Julius Šiaudvytis

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The Effect of Temperature Reduction on Heat Pump Performance

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Abstract

The Ground Source Heat Pumps (GSHP) in Finland are becoming a more and more popular way to provide buildings with necessary heat. This type of heat pump is usually installed as a main heat source, which covers the total heat demand for both Domestic Hot Water (DHW) and space heating. More challenging process is to heat up the DHW due to the higher temperatures required than for space heating. It leads to the relatively lower operational efficiency of the heat pumps.

In order to improve the efficiency of the GSHP the desired DHW temperature to produce must be reduced. However, the temperature reduction is quite limited because of the health risks. The Finnish National Building Code D1 and Decree of Housing Health states that the heat source must produce the DHW of 55 °C ant the water temperature in the farthest tap cannot be lower than 50 °C.

Therefore, in this study was decided to reduce the DHW temperature by 4 °C, based on requirements. This change of temperature allows to analyze how the Ground Source Heat Pump performance may be improved. Furthermore, the investigation will include such aspects as the noise produced by GSHP and how it will affect the surrounding living environment. Not only the performance will be analyzed, but the potential risks of Legionella survival as well. Overall, the combination of Ground Source Heat Pump performance and the water temperature quality analysis will give a clear view by the advantages and drawbacks.

Subject headings, (keywords)

Ground Source Heat Pump, GSHP, Coefficient of Performance, COP, Noise, Domestic Hot Water, DHW, Legionella bacteria

Pages	Language	URN
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Remarks, notes on appendices

Ground Source Heat Pump, Vapor Compression Cycle

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APPENDICES

1 INTRODUCTION

The Ground Source Heat Pumps (GSHP) in Finland are becoming a more and more popular way to provide buildings with necessary heat. Since the GSHP is usually installed as the main heat source, it has to produce the heat for both space heating and domestic hot water (DHW). The DHW production is a more challenging and more energy consuming task due to the need of hot water all around the year. Furthermore, the temperatures to achieve are relatively higher than in heating system. /1./

The higher the required temperature is, the higher the compression ratio in a GSHP should be. This leads to the increase of power consumption and operating efficiency reduction /2, p. 3:14./. Moreover, the noise emitted from the compressor is louder due to the higher compression ratio. Even though the heat pump is operating at lower set temperatures its operation is quite noisy. So, it is one of the biggest geothermal heat source drawbacks, which may disturb the surrounding living environment. /3, p. 132./

The main thing, which has the biggest influence on the ground source heat pump operating conditions is the regulations for the minimum DHW temperature to produce. Nowadays, according to Finnish National Building Code D1 it is compulsory to design and install a heat source so that it would be capable to achieve the DHW temperature of 55 °C /4, p. 8/. Also, the Ministry of Social Affairs and Health by the Decree of Housing Health states that water from the farthest tap should not be lower than 50 °C after the water delay /5, p. 2/.

These regulations are based on the microbiological contaminants appearance in supplied domestic hot water which is harmful for human health. One of the most common and dangerous microbes found in poorly produced DHW is Legionella pneumophila. It grows best in warm water, which, for example, is stored in pipework (including water heaters, faucets, and showers) and hot water tanks. Bacteria can affect human health negatively by causing either Legionnaire’s disease or Pontiac fever. /6./

The easiest way to ensure healthy DHW is to keep the certain temperature level of DHW that is described by regulations. On the other hand, the required water temperature is too high for human body. Therefore, the hot water must be mixed with cold water, in order to adjust the comfortable water temperature level and not to scald the skin. It means that the energy used to heat the water up to 55 °C is useless in most of the cases. Because of that, the hot water temperature reduction by 4 °C (from 55 °C to 51 °C) could be one of the energy saving solutions. Since the set temperature of 50 °C can be not enough due to the heat losses in distribution pipes, the set temperature of 51 °C should meet the recommendations for the tap water. /7./

Therefore, by this research the Ground Source Heat Pump will be analyzed at two different conditions – when it is producing the DHW of 55 °C and when the temperature is reduced to 51 °C. The analysis will include three different kind of aspects. First of all, the change of the heat pump Coefficient of Performance (COP) and the noise level will be analyzed. Secondly, the possibility of Legionella bacteria survival in the DHW distribution system after the temperature reduction will be studied. Finally, this study will lead to the discussion, where the advantages and drawbacks of the temperature reduction will be drawn.

2 AIMS

The main objective of this research is to study how the temperature reduction by 4°C affects the performance of the ground source heat pump. The main focus will be on coefficient of performance because it best describes the efficiency of the system. Moreover, one of my aims is to find out the change in noise level emitted by GSHP. Since the heat pump operation is quite noisy, it may disturb the living environment in surroundings.

The last one of my goals is to prove whether it is worth reducing the temperature for domestic hot water production in ground source heat pumps from 55 °C to 51 °C. From the microbiological point of view, the minimum DHW temperature in the system must be kept according to the water quality criteria. This is one of the most important factors, which should be taken into account in order to prevent microbiological contaminants, such as Legionella, to appear. Therefore, the literature analysis of Legionella survival will answer this question.

3 METHODS

In order to achieve the goals of this research, different kind of measurements on three heat pump systems will be carried out. The analysis of more than one heat pump performance will give more adequate results. It means that the results on how the performance changes will be more applicable for the bigger number of heat pumps, not only for those used in this research work.

First of all, the momentary COP of heat pumps will be analyzed, when the heat pump operates at two different conditions: producing DHW of 55 °C and 51 °C. In order to achieve as accurate results as possible, the pause between different measuring conditions will be made so that the temperatures in a system will stabilize. These temperatures needed for COP calculations will be determined as it is shown in Figure 1. The temperature sensors of the measuring device will be attached on the suction (1) and discharge lines (2) of the compressor and on the liquid line after the condenser (3). Also, the surface temperatures of inlet (4) and outlet (5) of the ground loop will be measured. If some of the points will be not reachable because of the heat pump construction, necessary temperatures will be taken from the own heat pump automation system.

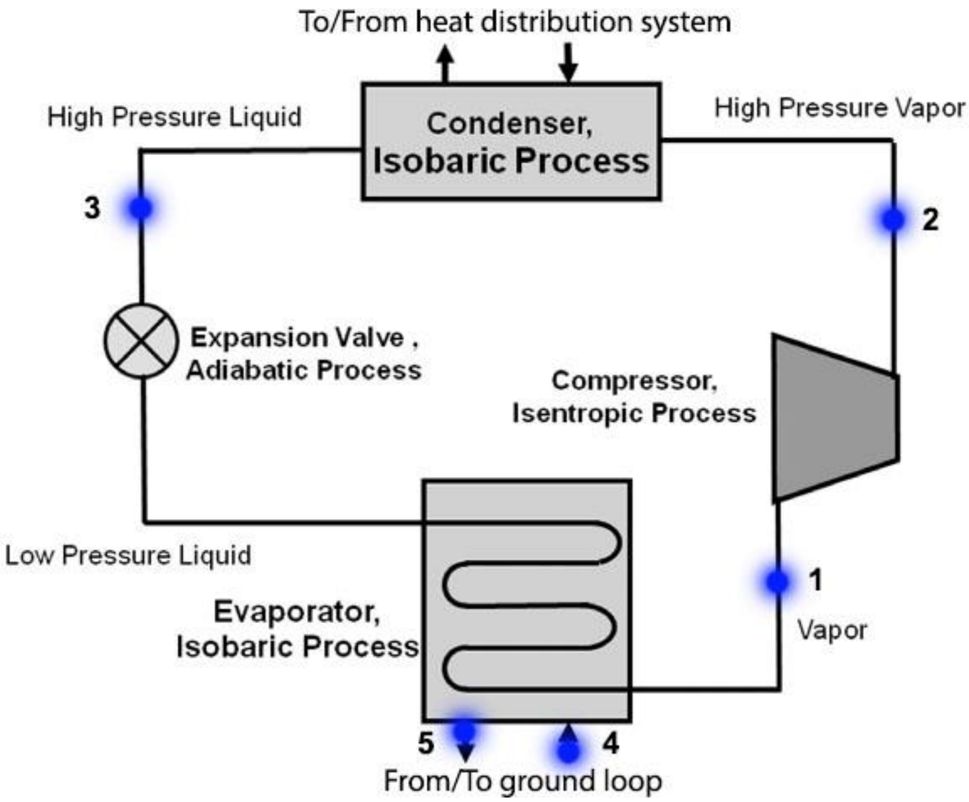

FIGURE 1. Heat pump principal scheme. 1-5 – measuring points /8, p. 239/

Later the collected temperature results will be used for the momentary COP calculations by using the software CoolPack. The software is a collection of simulation programs related to refrigeration. One of them, which is called Refrigeration Utilities will be applied in this research to calculate COP values and to design the vapor compression cycles. /9./

Moreover, the noise level mainly caused by the compressor will be determined, while the heat pump is operating in different conditions. The measurements will be taken in several places such as technical room, where the heat pump is installed and surrounding premises before eliminating the other sources of noise. In order to identify the noise level caused only by heat pump, the background noise in a technical room will be measured, when the heat pump is switched off. The results of total and background noise will be used for calculations. Other results will be compared to the building classifications. The comparison will show if the measured noise levels meet the requirements in researched buildings and if the situation is improved by reducing the DHW temperature.

At the final stage, the possibility of Legionella survival in the domestic hot water produced by heat pump will be analyzed. Since the bacteria might appear and multiply in water with a certain temperature, the temperature of DHW will be measured. Because of the heat losses in water distribution system, the temperature will be determined in the farthest tap from the heat source. In that way the lowest possible temperature in the whole DHW supply system will be found. Therefore, the literature research will be carried out according to the results in order to prove whether the temperature of DHW could be reduced without increasing the health risk.

4 DHW PRODUCTION BY GROUND SOURCE HEAT PUMPS

Ground source heat pump is an equipment, which is becoming more and more popular heat source in Finland for residential buildings. GSHP is able to take the energy stored in the ground, rock or water and to transfer it to the useful heat for the space heating and domestic hot water production. That capability of heat transfer is due to the vapor compression cycle, which requires four basic components in the system.

4.1 Heat Pump operation principle

The first component is a compressor, where the refrigerant in the form of low pressure saturated vapor is pressurized (1-2). It leads to temperature increase due to the smaller distance and bigger friction between gaseous particles. Then the refrigerant in a hot and high pressure vapor form enters the condenser, where the cooling and heat exchange process begins (2-3). In other words, the heat is transferred to the heat distribution system. The refrigerant changes its phase to the high pressure saturated liquid. At the next stage of refrigeration cycle the substance goes through the expansion valve, where decompression (or expansion) (3-4) begins. The low pressure mixture of liquid and gas readily evaporates (4-1) into low pressure saturated vapor form. The evaporation process is caused by transferring the energy from the ground loop surroundings. Later the refrigeration cycle is continuously repeating. The processes of Carnot cycle are visually represented in pressure-enthalpy diagram (Figure 2). /8, p. 238-239./

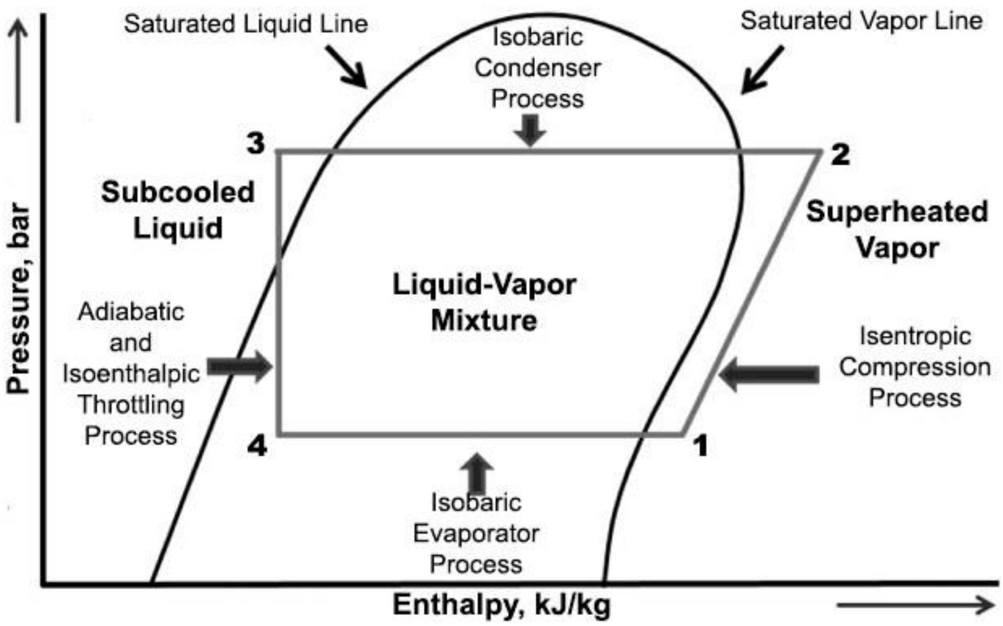

FIGURE 2. The refrigeration cycle in pressure-enthalpy diagram /8, p. 240/

4.2 Types of Ground Source Heat Pumps

Ground Source Heat Pump system may be separated into types according to the geothermal earth loop. Which type is the most suitable and efficient to the heat pump operation mainly depends on the available land, soil conditions and local installation costs at the site. Mainly the heat pump systems are divided into several groups based on the position how the pipe loop is placed underground. There are three basic types: horizontal, vertical and pond or lake type heat pumps. /10, 11./

One of the most cost-effective ground loop options for residential buildings is to install the pipeline horizontally. The single pipe loop is buried inside a long, narrow trench in a depth of approximately 1,2-1,8 meters underground. In most cases the supply and return pipes are buried with a particular horizontal distance between them in a depth of ~1,5 meters. Another layout of horizontal ground loop installation is represented by Figure 3-1. One of the disadvantages is that such systems require quite a big surface area. /10, 11./

When the building is located near a pond or a lake, as an option the geothermal loop can be easily placed there. The loop is coiled into circles and placed in a certain depth in a water, like it is shown in the Figure 3-2. As well as the other types of loops, the circulating mixture of water and antifreeze cools down the water around the loop, by taking the heat to the evaporation process. /10, 11./

Another ground heat exchanger solution is vertically installed geothermal loop, which is the most popular one in Finland. This option requires least available surface area, but the investment costs are relatively higher due to the depth of boreholes, which cannot be made without a special machinery. The pipe loop forming U-bend at the end is placed down to the borehole, which depth can exceed 200 meters. If geothermal loop is planned to be installed with more than one borehole, the pipe loops placed to each of them are connected to the horizontal piping system as shown in Figure 3-3. /10, 11./

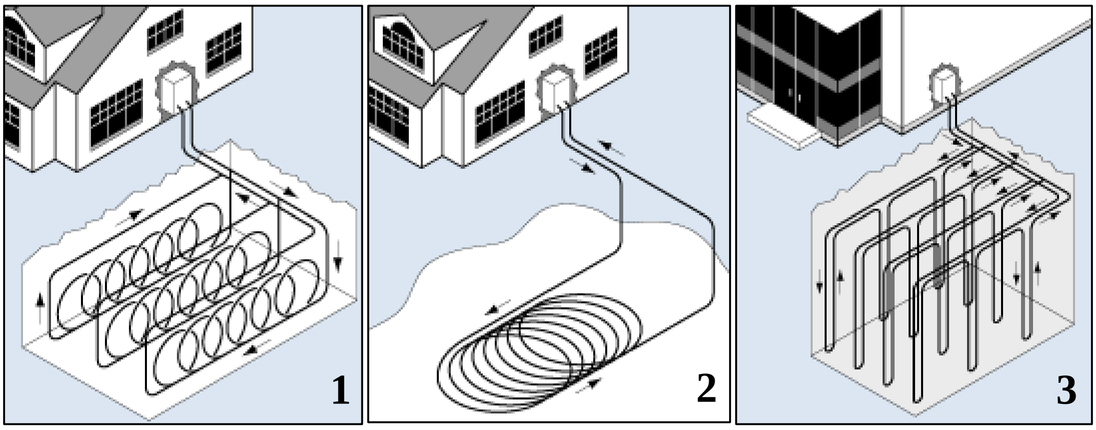

FIGURE 3. Closed ground loop types: 1-horizontal; 2-pond/lake; 3-vertical /11/

4.3 Compressors

Compressor is the most important part of a heat pump system, without it the heat transfer from the lower temperature medium to the higher one is impossible. Depending on this component construction the efficiency of operation varies. At the moment there are several types of them: reciprocating, rotary and scroll compressors. The most recent design of these are scroll compressors, which nowadays have increased their popularity in the heat pump systems. /12, p. 87./

Generally, this type of compressors has two scrolls – stationary and the one which is movable. The motion of movable against stationary scroll creates the suction and compression actions. The basic principle is represented by Figure 4. /12, p. 87./

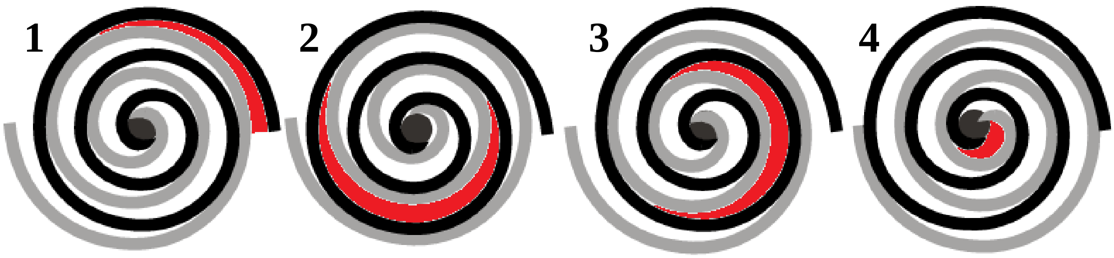

FIGURE 4. The principle of scroll compression process. 1 – Vapor enters an outer opening as one scroll orbits the other; 2 – The open passage is sealed as vapor is drawn into the compression chamber; 3 – As one scroll continues orbiting, the vapor is compressed into an increasingly smaller "pocket"; 4 – Vapor is continually compressed to the center of the scrolls, where it is discharged through precisely machined ports and returned to the system /12, p. 88/

This type of compression technology gives more advantageous operation in comparison with the reciprocating and rotary compressors. While operating, there are no volume losses caused by a residual refrigerant vapor. Due to the fact the suction and discharge vapors are separated by greater distance, the unnecessary heat losses are lower. Furthermore, as there are less moving parts it leads to the quieter and more efficient operation. /12, p. 88./

4.4 Heat Pump Coefficient of Performance

The ground source heat pumps operational efficiency is highly influenced not only by the construction of components discussed above, but by the operational conditions as well. In general, it is the set temperature, which should be reached by the heat pump for the space heating and domestic hot water purposes. In the first case the design of heating systems – radiator type or underfloor heating – has a big influence on efficiency. For example, the heat is produced more efficiently by GSHP to the underfloor heating system, which requires lower temperatures to achieve. In addition, this part of the system may be easily adjusted by automation according to the consumer needs. /13./

The heat production for domestic hot water is less flexible than for the space heating. As it was discussed above, the domestic hot water has minimum temperature limitations, which must be met. Therefore, the heat pump producing domestic hot water has to achieve higher temperatures, which causes lower operational efficiency.

All the factors, which affect the efficiency of the heat pump operation are included in one reference value – Coefficient of Performance. In general, it is the ratio between the amount of useful heat rejected from the condenser and the energy used to perform the work. Mathematically it is expressed by Formula 1. /2, p. 3:13./

$$COP_1 = \frac{Q_1}{E} \tag{1}$$

where: Q_1 – the heat rejected from the cycle, kW;

E – the required power input, kW.

The heat pump operating principle is based on a Carnot cycle, which gives the maximum theoretical COP. In order to analyze the cycle, the concept of entropy must be introduced. It is generally defined as a ratio of the heat transfer to a reversible process and the absolute temperature at which the heat transfer occurs. Applying this thermodynamic magnitude, the heat rejection and required power input are expressed by Formulas 2 and 3 respectively. /2, p. 3:17./

$$Q_1 = T_1 \cdot \Delta s \quad (2)$$

$$E = (T_1 - T_2) \cdot \Delta s \quad (3)$$

where: $T_1, T_2 -$ absolute condensing and evaporating temperatures, K;

Δs – change in entropy, $kJ/kg \cdot K$.

Inserting the formulas 2 and 3 to the first equation shows that the ideal coefficient of performance is dependent only on the high and low absolute temperatures as shown by Formula 4. This temperature difference in a vapor compression cycle occurs due to the compression and expansion processes of the refrigerant. After the compressor the pressure of refrigerant is raised in order to achieve the desired temperature in a condenser, which is connected to the heating and domestic hot water system. /2, p. 3:17./

$$COP_{1C} = \frac{T_1 \cdot \cancel{\Delta s}}{(T_1 - T_2) \cdot \cancel{\Delta s}} = \frac{T_1}{(T_1 - T_2)} \quad (4)$$

In order to reach the desired temperatures, certain pressure levels must be achieved. If the desired pressure to achieve is lower, the compressor consumes less power (E) by producing more useful heat (Q_1). As a result, this will increase the COP value, because of the smaller temperature difference between the condenser and evaporator (T_1 and T_2). This phenomenon can be clearly seen by the vapor compression cycle represented in Figure 5. /2, p. 3:14./

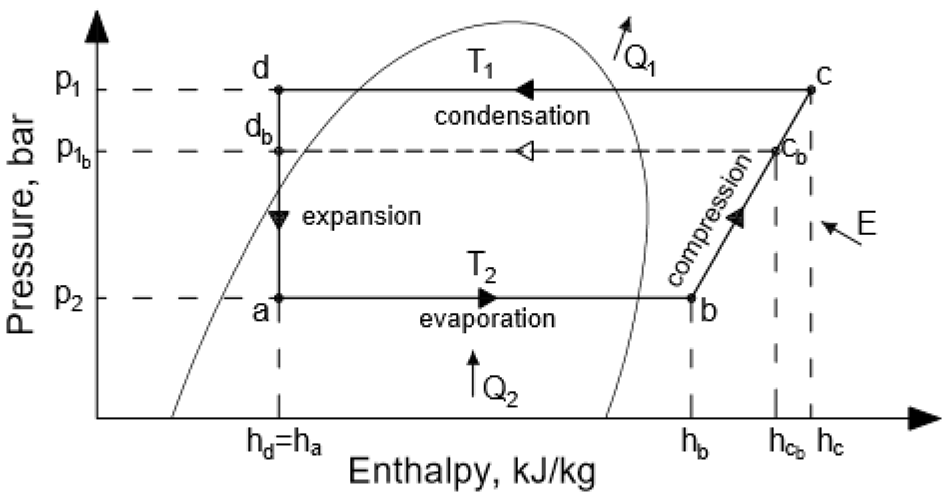

FIGURE 5. Vapor compression cycle

Furthermore, the COP is highly influenced by the other thermodynamic property called enthalpy. It shows the heat content in a substance. The change in enthalpy can be utilized to find out the heat power of the condenser, cooling power of the evaporator and the energy used in a compressor. The amount of useful heat and energy used can be found by combining Figure 5 and following Formulas 5 and 6. /2, p. 3:7-9./

$$Q_1 = q_m \cdot (h_c - h_d) \quad (5)$$

$$E = q_m \cdot (h_c - h_b) \quad (6)$$

where: q_m – the mass flow of refrigerant, kg/s;

h_c – enthalpy after the compression, kJ/kg;

h_d – enthalpy before the expansion process, kJ/kg;

h_b – enthalpy before the compression process, kJ/kg.

5 NOISE DUE TO GSHP OPERATION

5.1 GSHP as a source of noise

The desired pressure level affects not only the COP of the heat pump, but the noise emitted by the compressor as well. The scroll compressors have a fixed pressure ratio due to the construction of the scrolls. When the compression ratio is required to be higher than it is designed, the difference in pressure between the discharge port and the compression pocket appears. It causes a counter flow of gases, as shown in Figure 6, and generates pressure pulsations. Furthermore, the biggest pressure pulsations are produced, when there is a large difference between the suction and discharge pressures. Therefore, the scroll compressor is noisier when achieving higher pressures. /3, p. 132./

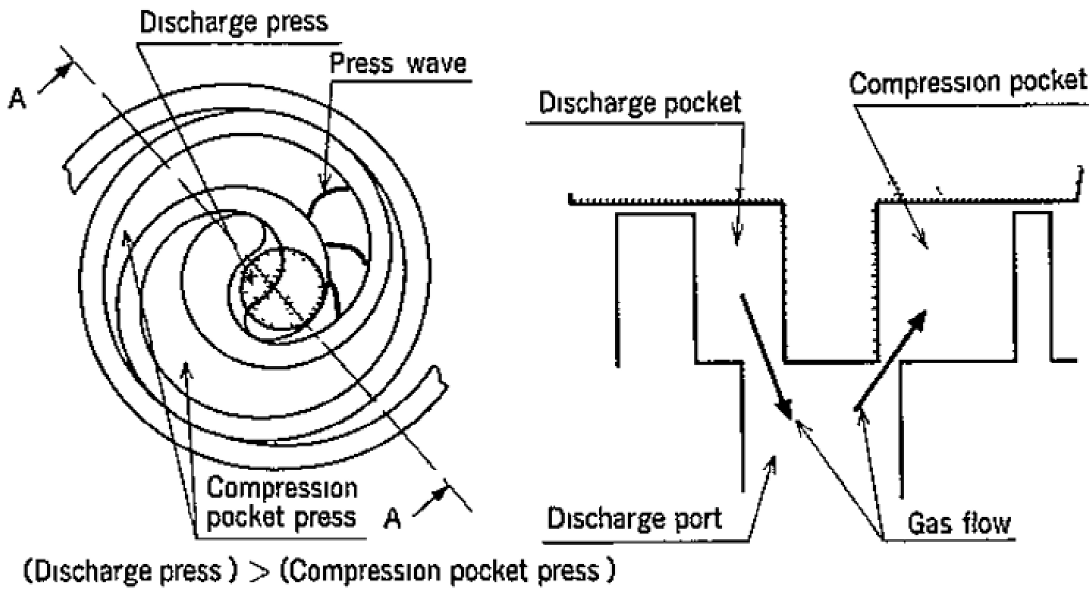

FIGURE 6. Cause of pressure pulsation /3, p. 133/

Another problem, which causes noise from the compressor is the vibration. The vibration effect appears due to the movable parts inside. Because every component is connected to each other, the vibrations can be easily transmitted through the heat pump unit base plate and pipes, which generates unnecessary noise as well. /14, p. 1./

The noise emitted only from the compressor due to its operation can be determined by analyzing the total noise emitted and the other sources causing a noise. For more precise results it is necessary to turn off the devices, which may have an influence on measuring noise level. First of all the background noise must be established, when the heat pump is turned off. Secondly, the measures must be taken when the heat pump is under operation conditions. The total noise produced only by the heat pump can be found by extracting the background noise values from those, when the heat pump is operating. Mathematically it is expressed by Formula 5. /15, p. 7./

$$L_A = 10 \log\left(10^{L_1/10} - 10^{L_2/10} - \cdots - 10^{L_i/10}\right) \quad (7)$$

where: L_1, L_2, L_i – the noise produced by the 1st, 2nd and 3rd sources, dB.

5.2 Permissible noise levels in living environment

This kind of disadvantage of the heat pump may affect the surrounding premises negatively, which usually are the living rooms. The unnecessary noise in the living environment can cause health problems such as depression or tiredness /16/. In order to prevent the sound irritations, a lot of researches have been done, according to which, the limitations for the noise levels indoors were invented /17, p. 7/. For example, in Finland, the limiting values of the sound level are described by the Classification of Indoor Environment 2008 /18/. Table 1 shows the permissible noise values for residential room spaces.

TABLE 1. The limitations of noise level, according to the classes S1, S2, S3

Measurement	S1	S2	S3
Weighted sound reduction index between two apartments, dB	≥58	≥55	≥55
Weighted normalized impact sound pressure level from surrounding spaces, dB	≤49	≤53	≤53
HVAC equipment sound pressure level in residential rooms, dB	≤24	≤28	≤28
HVAC equipment sound pressure level in kitchen, dB	≤33	≤33	≤33
Sound pressure level of sources external to the building from 7am to 10pm, dB	≤30	≤35	≤35
Sound pressure level of sources external to the building from 10pm to 7am, dB	≤25	≤30	≤30

Moreover, the permissible noise level inside the room spaces is set by International Organization for Standardization (ISO) as well. They have developed the noise rating (NR) curves, which include the frequency content of the sound and mostly are applied in Europe. The acceptable values for hearing preservation and annoyance are provided by Table 2. /19, p. 4-5./

TABLE 2. Acceptable noise levels in decibels of NR curves /19, p. 4, 11-12/

NR	Application	Octave Band Centre Frequency, Hz							
		63	125	250	500	1000	2000	4000	8000
25	Concert halls, re-cording studios	55,2	43,7	35,2	29,2	25,0	21,9	19,5	17,7
30	Private dwellings, hospitals, cinemas	59,2	48,1	39,9	34,0	30,0	26,9	24,7	22,9
35	Schools, flats, hotels, executive offices	63,1	52,4	44,5	38,9	35,0	32,0	29,8	28,0

In addition to the different noise level evaluation regulations, the human factor is also one of the most important rating criteria. The values of noise levels represented above are systematized and should be achieved in order to reach the desired environment of the building. However, it cannot fully guarantee that the occupant will be satisfied. Not always the higher sounds level could be irritating to the human ear than those of the lower level, because the sound consists of different sound frequencies. Table 3 shows the evaluation of the noise level in the environment based on occupants. /16, p. 5./

TABLE 3. Occupants' expected satisfaction for different sound classes according to DS 490:2007 /16, p. 5/

Sound classes describing acoustic conditions in dwellings		Occupants' evaluation	
Class	Characteristics according to DS 490 Summary based on information in DS 490	Good or very good	Poor
A	Excellent acoustic conditions Occupants will be disturbed only occasionally by sound or noise	>90%	
B	Considerable improvements compared to minimum given in class C Occupants may be disturbed sometimes by sound or noise	70 to 85%	<10%
C	Sound class intended as minimum requirement for new buildings Less than 20% of occupants are expected to be dis-turbed by sound or noise	50 to 65%	<20%
D	Sound class for older buildings with less satisfactory acoustic conditions Intended for e.g. renovated dwellings. Not intended for new buildings.	30 to 45%	25 to 40%

6 DRINKING WATER TEMPERATURE

Domestic hot water quality and health risks can be influenced by variety of factors. First of all, the water quality from the source must be ensured and the water must be treated in an adequate way so that the health risks due to microbes and other contaminant would be prevented. Furthermore, the water quality is highly affected by the distribution system pipework, for instance, the piping and plumbing material construction contributes to the microbial growth and biofilm formation. /20, p. 93./

Moreover, stagnation and low flow rate of the water in a distribution system increase the risks for the human health and reduce the drinking water quality. In that case, the dead ends of the distribution system pipework and storage tanks are the best places for microbial colonization. In general, it is not frequently used water systems. /21, p. 62./

The temperature of the water is the other very important parameter. This factor highly affects the appearance and survival of different types of microbes in distribution system pipework. A certain temperature level in a distribution system must be kept in order to prevent negative effects to water quality. However, it is important to understand, that the water quality is ensured not only by adjusting, for instance, the temperature level, but also by combining different types of factors together, which improves the quality of drinking water. /21, p. 63./

6.1 Temperature effect on Legionella

The drinking water supply systems from the water source to the customer's tap, sometimes may work as a transmission vehicle for a variety of hazardous agents. One group of pathogens is aquatic microorganisms including Legionella bacteria, which can cause harmful infections on humans such as Legionnaire's disease (pneumonia) or Pontiac fever. The number of these harmful pathogens in potable water distribution systems is affected by many factors. The most crucial one is temperature, which highly affects the formation of microbial biofilms in water distribution systems. /20, p. 89./

In general, Legionella has an ability to withstand temperatures of 50 °C for several hours and it does not multiply below 20 °C. Since the bacteria may be found even in low temperature water, it has no harmful influence on human health, because of small number of Legionella particles. When the water temperature becomes higher, it creates perfect environment for bacteria to grow. The best temperature range, where Legionella has greatest multiplication rate is found to be 37 - 42 °C. Below the 37 °C temperature, the bacteria multiplication rate is becoming lower until multiplication stops by reaching a critical temperature of 25 °C. Below this temperature there is a very low possibility that Legionella will multiply. /21, p. xxi, 64./

Exceeding the water temperature of 42 °C, Legionella multiplication is becoming slower as well. The increase of bacteria colonies can be stopped at the temperature of 46 °C. Higher water temperatures negatively affects the Legionella and it starts to die. How fast the bacteria will be destroyed depends on how high the water temperature is. For example, 1000 CFU (colony forming units) of bacteria per ml of water at the temperature of 50 °C dies in approximately 7 hours, while at the temperature of 60 °C would take approximately 10 minutes. The temperature effect on Legionella bacteria survival as a function of time is shown by Figure 7. /22, p. 9./

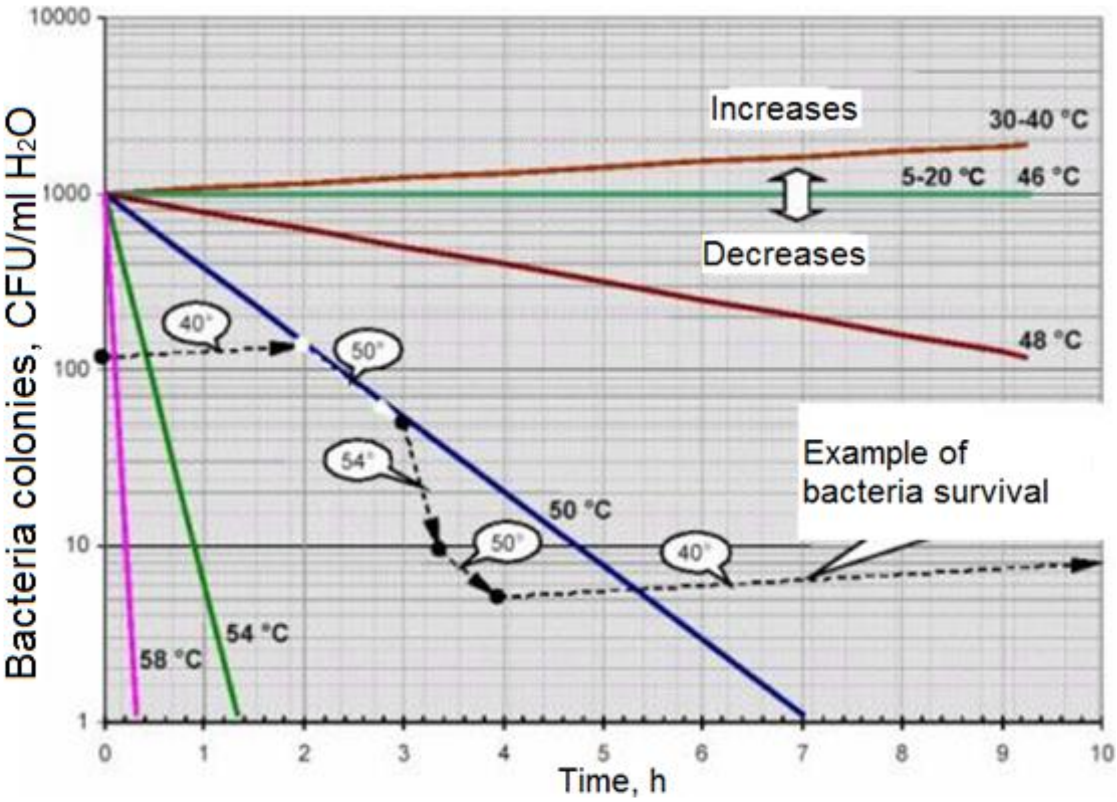

FIGURE 7. Temperature effect on Legionella survival /21, p. 9/

6.2 DHW temperature limits

Since the most suitable environment for Legionella survival is warm water, the temperature in domestic hot water distribution systems are limited by regulations and guidelines. For example, in Finland the heat source must be capable of producing the domestic hot water of at least 55 °C according to the Finnish National Building Code D1 /4, p. 8/. Also the Ministry of Social Affairs and Health in Finland gives recommendations for DHW temperature by the Decree of Housing Health. It says, that the temperature of DHW in a distribution system should be at least 50 °C, so that the bacteria would be prevented /5, p. 2/.

Due to the high temperature level of domestic hot water, it is used in most of the cases only mixed with cold water. The use of water, (for instance, for hands washing or shower) with the temperatures above 50 °C is harmful for human body. There is a risk to get the skin scalded. For example, it takes approximately 5 minutes to scald under the hot water of 50 °C and only 1 second under – 65 °C /7/. Because of that, the maximum temperature of DHW cannot exceed 65 °C according to the Finnish regulations D1 /4, p. 9/. Also, the taps should be installed so that too hot water is prevented by mixing the hot and cold water together. In that case, some energy could be saved by producing lower temperature DHW, which would be useful without mixing.

7 EXAMINATION OF DHW TEMPERATURE EFFECT

7.1 Measuring devices

This research requires several measuring devices to use. These devices are an 8 – channel thermocouple data logger, a sound analyzer and a thermometer. Also, some of the measurements will be done by GSHPs own automation systems (shown in Appendix 1) in parallel with thermocouple data logger.

Thermocouple Data Logger TC - 08

The 8 channels thermocouple data logger is used for surface temperature measurements. The TC – 08 model shown by Figure 8 allows to measure the temperatures in real time and to record the variations. The device has high resolution, accuracy and is capable to take up to 10 measures per second. Later collected data and the graphs of temperature variations can be easily exported to the Excel. The temperatures, which can be determined by TC – 08 can vary between -270 °C and +400 °C using T-type thermocouples. /23./

FIGURE 8. Thermocouple Data Logger TC – 08 /23/

Sound Analyzer Nor140

The sound analyzer Nor140 shown by Figure 9 is used to establish the noise level in any space – either outdoors and indoors. This measuring device has a variety of settings to choose how and what kind of noises will be measured. The most important features for this research are:

- Establishment of A-weighted levels simultaneously with C-weighted levels. It means that the device measures the sounds, which can be heard by human ear.

- Frequency analysis with 1/3-octave bands in the 0,4 Hz – 20 kHz range.
- Parallel detection of instantaneous Sound Pressure Level (SPL) and the Integrated Averaged SPL (L_{eq}). /24./

FIGURE 9. Sound Analyzer Nor140 /24/

Thermometer TA - CMI

TA – CMI (shown in Figure 10) is the multifunctional measuring instrument used to determine the characteristics of hydronic systems. The device has a possibility to measure the differential pressure, water flows and temperature. In this research, the TA – CMI will be used only as a thermometer for the DHW temperature determination. /25./

FIGURE 10. TA – CMI measuring instrument /25/

7.2 GSHPs descriptions

The researching objects are the existing ground source heat pumps, which are located around Mikkeli in Finland. All of these GSHPs transfer the heat from the ground by vertical geothermal loop. Since the heat pumps operate at the single family houses, heat capacity is approximately the same. However, there are some differences in how the systems are installed. Therefore, this subchapter describes each heat pump and its installation conditions in details.

7.2.1 GSHP No. 1

The Stiebel Etron WPF 10 E (shown in Appendix 2) ground source heat pump is manufactured in Germany and has operated since the year 2011. In general it has the basic construction which can be found in most of the heat pump units. Mainly it contains scroll compressor, condenser, expansion valve and evaporator. Moreover, the system is filled with 2,6 kg of R410A type refrigerant. The performance of this heat pump according to the manufacturer is represented by Table 4. /26, p. 48-49./

TABLE 4. Heat pump capacity by manufacturer at different desired temperatures /26, p. 48/

Desired conditions	Heat production, kW	Power consumption, kW	COP
35 °C	10,03	2,21	4,54
55 °C	8,36	3,77	2,22

The heat from the ground is taken by vertical geothermal loop which bottom part is at the depth of 194 meters. Approximately 190 meters of the loop are surrounded with the ground water. This part of the pipe is also known as the active pipe part. Furthermore, the heat by heat pump is transferred to the storage tank containing 650 liters of water. Due to the temperature stratification inside the tank the heat is transferred to the different heights of the tank according to the heat purpose. For example, if the domestic hot water is produced, the hot water from the condenser is transferred to the top of the storage tank. When the heat is needed for the space heating, the heat is transferred to the middle. The principal scheme how the heat pump and the storage tank are connected together is shown by Figure 11.

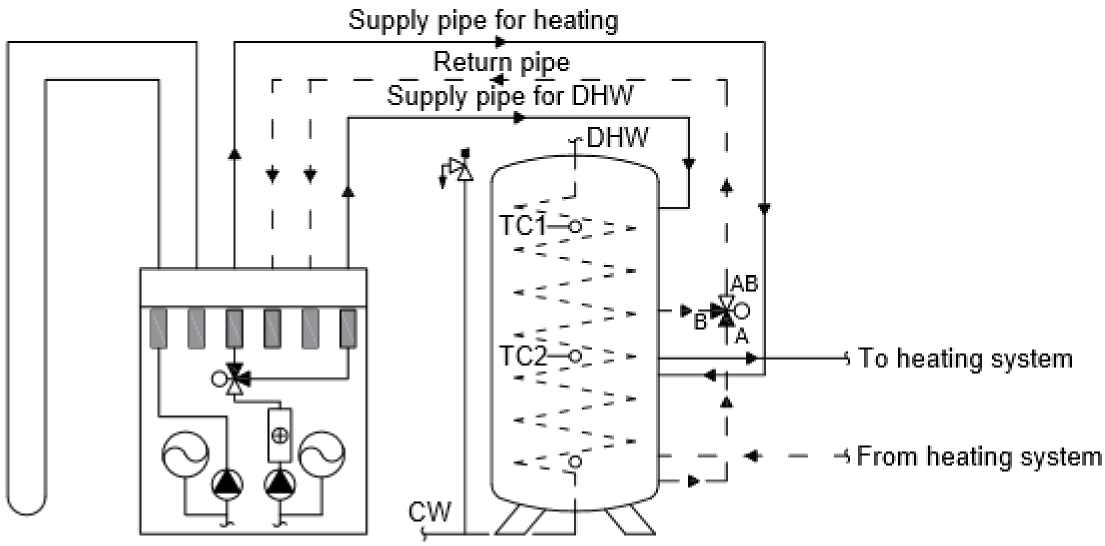

FIGURE 11. GSHP No. 1 installation scheme. TC1 – temperature sensor for DHW, TC2 – temperature sensor for space heating

The ground source heat pump is installed in a technical room which area is approximately 6 m^2. Technical room wall is in common with the wardrobe. The utility room is located next to it, where the noise level will be determined. The walls separating these room spaces consist of two 11 mm thickness layers of gypsum board and a mineral wool layer with the thickness of 100 mm. There are timber studs placed in a mineral wool layer as well. Furthermore, the wardrobe doors are partially open to the utility room. All these details are represented by Figure 12.

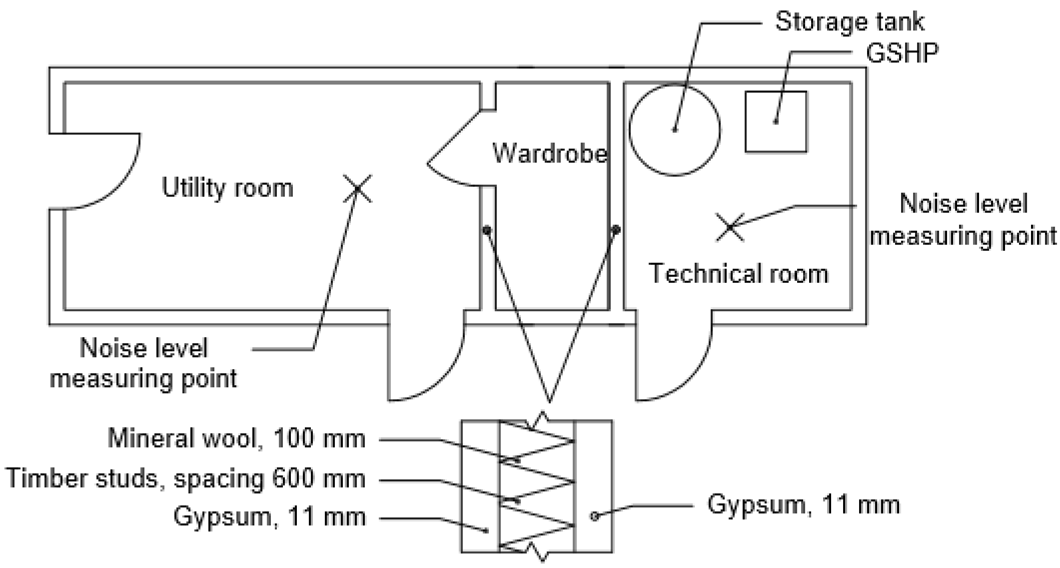

FIGURE 12. Floor plan of measuring room spaces

7.2.2 GSHP No. 2

The second ground source heat pump Geopro SH 7 (shown in Appendix 2) is produced by Finnish manufacturer Oilon Home Oy and has operated since 2011. In the construction the heat pump has an additional heat exchanger called desuperheater. This component is installed between the compressor and the condenser and is used for the domestic hot water production. Moreover, the biggest noise emitter – scroll compressor – is covered by the insulated metal box. All the other components are installed in the same way as the previous GSHP. The heat pump utilizes R407C type refrigerant, which total amount in the system is 1,3 kg. How efficiently the GSHP operates at certain conditions is provided by manufacturer in Table 5. /27, p. 23./

TABLE 5. Heat pump capacity by manufacturer at different desired temperatures /27, p. 21/

Desired conditions	Heat production, kW	Power consumption, kW	COP
35 °C	7,5	1,74	4,3
45 °C	7,2	2,06	3,5

The evaporator has a connection with a vertical ground loop, which is placed in a depth of 170 meters and has an active ground loop part of 162 meters approximately. The heat is stored in 700 liters volume storage tank by two heat exchangers – condenser and desuperheater. About 20 % of the water heated at the condenser goes through the desuperheater and is directed to the top of the storage tank, where the DHW is heated. All the rest of water coming from the condenser flows directly to the middle of the storage tank. The principal connection scheme of the GSHP and storage tank is represented by Figure 13.

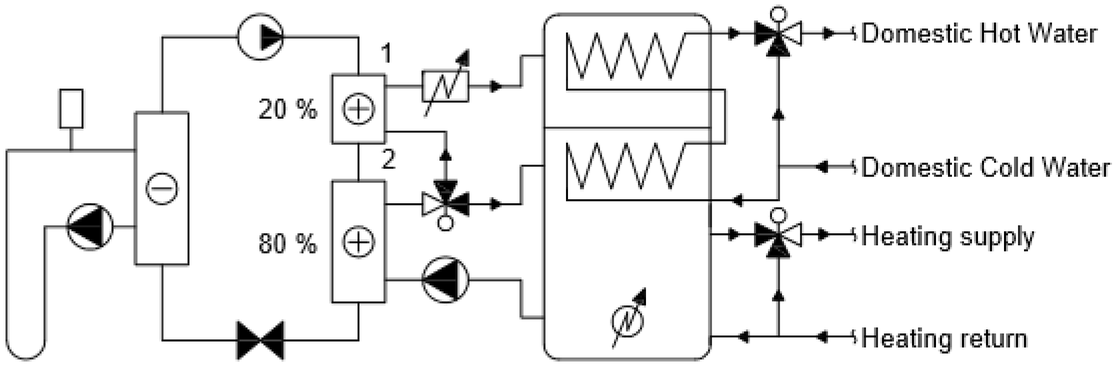

FIGURE 13. GSHP no. 2 installation scheme. 1 – desuperheater, 2 - condenser

The heat pump is located in the technical room which area is approximately 14 m^2. Around the technical room there is a bedroom and a fireplace. Both of the room spaces are treated as living environment, so the sound levels in those rooms will be carried out. The wall separating the bedroom and the technical room is made of two 13 mm thickness gypsum board layers and one layer of mineral wool (~50 mm thickness). In addition, this wall has a pipework for space heating installed in an insulation layer. Another wall has a construction only of a 100 mm thickness brick layer. The GSHP unit is placed near the brick wall as shown in Figure 14.

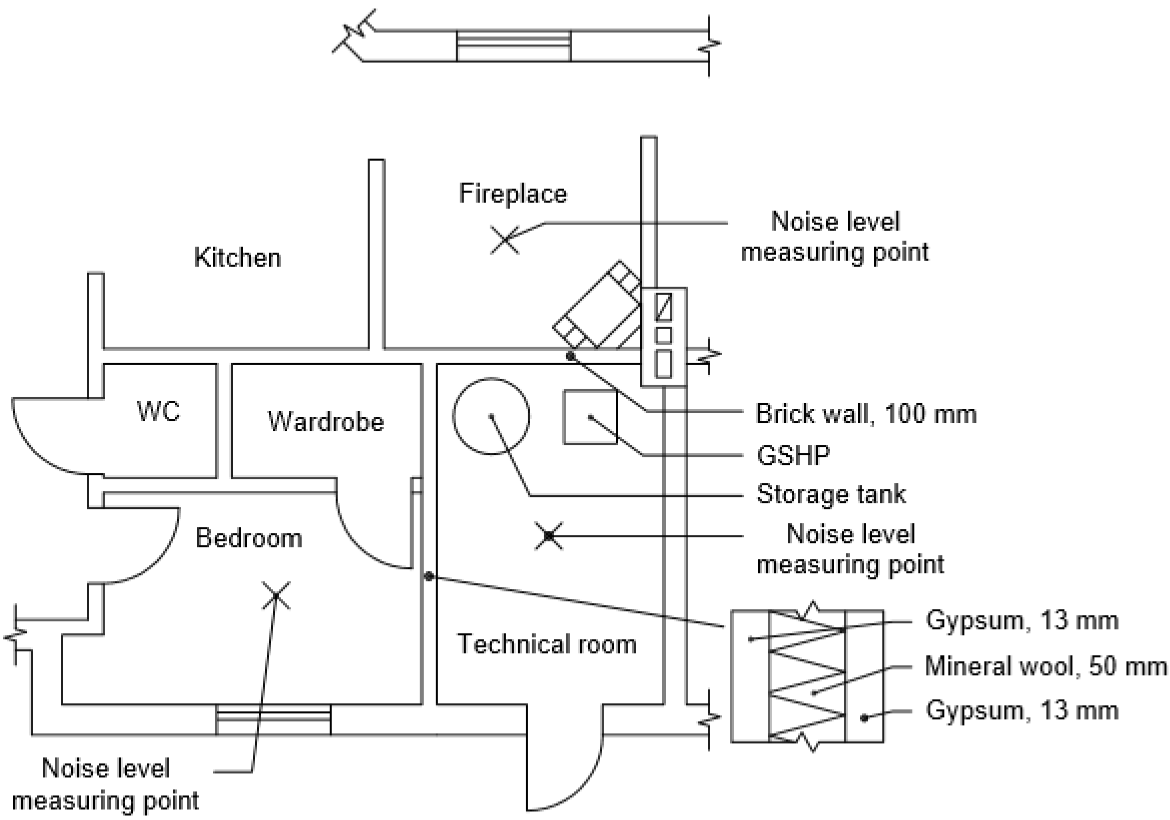

FIGURE 14. Floor plan of measuring room spaces

7.2.3 GSHP No. 3

The third GSHP is operating since the year 2013 and is produced by Bosh in Germany. Bosch Compress 5000 LW/M 9 (shown in Appendix 2) is a compact model, which has not only the heat pump components inside, but the DHW tank as well. This kind of heat pump is designed so that the domestic hot water is produced in a condenser directly. It means that the same drinking water is taken from the bottom of the tank to the condenser, returned to the top of the tank and later is distributed to the taps. Furthermore, as the GSHP is installed as the main heat source, the tank is separated into two spaces: one has a volume of 170 liters for the DHW and the other one is 30 liters volume of water for the space heating. The design of the tank is shown in the principal connection scheme by Figure 15.

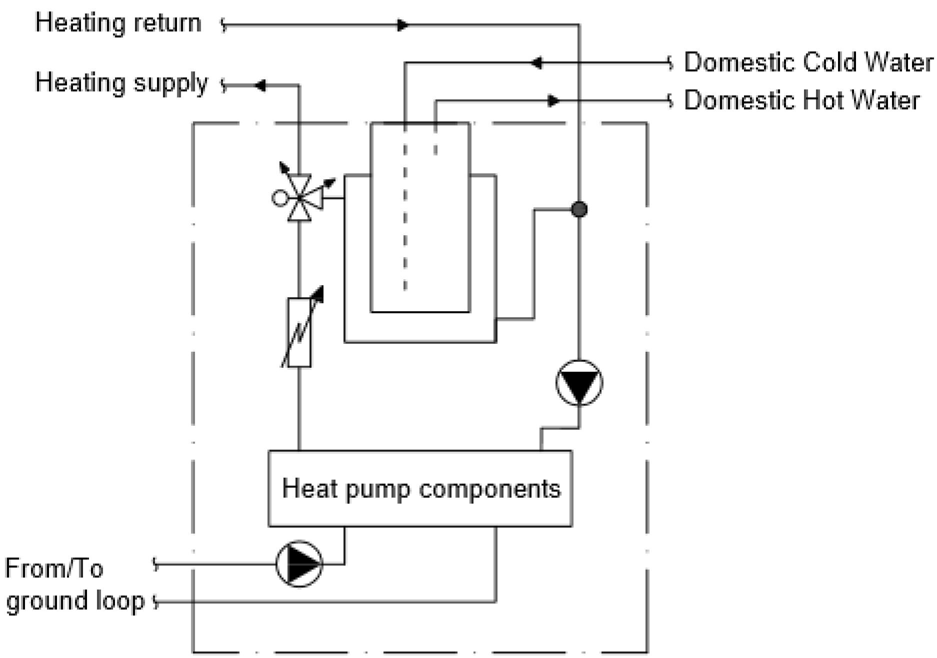

FIGURE 15. GSHP No. 3 installation scheme

From the construction point of view, this GSHP has the basic components installed – scroll compressor, two heat exchangers and expansion valve. The compressor is additionally insulated. Furthermore, the evaporator has a connection with the vertical ground loop, which is in depth of 185 meters. The top ground water level is in a depth of 7 meters approximately. The useful heat from the ground is transferred by using 1,8 kg of R407C type refrigerant in the system. The heat pump performance according to the manufacturer is shown by Table 6. /28, p. 18./

TABLE 6. Heat pump capacity by manufacturer at different desired temperatures /28, p. 18/

Desired conditions	Heat production, kW	Power consumption, kW	COP
35 °C	8,8	2,10	4,2
45 °C	8,2	2,48	3,3

Moreover, the GSHP is installed in a technical room which area is 8 m^2. Technical room has a wall in common with a bedroom and a garage. Separating walls have two layers of 13 mm thickness gypsum and 100 mm thickness mineral wool layer in between. The construction of the wall and a floor plan is shown by Figure 16.

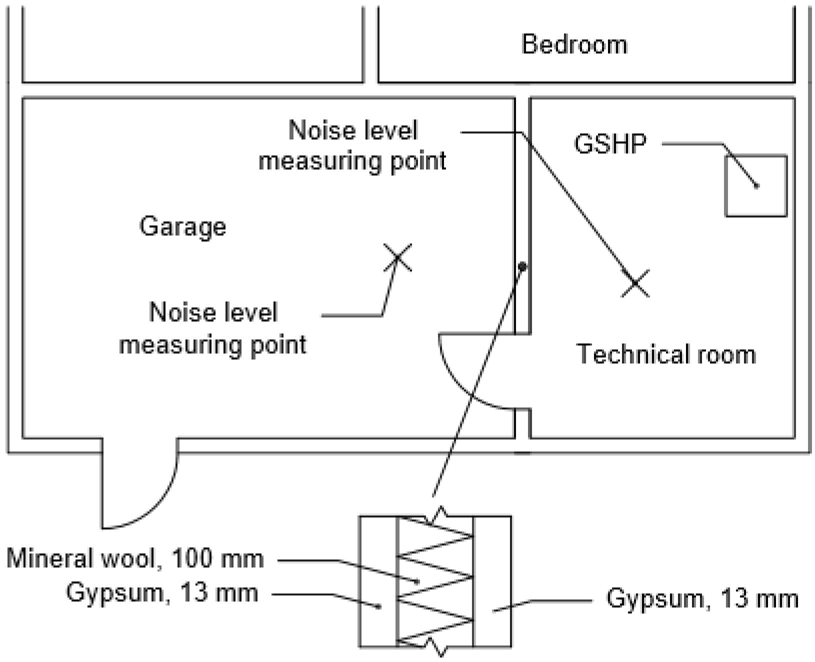

FIGURE 16. Floor plan of measuring room spaces

7.3 Results of the 1st GSHP performance

During the ground source heat pump operation all the temperatures, except evaporating temperature, is varying until the equipment achieves the desired temperature. The maximum achieved temperatures at the different points were established. The momentary temperature values, when the heat pump is operating at two different conditions is represented by Table 7.

TABLE 7. Measured GSHP temperatures at different points and conditions

Desired temperature 55 °C		Desired temperature 51 °C	
Measuring point	Temperature	Measuring point	Temperature
Suction line	7,2 bar	Suction line	7,2 bar
Discharge line	113,0 °C	Discharge line	101,0 °C
Liquid line	54,4 °C	Liquid line	50,5 °C

By the next step the momentary coefficient of performance before and after the temperature reduction are estimated by using CoolPack software. The software requires more values than it was possible to measure, therefore, some assumptions were made. For instance, the liquid line temperature is quite near the condensing temperature so it is assumed that the condensing temperature is the desired DHW temperature. Since the heat transfer is only caused because of the temperature difference, the refrigerant side temperature in a condenser is higher by 1 °C than that which is moved to the storage tank.

Moreover, the refrigerant vapor cycle is improved by the superheating and subcooling effect. It is recommended to superheat the low pressure vapor before the compressor at least by 5 K in order to ensure that the vapor before compression is dry. Also, it is recommended to subcool the liquid form refrigerant by few degrees to avoid bubbles in an expansion valve. In this research is assumed that the refrigerant is subcooled by 3 K. In addition, the circulation of refrigerant causes pressure losses in pipes. The maximum allowed pressure losses for the discharge and liquid line are 0,5 K, and for the suction line – 1 K.

All the other unknown values are covered by the isentropic efficiency. The value was chosen freely, so that the discharge temperature in the cycle would be approximately the same as it was measured. After these assumptions, the performance of heat pump was established as shown by Figures 17 and 18. In addition to this, the cycle diagram is drawn in Appendix 3.

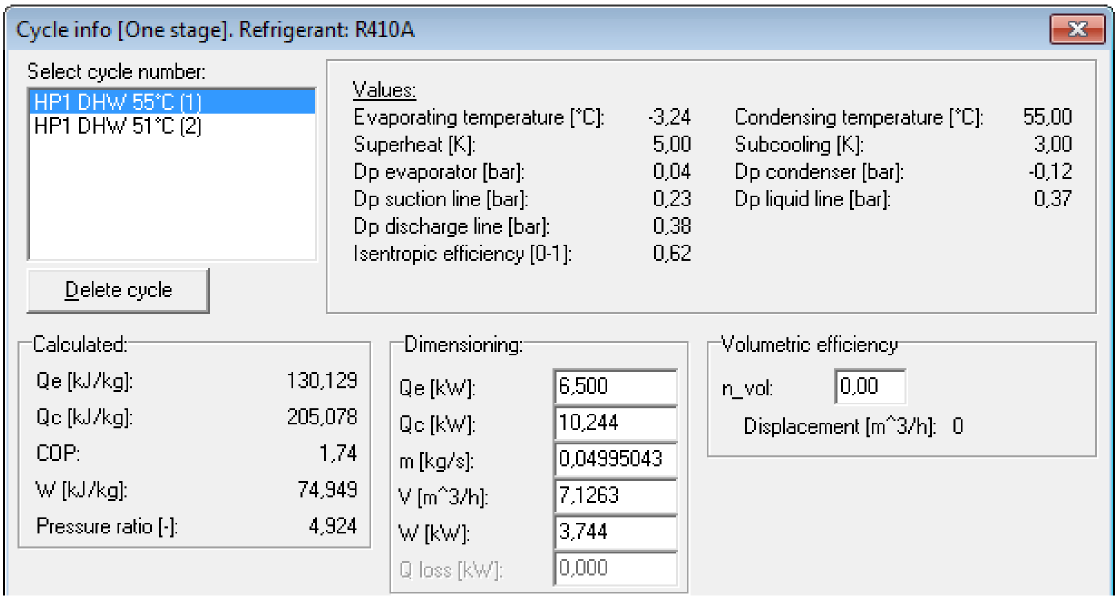

FIGURE 17. CoolPack cycle information, when GSHP is producing 55 °C DHW

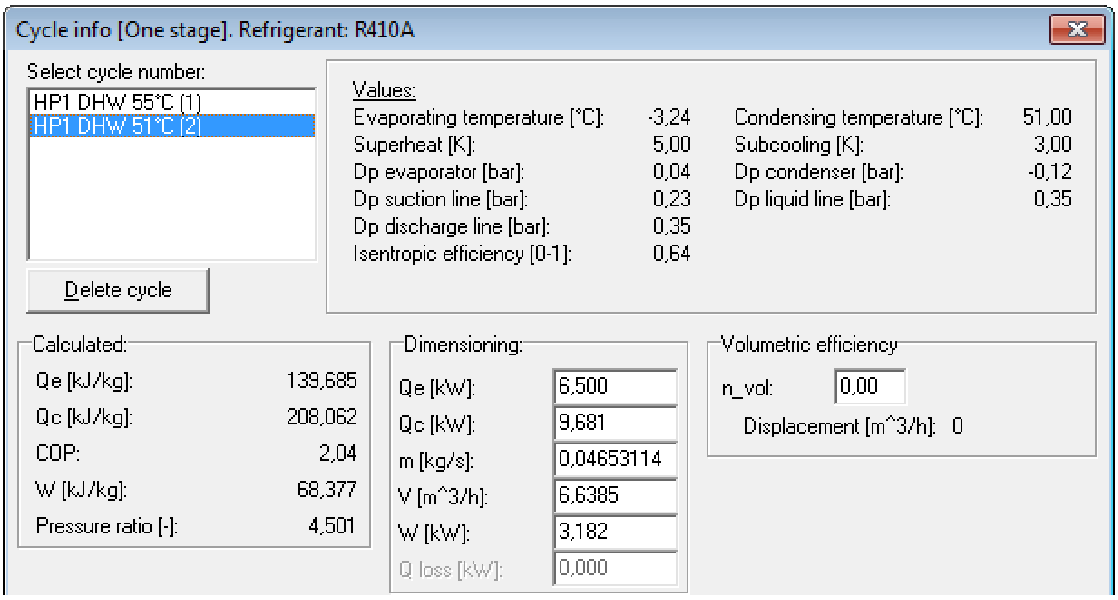

FIGURE 18. CoolPack cycle information, when GSHP is producing 51 °C DHW

Since the COP by the software is estimated for the cooling, by the next step the COP for heating is calculated by using Formula 1. The condensing power in the CoolPack is denoted as Q_c, which is divided by the consumed power (W). As a result, the COP value after the temperature reduction has increased from 2,74 to 3,04. It shows that the momentary COP after temperature reduction has increased by 11 %.

By the further steps, the noise emitted was determined, when the GSHP was operating near the set DHW temperature to achieve. The real time DHW temperature was provided by the heat pump's automation system. The averaged values for the total sound level of the 30 seconds period are represented by Figure 19.

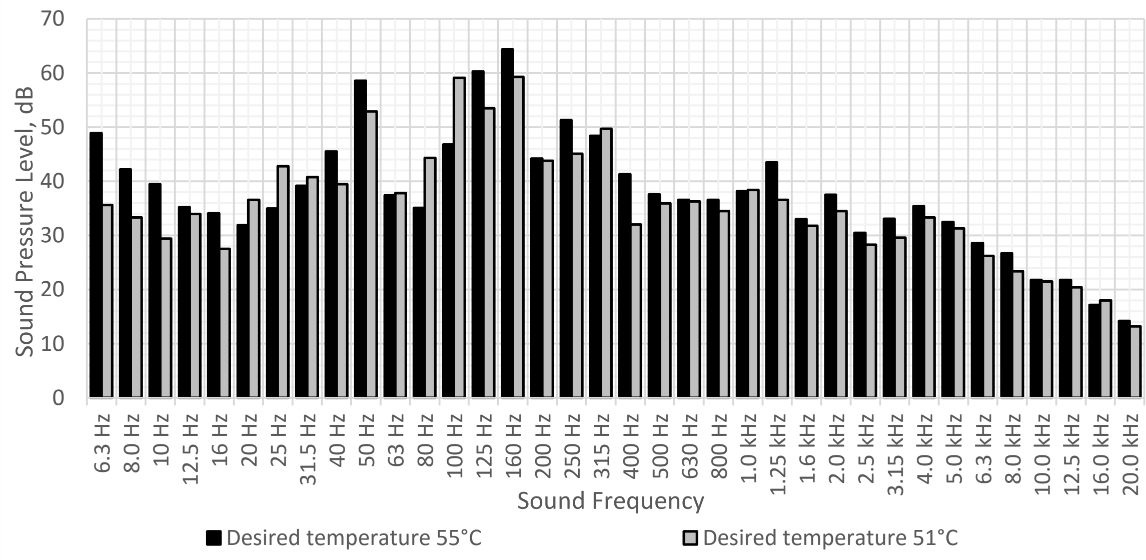

FIGURE 19. Total sound pressure levels at each frequency, when DHW of 55 °C and 51 °C is produced

When the GSHP was operating near 55 °C the measured total sound level was 54,0 dB. After the temperature reduction noise level has decreased to 50,3 dB. According to the Figure 19, the biggest influence on an equivalent noise level value has the sounds with lower frequencies. Also, the results show that most of the sound pressure levels are reduced when the desired GSHP temperature is reduced as well.

The averaged equivalent noise level with not operating heat pump is found to be 26,6 dB. According to the results the background noise contains more low frequency sounds as well. The results for the background noise are graphically represented by Figure 20.

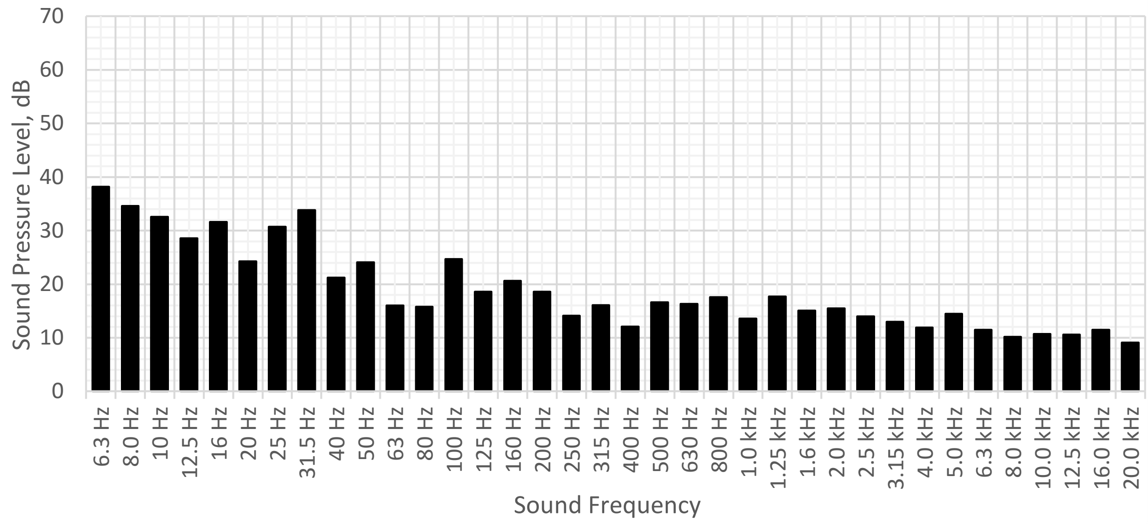

FIGURE 20. Background sound pressure levels at each frequency

Later, the noise produced only by the heat pump is calculated. The background noise level is subtracted from the total noise level measured according to the Formula 7. After these calculations it is found that the sound pressure level of the heat pump remains the same as the determined total noise level. A slight difference can be only found in separate sound frequency levels, which is shown by Figure 21. It means, that the background noise level is so low that it is put into the shade by the sounds emitted due to the heat pump operation.

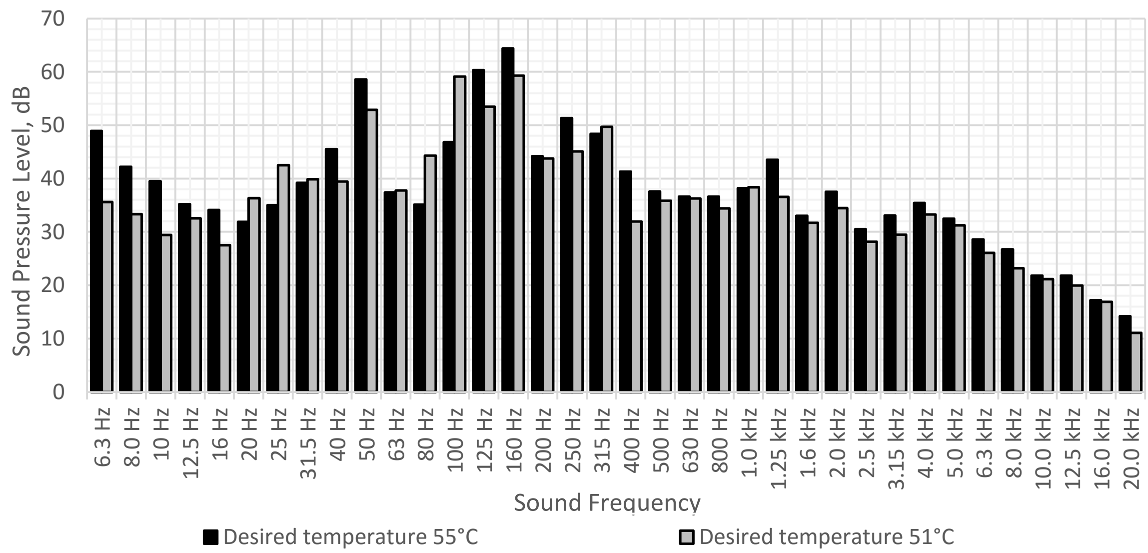

FIGURE 21. Different frequency sound levels emitted only by the heat pump

The equivalent noise level established in the utility room was 25,6 dB and 28,1 dB. After the DHW temperature reduction the noise level has increased. The Figure 22 gives the results of 1/1 octave bands, which are recalculated from 1/3 octave bands. There is a fact that human ear is the most sensitive for the sound frequencies that are in the range of 63 Hz – 8 kHz. Furthermore, additional calculations were done, because the comparison to NR curves of 1/3 octave bands would not be adequate (ISO gives the noise rating curves for certain sound frequencies of 1/1 octave bands). For example, it is clearly seen in the graph that after the temperature reduction the noise level of 250 Hz sound frequency was near the NR25 curve permissible limits.

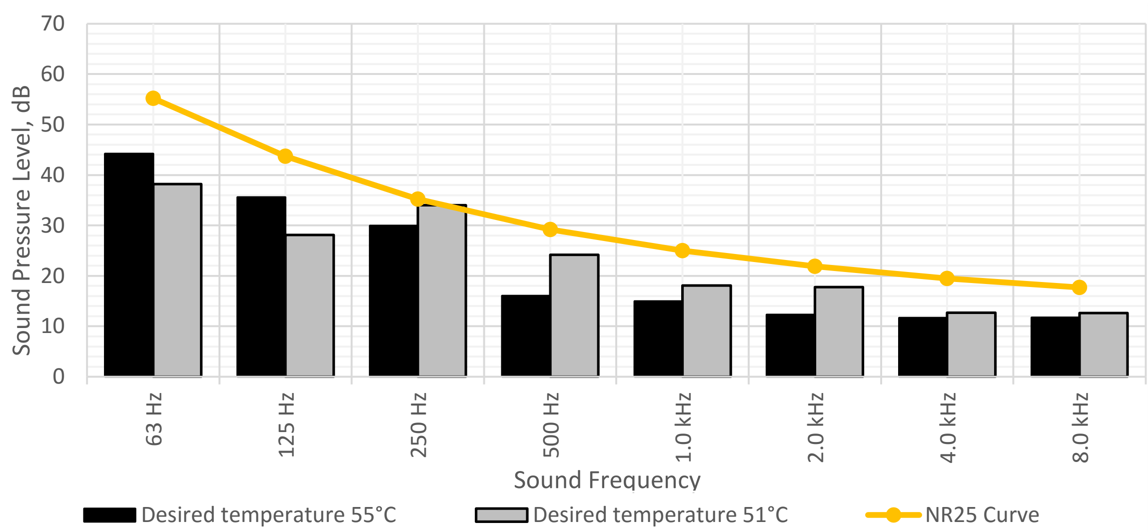

FIGURE 22. Total noise levels separated into frequencies in utility room

Comparing the change of the results with the measured sound levels in technical room it has changed oppositely. That kind of change could be influenced by several reasons. The first one is the properties of sound. The sound emitted from two different sources can cancel each other if it has the same frequency but the different phase. The second reason might be unadequate conditions. Since the house was not empty, the additional sound produced even shortly could have a huge influence on the averaged sound level results. Also, one of the possibilities is the different sound analyzer position.

At the latest step the DHW from the tap was measured. The results (shown by Table 8) after the GSHP temperature reduction was in a range provided by recommendations of Decree of Housing Health /3/. Furthermore, according to the Figure 7, the bacteria has no possibility to multiply and make colonies at 50 °C water temperature, but it may withstand this temperature approximately for 7 hours. The same amount of Legionella bacteria would be destroyed in 1 hour approximately when temperature is 54,4 °C.

TABLE 8. DHW temperature results from the tap

Desired DHW temperature by GSHP	Actual DHW temperature from tap
55,0 °C	54,4 °C
51,0 °C	50,0 °C

7.4 Results of the 2nd GSHP performance

The second GSHP temperatures in the different points was established mostly by the 8 channels thermocouple data logger. The measured values were compared to the GSHP own automation system. The values shown by both – data logger and automation system – was approximately the same. The results are represented by Table 9.

TABLE 9. Measured GSHP temperatures at different points and conditions

Desired temperature 55 °C		Desired temperature 51 °C	
Measuring point	Temperature	Measuring point	Temperature
Suction line	-2,4 °C	Suction line	-2,4 °C
Discharge line	88,7 °C	Discharge line	83,0 °C
After desuperheater	54,5 °C	After desuperheater	50,9 °C
Liquid line	39,3 °C	Liquid line	36,3 °C

In this case the condensing temperature is assumed to be the liquid line temperature. Since this GSHP has two separate heat exchangers on the condensing side, the way the performance is estimated slightly differs. Therefore, the desired DHW temperature is not the same as the condensing temperature.

All the other needed values are assumed to be the same as in previous case: pressure losses in discharge and liquid line – 0,5 K, in suction line – 1 K, superheating and sub-cooling – 5 K and 3 K respectively. The isentropic efficiency was chosen freely to set the discharge line temperature as determined. Because of the desuperheater and lower temperature in a condenser the isentropic efficiency is quite low – 0,46. It is because the heat pump model in the software has the basic construction – without desuperheater. Therefore, the idea is to set the right coordinates for the discharge temperature because the COP is dependent on enthalpy change according to the Formulas 5 and 6. The cycle information is provided by Figures 23, 24 and Appendix 3.

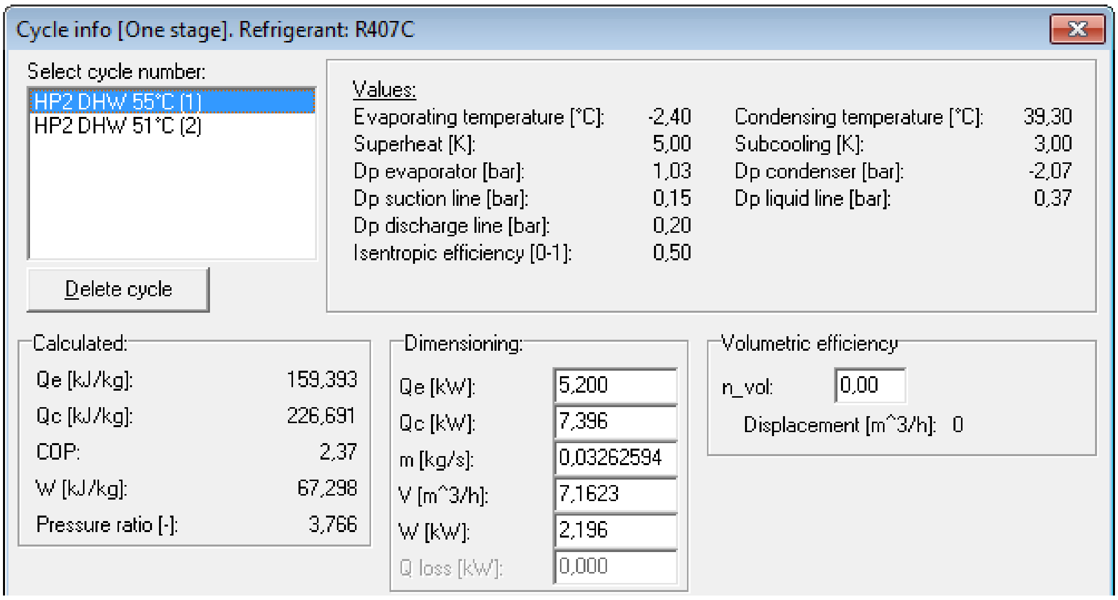

FIGURE 23. CoolPack cycle information, when GSHP is producing 55 °C DHW

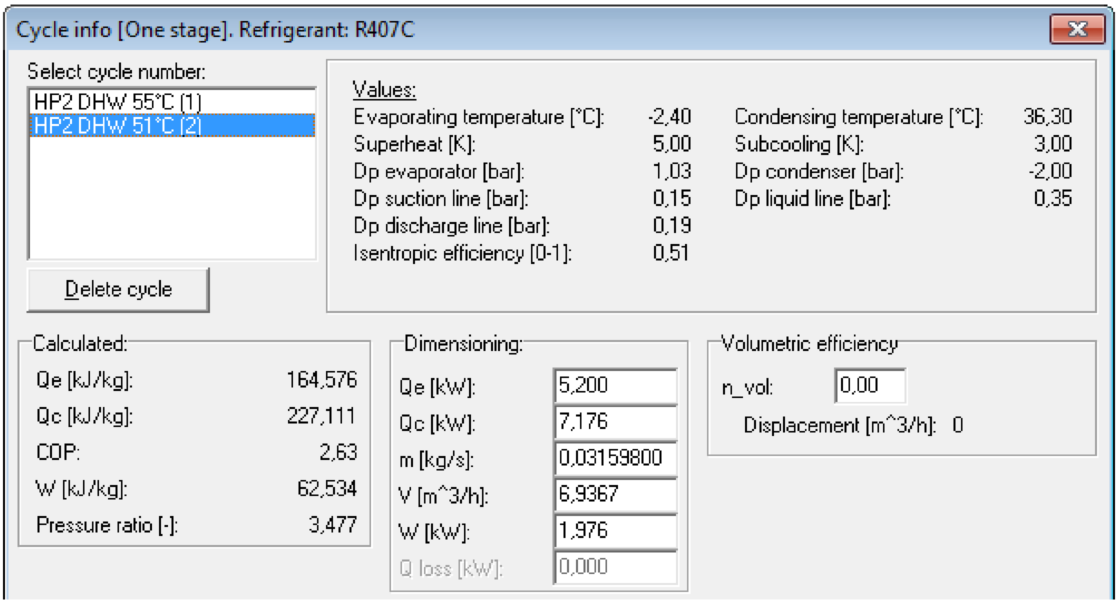

FIGURE 24. CoolPack cycle information, when GSHP is producing 51 °C DHW

At the next step the COP_1 for heating is calculated. The results show that the momentary COP value has increased from 3,37 to 3,63 after the temperature reduction. In this case the COP value was improved by 8%.

By the further steps, the background noise level in a technical room was established. The equivalent noise level was equal to 24,7 dB. The result separated in frequencies is shown by Figure 25.

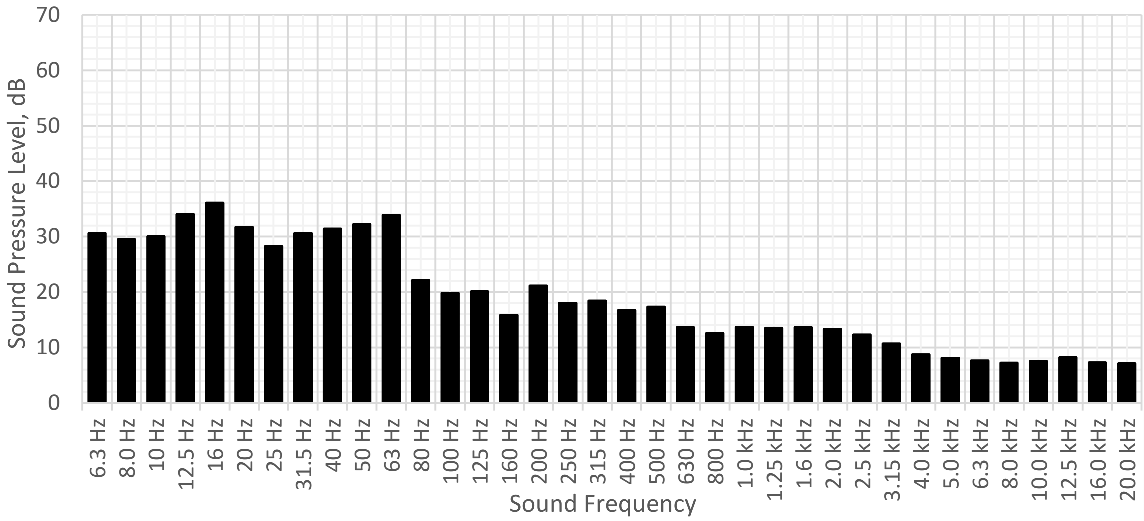

FIGURE 25. Background sound pressure levels at each frequency

Later, the noise levels in different GSHP operational conditions were determined. When the heat pump was producing 55 °C DHW the averaged sound pressure level was 43,1 dB. After the temperature reduction the noise level was almost the same – 42,9 dB. The sound frequency analysis provided by Figure 26 shows that the sound pressure level of different frequencies has no essential changes as well.

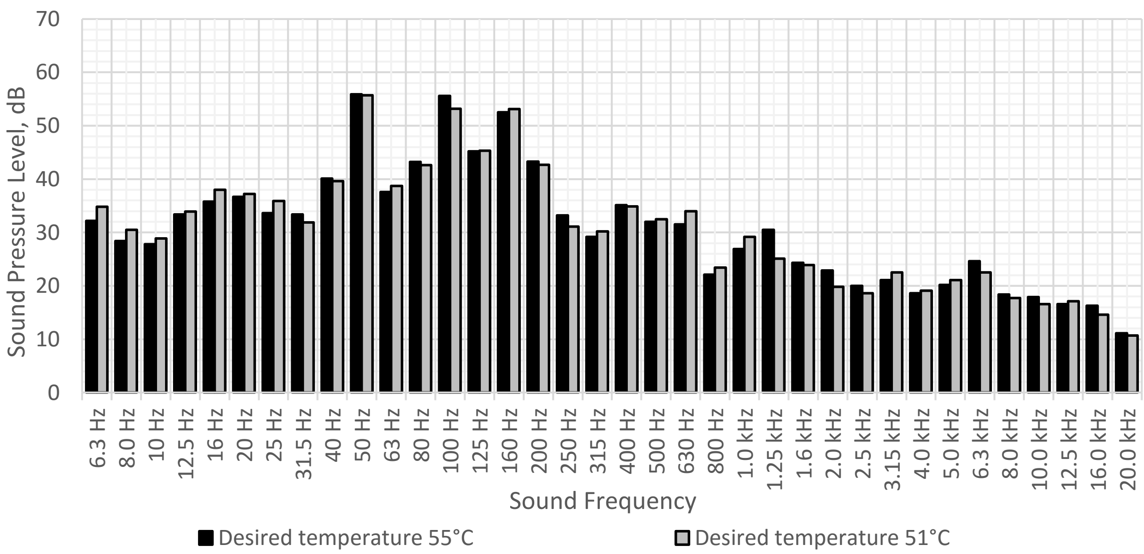

FIGURE 26. Total sound pressure levels at each frequency, when DHW of 55 °C and 51 °C is produced

With the next step the noise level produced only by the GSHP was calculated. As a result, when the heat pump is producing DHW of 55 °C and 51 °C the noise level without the background noise is 0,1 dB less than the total noise in both conditions. It means that the averaged noise levels are 43,0 dB and 42,8 dB respectively. Figure 27 shows that the GSHP mostly emits low frequency sounds. Moreover, the total noise level depends mostly on the noise emitted by the heat pump. The other sound sources has no essential influence.

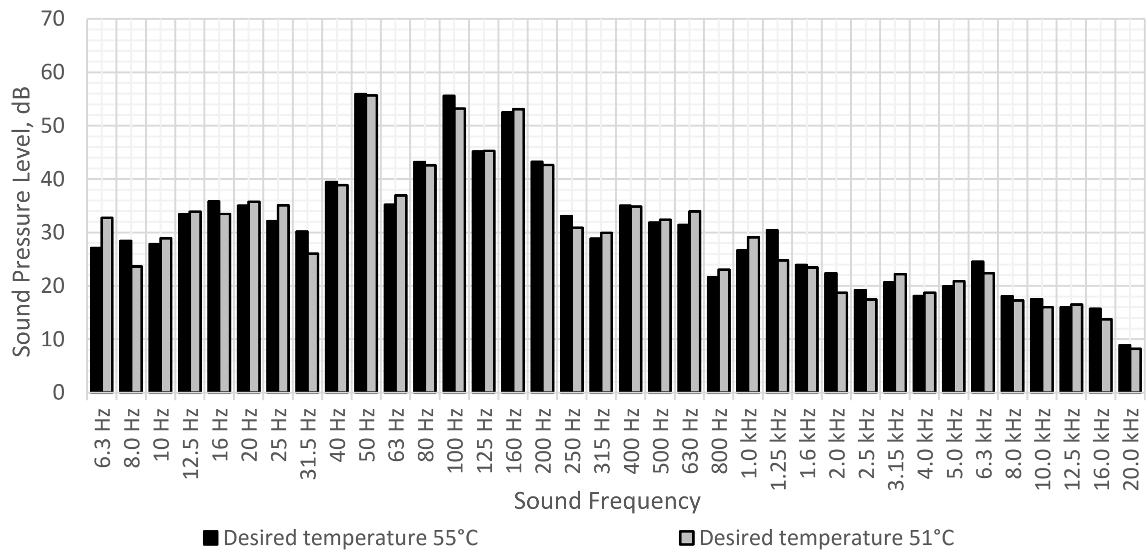

FIGURE 27. Different frequency sound levels emitted only by the heat pump

The Figures 28 and 29 represents the sound pressure levels and how it has changed in two surrounding room spaces – bedroom and fireplace. The wall between the technical room and the bedroom is made of the lighter construction than the wall of the fireplace. Therefore, the noise level in the bedroom was higher than in the fireplace. The equivalent averaged noise level in the bedroom was 26,5 dB, when the GSHP was operating at 55 °C. After the temperature reduction the noise level has increased to 28,1 dB. At the same conditions the noise level in the fireplace was increased from 24,0 dB to 24,1 dB.

Even though the change is minimum, the noise level tends to increase after the GSHP temperature reduction. The diagrams show that the noise produced by the heat pump is mostly of the low frequency sounds. The critical results were of 125 Hz sound in a bedroom, where before the temperature reduction noise level was near the NR25 curve limits and after the temperature reduction it was exceeded.

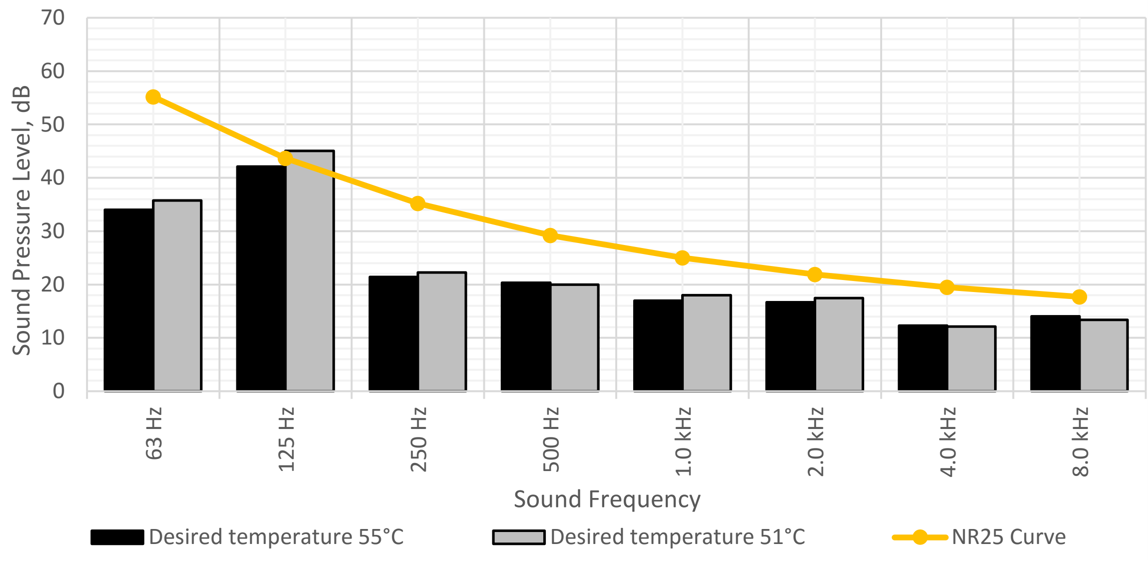

FIGURE 28. Total noise levels in a bedroom separated into frequencies

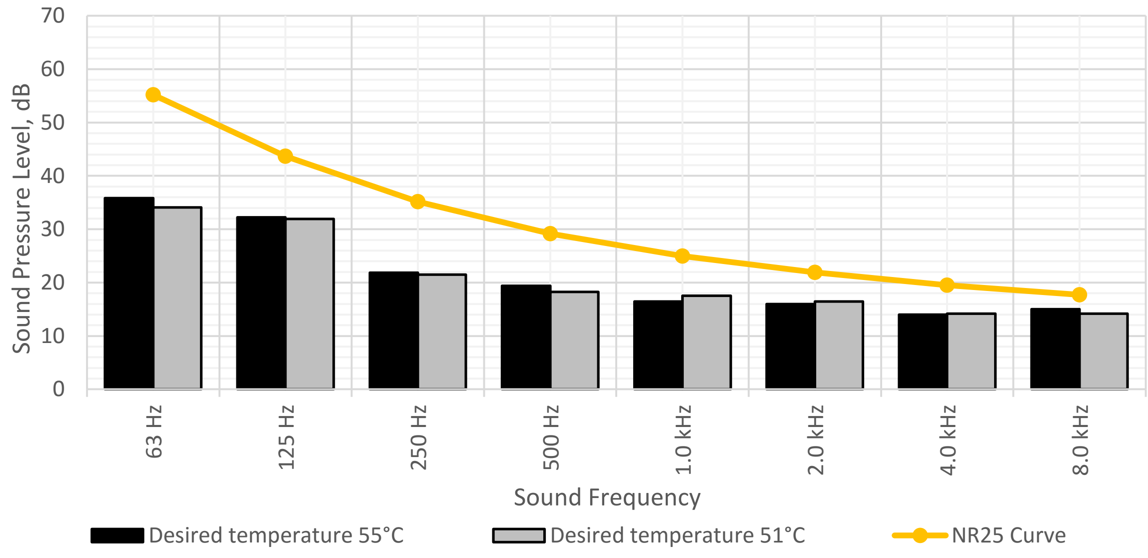

FIGURE 29. Total noise levels in a fireplace separated into frequencies

At the final stage, the temperature of DHW from tap was established. The results are shown by Table 9. The water temperature from the tap after the GSHP temperature reduction was 53,0 °C – the temperature from tap was 2 °C higher than the desired temperature to produce.

TABLE 10. DHW temperatures from the tap

Desired DHW temperature by GSHP	Actual DHW temperature from tap
55,0°C	54,8°C
51,0°C	53,0°C

The main reason for these results is the additional component - desuperheater. Since the hot water from the desuperheater is directed to the top level of the tank, it heats up the domestic hot water more than the automation system could measure. The temperature sensor for DHW is attached to the middle level of the storage tank. Moreover, when the heat pump was producing 55 °C DHW, the water temperature from the tap was not exceeding the produced one. It is because of the mixing valve in the DHW distribution system, which controls DHW supply temperature.

From the microbiological point of view, the Legionella bacteria in such temperatures has no possibility to multiply. If the bacteria was able to appear it would withstand not more than 3 hours. When the heat pump is operating without temperature reduction, the bacteria would die in 1 hour approximately. Furthermore, the possibility of Legionella to appear is quite low because there is no DHW storage tank. In addition, the temperature before the DHW leaves the storage tank is usually higher than it is set to produce.

7.5 Results of the 3rd GSHP performance

The results for the temperatures of the heat pump are represented by Table 11. Mostly it was taken from the GSHP own automation system. Since the liquid line temperature was not provided, it was measured by the thermocouple data logger.

TABLE 11. Measured GSHP temperatures at different points and conditions

Desired temperature 51 °C		Desired temperature 55 °C	
Measuring point	Temperature	Measuring point	Temperature
Suction line	-1,9 °C	Suction line	-1,9 °C
Discharge line	91,0 °C	Discharge line	83,0 °C
Liquid line	54,7 °C	Liquid line	50,3 °C

Since this ground source heat pump has the same components inside as the first one, all of the assumptions applied for the vapor compression cycle analysis are the same. As a result, the cycle information with the assumed input data is represented by Figures 30 and 31. The cycle diagrams for the different conditions are drawn in Appendix 3 as well.

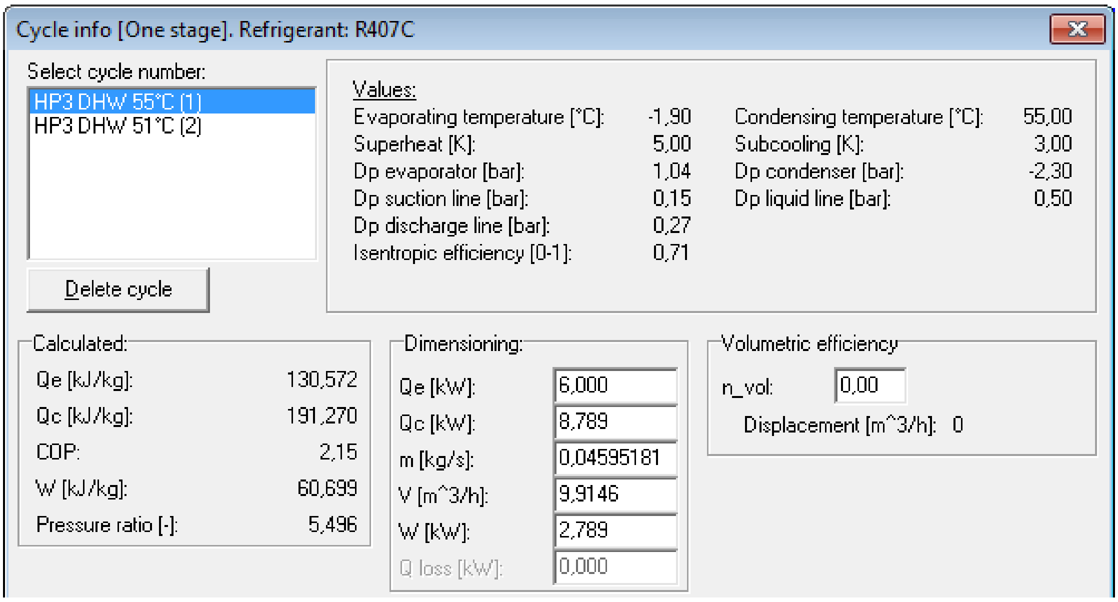

FIGURE 30. CoolPack cycle information, when GSHP is producing 55 °C DHW

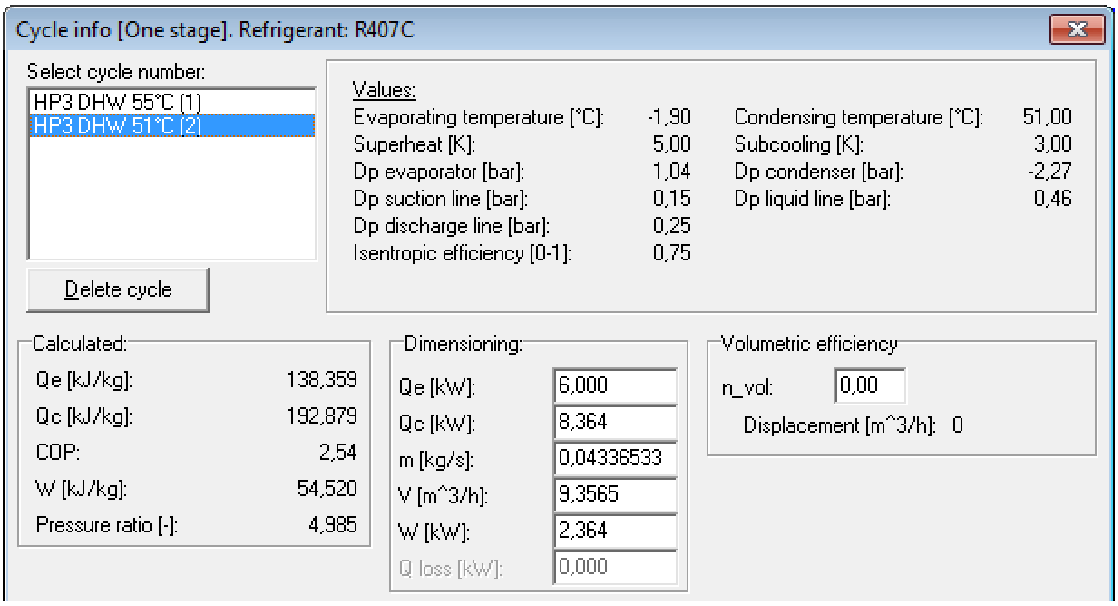

FIGURE 31. CoolPack cycle information, when GSHP is producing 51 °C DHW

The calculated momentary COP_1 values for the heating are 3,15 and 3,54. The temperature reduction of 4 °C had a positive effect on the momentary COP value, which was improved by 0,41. It means that the heat pump efficiency at the lower temperature is higher by 12%.

The established background noise level in the technical room was 22,2 dB. Mostly this value covers the low frequency sounds, which has the highest sound pressure levels. The distribution of the sound pressure levels at each frequency is shown by Figure 32.

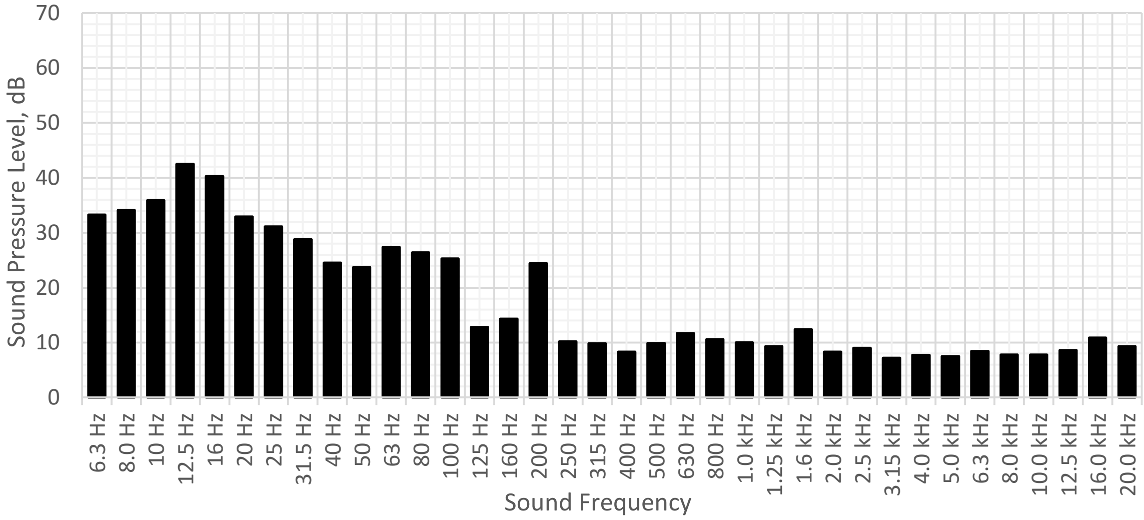

FIGURE 32. Background sound pressure levels at each frequency

When the GSHP was producing the DHW of 55 °C, the total sound level in the technical room was 41,4 dB. After the producing temperature was reduced, the heat pump operation became quitter – the noise level reduced by 2,1 dB. More details about the sounds emitted and how it has changed is shown by Figure 33. As it can be seen, the emitted sound pressure levels has mostly decreased. The highest reduction in sound pressure level was of the 31,5 Hz frequency sound.

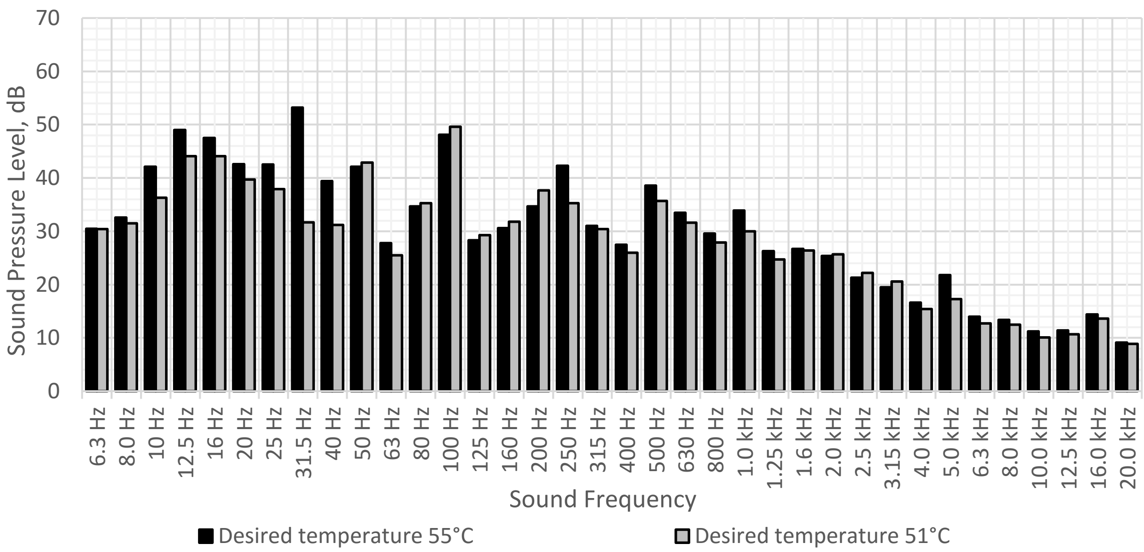

FIGURE 33. Total sound pressure levels at each frequency, when DHW of 55 °C and 51 °C is produced

At the next step the background noise was subtracted from the total noise level. The equivalent averaged values are found to be 41,3 dB (55 °C DHW produced) and 39,2 dB (51 °C DHW produced). The results show that the background noise has no impact on the total noise level – all the sounds emitted due to the GSHP operation has higher sound pressure level than from the other sources. Furthermore, as shown in Figure 34, this GSHP is mainly a source of low frequency sounds, which has the biggest influence on the equivalent noise level.

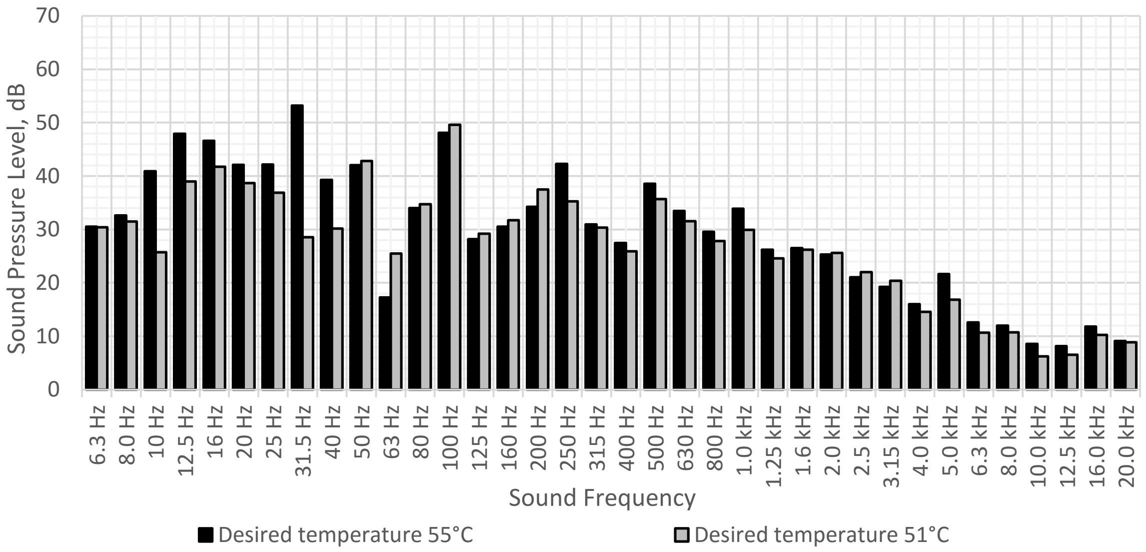

FIGURE 34. Different frequency sound levels emitted only by the heat pump

The noise emitted by the heat pump to the surrounding premises was measured to be 22,6 dB and, after the temperature reduction, 23,0 dB. In this case the change in equivalent sound level is not high – the difference is only 0,4 dB. Furthermore, after the temperature reduction the noise level has increased. The ground source heat pump started to emit more high frequency sounds, but the change in sound levels is the minimum. It may be clearly seen in Figure 35, which also proves, that there is no critical sounds levels emitted.

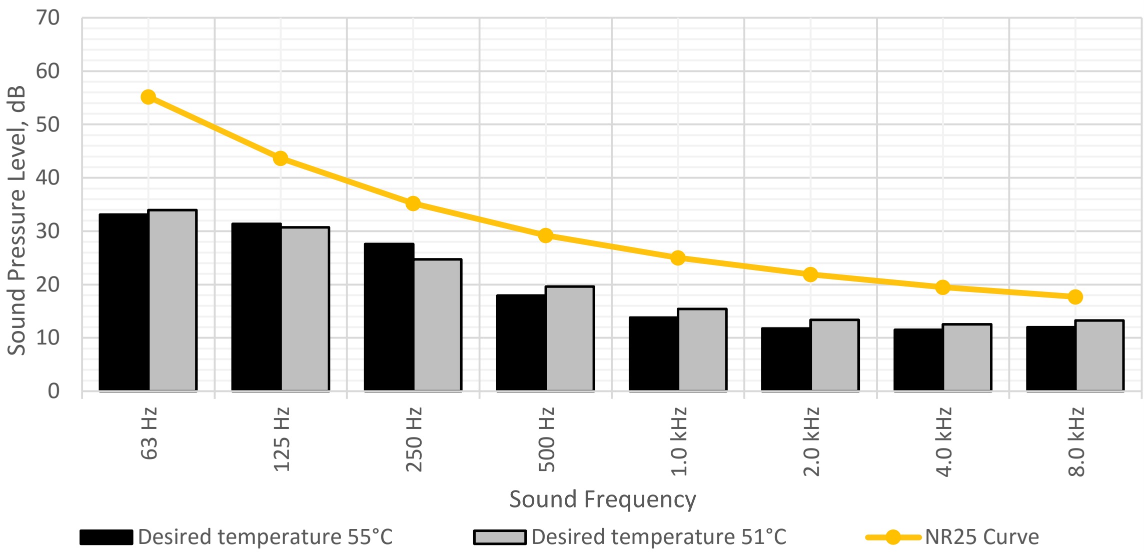

FIGURE 35. Total noise levels at each frequency in a surrounding room

At the final stage of this research, the DHW temperature from tap was determined as shown by Table 12. When the heat pump was producing the 51 °C DHW the actual water temperature from tap was lower than recommended by Ministry of Social Affairs and Health /3/. The reason for that is the pipework made of copper, which some part is installed in an unheated room space. Therefore, the DHW was cooled down because of the quite high heat losses.

TABLE 12. DHW temperature results from the tap

Desired DHW temperature by GSHP	Actual DHW temperature from tap
51,0 °C	49,3 °C
55,0 °C	52,8 °C

According to these results, possibility for Legionella multiplication is very low in such system. The bacteria is destroyed in 10 hours approximately when the supplied domestic hot water is 49,3 °C. At the normal GSHP conditions the bacteria will die in 3 hours.

8 IMPLICATION OF THE RESULTS

8.1 Change in Coefficient of Performance

The results from several ground source heat pumps have proven that the coefficient of performance is better, when the DHW temperature is reduced. By 4 °C temperature difference the momentary COP was improved from 8 % to 12 %. The summary of the results is shown by Table 13.

TABLE 13. Summary table of each GSHP performance

GSHP No.	Desired conditions	Momentary COP_1	Change in COP
1	55 °C	2,74	+11 %
	51 °C	3,04	
2	55 °C	3,37	+8 %
	51 °C	3,63	
3	55 °C	3,15	+12 %
	51 °C	3,54	

The smallest increase in COP was found on the GSHP with the desuperheater. On the other hand, this GSHP was operating in relatively higher efficiencies than the first and the third heat pumps. It means that the desuperheater is useful component, which helps to produce more heat with the lower power consumption.

The change in momentary COP was bigger in the GSHPs with the basic construction. The first and the third heat pump efficiency has increased by 11 % and 12 % respectively. Furthermore, these ground source heat pumps are operating with lower efficiency because of the bigger temperature difference between the condenser and evaporator. Therefore, more power is needed to operate the compressor in order to achieve higher temperatures.

8.2 Change in noise levels

The situation with the noise levels produced by the ground source heat pumps was also improved. The sound level of researched GSHPs was reduced from 0,2 dB to 3,7 dB according to the results. The results of noise emitted only by heat pumps are summarized by Table 14.

TABLE 14. Summary table for the GSHP generated noise level

GSHP No.	Desired conditions	GSHP noise level	Change in noise level
1	55 °C	54,0 dB	-3,7 dB
	51 °C	50,3 dB	
2	55 °C	43,0 dB	-0,2 dB
	51 °C	42,8 dB	
3	55 °C	41,3 dB	-2,1 dB
	51 °C	39,2 dB	

The biggest noise level reduction was established from the first GSHP. However, this heat pump was producing higher noise levels than the other equipment. The smaller change after the GSHP temperature reduction was found on the third heat pump. The noise level was reduced by 2,1 dB. Also the sound level is established to be lower than the first one. One of the reasons for the lower noise emitted might be the additional insulation layer on the compressor.

The reduction of noise level was very small from the second GSHP. The noise produced by the heat pump with desuperheater reduced only by 0,2 dB. In general, this change in sound level is not an essential one. The reason for that can be the unique GSHP construction, where the compressor is placed in the insulated metal box and the discharge line temperature is reduced by desuperheater. Therefore, the compressor even near the higher DHW temperature can operate at the design pressure ratio.

Moreover, the opposite results of the noise levels produced in a surrounding room spaces was determined. After the DHW temperature reduction, the noise levels in all of the room spaces have increased. The results are shown in summary Table 15.

TABLE 15. Summary table of the noise levels in surroundings

GSHP No.	Room name	Desired conditions	Noise level	Change in noise level
1	Utility room	55 °C	25,6 dB	+2,5 dB
		51 °C	28,1 dB	
2	Bedroom	55 °C	26,5 dB	+1,6 dB
		51 °C	28,1 dB	
	Fireplace	55 °C	24,0 dB	+0,1 dB
		51 °C	24,1 dB	
3	Garage	55 °C	22,6 dB	+0,4 dB
		51 °C	23,0 dB	

One of the reasons may be the properties of sound – when the sound of the same frequency is emitted from the different sound sources but the phase is different these sounds cancels each other. Therefore, when the GSHPs were producing the DHW of the higher temperature, some of the sounds were identical to the other source of sounds. After the temperature reduction it has changed so that the noise level has increased. Another possible reason can be the inaccuracy of the measuring process. For example, the results may be influenced by unnecessary additional sound sources or the measuring device could be in a slightly different position each time the noise level was established.

Moreover, the results of noise levels established is compared to the classification of the buildings (Table 1). Since the GSHP has to achieve the temperatures of DHW 55 °C, it is also operating near the lower temperatures. It means that the correct value of the noise emitted to compare would be near the lower DHW temperature produced.

The first researched object according to the sound level produced (28,1 dB) in the utility room meets the requirements for the S1 class of the buildings. Since the utility room is not a living room according to the purpose can be assumed as a kitchen. The permissible noise level for this class according to the Table 1 is 33 dB. If this room space was one of the living rooms, the noise level for this class would be too high.

The second building, according to the measured noise level in the bedroom is out of the permissible range for S3 class. The maximum sound level for this class is 28 dB, which was exceeded by 0,1 dB. Since the measured parameters do not meet the requirements, the situation can be improved by changing the wall construction. If the building was classified according to the results from fireplace (24,1 dB) – it would meet the requirements for S2 class and would not be far away from the S1 class.

The situation with the sounds produced to the surrounding room spaces was the best. According to the results, the noise level of 23,0 dB would meet the requirements for S1 class. Since the garage is not the living environment, the permissible noise level is high. If this room space would be the living room, the noise level for S1 class would be still by 1 dB lower.

8.3 Possibility of Legionella survival

The water temperature after the DHW temperature reduction was quite near the desired temperature level in all of the objects. The biggest decrease in the temperature was from the third heat pump, where the 49,4 °C water was supplied. Before the temperature reduction the water temperature from the tap was 52,8 °C. The water temperature after the reduction is under the recommended temperature level. Furthermore, Legionella bacteria in the DHW system could survive for more than 3 times longer period.

Almost the same phenomena is seen by the results of the first GSHP. After the DHW temperature reduction, the tap water was 50 °C. Even though, the value is in a recommended value, the risk of Legionella is increased. The time the Legionella could withstand in 50 °C is 7 times longer than in 54,4 °C. Furthermore, the possibility of Legionella appearance is minimal, because of the DHW system volume - there is no DHW storage tank, where the bacteria could easily form colonies.

According to the results of the second GSHP, the possibility of Legionella survival is almost not increased. Since there is a desuperheater, the DHW is with the higher temperature than the set to produce. Therefore, the risk of Legionella appearance may increase only in the pipework dead ends (because of mixing valve on DHW supply). The measured water temperature was 53 °C at the tap, which means that the temperature reduction would increase the time for Legionella survival 2 times approximately.

9 CONCLUSIONS

This study was designed to find out the change of ground source heat pump performance when reducing the domestic hot water temperature. Moreover, to analyze how the noise level of the heat pump is affected. The possibility of Legionella survival related to the DHW temperature was taken into account in order to prove the DHW temperature reduction.

The reduction of domestic hot water temperature has two different effects – positive and negative. The main results showed that the temperature reduction even by 4 °C increases the momentary GSHP operating efficiency by approximately 8 – 13 %. Also, the noise production by the heat pump reduces quite much – from 2,1 – 3,7 dB. An exception is a GSHP with installed desuperheater, on which the temperature reduction had almost no influence on the noise level produced.

The further studies proved that the DHW temperature reduction have a negative effect on the water quality. The risk on human health increases. The time, which Legionella bacteria can withstand in the water after temperature reduction becomes 2 – 7 times longer. However, the temperature level remains quite high and the bacteria has no possibility to multiply. Furthermore, the results stating unfavorable effect on the noise level in a surrounding room spaces is less important but worth mentioning. The increase of noise level in a nearest rooms, while the sound emission from the source is decreasing seems to be not adequate. Also, this phenomena cannot be avoided even the GSHP is set to produce warmer DHW, because an equipment operates at lower temperatures until it achieves the desired one.

Based on this research results, I would suggest to analyze an existing system in more detailed before saving energy. The lowest possible cause of health problems can be ensured in the systems with as low DHW volume as possible. Such systems are without the domestic hot water tank. Moreover, one of the advices would be to heat the DHW up to 60 °C once a day for about 10 minutes. The Legionella would be prevented because of quite small amount of bacteria particles in the water and inability to multiply.

This investigation was limited, because the actual domestic hot water quality could not be examined by taking the real water samples. As a reference result the DHW temperature was used for the analysis based on the other research. Therefore, the further research may include the real examination of water samples. The combination of Building Services Engineer and the specialist of microbiology would be one of the best solution for such study. Moreover, the performance of ground source heat pump may be analyzed for a longer time period. The momentary COP does not show the real GSHP efficiency, because the COP varies every moment. Also, every start and stop of the heat pump consumes more power than it is normally operating.

LITERATURE

1. The Finnish Heat Pump Association. Growth in heat-pump sales volumes in Finland – 670,000 heat pumps are drawing 5 TWh worth of renewable energy from around buildings. 2015. PDF document. http://www.sulpu.fi/documents/184029/189661/SULPU%20Pressrelease%201_2015.pdf. Referred 14.10.2015.
2. Granryd, E., Ekroth, I., Lundqvist, P., Melinder, Å., Palm, B., Rohlin, P. Refrigerating Engineering. Stokholm: Royal Institute of Technology, KTH. 2009.
3. Itoh, T., Fujitani, M., Takeda, K. Noise Reduction of Scroll Compressor by Pressure Pulsation Control. 1995. PDF document. https://www.mhi.co.jp/technology/review/pdf/e323/e323132.pdf. Referred 8.11.2015.
4. D1 Suomen Rakentamismääräyskokoelma. Kiinteistöjen Vesi- ja Viemärilaitteistot, Määräykset ja Ohjeet. Ympäristöministeriö. 2010.
5. Sosiaali- ja Terveysministeriön Asetus. Asunnon ja muun oleskelutilan terveydellisistä olosuhteista sekä ulkopuolisten asiantuntijoiden pätevyysvaatimuksista. 2015. PDF document. http://stm.fi/documents/1271139/1408010/Asumisterveysasetus/. Referred 5.11.2015.
6. Public Health Agency of Canada. Legionella. WWW document. http://www.phac-aspc.gc.ca/id-mi/legionella-eng.php. Updated 18.10.2015. Referred 18.10.2015.
7. Namų šildymas. Kas tai yra legionelės. WWW document. http://www.namusildymas.lt/2011/05/04/kas-tai-yra-legioneles/. Updated 5.11.2015. Referred 5.11.2015.
8. Rauf, S. Bobby. Thermodynamics Made Simple for Energy Engineers. United States of America: The Fairmont Press, Inc. 2011.
9. IPU. CoolPack. WWW document. http://en.ipu.dk/Indhold/refrigeration-and-energy-technology/coolpack.aspx. Updated 27.11.2015. Referred 27.11.2015.
10. Minnesota Geothermal Heat Pump Association. Geothermal Loop Options. WWW document. http://minnesotageothermalheatpumpassociation.com/geothermal/earth-loop-options/. Updated 22.10.2015. Referred 22.10.2015.
11. Energy Saver. Geothermal Heat Pumps. WWW document. http://energy.gov/energysaver/geothermal-heat-pumps. Updated 22.10.2015. Referred 22.10.2015.

12. ACCA, PHCC Educational Foundation, RSES. HVACR 401: Heat Pumps. United States of America: Cengage Learning. 2011.
13. Energy Saving Trust. Ground Source Heat Pumps. WWW document. http://www.energysavingtrust.org.uk/domestic/ground-source-heat-pumps. Updated 23.10.2015. Referred 23.10.2015.
14. Newland, J. Vibration Comparison of Scroll & Rotary vs. Reciprocating Technology. PDF document. http://www.bristolcompressors.com/files/7913/7771/5745/compression_technology_vibration.pdf. Referred 8.11.2015.
15. McQuay International. HVAC Acoustic Fundamentals. PDF document. http://www.vibrationdata.com/tutorials2/AG31-010lo.pdf. Referred 8.11.2015.
16. Rasmussen, B. Sound classification schemes in Europe – Quality classes intended for renovated houses. 2010. PDF document. http://vbn.aau.dk/files/43741580/SoundClassesEuropeRenovatedHousing_TU0701_UniversityMalta_May2010BiR.pdf. Referred 9.11.2015.
17. Jagniatinskis, A., Mickaitis, M., Fiks, B. Development Classification Scheme for Evaluation Dwellings Sound Insulation Performance in Lithuania. Procedia Engineering. Ejournal, PDF document. http://www.sciencedirect.com/science/article/pii/S187770581300790X. 57, 443-449. 2013.
18. LVI 05-10440 en. Classification of Indoor Environment 2008. 2010.
19. Cirrus Research Plc. Calculation of NR & NC Curves in the optimus sound level meter and the NoiseTools software. 2013. PDF document. http://www.cirrusresearch.co.uk/library/documents/technical_papers/TN31_Calculcation_of_NR_and_NC_Curves_in_the_optimus_sound_level_meter_and_NoiseTools_software.pdf. Referred 8.12.2015.
20. Committee on Public Water Supply Distribution Systems: Assessing and Reducing Risks. Drinking Water Distribution Systems: Assessing and Reducing Risks. United States: National Academies Press. 2006.
21. Bartram, J. Legionella and the Prevention of Legionellosis. World Health Organization (WHO). 2007.
22. Energiateollisuus Ry. Kaukolämmön Lämmönjakokeskusten Kytkennnät ja Lämmönsiirtimien Mitoitusoämpötilat. 2011. PDF document. http://energia.fi/sites/default/files/ljk-kytkennat_mitoituslampotilat_poyry_2011.pdf. Referred 4.11.2015.

23. Pico Technology. Thermocouple Data Logger. WWW document. https://www.picotech.com/data-logger/tc-08/thermocouple-data-logger. Updated 13.11.2015. Referred 13.11.2015.
24. Norsonic. Sound Analyzer Nor140 – “Multi-Tool”. WWW document. http://www.norsonic.com/en/products/sound_level_meters/sound_analyser_nor140/Sound+Analyser+Nor140+-+%22MULTI-TOOL%22.9UFRjQYk.ips. Updated 13.11.2015. Referred 13.11.2015.
25. IMI Hydronic. TA – CMI Measuring Instrument. PDF document. http://www.imi-hydronic.com/ProductFiles/Products/documents/Archive/Measuring%20Instruments/TA-CMI_EN_MAIN.pdf. Referred 13.11.2015.
26. Stiebel Eltron, Ltd. Ground Source Heat Pump Installation and Operation. User Manual.
27. Oilon Home Oy. Operation Manual SH 7 – SH 28. PDF document. http://www.oilon.com/uploadedFiles/OilonHome/Materials/SH%20EN%20Operation%20manual.pdf. Referred 8.12.2015.
28. Bosh. Compress EHP 5000. 6-17 LWM 6-17 LW. PDF document. http://onninen.procus.fi/documents/original/12546/5/1/Compress5000N_LW_IM_FIpieni.pdf. Referred 8.12.2015.

APPENDIX 1.

Researched Ground Source Heat Pump automation systems

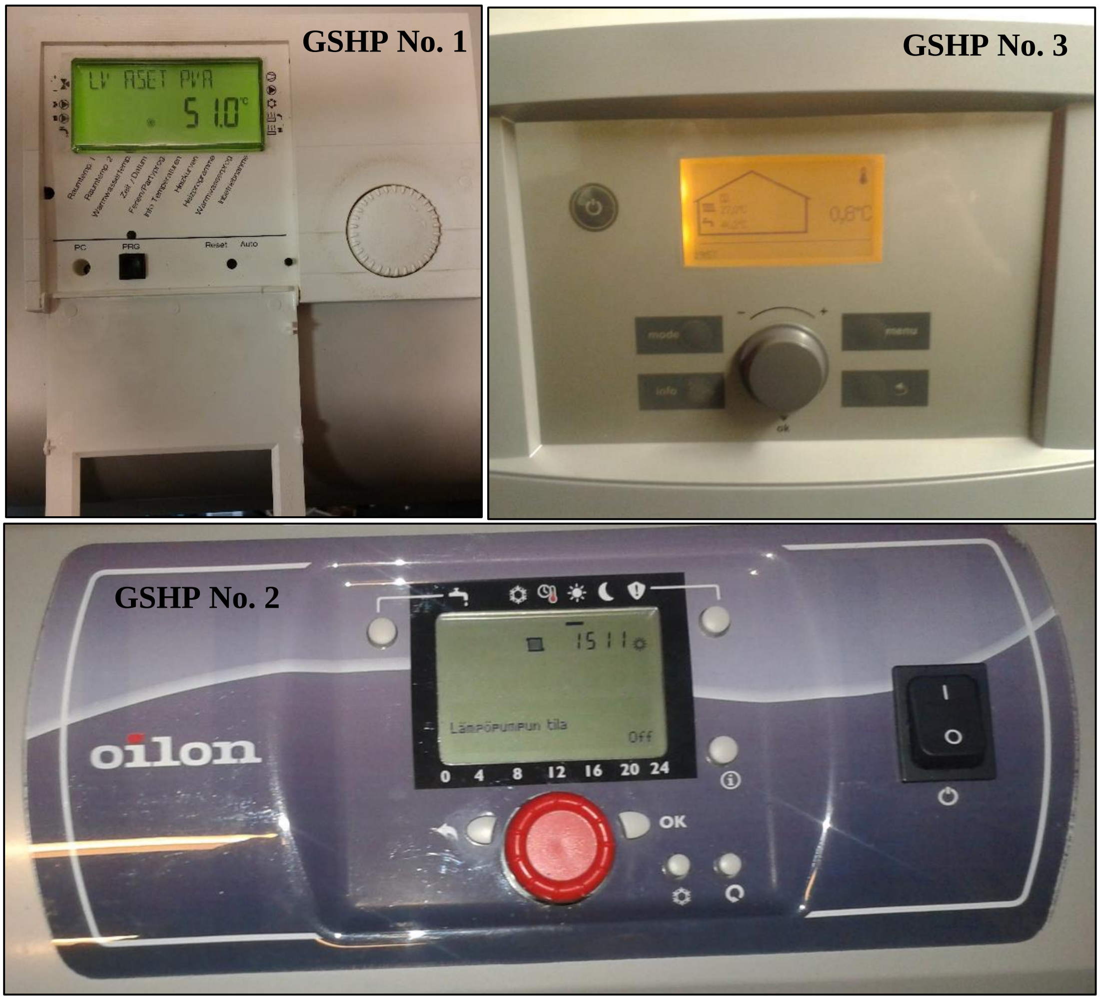

FIGURE 36. GSHPs' automation systems

APPENDIX 2(1).

Researched Ground Source Heat Pump systems

FIGURE 37. GSHP No. 1

FIGURE 38. GSHP No. 2

Researched Ground Source Heat Pump systems

FIGURE 39. GSHP No. 3

APPENDIX 3(1).

Vapor-Compression Cycle diagrams

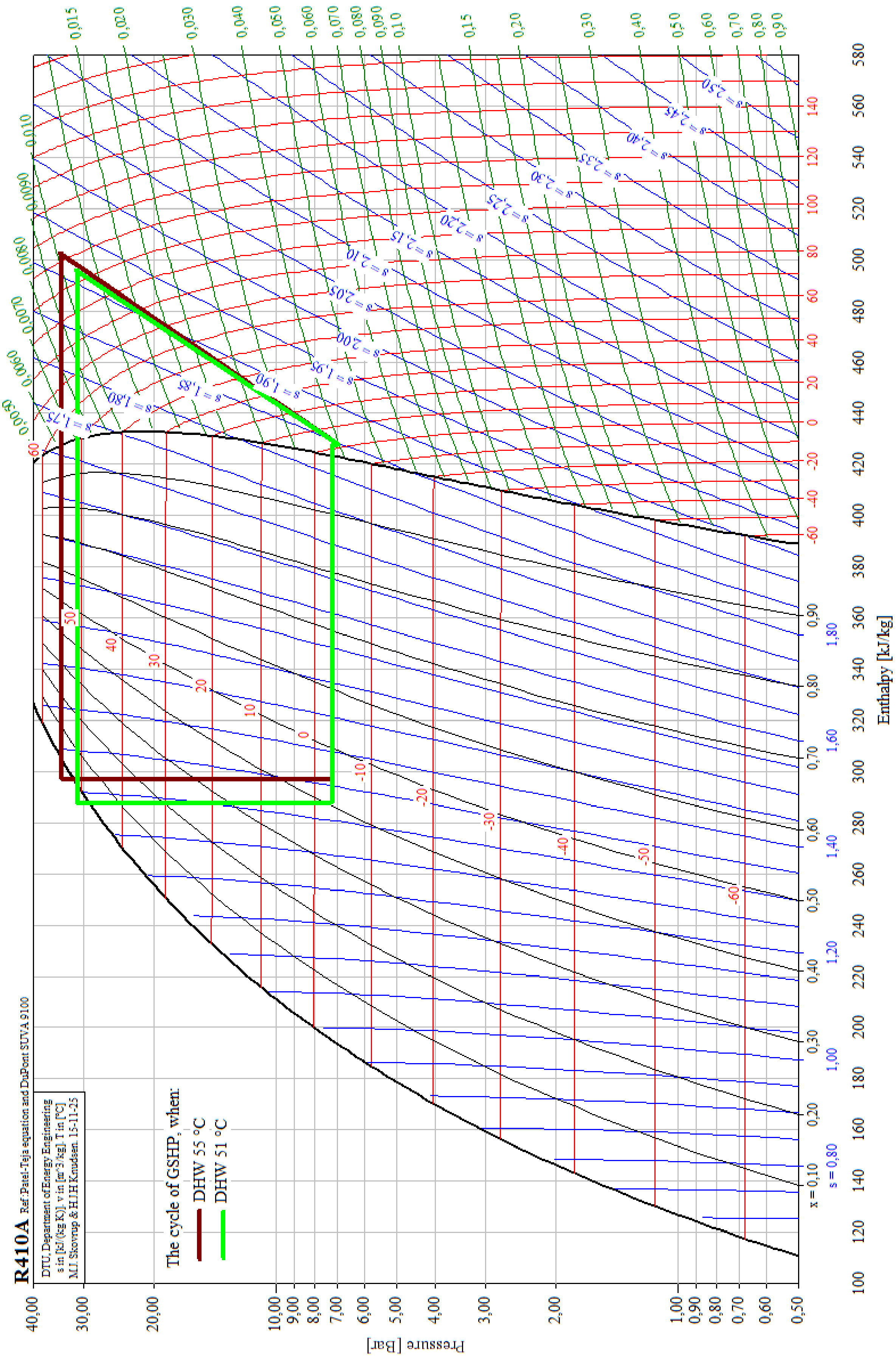

FIGURE 40. Vapor-compression cycle diagram of the 1st GSHP

APPENDIX 3(2).

Vapor-Compression Cycle diagrams

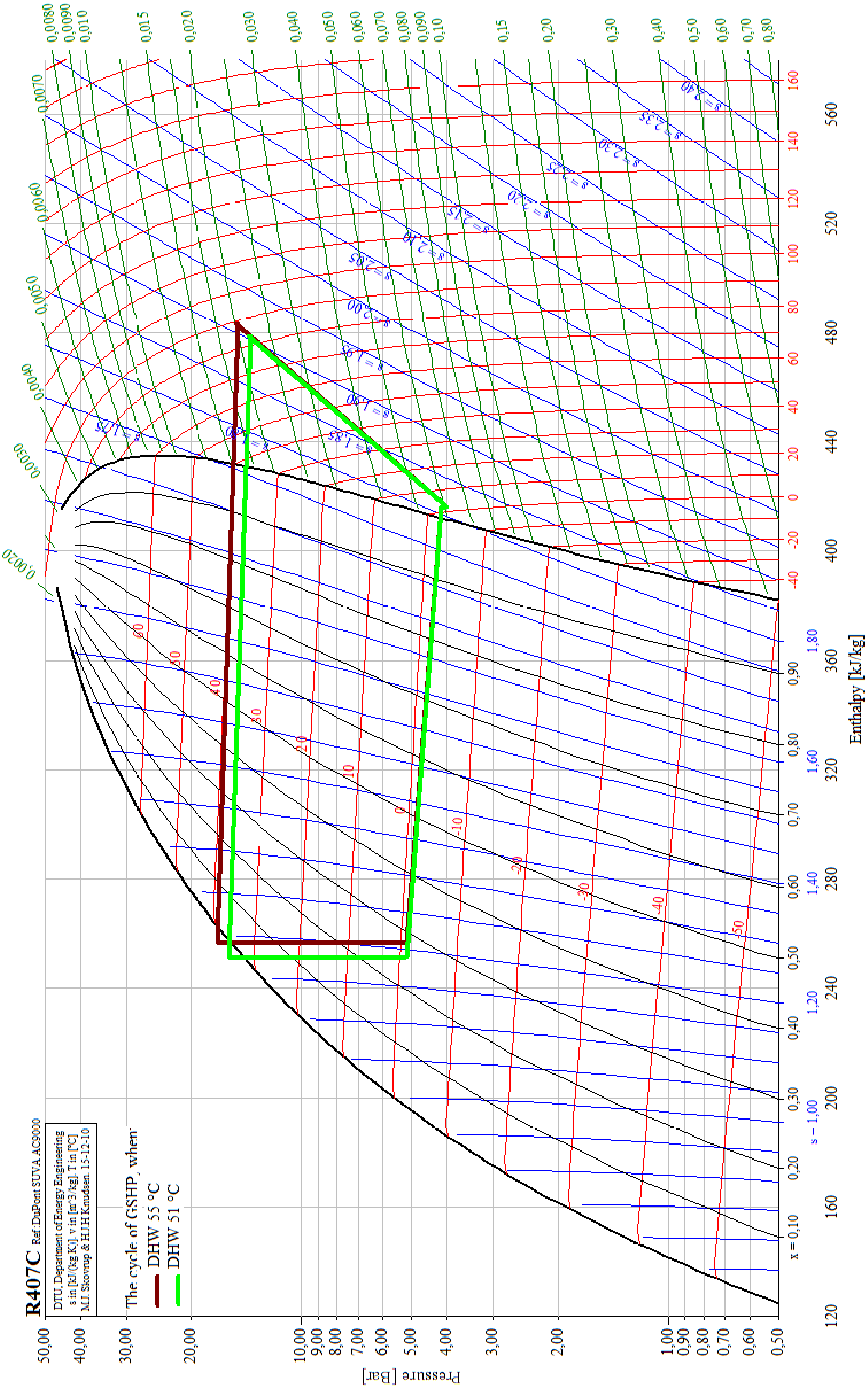

FIGURE 41. Vapor-compression cycle diagram of the 2nd GSHP

APPENDIX 3(3).

Vapor-Compression Cycle diagrams

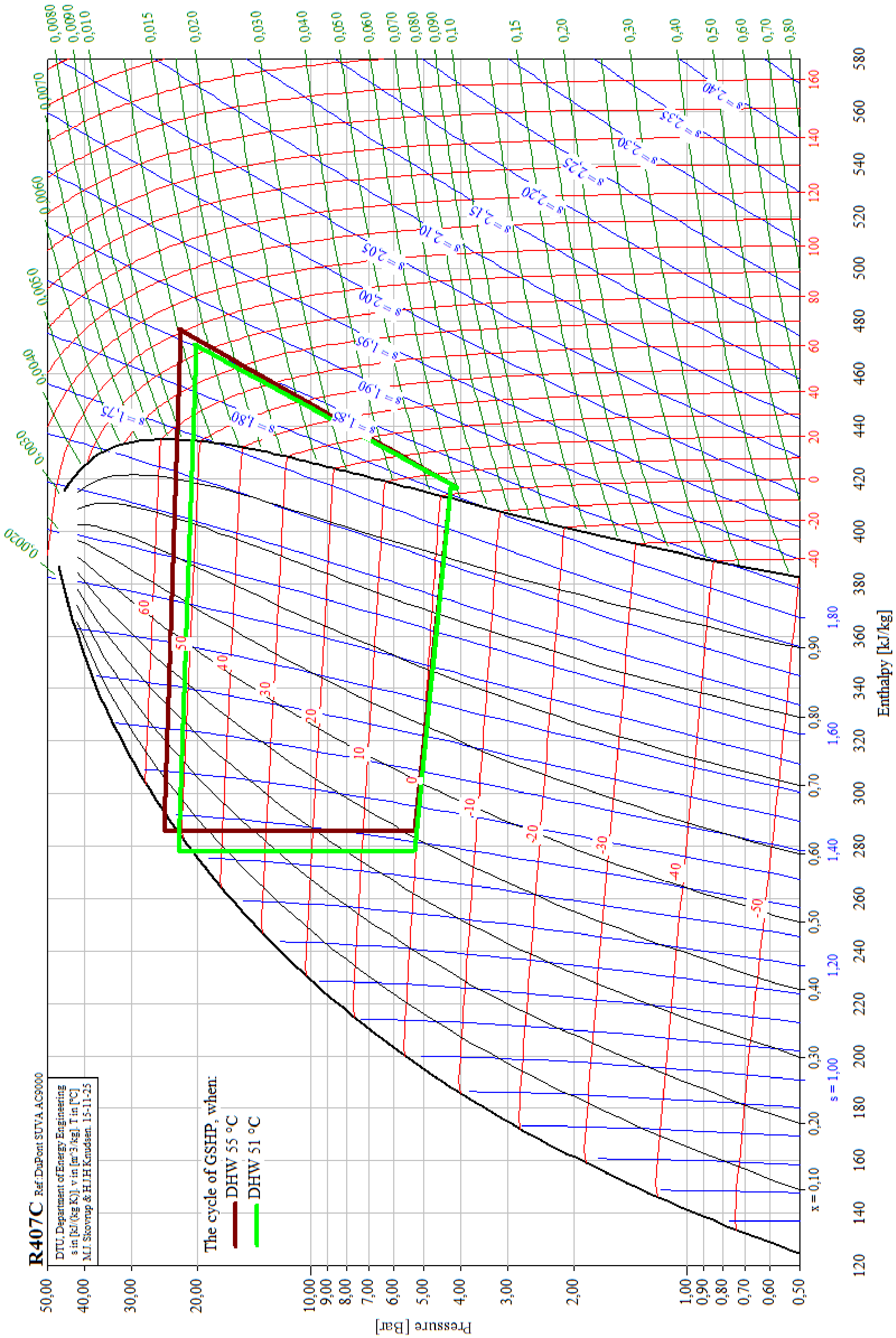

FIGURE 42. Vapor-compression cycles diagram of the 3rd GSHP