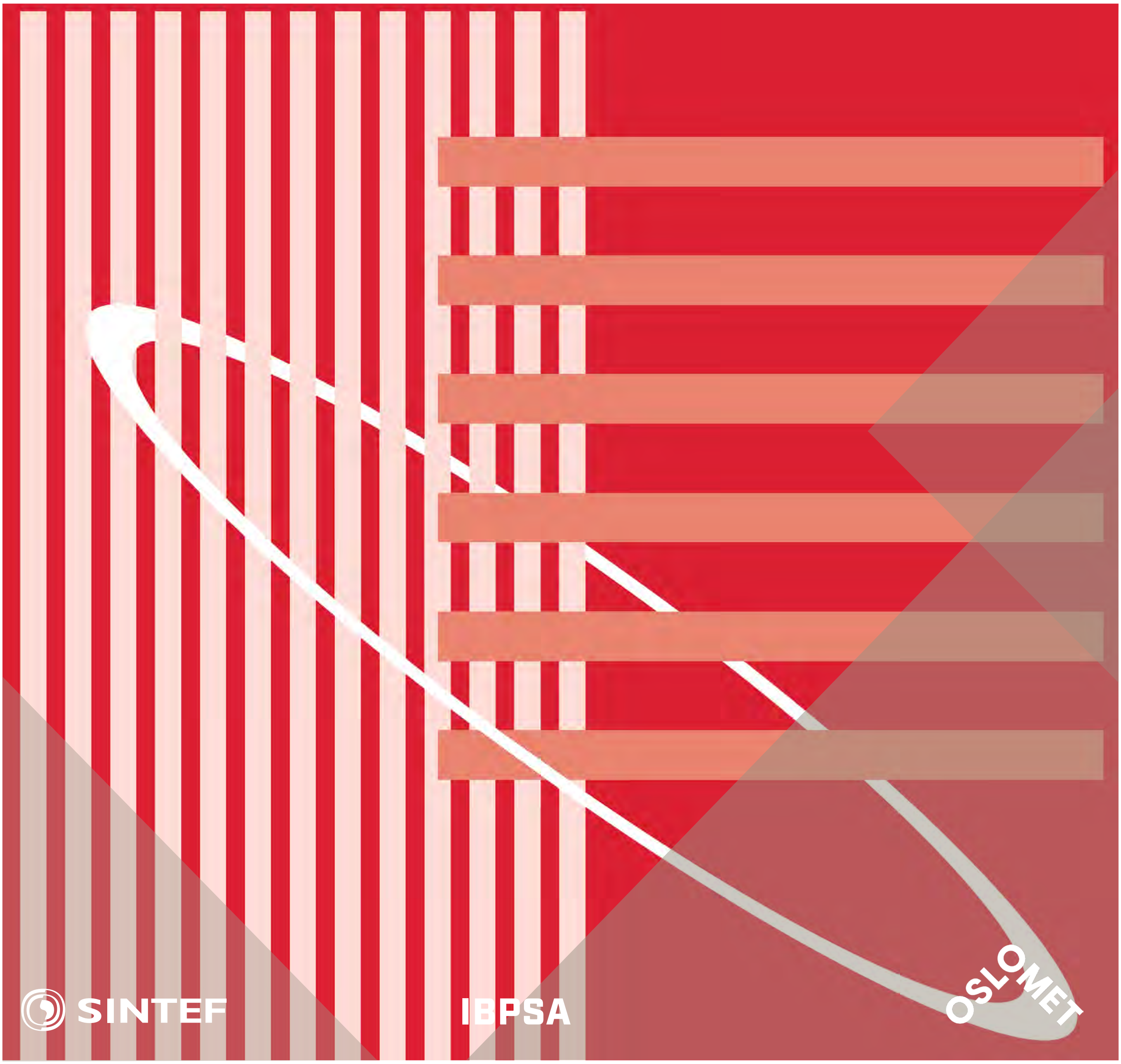
International Conference Organised by
IBPSA-Nordic, 13th–14th October 2020,
OsloMet

BuildSIM-Nordic 2020

Selected papers



SINTEF Proceedings

Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

BuildSIM-Nordic 2020

Selected papers

International Conference Organised by IBPSA-Nordic,
13th–14th October 2020, OsloMet

SINTEF Academic Press

SINTEF Proceedings no 5
Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild
BuildSIM-Nordic 2020
Selected papers
International Conference Organised by IBPSA-Nordic,
13th–14th October 2020, OsloMet

Keywords:
Building acoustics, Building Information Modelling (BIM), Building physics, CFD and air flow, Commissioning and control, Daylighting and lighting, Developments in simulation, Education in building performance simulation, Energy storage, Heating, Ventilation and Air Conditioning (HVAC), Human behavior in simulation, Indoor Environmental Quality (IEQ), New software developments, Optimization, Simulation at urban scale, Simulation to support regulations, Simulation vs reality, Solar energy systems, Validation, calibration and uncertainty, Weather data & Climate adaptation, Fenestration (windows & shading), Zero Energy Buildings (ZEB), Emissions and Life Cycle Analysis

Cover illustration: IBPSA-logo

ISSN 2387-4295 (online)
ISBN 978-82-536-1679-7 (pdf)

SINTEF Academic Press
Address: Børrestuveien 3
PO Box 124 Blindern
N-0314 OSLO
Tel: +47 40 00 51 00

www.sintef.no/community
www.sintefbok.no

SINTEF Proceedings
SINTEF Proceedings is a serial publication for peer-reviewed conference proceedings on a variety of scientific topics.
The processes of peer-reviewing of papers published in SINTEF Proceedings are administered by the conference organizers and proceedings editors. Detailed procedures will vary according to custom and practice in each scientific community.

Planning a low carbon urban area in Helsinki with dynamic energy simulations

Santeri Siren
Ramboll Finland Oy, Espoo, Finland
santeri.siren@ramboll.fi

Abstract

The city of Helsinki has a target to achieve carbon neutrality in 2035.

The objective of this project was to use energy simulations to study and compare multiple different energy production alternatives for new Malmi airport area in Helsinki and determine which of them would be suitable for achieving low carbon emissions cost efficiently.

Totally 284 energy system variations were simulated.

Results show that the carbon emissions from energy production can be cost effectively decreased compared to local business as usual solution. Ground source heat pump-based systems proved to be one of the most effective solutions.

Introduction

Finland has committed to reduce the greenhouse emissions 40% compared with 1990 levels until 2030, and 80% compared with 1990 levels until 2050 [1], [2]. Most of the major cities in Finland have their own individual carbon neutrality targets and strategies for achieving them.

The city of Helsinki has the target to achieve carbon neutrality in 2035 [3]. This will require major changes in many areas such as local energy production methods, improving energy efficiency in the existing building stock as well as minimizing the energy demand of new construction.

The Malmi airport area is the most significant area in Helsinki for upcoming new construction in near future. According to the city land use plan there will be 1.35 million square meters of new construction in that area during 2020s. In the land use plan this area is divided in to 10 sub areas. All the sub areas will be designed separately using individual themes and they will be built in a specific order during a total 25 – 30-year period. This project concentrated on the first two sub areas: Nallenrinne and Lentoasemakortteli. In these two sub areas there are totally 267 914 m^2 of planned new construction. The major part of the new buildings will be residential.

Table 1. New construction building quantities planned in Nallenrinne and Lentoasemakortteli areas

	Nallenrinne	Lentoasemakortteli
Appartment buildings [m^2]	128 700	95 300
Commercial buildings [m^2]	2 600	0
Schools [m^2]	1 500	11 500
Car park buildings [m^2]	4 400	19 150
Other [m^2]	-	4 764
Total [m^2]	137 200	130 714

The objective of the project was to compare different solutions for a heating and cooling energy production system that serves Nallenrinne and Lentoasemakortteli sub areas. The focus of the calculations was in the life cycle emissions of produced energy and the life cycle cost of different systems. The results will serve as a guideline in the future planning of the Malmi airport area energy production solutions. Local electricity production with photo voltaic was also included in the study. The idea was that the results of this project can be also applied in general planning of the other sub areas as well.

Methods

This project included a development of a simulation platform for running urban area level dynamic energy simulations that could be used for simulating and comparing different types of energy systems serving the Nallenrinne and Lentoasemakortteli sub areas.

Developing the simulation platform

The simulation platform can be broken down to four main components:

- Energy simulation for modelling urban area energy systems
- Life cycle cost calculation
- Life cycle emission calculation
- Result data reporting and visualization environment

The simulation platform consists of several software's that are connected to each other via interfaces. Scripting was used to automate the data flows between the different components and software's.

IDA ICE (v4.8) was used as the main energy simulation software for running the energy system simulations. IDA ICE is mainly used for building energy simulations but in this case the focus was heavily on urban area energy system modelling.

The energy simulation component of the platform included a lot of different kind of simulation components for modelling a wide variety of energy production systems and a methodology for creating an urban area simulation model including all the building blocks, local building integrated energy production units, area level energy production units, control and adjustment components and also heating, cooling and electricity distribution networks connecting all the building blocks and energy production components together. Scripting was used for automating the creation of the simulation models of all the predefined scenarios, running the simulations and gathering all the wanted results for post processing purposes. The main results from the dynamic energy simulation included e.g. building block energy demands, energy production of different systems and units and some essential information about occurred maximum power values of different devices during the simulation.

The LCC component of the platform is used for making all the financial calculations related to the different types of energy systems that are being simulated. Investment costs, maintenance costs and renewal costs were specified for every different energy production related technology included in the study. Also, the cost data for building the local heat distribution networks and required heat exchangers etc. were obtained. Most of the cost values were obtained from local Finnish technology suppliers and contractors. The effects of the unit's size on the nominal cost were also considered. E.g. a large heat pump system has as smaller nominal investment cost than a small system [€/kW]. The energy and fuel costs were based on the public pricing of local suppliers. All the cost data was used for creating a cost database that was integrated with the life cycle cost analysis calculator. The results from the energy simulation were used as initial values for the LCC calculations.

The inflation rates for different cost parameters in LCC calculations are always just guesses and thus they cause uncertainties in the results. Because of this a sensitivity analysis function was created in the result visualization environment. With this function the user can easily change any of the interest rates related to LCC and the result charts and diagrams will automatically update accordingly. This makes sensitivity analysis very easy and effortless.

The emission calculation component of the platform is used for determining the CO_2 emissions generated from the heating, cooling and electricity production related to the selected energy production systems. Because estimating the emission factors is not unambiguous, several scenarios were used for different emission factors and the forecast of how they will develop during the lifecycle of 30 years. The long-term annual development of the emission factors as well as the monthly based fluctuation were considered in the calculations.

The simulations produce large amounts of result data and a reporting and data visualization environment was developed to make viewing and analyzing the results easy. Tableau software was used to create an interactive data visualization environment for specialists, client and other stakeholders to study and analyze results. Several dashboards were constructed to present different aspects of the main results such as financial, energy and emissions. The dashboards included an interactive map-based user interface that could be used for easily navigating all the results from the whole area perspective to single buildings and blocks individually. The visualizations and dashboards can be published online in a cloud-based system and they can be accessed via almost any device that has an internet connection.

A main user interface was also developed for the simulation platform. The UI can be used to quickly set up the main case parameters such as all the buildings and energy demand information, different energy production technologies, automatic system sizing [kW] and setting up different combinations of systems in the area (distributed and centralized). The UI was created so that it is easy to set up as many different parallel scenarios as needed. For example, in this case totally 284 different scenarios were set up and then simulated with a single press of a button.

Determining the energy demand of the buildings

The upcoming buildings planned for the examined area were divided into 6 different building types:

- Residential apartment building
- Commercial buildings
- Schools
- Car park
- Fire station
- Grocery store

Hourly based nominal heating, cooling and electrical energy demand were defined for each building type (kWh/m^2). For residential buildings the energy demand values were based on actual measured values of 50 recently built (2013-2018) apartment buildings in Helsinki.

Simulated values were used for all the other building types. The simulated values were average values from several recent design projects made by Ramboll Finland. The hourly based nominal demand profiles included the following individual profiles:

- Space + AHU heating demand
- Domestic hot water heating
- Space + AHU Cooling
- Electricity

The electricity demand consists of all other electrical loads except electrical demand of local heating and cooling production systems (e.g. heat pumps). That part of the demand was calculated separately based on the energy system simulations. The electricity demand profile included also a profile for charging electrical cars.

The simulated energy demand values were based on Helsinki energy test year 2012 weather data [4]. This is an hourly based weather data file published by the Finnish meteorological institute and it represents a typical climate currently in southern Finland. The measured energy demand values were modified to correspond with the same climate data.

The two examined sub areas were divided into 18 individual blocks. These blocks can be seen in Figures 1 and 2.

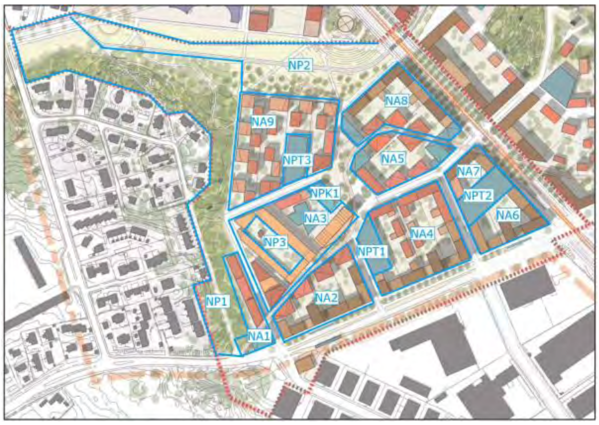


Figure 1. The area of Nallenrinne and its blocks

Figure 2. The area of Lentoasemakortteli and its blocks

The number of square meters of different types of construction planned for each block were calculated based on the latest Helsinki city planning material.

For each block the total energy demand was based on multiplying the nominal demand profiles with corresponding square meters. The result was hourly based energy demand profiles of heating, cooling and electricity for each block. These results were used as initial values in the energy system simulations.

Simulating energy system variations

Different types of energy production technologies to include in the study were defined together with the project team and client. In the simulations the included technologies could be used as a local building integrated system (B) or a centralized system that serves the whole area of Nallenrinne and Lentoasemakortteli (C). Some of the technologies could be used as both (B/C). The following technologies were selected

1. District heating (B/C)
2. Ground source heat pump system [GSHP] (300 m deep boreholes, B/C])
3. Geothermal heat pump system (2000 m deep boreholes) (B/C)
4. Local heating plant (wood pellets) (C)
5. Gas boilers (bio / natural gas) (B)
6. Electrical boilers (B)
7. Wastewater heat recovery system (B)
8. Two-way heat trade system (with heat pumps) (B)
9. District cooling (B)
10. Air cooled chillers (B)
11. CHC system (B)
12. Free cooling from geothermal boreholes (B)
13. Building integrated photo voltaic [PV] (roof installation, B)

Also, two different options were included for a local low temperature heating distribution network

- Supply temperature of 50 °C
- Supply temperature of 70 °C

The main difference between these two options is that with the 70 °C temperature level domestic hot water (typically 60 °C in Finland) can be directly obtained from the network. With the 50 °C temperature local heat pumps were used to prime the temperature level for the domestic hot water. The temperature level also affects the COP values of all heat pump systems connected to the local heat distribution network. The low temperature option enables better efficiency of heat pumps.

A specific simulation component was created in IDA ICE for every different energy production technology listed above. These components were integrated as a part of the simulation platform. Totally 284 different energy system combinations were defined from the above-mentioned technological solutions. Each of the combinations includes different kinds of heating, cooling and electricity production systems and energy distribution solutions for satisfying the energy demand of Nallenrinne and Lentoasemakortteli sub areas. These combinations included also centralized and de-centralized solutions of different technologies such as ground source heat pump systems etc. The simulation platform was used for sizing the production units, generating corresponding simulation models, running the energy simulations, LCC calculations, emission calculations and extracting specified results for all the 284 alternatives into the reporting environment.

The LCC calculation was conducted including the calculation of net present values of all the scenarios in the study during the specified lifecycle (30 years). All the important factors were included in the calculation such as investment costs, maintenance costs, renewal costs, purchased energy etc.

Results

The calculations and simulations described in the Methods section produced a very large amount of data, including energy, power, financial and emissions related information. Only the very essential values were reported in the final report of the project and will be presented here.

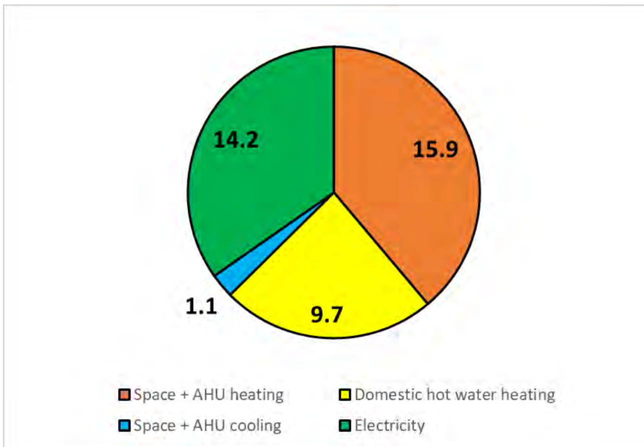


Figure 3. building energy demand of the studied area [GWh/a]

Results show that the major part of the total energy demand comes from heating demand. Domestic hot water has a significant share because most of the new buildings are residential buildings.

Figure 4 shows how all the simulated 284 cases position themselves on a lifecycle cost vs. life cycle emissions chart. The color of the points represents the type of the system as follows.

- Red: Only decentralized building integrated heating and cooling systems
- Blue: Heating only with district heating
- Green: Heating by both DH and building integrated systems
- Yellow: Only local centralized heating systems (no DH)

Five individual scenarios (marked in figure 4) were selected as recommendations, one from each category except two from green category. Also, scenario no.5 was displayed separately because it represents the typical business as usual option in Helsinki area, which is only district heating and district cooling.

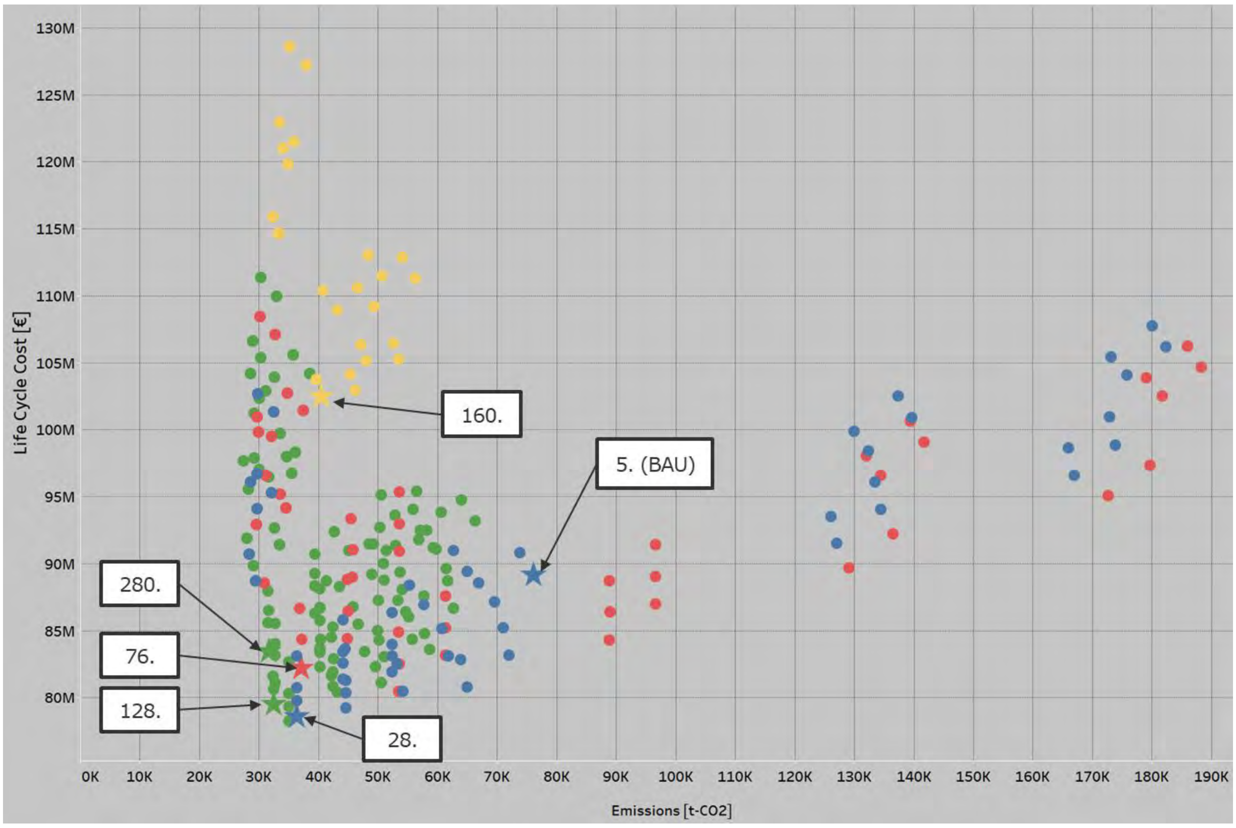


Figure 4. Life cycle cost [M€] and life cycle emissions [t CO2] for a 30-year period for all the 284 simulated scenarios.

Table 2. the technologies used in each of the selected scenarios.

Scenario no.	Centralized Heating systems	Building integrated heating	Cooling	Waste water heat recovery	Photo Voltaic	Heating distribution network
5. (BAU)	DH	-	DC	No	No	District heating network
28	DH	-	Fee cooling + CHC	Yes	Yes	District heating network
76	-	GSHP	Fee cooling + CHC	Yes	Yes	-
128	GSHP + DH	GSHP	Fee cooling + CHC	Yes	Yes	70 °C network
160	GSHP+ local heating plant (biofuel)		CHC	Yes	Yes	70 °C network
280	GSHP + DH	GSHP	Fee cooling + CHC	Yes	Yes	50 °C network

The following figures summarize the main results of the study concerning the six selected system combinations.

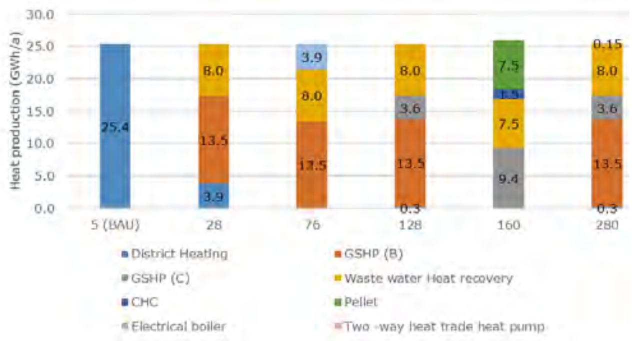


Figure 5. Heating production breakdown of the selected scenarios [GWh/a]

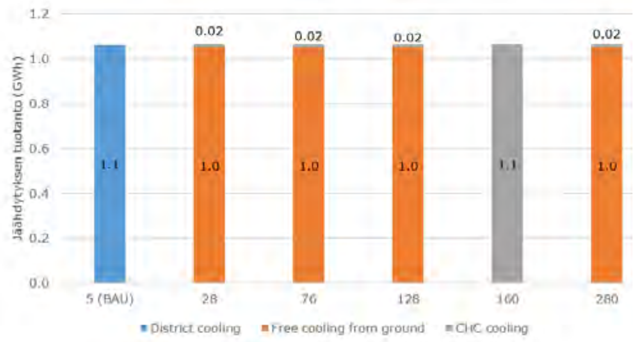


Figure 6. Cooling production breakdown of the selected scenarios [GWh/a]

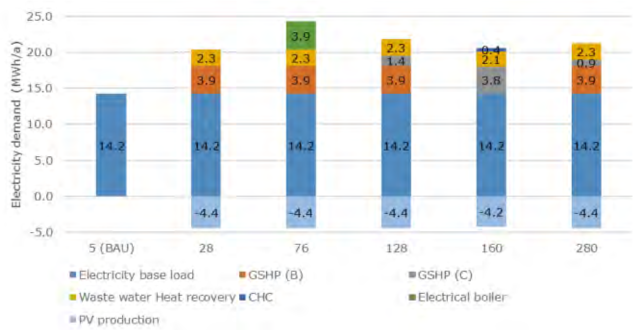


Figure 7. Electricity demand breakdown of the selected scenarios [GWh/a]

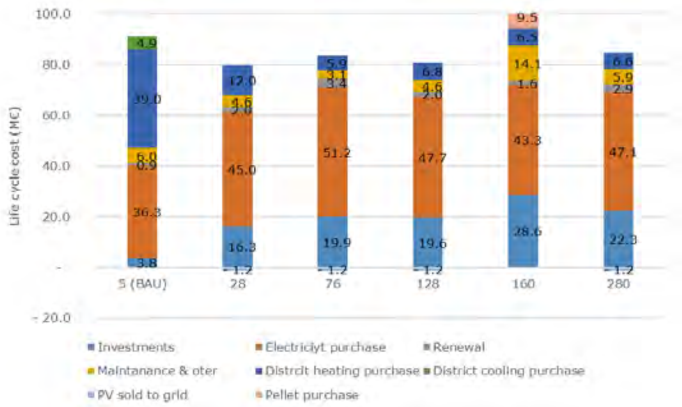


Figure 8. Life cycle cost breakdown of the selected scenarios [M€]

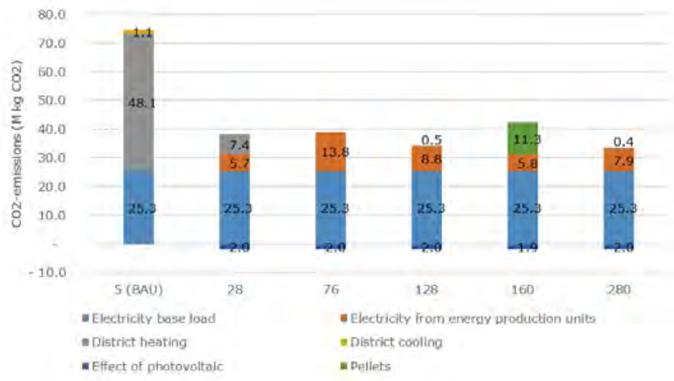


Figure 9. Life cycle emissions of the selected scenarios [M kg CO_2]

There were a lot of other interesting results and details that came out during this project but cannot be presented here due to lack of space.

Discussion

The main challenge in this project was to develop the new simulation platform for running batch based urban area energy simulations semi automatically. A lot of work was put into this and the result was quite satisfying. The simulation platform can now be used relatively easy to generate a lot of different scenarios, automatically generate the corresponding simulation models and running the dynamic simulations. Also, the LCC and CO_2 emission calculations as well as the visualization environment for analyzing the result data were integrated as a part of the simulation platform. The system is very scalable for almost any size of urban area, and it can be used in similar projects in the future.

As figure 4 suggests there were a lot of other interesting results and details that came out during this project but cannot be dealt with here due to lack of space.

The final report of this project was published as a public document on Helsinki's web page [5].

The results are being studied by the city officials for future developing of the Malmi area. Already at least one project has been started on the basis of this study to design a GSHP based semi centralized energy production system in a more detailed level. This could be used in the Malmi area as well as any other areas also.

In future studies it would be interesting to include heating and electrical storages and demand response in the simulations and study their potential. In this project these solutions were framed out because the main study was already very extensive.

Conclusion

Results showed that a significant reduction to emissions can be obtained cost efficiently using the studied energy system options compared to the business as usual case.

Most of the recommended scenarios were based on ground source heat pump systems at some level. Heat pumps are usually a strong option emission vise because they use only one unit of electricity to produce multiple units of heating (or cooling). The local district heating emission factors are just not low enough compared to electricity to compete with this. The major problem with ground source heat pump systems is that they practically always need another heating system to support them, because the maximum power they can produce is quite limited. This is because it is not cost effective to size a GSHP system to cover 100% of heating energy demand.

The supporting system increases the life cycle cost significantly even it is used to produce relatively low share from the total energy demand. The study indicated that there is enough space to drill boreholes on most of the building sites for achieving a 90% heating energy cover when using de-centralized systems. There is also a large park area nearby for the centralized ground source heat pump system options.

The wastewater heat recovery systems show great potential in almost all the cases, mostly because there are so much water usage in the area due to high share of residential buildings. A heat pump is always recommended to be used with the heat recovery system to increase the potential.

Local building integrated PV can compensate a relatively small portion of the total electricity demand (about 4.4 GWh/a). However, the PV systems are financially feasible investment and help to reduce the emissions. The largest restriction for PV in this study was the lack of available installation space on building roof areas. Façade mounted or ground mounted PV systems would be interesting to study further for increasing the local renewable electricity production.

A local bio fueled (wood pellets) heating plant would generate the lowest amount of emissions if pellets were considered emission free. However, in this study this was not the case and the biofuel plant-based scenario had the second highest emissions of all the recommended cases. Also, the local heating plant-based solution was the most expensive of all the recommended scenarios.

The recommended systems have clearly larger investment costs than BAU, but the life cycle costs were lower in most of the cases.

Two-way heat trade didn't have a lot of potential in the studied area because the residential buildings mostly just consume heat and do not produce significant excess heat flows. Two-way heat trade potential could be increased by adding diversity to the building types in the area, such as offices, shopping malls, data centers etc. This would also support better the low temperature heating distribution solutions.

References

[1] Ministry of employment and economy. Energy and climate roadmap 2050; 2014. Available: https://tem.fi/documents/1410877/2628105/Energia-+ja+ilmastotiekartta+2050.pdf/1584025f-c5c7-456c-a912-aba0ee3e5052/Energia-+ja+ilmastotiekartta+2050.pdf [Accessed 2020]

[2] Government report on the National Energy and Climate Strategy for 2030; 2016. Available: https://tem.fi/documents/1410877/3570111/Kansallinen+energia-+ja+ilmastostrategia+vuoteen+2030+24+11+2016+lopull.pdf/a07ba219-f4ef-47f7-ba39-70c9261d2a63/Kansallinen+energia-+ja+ilmastostrategia+vuoteen+2030+24+11+2016+lopull.pdf [Accessed 2020]

[3] City of Helsinki. Carbon neutral Helsinki action plan; 2019. Available: https://www.hel.fi/static/liitteet/kaupunkiymparisto/julkaisut/julkaisut/HNH-2035-toimenpideohjelma.pdf [Accessed 2020]

[4] Finnish meteorological institute. Test reference year 2012 for building energy demand and impacts of climate change; 2011. Available: https://www.ilmatieteenlaitos.fi/energialaskennan-testivuodet-nyky [Accessed 2020]

[5] Hiilineutraalin Malmin lentokentän alueen energiaselvitys. Ramboll Finland Oy; 2019. Available https://www.hel.fi/hel2/ksv/liitteet/2019_kaava/4844_1_energiaselvitys_30102019.pdf [Accessed 2020]: