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SHORT COMMUNICATION

Impact of ground source heat pumps on house sales prices in Finland

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Abstract Buildings contribute to approximately 28% of global energy-related emissions. Heat pumps are a key technology for decarbonising the heating emissions of buildings. This study focuses on ground source heat pumps (GSHP), which are increasingly used in colder regions. Since, for an average home, the capital expenditure of GSHP can be an order of magnitude higher than that of traditional heating, it is important to understand whether GSHP has an impact on house transaction prices. A hedonic price model was constructed to estimate the sales prices of detached houses, where heating type is the main variable of interest. The hedonic analysis revealed that for detached houses, GSHP had a statistically significant positive impact of 5.33% on house sales prices. Further analysis puts the premium in the context of housing prices in different locations in Finland. An average house in the Helsinki Metropolitan Area (HMA) could cover the required capital expenditure of a GSHP system with the sales price premium, whereas in other areas in Finland, 5 years of energy savings are required on top of the premium. Hence, in locations with lower housing prices, the house must be owned for a longer period to recoup the investment costs. This is important to understand when national energy aid policies are planned to accelerate investments in heat pumps.

Keywords Heat pump · House prices · Hedonic model · Energy prices · Housing market

Introduction

Buildings contribute to approximately 28% of global energy-related emissions (IEA, 2020a). In the USA, 20% of the nation's greenhouse gas emissions come from heating, cooling and powering households (Goldstein et al., 2020). In Germany, private households' energy consumption causes approximately 31% of Germany's total CO2 emissions (Destatis, 2021; Ritchie & Roser, 2020). In the UK, heating in the residential sector accounts for approximately 21% of CO2 emissions (National Statistics, 2020a, b). In Finland, building heating and electricity consumption caused 36% of all emissions, of which roughly two-thirds were from heating (SYKE, 2020).

Heat pumps are a key technology for decarbonising the heating sector. Currently, only 5% of global heat is delivered with heat pumps, but this may triple by 2030, and eventually, heat pumps could cover 90% of the global space and water heating needs for low emissions (IEA, 2020b). Ram et al. (2019) calculated that by 2050, over €7 trillion will be invested into individual heat pumps that heat or cool buildings. Currently, the European Commission (2022) and its

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member countries are planning major subsidy policies to encourage the adoption of heat pumps to displace natural gas for heating.

Heat pumps use electricity to draw energy from the surrounding air, water or ground (Staffell et al., 2012). They are highly energy efficient, as one unit of electricity can deliver many units of heating or cooling. Heat pumps can reduce emissions by over 90% compared to fossil fuel heaters if the electricity system powering them has low emissions (Vimpari, 2021). Although they have higher initial investment costs than traditional fossil-fuel-based heaters, heat pumps have lower operating costs due to their high efficiency in energy conversion. This high capital expenditure can hinder investment, even if high economic and environmental benefits are proven.

One important practical question for households is whether the upfront investment is reflected in house sales prices. The lifecycles of these investments can be up to 30 years, with payback periods ranging from 5 to 15 years, whereas homes are switched in shorter periods. A homeowner might wonder whether the annual energy savings are enough to cover the initial investment cost. If the heating system has a positive impact on sales prices, the homeowner does not have to rely only on energy savings to recoup upfront costs. This topic is related to a growing body of literature that has measured the effects of different energy efficiency measures' impacts on housing prices using statistical methods. Previous research suggests that decreased energy costs are among the key reasons for price premiums for energy-efficient homes (e.g. Dastrup et al., 2012; Shen et al., 2021).

This paper adds to the literature by examining the effect of GSHP, a particular type of heat pumps,[1] on house transaction prices in Finland. A dataset of 19,008 transactions in eight large cities in Finland between 1999 and 2018 was used. For detached houses, four heating types dominate in these cities: direct electricity, district heating, oil and ground source heat pump (GSHP), with an approximate market share of 52%, 21%, 20% and 7%, respectively. Traditionally, district heating has been very cost-effective, but tightening environmental regulations and the cost-effectiveness of heat pumps have increased the competition for district heating companies. Figure 1 presents the average historical heating prices for these four heating types for the period 1998–2019, as well as housing price development in the Helsinki Metropolitan Area (HMA) and the rest of Finland (Statistics Finland, 2021a, b). For GSHP, an average coefficient of performance (COP) of three was used, i.e. one unit of electricity is required to produce three units of heating (Vimpari, 2021). Oil heaters are assumed to have an average efficiency of 80%, as older boilers may have an efficiency between 60 and 70% and modern boilers up to 95%.

According to Fig. 1, the oil price increased by 340%, electricity by 131% and district heating by 142%, whereas house prices in the Helsinki Metropolitan Area increased by 119% and in the rest of Finland by 60%. District heating was cheaper than oil and electricity, but GSHP was the most cost-efficient heating type. However, GSHP requires a high upfront investment compared to the other heating methods. For example, in the UK, for a detached house requiring 10 kW of heating capacity, approximately €1 600 must be invested for a direct electricity-based system, €2300 for a gas- or oil-based system, and €13,700 for a GSHP-based system (Scottish Government, 2021).

Given that GSHP requires a high upfront investment and significantly reduces heating costs, the following main hypothesis was set: There is a sales price premium for GSHP-heated houses compared to other heating systems. This was tested by constructing a hedonic price model.

Previous literature

There is a vast body of literature that utilised hedonic regression to estimate how different variables explain housing prices. Within the field of this study, i.e. how energy-related characteristics impact housing prices, this methodology has been used within the context of energy efficiency ratings, rooftop photovoltaics, solar heaters and, most recently, air source heat pumps,

Deng et al. (2012) examined whether high energy efficiency, as measured with the Green Mark label, impacts the sales prices of apartments in Singapore. The label was found to command a 4 to 6% premium. Kahn and Kok (2014) investigated how green labels

[1] Commonly available heat pumps on the market are air source heat pumps, ground source heat pumps, water source heat pumps and exhaust air heat pumps.

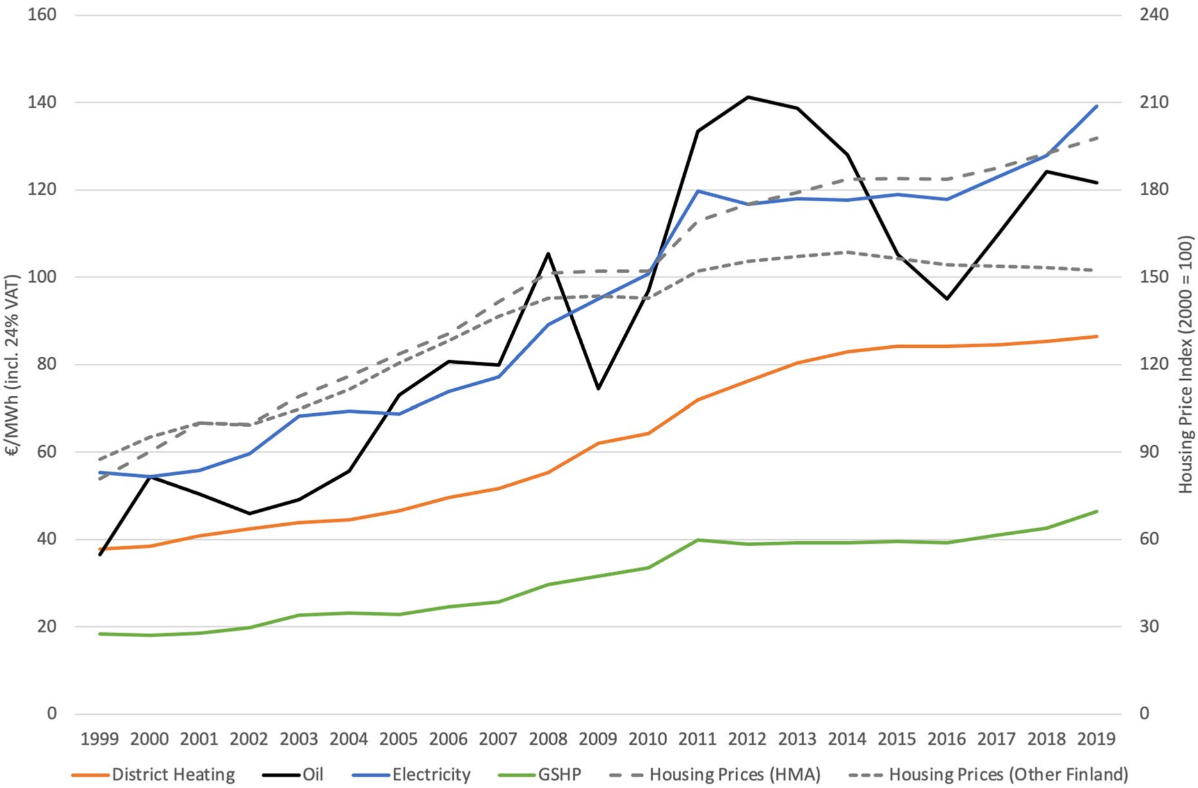

Fig. 1 Average historical heating prices and housing price development in Finland

such as Energy Star or LEED affect housing transaction prices. Their results suggested a 2 to 4% premium for energy-efficient homes, depending on location and building characteristics. Walls et al. (2017) examined house transactions in the USA. Spatial matching, propensity score matching and regression analysis found a 2% premium for Energy Star in Portland, Oregon, but no premium in Austin, Texas. Local certificates had larger premiums (4% and 9%, respectively), but these certificates often represented more qualities than energy-related improvements. Cerin et al. (2014) investigated the impact of the European Energy Performance Certificate (EPC) on housing prices in Sweden. They found that energy performance was not always rewarded in terms of price, depending on building age and price class. Fuerst et al. (2015) investigated whether a high-energy performance rating, as measured by the European energy performance rating (EPC), has an impact on housing prices in the UK. The findings suggest that an A/B rating commands a 5.0% premium and a C rating commands a 1.8% premium compared to the holdout rating of D. Similarly, Fuerst et al. (2016) examined whether high-energy performance ratings commanded a price premium for apartment transactions in Finland. A premium of 3.3% was found for the top three energy performance categories, which dropped to 1.5% when a set of neighbourhood characteristics was added to the model. In contrast, Yoshida and Sugiura (2015) analysed the transaction prices of green buildings in Tokyo. Their model suggests that a green building with renewable energy and recycled materials can result in a price discount due to higher lifecycle costs for the user.

Dastrup et al. (2012) examined the impact of rooftop photovoltaics (PV) on house transaction prices in California. They noted that the value was generated through energy savings and communicating that a home is green. A hedonic pricing model, as well as a repeat sales approach, found a 3.6% premium for homes with PVs. Similarly, Hoen et al. (2013) examined the impact of PV on house prices in California. A hedonic pricing model revealed a 3.6% price premium with a 1% significance. The price premium was found to be slightly higher than the system's upfront costs. Qiu et al. (2017) examined the impact of PV and solar heaters on residential home values in Arizona. They employed semi-parametric, non-parametric and hedonic regression to test whether a treatment group with solar systems has a price premium compared to a control group. The study found a 17% premium on sales prices for properties with installed PV; no premium was found for solar heaters. The percentage premium is rather large due to low housing and land prices in Arizona.

Shen et al. (2021) estimated how the installation of an air source heat pump impacted house prices in the USA. They used different methods and found a premium of between 4.3 and 7.1% for heat pump transactions. The results also showed that the premium was higher in regions with more environmentally conscious and middle-class people, as well as in regions with a milder climate.

Methodology

In hedonic price regression, a specific set of characteristics is used to form an equilibrium that defines the price of goods (Rosen, 1974). The common denominator in the previous literature is that first, a model containing a set of temporal, locational and building characteristics is used to form an equilibrium model, which is then enriched by a set of energy-related characteristics. Depending on the type of characteristics, these are set as continuous variables or categorical variables. Continuous variables, such as the dependent variable, price, are often defined in levels or in its natural logarithm transformation, which often may increase the explanatory power of the equation. Categorical variables are used to analyse the impact of a specific categorical (dummy) characteristic on price.

In this study, the following equation was used to estimate the price of a dwelling:

$$ln\left(P_{itm}\right) = \beta_0 + \sum_{j=1}^{J} \beta_j B_{ji} + \sum_{t=1}^{T} \beta_t D_{ti} + \sum_{l=1}^{L} \beta_l S_{li} + \epsilon_{itm} \quad (1)$$

where ln(P) is the logarithmic for the price of transaction i at year t and month m, β_0 is the intercept, B_j is a vector of j building variables, including heating type, D_t is a vector of t temporal variables, S_l is a vector of l locational variables and ϵ is the error term of the model.

This methodology was used to analyse whether having GSHP as a heating type increases transaction price of a detached house. This was studied with two different models, i.e. including one of the following variables in the building variables:

1) GSHP (true/false)
2) Heating type (categorical): direct electricity, district heating, GSHP or oil (hold-out: direct electricity)

Given that GSHP has the highest capital expenditure and is the cheapest form of heating, it should have a price premium against other heating types. The second model was used to test and estimate how different heating types perform individually against direct electricity, which is the most expensive heating type, as well as the most used for detached houses in Finland. Python Statsmodels (2022) was used to conduct the analysis, with ordinary least squares (OLS) as the method.

Data and descriptive statistics

The main dataset was a housing transaction database collected by the Central Federation of Finnish Real Estate Agencies (KVKL). It includes nearly two million transactions between 1999 and 2018 in Finland (KVKL, 2019), also including other building types, such as apartments and semi-detached houses, which are almost always run by housing cooperations in Finland. This data often does not include the heating type of the building. However, cities' building departments maintain a technical building database that includes this information. Eight large Finnish cities provided this data, which was merged with the transaction data by using the exact street addresses of buildings within both databases (Building data, 2020). To ensure exact matching, the street addresses in the housing transaction database were cleaned using the Levenshtein distance method, which was used for comparing (and correcting) addresses with the official street addresses used in the cities' building databases. Levenshtein (1966) is a method that calculates distances between words and can be used to clean data. Furthermore, Statistics Finland collects socioeconomic data in a

Table 1 Hedonic model variables

Group	Variable	
Building variables (B_j)	Squaremeter	Linear
	Building age	Linear
	Kilometres to CBD	Linear
	Condition	Categorical: poor, decent, good, excellent (hold-out: decent)
	Lot ownership	Categorical: true/false
Temporal variables (D_t)	Sale year	Categorical: 1999–2018
	Sale month	Categorical: 1–12
Locational variables (S_l)	Postal code	Categorical: 350 postal codes
	Household with children	Percentage
	Home ownership rate	Percentage
	Unemployment rate	Percentage
	Share of pensioners	Percentage
	Share of university education	Percentage
	Median income	Linear
	Average area per person	Linear

raster database (raster size 250 m × 250 m) in Finland (Statistics Finland, 2021c). This data were added to the database based on the nearest publication year (Table 1).

The remaining data were then cleaned for outliers (above and below three standard deviations) based on floor area (sqm) and unencumbered transaction price (€). Cleaning was done separately for each city, as there are major differences in housing prices between the cities. Additional cleaning was done by removing transactions with the 'unknown' condition. Finally, new developments were also removed, as this study wanted to focus on the transactions of existing buildings. The final dataset included 19,008 transactions of detached houses in eight cities (Helsinki, Espoo, Vantaa, Turku, Tampere, Lahti, Kuopio and Oulu), home to over two million inhabitants. Tables 2 and 3 provide descriptive statistics of the data used.

In the tables, the transaction prices were adjusted for 2020 using housing price index data available for the Helsinki Metropolitan Area and the rest of Finland (Statistics Finland, 2021b). However, for the hedonic regression model, this adjustment was not made because the temporal variables should capture the market conditions over time. Direct electricity dominates with a 52% share as a heating source, while district heating has a 20% share, oil 21% and GSHP 7%. Houses with GSHP are clearly higher valued than the average, and oil is the opposite. However, this difference fades away when looking at the prices at the city level, where GSHP prices are quite close to the mean prices of all the buildings. For other characteristics, some differences can be identified. Oil-heated houses are older and their condition is not as good as others. Figure 2 shows how different types of heating have evolved over time. Direct electricity and district heating have had a rather stable share of total house transactions, with shares of 50% and 20%, respectively. Oil's market share in the transaction seems to be decreasing, while the share of GSHP has increased over the last few years.

Hedonic regression results

The estimation results are presented in Table 4. In the first column, GSHP was tested against other heating types and in the second column separately against each heating type. The adjusted R^2 numbers of 0.851 indicate high performance for both models.

The building characteristic variables worked as expected. A larger floor area and better conditions increase the transaction price, whereas older buildings, longer distance from the CBD and leasehold decrease the transaction price. Our variable of interest, GSHP as a heating type, increases the transaction

Table 2 Summary statistics

	Direct electricity		District heating		GSHP		Oil		All	
	$N = 9928$		$N = 3885$		$N = 1241$		$N = 3954$		$N = 19{,}008$	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
House characteristics										
Price (€)*	294 461	159 434	303 999	163 218	363 040	200 212	248 401	142 437	291 307	162 208
Price (€/sqm)*	2 316	1 027	2 345	1 001	2 549	1 144	1 954	927	2 262	1 023
Size (sqm)	127	37	130	35	143	43	129	39	129	38
Construction year	1 981	22	1 986	17	1 979	25	1 966	17	1 979	21
Distance to CBD (km)	12,4	7,5	9,1	5,1	10,1	6,2	9,1	7,1	0,7	7,1
Condition distribution										
Excellent	0,00		0,01		0,02		0,00		0,01	
Good	0,72		0,77		0,63		0,54		0,68	
Decent	0,24		0,20		0,29		0,41		0,27	
Poor	0,03		0,02		0,06		0,06		0,04	
Leasehold	0,23		0,50		0,20		0,24		0,29	
Neighbourhood characteristics										
Median income per capita (€)	40 509		44 335		43 734		36 647		40 698	
Mean size per capita (sqm)	33		37		35		35		35	
Homeownership rate	0,68		0,78		0,70		0,71		0,71	
University degree	0,48		0,40		0,50		0,40		0,45	
Share of households with children	0,29		0,37		0,31		0,26		0,30	
Unemployment rate	0,03		0,04		0,03		0,04		0,03	
Share of pensioners	0,13		0,15		0,15		0,19		0,15	

*Prices inflated to 2020 with house price indices

Table 3 City-level price statistics (€/sqm)*

	Direct electricity			District heating			GSHP			Oil			All		
	Mean	*SD*	*N*	Mean	*SD*	*N*	Mean	*SD*	*N*	Mean	*SD*	*N*	Mean	*SD*	*N*
Espoo	3 473	813	1 742	3 604	807	568	3 867	970	229	3 319	831	221	3 520	836	2 760
Helsinki	3 455	900	798	3 711	1 030	382	3 409	1 124	187	3 377	1 002	470	3 484	985	1 837
Kuopio	1 468	450	634	1 832	318	722	1 692	451	36	1 381	436	263	1 618	440	1 655
Lahti	1 551	384	1 142	1 667	353	653	1 595	364	82	1 429	411	631	1 552	392	2 508
Oulu	1 452	373	2 186	1 608	351	824	1 519	417	133	1 194	361	490	1 455	388	3 633
Tampere	2 132	485	1 320	2 293	453	295	2 051	478	255	1 937	460	892	2 079	486	2 762
Turku	1 854	460	761	1 894	528	18	1 832	467	210	1 650	473	807	1 760	478	1 796
Vantaa	3 039	645	1 345	2 832	573	423	3 112	650	109	2 764	693	180	2 976	644	2 057

*Prices inflated to 2020 with house price indices

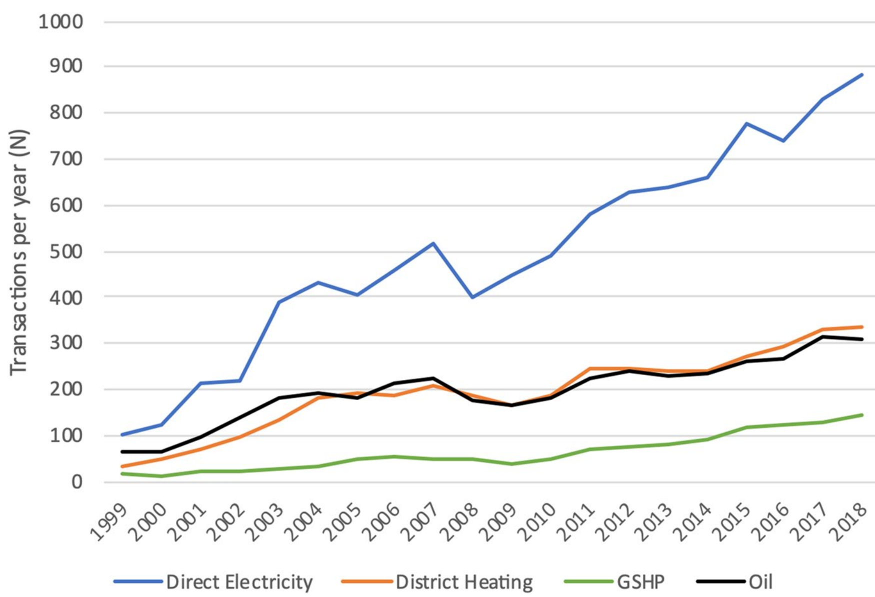

Fig. 2 Development of different heating systems

price of detached houses by 5.33%[2] (4.08 to 6.61%, with a 95% confidence interval) compared to other heating types. This finding is statistically significant at the 1% level. Thus, the main hypothesis was supported. This was further tested in the second column by inspecting each heating system individually against direct electricity. Again, GSHP commands a price premium of 4.85% ($p<0.01$), while district heating commands a lower price premium of 1.27% ($p<0.05$). Oil decreases the transaction price by 2.31% ($p<0.01$). These secondary model's findings were somewhat aligned with the heating costs presented in Fig. 1: GSHP is clearly less expensive than direct electricity, and district heating is also less expensive. On the other hand, oil is approximately on the same level as direct electricity, but its price has high volatility, requires effort from the owner to refill the oil boilers and produces local pollutants. These could be the reasons behind the negative price premium.

Table 5 provides robustness testing by first stepwise increasing the characteristics and then analysing how removing both age and/or condition changed the models. It is known that both can have a major effect

[2] The results exponentiated for interpretation.

Table 4 Hedonic OLS regression estimates of log sales prices

	GSHP^A		Heating type^B	
	Coefficient	*SE*	Coefficient	*SE*
Intercept	12.6308***	0.1405	12.6097***	0.1404
C(GSHP)[T.True]	0.0519***	0.0060		
C(heating_type)[T.district_heating]			0.0126***	0.0046
C(heating_type)[T.GSHP]			0.0474***	0.0062
C(heating_type)[T.oil]			−0.0228***	0.0041
Sqm	0.0039***	0.0000	0.0039***	0.0000
Age	−0.0051***	0.0001	−0.0049***	0.0001
Distance to CBD	−0.0161***	0.0015	−0.0160***	0.0015
C(condition)[T.excellent]	0.3189***	0.0200	0.3170***	0.0200
C(condition)[T.good]	0.1800***	0.0037	0.1791***	0.0037
C(condition)[T.poor]	−0.2987***	0.0080	−0.2995***	0.0080
C(lot_ownership)[T.rented]	−0.0561***	0.0040	−0.0593***	0.0041
Sale year and month fixed effects	Yes			
Postcode fixed effects	Yes			
Neighbourhood characteristics	Yes			
N	19,008			
Adj. R2	0.851		0.851	

Statistically significant at ***1% level, **5% level, *10% level. [A]GSHP true/false, i.e. other heating types as one category. [B]Every heating type as own category, direct electricity omitted. The following categorical variables are omitted: condition = decent, lot_ownership = own

on heating costs, as older buildings that are in a bad condition have lower energy efficiency.

When a location is controlled, the GSHP premium drops dramatically. This is expected because in the dataset, GSHP houses had a larger market share in cities with higher prices (see Tables 2 and 3). Adding the lower-level, time-varying neighbourhood characteristics did not have a significant effect on either the performance or the estimates. When building characteristics were added, the performance increased by approximately 0.22 in both regression models, but the price premiums also decreased. This change was then further analysed by excluding first age, then condition and then both from the final model. The performance remained high, but interestingly, these exclusions decreased the price premium. This suggests that GSHP houses did not have some unseen conditional effect that accounted for the estimated GSHP price premium.

Further analysis was conducted by estimating how the premiums had developed over time and in different cities. Two regression models are created with interaction variables, see Table 6.

There positive premiums have been quite consistent since 2010, when the heating costs also started to increase more rapidly than housing prices, as presented in Fig. 1. However, the positive housing price developments were fuelled by higher loans and very low interest rates. Since heating costs are paid by available income rather than the debt that is used for buying the house itself, the increasing trend in premiums could be linked to the ratio between available income and energy costs. Figure 3 presents the indexed development of electricity prices and district heating (oil is excluded given the high volatility), as well as wages and salaries in Finland (Statistics Finland, 2021b, d). Up until the financial crisis in 2007–2009, heating costs and wages followed each other. However, since the financial crisis, there has been a clear and growing gap between these indexes. Regarding the municipality interaction variable, 6 municipalities have a statistically significant positive price premium with quite a bit of volatility between the size of the premium.

Economic return of GSHP in detached houses

The total economic and environmental performance of GSHP was estimated for an average detached house in Finland. At the end of 2020, the average selling price of an old, detached house in HMA was 3 369 €/sqm and in the rest of Finland, it was 1 497 €/sqm (Statistics Finland, 2021b). Based on

Table 5 Sensitivity analysis of regression estimates

GSHP[A]							
	1	2	3	4	4a	4b	4c
C(GSHP)[T.True]	0.2175***	0.0976***	0.0898***	0.0519***	0.0555***	0.0363***	0.0374***
	(0.0140)	(0.0096)	(0.0094)	(0.0060)	(0.0064)	(0.0067)	(0.0076)
Sale year and month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Postcode fixed effects		Yes	Yes	Yes	Yes	Yes	Yes
Neighbourhood characteristics			Yes	Yes	Yes	Yes	Yes
Building characteristics				Yes	Yes	Yes	Yes
Exclude age					Yes	Yes	Yes
Exclude condition						Yes	Yes
Exclude age and condition							Yes
N				19,008			
Adj. R2	0.1309	0.6179	0.6332	0.8507	0.8282	0.8119	0.7609
Heating type[B]							
	1	2	3	4	4a	4b	4c
C(heating_type)[T.district_heating]	0.0661***	0.0394***	0.0353***	0.0126***	0.0262***	0.0121**	0.0338***
	(0.0089)	(0.0071)	(0.0070)	(0.0046)	(0.0049)	(0.0051)	(0.0057)
C(heating_type)[T.GSHP]	0.2023***	0.0810***	0.0762***	0.0474***	0.0436***	0.0297***	0.0184**
	(0.0142)	(0.0097)	(0.0096)	(0.0062)	(0.0066)	(0.0069)	(0.0077)
C(heating_type)[T.oil]	−0.1354***	−0.0832***	−0.0710***	−0.0228***	−0.0564***	−0.0305***	−0.0874***
	(0.0089)	(0.0064)	(0.0063)	(0.0041)	(0.0043)	(0.0046)	(0.0051)
Sale year and month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Postcode fixed effects		Yes	Yes	Yes	Yes	Yes	Yes
Neighbourhood characteristics			Yes	Yes	Yes	Yes	Yes
Building characteristics				Yes	Yes	Yes	Yes
Exclude age					Yes	Yes	Yes
Exclude condition						Yes	Yes
Exclude age and condition							Yes
N				19,008			
Adj. R2	0.1480	0.6228	0.6368	0.8510	0.8303	0.8124	0.7658

Statistically significant at ***1% level, **5% level, *10% level, standard errors in parenthesis. [A]GSHP true/false, i.e. other heating types as one category. [B]Every heating type as own category, direct electricity omitted

building data statistics, the average house in HMA was constructed in 1984 and has a living area of 181 sqm (Statistics Finland, 2021c). The corresponding house in the rest of Finland was constructed in 1972 and has an area of 143 sqm. Using the above square metre prices, the respective values of these houses were estimated at €609 789 and €214 071. Thus, the premium of 5.33% would indicate a price premium of €32 484 in HMA and €11 404 in the rest of Finland.

Using the methodology presented by Vimpari (2021), the actual energy consumption of these buildings was estimated based on the floor area, construction year and location. For the rest of Finland, the city of Kuopio (located in the centre of Finland) was used as a reference point, as the climate is colder and

Table 6 Interaction variable estimations for GSHP houses

Interaction variable for sale year:GSHP true			Interaction variable for municipality:GSHP true		
	Coefficient	*SE*		Coefficient	*SE*
Intercept	12.6364***	0.1405	Intercept	12.5322***	0.1624
C(GSHP)[T.True]:C(sale_year)[1999]	−0.0186	0.0514	C(GSHP)[T.True]:C(municipality)[Espoo]	0.0932***	0.0142
C(GSHP)[T.True]:C(sale_year)[2000]	−0.0317	0.0570	C(GSHP)[T.True]:C(municipality)[Helsinki]	0.0374**	0.0155
C(GSHP)[T.True]:C(sale_year)[2001]	0.0574	0.0434	C(GSHP)[T.True]:C(municipality)[Kuopio]	0.0162	0.0340
C(GSHP)[T.True]:C(sale_year)[2002]	−0.0147	0.0415	C(GSHP)[T.True]:C(municipality)[Lahti]	0.0641***	0.0223
C(GSHP)[T.True]:C(sale_year)[2003]	−0.0157	0.0406	C(GSHP)[T.True]:C(municipality)[Oulu]	0.0783***	0.0176
C(GSHP)[T.True]:C(sale_year)[2004]	0.0654*	0.0357	C(GSHP)[T.True]:C(municipality)[Tampere]	0.0319**	0.0133
C(GSHP)[T.True]:C(sale_year)[2005]	0.0836***	0.0288	C(GSHP)[T.True]:C(municipality)[Turku]	0.0430***	0.0148
C(GSHP)[T.True]:C(sale_year)[2006]	0.0226	0.0283	C(GSHP)[T.True]:C(municipality)[Vantaa]	0.0235	0.0198
C(GSHP)[T.True]:C(sale_year)[2007]	0.0037	0.0296	Sale year and month fixed effects	Yes	
C(GSHP)[T.True]:C(sale_year)[2008]	0.0555*	0.0298	Postcode fixed effects	Yes	
C(GSHP)[T.True]:C(sale_year)[2009]	0.0311	0.0338	Neighbourhood characteristics	Yes	
C(GSHP)[T.True]:C(sale_year)[2010]	0.0853***	0.0287	Building characteristics	Yes	
C(GSHP)[T.True]:C(sale_year)[2011]	0.0990***	0.0250	*N*	19,008	
C(GSHP)[T.True]:C(sale_year)[2012]	0.0499**	0.0235	Adj. R2	0.851	
C(GSHP)[T.True]:C(sale_year)[2013]	0.0190	0.0227			
C(GSHP)[T.True]:C(sale_year)[2014]	0.0417*	0.0219			
C(GSHP)[T.True]:C(sale_year)[2015]	0.0315*	0.0191			
C(GSHP)[T.True]:C(sale_year)[2016]	0.0624***	0.0189			
C(GSHP)[T.True]:C(sale_year)[2017]	0.0771***	0.0182			
C(GSHP)[T.True]:C(sale_year)[2018]	0.0846***	0.0175			
Sale year and month fixed effects	Yes				
Postcode fixed effects	Yes				
Neighbourhood characteristics	Yes				
Building characteristics	Yes				
N	19,008				
Adj. R2	0.851				

heating requirements are higher compared to HMA, which is in the south. Oil was used as the current heating system. Table 7 presents details regarding current heating costs and emissions, as well as the numbers of whether GSHP is the heating system. Additionally, some details of GSHP are provided, together with key financial parameters, such as the payback period and the internal rate of return (IRR). The heating costs and emissions are higher for the building in the rest of Finland, even though they are 21% smaller. The locations in a colder region, as well as an older construction year with worse insulation, are the reasons for this. However, savings from GSHP are larger for the building in HMA, a key reason being that the coefficient of performance for GSHP is higher in southern Finland and electricity (distribution) prices are lower. Heating costs and emissions in HMA are reduced by approximately 71% and 94%, respectively, compared to the buildings in the rest of Finland, with 58% and 93%, respectively. In both cases, the payback period for the investment was approximately 10 years without considering the potential sales price premium. The lifecycle investment performance (IRR) was slightly better for the building in HMA.

Finally, the number of years of energy savings on top of the price premium required to cover the capital expenditure of GSHP was calculated. In HMA, 0 years of energy savings plus the price premium cover the investment costs, whereas 5 years are needed in the rest of Finland. This highlights the relationship between the investment costs of a GSHP system and housing prices. The relative investment

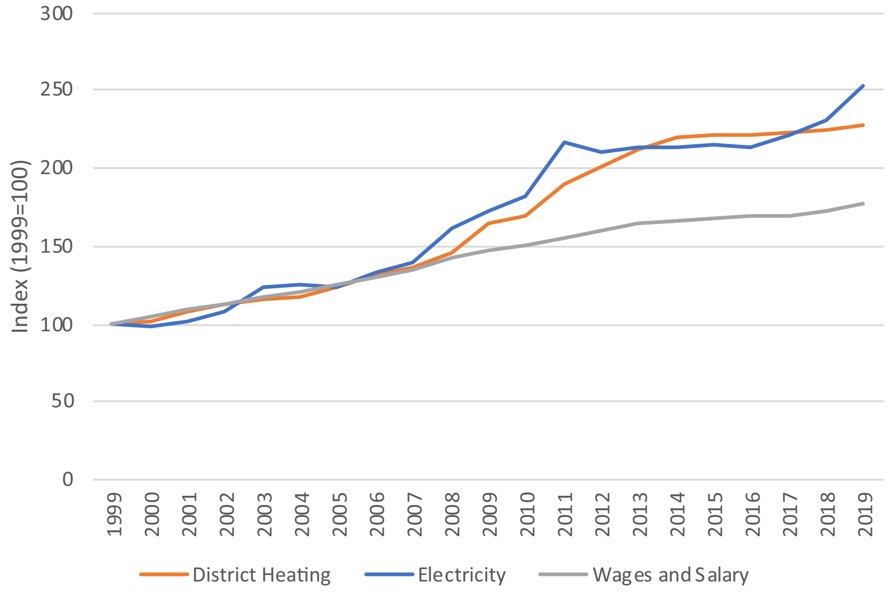

Fig. 3 Development of heating costs and wages in Finland

Table 7 Overall economic and environmental analysis of GSHP in an average detached house

	HMA	Other Finland
Average detached house		
Price (€/sqm)	3 369	1 497
Average construction year	1 984	1 972
Average floor area (sqm)	181	143
Price, average detached house (€)	609 789	214 071
Energy consumption (MWh p.a.)	35	38
Heating costs, oil (€ p.a.)	3 500	3 800
Heating emissions, oil (kg CO2-ekv p.a.)	10 300	11 200
GSHP investment		
Heat pump investment Cost (€)	26 000	22 000
Heat peak power demand (kW)	17	14
GSHP peak power demand (kW)	13	11
Borehole production (kWh/metre)	100	90
Heating costs, GSHP (€ p.a.)	1000	1600
Heating emissions, GSHP (kg CO2-ekv p.a.)	600	800
Savings on heating costs (€ p.a.)	2500	2200
Reduced emissions (kg CO2-ekv p.a.)	9 700	10 400
Payback period (a)	10,4	10,0
IRR	10,9%	9,9%
GSHP premium		
Mean (5.33%)	32 484	11 404
Lower bound (4.08%)	24 886	8 736
Upper bound (6.61%)	40 302	14 148
Years to cover investment cost minus price premium		
Mean (5.33%)	0,0	4,8
Lower bound (4.08%)	0,5	6,0
Upper bound (6.61%)	0,0	3,6

cost is approximately the same in both locations, but the sale prices have larger differences, as the average price for an old detached house is 125% higher in HMA than in the rest of Finland.

Discussion

Previous literature utilising hedonic regression analysis has found price premiums for energy efficiency, rooftop PV and air source heat pumps in several markets. Heat pumps are a key technology for decarbonising the heating and cooling emissions of buildings, as pointed out in several research papers and industry reports. This study focused on GSHP, which is a key heating technology in colder regions. GSHP is more expensive than air source heat pumps; hence, analysing their impact on sales prices is an important addition to existing literature.

A hedonic model was built to examine whether a GSHP system commands a price premium over traditional heating types that have much lower capital expenditures than GSHP. The model was applied to a dataset of 19,008 house transactions in eight large Finnish cities.

For detached houses, a statistically significant 5.33% sales premium was found. Transforming this premium into monetary values, using the average sales price of detached houses in HMA and the rest of Finland, indicated respective premiums of €32,484 and €11,404. Based on housing market dynamics, this is an important aspect to highlight, as the capital expenditures of a GSHP system are similar across housing markets, but the value of houses is not. This would indicate that the investment cost of a GSHP system is captured in the sales price more easily in locations with higher sales prices. The energy savings analysis shed light on this, as the sales price premium could capture the investment cost of a GSHP system, whereas in the rest of Finland, 5 years of energy savings are required. Hence, in locations with lower prices, the owner would have to keep the house for a longer period to recoup the investment in the GSHP. This is important to understand when national energy aid policies are planned.

Previous literature, such as Kuminoff et al. (2010), has stated that there are challenges when interpreting the results of linear hedonic regressions. As the data do not identify the timing of the installed heating system, a model comparing the pre- and post-installation of GSHP cannot be constructed. Hence, there might be unobservable characteristics, especially those related to individual housing attributes that were not identified by the used model and may influence the found premium. Controlling for building characteristics, age and condition is done to mitigate this potential impact, as well as analysing the found premium through time.

According to the European Commission (2020), there are 40 million detached houses in Europe. Most of these homes are heated with either burning fossil fuels or using low-efficiency direct electricity. Thus, massive upfront investments are required from building owners in high-efficiency heat pumps. For homeowners to invest, it is important to understand the economics of these investments, both in terms of what they do to annual heating costs, as well as how they impact sales prices.

Similar research should be conducted in different markets to understand whether a premium can be found when the dominant heating type is based on gas boilers (as in many European or North American markets) and/or when electricity prices are higher. More findings from other datasets would strengthen the findings of this paper, as there might be some unobserved attributes that explain the price effect of the heating system.

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Data Availability The data is not available freely.

Declarations

Conflict of interest The author declares no competing interests.

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