Urban Energy Transition and Heating of Apartment Buildings

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***Abstract*—The on-going energy shift includes major changes in heating of buildings. As a modern solution in cities, bigger apartment buildings are nowadays choosing ground source heat pumps for heating. The first experiences of these heatings from Helsinki, Finland report considerable high needs of electrical energy and demand. The local electricity distribution system is an enabler of the energy transition. For the needs of network planning and future scenarios, new profiles of these apartment buildings having ground source heat pumps are presented. They were applied to model the future network loadings in various points of the distribution network. In Helsinki city, the studies presented a positive outcome that this urban energy transition is possible without any major challenges in the local distribution network. This can support the customers to proceed in their energy shift simultaneously lowering the carbon footprint of the whole city.**

***Index Terms*-- apartment building, energy transfer, heating, heat pump,**

I. Introduction

In Europe, the greenhouse gas emissions are to be decreased by 55% by 2030 compared to 1990 and climate neutrality is reached by 2050 [1]. Actions are needed in every sector. Among manifold measures, new electrification of heating and traffic are crucial in a city environment to promote the on-going global energy shift.

In Helsinki, the capital of Finland, the heating of buildings is the major source of greenhouse emissions (> 50%) while the traffic produces ca. 25% and electricity consumption 15%. District heating is the most popular heating type in Helsinki. Currently its primary energy sources are fossil fuels, namely gas and coal. It has been announced Helsinki to be a carbon free city by 2030 [2]. Solutions in space heating of buildings play a key role in achieving this target.

Ground source heat pumps (GSHP) are a modern heating alternative and the sales have rapidly increased for years [3], [4]. In Europe, the geothermal heat pumps are more popular in Nordic and alpine countries due to cold climate [5]. In Finland, in the first quarter of 2022, the sales of GSHP have grown 90% compared to the last year, and the growth has mainly been on larger pumps [6]. Nowadays, there are GSHP ratings up to industrial sized GSHPs covering wider temperature ranges and producing in addition to heat also cooling. The efforts in the technology development have resulted to positive popularity and lower cost. In Helsinki in heating of buildings, GSHPs became first popular in single houses outside the city centre [7]. The popularity has accelerated and nowadays also the very first apartment houses and office buildings in dense city areas have installed GSHPs. When changing a heating type, e.g., renovation from oil or district heating to GSHP, electrical energy consumption and demand will considerably increase.

In a dense city environment, these heating changes might challenge the local electricity distribution system and are worth the further analyses. The influence on GSHP of heating renovations of single houses showed considerable changes of electricity usage of the customers [7]. However, the effects on the distribution network in suburban areas of Helsinki did not cause any major concern [8]. Now, at this new stage of having GSHP in apartment buildings, if possible due to underground infrastructure, even in a dense city centre, means considerable high and additional electricity usage (energy and demand).

The paper reports real-case measurements and novel analyses of apartment buildings that have recently changed their heating type from oil or district heating to GSHPs [9]. The increase in peak electrical power and in annual energy are presented as well as the loading changes at the real estates' connection points. The effects on the low voltage distribution network are discussed.

For planning and long-term scenario needs, the distribution electricity company needs profiles of these new load types, now GSHPs. Thus, the new, hourly profiles of electricity usage of buildings with different heating types were created from hourly AMR (Automatic Meter Reading) and reported [10]. Additionally, a new tool for scaling the profiles according to the characteristics of the apartment building, like volume, total area, number of floors, number of apartments, construction year of the apartment houses is presented [11]. The new scaled profiles of buildings having GSHPs were applied to make scenarios of future loadings at distribution transformers and in one specific city district. The tool is especially useful in converting future city development plans announced as future floor-areas of new households and office buildings into changes of electrical energy and demand of the coming decades also at higher levels of the power system. This kind of future planning reveals how the local distribution network will manage the energy shift with new electrification of heating.

II. Helen DSO Operating in Helsinki City

Helen Electricity Network Ltd. (Helen DSO) is the local distribution company (DSO) in Helsinki, the capital of Finland. The service area is ca. 16 km x 16 km. The company is the subsidiary of the energy company Helen Ltd. (Helen), which in turn, is owned by the city of Helsinki.

Helen DSO supplies ca. 414 000 customers through 36 000 connection points. Helen DSO operates the local low voltage, medium voltage and 110 kV power system. In Helsinki, the annual consumption of electricity is ca. 4.6 TWh/a, and the peak load approximately 790 MW (2021). The service sector accounts for half of the electricity consumed, and residential customers one third. The consumption of industrial loads (6%) is relatively small.

The city of Helsinki is the capital of Finland with its ca. 660 000 inhabitants (2021) having households mainly living in apartment buildings and additionally in row and single houses. For housing in apartment and row houses, there are ca. 15 000 buildings representing ca. 25% of the total electrical energy consumption in Helsinki. According to the data obtained from [12], the heating of apartment buildings for housing is mainly with district heating (97%), oil (1.5%), and GSHP (1%). In row houses, the buildings are heated by district heating (76%), electricity (16%), oil (5%), and GSHP (2%). Additionally, to buildings for housing, there are ca. 750 large office buildings (floor area over 1 000 m^2) representing 15% of the electricity consumption in the whole city. District heating is the most popular (98%) heating type in these office buildings but also some oil heated buildings still exist.

There is now an increased interest to choose GSHP as a heating type also in the bigger apartment and office buildings. This development is expected to accelerate. Choosing a GSHP needs a permission from the Helsinki city authorities while drilling of geothermal wells is not possible everywhere in Helsinki because of various underground infrastructures (metro, tunnels, pipe lines of district heating, district cooling, water and waste water, electricity underground cables, etc.).

III. Measurement Data of Present GSHPs

In Finland, since 1.1.2014 AMR meters were installed to every customer. Thus, there is a wide data set of hourly energy measurements of electricity usage. This data has been applied for manifold analyses, here to research the electricity usage of apartment buildings heated by GSHPs.

GSHPs became more common first in single houses in the beginning of 2010s. The first GSHP analyses included those single houses that had changed their heating type from oil or electricity storage heating to GSHPs [7]. The shape of the new profiles was like the profiles of a single houses having direct electricity for heating. When having changed the heating type of a single house from electricity storage heating to GSHP the electricity consumption was halved. The annual electricity consumption was doubled in changes from oil to GSHP. Thus, there was a considerable change in the electricity usage.

Now, GSHPs are installed also to bigger buildings, like apartment and office buildings. The on-going decarbonization encourages especially the real estates still having oil as a heating type to change their heating type. In the heating renovations, also other energy saving actions may be included, like installing solar power, having various energy efficiency measures as well as adding heat recovery systems.

Helsinki has now the first apartment buildings with GSHPs. In this research, the analyzed data included altogether 41 real estates having altogether 67 buildings. The former heating type was oil or district heating. The measurement data of the connection point includes all the electricity usage of the buildings belonging to the real estate in question. Also, more specific measurement data was used when possible and that included only the real estate's GSHP electricity usage.

As an expected result, the electricity usage of the GSHP buildings is strongly temperature dependent (Fig. 1). After the heat renovation, the peak demand as well as the annual electricity consumption increased (Fig. 2, Fig. 3). As an average, the peak demand of electricity increased by 90 kW and the annual electricity consumption by 150 MWh.

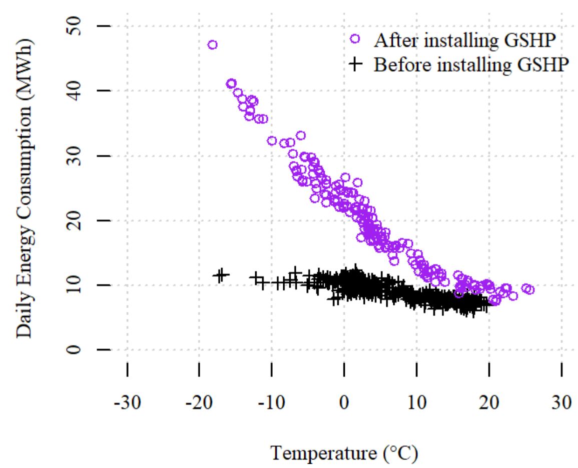

Figure 1. Temperature dependency of GSHP apartment buildings group before and after heating renovations.

During the planning phase of a heating renovation, the total capacity of GSHPs may be rated to cover only a portion of a heating demand needed instead of a full peak demand. At the time of the investment decision, GSHPs rated for only a part of the peak load capacity are appealing because of their lower investment cost and as the active time of an additional heating resource is short it does not cause major increase in yearly energy consumption. During cold outdoor temperatures, these GSHPs of a partial load capacity are no more able to produce the total heat demand but an additional source is needed, e.g., district heating or more commonly electrical resistance for heating is connected on below certain temperatures. Fig. 4 and Fig. 5 show an example where during outside temperatures lower than ca. -13 °C (Fig. 4 orange dotted line) the electrical resistance is connected on causing remarkably high demand of electricity. If there would be a warm wintertime this electrical resistance would not be needed at all. In the past 30 years, on an average year in Helsinki, there has been 23 and 118 days when the lowest temperature of the day was under -10 °C and 0 °C, respectively. About 50 km north, the number of days were 39 and 156, and 250 km north 55 and 177 days, respectively [13].

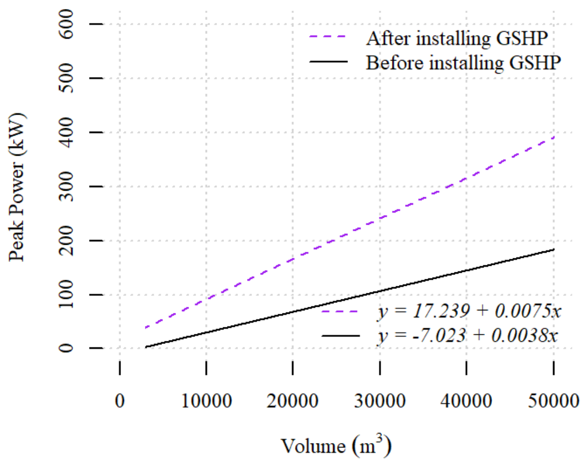

Figure 2. Peak power at connection point of GSHP before and after a heating renovation and total volume of apartment buildings.

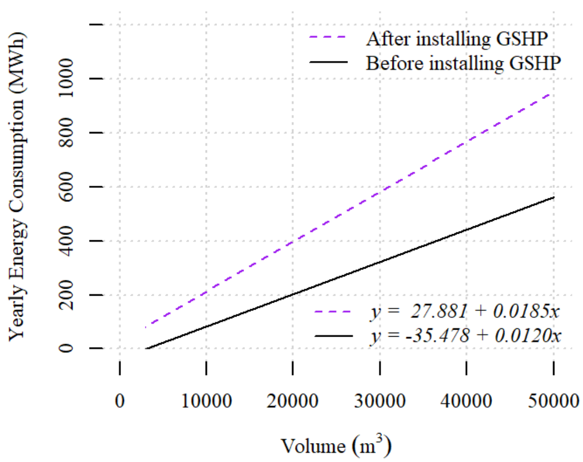

Figure 3. Annual electrical energy of GSHP before and after a heating renovation and total volume of apartment buildings.

When deciding the investment, the partially dimensioned GSHPs might interest the customer as this system has a lower investment price. On the other hand, while the distribution network is built to last decades according to the maximum demand, DSOs would prefer full capacity GSHPs. Their demand would be smoother than the solutions with partial load capacity GSHPs that have short-term peaks occasionally possibly lasting only a few hours during the winter. The electrical resistance of the partial load capacity GSHP means considerably higher electricity costs for the customer due to power tariff.

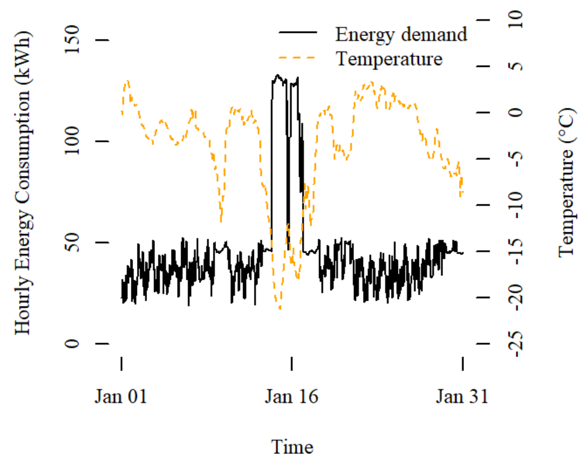

Figure 4. Hourly electricity consumption (demand) and outdoor temperature of a partial load capacity GSHP in January 2021.

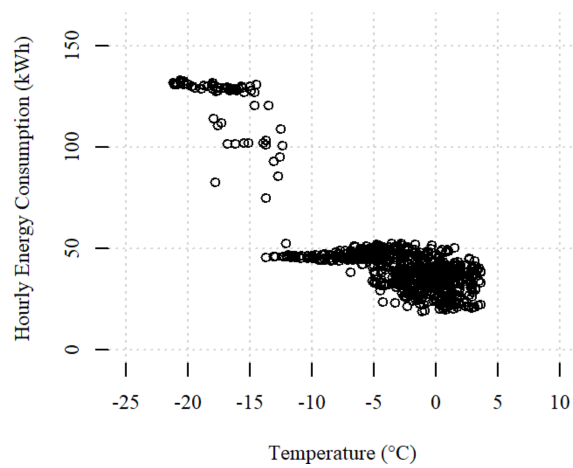

Figure 5. Hourly electricity usage (demand) as a function of outdoor temperature of a partial load capacity GSHP in January 2021.

When planning, the alternatives are a full or a partial capacity GSHP. The customer decides the investment. For both alternatives, the free capacity of the present electricity connection point should be ensured. If there would not be enough capacity for the new heating resource, the fuse size of the connection should be increased and the customer pays for the change. For the electricity distribution company under the study, especially interesting are pre-renovation connection points with fuse size of 3 x 250 A. If there is a need to increase the size, it is at such limit that the DSO would be forced to construct an additional parallel low voltage cable to the connection point. This cost is addressed to the DSO and finally to all customers. In dense urban downtown environments, this might cause challenges to the DSO because of high excavation costs and limited space of new underground cables. Additionally, high charges related to the reservation of infrastructure, such as rents may arise in cases when, e.g., additional room is needed for new distribution transformers. Checking the pre-renovation loading from AMR measurements is important as an aim to first utilize the free capacity and only after that to enlarge the connection size. In these analyzed Helsinki cases, the average loading rate at the connection points were after the renovation only 48% of the nominal fuse size. In past in Helsinki, the bigger connection points were oversized. Within this on-going energy shift, this means that typically, there is network capacity at the connection points to do the heating renovations without additional investments to the infrastructure. Thus, from the DSO's side, the customers can be encouraged to perform their de-carbonization of their heating.

IV. Modelling GSHPs and Simulations

The popularity of GSHPs is expected to rapidly increase. For network planning purposes and for various spatial long-term forecast DSOs need models of these new load types. The models are applied to analyze the effects of the energy shift, now the heating renovations, along the whole electricity distribution network.

A. Scaled and New Profiles of GSHPs

In Finland, the AMR data reports the loading of the metering point. Additionally, the huge AMR data set can be utilized for modelling purposes, like updating old profiles and creating profiles of new customer/load types. This kind of a project was performed for Helen DSO's metering and connection points applying three years (2016 - 2018) AMR measurement data of ca. 385 000 metering points and 35 000 connection points [10]. The profiles were created by a clustering method described in [14], resulting simultaneously to the customer classification into similarly behaving groups and to customer group specific load profiles with deviation terms, reference temperatures, and temperature coefficients. Load profiles are helpful in many cases and can be turned into meaningful variables like yearly energy consumption or peak power. With the deviation terms, we can estimate probabilistically peak power even after adding several different load profiles together. Furthermore, Fig. 6 shows that with the profile specific temperature coefficient, we can simulate more realistic profiles or to obtain peak values for rarer temperatures.

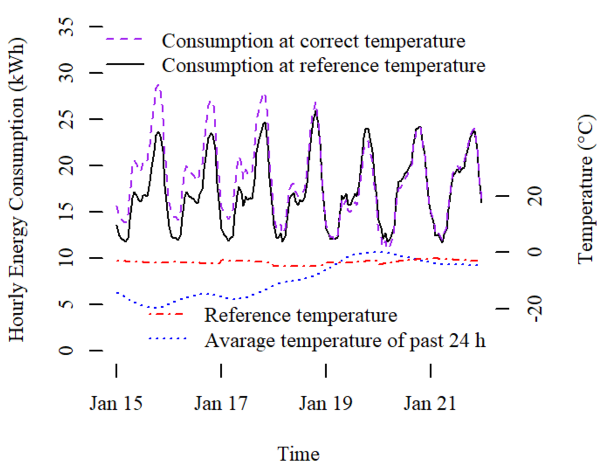

Figure 6. Simulated hourly week profile of mean electricity usage of an apartment building with GSHP. Dashed purple line is corrected consumption at an average temperature of past 24 h and solid black line is consumption at reference temperature. Assuming full load GSHP.

Additionally, a new tool for scaling the profiles according to the characteristics of the apartment building, like volume, total area, the number of floors, the number of apartments, the construction year of the apartment houses was created [11]. When determining characteristics mentioned above the apartment building profile can be scaled according to the characteristics of the building. Different building types with different profiles can be combined using statistical methods and extend the study to arbitrary large areas including several different customer types.

B. Renovation Impacts on Loads of Distribution Transformers

Simulations of the effects of apartment buildings changing heating from oil to GSHPs on distribution transformers were performed by applying the new and scaled profiles. As one example of the simulation results, there is a distribution area supplied by a 630 kVA distribution transformer serving altogether eight apartment buildings. Nowadays one building is heated by oil and seven heated by district heating. It was simulated a case where all these eight apartment buildings make a heating renovation to GSHPs. Before the heating renovation the max loading rate of this distribution transformer was 50% and afterwards ca. 90%.

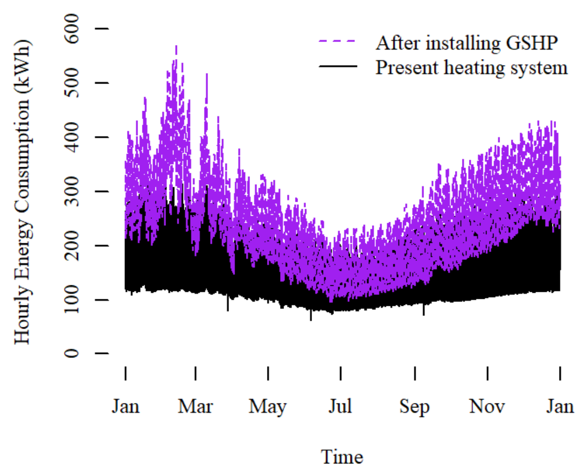

Figure 7. Simulated hourly electricity usage of eight apartment buildings with present heating system and after installing GSHP. The profiles are modified with standard deviation so that the actual measured consumption should have 95% probability of being under the profiles assuming normal distribution. Both profiles have been corrected with temperature coefficient using true daily temperatures from 2021 till October.

As a second case, concerning the loadings of distribution transformers, it was analyzed those distribution transformers of Helen DSO that mainly supply apartment buildings. About 90% of the annual energy at the distribution transformer level is consumed by the apartment buildings. The present loadings were low (< 25% of nominal). Thus, there is free capacity for heating renovations. One critical characteristic which considerably affects future loadings experienced in the network is the decision whether full or partial load GSHPs are installed. As a result of the performed analysis, e.g., distribution transformers of 1 000 kVA nominal capacity could support 15 apartment buildings with full capacity GSHPs and alternatively 60% partial capacity GSHPs only eight renovations (Table 1). This is noteworthy. From the DSOs side, this underlines the preferred option of full capacity GSHPs instead of partial capacity GSHPs. However, on the customer side, the customer would need to value and estimate the costs (i.e., investment, possible fuse size enlargement, operational costs, etc.).

TABLE I. AVERAGE FREE CAPACITY OF DISTRIBUTION TRANSFORMERS AND RESPECTIVE NUMBER OF GSHPS

Nom. power of distribution transformer (kVA)	***Free capacity of distribution transformer (kVA)***	**Number of GSHPs** *Share of partial capacity GSHPs*			
		100%	***90%***	***80%***	***60%***
1000	730.8	15	13	11	9
800	527.9	11	9	8	7
630	403.8	8	7	6	5
500	290.1	6	5	4	3
300	119.8	2	2	1	1

C. Heating Renovation Scenario in a City District

Additional simulations were performed to find out the influence of heat renovations on a primary 110 kV / 20 kV substation supplying a city district. There are primary substation areas supplying city districts from the dense city downtown having only apartment buildings of shops, offices and housing to sub-urban city districts more far away outside the urban city centre having residential row and single houses. A simulation was made to a city district where the annual energy consumed in apartment buildings was highest in Helsinki. The energy consumption in apartment buildings, represented 36% of the annual energy of the whole city district. Nowadays, 11% of the buildings in this area is heated by oil and 89% by district heating. If all the oil heated buildings make a heat renovation to full capacity GSHPs the max load would increase by 8% and the annual energy by 7%. Also, this simulation strengthened the view that even a quick transfer from oil to GSHPs can be enabled by the DSO with the present infrastructure of the electricity distribution capacity.

V. CONCLUSIONS

In Helsinki, GSHP heating renovations, to replace oil and district heating, are now installed also to large apartment buildings. The present distribution network can welcome this energy shift to lower the city's carbon footprint. The AMR measurements serve as a resource for new generation of tools when determining the present loadings of the customers' connection point. With the tools new profiles were created for the DSO's needs to simulate the influence of the heating renovations of GSHPs. In Helsinki, the present distribution network can welcome even quick heating renovations. A DSO is an enabler of the energy shift and together with the end-use customers the aim of lowering the carbon footprint can be realized.

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