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ORIGINAL RESEARCH

Heat pumps in subarctic areas: current status and benefits of use in Iceland

Reynir Smari Atlason[1] · **Gudmundur Valur Oddsson**[2] · **Runar Unnthorsson**[2]

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Abstract Heat pumps use the temperature difference between inside and outside areas to modify a refrigerant, either for heating or cooling. Doing so can lower the need for external heating energy for a household to some extent. The eventual impact depends on various factors, such as the external source for heating or cooling and the temperature difference. The use of heat pumps, and eventual benefits has not been studied in the context of subarctic areas, such as in Iceland. In Iceland, only remote areas do not have access to district heating from geothermal energy where households may, therefore, benefit from using heat pumps. It is the intent of this study to explore the observed benefits of using heat pumps in Iceland, both financially and energetically. This study further elaborates on incentives provided by the Icelandic government. Real data were gathered from the Icelandic energy authority for the analysis. It was found for the study database of 128 households that the annual electricity use was reduced from 37.8 to 26.7 kWh (an average 29.3% reduction) after installation of heat pumps. Large pumps (9.0–14.4 kW) and small pumps (5.0–9.0 kW) saved an average of 31.4 and 26.0% (95% confidence intervals), respectively. On average, households used approximately 26 MWh after installing a heat pump. When installing a small pump (5–9 kW), the mean annual saving (and 95% confidence intervals) was 10.6 (±2.7) MWh (approximately 26%). However, when installing a larger pump, mean annual savings were 11.3 (±1.6) MWh (Approximately 31%).

Keywords Energy efficiency · Heat transfer · Sustainability

Introduction

The easily reachable oil and gas, often required for societies in cold areas to operate, are expected to be depleted in foreseeable future [1]. The effects of the depleting fossil fuels on societies can, however, be mitigated using alternative, complementing technologies such as heat exchangers. Residential heat exchangers use the heat difference between ambient and ground (or air) temperatures. These systems are generally referred to as heat pumps. It has been stated that ground source heat pumps systems (GSHPs) are promising technologies in the heating and cooling sector. They have subsequently received recent academic attention [2]. Due to the technological nature of heat pumps, research attention has been evident for the utilization in areas where energy access is not abundant, as the use of GSHPs, but also air source heat pumps (ASHPs), has the potential to relieve stress on surrounding energy systems [3]. In an estimate of 1.25 million, such pumps were in use in Europe alone in 2011 [4].

Rigorous research has been done by the Cold Climate Housing Research Center (CCHRC) in Alaska, which this paper complements by including data from Iceland.

Novelty of this research: With the use of a fairly complete data set, this paper demonstrates the benefits of using heat pumps in subarctic areas. The data include most if not all users of heat pumps in Iceland that lack access to geothermal energy for domestic heating. The location and accuracy of data used in the analysis provides a novel insight into the benefits of using heat pumps in subarctic areas.

✉ Reynir Smari Atlason
resa@iti.sdu.dk

[1] Department of Technology and Innovation, University of Southern Denmark, Odense, Denmark

[2] Faculty of Industrial Engineering, Mechanical Engineering and Computer Science, University of Iceland, Reykjavík, Iceland

Heat pumps

At depths only a little greater than 1–2 m, the earth's temperatures are relatively constant. The sub-ground temperatures are generally warmer in summer but cooler in winter, typically allowing for GHP COP of 4.0, in some cases even better [5]. COP, or the coefficient of performance, is the ratio of heat or cold provided to the amount of electrical energy consumed. The COP essentially describes the efficiency of a heat pump. The heat output from the condenser ($|Q|$) is compared to the power supplied to the compressor (W). The ratio can be described as follows: $\mathrm{COP} = \frac{|Q|}{W}$.

For example, if a heat pump used for cooling is defined with a COP = 2, 2 kW of cooling is provided ($|Q|$) for each kW of power consumed by the compressor (W) [6]. The value of such calculations has been expanded using the seasonal performance factor, or SPF. The SPF is represented by ϕ. The SPF is represented by: $\phi = \frac{Q}{W}$, where Q is the thermal energy output of the heat pump over a year and W is the energy used by the pump over the same period. The difference between COP and SPF is that the COP gives a ratio based on conditions at a given time while the SPF over a time period, including the consumption of auxiliary devices. However, the COP is different for heating and cooling, as the application of interest is different. For heating, the COP can be represented as follows: $\mathrm{COP}_{\mathrm{heating}} = \frac{|Q_{\mathrm{H}}|+W}{W}$, where Q_{H} is heat delivered to the outside (cold) reservoir. For cooling, the COP can be represented as: $\mathrm{COP}_{\mathrm{heating}} = \frac{|Q_{\mathrm{C}}|}{W}$, where Q_{C} is the thermal energy removed from the hot reservoir.

A simplified diagram showing the principle behind closed loop geothermal heat pumps is shown in Fig. 1.

Heat pumps use a working material that operates either in gas or liquid form. Refrigerants such as R22: $\mathrm{CHClF_2}$ has traditionally been used as a working medium in geothermal heat pumps, but because of their heavy environmental impact, they are being used to a lesser extent. Hydrofluorocarbons (HFCs) are instead gaining popularity and are replacing R22. These are R-134a, R-143a, R-152a, R-404A, R-407 A,B,C, R-410A, and R-507 to name a few. The process or transformation of the material can be divided into four stages [7]. (1) The working material gathers heat from the exterior, making the material boil and turn to gas. (2) The gas is compressed, increasing the pressure and temperature until high enough to use for domestic heating. (3) As the gas travels through the condenser, the working material releases heat and the gas becomes liquid. (4) The material is lead to an expansion valve, directing it back to stage one where it gathers heat from the environment. The pump itself is generally located indoors or in a space relatively close to an electric outlet.

Different types of heat pumps are available, depending on the method used to retrieve energy and to deliver it. In Iceland, a majority of heat pumps work under air-to-air conditions. In fact, approximately 70% of heat pumps in Iceland (that are subsidized by the government) can be estimated to work under air-to-air conditions.

Heat pumps differ quite substantially. They all, however, work using the same principles by transferring heat from one place to another, either from the exterior to the interior or vice versa.

Some of the recent academic interest has been on national benefits of heat pumps, and on industrial pumps in particular [3, 8]. It has further been demonstrated that within Europe, Sweden and Austria have more installed units in absolute numbers than any other nation [9].

COP in cold areas

The CCHRC and others have shown that air source heat pumps operating under similar temperatures as in Iceland are estimated to have a coefficient of performance (COP) between 5 (temperature Δ is 20 °C) and 2 (temperature Δ is 60 °C) [10]. The variation between heat pump models from different producers seems to be little in this context. When looking into SPF of air source pumps in central England, operating at only slightly higher temperatures than in Iceland, the estimated monthly COP ranges between 3.08 and 3.45, where the lowest values are experienced during the coldest months. Data from the CCHRC in Alaska have furthermore demonstrated the COP of ASHPs to be between 1 and 6 when studying three different heat pumps in the temperature range from −23 to 15 °C [11].

- It is the intent of this paper to investigate the benefits (in energy and economic terms) heat pumps provide in Iceland and how the Icelandic government has promoted the use of such systems. We use a multi-year data from 128 pumps in rural Iceland areas collected by the Icelandic National Energy Authority. The pumps sizes vary from 5 to 14.4 kW. In this paper, we analyze data collected by the NEA, in line with a descriptive analysis of the incentives provided by the Icelandic government. Our results provide policymakers in relevant regions insights into observed benefits of heat pump use in Iceland, which may also be applicable elsewhere.

Energy use in Iceland

At present, most of the energy used within Iceland is either from geothermal or hydro power plants [12]. According to

Fig. 1 Simplified version of a closed loop geothermal heat pump system

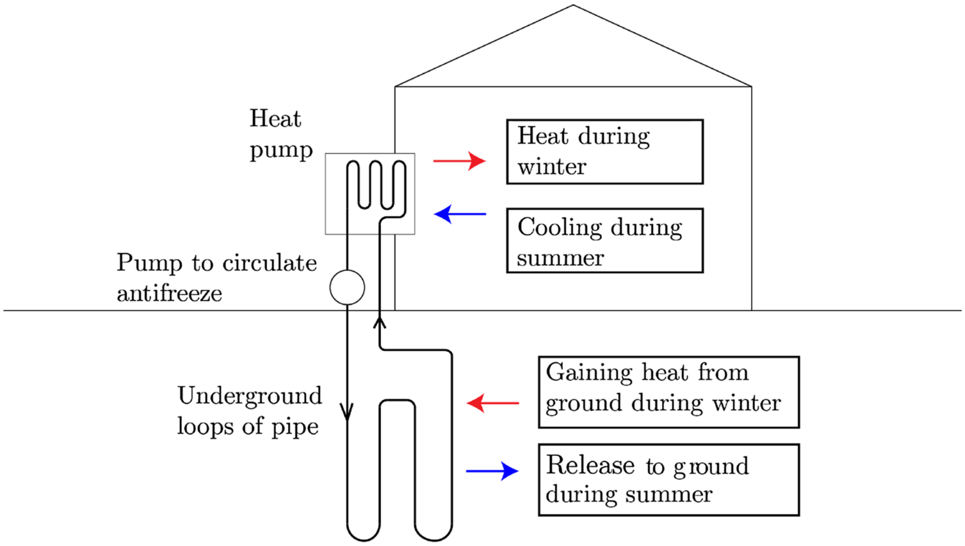
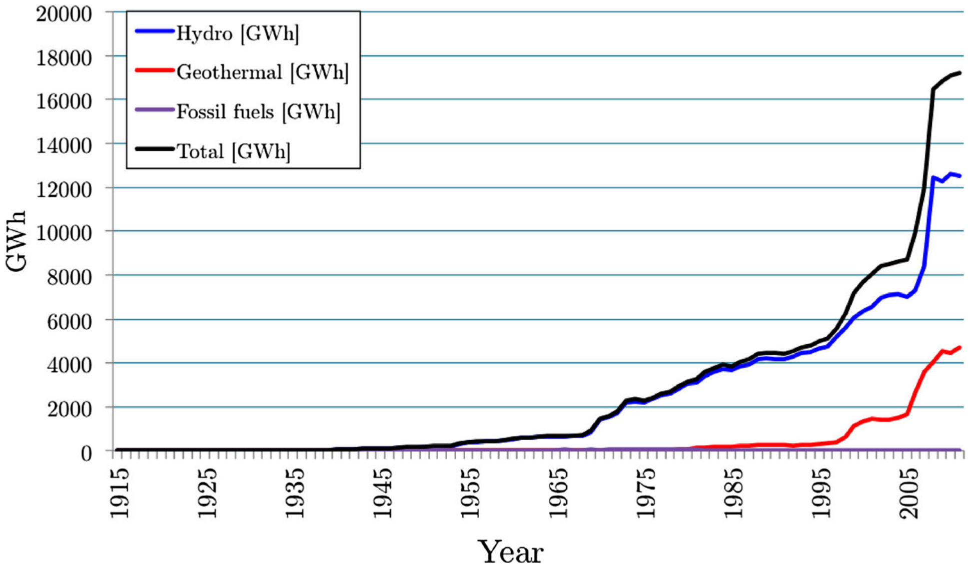


Fig. 2 Direct energy use in Iceland from 1915 to 2011 [12]



Orkustofnun (The Icelandic Energy Authority), electricity production from hydro began in 1920, with less than 1 GWh hour produced. Subsequently, electricity production from geothermal began in 1969 with 2 GWh produced [12]. The amount of power produced in GWh has increased rapidly and in 2010, 17 TWh were produced in total from hydro and geothermal. This can further be seen in Fig. 2. Interestingly, power usage dropped significantly for the first time in the history of Iceland's power production in 2008. The drop in energy consumption is likely related to the financial crisis, in which Iceland was hit very hard.

Environmental conditions in Iceland

To get a more holistic view of the environment the heat pumps operate in, real data were provided by the Icelandic Meteorologic Institute (IMO) on ground and air temperatures. The IMO collects data hourly from five locations distributed around Iceland. Daily means were provided by the IMO for an 11 year interval, from the beginning of 2006 throughout January 2017. The data were collected from the following locations: (1) Reykjavik, (2) Hveravellir, (3) Modruvellir, (4) Hallormsstadur, and (5) Thykkvibaer. A gradient of temperatures is collected at these locations based on depth of measurement. For all locations except Hveravellir, measurements are collected at 5, 10, 20, and 50 cm depths. At Hveravellir, the gradient is 5, 20, 50, and 100 cm. A plot of ground temperatures at Hveravellir can be seen in Fig. 3. One should pay special attention to temperatures at 100 cm depths as this depth is closest to depths where horizontal geothermal heat pumps operate.

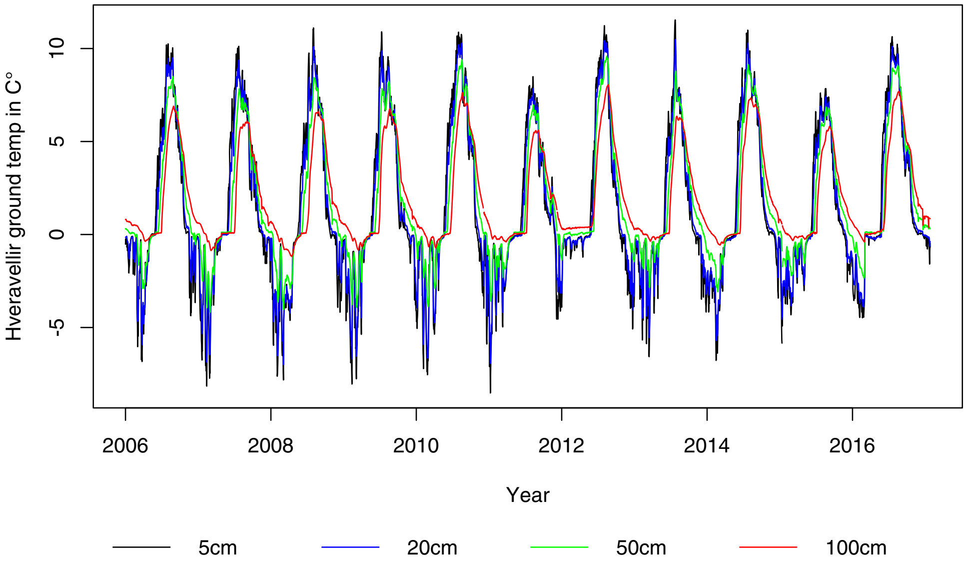
To better understand the environment pumps in Iceland operate under, mean temperatures at 50 cm depth were computed using the data sets. This means that an average year was computed for each location. For the computation, data points from 11 years of monitoring were used. These results can be seen in Fig. 4. Demonstrating the ground temperatures is of great importance to this paper, as it provides stakeholders a detailed view of the geological conditions that Icelandic pumps are operating under, and what the expected savings may be under such conditions. Furthermore, when covered with vegetation, Icelandic soil is generally dominated by Andisols. Desert areas in Iceland are dominated by Vitrisols and some wetland areas are dominated highly organic Histosols [13]. Andisols are classified based on their colloidal constituents ($\mathrm{AL_{ox}} + 1/2\mathrm{Fe_{ox}} > 2\%$) [14]. Thermal conductivity of soils relies on factors such as organic matter amount, nature of the minerals, water amount, bulk density, vegetation, and temperature. The data set used in this study did not include site-specific data on soil thermal conductivity [14].

In Iceland, geothermal energy has been used for various activities, both industrial and not. The access to geothermal energy in Iceland is of great benefit to the nation, but not all areas do have access to the resource. Several areas are not located favorably where access is limited to geothermal energy and district heating. Iceland is a relatively cool country, even though temperature differences are not extreme between summer and winter, the temperature average is not high. Figure 5 demonstrates average temperatures between the year 1990 and 2016. One can see that temperatures are not high enough to provide comfortable living conditions without external heating, even during the summer months where the highest averages only reach approximately 12 °C. Areas without district heating access, therefore, need to rely on hydro power electric generation, or electricity generation by other means for heating. Doing so can prove costly unless other solutions are provided, such as governmental subsidies or incentives. In that regard, the government has the potential to subsidize either the electricity price directly or technological solutions that mitigate the need for electricity.

Governmental subsidies

According to paragraph 6, law nr. 78/2002, that deals with subsidies of energy cost for heating in Iceland, the Icelandic government assists the public with heating costs where geothermal energy is not easily accessible. Depending on the location, the government pays from 3 cents (3.3 ISK) per kWh up to 5 cents (5.24 ISK) per kWh. Households eligible for such subsidies do not have access to district heating [16]. Approximately 9 million USD (one billion ISK) is used annually by the government to assist households with domestic heating. This amounts to approximately 350 GWh annually [17]. It is, therefore, in the Icelandic governments interests to provide a method for households to generate heat, which eventually reduces the costs of subsidies. The Icelandic Energy Authority (Orkustofnun) has also provided an online calculator, where potential governmental subsidies available for heat pump purchasing are shown. Specific circumstances are required to qualify for a governmental subsidy in Iceland. The main requirement is that residents do not have access to geothermal energy. The data set used in this study only includes data gathered by the NEA of households which have installed pumps and received subsidies. It is, therefore, known that the pumps used for the analysis in this study are all located in areas void of geothermal energy in

Fig. 3 Visualisation of ground temperatures at Hveravellir at different depths between 2006 and 2017



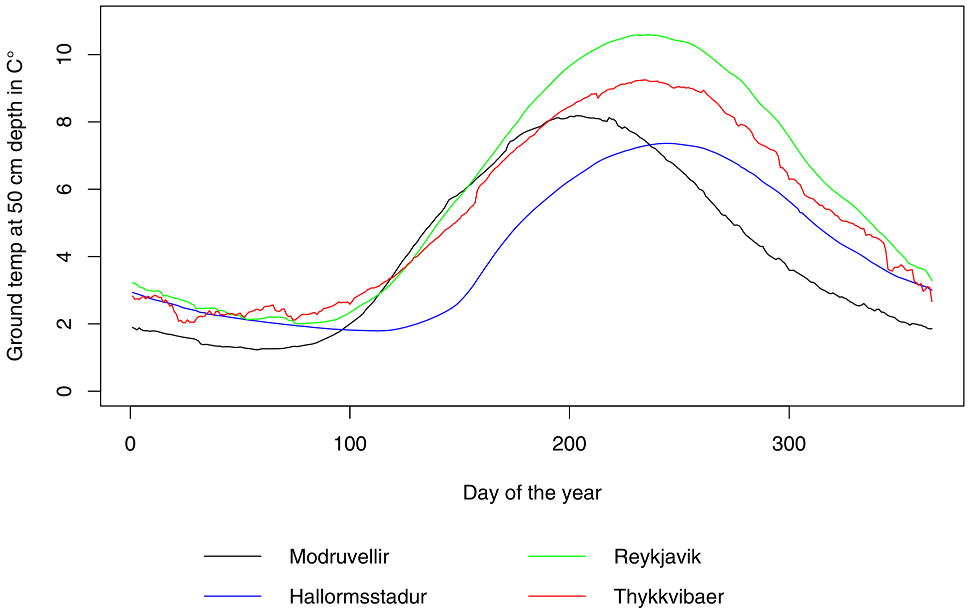


Fig. 4 Visualization of average ground temperatures at 50 cm depth at various locations in Iceland over a 11 year period

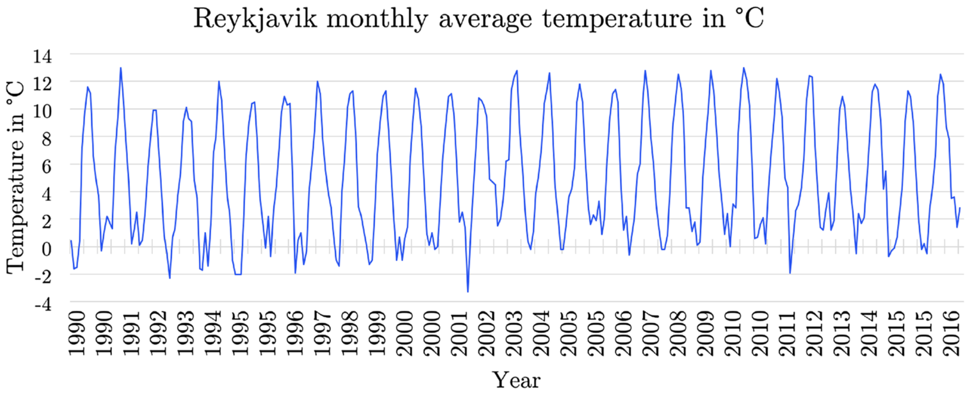


Fig. 5 Monthly average temperatures in Reykjavik between the year 1990 and 2016. Weather data retrieved from Reykjavik meteorological weather station, WMO-number 4030. Location is 64°07.648′, 21°54.166′, and 52 m above sea level [15]

quantities viable for practical use such as house heating, and electric heating has most likely been used for heating prior to the heat pump installation.

Methods

As heat pumps are subsidized by the government, a relatively good record is kept on the heat pumps subsidized. Data were collected and provided by the Icelandic energy authority. Each data entry contained (1) information about the size of the pump in question, (2) the average energy use for heating at the household for the last 5 years, and (3) the average energy use after installation of the pump. The average energy use after installations was based on a minimum of 1 year and maximum 5 years. The data set also included the difference in kWh and percentage. Some data entries included more than one pump at a household. Such entries were omitted as the contribution of each pump was not known.

Average savings and use (mean and a 95% confidence interval) was calculated for the following scenarios: (1) the energy consumption of all households, before installing and after installing a heat pump, (2) the energy use of households before and after installing a heat pump larger than 5 kW and smaller than 9 kW, and (3) the energy consumption of households before and after installing a heat pump larger than 9 kW and up to 14 kW.

After omitting data entries containing two or more pumps, entries where the size of the pump was not known or some of the averages were not included, 128 entries were left.

After calculating the expected mean savings from the heat pumps, available resources from the Icelandic Energy Authority were investigated. Subsidies provided by the Icelandic government were then calculated based on expected energy savings. It should be noted that the total energy consumption of households is analyzed, rather than efficiency of individual pumps who only contribute to lower energy consumption for heating and cooling.

Results

In this section, the results are shown in three subsections. The first deals with the whole data set, while the two following have split the data set into two categories: first, small heat pumps are analyzed, while the latter deals with larger pumps.

Overall results

When looking at the data set, one can see that households using between 20 and 50 MWh per year make up the majority of households installing a heat pump. Figure 6 depicts the distribution of households and the energy consumption per year before installing a heat pump. Of the 128 households included in the data set, 107 used between 20 and 50 MWh per year, or 83%.

On average, 37.8 kWh were used for heating prior to installation of a heat pump. This average was reduced to 26.7 kWh after a heat pump installation, resulting in a decrease of 11 kWh or 29.3%. When looking at a normal distribution of the energy use before installing a heat pump, one can see that within 95% confidence interval of the mean, the range is between 35.6 and 40.1 kWh, but after installation, the same interval is reduced to 24.3 and 29.1. This is further shown in Fig. 6. As was mentioned, the average saving was 11.1 kWh, when looking at a normal distribution of the savings from the heat pumps, one can see that within the 95% confidence interval, it ranges from 9.7 to 12.5 kWh savings over a year.

Small pumps

In this section, small pumps are analyzed. The pumps are from 5 up to 9 kW. Of the 128 pumps used, 47 fit within this constraint. It is the intent of this section to analyze the observed savings from the pumps and what can be expected.

By looking at Fig. 7, one can see that on average, the savings from installing a small heat pump are 10.6 kWh over a year, a reduction of 26%. The use before installing is estimated to be between 36.8 and 44.9 kWh when looking at the confidence interval. This is decreased to 25.3 and 35 kWh when looking at the use within the confidence interval after installation of the pumps. Figure 7 also demonstrates that within the 95% confidence interval, the mean savings are estimated to be between 8 and 13.3 kWh.

Large pumps

In this section, households that purchased larger pumps are analyzed. These pumps are from 9 up to 14.4 kW. A great majority of these pumps are 9.1 kW. 81 entries are used for this analysis. By looking at Fig. 8, one can see that before installing a heat pump, the expected value of energy use can be seen to be between 33.4 and 38.7 kWh per year. After installing the pumps, the users could expect the energy use to be between 22.3 and 27.1 kWh per year. The mean difference between those two plots is 11.4 kWh.

As can be seen by looking at Fig. 8, the mean value for energy savings if the user has installed a pump between 9 and 14.4 kW is a little less than 11.4 kWh over a year, or a reduction of 31.4%. Between the 95% confidence interval, the expected mean value is between −13.0 and −9.7 kWh per year. This means that there is a 95% probability that mean savings are between 9.7 and 13 kWh annually for the sample when installing a heat pump sized between 9 and 14.4 kW. Savings from installing pumps are further demonstrated in Table 1.

Potential subsidies

After analyzing the data set, it is possible to visualize how much is likely to be subsidized by the government. This can be done using available resources provided by the Icelandic Energy Authority [Orkustofnun (Orkusetur)] [17].

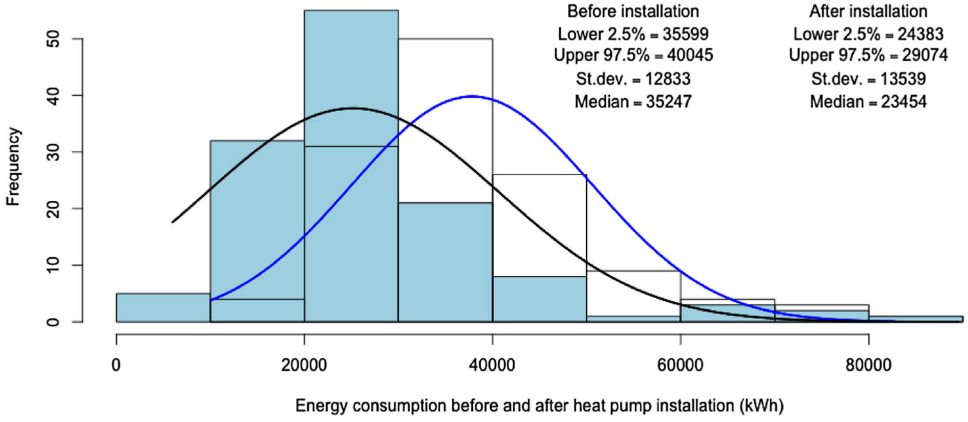


Fig. 6 Normal distributions for annual energy use before and after installation for the whole data set. Blue bars indicate consumption after installation; transparent bars indicate energy consumption before installation

Fig. 7 Normal distribution and a histogram for change in energy consumption after installing a small pump (from 5 to 9 kW)

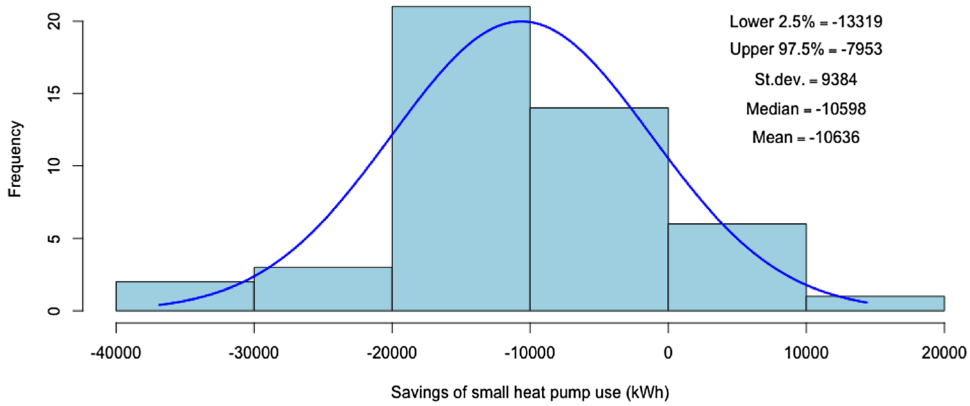


Fig. 8 Normal distribution and a histogram for energy savings after installing a large pump (from 9 to 14.4 kW)

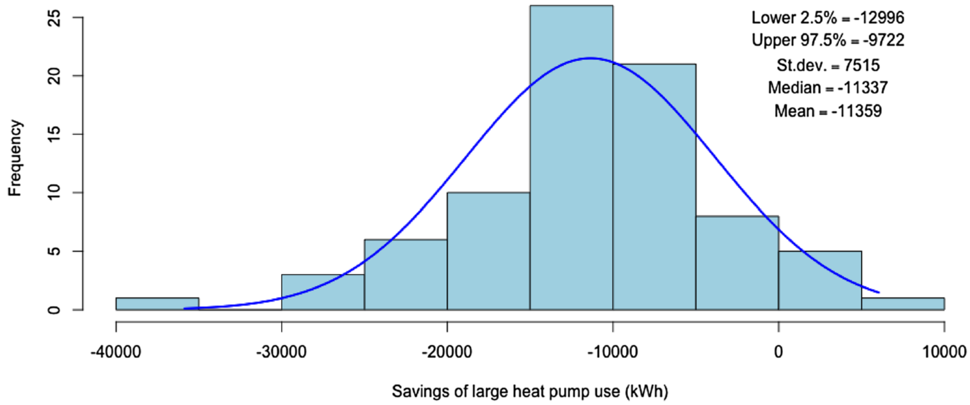


Table 1 Summary of annual energy and financial savings between pump sizes

Pump size (kW)	Av. annual use before install (MWh)	Av. annual use after install (MWh)	Mean annual savings (MWh)	Mean annual savings in USD
5–9	40.8	30.2	10.6 (26 %)	636 $
95% CI	±4	±4.7	±2.7 (25 %)	±167 $
9–14	36.1	24.7	11.4 (31 %)	707 $
95% CI	±2.6	±2.4	±1.6 (14 %)	±99 $

Financial values are given in 2017 USD. Financial savings are calculated based on rural electricity price in Iceland for homes using electricity for heating or 6 US cents per kWh without subsidies

Subsidies vary depending on the location of the household. In this study, it assumed that the household is located on the Reykjanes peninsula. The subsidies are independent of installation and purchasing cost but are sensitive to the savings provided by the pump. Installing a large pump (between 9 and 14 kW), in a household that uses 36.1 kWh per year, and a reduction by 30% results in a subsidy of approx. 3000 USD (341.000 ISK) by the government. This is a one-off payment. Installing a smaller pump (5–9 kW), where the household uses 40.8 kWh per year and the saving is estimated to be around 25% results in a slightly smaller subsidy, amounting to 2800 USD (approximately 321.000 ISK), also a one-off payment. The payments vary slightly between locations of the households. The household installing the smaller pump would, for example, get approximately 4000 USD (approx. 441.000 ISK) if it was located in a rural area in the Icelandic North-West fjords.

When looking at the cost of installing air-to air heat pumps, it can be seen that they are priced between 1.800 USD (5.2 kW, Panasonic CZ 9) and 3.200 USD (7.75 kW Panasonic HZ 12) [18]. GHPs are slightly more expensive, 5 kW Panasonic Monoblock is priced for approx. 5.800 USD, 9 kW of the same type for 8.500 USD, and a 16 kW for 11.750 USD [19]. As most of the pumps analyzed in this data set are ASHPs, we can estimate that majority of annual savings are somewhere in the range demonstrated in Table 1. Using the mean annual savings of small pumps, 636 USD, the payback period for a 5.2 kW Panasonic CZ 9 would be roughly 3 years excluding the one-off payment from the government. The subsidy provided by the government seems, however, to fully, or mostly, cover the initial cost of the ASHPs, where the user then almost instantly begins reaping the economic benefits.

Discussion

The previous studies have demonstrated that ground source GHPs in cold areas can maintain a COP up to 3 [20]. However, the definition of cold, or subarctic areas needs to be clarified, as cold areas in Turkey for example have a ground temperature of up to 24 °C in July [20]. Such studies are, therefore, not looking into heat pumps in a cold areas in the same way as is being done in this study where temperatures at 50 cm depths rarely go above 10 °C. It has been demonstrated that the use of GHPs in Europe is merely in the early stages with a large potential for improvements. This is specially relevant when looking into carbon emission savings. It has been shown that if the European market fully saturates, a 30% of carbon emission can be mitigated [4]. The amount mitigated in Europe has previously been estimate to be 3.7 Mio t CO_2, a mere 0.74% [4]. The potential for climate change mitigation is, perhaps, marginal in this context, but should be considered when looking into energy developments in subarctic areas. The potential mitigation is also sensitive to the energy supplied to the GHP, and the energy being mitigated [21]. Industrial use of GHPs is being investigated and has been shown to be viable, for example in greenhouses [22]. This proves interesting in the context of Iceland, as a large portion of domestic vegetable production takes place in greenhouses.

In a larger, global context, the results from this study can potentially serve as a starting point for policymakers who govern rural subarctic areas where heat pumps might lessen the pressure on the energy systems. The paper provides insights into how the pumps may be promoted, and how much savings users can expect using them. According to the Kppen climate classification, subarctic areas (where this study is without doubt most applicable) include Siberia, some areas of Scotland, The Western and Eastern Alps which includes areas within France, Switzerland, Germany, Italy, and Austria [23]. Other areas include the center of Romania, regions of Germany, The Polish Tatra Mountains, and The Pyrenees, which include areas within Andorra, France, and Spain. Most Interior of the northern half of Scandinavia, and Western and South-central Alaska [23]. The Rocky Mountains in Colorado, Wyoming, Idaho and Montana and the White Mountains of New Hampshire and much of Canada [23]. In parts of East Asia, like China, the Siberian High fabricates cooler winters than places like Scandinavia or Alaska interior but dry, so that snow cover is little, contributing to a subarctic climate in vast areas of Mongolia. Large areas of Russia are in subarctic climate. Some areas of China are also classified as subarctic, along with areas in Tibet, India, and North Korea [23].

Interestingly in Iceland, the buyers of larger heat pumps generally used less electricity prior to installation than those who purchased smaller pumps. It is difficult to identify reasons for this, as they can be of various kinds. In addition, such analysis as shown in this report is sensitive to the user behavior. For example, a user might decide to upgrade his house in terms of energy efficiency, by doing so the user would buy a heat pump, but might also buy better insulating windows and a better insulation for the roof. It is not possible to know if such behavior is present. Households that had two or more pumps were not included in this study; this was done to omit the skewness that such inclusion would bring. In addition, the measurements that showed the average energy use after the pump installation may not be very accurate. Some are the average of 5 years and some only the measurement for 1 year. The data set used does also not show how many measurements are behind each average. This also skews the results as the average might change when more measurements are added. When comparing savings to households previously using oil-fired appliances, the savings are substantially smaller which can be directly linked to the cost of purchasing oil for heating. According to the CCHRC, a 2000 ft^2 household would save approximately 1000 $ per year using ASHP if previously using oil for heating in Southeast Alaska [24]. On average, the savings seem to be slightly less in Iceland, or around 630 $ (when installing a small pump) and 700 $ when installing a large pump as can be seen in Table 1.

Conclusion

This paper studied the potential savings of heat pump users in subarctic environment, namely within Iceland. The users of heat pumps operating under similar conditions may expect approximately 30% electricity use reduction when using pumps between 9 and 14 kW. Users using pumps sized between 5 and 9 kW may expect a decrease of approximately 26% per year. If applicable, such conditions result in a governmental subsidy of approximately 2700–3600 USD (300.000–400.000 ISK), depending on the location of the user. This study provides an indicator that areas with similar climate as Iceland may benefit from installing heat pumps regardless of the cool climate. Using solutions such as heat pumps in subarctic areas may lessen the strain on energy systems and provide stronger energy security in cool areas.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interests.

References

1. Shafiee, S., Topal, E.: When will fossil fuel reserves be diminished? Energy Policy **37**(1), 181–189 (2009)
2. Conti, P.: Dimensionless maps for the validity of analytical ground heat transfer models for gshp applications. Energies **9**(11), 890 (2016)
3. Yang, W., Zhou, J., Wei, X., Zhang, G.: Current status of ground-source heat pumps in china. Energy Policy **38**(1), 323–332 (2010)
4. Bayer, P., Saner, D., Bolay, S., Rybach, L., Blum, P.: Greenhouse gas emission savings of ground source heat pump systems in europe: a review. Renew. Sustain. Energy Rev. **16**(2), 1256–1267 (2012)
5. Tester, J.W., Drake, E.M., Driscoll, M.J., Golay, M.W., Peters, W.A.: Sustainable Energy: Choosing Among Options. MIT Press, Cambridge (2012)
6. Blanchard, C.H.: Coefficient of performance for finite speed heat pump. J. Appl. Phys. **51**(5), 2471–2472 (1980)
7. Orkurannsóknir, Í.: Varmadælur, hagkvæmni á íslandi, report prepared by ragnar k. Ásmundsson, Orkustofnun (2005)
8. Lee, J.-Y.: Current status of ground source heat pumps in korea. Renew. Sustain. Energy Rev. **13**(6), 1560–1568 (2009)
9. Sanner, B., Karytsas, C., Mendrinos, D., Rybach, L.: Current status of ground source heat pumps and underground thermal energy storage in europe. Geothermics **32**(4), 579–588 (2003)
10. Staffell, I., Brett, D., Brandon, N., Hawkes, A.: A review of domestic heat pumps. Energy Environ. Sci. **5**(11), 9291–9306 (2012)
11. Stevens, V., Marsik, T., Hammer, C.: Air source heat pump potential in Alaska. Technical report, Cold Climate Housing Research Center (2015)
12. Palsson, O., Jonasson, T., Bardadottir, H., Sturludóttir, L.K., et al.: Orkutolur. Technical report, Icelandic Energy Authority (2005)
13. Arnalds, O.: Soils of Iceland. Jökull **58**, 409–421 (2008)
14. Arnalds, O.: The Soils of Iceland. Springer, Berlin (2015)
15. Icelandic Meteorological Office. Temperatures in reykjavik (2016). http://www.vedur.is/Medaltalstoflur-txt/Stod_001_Reykjavik.ManMedal.txt. Accessed 2 May 2017
16. Stjornartidindi. Auglysing um nidurgreidslur hushitunarkostnadar (2011). http://www.stjornartidindi.is/Advert.aspx?ID=80085729-441f-42fa-974c-95825247eef0 Accessed 5 May 2017
17. Orkustofnun. Varmadælur. http://os.is/jardhiti/varmadaelur/. Accessed 20 Aug 2016
18. Lofttaekni. Panasonic loft/loft. http://lofttaekni.se/panasonic%20/index.html. Accessed 15 Jul 2017
19. Lofttaekni. Panasonic loft/vatn. http://lofttaekni.se/panasonic%20loft%20i%20vatn.html. Accessed 2 Jul 2017
20. Bakirci, K.: Evaluation of the performance of a ground-source heat-pump system with series ghe (ground heat exchanger) in the cold climate region. Energy **35**(7), 3088–3096 (2010)
21. Blum, P., Campillo, G., Münch, W., Kölbel, T.: Co$_2$ savings of ground source heat pump systems-a regional analysis. Renew. Energy **35**(1), 122–127 (2010)
22. Esen, M., Yuksel, T.: Experimental evaluation of using various renewable energy sources for heating a greenhouse. Energy Build. **65**, 340–351 (2013)
23. Peel, M.C., Finlayson, B.L., McMahon, T.A.: Updated world map of the Köppen–Geiger climate classification. Hydrol. Earth Syst. Sci. Discuss. **4**(2), 439–473 (2007)
24. Stevens, V., Craven, C., Garber-Slaght, R.: Air source heat pumps in southeast alaska. Technical report, Cold Climate Housing Research Center (2013)