsinki. Photo: Helen Ltd.

Thanks to the Mustikkamaa rock cavern heat storage facility, it will no longer be necessary to use and produce district heat consumed in Helsinki all at the same time, since the heat storage will bring flexibility to the system. Heat or surplus heat produced with a high efficiency rate will be stored in the facility when the heating need in Helsinki is not at its highest. The new heat storage can be used throughout the year. Especially during winter, it may not be necessary to start up heating plants operating on oil or gas allowing reduction in the use of fossil fuels. At the same time, the use of renewable fuels and CHP will be increased. (Helen 2018b)

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Based on computational comparisons with oil, the heat storage facility will reduce the use of fossil fuels by 1,000,000 litres of oil per year. The rock cavern heat storage facility will decrease Helen's carbon dioxide emissions by 21,000 tonnes per year. (Helen 2018b)

The heat storage facility will provide flexibility to the energy system as it will balance variable heat consumption through charging and discharging. When discharging the heat of the storage facility, the heat can be utilized as such in the form of district heat. The effective water volume in the heat storage facility is 260,000 cubic meters and the total volume is 320,000 cubic meters. The charging and discharging capacity is 120 megawatts. The water in the heat storage facility is not connected to the water in the district heating network. Heat is transferred from the water in the facility into the water in the district heating network by means of heat exchangers. It takes four days to fill the heat storage facility with heat, and it can be discharged in four days. The heat storage facility will be located completely underground. No structures will be built above the ground level, and the storage of heat will not have an impact on other activities in Mustikkamaa. (Helen 2018b)

The Mustikkamaa heat storage facility will improve the energy efficiency of the energy system in Helsinki. It can be used for increasing profitable operating time in combined heat and power generation and improving its possibilities of operating on the market also in the future. (Helen 2018b)

3.2.3 New heat pump utilizing sea water

The decision to invest in a new and unique heat pump utilizing sea water was done in 2019. Helen will build a heat pump in connection with the Vuosaari power plant, utilizing the power plant's own cooling water circulation and the heat of sea water as heat sources. The heat pump will be built as a part of the process of the Vuosaari CHP plant, to be located in a separate annex next to the current power plant building.

A heat pump of this scale utilizing the heat of the sea water is unique in Finland. The heat pump will utilize thermal energy absorbed in sea water during the summer and the excess heat from the internal cooling water circulation in the Vuosaari power plants, turning it into district heat. The heat pump is a good solution to increase the efficiency of the Vuosaari power plants' own production process. With the heat pump, Helen will be able to recycle the excess heat of the cooling waters in the production process and utilize it in the district heating network. By utilizing the heat of sea water, Helen can extend the annual operating time of the heat pump and that way improve the profitability of the investment. (Helen 2019d)

It is estimated that the heat pump will be utilizing, on average, 20 per cent of the heat of the sea water and 80 per cent of the excess heat of cooling waters from the power plant's internal process circulation. The district heat output of the heat pump is about 13 MW and district cooling output 9.5 MW. The construction

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will start in 2020, and the new heat pump will be in production use by 2022. The heat pump will reduce Helen's carbon dioxide emissions by an estimated 30,000 tons per year. (Helen 2019d)

The smart energy system and the district heating and cooling networks in Helsinki make it possible to combine new technologies and production methods in a flexible way. At Helen, heat pumps are seen as an important part of the future energy system: they are a natural way to utilize new heat sources in district heat production.

3.2.4 Plans of bioenergy heating plants

Helen has also published other plans, which are currently still in the planning phase or waiting for the decision on investment. Helen has investigated the possibilities of building bioenergy heating plants in different parts of Helsinki. Currently, bioenergy heating plants are planned to Vuosaari, Patola and Tattarisuo in order to phase out coal in 2029. Biomass will play a role in the road to carbon neutrality by 2035.

The Vuosaari bioenergy heating plant would be located next to Helen's existing power plant site in Vuosaari. The planned size of the Vuosaari bioenergy heating plant is about 250 MW, with wood chip as the main fuel. The Vuosaari bioenergy heating plant would replace a part of the of the coal use of the closing Hanasaari CHP plant. Currently, the objective is to enable an investment decision on the Vuosaari bioenergy plant in spring 2020 and then it would be in production use in 2023. (Helen 2019e, Helen 2019f)

Helen's other plans in bioenergy include a bioenergy heating plant in Patola and in Tattarisuo, but final investment decisions are not yet done. The bioenergy heating plant of Patola would produce district heating from pellets and its nominal heat input is planned to be ca 120 MW. The bioenergy plant would be in use earliest in 2023. (Helen 2019g)

The size of the Tattarisuo heat power plant would be ca 130 MW. The new biomass heating plant has two implementation options; it will either use biomass as a fuel or a combination of biomass and recovered fuel. (Helen 2019h)

3.2.5 Preliminary plans of seasonal heat storage

Helen is planning a seasonal energy storage facility for the Kruunuvuorenranta rock caverns. The plans have been published, but no investment decision has been made. The seasonal energy storage solution would be a part of the energy system of an ecological district with a new way of utilizing sea water heated by the sun and the recycled heat of residential buildings. The envisaged project will utilize the rock caverns located beneath Kruunuvuori, one of which has previously been used as an oil stockpile. (Helen 2019i)

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In terms of its implementation, the designed solution is unique both in Finland and on a global scale. The energy solution designed by Helen is based on a model where heat pumps are used for the heating and cooling of buildings. In summer, the caverns will be filled with surface water heated by the sun and collected from Kruunuvuorenselkä, and in the winter this water is utilized as the energy source for heat pumps. In the summer season, surplus solar heat from buildings is also collected for processing and recycling for the use of the residents. Therefore, in the model, the sea water and buildings heated by the sun function as a source of heat for the heat pumps, and heat is collected and distributed in the heating networks in the district. The capacity of the planned seasonal energy storage facility will meet as much as one-third of the heating energy need of the entire Kruunuvuori district. (Helen 2019i)

The plans include two rock caverns, one is about 16 meters wide and the other about 18 meters wide. The height of the caverns is about 30 meters. The length of the larger cavern is 326 meters and that of the smaller one is 245 meters. The bottom of the caverns is 50 meters below the sea level. The total volume of the caverns is about 300,000 m^3. Figure 4 describes the basic principle of Kruunuvuorenranta seasonal energy storage facility. (Helen 2019i)

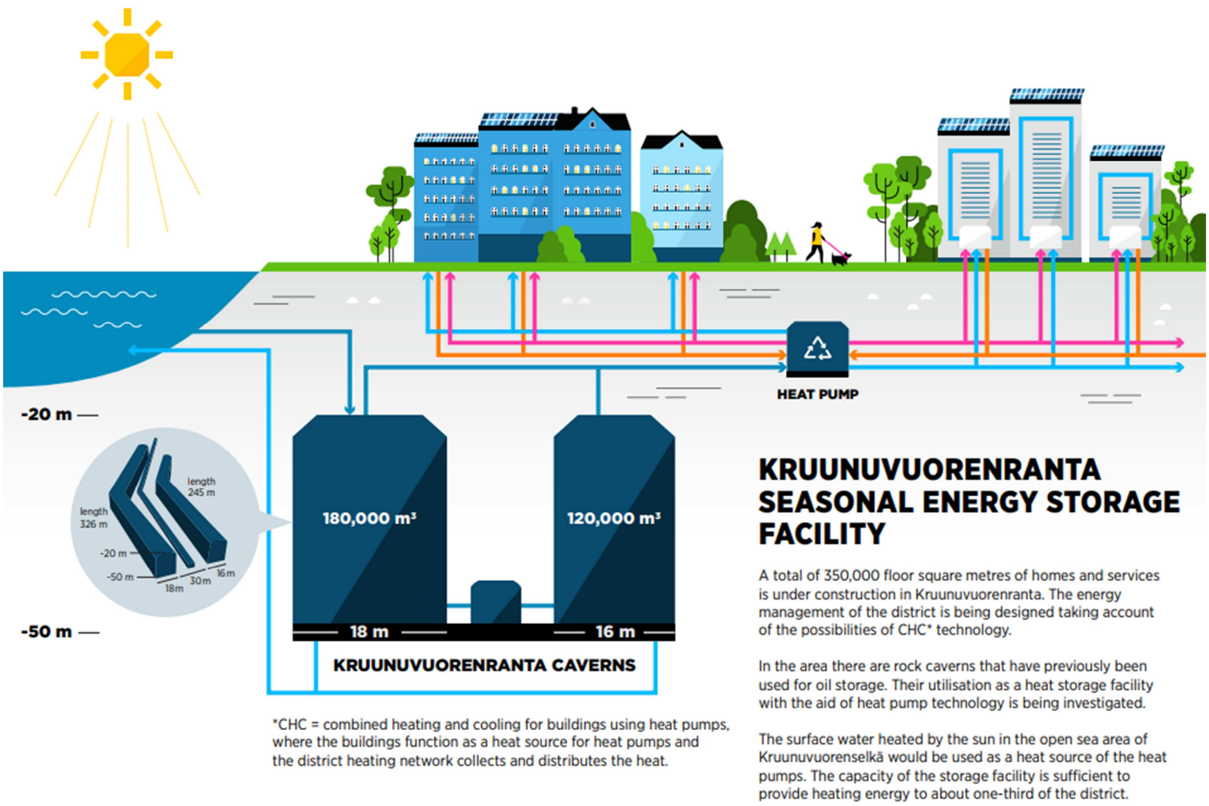

Figure 4: Plans of Kruunuvuorenranta seasonal energy storage facility. Figure: Helen Ltd.

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3.3 Identifying potential future improvements for district heating and cooling

A workshop on potential future improvements for district heating and cooling was held between HELEN and VTT on 24.5.2017. The objective of the workshop was to analyze the current and the potential future improvements for district heating and cooling in Helsinki. Total of six experts from HELEN participated to the workshop, representing different district heating and cooling application areas, backgrounds and positions at Helen. The list of participants and their fields of expertise are presented in Table 4.

The findings and the feedback provided a one starting point for developing and evaluating district heating and cooling improvements in Helsinki. VTT had developed a set of questions to guide the discussion at the workshop, focusing on the four mySMARTLife Helsinki demonstration actions:

- Action 13: Estimation of the demand response cost value; integration models to energy market, analysis of impact at city level
- Action 16: Integration of renewables and waste heat sources in the network
- Action 14: Optimize the amount of renewables in the district heating
- Action 19: Optimize the storage system in the district heating and cooling.

The question framework for the workshop is reported in the Annex 4.

Table 4. HELEN&VTT workshop participants on 24.5.2017

Participant short name	Name	Role in organization
HEN	Anssi Juvonen	Product specialist, analytics
HEN	Jussi Kukkonen	Developer manager in energy system development
HEN	Henrikki Nuutinen	Design manager in heat investment projects
HEN	Tero Korhonen	Project manager in heating preliminary and general studies
HEN	Janne Inkinen	Specialist in development projects
HEN	Kristiina Siilin	Project specialist in new energy solutions
VTT	Mari Hukkalainen	Senior scientist in energy solutions of eco efficient districts
VTT	Miika Rämä	Senior scientist in energy systems

3.4 Comparing centralised and building specific heating and cooling systems

The discussion at the HELEN&VTT workshop was started by comparing the pros and the cons of centralized and building specific heating and cooling systems. Comparing centralized and distributed systems is not trivial and depends on various aspects. There is not one unambiguous solution. However, some characteristics can be specified.

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Centralized systems are characterized by reliability and higher efficiencies from system point of view that a combination of distribution units. A single unit can be more efficient than a centralized system, but simultaneity factor (peak consumption of every consumer is not exactly at the same time) results in lower total capacity requirement e.g. in terms of heat demand (approximately 0.85) and for cooling (0.6 - 0.65). This also brings cost efficiency, e.g. the Katri Vala heat pump plant has 6,000 h of full load hours. Regional or area specific differences do exist; district heating and cooling does not suit every location. Centralized system can also be more versatile from the optimizing point of view. This is why centralized systems are attractive in terms of flexibility. Centralized systems are also less volatile and more predictable in pricing. Distributed systems simply have more units to maintain and operate, and maintain costs can come at surprise (e.g. a valve adjustment in a building with a heat pump can cost 2,000 €). This can lead to higher operation and maintenance costs and due to the higher capacity requirement, also to higher investment costs. (Helen 2017a)

Schemes for adding more renewables in the often fossil-based centralized system already exist. An example of this is Helen’s renewable district heating product; at the moment with an extra fee the customer gets 100 % renewable heat. Helen offers renewable district heat product to B2B customers based on wood pellets and so called circular heat product based on heat pump production. Renewable district heat for B2C customers is based on heat pumps utilizing purified sewage water as a heat source. These are great examples of district heat’s flexibility; renewable heat is available to customers without any extra investments in the customer end.

Distributed systems (a single unit) are more easily replaced, which can potentially lead to an accelerated change in heat supply of a system. Centralized systems, on the other hand, should benefit from economy of scale. Distributed systems can be, from consumer point of view, more economic, especially the hybrid systems combining centralized source of heat (as backup) with a distributed source. Psychological factors, such as self-determination (“I run my own systems myself”), are in line with distributed solutions. (Helen 2017a)

There seems to be a loop in evolution of heating systems. Distributed systems evolve into centralized systems that are now developing characteristics of distributed systems again but most likely only in some limited extent. Future is very likely to be a combination of both. The systems should be looked as holistic entities, whereas currently it can be that the holistic benefits are not seen (including benefits for the energy company, customer and society). For example, the building level heat pumps require usually back-up from the electricity grid or district heating network during peak power demands. Needs of many should outweigh the needs of one, but it is far from trivial how this ideal should be sold to paying customers. There is a shortage of impartial and reliable information for the consumers on the choices available and the impact of those choices. (Helen 2017a)

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4. Value of heat demand response, preliminary evaluation project and pilots

This chapter describes the proceedings of heat demand response in Helsinki. The Subchapter 4.1 presents an on-going preliminary evaluation project of Helen on the topic of heat production optimization and heat demand response potential in Helsinki, which also contributes to the mySMARTLife actions of district heating and cooling, especially to actions 13 and 19. The Subchapter 4.2 briefly explains the different kinds of heat demand response pilots done by Helen within mySMARTLife and also outside mySMARTLife.

The purpose of heat demand response solution is to reduce the need for heat during peak consumption hours and enable greater flexibility. Generally, the peak hour energy production, that follows peak consumption, is more expensive than the basic energy production, due to the usage of more expensive energy sources, fuels and energy purchasing. This is why peak consumption leads to increasing of the costs and emissions of energy production. With consumption being shifted to a different time of the day, the demand response flattens out peaks that would otherwise occur, so that the expensive peak energy production is less needed. Basically, in heat demand response, the buildings are controlled with their automation systems in a way, that their heating system is using less energy than usual during the assumed peak consumption period, because of the controlling of heat usage. However, even if the energy consumption is less during the assumed peak consumption period, the situation is compensated afterwards, because the building still in general needs the certain amount of energy in order to be warm enough. Although the total energy consumption is not decreasing, and there are no energy savings, the heat demand response and smoothing of the peak consumption have influence on the structure of energy production - because of those the energy company does not have to use more expensive production plants and the emissions can, in theory, decrease.

Helen is currently evaluating the potential of heat demand response in Helsinki, the benefits in system level and the possibilities to implement demand response. Figure 5 below illustrates the basic principle of how heat demand response could bring energy production savings.

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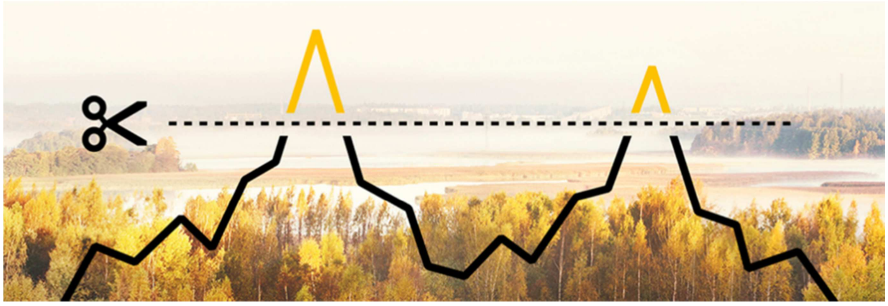

Figure 5: The idea of heat demand response is to cut consumption peaks and shift the consumption to other hours of the day. (Picture: Helen Ltd.)

One of the potential improvement points discussed in the HELEN&VTT workshop in 2017 was the value of demand response in district heating and cooling systems and what does it comprise of. The experts at Helen told that short-term comfort remains an issue and must be taken into account. If heat demand response is executed by lowering the room temperature, it should be noted that the operative temperature is different than the indoor temperature. (Helen 2017a)

Figure 6 illustrates the city energy system of Helen. Heat demand response is done between production, customers and storage systems. Heat demand response brings additional flexibility to the system and results in lower emissions and production costs if large volumes of buildings participate. The cavern heat storage facility depicted in the figure 6 will start operation in 2021 and Helen is currently planning to install bioenergy heating plants in Helsinki in order to reach the CO_2 emissions reductions targets. SunZEB concept is discussed more in detail in chapter 5 and the concept will be implemented in one apartment block of Kalasatama, Helsinki.

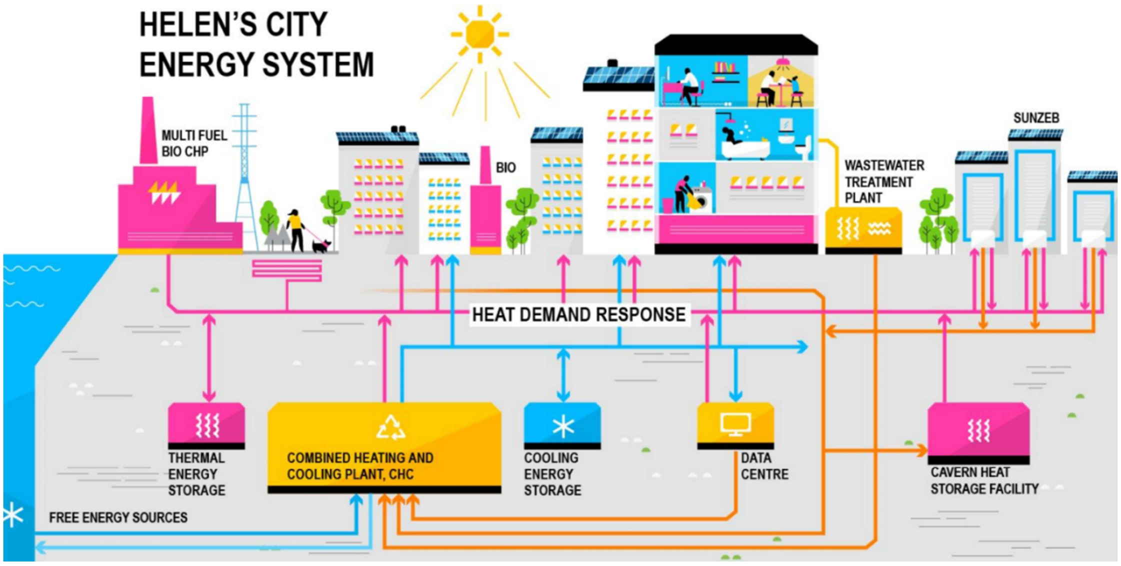

Figure 6: Helen's city energy system illustrating district heating network, heat production, storage systems, utilization of waste heat sources and heat demand response. (Figure: Helen Ltd.)

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4.1 Preliminary evaluation project on production optimization and heat demand response potential

Helen started a preliminary evaluation project on production optimization and demand response of district heating in 2019, which contributes to the mySMARTLife actions of district heating and cooling, especially to theaction 13 but also to the action 19. The objective of the project is to define the most profitable and realistic way of deployment of demand response of district heating. An internal final report of the preliminary project is finished by the end of the year 2019 and it will give the direction for Helen on how to deploy heat demand response in Helsinki in the future. The ways of deployment are assessed from different perspectives, such as production optimization of district heating network, the current technologies of demand response of district heating in terms of building automation, and from customers' perspective. The key study questions are:

1) What is the impact of heat demand response on energy production?

2) Is heat demand response considered as profitable from the perspectives of an energy company and customers or are there some other benefits not related to economics?

During the preliminary evaluation project, Helen decided to invest in production optimization system, which is a real time extension to existing automation and production planning system, and enables effective control of heat demand response in the future, if it becomes more common. The system optimizes the supply water temperature, pressure differences and pumping of the district heating network and coordinates the power of the heating plants and heat accumulators. More details about the decision to install an extension to the existing automation and production planning system are reported in Chapter 6.

According to Pöyry (2018) and Valor Partners (2015) the potential of heat demand response is less for those district heating networks that already have more cost-efficient energy storages and diverse production. Currently, Helen is planning a huge heat storage in Mustikkamaa, which will be in operation in 2021. To some extent, these kinds of heat storages can weaken the profitability of heat demand response due to their economies of scale. When it comes to customer interest, some customers have interests in heat demand response in Helsinki and Helen has participated in pilots with these customers. At the moment, it seems that the motivation for customers arises from carbon neutrality targets for 2035 and from responsibility, not necessarily from the actual energy savings or economic point of view. Helen has also enabled heat demand response in the terms and conditions of district heating in November 2019.

4.2 Heat demand response pilots

This subchapter discussed the different heat demand response pilots done by Helen within mySMARTLife (pilots with smart thermostats) and also outside mySMARTLife project (other pilots of Helen). The piloting started with Helen's "Heat promise" and with mySMARTLife pilots in one apartment building in Merihaka

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and in Viikki Environment House. Helen is currently also piloting heat demand response in apartments owned by Heka (Helsingin Kaupungin Asunnon Oy, apartments owned by City of Helsinki). Furthermore, during the preliminary evaluation project in autumn 2019, Helen started a demand response pilot with a hospital.

4.2.1 Voluntary participation via a campaign

The pilots of heat demand response started with a campaign. Voluntary heat demand response was piloted by Helen with a concept of sending text messages to customers when reducing heat consumption would have positive effect on system efficiency. The voluntary demand response was a campaign called "Heat promise" and it was piloted in winter 2016-2017. The active volunteers who signed up in Enne-community established an energy community where each individual made an impact with their actions. (Helen 2017b)

The scheme where customers voluntarily participate in demand response has been also studied in Master's thesis by Erik Jokinen in 2013 (Jokinen 2013). Jokinen found out that the system flexibility produced 50-100 MW variations in demand corresponding to 2-4 % in peak demand. As calculated by Jokinen this would result in a small economic benefit for Helen (ca 10,000 €). However, user behavior has a role to play concerning e.g. morning and afternoon peaks. The need for the heat demand response can also be questioned, because energy storage systems in Helsinki are also taking care of the demand for the heat demand response. (Helen 2017a)

4.2.2 Pilot projects

Outside mySMARTLife pilots, Helen has piloted demand response via building-level control, i.e. changing the set value of water coming to the radiator network, with Heka. In mySMARTLife, Helen has tested demand response via room-level control, i.e. changing the set value of indoor temperature via smart thermostats. Since smart thermostats are rather new technology and still rare in the buildings of Helsinki, heat demand response via building level control is more promising way to reach larger volumes of apartment buildings to heat demand response. In the hospital pilot of Helen with HUS Helsinki University Hospital, both the radiator network and the ventilation network temperatures are controlled and the water set values are changed in order to study the demand response capability of the building. Tentatively, according to the assessment and simulations of a consulting company, it seems that ventilation network has a lot of demand response potential in non-residential buildings.

Helen's pilot with the hospital is running at least for the heating season 2019-2020. The objective is to study if the hospital can carry out demand response of heat without compromising the circumstances of the premises. In the pilot, Helen is sending demand response command signals to a user interface

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system, which is provided by the building automation supplier. In addition, one goal is to assess if the demand response of hospital buildings and buildings alike could have an effect on lowering the emissions of energy production if more hospitals and other buildings that include ventilation units participated in demand response.

Within mySMARTLife, Helen has piloted heat demand response in one apartment building in Merihaka and in Viikki Environment House. In these buildings, heat demand response was piloted via smart thermostats that were installed as a part of mySMARTLife project. Merihaka apartment building uses smart heating system provided by Salusfin and Viikki Environment House uses the smart heating system provided by Fourdeg. During heating season of 2018-2019, heat demand response was successfully piloted in Viikki Environment House and in four voluntary pilot apartments of Merihaka apartment building. The heat demand response commands determined by Helen were -1, +1, 0 Celcius degrees during the pilot. In addition to technical piloting, feedback on thermal sensations was collected via a QR-code from the residents of the apartments / employees of Viikki Environment House. VTT analyzed the feedback and temperature measurements and no clear correlation was found between the demand response commands and thermal sensations of residents / employees. The results of Merihaka and Viikki pilots are discussed more in detail in D4.4 and the heat demand response commands of Helen used in the mySMARTLife pilots are presented in D4.23.

Helen has piloted heat demand response with Heka via building level control. The pilot started with negotiations with Heka in 2017 and heat demand response started for the heating season of 2018-2019 with ca 20 heat distribution centers. Heat demand response pilot in Heka buildings will continue to the heating season 2019-2020 with about 30 heat distribution centers. In spring 2020, technical capability for heat demand response should be easily accessible in ca 300 heat distribution centers in the buildings owned by Heka. During the research phase of the pilot, the heat demand response commands have been done as a prototype. However, if used in production in the future, the demand response commands will be based on automated calculation reflecting the production status.

As a part of Heka pilot, analytical estimations will be done about the heat demand response potential in Helsinki. One of the objectives of the project has also been to test and enable heat demand response technically. In addition, a paper survey was conducted for few Heka buildings with the objective to get knowledge on thermal sensations of residents. The feedback survey was conducted in fall 2019 and ca 35 % replied. Heka pilot will continue at least until the end of heating season 2019-2020.

Furthermore, to evaluate the effects of heat demand response on the operative temperature of the room, Helen has done heat demand response tests in two empty office rooms for research purposes. Several temperature sensors and measurement devices of operative temperature were installed in the empty office rooms in fall 2019. The objective of these tests was to demonstrate apartment room conditions and investigate the effects of heat demand response commands to the operative temperature.

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5. Renewables and waste heat sources in the network

Combined Heating and Cooling, CHC, stands for production of cooling in the same process with heat production. CHC enables the production of heating and cooling with efficient utilization of free energy sources, such as cold sea water, solar energy and co-generation i.e. recovering waste heat from properties with district cooling. In other words, the new CHC production enables energy recycling with highest possible efficiency with existing technologies.

The basis of the CHC system is in the urban city structure and the coincident emergence of heating need, cooling need and surplus energy. Office buildings require cooling while apartment buildings next door are in need for hot water, also during the warm season when the cooling need is peaking. Office buildings including shopping centers, data centers etc. generate surplus heat that can be utilized in heat production instead of condensing it into the air. During the winter time, CHC system collects the excess heat from data centers and purified wastewater for using the heat where it is needed. The renewable district heat produced with district cooling is returned to the properties connected to the district heating and cooling system for utilization.

Heat pump plants operate as the key element in Helen's CHC system collecting and processing energy flows in the CHC energy chain. The CHC system using heat pumps can collect solar energy and other waste energies with district cooling enabling the building to act as a source of renewable energy. The CHC system collects energy and produces simultaneously cooling. Several heat sources are efficiently utilized and combined in a single system as depicted in the Figure 6 in Chapter 4.

Helen's Katri Vala heat pump is one of the largest heat pump plants in the world utilizing heat from purified sewage water and to produce heating and cooling in the same process (105 MW heating and 70 MW cooling). Different energy flows are separated and processed to the correct temperature levels for reuse in heating and cooling. The heat energy utilized for district heating is obtained with heat pumps from the incoming purified wastewater from the Viikinmäki waste water treatment plant with a water flow of 11,000 cubic meters per hour. District cooling energy is also obtained directly from the sea with heat exchangers.

The positive climate impacts achieved with the CHC cooling with Katri Vala heat pump plant are identified as lower emissions generated in the energy production when compared to an equivalent building specific cooling system using compressor-operated cooling production. The utilization of waste heat sources and renewable energy in the district heating and cooling networks of Helsinki will grow with the new investments presented in Subchapter 3.2 New investments in heating and cooling production and heat storages.

CHC solution is particularly well suited for the new zero- and plus-energy houses where the management of heat and energy flows is extremely important. The shading of structures and cooling of indoor spaces in

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the summer are a necessity if the surplus energy is not recovered. It is also necessary to prevent a building, which uses only a little energy in the winter, from turning into an energy guzzler in the spring, summer and autumn.

At HELEN&VTT workshop, a question argued that presumably future energy system will be more distributed than currently, and the experts told that actually Swedish wind power is guiding Helen's system towards distributed system. When increasing the distributed energy sources, ensuring high system level efficiency is important. In HELEN experts view, firstly, fully or partly distributed system can be operated either as a market place based on price signals or as a single fully optimized system. Price signal based independent operation of alternative sources of heat may be easier to implement, but it might not reach optimal system operation. Some of the envisioned sources of heat such as condensing heat from supermarket cooling system might not be controllable, at least without a local heat storage solution. (Helen 2017a)

In addition, the control logics of more distributed energy systems were discussed. Whether the distributed production should be controlled in a centralized manner (energy company controlling the small distributed production by themselves), or distributed (small producers control their own production according to the energy price). In the end, it is a question of trading with the energy price. It is likely that there will be a wholesale heat market, if we evolve towards distributed energy systems. However, the concept would likely be better if the systems would be controlled centrally e.g. by HELEN, resulting also easier possibilities for organizing the maintenance. In general, if there are unutilized heat energy resources, it would be beneficial to use them, as long as markets are responsible for the system. One way or another, in the end, the end customer still needs to pay the bill.

It would be a challenge to assure that the distributed system would be sensible and profitable, and there are many open questions, such as: who would own the plants and the small production sites, are e.g. the control services offered for the end users, etc. Often small heat sources are better to be utilized locally, and not connected to a network. Centralized production would assure the reliability of the service. High efficiency will be guaranteed by patience, logic and market-based mindset. Having two separate, but overlapping systems (centralized and distributed) is not likely to be as efficient as an integrated, single system. Most likely the future systems will rely on a combination of (clustered) distributed and centralized heat sources; perhaps consisting of district level hybrid systems as a part of the whole city energy system. The energy grid could operate as a platform, where different components (electricity, heat, cooling) can be brought and new opportunities created. (Helen 2017a)

Integration of small, separate heat sources also requires an open, replicable and affordable connection method and either common guidelines/standards (if executed through regulation), or bilateral contracts. However, the HELEN experts noted that it would be a challenge to create an open district heating and cooling grid that would be suitable for all, without raising the cost level too high.

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Current market based solutions, such as combined heating and cooling in Helsinki, can already provide a good platform for new concepts and businesses. Block chain and IoT (Internet of Things) as technologies can support new business models for distributed heat supply, but they are still under development. These would also require installing certain types of sensors and sensor formatting for the customers to achieve the benefits and to get enough data. Typically, everyone builds their own systems at the development phase, and the different systems are not interoperable. (Helen 2017a)

The role of energy positive blocks or areas in district heating systems has also been discussed. In principle, it was considered as a possible concept, even though economically it would be more favorable to develop the whole metropolitan area. Some separate, area-specific systems exist (such as in housing fair district in Vaasa) in Finland. However, often when the existing separate district level systems need to be renovated, they are wanted to be connected to the city's district heating grid, as in Tuomarinkylä and Santahamina areas in Helsinki, as they have not fulfilled the expectations. Especially maintenance issues have proven difficult when significant reinvestment is needed. There is no reason why they should not be improving the system, although much of the benefits of district heating are due interconnected demand, so totally separate, disconnected areas do not seem reasonable when high flexibility is targeted. It would be a challenge to integrate the neighboring blocks to operate together, e.g. in standardized temperature and heat distribution pressure. They could be controlled reasonably, if there is no significant changes in the network, such as large height differences or height buildings. In addition, the maintenance of such grids would be one question, perhaps there would be need for offering maintenance services. IT technologies can support the control of the grid, e.g. IoT sensors, reading and controlling of sensors, billing, etc.

5.1 Optimization and integration of renewable energy sources

5.1.1 Discussion on integration of RES in DH systems and introduction to area of Tali

As modern buildings become more energy-efficient the share of domestic hot water in total heat demand grows. This can be observed in a yearly heat demand duration curve and in the long run it will increase fluctuation and amplify morning and evening peaks in heat demand. With the share of 50 % of the total heating capacity, residential buildings are the biggest customer segment in Helen's DH system. Increasing fluctuation causes challenges in the heat production and distribution. In newly built areas, domestic hot water based demand is already defining for network design. (Helen 2017a) Currently DH meters collect only hourly consumption data and this way the impact of heating hot domestic water fades in the measurements.

The available and most promising new heat sources in Helsinki were also discussed at the workshop. Heat pumps seem the most obvious choice, but the problem is the lack of available heat sources. Boreholes cannot supply heat for the entire city, restricted by the possible amount of boreholes drilled to plots. Sea water is currently considered problematic due to water quality, problems with the freezing,

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shallow coast, space limitations (where to find enough space) and investment costs (e.g. would require titanic heat exchangers). It is possible that some blocks could be provided with sea water heat pumps.

There are also other heat sources, such as data centers. Other sources within the city such as supermarket condensing heat cannot supply the whole heat demand either. However, the capacity of large-scale heat pumps is growing, and combining different available heat sources could enable a significant share of heat pumps in heat supply. In addition, electric resistor based heating might be interesting in presence of cheap electricity due to low investment costs. Geothermal heat (as a direct heat supply for DH) is an interesting option for many cities, but still uncertain in Finland. The only deep geothermal heat project in Finland is currently under implementation by St1 in Otaniemi, Espoo (St1 2019). Similar kinds of deep geothermal heat could be produced in Helsinki on approximation in 5 bore holes, producing in total less than 100 MW. (Helen 2017a)

Bioenergy and biomass will be a part of the road to carbon neutrality since it is one of the fastest ways to replace coal. However, bioenergy and biomass also face uncertainty, mainly due to restrictions on the placing of such energy production plants. The involved logistics, storage related problems, fuel acquisition in the long term, and public acceptance are all issues as well as the uncertainty related overall sustainability of biomass use and the ongoing policy debate. For example, pellets would be needed in huge amounts, and because it is self-flammable, its storing is difficult in large amounts. Realistically, perhaps around 1 - 1.5 TWh could be produced from pellets. Real life examples for solar heat were enquired. Currently, the real life implemented solar heating solutions in Finland are building level solutions, as e.g. heating of the hot domestic water in a zero energy building in Järvenpää with 35 solar collectors, each 2,5 m2 (Järvenpään mestariasunnot 2015). Roof surfaces could be utilized either for PV or solar collectors, but as heat demand is low in summer time, PV could be more favorable option. In small sites, solar heat could substitute old oil boilers. For heat supply, PV + heat pump can outperform solar collectors in economic terms.

There are many other alternatives also, such as fuel cells, micro turbines, orc, and energy conversion to hydrogen, pyrolysis oil, and even small scale nuclear heat plants (as a technical option, but politically challenging topic), etc. In the end, there is no single, one option for total heat supply. The future system will rely on a combination of different heat sources. Energy production will be part of the circular economy; lastly utilizing the material as energy. (Helen 2017a)

A question was raised in the HELEN&VTT workshop that what happens for the competitive position of Helen after increasing the share of RES - and should the target rather be emission/carbon-free system than RES based system. (Helen 2017a) Therefore, the following optimization modeling exercise concerning Tali area in Helsinki was implemented.

The island area Tali is ideal to study the levels of district heating temperature variations as a function of outdoor temperature or local heat production for example by heat pumps. Decreasing the DH supply

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temperature results in lower heat losses and provides an opportunity to increase renewable energy sources into the network. The area of Tali consists mainly of residential buildings built in ca 90's and it is therefore representing quite common residential city area. The flow rates and temperatures of Tali area have been collected in order to study possible development for the network. The results presented in the Subchapters 5.1.2 and 5.1.3 are based on simulations and optimization to evaluate the possible improvements and no actual implementations in the Tali area are done during the mySMARTLife project. The results of the simulation and optimization of Tali area are also applicable in the same type of residential building areas.

5.1.2 Description of the Tali optimization model

The purpose of the modelling exercise is to analyze the effects of increasing self-sufficiency in terms of heating and gradual separation from the local DH network in terms of centralized DH supply. The renewable energy production capacities and hourly operation in terms of heating inside building area are optimized in order to minimize annual total costs, including annualized investment costs, under constraints representing decreasing heat supply from the DH network. The aim is to find the most suitable energy production mix, consisting of ground heat pumps, exhaust air heat pumps, solar collectors producing heat energy supported by heat storages and photovoltaics generating electricity, for a more self-sufficient building area. Two separate modeling years (2015 and 2018) are used in order to provide some variation in terms of heat load and energy prices.

Linear optimization model is used to find cost-optimal hourly operation of energy system and optimal investments in energy supply units in terms of building area by minimizing the total annual energy system cost including annualized investment costs. Cases for decreased supply of DH are constructed by first running a base case without any DH supply limit. Level of DH supply from results of this base case is used as basis for the 100 % case, separately for 2015 and 2018 cases. The annual level of DH supply is then decreased by 20 % steps until DH supply is eliminated. In the case of low DH temperature, same supply level limits are used as in the normal DH temperature cases. Figure 7 illustrates the levels of DH supply in the base case (for both 2015 and 2018) and points out the basis for the percentage-based scenario names, used in the results below, for the cases with decreasing DH share. In addition to cases with decreased DH supply level, a reference case, in which distribution of heat between buildings is eliminated and supply of heat from DH network and centralized ground heat pump is also removed, is used for system cost comparisons.

Measured hourly DH consumption data and basic information on the connected buildings are the main input data used. Table 5 presents the key parameters describing the Tali area and Table 6 lists the input data used for the modelling and provides details on principles, assumptions and methods. Finally, Figure 8

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illustrates the time series for energy prices used in the method, and Figure 9 presents the principled structure of the model with optional components for the optimisation to choose from included.

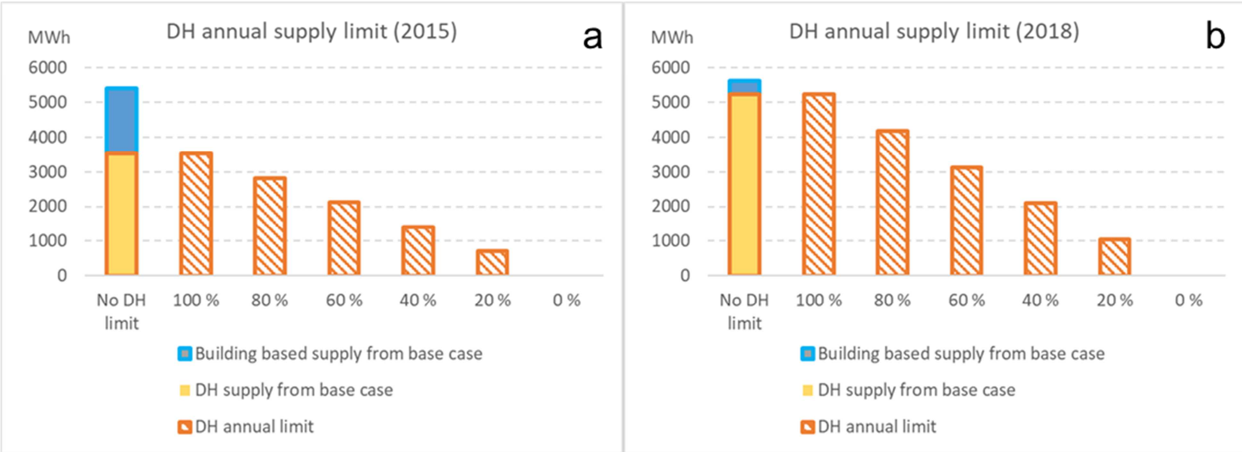

Figure 7: The basis for constraint for annual DH supply in building area in 2015 (a) and 2018 (b)

Table 5: Key parameters describing the case system of Tali in Helsinki, Finland

Key parameter	Value
Number of consumer buildings	16 buildings
Total floor area	38,000 m^2
Local distribution network length	1 400 m
Total district heating consumption	5.6 GWh (average)
Share of domestic hot water consumption	45 % (average)
Heat demand density	3.9 MWh/m

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Table 6: Definition of input used by the optimisation model

Input data	Method and main assumptions
Heat demand time series for SH and DHW	As no space heating (SH) demand is present in summertime, this period is copied throughout the year to generate separate time series for domestic hot water (DHW) and by subtracting this from the total demand, for SH. Individual hours with missing or excess demand during spring/autumn are added to the SH demand or omitted if the resulting SH demand would drop under 0 kWh/h.
Ground source heat pump (GSHP) maximum capacity	Maximum capacity is defined as the total maximum demand during a year.
Exhaus air heat pump (EAHP) maximum capacity	The capacity is calculated using the data on building volumes and by assuming 0.5 air changes in an hour and a 15 °C temperature difference for the airflow through the heat recovery system.
EAHP maximum production	Seasonal variation of humidity of the air is taken into account (measurement data from Helsinki, the impact varies between 71-100 %), and the maximum production for EAHPs is given as time series.
Photovoltaics (PV) panel and solar collector (SC) maximum area	The available roof area available for PV panels or SCs is calculated using the total floor area, estimated number of floors and an assumption that 60 % of the roof area can be effectively used for the purpose.
Heat storage maximum capacity	Maximum storage size defined as the number of hours times the capacity of a specific heat supply system. The number of hours are 2.5 h and 24 h for building level storages and an area level storage, respectively. The capacity is the defined maximum capacity for a GSHP for both buildings and the area.
Heat pump coefficient of performance (COP)	COP time series for the heat pumps (EAHP, GSHP) are calculated for each type of heat use (SH, DHW, storage, DH network). The COPs are based on assumed temperatures of the heat source and the point of demand, e.g. borehole for GSHP (3-8 °C, heat source) and radiator inlet and outlet temperatures (outdoor temperature based control, varying e.g. 70-40 °C for inlet) common in Finland. Carnot efficiency of 35 % is assumed.
Investment costs	Investment costs for each technology are estimated according to (Garcia 2012).
Other costs	Other costs include electricity prices (market price, grid costs, taxes), see (Nord Pool 2019), (Helen 2019j) and (Finnish Tax Administration, 2019). DH tariffs for heat purchased from (Helen 2019k) and modelled hourly DH marginal prices, using optimisation model from (Lindroos 2019) and current DH production profile from (Finnish Energy 2019) for heat sold to network. See Figure 8 for hourly prices.

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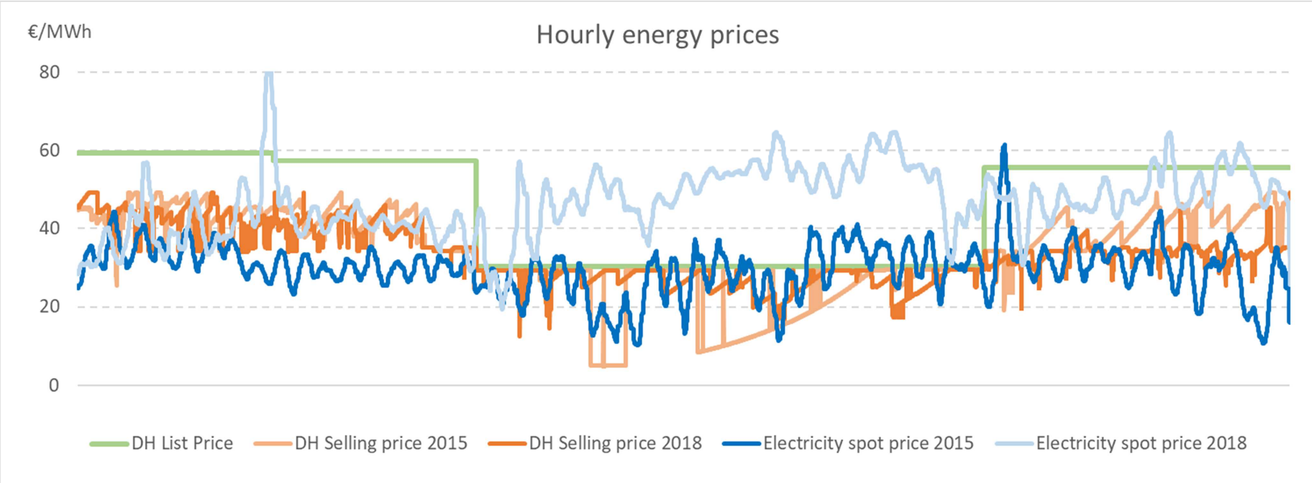

Figure 8: Hourly energy prices used in the model. Note 1 - electricity prices illustrated here are 3 day moving average values. Note 2 - same DH list price is used for 2015 and 2018 cases. Grid fee + taxes for electricity is 55 €/MWh

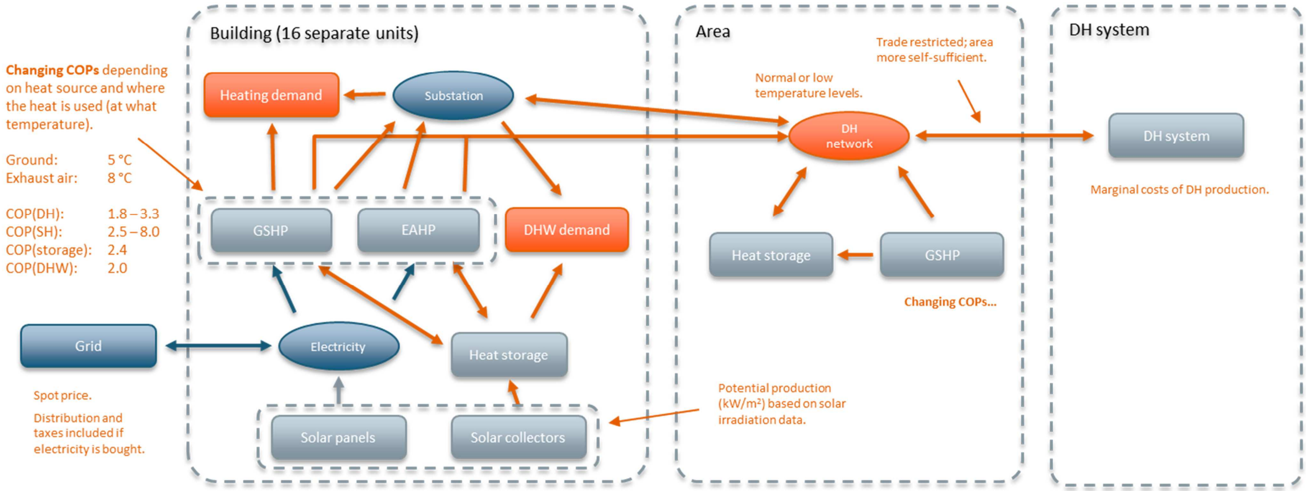

Figure 9: The basic structure of the simulated Tali building area energy system

5.1.3 Results and conclusions

Results presented here are based on the hourly annual optimization of the energy system in the building area with constraints concerning DH supply. These results are examined on annual level in terms of heat supply, costs and production capacities. The costs of energy system presented here include annual operating costs, and, in addition, investment costs of all the production or storage technologies added into the energy system, annualized by using discount rate of 7% and investment horizon of 20 years. Profits generated by selling surplus electricity or DH are presented in these results as negative costs.

Figure 10 depicts heat supply inside the energy system of the building area in the normal heat temperature case and total cost of the energy system at different levels of DH supply share.

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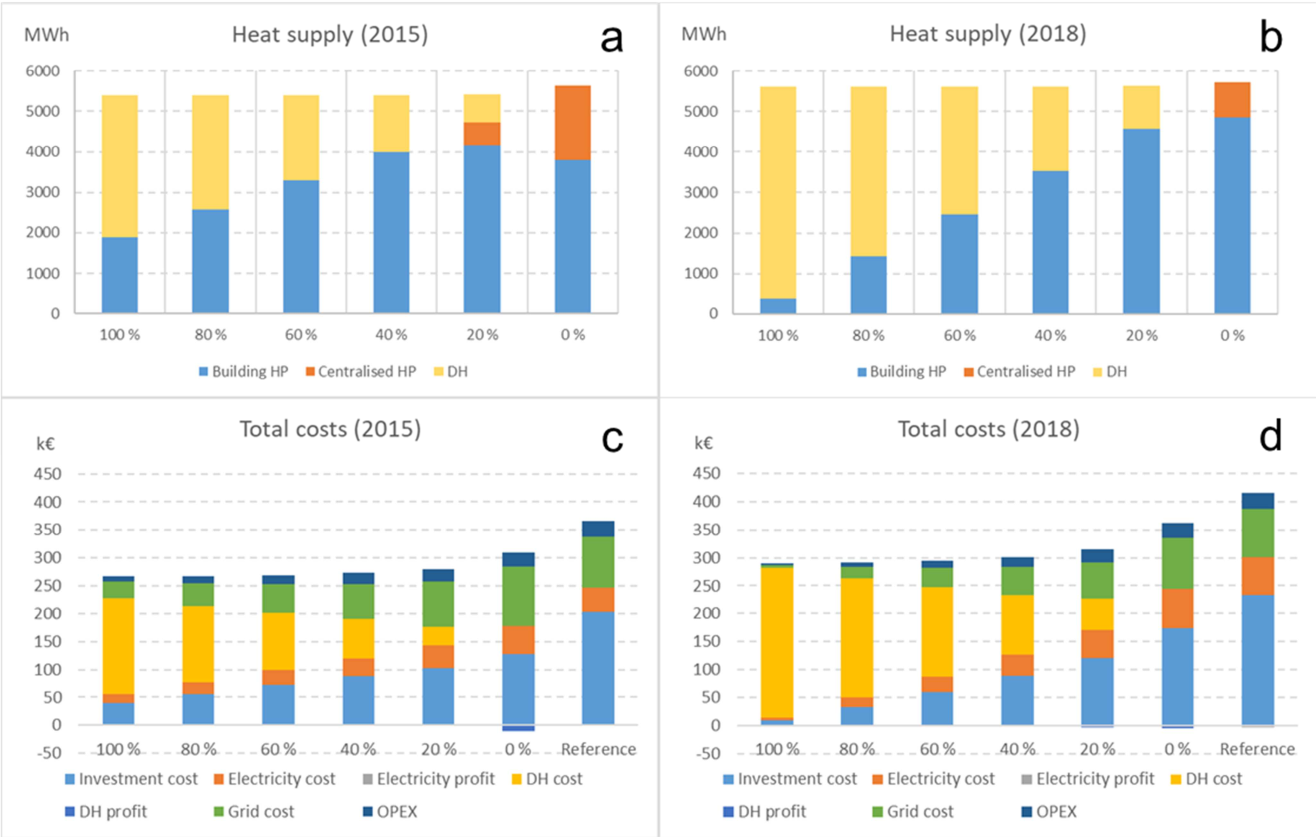

Figure 10: Heat supply (a-b) and total costs (c-d) of energy system in building area as a function of maximum share of DH supply in the case of normal DH temperature

The results presented in Figure 10 indicate the following points:

- Building based ground heat pump production increases as share of DH in system heat supply decreases, with share of building based ground heat pumps reaching 85 % in the 2018 case (77% in year 2015)
- At 20 % and 0 % shares, production of centralized ground heat pump increases in cooperation with centralized heat storage with 33 % share in year 2015
- The capacity of centralized ground heat pump in the 2015 case at 0 % DH level is 440 kW (372 kW in the 2018 case) and utilization factor is 48 % (26 % in the 2018 case)
- Heat storage has maximum capacity (38808 kWh) with merely 19 cycles (in year 2018), and 3366 kWh (9 % of maximum capacity) with 73 cycles (in year 2015)
- Total costs of energy system increase, mainly due to investment costs of ground heat pumps and grid costs of consumed electricity

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- In the 2015 case total costs are 12 % higher at 0 % DH supply level when compared to 100 % level, whereas in the 2018 case corresponding increase is 24 %
- Total cost in reference case, in which DH network is entirely disabled inside the building area, is in all cases higher, that is, 22-37 % (compared to 100 % and 0 % DH share) in 2015 and 15-43 % in 2018
- Volume of sold surplus heat from building area into DH network is marginal in all cases
- Levelized cost of energy for building area is 55 €/MWh in 2015 and 64 €/MWh in 2018

Figure 11 depicts the similar results from the low DH temperature cases.

Figure 11: Heat supply (a-b) and total costs (c-d) of energy system in building area as a function of maximum share of DH supply in the case of low DH temperature

These results presented in Figure 11 indicate the following points:

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- Building specific production investments are at lower level and centralized ground heat pump dominates the heat supply in energy system, especially in the 2015 case, regardless of constraint concerning availability of DH
- The high utilization of centralized heat pump is based on its higher COP values (based on lower supply temperature level)
- Surplus heat is sold to DH network when DH supply is limited to 0 %, 763 MWh in the year 2015 case and 359 MWh in year 2018
- Total cost in reference case is in all cases higher, that is, 36-41 % (compared to 100 % and 0 % DH share) in 2015 and 24-43 % in 2018
- Levelized cost of energy is 50 €/MWh in 2015 and 59 €/MWh in 2018

Figure 12 depicts the development of heat storage capacity, number of annual heat storage cycles and PV capacity in the normal temperature case in years 2015 and 2018. The capacity values here represent the percentage of installed storage capacity from maximum capacity level defined for each building.

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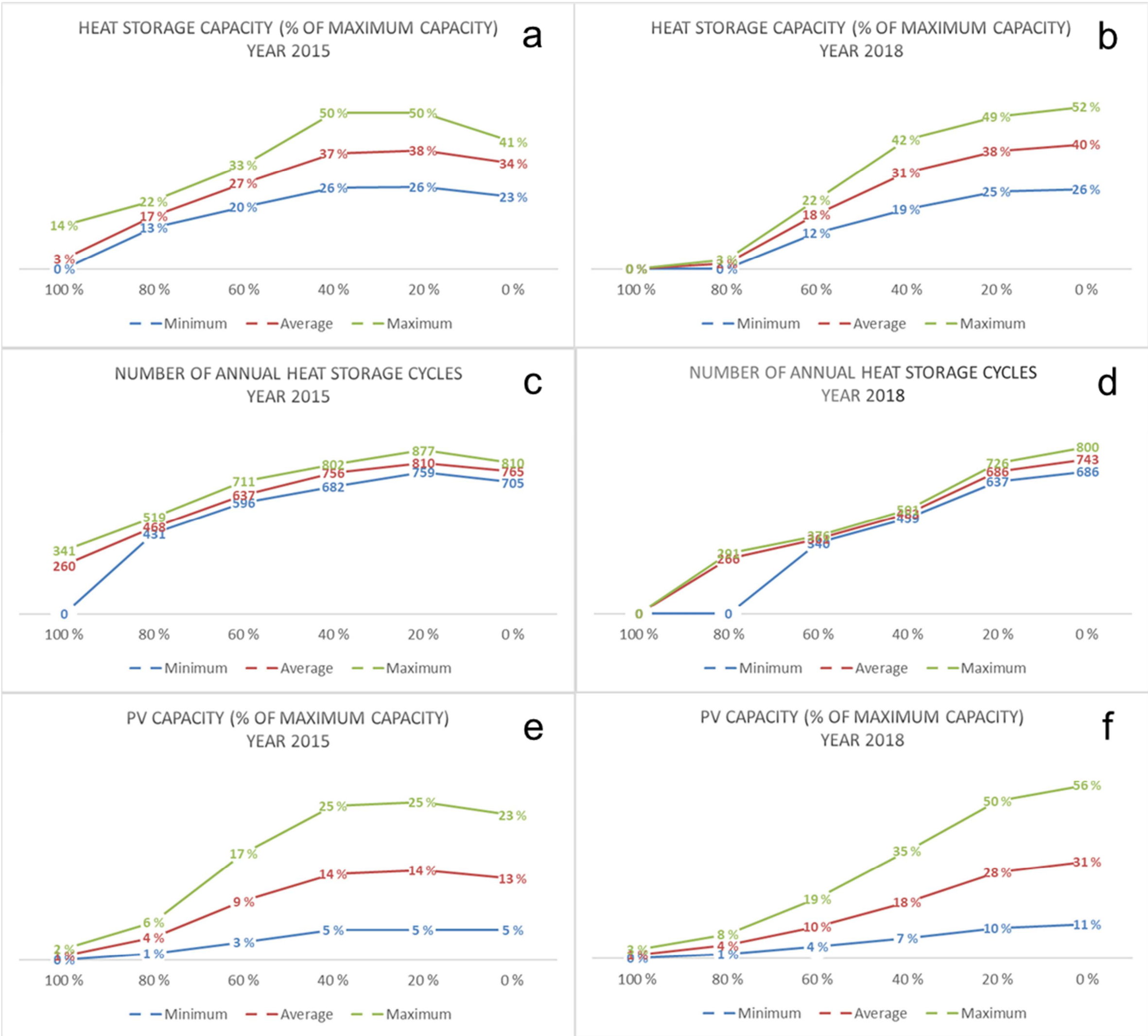

Figure 12: Development of heat storage capacity (a-b), number of annual storage cycles (c-d) and pv capacity (e-f) in buildings 1-16

Following points emerge from the results presented in Figure 12:

- As DH supply is limited, heat storage capacity increases in all buildings
- Annual number of storage cycles increases
- In the 2015 case, storage capacity growth stops at 40 % level due to utilization of centralized ground heat pump
- PV capacity increases as buildings produce own electricity in order to save (grid) costs
- In the year 2018, higher electricity prices cause higher investments in PV

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The results obtained from various optimization model runs with varied model parameters bring forward the following other observations:

- The investment cost of solar collectors must decrease 65 % for any capacity to appear, and the level of capacity is at 0-9 % of the building specific maximum capacity
- In the case of exhaust air heat pumps, investment cost has to decrease 30 % in order to have capacity in buildings (44-100 % of maximum capacity).
- The role of centralized ground heat pump diminishes greatly, in the case of normal temperature, when its investment cost approaches the investment cost of building specific ground heat pump.

The results presented in this deliverable provide the following main conclusions based on modelling exercise concerning the energy system of Tali building area:

- Self-sufficiency from district heating inflicts 12-24% higher total costs in normal DH temperature case
- Solution for building area heat supply is a package consisting of a ground source heat pump, a heat storage and PVs
- Centralized ground source heat pump added with a heat storage completes the building area system if DH based supply is excluded
- The role of centralized ground source heat pump in energy system is greater in the low temperature case due to higher COP values.
- Selling of surplus heat (back to the DH system) is marginal in all cases, however, moderate in the low temperature case.
- Exhaust air heat pumps and solar collectors are not feasible with current cost structure
- Buildings utilize existing DH network for local heat exchange

5.2 Optimization and integration of waste heat sources

5.2.1 SunZEB

The idea of SunZEB (zero energy building) is to utilize solar heat in the system level as efficiently as possible. The pioneering solution combines building structure design and the CHC system to meet the increasing need for housing comfort, right temperature and daylight, with minimal environmental impacts. The innovation is in the utilization of district cooling and building structure as a large solar energy collector to recover and recycle used energy, waste heat from electrical appliances and heat from tap water. The energy is captured with the aid of advanced windows and building services technology combined with a regional CHC system. The first real life demonstrations of SunZEB buildings are currently (in 2019) under

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construction in the 2nd demonstration area of mySMARTLife project, Kalasatama (see building level details in D4.2). The technical details of the SunZEB concept have been previously reported by Shemeikka et al. (Shemeikka et al. 2015)

A CHC solution is particularly well suited for the new zero- and plus-energy houses where the management of heat and energy flows is extremely important. The shading of structures and cooling of indoor spaces in the summer are a necessity if the surplus energy is not recovered. It is also necessary to prevent a building, which uses only a little energy in the winter, from turning into an energy guzzler in the spring, summer and autumn.

The management of energy flows in a SunZEB building brings added value to the real estate owners and residents in the form of architectural opportunities and energy efficiency raised to a whole new level. The properties and size of windows are designed so that solar energy can be utilized as much as possible with the aid of building services technology for heating and cooling the building. We can already see the solution having a full potential of achieving a situation where a property cooled with district cooling in the summer period produces solar energy in excess of its own need. All this renewable energy produced is collected without separate solar heat collectors. Buildings connected to the district heating and cooling system will also give a new look to the future cityscape.

Large window surfaces allowing natural light and heat of the sun to access indoors in the summer and winter can also be widely used in low-energy solutions. It also enables the collection of surplus heat generated by the sun and the utilization of this recovered heat in the CHC system. The utilization of the recovered heat through the CHC system again enables the building of extremely energy-efficient net-zero energy buildings and even energy-plus buildings in the urban structure.

For the real estate owners and the residents, this innovation enables eco-efficient apartments with natural lighting and enhanced living comfort. In the scale of a city, the SunZEB innovation is significant. An equivalent level in energy efficiency and production of renewable energy would not be possible to achieve in the scale of an individual building or a city block even with energy storages due to the high variations in consumption and production.

The innovation enables increased use of solar energy in towns, which will have an impact on the entire energy system. As a result of our invention, cooling of properties is not the same as wasting energy – on the contrary.

5.2.2 SunZED concept: solar-based Zero Energy District

The broadening of the building level SunZEB concept to the district level SunZED concept has been studied earlier in the Vartiosaari case in Helsinki by Paiho et al. (Paiho et al. 2015). SunZED is a name of a concept for combined district heating and cooling system enabling the recycling of energy flows (Sun =

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Sun, ZED = Zero Energy District). Paiho, Hoang and Hukkalainen (Paiho et al. 2017) studied solar energy solutions and seasonal thermal energy storage solutions at the district level in an area under preliminary urban planning. The practical implementation of the SUNZEB concept is currently being tested in Kalasatama area (see details in Deliverable 4.2).

The energy demand analysis of Vartiosaari compared two different building stocks, namely with SunZEBs (solar-based Zero Energy Buildings) representing potential future zero energy building, and with a reference stock containing buildings built according to the 2012 Finnish building codes. The SunZEBs required less heat but more cooling than the 2012 reference buildings. The advantage of the SunZEBs is that they can be designed and operated as an active part of the SunZED (solar-based Zero Energy District) concept through a combined district heating and cooling system, which enables recycling of energy flows. In this concept, the summer time excess heat can be recovered from the buildings with a heat pump and district cooling and utilized elsewhere through the district heating network, mainly for heating domestic hot water. The Sankey diagram of energy flows in SunZED concept and the reference district following current building codes from 2012 are presented in Figure 13. This figure visualizes the difference of the SunZED concept, especially the reduced need for heating energy demand. (Paiho et al. 2017)

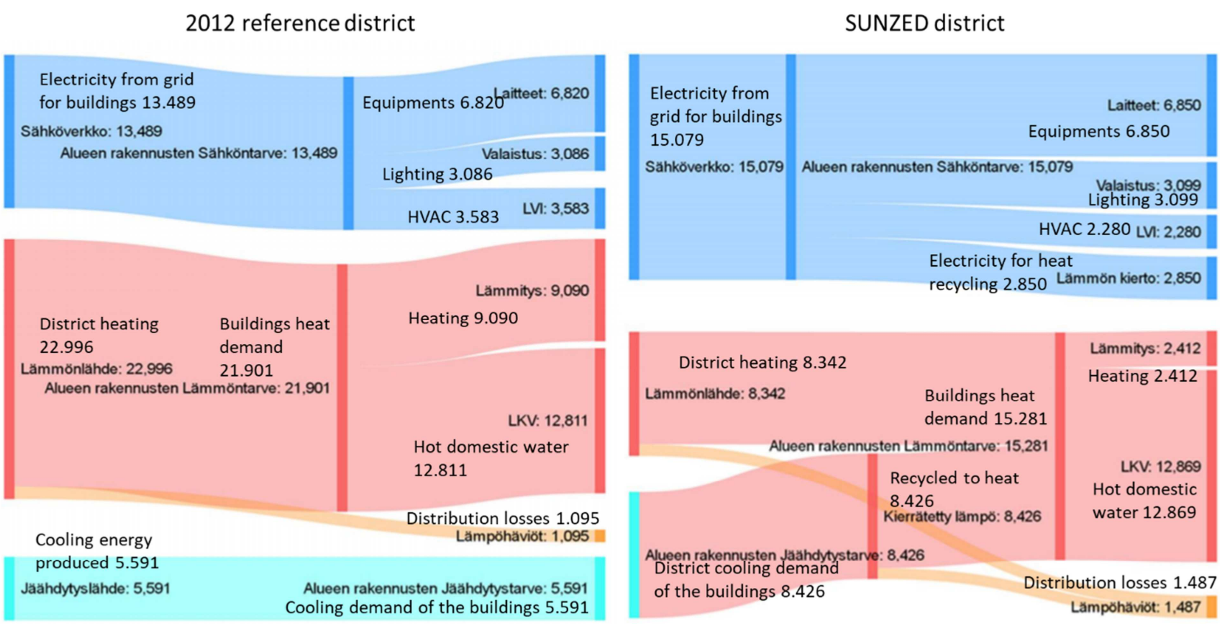

Figure 13: The Sankey diagram showing the energy flows (GWh/a) in SunZED district, the concept has been studied in Vartiosaari case Helsinki. (Figure modified from: Paiho et al. 2015)

Comparisons showed that the simulated SunZEBs model consumed about half of the real life heating consumption in recently built existing residential districts in Helsinki (built according to the older 2007 Finnish buildings codes). In addition, the self-sufficiency in heat production of Vartiosaari was analyzed

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when increasing the amount of solar collectors in the case district and storing heat seasonally either to a borehole or a tank thermal storage. With the both storage solutions, the most optimum solar collector area would be 5 % of the total building floor area in the district. This would result the self-sufficiency in heating energy to be over 30 %. If the total heating demand of Vartiosaari would be produced with a district-scale ground source heat pump system, which would be used also as a seasonal borehole thermal storage of solar heat, this borehole field would require about 20,000 m^2 of land area. If the same amount of solar collectors was connected to seasonal water tank storage and the remaining heat supplied from district heating, the water tank would need a space of 230 m^2 and its height would be 8 m. This analysis showed that about 60% of self-sufficiency in heat production could be technically possible in this area, resulting in CO_2 reduction by around 50%, and sulphur dioxide and particulate emissions by up to 70% compared to the business-as-usual situation. (Paiho et al. 2017)

5.2.3 Implementation of SunZEB concept in Kalasatama

The first SunZEB block will be built in Kalasatama in Helsinki. The block, including four apartment buildings, is based on the SunZEB model explained in Chapters 5.2.1 and 5.2.2 and developed by VTT (Technical Research Centre of Finland) together with Helen Ltd. The concept is very well suited to an urban city environment of Kalasatama and its target is to utilize solar energy as efficiently as possible. The housing quality and energy efficiency of the residences built in the area will be in line with future requirements.

The architectural solutions used in the block of SunZEB houses of Kalasatama are modern and light. The SunZEB concept enables large window surfaces and comfortable indoor conditions during all seasons. During summer, excess solar energy and other waste energies are harnessed and stored and the excess heat is then utilized by the district heating system of Helsinki. During winter, radiation from the low-hanging sun heats spaces and creates a lot of natural light for the apartments.

The construction of the Kalasatama SunZEB block has started in the end of 2018. Asuntosäätiö, Fira and the Kojamo Group will each build their own property in the same city block. The first phase includes the construction of Asuntosäätiö's Hitas site and Kojamo's Lumo rental apartments. The sites of Fira and Asuntosäätiö will be added during the second phase of the implementation. (Helen 2017c) The first SunZeb block will increase the use of renewable energy as well as utilization of waste heat sources in the system level. The first SunZEB building is expected to be ready in spring 2020. More details of Kalasatama smart district are presented in D4.2.

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5.3 Requirements for lower distribution temperatures in district heating

The distribution temperatures were raised to the discussion at the HELEN&VTT workshop. HELEN experts reckon that if a system would be built from scratch now, the distribution temperatures could be as low as the domestic hot water regulations allow; meaning supply temperature of roughly 65 °C (e.g. similarly as in Tuomarinkylä district with 65 °C). In this case, the choice of materials would also be different. Plastic pipes work well in temperatures under 70 °C. The friction coefficient in plastic pipes is also a significant factor; being about 1/10 of currently used steel pipes; and in addition they are less expensive also. If the district cooling systems would be redesigned now, significantly less expensive materials would be available nowadays. (Helen 2017a)

One concept could be to use different temperatures and pressures in main lines and distribution networks. However, in this case distributed heat sources would need to be used within the individual areas. Another concept would be to use temperature level of 35 °C for space heating and to use other sources of heating for raising the temperature level for domestic hot water supply, although the current capacity of the pipes would not always be sufficient for this concept. (Helen 2017a)

Moving from current temperature levels (90 °C on average) to a supply temperature of 60 °C will result in lower heat transport capacities. This could be overcome by distributed pumping, but with added costs. Issues related to thermal strain in steel pipes are known, but their effect in maintenance costs less so. Most obvious barriers are the current building specific heat distribution systems and the radiators within the buildings, mostly compromising of old building stock. The radiator networks and heat exchangers in the old buildings are dimensioned for 90/60 °C temperatures, and replacing of them during required renovations would require 30-year timeframe, before all buildings' heating systems could have been changed. However, there is some over-dimensioning in the old radiators and the issue can be further alleviated by increasing flow rates. The current distribution temperature of 90 °C is used among others due to long distribution lengths, e.g. from Helen's Vuosaari power plant. (Helen 2017a)

The system is already in a state of change due to new buildings, increased energy efficiency and higher shares of domestic hot water in total heat supply. This can be observed in a yearly heat demand duration curve. (Helen 2017a)

5.4 Terms for the plot assignment

Terms for the plot assignment were also mentioned by Helen (in the Helen & VTT workshop in 2017) as one important aspect to be considered. Terms for the plot assignment is a practical tool for enabling easier implementation of smart building solutions integration to the district heating and cooling systems, if e.g. heat demand response proves to be a viable concept in the on-going pilots. If the buildings would be designed already early as such a way that they would be able to be operated as an active node in the energy system, the implementation costs for such systems could be reduced later. These kinds of pre-

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conditions can be put to the terms for the plot assignment. Especially, the benefits for the buildings and the building developers should be clarified: what kind of terms for the plot assignment are really beneficial and viable for them.

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6. The optimization of district heating and cooling systems

This chapter includes the optimization model of heat storages systems in the terms of profitability as well as future improvements in the optimization of the heat production and district heating network of Helsinki. The first sub-chapter describes the discussions between the experts of Helen and VTT in a workshop held in 2017 as well as presents the results of a heat storage optimization model done under mySMARTLife project by VTT. The second subchapter concentrates on Helen's future improvements in the optimization of district heating systems.

6.1 The optimization of heat storages in the DH network in Helsinki

The potential and the benefits of heat storages were discussed at HELEN&VTT workshop in 2017. From Helen's point of view, seasonal storage systems do not have a high and sufficient role in Helsinki, while short-term storage (peaks for a few hours and/or days) and flexibility do. This is why demand response may have a future in district heating as it basically corresponds to a heat storage. The boundaries for designing heat energy storage are physical: how big storage systems can be put to urban environment and how much is and where they are allowed in the urban planning. (Helen 2017a)

The heat production is controlled in relation to the electricity price, and therefore the volatility of the electricity price has a great effect to the economic performance. Even in Helsinki, the wind power production in Sweden affects to the economic profitability of the heat storages. This issue would be aided by increasing the flexibility of the energy system. This fact makes it challenging to model and simulate the operation of energy storage systems. (Helen 2017a)

Heat storage systems in Helsinki have already replaced the need for boilers in terms of energy, but they are still sometimes needed due to temperature requirements. As the share of domestic hot water in total heat demand grows, distributed local storage solutions may become more relevant. In newly built areas, domestic hot water based demand is already defining for network design. The use of small storage close to the point of consumption could reduce the pipe sizes and, as a consequence, the investment costs for the distribution network. (Helen 2017a)

The impact of additional large-scale heat storage capacity in the DH system in terms of increased profit was studied by VTT using an EnergyPRO (EMD International A/S 2017) optimization model for the Helsinki DH system. The model was configured according to the future plans in 2017 for the year 2024. The main changes compared to the system (in 2017) are additional heat pump (22 MW) and biomass (92 + 150 MW) based capacity and the decommissioning of coal-fired Hanasaari CHP plant.

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The results were compared to annualized investment costs of the corresponding heat storage capacity increase. A range of investment costs for thermal storage (0.1-10 €/kWh) were considered (IEA ETSAP 2013), along with the investment costs reported by Helen for the new Mustikkamaa heat storage (1.3 €/kWh). The value of 1.3 €/kWh is calculated based on publicly reported investment cost of new Mustikkamaa heat storage and on the amount of stored energy, 11600 MWh. (Helen 2018b) The results of the model are shown in Figure 14.

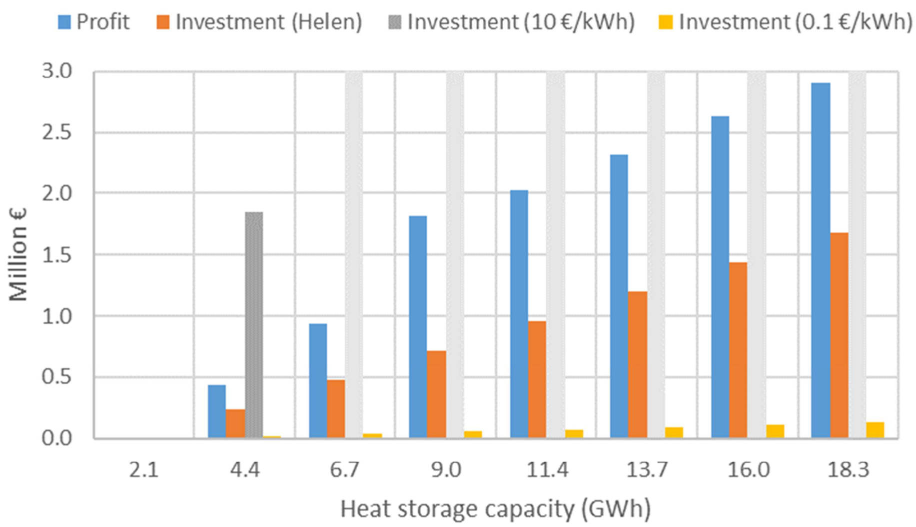

Figure 14: Comparison of increased profit and annualized investments costs for Helsinki DH system

The results show that adding heat storage capacity increases the operational profit of the system. Based on the studied range of capacities (existing 2.1 GWh to 18.3 GWh), the system could still benefit from additional storage capacity - the saturation point is not yet reached. However, the profitability (annualized investment costs deducted from the profit) depends highly on the realized investment costs. The upper range (10 €/kWh) of the investment costs does not seem profitable at all, the light gray bars in Figure 14 go well beyond the scale and are heavily unprofitable. Based on the reported investment costs of Mustikkamaa heat storage by Helen (1.3 €/kWh) we can roughly estimate that 2-3 €/kWh investment costs would be a break-even point concerning the profitability of the investment.

6.2 New solutions to better optimize the heat production in Helsinki

Helen aims towards carbon neutral energy production by 2035. The optimization of heat production and district heating network is among the means of reaching the target. As one result of the preliminary evaluation project of Production optimization and demand response of district heating in Helsinki, Helen

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has made a decision to acquire a digital control system that will better optimize the district heating network. The new system will enable reduction of both, emissions and costs.

The digital optimization for district heat production and network will enable the management of production, consumption and distribution in the entire district heating network through a single solution. In addition, the platform will allow efficient building of demand response control in the future, which will bring new opportunities to reduce emissions and costs of production.

The new system will be a real-time extension to Helen's existing automation and production planning systems. The extension for Helen will be implemented by Valmet. The optimization application for the district heating network is a part of Valmet's industrial internet services for customers in the energy industry. With the new system, Helen will improve the energy efficiency of the entire district heating network as the network can be used in a more optimal way. The system optimizes the temperature, pressure differences and pumping of supply water in the DH network and coordinates the outputs of the heating plants and district heat storages. In addition, it will enable automated management of the district heating network and plants. The new optimization system will start in operations in spring 2021. (Helen 2019l)

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7. Conclusions

Development has occurred over time in the district heating network in Helsinki and in Finland. The structure of Finnish energy system shifts from time to time: in early days people used their own sources of heat to keep themselves warm. In order to improve the system efficiency, to make heating more reliable and to serve larger geographical areas, the production was centralized with distribution network covering the districts. At the moment, current trend is to utilize more distributed sources in addition to the efficient centralized system.

The Tali area optimization model by VTT gave perspective for the possibilities of decentralized, local and renewable based production. According to the model of Tali area, solution for local heat supply of residential building area is a package consisting of a ground source heat pump, a heat storage and PVs. Centralized ground source heat pump added with a heat storage completes the building area system in a case that DH based supply would be excluded. According to the model, exhaust air heat pumps and solar collectors are not feasible with current cost structure.

Another field of study was optimization of heat storages as well as heat demand response. The heat storages optimization model of VTT focused also on the economical point of view and the profitability of heat storages implementation in Helsinki. The district heating system in Helsinki could still benefit from additional storage capacity, the saturation point is not yet reached. However, the profitability (annualized investment costs deducted from the profit) depends highly on the realized investment costs of the new storage system.

In 2019, Helen started a preliminary evaluation project on heat production optimization and potential of heat demand response. The objective of the demand response study is to determine the most realistic and profitable way of deployment of demand response of district heating. In addition, during the preliminary evaluation project, Helen decided to invest in a production optimization system, which is a real time extension to existing automation and production planning system, and enables effective control of heat demand response in the future, if it becomes more common. The deliverable discussed also several heat demand response pilots that are currently on-going in Helsinki.

The current system of district heating and cooling network operated by Helen as well as the planned new improvements meet well the high level goals of mySMARTLife project. Helen's network is fed with energy efficient CHP production (combined heat and power) but growing amount of heat comes from recycled waste heat sources such as sewage water and solar heat collected from buildings with district heating network. Helen's environmental goals of becoming carbon neutral by 2035 and abandoning coal-fired power plant in Hanasaari in 2024 are also well aligned with mySMARTLife project goals.

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Annex 1: Overview of Helen's district heating and cooling production plants

Table 7: Overview of Helen's district heating and cooling production. Source: Helen Ltd. For planned new investments, see Chapter 3.2

Power plant	Heating/Cooling/Electricity	Size	Produced from	Additional info
Vuosaari CHP, Helsinki	Heating & electricity	Heat 580 MW, electricity 630 MW	Natural gas	CHP plant
Hanasaari CHP, Helsinki	Heating & electricity	Heat 420 MW, electricity 220 MW	Coal and wood pellets	CHP plant, to be closed by the end of 2024
Salmisaari CHP, Helsinki	Heating & electricity	Heat 300 MW, electricity 160 MW	Coal and wood pellets	CHP plant
Katri Vala heat pump plant, Helsinki	Heating & cooling	Heat 105 MW, cooling 70 MW	Purified waste water, return water from district cooling, and electricity	Located under the Katri Vala Park in Sörnäinen, Helsinki. To be expanded by 2021 with new heat pump (heat output 18 MW and cooling output 12 MW).
Esplanade heat pump plant, Helsinki	Heating & cooling	Heat 22 MW, cooling 15 MW	Return water from district heating & cooling, and electricity	Started operations in 2018. Located under the park of Esplanade in Helsinki City Centre.
Heating plants in various locations in Helsinki	Heating	ca 2,200 MW in total	Natural gas, fuel oil, coal, wood pellets	Heating plants located in various parts of Helsinki guarantee a sufficient heat supply during extremely cold weather, in power plant fault situations and during maintenance outages.
Salmisaari, absorption heat pumps	Cooling	35 MW	District heating	
Salmisaari, cooling compressors	Cooling	10 MW	Electricity	
Salmisaari, free	Cooling	40 MW		

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cooling utilizing sea water			Electricity	
Hanasaari, free cooling utilizing sea water	Cooling	30 MW	Electricity	

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Annex 2: Overview of Helen's heating and cooling storages

Table 8: Overview of Helen's heating and cooling storages (accumulators). Source: Helen Ltd., based on values in 2018

Heating/Cooling storage	Heating / cooling storage	Volume	Discharging capacity
Salmisaari, Helsinki	Heating	20,000 m^3	120 MW
Vuosaari, Helsinki	Heating	25,000 m^3	100 MW
Pasila, Helsinki	Cooling	11,000 m^3	20 MW
Esplanade, under the Esplanade park, Helsinki.	Cooling	26,000 m^3	35 MW
Salmisaari (cooling)	Cooling	1000 m^3	3 MW

Table 9: Plans of new heat storages by Helen (as of November 2019). Source: Helen Ltd.

Heating/Cooling storage	Heating / cooling storage	Volume	Discharging capacity	Additional info
Mustikkamaa, Helsinki	Heat storage	260,000 m^3	120 MW	To be located in old rock cavern in Mustikkamaa. Starting in operations in 2021. Discharging capacity 120 MW is sufficient for about 4 days. The stored energy is from district heating.
Kruunuvuori, Helsinki (preliminary plans)	Seasonal heat storage	300,000 m^3	ca 3 MW	Preliminary plans published, no investment decision. Seasonal energy storage utilizing sea water and recycled heat of the buildings.

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Annex 3: Carbon dioxide emissions of Helen's energy production and the share of renewable energy

Helen strives to reduce the carbon dioxide emissions of its energy production by 40 per cent by 2025 compared with the 1990 levels. Helen's target is to reach carbon neutral energy production in 2035.

Helen produces energy mainly with its own power plants and heating plants in different parts of Helsinki. Helen also supplements its production from outside Helsinki through associated companies and purchases.

In 2018, Helen produced 6,700 gigawatt-hours of electricity, 7,200 gigawatt-hours of heat and 190 gigawatt-hours of cooling. In 2018, the share of renewable energy in Helen's energy mix was 12 %. Carbon-free production accounted for 22 %. Helen generates carbon-free energy from nuclear power and renewable energy: hydropower, wood pellets, wind power, biogas and solar energy, as well as from various waste energy flows with heat pumps. (Helen 2019m) The Figure 15 presents the carbon dioxide emissions of Helen's fossil fuel based production in 2018 and shows a comparison to the level of 1990 as well as to the target level of 2025.

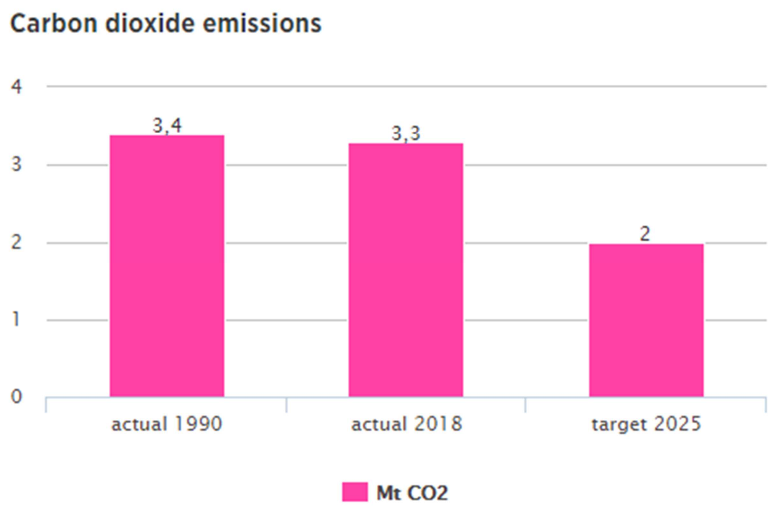

Figure 15: Comparison of carbon dioxide emissions of Helen's fossil fuel based production: actual 1990, actual 2018 and target 2025. Source: Webpage of Helen Ltd. (Helen 2019n)

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Annex 4: The question framework of the HELEN&VTT workshop on 24.5.2017

- What are the pros and cons of both centralised and building-specific heating and cooling systems?
- What is the value of demand response in district heating and cooling systems and what does it consists of?
    - Demand response vs. centralised heat storages as providers of flexibility; do they compare and are both actually needed?
    - What will be the consumer benefit for providing demand response services for the system?
- What are the benefits and potential of energy storages?
    - Is there a need for additional storage capacity? Should they be short-term and/or seasonal?
    - How do storages perform in economic terms?
- Presumably the future energy system will be more distributed; how should such a system be controlled?
    - Utility controlling the whole system or consumers operating independently based on price signals?
    - Should the utility to offer maintenance, control and operation services?
    - Who would own the distributed production resources?
- If a more distributed system is implemented, how will the efficiency and performance of the whole system be confirmed?
- What new heat sources there are available in Helsinki and what seem the most promising?
    - Evaluate them in terms of costs, potential and adaptability?
- What is the role of energy positive blocks or neighbourhoods in a district heating system?
- In what time frame can lower distribution temperature be reached and what will it require?
    - If the system would be designed today from scratch, what solution would be used?
    - What solutions are implemented now for new neighbourhoods?
    - Have the basic design principles changed for district heating and cooling?

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