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Individual ground source heat pumps: Can district heating compete with real estate owners' return expectations?



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ABSTRACT

Technological development has decreased costs and improved the efficiency of heat pumps (HPs). In some cases, heat produced with HPs is already less expensive compared to district heating (DH) systems that have high market shares in many European countries. This has generated a phenomenon in which old customers are leaving DH systems, and new customers are not joining DH even if it is available. The study evaluates the economic performance of alternative heating systems (DH, ground source HP with electricity, and a hybrid of these two) for new buildings in selected city in Finland: residential, office, retail and industrial. The aim of this study is to demonstrate the rationale for property owners to invest in ground source HPs. In addition, the study examines whether DH pricing can be developed to improve the competitiveness against HP systems. The results show that currently, HPs are highly profitable for all studied customer types with current DH pricing models used in selected DH company. However, with new pricing models, the competitiveness of DH improves substantially. In conclusion, we suggest that DH companies renew their pricing models to include several customers segments as well as hybrid heating customers.

1. Introduction

Thermal energy accounts roughly for 50 % of the total energy consumption in the European Union (European Commission, 2016). District heating (DH) currently has a market share of 11 % (Ram et al., 2019; REN21, 2018) and 13 % (Connolly et al., 2014) at the global and EU level, respectively. However, DH is expected to grow extensively (Paardekooper et al., 2018; Ram et al., 2019). There are many countries with substantial installed DH capacity, such as China (463 GW_{th}), Poland (57 GW_{th}), Germany (51 GW_{th}), and South Korea (30 GW_{th}) (Euroheat & Power, 2017). Similarly, the market share of DH is substantial in other countries such as Iceland (92 %), Latvia (65 %), Denmark (63 %), and Estonia (62 %) (Euroheat & Power, 2017). Finland is a good example where both the capacity (23 GW_{th}) and market share (46 % of the total space heating) are high (Euroheat & Power,

2017; Finnish Energy, 2019). Traditionally, DH companies in Finland have been owned by municipalities (Energiateollisuus ry, 2006), and their role has been to offer reasonable priced heat for their customers. This has defined the structure of DH production in Finland: DH systems are centralised systems in which the base load is covered by large combined heat and power (CHP) plants or large heat production plants, and the peak load is covered with heat-only-boilers (HOB). Large CHP plants produce cost-efficient heat that is profitable for DH companies, while peak production is mainly produced in often costly, fossil-fuelled HOBs. Traditionally, DH covers 100 % of its customers' heat demand.

Many studies predict that DH will play an important role in future energy systems (Lund et al., 2014; Paardekooper et al., 2018; Ram et al., 2019; Werner, 2017). Still, DH systems are facing many changes due to the need to decrease emissions. Additionally, customers' energy efficiency actions and the lower energy consumption levels of new

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Abbreviations: CAPEX, capital expenditure; CF, cash flows; CHP, combined heat and power; COP, coefficient of performance; DH, district heating; EB, electric boiler; EC, electric connection; EU, European Union; HDD, heating degree days; HOB, heat-only-boiler; HP, heat pump (ground source); IRR, internal rate of return; NPV, net present value; *OPEX*, operating expenses; VE, Vantaa Energy Ltd; *C*, heat load, connection load; *C*_{Aver}, average heat load; *C*_{Max}, maximum heat load; *C*_{Meas}, measured heat load; *E*_t fixed annual electricity capacity costs; *H*, amount of heat or electricity (kWh) required; *H*_{dh}, Consumed DH energy; *H*_{eb}, Electricity required for EB; *H*_{hp}, electricity required for HP; *H*_{open}, Energy sold to Open DH; *L*_{dht}, load demand cost for DH; *L*_F, fixed component based on the connection load; *P*_{dht}, price of DH at time *t*; *P*_{et}, price of electricity; *P*_{opent}, price received for energy sold to open DH; *r*, discount rate; *t*, lifecycle of the investment (year); *a*, factor *a*, calculated by dividing the base heat load capacity (MW) and maximum heat load capacity based on the DH system

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buildings have an impact on DH business (Magnusson, 2012). These challenges force DH companies to reconsider their business models. According to Paiho and Saastamoinen (Paiho & Saastamoinen, 2018), major development eff ;orts in DH business should focus on new production alternatives (including hybrid systems) together with the end users and clients. As technological development has decreased prices of decentralised heating systems, such as heat pumps (HPs), competition between different heating systems has increased. Studies have shown that decentralised HP systems deliver significant cost savings compared to traditional DH systems in different building types, such as apartment buildings (Niemelä, Kosonen, & Jokisalo, 2017), office buildings (Niemelä et al., 2015) and educational buildings (Niemelä, Kosonen, & Jokisalo, 2017), office buildings (Niemelä et al., 2017) and educational buildings (Niemelä, Kosonen, & Jokisalo, 2016).

Traditionally, DH has been the price setter with the lowest price levels of heating, and this has enabled DH to grow in many areas (Björkqvist, Idefeldt, & Larsson, 2010; Difs & Trygg, 2009). However, the decreased costs of other heating systems, such as HPs, together with higher costs of DH production, means that the DH companies must respond to price levels defined by their competitors (Björkqvist et al., 2010). Typically, a DH price consists of the energy cost and load demand cost as well as a one-time connection fee when joining the network (Finnish Energy, 2014; Korjus, 2016). To some extent, DH companies have developed pricing to be more dynamic and transparent, which has been recommended in several studies (Dominković, Wahlroos, Syri, & Pedersen, 2018; Reino, Härm, & Hamburg, 2017; Song, Wallin, Li, & Karlsson, 2016; Song, Wallin, & Li, 2017; Syri, Mäkelä, Rinne, & Wirgentius, 2015). According to Björkqvist et al. (Björkqvist et al., 2010), it is possible to influence the customers' consumption profile by developing DH pricing. For example, customers can be incentivised to limit their peak load demand with a pricing model that has different price levels representing the DH production costs (by different seasons or by base and peak load levels) (Björkqvist et al., 2010).

As the literature review above shows, technological development of ground source HPs has tightened the competition of heating systems, and HPs bring cost savings to the customer. So far, little attention has been paid to how DH businesses should change to stay competitive by, for example, renewing the DH pricing. To understand how to develop DH pricing, more studies on current pricing are needed. This study focuses on the markets where customers are leaving DH systems or choosing alternative heating systems even when DH is available ("exitcustomers"). There are no statistics on these exit-customers in the Finnish case, but according to some DH companies, the number of exitcustomers is still small compared to the new customers connecting to the DH systems. Still, a growing number of customers, even ones that recently joined the DH system, have since left the system and have publicly mentioned economic and environmental factors and self-sufficient energy production as the main reasons for the switch.

The purpose of this study is to evaluate the profitability of alternative heating systems for recently constructed buildings. The heating systems included in this study are DH, ground source HP (referred as HP from now on) with electric boiler, and a hybrid of these two. This study concentrates on Finnish context and in one selected city with DH system. This evaluation utilises the principles of real estate economics to understand the financial motivations of building (property) owners when choosing a heating system. These findings are used to examine whether DH pricing can be developed to retain competitiveness. This study also provides an overview of 50 different DH pricing methods used in Finland and examines how DH pricing can encourage customers to actively participate in a DH system.

This paper is organized as follows: Section 2 connects a review of literature that is relevant to an analysis of DH pricing methods. Section 3 discuss the methods and data used for comparing the alternative heating systems. Section 4 presents the results and then Section 5 concludes the study.

2. District heating pricing

This section has two functions: first it analyses the DH pricing methods used currently in Finnish DH systems to find out what kind of pricing methods are used, whether there is a DH pricing method that would acknowledge different consumption profiles and whether there is a pricing method that would encourage customers to use DH as a part of hybrid heating. Secondly, this section gives a literature review on how DH pricing should be developed regarding above mentioned features. Altogether this chapter provides background to the case study followed after this chapter.

2.1. District heating pricing models in Finnish companies

All together there are 177 separate DH systems in Finland. In this study, the pricing models of 50 largest DH systems in Finland were analysed. These selected DH systems represent 85,5 % of the total heat sold in 2018 (all together 33,450 GW h) (Finnish Energy, 2019). The data for the pricing methods were collected from the companies' webpages. Yearly heat costs (including energy cost and load demand cost) for four customers (residential, office, retail, and industrial) were calculated with the current pricing methods used in these50 DH systems. The hourly heat consumption data for the year 2016 for each customer were used as an input data to acknowledge the specific heat load profile of each customer. The customer types and their consumption profiles are presented with more detail in Section 3.3 and in Fig. A1 (Appendix A).

The analysis shows that the DH pricing models, i.e. how customers' total heat price is divided in different cost items, used in Finland are similar even though the DH system sizes and production units vary. The analysis also showed that all customer types are priced with similar methods, i.e., different consumption profiles are not considered in pricing. The typical pricing models in Finland consist of three components: one-time connection fee (investment cost), energy cost, and load demand cost. The connection fee is typically determined by the customer's design heat load. The customer pays an energy cost (ϵ /MWh), which covers the variable costs of heat production. Out of the studied DH companies, 76 % used a constant energy price over a year, but especially large- and medium-sized DH systems have moved towards seasonally or monthly changing energy cost models. Twenty-two percent of the studied DH systems offered customers the possibility to purchase DH produced with renewable fuels (for an extra fee).

Customers also pay a monthly fixed load demand cost. Load demand costs cover non-operational costs and heat production plants needed for customers' maximum heat load. Even though actual remote heat measurements are carried out, 63 % of the studied DH systems used design heat load or water flow as the basis for the load demand cost. The rest of the DH systems use actual measured loads. This study reveals that determination of maximum heat load based on measured heat consumption varies by DH system: one way is to determine the load demand cost based on customers' maximum heat load in a yearly level (three DH systems used a time frame of three years). In some cases, single hourly maximum peak loads have been removed by taking the running average of three hours of heat load. Another common method is to use consumption data from the previous year in a regression analysis to find the load level of the corresponding design temperature of the location (for example, -26 °C in Vantaa) (Finnish Energy, 2014). This minimises the risk for DH company to ensure production capability even on the coldest winter days (Björkqvist et al., 2010).

Many DH systems also offered several load demand cost categories that enable customers to lower their heating costs if they implement energy efficiency or demand side management. However, lowering single peak heat loads have minor decreases in heat costs. Besides energy cost and load demand cost components, some DH companies charge or reward customers by an energy efficiency with cooling cost (referring to how DH water cools down in customers' appliances), but

K. Kontu, et al.



Fig. 1. The annual price of DH for the four customer types in different DH systems (each column represents one DH system, in ϵ /MWh) and the average share of the load demand cost component in DH price (light blue dots, in %). The red column presents the pricing in one selected city in Finland which is used in case study later on this study.

the use of this component has been reduced and is used by only one DH company included in this study.

Fig. 1 shows that the average DH price level varies extensively based on different customer types, e.g., the average price is 66 C/MWh for apartments (largest customer group in Finland with 81 % of the customers (Finnish Energy, 2019)), but 92 C/MWh for retail buildings. The high price goes together with the high share of load demand cost, as shown in Fig. 1. Apartment buildings, which typically have a smoother consumption profile, have lower total prices. Customers with a small heat consumption, but a high heat load in single days (such as newly built retail and office buildings), are impacted more by the load demand cost component. This can result in DH prices so high that competing with alternative heating systems might be difficult.

2.2. Literature review on district heating pricing

As was found in DH pricing models used in Finland, all customer types are priced with similar methods, i.e., different consumption profiles are not considered in pricing. In reality, the customer types are very heterogeneous with divergent consumption profiles with different levels of full load hours and temporal differences in daily peak heat loads. This can also be seen from the customer types used in this study (see Table 2 and Fig. A1 in Appendix A). As suggested in Björkqvist et al. (Björkqvist et al., 2010) and in Li et al. (Li, Sun, Zhang, & Wallin, 2015), DH companies should consider different customer types in their pricing models accordingly. With current pricing models, the share of load demand cost varies between different customer types resulting higher DH cost for customers with small heat consumption but a high heat load in single days. Current pricing models and strategy is competitive especially for customers with smooth heat load profile. Also a study by Sernhed et al. (Sernhed, Gåverud, & Sandgren, 2017) found that different DH customer groups (real estate companies and housing associations/homeowners) value different factors in pricing. Large customers, such as real estate companies, valued predictability and freedom of choice. Homeowners and housing associations valued simple and understandable pricing methods. Homeowners also valued a high share of variable costs to make sure that they pay for what they consume.

In DH pricing in Sweden, different customer types are identified by category number (Stridsmann, Ryden, & Göransson, 2012), where load demand cost is calculated by dividing heat consumption by peak load hours. A category number is theoretical, and it is determined for

different customer types and mainly used for large customers. In Finland, this type of categorisation does not exist, which can lead to situations in which the load demand component covers half of the DH bill. Customers with hybrid heating systems are also neglected in DH pricing; only one DH system had official pricing for hybrid systems.

As in Finland, DH pricing have moved towards seasonally or monthly changing energy cost models also in Sweden (Sernhed et al., 2017). This means that DH companies are renewing pricing to increase transparency (Song et al., 2017) of the marginal cost of DH production. In situations where customers want to optimise their consumption profile (i.e., demand side management or demand response), the load demand component has to be based on the actual load and a short as possible time frame (Song et al., 2016, 2017).

3. Methods and data

This section covers the methodology and data used in this study. First, it explains how the profitability of HPs are evaluated, from the perspective of both property owners and energy companies. Second, it explains how heating and DH pricing alternatives have been developed. Third, input data is presented. The analysis is carried out for four different customer types (residential, office, industry, and retail) of recently constructed (following the newest building regulations) buildings located in the city of Vantaa, Finland. The DH system of Vantaa Energy Ltd (VE) is used as the comparison because the customers' heat consumption data is received from VE. Consumption profiles of customers and the VE DH system are presented in Section 3.3.

3.1. Optimising heat pump size

To calculate the economic opportunity of HPs for property owners, a sophisticated spreadsheet tool was constructed. The tool optimises the size of the HP so that economic value is maximised (measured by net present value [NPV]) for property owners. Net present value is one of the most widely used metrics to compare investments, and it is calculated by adding the present value of future cash flows (CFs) and deducting the initial capital expenditure (CAPEX):

$$NPV = -CAPEX + \sum_{1}^{t} \frac{CF_t}{(1+r)^t}$$
(1)

where t is time and r is discount rate. In this case, the CAPEX is comprised of three components: cost of the HP, cost of the electric boiler

(EB), and cost of upgrading to a larger electrical connection (EC) to accommodate the higher peak power required by the system. The CF is comprised of seven components, where i to iv have variation on an hourly level, and v to vii are fixed annual costs:

- i Avoided DH energy costs
- ii Electricity costs to operate the HP
- iii Electricity costs to operate the EB
- iv Revenue from energy sold to open DH (If open DH is allowed)
- v Avoided DH load demand costs
- vi Other maintenance costs of the HP
- vii Fixed costs for higher electricity capacity connection

Thus, the above equation is as follows:

$$NPV = - (HP + EB + EC)$$

$$\sum_{1}^{8760} \left[H_{dh} * P_{dht} - \left(\frac{H_{hp}}{COP} + H_{eb}\right) P_{et} + H_{open} \left(P_{open_{t}} - \frac{P_{et}}{COP}\right) \right]$$

$$+ \sum_{1}^{t} \frac{+ L_{dht} - OPEX_{t} - E_{t}}{(1+r)^{t}}$$
(2)

where H_{dh} = consumed DH energy, P_{dht} = price (\notin /MWh) of DH at time t, H_{hp} = electricity required for HP, H_{eb} = electricity required for EB, P_{et} = price of electricity, H_{open} = energy sold to Open DH (if allowed by the DH network; the Open DH concept is explained in the following section), P_{open_t} = price received for energy sold to Open DH, L_{dht} = load demand cost for DH, OPEX = operating expenses of HP, E_t = fixed annual electricity capacity costs and r = used discount rate. In the equation, we assume that the energy prices $(P_{dht}, P_{et}, P_{open_t}, L_{dht}, E_t)$ increase over time on average (i.e., hourly prices are adjusted upwards with the numbers mentioned in Table 3), but the hourly consumption and price profiles within a year do not change over time (e.g., they are both connected to the outside temperature, and this is not changed by time). The lifecycle of the investment, t, can be found in Table 3. In component iv, Open DH is a business model in which customers have a possibility to sell extra heat (waste heat) with given temperature levels to the DH network with predetermined prices. The concept is described in detail later in Section 3.2.

It is also mentioned that the inner sum symbol sums all hours of the year. 2016 was a leap year with 8784 h. On top of the NPV, the *internal rate of return (IRR)* is also calculated. The IRR is also a widely used financial metric, and it is used to solve the discount rate r in the equation by setting the NPV to zero. If the solved rate is higher than the investor's required rate of return (property owner's return target), the investment should be undertaken. Often, both NPV and IRR are calculated.

A large part of the system's total cost comes from the EC and E_t . The EC is a fixed, one-off cost based on the maximum peak power required (ϵ/kW); E_t is calculated by multiplying the year's peak power hour (kW) by a fixed annual cost (€/kW/a). To calculate the annual electrical peak power between buildings using DH or HP + EB, hourly electricity consumption data (without heating) was retrieved for the different building types ("Vantaa Energy - Company webpage," 2018). This, combined with the electricity consumption profiles of HPs and EBs, created a total hourly electricity consumption profile (i.e., including electricity used for both heating and electricity). While analysing these profiles, it was noted that there could be significant benefits to utilising the demand response to some of these hours, due to the pricing logics of the electric capacity. It was assumed that 0,5 % of the year's hours could participate in demand response to smooth out some of the peak power hours. This kind of peak shaving can be easily attained with a hot water reservoir, which are commonly used in practice and have very low capital expenditures.

HP together with EB are assumed to produce the same amount of energy as would be bought from DH (i.e. $H_{dh} = H_{hp} + H_{eb}$). The HP

should cover the optimal amount of the base load, and the EB the peak loads because relative CAPEX (ϵ /kW) for an HP is much higher than for an EB, i.e., overinvestment into HPs decreases the profitability of the system. This optimal balance can be found by maximising the NPV. In Eq. (2), all of the parameters except the original amount of required heating, which is expected to be constant, are related to the size of the system. Thus, the maximum NPV can be found by iterating the size of the HP.

The used discount rate has a major impact on the NPV due to discounting logics, i.e., the higher the discount rate, the lower the present value of future CFs. Traditionally, it has been noted that defining a correct discount rate for an energy investment is difficult (Aldersey-Williams & Rubert, 2019; Joskow, 2011). Since we are analysing how an on-site energy system creates value for a property owner, we will follow the methodology presented by Vimpari and Junnila (Vimpari & Junnila, 2017). In their analysis, Vimpari and Junnila argued that onsite energy investments should be evaluated utilising real estate economics to identify how they create value for the property owners. In short, this means that if an energy investment is an integral part of the property, it can be discounted with the same discount rate as the underlying property because this is how property owners evaluate their investments. In the current study, we follow the same logic and use the available property information to define correct discount rates for the building types analysed in this study. This allows us to optimise the plant according to the decision-making of the property owner.

Simultaneously, we can also calculate a more traditional energy investment metric to compare the energy costs of the NPV optimized system to DH. The first year heating costs of the HP system is compared to the current annual price of DH using the following formula:

$$Heating \ cost = \frac{CAPEX_1 + OPEX_1 + Energy_1}{H_1}$$
(3)

where $CAPEX_1$ = annuity of capital expenditures for the first year, $OPEX_1$ = operating expenses of the HP system, $Energy_1$ = energy related costs of operating the HP system (i.e., parts ii, iii and vii of Eq. (2)) and H_1 is the amount of heat required (i. e. $H_{dh} = H_{hp} + H_{eb}$). It is highlighted that we are only calculating the heating cost for the first year because we are comparing the HPs cost of energy to the current DH cost of energy. We are not comparing two new investments, i.e. it is unknown what kind of investments will be done to the current DH network, and how will they affect the DH pricing in the future.

3.2. Heating alternatives, pricing methods for district heating, and Open DH

Table 1 presents heating model alternatives compared in this study where different shares of heat demand are covered by DH, HP, or alternative hybrid heating. Also, the profitability of Open DH is analysed.

Table 1	
Heating	Alternative

ficating miternatives.		
HP1: HP and electricity	HP2: HP and electricity with Open DH system	HP3: Hybrid, HP and DH peak and Open DH
Electricity HP DH1: DH with existing pricing	Electricity HP Open DH DH2: DH with peak and base pricing	DH peak HP Open DH DH3: DH base heat and electricity
DH	DH peak DH base	Electricity DH base

Table 2

Building Information and Heat Consumption Data.

	Area	Yearly Heat Consumption	Maximum Heat Demand	Full Load Hours Per Year	Average Load Per Maximum Load
	m²	MWh	kW	h	%
Residential	6 700	476	308	1547	17,6
Office	8 000	469	576	814	9,3
Industry	20 000	1 072	693	1546	17,6
Retail	5 500	185	253	730	8,3

In HP1, most heating is covered by an HP, but electricity for electric boiler (EB) covers the peak heat demand. In HP2, a customer has the opportunity to sell excess heat to Open DH. In HP3, base heat is covered by an HP but peak heat by DH; additionally, customers also can sell excess heat to a DH company. In HP2 and HP3 alternatives, the customers are former DH customers so there are no investment costs for DH system. In all cases, the HP is sized by maximising the profitability, as explained above. This investment cost could be decreased by using DH for peak loads instead of electricity. In the HP3 alternative, the profitable price level for peak heat is analysed.

The DH connection would also enable customers to sell their waste heat to Open DH systems in times when it is profitable for customers. In the Open DH system, customers can compete with their producer's own heat production, and the producer sets a market price for waste heat based on its own production costs (Kontu, 2015; Syri et al., 2015). If a customer can deliver heat at a lower price, the producer will buy it. In the Open DH concept in this study, heat can be sold for either supply or return pipes. Heat for supply pipes is the most valuable product, and it is transferred from a customer's building to a producer's heat network. The price level is set according to the variable cost of the energy company's own production costs. Heat for a return pipe is water, which required temperature level is similar to the DH return water. The heat is transferred to the producer's heat network through the DH producer's return pipe.

In DH1, DH covers the entire heating demand with the existing pricing method, i.e., changing energy cost and the load demand cost based on either connection capacity or measured load. The variables for pricing are the current pricing of VE ("Vantaa Energy, District heating prices, 2019). Load demand cost (L, \notin /year) is calculated as:

$$L_{dh1} = L_F + L_v * C$$
 (4)

where L_F is a fixed component based on the connection load (€/year), L_v is the variable component based on the connection load (€/kW/year), and *C* is the connection load (kW). Energy cost P_{dh1} is calculated by multiplying consumed heat energy H_{dh1} with the given DH price, which changes in a monthly level.

In DH2, DH covers the entire heating demand with a pricing method where base and peak loads are priced differently. The load demand cost component was developed for a more even pricing between different customers types. Load cost is an annual cost, and it is calculated as

$$L_{dh2} = C_{Meas} * \frac{HDD_{base}}{HDD_{lastyear}} * \frac{C_{Aver}}{C_{Max}} * k * 12$$
(5)

where C_{Meas} is the measured heat load, HDD_{base} and HDD_{lastyear} are the heating degree days of the last year (in this study, year 2015) and the base year (which is year 2008 for Vantaa (Finnish Meteorological Institute, 2019)), C_{Aver} is the average heat load and C_{Max} is the maximum heat load. Since we only have consumption data from one year, C_{Aver} and C_{Max} are calculated from the year 2016. Heating degree days were included to account for the different temperatures of different years. Factor k can change yearly according to the maintenance needs of heating plants, etc. In this study, it was set to a value of 15 to have the level of load demand costs for the sum of the customers be the same level as in present pricing.

In DH2, the energy cost is calculated in two levels, covering base (H_{Base}) and peak heat energies (H_{Load}) , and prices are given for each of

them (P_{Base} and P_{Peak}). The limit of base and peak loads (α) comes from the DH system and its share of the base load and maximum load.

$$P_{dh2} = H_{Base} * P_{Base} + H_{Peak} * P_{Peak}$$
(6)

For each customer, the level of base and peak load is calculated by multiplying the maximum heat load of the year with factor. Factor α is based on the DH system itself, and it is calculated by dividing the base heat load capacity (MW) and maximum heat load capacity. For VE, $\alpha = 0.615$ (with 400 MW of base heat production and 650 MW heat load in general).

In DH3, the base heat is produced with DH and the peak heat with electricity from EB. As DH produces only base heat, its design load is smaller and measured to be the same size as HP in HP1 alternative. A larger share of base cost increases the cost of DH for customers with the current pricing method, especially for customers with only a small number of peak load hours. Also, for a DH company, the most profitable heat production is the base load; peak heat can even be unprofitable. In DH3, two alternating pricing methods are used: DH3_A with current VE pricing and DH3_B with new pricing as in DH2 alternative.

3.3. Consumption data, district heating system, and input data for heat pump optimiser

Hourly heat consumption data from four different customer types (residential, office, industry, and retail, all built after 2012 when building energy efficiency regulations were significantly tightened) was used as input data. The buildings were located in Vantaa. The minimum outside temperature in 2016 in Vantaa was -27,8 °C (Finnish Meteorological Institute, 2018). The details of the buildings are presented in Table 2. Consumption profiles and average weekly consumption rhythms are presented in Fig. A1 in Appendix A.

Because the customers were located in Vantaa, the DH system in the city of Vantaa is used as an example. Vantaa is the fourth most populated city in Finland and part of the capital area. The DH system is run by VE ("Vantaa Energy - Company webpage," 2018), which is the fifth largest DH producer in Finland (it sold 1680 GW h of heat in 2017). Eighty-nine percent of residents are connected to the DH system (Finnish Energy, 2019). The number of residential customers in 2017 was 3626 (76 % of all customers), and they consumed 52 % of the heat energy in 2017 (Finnish Energy, 2019). The DH system consists of several production units that are presented in Fig. A2 in Appendix A. In the figure, heat production according to outdoor temperature as well as maximum heat production levels with different production units are shown (Finnish Energy, 2019; Kontu, Vimpari, Penttinen, & Junnila, 2018). The base load is covered with waste-to-energy and biofuelled CHP plants. The DH price for customers with newly built buildings in VE represents the average price level of DH in Finland (see results of Chapter 2.1, red columns in Fig. 1) which justifies the use of VE pricing in this study. The sensitivity analysis was performed with highest and lowest DH pricing to evaluate the profitability of alternatives HP1 and DH1

In VE, prosumers can sell heat to the DH system, but individual contracts are required. In this study, pricing for an Open DH concept for VE is developed. Heat can be sold to either supply or return pipes with different price levels. Required temperature levels of heat according to the outdoor temperature are set for the same level as in the Fortum

Table 3							
Input Values for the HP Optimiser.							
		Residential	Office	Industry		Retail	Reference
Property yield	%	4,2	6,0	6,6		4,6	(Datscha, 2018)
COP		3,5	3,6	4		3,6	(Oilon Oy, 2019; One1, 2017)
Outlet temperature of heat, to OpenDH system	ů	60	50	40		50	(Oilon Oy, 2019; One1, 2017)
Investment cost, sum	€/kW	1300	006	006	006		
- Long-term (pump and bore well), 70 %	€/kW	910	630	630	630		(Oilon Oy, 2019; One1, 2017)
- Short-term (compressor and project), 30 %	€/kW	390	270	270	270		(Oilon Oy, 2019; One1, 2017)
- Electric boiler	€/kW	45-80	35-65	35-65	35-65		(Termax et al., 2019)
- Electrical connection increase	Ψ	According to pricing in ¹	Vantaa Energy				Vantaa Energy Electricity Grid, (2019)
Maintenance cost	€∕kW	5,9	5,4				(Oilon Oy, 2019; One1, 2017)
Operating lifetime							
- Long-term (pump, bore well, boiler)	a	30					(Oilon Oy, 2019; One1, 2017)
- Short-term (compressor and project)	a	15					(Oilon Oy, 2019; One1, 2017)
DH price increase (in real terms)	%	2,5					(Statistics Finland, 2019)
Electricity price increase (in real terms)	%	2,5					(Statistics Finland, 2019)
DH price		DH connection fee, ener	gy and load demand	d costs according to	the pricing of Va	antaa Energy	(Vantaa Energy, District heating prices, 2019)
Electricity price	€∕h	2016 spot-price + spot-p	premium + electricit	ty transfer + electri	city taxes		Nordpool (2017); Verohallinto (2019); Vantaa Energy

Electricity Grid

Vantaa Energy Electricity Grid (2019)

According to the pricing of Vantaa Energy

€/kW

Electricity demand charge

(2019)

Sustainable Cities and Society 53 (2020) 101982

Open DH system in Espoo (Fortum, 2019) since these cities are neighbouring cities. In Fig. A3 in Appendix A, the heat prices, as well as the required temperature levels, are presented according to the outdoor temperature. The customer must optimise in which product the heat should be sold. This naturally depends on the temperature level of the waste heat, which affects how much the temperature has to be increased before feeding it to the DH network. The higher amount of compensation needed for heat for the supply pipe is one factor influencing the optimisation process. Still, the coefficient of performance (COP) of the HP decreases if a larger temperature increase is needed. This also increases the amount of electricity needed. As can be seen in Fig. A3 in Appendix A, when the outdoor temperature is higher than 5 °C, the price levels of supplied heat are very low. This is due to the low marginal cost of heat production in Vantaa, which is covered by a waste-fuelled CHP plant.

The input values for the HP calculator are presented in Table 3 The input values for HPs (COP, outlet temperature of heat to Open DH system, investment, maintenance cost, operating lifetime) are received from quotations from an HP producer (Oilon Oy, 2019) as well as an HP profitability report done for VE (One1, 2017, p. 1). The COP values are higher with a lower requirement of heat temperature from HPs. District heating prices for connection, energy, and load demand costs are the present prices from VE ("Vantaa Energy, District heating prices, 2019). Value added tax (24 %) is included in the costs of residential buildings. Sensitivity analysis was performed for different COP values by increasing and subtracting COP with one from the initial COP values.

The total electricity price is calculated by adding VE's current electricity transfer prices ("Vantaa Energy Electricity Grid (Vantaan Energia Sähköverkot Oy), Prices (2019)) and electricity taxes ("Tax rates on electricity and certain fuels," 2019) to the hourly spot prices (Nordpool, 2017). In the base case, the hourly electricity price from 2016 (spot-price of Finland) was used with a rather low average value of 32,4€/MWh. For the sensitivity analysis, an electricity spot-price series from 2018 was used from the Finnish price to present higher price level (average 46,8€/MWh) and from the Danish DK1 price to show a more volatile price series (average 44,1€/MWh). On top of the spot-price, a spot-premium of 2 €/MWh is added based on quotes from three commercial spot-electricity traders in Finland. The spot-premium is the fee that has to be paid for spot-electricity traders.

4. Results

This section presents the main results of the current case study. In Section 4.1, the profitability of an HP system was compared with a DH system with current pricing, and a sensitivity analysis was conducted. In Section 4.2, the results with renewed DH pricing and different hybrid heating systems were presented.

4.1. Profitability and costs of heat pumps compared with district heating system

The first column in Table 4 (HP1) presents the NPV and IRR for the different building types. The HP is optimised to maximise the NPV of the investment. The results show that the HP is highly profitable for all studied customer types, i.e., NPVs are highly positive, and IRRs are nearly two to four times higher than the underlying property yields (i.e. the location specific discount rate reflecting the required rate of return for the property investment and they are determined by the property market professionals and researchers based on market observations) depending on the customer type. The first two bars in Fig. 2 show the energy and investment costs of HPs ("HP1") and DH with current pricing ("DH") for the first year (heating cost with Eq. (3)) (ϵ /MWh). An optimised HP (HP1) has 18%–33% lower costs compared to DH with current pricing. If only energy costs are compared, the energy costs of HP systems are 46%–66% lower compared to DH. Since HP is sized to maximise the NPV, HP sizes are small compared to peak loads, e.g., for

6

Table 4

Results and Sensitivity Analysis of HP Sizewith DH (Current Pricing in VE).

	Н	IP1 (Optimis	ed HP)	HP 100%			HP 75%			HP 50%		
	NPV, € (IRR, %)	HP size, MW (%)	HP prod, MWh (%)	NPV, € (IRR, %)	HP size MW, (%)	HP prod, MWh (%)	NPV, € (IRR, %)	HP size MW, (%)	HP prod, MWh (%)	NPV, € (IRR, %)	HP size MW, (%)	HP prod, MWh (%)
Residential (property yield 4,2%)	321 400	0,109	453,8	130 600	0,308	476	236 500	0,231	475,8	315 700	0,154	470,5
	(15,9 %)	(35,4%)	(95,32%)	(6,5 %)	(100%)	(100%)	(9,2%)	(75%)	(99,94%)	(13,1%)	(50%)	(98,83%)
Office (property yield 6%)	168 500	0,170	437,3	-88 900	0,576	469	47 000	0,432	468,6	140 900	0,288	462,2
	(13,1 %)	(29,5%)	(93,24%)	(4,5%)	(100%)	(100%)	(7,0%)	(75%)	(99,92%)	(10,0%)	(50%)	(98,55%)
Industry (property yield 6.6%)	322 400	0,303	1 023,1	93 300	0,693	1072	248 200	0,520	1068,7	318 200	0,347	1043,6
	(14,8 %)	(43,8%)	(95,46%)	(7,9%)	(100%)	(100%)	(10,8%)	(75%)	(99,72%)	(13,9%)	(50%)	(97,37%)
Retail (property yield 4.6%)	161 000	0,108	178,4	51 100	0,253	185	111 200	0,190	184,5	155 200	0,127	181,1
	(14,2 %)	(42,6%)	(96,52%)	(6,3%)	(100%)	(100%)	(8,9%)	(75%)	(99,82%)	(12,8%)	(50%)	(98,01%)

an office building, the maximum heat production with an HP is only 30 % of the maximum heat demand, and the rest of the consumption is covered by electricity. Still, 93,2 % of the annual heat consumption is covered by HPs due to the steep duration curve of customers heat consumption, as shown in Table 4. This is an interesting result that partly explains the high costs of DH because traditionally, DH systems cover customers' whole heat consumption.

Sensitivity analysis presents what happens to the profitability if HPs cover 100 %, 75 %, or 50 % of the maximum heat load. If HPs cover 100 % of the heat demand, the total costs (in ϵ /MWh) for HPs is higher than for a DH system, see Fig. 2. Sizing a HP system for 75 % of the maximum heat demand, the HP investment gets profitable, but the HP would cover 99,7%–99,9 % of the heat energy for the buildings. A 50 % HP would cover 97,4%–98,8 % of the required heat energy, but with the smaller investment cost, the HP investment is much more profitable. What stands out is that the price of the peak heat demand is extremely expensive when it is covered by an HP.

The results of sensitivity analysis for different COPs and electricity price profiles (see Table 3 in Section 3.3 for explanation) are shown in Table A1 in Appendix A. The sensitivity analysis reveals that HP systems stay profitable even with lower COP values. Also, using different electricity spot-price profiles has only a minor effect on profitability. The electricity spot-price only covers approximately 30%–45% of the whole retail price as the costs of electricity transfer and taxes form the rest. The results of the sensitivity analysis with the cheapest and the most expensive DH prices shows the high variation of profitability of HPs with IRRs changing from 2,4 %–6,4 % with the cheapest DH price and 25,4 %–32,2 % with the most expensive DH price (Table A1 in Appendix A).

4.2. Hybrid systems and new pricing methods for district heating

The results of the case study indicate that DH with current pricing

used in case study is an expensive alternative for newly constructed buildings. New pricing methods for DH as well as different hybrid heating models were developed and compared with HP systems. In Fig. 3, the energy and investment costs of hybrid heating systems are compared with different DH pricing methods. Table 5 presents the financial evaluation of these systems. The first two bars in Fig. 3 present the costs of HP (HP1) and DH with current pricing (DH1). The third bar shows the results of heating alternative DH2 where DH covers 100 % of heating, but with a new pricing method ("peak and base pricing") that has different prices for base and peak demand (45 and 70€/MWh are used, respectively). Additionally, load demand cost is renewed so that it accounts for the different consumption profiles of different customer types. The pricing method is described in more detail in Section 3.2 (heating alternative DH2). The sum of the load demand cost for all customers is equalised between the different customer types. In Fig. 3, it is clear that the DH price stays at the same level for residential and industry buildings, which have higher consumption full load hours (approximately 1500), but decreases for office and retail buildings (approximately 800 full load hours). Still, HPs are the most profitable heating alternative for all customer types.

In Fig. 3 and Table 5, the results of the energy costs of two hybrid heating alternatives, DH3, are presented where DH covers only the base load with same design load as an HP system, and the peak load is covered by electricity. Two different DH pricing methods are used: current pricing used in case study (DH3_A) and peak and base pricing (DH3_B) where the price for the base load is set to 35ϵ /MWh. With the smaller DH sizing and the new pricing method, HP is not profitable. Thus, the new DH pricing benefits owners of office and retail buildings the most because the current DH pricing is expensive for steep consumption profiles.

Two different heating models, where the main heating system is an HP with a possibility to sell excess heat to DH, are included in the study. In HP3, peak heat is covered by DH instead of electricity. Table 5 and



Fig. 2. Comparison of energy (solid blue column, includes the load demand cost in DH) and investment costs (striped column) of HPs and DH (with current pricing) for different customer types.



Fig. 3. Comparison of energy (blue column, including load demand cost in DH) and investment costs (striped column) of HP and DH systems. DH1 with current pricing, DH2 with base and peak prices, DH3_A with smaller DH connection and current pricing, DH3_B with smaller DH connection and new pricing methods.

Table 5	
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Results of Different DH Pricing Methods for HP, DH, and Hybrid Models.

		HP1	DH2	DH3 A (Small DH with Current Pricing)	DH3 B (Small DH with New Pricing)	HP3 (HP with DH peak price 300€)
Residential (yield 4,2%)	NPV, €	321 400	324 500	186 400	24 500	335 400
	IRR, %	15,9 %	16,1 %	11,2 %	5,3 %	13,6 %
Office (yield 6%)	NPV, €	168 500	51 500	33 300	-135 000	200 800
	IRR, %	13,1 %	8,4 %	7,6 %	-3,7 %	12,7 %
Industry (yield 6.6%)	NPV, €	322 400	360 800	227 700	-127 600	345 600
	IRR, %	14,8 %	15,7 %	12,6 %	0,7 %	14,0 %
Retail (yield 4.6%)	NPV, €	161 000	24 900	60 300	$-62\ 200$	162 700
	IRR, %	14,2 %	6,3 %	8,5 %	-1,2 %	13,2 %

Table A1 in Appendix A show the results of the HP system, where the peak heat is produced with DH (HP3 alternatives). This shows that the price level for DH can be high—around 300€/MWh for customers to have profitability values similar to those of the HP system with electricity—as in this alternative, customers avoid extra investment for a larger EC as well as an EB for peak production. The results in Table A1 in Appendix A show that participating in Open DH does not increase the profitability of the HP system with the given price levels for excess heat. In this study, the excess heat was not primed (extra heated), and thus it was suitable only for DH return pipes due to the lower temperature levels. This results in a rather low compensation of excess heat from the Open DH system.

5. Conclusions

Several studies have identified the important role of DH in future energy systems and recognised multiple challenges that current DH systems are facing. One of the most important challenge is the technological development of other heating systems that increases competition in the market and decreases customers' costs of heating. The purpose of this study was to evaluate different heating systems (DH, ground source HP with electric boiler, and a hybrid of these two) for different types of buildings and to use these results as a basis to examine how current DH pricing could be developed to retain its attractiveness in the new competition landscape. The study concentrated on Finnish context.

The results of the case study show that ground source HP is highly profitable for all studied customer types when compared to DH with current pricing methodology. The DH price used in the case study represented the average level in Finland. The results indicate that the most profitable HP sizes are small compared to peak loads (30%–44%), still producing approximately 93%–97% of the annual heat demand depending on the customer type. Similar results of HP profitability were found in previous studies as well (Niemelä, Kosonen et al., 2017; Niemelä et al., 2016, 2017; Niemelä, Levy, Kosonen, & Jokisalo, 2017). The most interesting finding was the expensiveness of producing a peak load, which was analysed using a sensitivity analysis where HP size was set as 100 %, 75 %, and 50 % of the maximum peak load. The results

show that when the HP was sized for the whole heat demand (100 %, similarly to the current size of DH systems), HP investment increased the total costs (in ϵ /MWh) to a higher level than the DH systems. However, when HP was sized to cover 50 % of the maximum peak load, the HP system was already highly profitable compared to current DH system and still covering in average 98 % of the heat energy. This is due to the steep duration curve of customers' heat consumption profiles. The study presents a quantitative methodology and points out that optimising the size of the HP system has a great impact on the profitability and costs of HP systems. Additionally, comparing the profitability to the underlying properties reveals how lucrative the returns are from the property owners' perspective. However, the profitability of heating system must be studied case by case as was showed in the sensitivity analysis where different price levels of DH was included.

The results further support the idea of renewing the current pricing of DH. Currently, different types of customers are priced using the same pricing methods even though the customer types are very heterogeneous. This results in large differences in the cost of DH for customers: on average, the price for a residential customer is 66€/MWh whereas it is 92€/MWh for a retail customer. Beside this, DH companies should provide the opportunity for customers to participate in hybrid heating systems by developing pricing methods. Current pricing methods neglect hybrid heating systems, but this study shows that participating in hybrid heating systems is a great opportunity for DH companies as well. Results of hybrid heating systems, where DH covered the base load and electricity the peak load, show that it is possible for DH companies to compete with HP systems with a much lower cost than with current pricing and sizing of DH. Also, DH companies should consider offering peak load capacity for customers with HPs (customers buying DH instead of electricity). The larger electricity connection increases the cost of peak loads (in cases of HP and electricity); the results of this study show that higher prices could be asked for providing DH for peak loads. These findings also suggest that demand response actions are valuable in hybrid heating systems where EB covers peak heat load. By optimising heat use or electricity use during the peak load hours could save investment cost of electricity demand charge.

The results of current DH pricing methods used in Finland show that DH pricing is developed to its largest customer segment: residential buildings. District heating costs for other customer types with different consumption profiles are high mainly due to the high level of the base demand cost. District heating businesses should develop and diversify pricing methods, taking different customer types into account, as well as offer different hybrid heating alternatives to be competitive with other heating systems. There are characteristics in DH that are appreciated by customers, such as reliability (99,98 % in 2017 in Finland (Finnish Energy, 2019)), ease, and care-free nature, and DH companies should consider how to price these characteristics.

District heating systems and pricing have strong national- and system-level characteristics. The comparison of profitability of heating alternatives in this study is limited to the Finnish case and input values of the case study. Further research should be extended to study different locations and the impact on national level energy systems if the share of individual HPs increases and more peak heat demand becomes covered by electricity. Another limitation is that the concentration of this study

Appendix A

was on the newly built buildings with steep consumption profiles; further study should be extended to different consumption profiles of customer types. Research should also cover analysing the emissions levels of different heating alternatives. It can be mentioned that the CO₂-emissions factor in current DH production in case study is 247gCO2/kWh ("Vantaa Energy - Company webpage," 2018) while for electricity production it averages 164gCO2/kWh in Finland (Motiva, 2018) which refers to much lower emission level of HP compared to DH system in this case.

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Fig. A1. Duration curves and the weekly average consumption of single buildings for different customer types.



Fig. A2. The heat production in a VE DH system according to outdoor temperature. Maximum heat production levels with different production units are shown.



Fig. A3. Heat prices for supply and return pipes as well as required temperature levels for an Open DH system in a VE DH system.

Table A1

Results of a Sensitivity Analysis of COP (Increasing and Decreasing COP with Value 1), a Sensitivity Analysis of Different Electricity Price Series (Spot-Price Series from FI2018 and DK1-2018), Heating Alternative HP2, HP with Different Peak Prices of DH, and with minimum and maximum DH price.

		Optimised HP	Sensitivity COP	Analysis,	Sensitivity A Electricity Pr	nalysis, rice	HP2 with OpenDH	HP3 (HP wi	th DH)	Sensitivity analysis, different DH price	
			COP +1	COP -1	FI2018	DK1-2018		Peak Price 100€	Peak Price 200€	Cheapest DH price	Most expensive DH price
Residential (yield 4,2%)	NPV, €	321 400	385 570	202 300	279 200	291 300	321 720	397 500	356 600	50 900	657 520
	IRR, %	15,9%	17,5%	11,9%	14,5%	14,9%	15,4 %	18,5 %	15,0 %	6,4 %	25,9 %
Office (yield 6%)	NPV, €	168 500	209 200	96 200	157 200	166 100	183 430	287 200	235 200	-66 370	719 920
	IRR, %	13,1%	14,3 %	10,4%	12,7%	13,0%	13,2 %	18,9 %	14,8 %	2,4 %	32,2 %
Industry (yield 6.6%)	NPV, €	322 400	387 300	207 500	285 800	303 100	322 620	444 300	381 100	-5 860	791 020
	IRR, %	14,8%	16,6 %	12,2%	14,0%	14,4%	14,5 %	18,6 %	15,3 %	6,4 %	25,9 %
Retail (yield 4.6%)	NPV, €	161 000	172 600	124 000	153 900	157 600	168 680	211 100	178 000	-560	396 360
	IRR, %	14,2%	20,5 %	16,2%	13,7%	13,9%	14,4 %	22,4 %	15,5 %	4,6 %	25,4 %

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