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Evaluation of the financial benefits of a ground-source heat pump pool with demand side management: Is smart profitable for real estate?



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ABSTRACT

Keywords: Demand side management Frequency reserve markets Ground-source heat pump pool New cash flow Power peak shaving Real estate Adoption of various smart control-compatible heating systems is increasing in the heating market. Simultaneously, smart electricity control, often referred to as demand side management (DSM), has raised interest as a core enabler of future sustainable cities. The technological viability of DSM is increasingly researched, but its profitability for real estate has remained unclear. This study examines the economics and environmental implications of DSM by analyzing an energy model using hourly-level energy consumption data in Finland. Accordingly, this study observes new cash flows generated after a daily 2-hour peak shaving of a ground-source heat pump pool in the Helsinki region. Although, DSM decreased the pool's peak electricity consumption, the economic potential of smartness was only $0.03 \notin$ /sqm/year, equaling 1% of savings in the energy costs. Furthermore, DSM generated surprisingly low (i.e., 0.02%) reduction in carbon emissions. Despite of the current minor benefits for the real estate owners in the Finnish power market, the end-user smart electricity control likely has a crucial role in the future electricity system with large quantities of intermittent renewable production. Thus, engaging real estate owners in DSM through alternative (monetary) incentives, and other strategic benefits, is essential to support the future energy system decarbonization.

1. Introduction

Cities are a major climate change contributor, as they are estimated to be responsible for 75% of worldwide greenhouse gas emissions (Lund, Mikkola & Ypyä, 2015). Furthermore, urban areas account for the greatest shares of the global population and economic activity fostering energy usage (IEA, 2016a). However, urbanization also provides opportunities for considerable low-carbon actions, especially within the energy-intensive building stock. Currently, the building stock consumes approximately 40% of the final energy and is responsible for more than one-third of the produced carbon emissions globally (United Nations Environment Programme, 2021). From these shares, building heating and cooling are responsible for a vast majority. The high heat demand, especially in cold climate cities, is often still covered with a fossil fuel-based district heating (DH) network (Patronen, Kaura, & Torvestad, 2017). However, aligned with the cities' low carbon pathways, DH systems must, in the coming years, withdraw themselves from burning fossil fuels (Laine, Heinonen & Junnila, 2020). This can be seen to further foster the energy market transformation and the uptake of electricity-based heating solutions in cities.

Recent years have shown a growing amount of discussion regarding the ability of information and communication technologies to foster a carbon-neutral economy through energy system electrification and the development of energy power grids (IEA, 2019). The electrification enables transformation from a highly centralized and fossil-fuel-based energy system toward a decentralized energy system and enables the efficient deployment of renewables (Van Nuffel, Gorenstein Dedecca, Smit, & Rademaekers, 2018). In the future energy system, renewables are cost-efficiently converted into electricity. Thus, clean electricity is expected to become the primary energy carrier in future low-carbon cities (Connolly, Lund & Mathiesen, 2016). However, the large-scale utilization of fluctuating renewable energy will increase the power grid's vulnerability to failures, for instance, when the energy demand exceeds production (Bloess, Schill & Zerrahn, 2018). This aspect is especially crucial in cold climate country cities, where seasonably high demand for space heating in buildings exists (Cao, Dai & Liu, 2016).

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Abbreviation: DH, District heating; DSM, Demand side management; FCR-DF, requency containment reserve for disturbances; FCR-N, Frequency containment reserve for normal operation; GSHP, Ground-source heat pump pool; HMA, Helsinki Metropolitan Area; HP, Heat pump; PVs, Photovoltaics; SRI, Smart readiness indicator; TES, Thermal energy storage.

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Recently, sector coupling has been introduced as a strategy to bring flexibility to the energy system. Sector coupling, in principle, refers to integrating energy-consuming sectors with power-producing sectors, and power-to-heat is one of the core application areas within the framework (IEA & IRENA, 2017). According to Bloess et al. (2018), several promising power-to-heat strategies exist. As a sector coupling supportive technology, heat pumps (HPs) have appeared as an especially appealing solution because of their high coefficient of performance (Van Nuffel, Gorenstein Dedecca, Smit, & Rademaekers, 2018). Specifically, in a decentralized energy system, HPs can be powered by the electricity grid directly or by a local generator or energy source, such as rooftop solar photovoltaics (PVs) installations. According to the International Renewable Energy Agency (IRENA, 2019) analysis, the role of HPs in building heating must increase dramatically in the future to achieve the set decarbonization targets. However, HPs currently cover only 5% of global heating demand (Halozan, 2017). The long-term decarbonization goals can be achieved by tripling the share of residential HP installations globally by 2030 (IEA, 2020).

In addition to HPs, some flexibility potential can be untapped by utilizing the passive heat storage in buildings, where a massive thermal energy storage (TES) capacity exists. Various local TES options, where the energy is stored in building mass or the interior and released in a non-controlled way, have increased attention as promising energy efficiency improvements in recent years (Bloess et al., 2018; Fischer, Wolf, Wapler, Hollinger & Madani, 2017). For instance, Klein, Herkel, Henning and Felsmann (2017) evaluated the technological potential of different storage options, including batteries, fuel switches, and thermal storage units (e.g., water tanks and thermal building mass). As expected, the researchers found batteries to be the most effective and efficient option in the studied HP system. However, the batteries' load shifting potential is strongly linked to their capacity, thus driving the investment cost. The thermal building mass was also found as an appealing energy storage option (Klein et al., 2017). The mass can store large amounts of thermal energy, with minor temperature differences during the heating season. Other researchers also obtained similar findings (Bloess et al., 2018; Kensby, Trüschel & Dalenbäck, 2015; Le Dréau & Heiselberg, 2016; Reynders, Nuytten & Saelens, 2013). In these research papers, HPs integrated with passive TES solutions were particularly convenient options for efficiently managing the heat energy consumption in buildings.

Despite HPs' and TES systems' applicability as future core lowcarbon technology solutions in buildings, the efficient utilization of power-to-heat technologies and various power grid flexibility supportive services in building heating and cooling lags crucially behind in many European cities (Bloess et al., 2018). Currently, a single building's ability to provide any flexibility services for the power grid has remained restricted due to the limited capacity of one heating unit. However, as Geidl, Arnoux, Plaisted and Dufour (2017) showed, collecting a high number of on/off-type of HPs that complement each other can result in a virtual power plant providing grid services in a dynamic and precise way for the power system. Due to the high thermal inertia of the building mass, loads can be shed without negatively affecting indoor air conditions. Pooling HPs can also be seen to facilitate renewable energy resource integration, as the increased demand side flexibility reduces the need for backup power generation capacity (Van Nuffel, Gorenstein Dedecca, Smit, & Rademaekers, 2018). Traditionally, fossil fuels are utilized to cover the peak demands in the heating season, especially in cold climate cities.

An HP pool's technological viability to provide demand side flexibility for the power system has been shown by several studies. Simulation-based studies (Fischer, Wolf & Triebel, 2017), as well as real-life studies (Geidl et al., 2017; Larsen, Pinson, Leimgruber & Judex, 2017), have shown the pool's ability to shed loads from the power grid. In a pooled HP system, demand side flexibility, referred to as demand side management (DSM) in this paper, is traditionally performed either by peak shaving or using ancillary services (IEA, 2017). Peak shaving is a relatively simple application of DSM, where heating devices are blocked during peak consumption hours to cut the power system load. However, DSM might also be performed by actively managing the electric loads instead of generation (to balance the production and demand of energy), which can be achieved by using ancillary services, as shown by Fischer et al. (2017). Overall, the smart control of heating and cooling systems enables the shift from power grid peak periods and improves the match of demand with, for example, daily solar production cycles (Reynders et al., 2013; Stinner, Huchtemann & Müller, 2016). DSM can be controlled based on price, direct load, or market (Hao, Corbin, Kalsi & Pratt, 2017). These services are divided into primary, secondary, and tertiary control (Geidl et al., 2017).

Aligned with the recent policy discussion (IEA & EBC, 2017), future low-carbon and sustainable cities are expected to lean strongly on sector coupling and various power-to-heat technologies. In the future, buildings are forecasted to actively react to signals from the power grid to balance the demand with the fluctuating production of renewables (IEA, 2019). As part of the system, DSM services, also referred to as building smartness, play a crucial role. The aims to increase buildings' smartness is strongly enhanced in the EU directives, such as in the amended Energy Performance of Buildings Directive (The European Parliament and the Council of the European Union 2018). Aligned with the EU vision, the untapped potential of buildings in supporting the energy system transformation must be highlighted, and the buildings' role as energy producers and flexibility providers must be enhanced. As a policy action to the vision, the development work of a smart readiness indicator (SRI) for buildings was launched, and the three-year development project was recently finished. The building services' readiness to support the power grid, referred to as the smart grid, is strongly enhanced within the SRI rating system (Janhunen, Pulkka, Säynäjoki & Junnila, 2019). In addition, the smart services' influence on the buildings' energy efficiency and occupant comfort is considered (Verbeke, Aerts, Reynders, Ma & Waode, 2020).

One of the key aims behind the development of the SRI rating system is to raise awareness of the benefits of smartness for real estate owners (Verbeke et al., 2020). Today, the benefits of smart electricity control and various DSM installations is well understood from the energy producers' and energy grid's perspectives (Strbac, 2008; Järventausta et al., 2015). Furthermore, various applications of DSM in building heating haven been widely studied (Dahl Knudsen & Petersen, 2016; Hedegaard, Pedersen & Petersen, 2017; Pedersen, Hedegaard & Petersen, 2017). Overall, it has been found that applying various DSM applications can help to increase the grid capacity, reliability, and clean power (Gelazanskas & Gamage, 2014). However, the end-users, i.e., real estate owners', viewpoint is still less studied. A comprehensive understanding of the real estate owners value creation logic towards DSM is still missing from the literature. Realizing the motives of the world's largest asset class in smart electricity control is crucial to enable the decarbonization of the energy system.

Traditionally, the profitability of power grid supportive installations in buildings has been measured from the energy industry perspective. However, such an approach does not reveal the value of energy improvements on the property, as discussed by Leskinen, Vimpari and Junnila (2020b). As the property owners are the parties that typically "provide" the service to the energy markets and, in many cases, make the required investments, the issue should be studied from their perspective. The effect of the capitalized value of the savings generated from various energy efficiency improvements, such as PVs and HPs, has been shown by several researchers (Christersson, Vimpari & Junnila, 2015; Leskinen et al., 2020b; Vimpari & Junnila, 2019). Thus, from the real estate owner's perspective, the most attractive incentive to invest in smartness would be improved cash flows gained by the investment. Such cash flows are typically produced by energy savings but can also be the income received from the containment frequency market, as shown by Janhunen, Leskinen and Junnila (2020).

In the coming years, as a side effect of the upcoming electrification of the energy system, the share of power-to-heat technologies, including HPs, is expected to increase dramatically (IEA, 2020). As a result, the consumption of electrical energy will increase, and energy consumption will decrease (due to the increased energy efficiency of the heating solutions) (IEA, 2019). Thus, an increasing number of buildings will have the technological potential to provide flexibility services for the grid. Nevertheless, attending the reserve markets is rarely available for traditional buildings or households, as the reserve potential of a single HP unit is limited. Therefore, in future cities, the possibility of cutting the grid load could be considerably increased if the smart electricity control would be simultaneously applied in all HP units in the building stock. However, whether the city-level application of DSM in electrified heating and cooling can provide meaningful cash flows and profits for real estate owners remains unclear.

The purpose of this study is to examine the financial benefits of DSM in electrified heating for real estate owners. In addition, the study aims to evaluate the climate mitigation implications of smart electricity control, which is typically the primary driver of smart buildings at the national level. In the present study, DSM was modeled to the properties of the Helsinki Metropolitan Area (HMA), where a cold climate country specific HP application, i.e., a ground-source heat pump (GSHP) heating solution, was installed. However, the study's focus is not on the technological realization of DSM control of a GSHP pool at a city level. Instead, the aim is to observe the changes in peak energy consumption, subsequent cash flow, and carbon emission implications for real estate owners to understand their willingness to invest in environmentally beneficial systems from an economic perspective.

The paper is divided into five sections. The first section describes the motivation and outlines the context of the paper. The second section presents the applied methods and data relating to the DSM control modeled to the HMA building stock. The results evolved from the analysis are shown in the third section. In the fourth section, the results are discussed, and the fifth section concludes the paper.

2. Methods and data

In this study, the financial benefits and climate mitigation implications of DSM control in the HMA building stock were observed. This section introduces the methodology and data applied to conduct this study.

2.1. Estimating the heating consumption, costs, and emissions of a GSHP pool in the HMA

In this study, an energy model using hourly level data for the year 2019 was utilized to estimate the heating consumption, costs, and emissions of GSHP buildings in the HMA. The energy model is based on the same data presented by Vimpari (2021), from which a more detailed description of the dataset can be found.

2.1.1. Building data

In his study, Vimpari (2021) collected the building data for the eight largest cities in Finland. Based on the accumulated dataset, the building data for this study was formed. However, in the present study, the dataset was narrowed down to cover Helsinki, Espoo, and Vantaa, which form a 1.19 million population HMA. The building data, including technical information, such as building type, size, volume, heating type and construction year, was collected for every building in the area. As Vimpari (2021) described, data not including area, construction year and heating types were omitted, as well as buildings with a size of less than 100 sqm. However, the 100 sqm represents the total area of the building. Thus, apartment buildings, for instance, were not excluded from the dataset because their total floor area is the aggregate of all of the apartments (and other spaces) within the building. The final dataset included 78 888 buildings, with a total floor area of 79 706 587 sqm. In recent years, the market share of GSHP heating solution has dramatically increased in Finland (Statistics Finland, 2019). In this study, the energy model was constructed based the techno-economic characteristics of the GSHPs in the area (in total 6 403 buildings after cleaning the dataset).

2.1.2. Techno-economic characteristics of GSHP

GSHP is a renewable energy system, as it utilizes solar energy that has been stored in the ground. However, electricity is needed to deliver heat energy into the water and circulate hot water in the building system. The amount of required electricity depends on the HP coefficient of performance, which depends on technical specifications of the HP system, outside temperature, and required temperature for water circulation used in space and water heating. In this study, the coefficient of performance was calculated on an hourly resolution based on the above parameters. A detailed description of the calculus is provided by Vimpari (2021).

Heating and electricity consumption are always strongly linked to building type and construction year (Aksoezen, Daniel, Hassler & Kohler, 2015; Howard et al., 2012). In this study, the GSHP consumption profiles were developed for four property types: residential, retail, industrial, and office, where the buildings were constructed between the 1930s and 2010s (i.e., in nine different decades). The profiles for both heating and electricity were based on hourly resolution consumption data (Helsinki region infoshare, 2020). The data was enriched by multiple research papers and reports (Vimpari, 2021). GSHP is an electricity-based heating system. Therefore, heating costs were calculated based on three main components: energy cost (Nordpool, 2020), local distribution cost (Caruna, 2020; Helen Electricity, 2020; Vantaan Energia, 2020), and electricity tax. Finally, heating emissions were calculated by multiplying the estimated energy consumption with GSHP CO2 emission coefficients. A detailed description of the calculated heating consumption, energy costs, and produced emissions for GSHP buildings is provided by Vimpari (2021).

2.2. Influence of DSM on the techno-economic characteristics of the GSHP pool

In the present study, DSM was modeled to remove two top peak hours per day (Kärkkäinen et al., 2004); that is, the third-highest hour of the day was the new daily peak power required after DSM actions. This modeling was performed every day of 2019. Daily energy consumption was assumed not to be reduced from DSM actions; that is, the consumption curve was flattened, and the energy required for the peak hours was returned into other hours of the day (Kensby et al., 2015; Le Dréau & Heiselberg, 2016). The economic benefits from these actions are then related to potentially reduced peak power costs to the electricity distribution companies and potential payments from national grid operators through capacity markets. The potential environmental benefits come from reduced power usage during peak hours, which can have higher emissions than other hours of the day.

Economic savings from DSM are estimated by calculating the difference between peak power costs before and after DSM actions using the following formula:

$$C_{\text{peak}} = \sum_{i=1}^{12} P_i * D_i \tag{1}$$

where C_{peak} is the peak power costs (\in) , *i* is the month of the year (distribution networks often have different monthly tariffs), *P* is the monthly peak power consumption (kW), and *D* is the monthly distribution cost per power ((\in/kW)). The monthly distribution cost has different tariff bands depending on the annual maximum peak power. Thus, DSM can have implications for both *P* and *D*. These have been accounted for in the calculations, individually for every building, by estimating the effect of DSM on the overall consumption profile and subsequent monthly and annual peak power requirement.

Pre-DSM emissions are calculated using the following formula:

$$E = \sum_{i=1}^{8760} H_i * K_i$$
 (2)

where E is the emissions (gCO₂), *i* is the hour of the year, *H* is the hour's power demand (kW), and *K* is the electricity system's emission factor for the given hour (gCO₂/kWh). The post-DSM emissions are calculated using the following formula:

$$E_{DSM} = \sum_{n=1}^{365} \sum_{i=1}^{24} H_{DSMi} * K_i + (H_i - H_{DSMi}) * \overline{X_{i=1}^{24}} K_i$$
(3)

where E is the post-DSM emissions, *n* is the day of the year, *i* is the hour of the day, H_{DSM} is the hour's power demand post-DSM, and $\overline{X_{i=1}^{24}}K_i$ is the day's mean emission factor (gCO₂/kWh). The two peak hours shifted are assumed to have an emission factor of the day's mean. This might be an overestimation of the actual difference but provides a good optimistic scenario for the benefits.

2.3. Estimating the potential payments from the capacity reserve markets

The smart electricity control of the modeled GSHP pool was evaluated to create new cash flows for a property owner through decreased energy costs. However, DSM actions were additionally expected to generate new income through the capacity markets.

Finland's power distribution network is a part of the Nord Pool power market and is managed by the national transmission system operator Findgrid. The power grid must be constantly balanced. Thus, the need for reserves is continuous. Findgrid purchases reserves from the capacity markets to maintain the balance. These reserve products, including power plants and consumption resources, may vary remarkably in terms of reserve size, activation speed, and whether the reserve can increase or decrease its electric power (Fingrid, 2021b).

In this study, DSM was estimated only to decrease the power consumption of the GSHP pool, limiting the reserve's applicability in the power markets. However, the GSHP pool could potentially be used to balance disturbances in the grid, such as in the Frequency Containment Reserve for Disturbances (FCR-D) market. FCR-D market products are automatically activated to reduce their consumption according to grid signals. The minimum bid size for the reserve is 1 MW, and the price level in the yearly market is approximately 2 €/MWh (in 2019, the price was 2.4 €/MWh) (Fingrid, 2019a). In the hourly market, the price level may vary from couples of euros to dozens of €/MWh (in 2019, the volume-weighted average price was 9.4 €/MWh) (Fingrid, 2019a). The potential payments received through the capacity markets are calculated based on the bid size (MW), reserve hours (h), and list price (€/MWh). The yearly and hourly market agreements for FCR-D reserves in the Nordic market are identical in terms of their conditions, content, and agreed payments (Fingrid, 2021a).

3. Results

In this section, the results from the analysis are described. First, the changes in energy consumption profiles and carbon emission implications of the GSHP pool are introduced before and after DSM activation in the HMA. Second, the subsequent cash flows for real estate owners are presented.

3.1. Techno-economic implications of DSM in the current energy system

In this study, DSM was modeled to the current HMA energy system, where 2% of the indoor floor area is heated with GSHP. In Table 1, the techno-economic characteristics of the GSHP pool are shown by property types before and after applying DSM control.

Table 1 indicates that by far, the greatest reserve size (i.e., the building's ability to store thermal energy in its interior) lies in residential buildings, covering approximately 80% of the floor area of the GSHP buildings in the studied area. The other types of buildings account for 10% (industrial buildings) or less (office and retail buildings) of the total heated floor area. Surprisingly, despite the residential buildings' reserve sizes, the DSM actions' influence on the possible reductions in peak consumption was limited. The DSM action reduced the residential buildings' peak consumption by only 8.7%. On the contrary, retail buildings provided the most considerable percentual potential to cut the load from the grid by 9.6% despite the property type's relatively small TES capacity. From the technological perspective, the office buildings seemed to give the least potential for peak shaving, as only a 1.9% reduction was achieved with DSM control. However, the retail, industrial, and office buildings' ability to cut the load was restricted by their ability to store thermal energy. In total, the GSHP pool with the DSM control was able to cut the load from the grid by 8%.

In terms of the economic implications, Table 1 shows only a 1.3% reduction in the GSHP pool's energy costs (i.e., peak power costs that are paid to the local distribution companies) after DSM. Despite the residential building's large thermal capacity, the DSM actions affected the energy costs by 0.03%, which was the smallest percentual reduction among the studied property types. The greatest economic potential of DSM appeared to be among office and retail buildings, as both property types resulted in approximately a 9% reduction in energy costs after deploying the DSM control. Within the industrial buildings, the potential of DSM to cut the costs remained around 2%.

Despite DSM's ability to cut the load from the grid, the difference after DSM activation on the produced emissions remained close to zero (0.02%) within all the studied property types. Due to this surprisingly low climate mitigation implication, the relation between DSM control and emissions was further studied. A sensitivity analysis with the dataset was performed.

3.1.1. Climate mitigation potential of DSM

The climate mitigation implications of DSM were closely observed by further elaborating the interaction between the GSHP pool's peak

Tai	ble	1
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Estimated heat consumption, costs, and emissions for GSHP buildings.

Туре	Floor area (som)	Residents	Heat consumption (MWh, thermal)	Peak cons	sumption	(MW,	Energy cos	sts (€)		Emissions	(kgCO2)	
				Current	DSM	Difference	Current	DSM	Difference	Current	DSM	Difference
Residential	1 546 050	36 144	181 162	20.64	18.84	91.3%	5 715 781	5 699 065	99.7%	5 190 541	5 189 415	99.98%
Retail	70 565		10 447	1.05	0.95	90.4%	215 360	197 092	91.5%	194 945	194 902	99.98%
Industrial	171 151		12 031	1.23	1.17	94.9%	235 374	230 471	97.9%	582 564	582 438	99.98%
Office	126 223		14 568	1.95	1.92	98.1%	283 534	258 951	91.3%	414 421	414 331	99.98%
Total	1 913 989	36 144	218 207	24,9	22.9	92.0%	6 450 049	6 385 578	98.69%	6 382 471	6 381 086	99.98%

shaving and produced emissions in HMA. Traditionally, cold winter days provide the best techno-economic potential for DSM, as the electricity price is higher. Usually, the emission rates also increase during those cold days, as energy sources with higher emissions rates are often needed to balance the increased demand from space heating. Therefore, a sensitivity analysis for the dataset was performed during the coldest day of the week of 2019. In the analysis, for the sake of clarity, the GSHP heated floor area was presented in a 5 000 sqm building size and categorized by the four studied property types. Fig. 1 illustrates the effects of the 2-hour daily power peak shaving on the produced emissions during the coldest week of 2019.

The figure shows how the retail buildings consume the greatest share of electricity during the cold winter days, thus being responsible for the highest amount of produced emissions. However, even though the retail buildings consume electricity the most, the effect of DSM remains relatively small. A similar finding also concerns the other property types: the influence of DSM on electricity consumption remains small even on the coldest week of the year, which also reflects the tiny difference in emission rates before and after DSM activation. Over 200 gCO₂/kWh was crossed only twice during the week, that is, around the hours of 50 and 70 in the figure. During the electricity emission peak, that is, hour 50 in the figure, a peak shaving was performed for each property type. Based on the analysis, the electricity emissions vary greatly daily and thus do not always correlate with the power peaks. Furthermore, even during the coldest week of the year, the produced emissions remained relatively small in Finland.

3.1.2. Power peak production profile in Finland

The emission production profile of the electricity used in the Nordic power market was better examined by further analyzing the electricity production profile provided by the national transmission operator. In Finland, the coldest day of the year 2019 was on the 28th of January at 8–9 am, during which the highest peak consumption hour was achieved (Fingrid, 2019b). However, during the coldest week of the year, the highest peak production hour was on the 21st of January at 6–7 pm. Therefore, the electricity production profile on that day, when the power peak was achieved, was further analyzed. The electricity production profile on the 21st of January is shown in Fig. 2.

As shown in the figure, the peak production hour was approximately 7 pm. The electricity prices on that day varied between 50 and 90 \notin /MWh, and the reserve size ranged from 9 000 to 11 000 MW. On the 21st of January, the electricity demand in Finland was covered with a mix of six energy sources: combined heat and power (cogeneration DH), nuclear power, industry, hydropower, and wind power. "Other

production" methods covered the smallest amount of energy, and solar energy was not available on that day. The graph shows that in Finland, the available renewables, that is, hydro and wind power, have been utilized as the primary energy sources to provide flexibility for the grid. In particular, the hydropower capacity has been increased to match the electricity production with the demand on peak hours. The electricity production profile explains the low emission rates of DSM actions in the studied GSHP pool: the highest peak production hours are covered with renewable hydropower, which does not increase the environmental load of the produced electricity.

3.2. Profitability of DSM on a property level

In the previous section, DSM was found to influence the energy costs of the GSHP pool related to the decreased peak power costs, which are paid to distribution companies. However, in addition to the reduced energy costs, the new income for real estate owners was generated through the frequency containment reserve markets. In the Nordic reserve market, the minimum bid size for the studied FCR-D product is 1 MW. In 2019, the GSHP pool provided the minimum bid size for the reserve markets for only 56 h. Thus, depending on the reserve market, the yearly compensation was calculated to be $526 \notin$ (hourly market) and $134 \notin$ (yearly market) for the pool. Table 2 presents the subsequent cash flows for real estate owners gained by DSM.

Based on the results, the share of the income received from the reserve markets was less than 1% from the new income generated by DSM. Thus, the economic benefits were mainly achieved by the decreased energy costs related to the peak power consumption of the pool. However, the energy costs decreased only approximately 1%. Therefore, in total, the annual subsequent cash flows generated by DSM for real estate owners were only 0.03 \notin /sqm for each property type. Currently, the share of GSHP buildings in the HMA is around 2%. In the future, it is expected that the share of GSHPs would be increased to 20%. However, based on the results of this study the expected economic implications on the property level would still remain irrelevant.

4. Discussion

This study was set to examine the profitability of smart electricity control (i.e., DSM) in the Nordic electricity-based heating market. The aim was to determine whether the smart electricity control of a GSHP pool can provide meaningful cash flows and profits for real estate owners. As an additional aim, this study observed the environmental implications of DSM on a city scale. The study showed that despite the



Fig. 1. Peak shaving by 2 h, GSHP, 5 000 sqm building size, coldest week (4) of 2019.



Fig. 2. Electricity production data in Finland on the 21st of January in 2019 (Fingrid, 2019c).

Table 2Annual new cash flows for real estate owners.

Building type	Floor Area (sqm)	Decreased energy costs (€)	Compensation from the hourly reserve markets (€)	New cash flow (€)	New cash flow (€∕sqm)
Residential	1 546 050	52 077	425	52 503	0.03
Retail	70 565	2 377	19	2 396	0.03
Industrial	171 151	5 765	47	5 812	0.03
Office	126 223	4 252	35	4 286	0.03
Total	1 913 989	64 471	526	64 997	0.03

building stock's applicability as a giant short-term TES, the feasibility of DSM in increasing the power system flexibility remained limited. In addition, the economic potential of DSM appeared meaningless for real estate owners. Surprisingly, the smart electricity control of the GSHP pool did not remarkably reduce the produced emissions on a city scale.

Overall, the climate mitigation potential of DSM appeared surprisingly low when considering the political aims to cut the environmental load by increasing the smart electricity control in buildings (The European Parliament & the Council of the European Union, 2018). A few reasons for the low effect on emissions were identified by conducting a sensitivity analysis with the applied dataset. First, the performed smart control actions (i.e., peak shaving) do not save energy. Instead, the energy consumption is transferred from the peak hours, influencing the peak power costs paid to the electricity distribution companies. Second, the electricity produced in the current Nordic power system is already close to 90% carbon-free (IEA, 2016b). Thus, the peak demand hours in Finland are primarily balanced by increasing the production of renewable hydropower. In the energy model applied in the present study, electricity was estimated to produce emissions on average 81 g CO₂/kWh. In a power system where burning fossil fuels still balances the grid, the effect of DSM in cutting the power peaks would have a more

considerable (positive) effect on the produced emissions.

In addition to the surprisingly low environmental implications of DSM, the economic profit of smartness remained small (i.e., only 0.03 €/sqm/year). In this study, the DSM activation generated a two-fold economic benefit for a real estate owner. Primarily, the owner gains benefit from the decreased energy costs. The percentual decrease in the energy costs, which are paid to the distribution company, depends on the heating system's peak power consumption. However, buildings utilize energy, not power as such, but the decreased energy costs were related to the heating system's ability to cut power. Thus, the economic profit gained through the cut power peak consumption did not reduce the energy costs considerably, as the study results showed. Moreover, in Finland, the total electricity bill comprises three components: energy, distribution, and tax, from which the two latter ones include over half of the costs and cannot be affected by DSM (Finnish Energy, 2021). Accordingly, the national pricing mechanism of electricity significantly affects the profitability of DSM in electrified heating and cooling.

Secondly, a real estate owner gains profit from DSM by receiving compensation from the capacity markets. In addition to the fixed pricing, the paid compensation is dependent on the number of reserve hours and the bid size. In 2019, the studied GSHP pool was able to participate in the reserve markets only for 56 h. The number of reserve hours was surprisingly low, and a few reasons were found to explain the result. The GSHP pool was observed to participate in the FCR-D markets. The FCR-D products are activated to balance big frequency deviations, and the minimum bid size is 1 MW. By contrast, the minimum bid size in the Frequency Containment Reserve for Normal Operation (FCR-N) market is only 0.1 MW (Fingrid, 2021b). Furthermore, the compensation per MWh in the FCR-N hourly market is more than twice as much in the FCR-D hourly market. However, in the FCR-N market, the products must be able to increase and decrease the load. The modeled DSM control of the GSHP pool was only able to reduce the load from the grid.

The marketplace and the fixed pricing set by the national transmission company were considered to have the greatest effect on the economic profitability of DSM. However, the high energy efficiency of GSHP was found to also significantly affect the profitability of DSM. GSHP can provide more than three times more thermal energy compared with the electricity it consumes (GSHP Association, 2021). Furthermore, in the present study, only the daily two peak hours were cut, which restricted the reimbursements received from the capacity markets. More reserve hours could potentially affect the indoor conditions and comfort of the building users, especially in the Nordics (Kärkkäinen et al., 2004).

Even though the results of this study showed only a minor benefit of smart electricity control for real estate, the implementation of DSM from the energy system point of view is crucial. The increasing share of intermittent renewables in the energy mix will set the pressure to introduce DSM supportive applications and services in real estate to maintain reliable and secure energy supply also in the future (IEA & IRENA, 2017). Strbac (2008), for instance, has addressed the core role of DSM in reducing the future energy generation margin, improving the transmission grid investment and operation efficiency, improving distribution network investment efficiency, and managing the demand-supply balance in systems with intermittent renewables. Thus, the implementation of DSM can significantly further the transformation from the current centralized energy generation system towards distributed, and renewable based, power systems.

Today, various strategies to increase the energy system reliability exists. Especially, the utilization of various sized reserves and end-user smart electricity control are at the core of future DSM strategies (Muratori, Schuelke-Leech & Rizzoni, 2014). Accordingly, the building stock's passive reserve potential has been widely discussed as a low-cost opportunity to balance the future electricity network's intermittent energy generation (IEA, 2019). However, as discussed by Strbac (2008), the economic potential of DSM is strongly linked to the power systems stress. Accordingly, in systems that need reinforcement the value of DSM will be high and vice versa. Thus, as the present study results showed, in 2019 the Nordic power system had spare (renewable energy) capacity available and the benefits of DSM was low, also for the real estate.

The results of the present study indicated, that smart electricity control in the Nordics does not yet provide meaningful cash flows for private property owners. Thus, it seems that to generate meaningful cash flows from the reserve markets today, an investment in an on-site battery storage system is required. However, a battery's load shifting capacity affects the investment cost. The economics of an on-site battery investment can, however, appear as lucrative business opportunity for professional property owners. Surprisingly, the financial profitability (alone) is not yet a strong enough investment incentive for them. This was shown in one on-site energy improvement investment studied by Janhunen et al. (2020), where the greatest economic value was gained by the reserve potential of a 2 MW / 2,1 MWh battery. The studied investment in energy performance gained not only high return-on-investment (over 10%) but also other strategic values affecting significantly the investment decision-making process. From the property owner interviews (Janhunen et al., 2020), it was found out that the estimated benefits gained through the improved image and mitigation of environmental and energy price risks were more valuable than the financial profitability (due to the new technology and pricing risks related to the battery and income from the capacity markets). Furthermore, the role of separate smart service provider was eminent in the investment decision-making process.

Generally, financial profitability is the most eminent investment driver of on-site energy improvements for real estate owners. In the past decade, however, the environmental performance has also been widely acknowledged in the investment decision-making process. Accordingly, green certifications, for instance, have been found to have a strong positive impact on property values (Leskinen, Vimpari & Junnila, 2020a; Vimpari & Junnila, 2014). It appears that in the future low-carbon energy systems the real estate owners are not interested in only cost savings but also environmental implications as well as increasing self-sufficiency, which can protect the property from rising electricity prices. The increased self-sufficiency can be achieved, for instance, through on-site PVs installations, which have raised awareness not only as sustainable but also profitable from the real estate market point of view (Vimpari & Junnila, 2017). Accordingly, the implementation of DSM supportive applications and services in buildings might, in the future, gain lucrative monetary benefits for real estate owners.

As previously discussed, the benefits of smart electricity control from the power grid perspective can be realized already today. DSM in heating, for instance, can stabilize consumption profiles, reduce peak demand, and increase the overall efficiency of the energy system (Oconnell, Pinson, Madsen & Omalley, 2014). Today, the benefits of DSM from the grid perspective are strongly linked to the system stress, but the economics from the real estate owners' point of view are still not that straightforward. Even though the DSM in electrified heating does not yet generate considerable cash-flows for a great share of real estate owners, it is possible that the strategic benefits encourage investments in DSM supportive technologies and services in the future. Accordingly, the relevance of smart energy certifications, such as the EU-driven SRI, might become eminent in enhancing the uptake of DSM in real estate. However, to efficiently deploy the reserve potential that occurs in the building stock, the results of this study suggest separate DSM operators to design business models for smart operations and negotiate and purchase these services from real estate owners.

Some limitations of the study are discussed. First, some limitations concerned the building data applied in the present study. The hourly profiles used were constructed from an open-source dataset based on aggregate data of many buildings. In practice, every building has its specific consumption profile, which is especially applicable for commercial buildings. However, building heating has a strong correlation with the outside temperature. Hence, buildings with the same type of use and construction year have similarities. Thus, this is not seen as a problem when interpreting the results of the study. However, an interesting study is on whether individual (especially large commercial buildings) consumption profiles have more potential for DSM actions than found in this study.

Second, some limitations were related to the estimated payments from the capacity reserve markets. In this study, it was assumed that every hour when the GSHP pool provided the 1 MW reserve for the grid (i.e., in total 56 h), the pool received compensation from the market. However, as the FCR-D products balance the grid in disturbances, reserve capacity is not always needed. Moreover, in this study, a volumeweighted average for 2019 was utilized to evaluate the yearly compensation, which might have influenced the results, as the pricing varies hourly. However, the new income from the capacity markets was less than 1% of the new cash flows generated by DSM. Thus, it had only a minor influence on the results of this study.

5. Conclusion

Smart electricity control, i.e., demand side management (DSM), in building heating is perceived as a core enabler of future sustainable cities. The increasing uptake of renewables requires developing a flexible electricity network and the uptake of smart control-compatible heating appliances to maintain the balance in the power grid. Despite the technological viability of DSM, only a little weight has been given to the profitability of smart electricity control for real estate owners in the policy discussions. However, real estate will have a core role in financing the ongoing energy system transformation. The present study was set to study the benefits of one application of DSM (i.e., peak shaving) in a Nordic electricity-based heating market from the property owner's point of view.

In the study, a daily two-hour-peak shaving was modeled to a ground-source heat pump pool (GSHP) comprised of 6 403 buildings in the Helsinki Metropolitan Area. Surprisingly, the results showed only a minor economic and environmental potential for DSM. The analysis revealed an 8% decrease in power peak consumption, generating only 1% annual savings in energy costs after the DSM activation. The decreased savings in energy costs and compensation received through

the capacity markets generated a 0.03 €/sqm/year increase in cash flows on a property level. Furthermore, DSM did not affect the produced emissions, as only a 0.02% decrease was gained at the city level. Despite the technological viability of DSM, the results indicated that attending to the reserve markets does not appear to be an appealing option for a single property owner. Furthermore, the environmental implications of smartness were far less eminent than expected, given that Finland's power production for both primary and frequency markets is already relatively "clean". The climate mitigation potential of DSM, especially in the Nordic countries, is not alone enough to motivate property owners to provide flexibility for the power grid.

In general, the technological viability of various DSM strategies is well covered in the literature. However, considering the importance of real estate in enabling the energy system transformation, the real estate perspective should be further researched by utilizing more sophisticated smart electricity control strategies. Thus, the results of this study highlight the importance of an in-depth analysis of the value creation logic of smart electricity control for real estate. Overall, more financial incentives and other motives for property owners are required to fully deploy smart electricity control in future heating and cooling systems. Furthermore, in the future, new market drivers, such as the EU-driven smart readiness indicator, are possibly required to support the cities' pathway toward a smarter and more sustainable future. The influence of these market drivers should, however, be further studied.

Declaration of Competing Interest

None.

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