Jonas Strautnikas

T6614KA

ANALYSIS OF EXHAUST AIR-SOURCE HEAT PUMP

Bachelor’s Thesis
Double Degree Programme
in Building Services Engineering

January 2015

MAMK
University of Applied Sciences

MAMK
University of Applied Sciences

Date of the bachelor's thesis

January 2015

Author(s)

Jonas Strautnikas

Degree programme and option

Double Degree in Building Services Engineering

Name of the bachelor's thesis

Analyzis of exhaust air-source heat pump

Abstract

Nowadays people are trying to find out nature friendly heating systems. One of the possibilities is an exhaust air-source heat pump. In this research there will be analysed, calculated annual electricity energy consumption, annual investment of the exhaust air-source heat pump in the shipping container house. Moreover there will be compared the difference between two cases of an exhaust air-source heat pump. In the end the annual electricity energy consumption and annual investment to the system will be compared of two different systems. One of the system is an exhaust air-source heat pump. Another is a ground source heat pump. If an exhaust air-source heat pump would be changed to ground source heat pump, the pay back time will be taken into account.

Subject headings, (keywords)

Exhaust air-source heat pump, ground source heat pump, annual electricity energy consumption, annual investment, heat demand

Pages	Language	URN
44	English	

Remarks, notes on appendices

Tutor

Jarmo Tuunanen

Employer of the bachelor's thesis

CONTENTS

1 Introduction 1

2 Aims 2

3 Methods 2

  3.1 Description of the building 3

4 Basics of the heat pump 4

  4.1 Types of the heat pump systems 5

  4.2 Exhaust air-source heat pump 7

  4.3 Geothermal ventilation 8

  4.4 NIBE F470 9

5 Heat loss calculations 11

  5.1 Heat loss of building envelopes 11

  5.2 Heat losses through construction elements 11

  5.3 Heat losses through thermal bridges 14

  5.4 Air flows heated by the heat emitters 17

  5.5 Heat demand of leakage air 17

  5.6 Heat demand of the ventilation of supply air 19

  5.7 The total heat demand for each room or space 21

6 Annual electricity energy consumption and annual costs calculations 22

  6.1 Annual energy consumption calculations of circulation pump 22

  6.2 The annual electricity energy consumption of a ventilation fan calculations 26

  6.3 The annual electricity energy consumption of compressor and immersion heater 28

  6.4 The annual costs of NIBE F470 exhaust air – source heat pump 32

7 Annual electricity energy consumption calculations of second case and comparison of the two cases 33

  7.1 Calculations of the electricity energy consumption of a second case 33

7.2 Comparison of the two cases 35

8 Calculations and comparison of ground source heat pump and exhaust air-source heat pump. 39

9 Conclusion.. 43

References 44

APPENDIX 1

APPENDIX 2

NOMENCLATURE

A	Area if the element (m^2)
$A_{envelope}$-	Area of the building envelope, base floor included (m^2)
3600	Factor for changing units from m^3/h to m^3/s
$c_{p\ water}$	Specific heat capacity of water (J/kgK)
c_{pair}	Specific heat capacity of air (J/kgK)
COP	Coefficient of performance of the heat pump
E	Electricity energy consumption (kWh)
Δh	Enthalpy difference (kJ/kg)
h_1	Enthalpy of the air at +21 ℃ (kJ/kg)
h_2	Enthalpy of the air at +1 ℃ (kJ/kg)
l	Length of the element perpendicular to the heat flow (m)
P	Power output of the device (kW)
Q_{coil}	Capacity of supply air battery (kW)
q_{50} -	Leakage air value ($m^3/h \cdot m^2$)
q_m	Mass flow of the air (kg/s)
$q_{v,\ leakage\ air}$ -	Leakage air flow rate (dm^3/s)
$q_{v,\ supply\ air}$	Supply air flow rate (dm3/s)
$q_{v,\ supply\ air}$	Supply air flow (dm^3/s)
t	Time period in hours (h)
$T_{supply\ air}$	Supply air temperature (℃)
T_S	Design indoor air temperature (℃)
$T_{u,dim}$	Dimensioning outdoor air temperature (℃)
Δt	indoor and outdoor dimensioning temperature difference (℃)

U	Heat transfer coefficient of the envelope element (W/m^{2}K)
X	Factor, which describes storeys of the building
ρ_{water}	Density of water (kg/m^3)
ρ_{air}	Density of air (kg/m^3)
Ψ	Thermal bridge heat transfer coefficient (W/mK)
Φ_{el}	The heat loss of the envelope elements (W)
$\Phi_{\text{leakage air}}$	Heat loss of the ventilation in the room of supply air (W)
$\Phi_{\text{make-up air}}$	Heat loss of the ventilation in the room of make – up air (W)
$\Phi_{\text{supply air}}$	Heat loss of the ventilation in the room of supply air (W)
Φ_{vent}	Ventilation heat losses (W)
Φ_{Ψ}	The heat loss of the thermal bridges (W)
$\emptyset_1$	Amount of the energy produced by the condenser (kW)
$\emptyset_2$	Amount of the energy taken into the evaporator (kW)
$\emptyset_{\text{total}-\emptyset_1}$	Amount of the energy compensated by compressor (kW)
$\emptyset_{total}$	Amount of the energy needed to produce for heating purposes (kW)
Φ_{en}	The heat loss due to heat transmission through the envelopes (W)
Φ_{house}	Total head demand of the building (W)

1 INTRODUCTION

More and more people use heat pump to produce heating energy for ventilation and heating system. Specially they are used in Finland. Underground pipelines can be placed in a lake, river, under the ground and used as exhaust air-source heat pump. Basically pipelines can be placed everywhere, from where it is possible to get the heat. It depends on what purpose heat pump is used. As pre-heating system or as a pre-cooling system. It just have to be placed somewhere where is possiblity to get a cold (medium, which has lower temperature than supply air in ventilation system) and a heat.

Nowadays people try to find new building construction materials, which would be long-lived, cheap and easy to install. One posibility is weathering steel, which can be used to manufacture shipping container. Shipping containers houses are becoming more and more popular all over the world. In this type of houses there is everything you need: easy to install, durable, practical and even mobile. Shipping container house does not look energy efficient as for example brick or wooden houses. However that is not a true. If there is required amount of insulation, the shipping container house become efficient and consumes low energy as most popular houses made from brick or wood. Every construction has U-value, which has to satisfy National Building Code and it does not matter with which materials you reach the required U-value.

This Bachelor‘s thesis is based on real project, which will be realized in 2015 summer. Owner of shipping container house asked to analize HVAC system, which produce heat for heating, hot tap water and supply air for ventilation system. This system should produce all of the required heat. To produce this needed heat, exhaust air-source heat pump had been chosen. On the basis of calculations it will be found out electricity energy consumption and annual costs of this system. First it is needed to calculate heat loss through the envelopes of the building. Then calculatations of the amount of energy needed for heating purposes. Calculations for hot tap water demand will not be included. In addition, to prevent freezing in this system, geothermal ventilation is chosen to heat up incoming outdoors air. Underground ducts will be buried under the ground to increases temperature of the incoming outdoor air. In the end exhaust air-source heat pump will be compared with a ground source heat pump.

2 AIMS

The main aim of the Bachelor‘s thesis is to find out electricity energy consumption and annual costs of the exhaust air-source heat pump in residential house. It is a new and uncommon system, which heats up water used for hot tap water, heating system and supply air coil. There will be calculated annual amount of the electricity energy consumption of this system according to degree days temperatures. Then transfer this amount of energy to the price according to Finnish prices. After this to check what is the difference between two cases, when there is a difference between air flow rates. One case has the maximum air flow rate and another one has the minimum air flow rate. These air flow rates are limited by the fans. Another comparison will be to compare exhaust air-source heat pump with a ground source heat pump. To find out difference between an annual electricity energy consumption and annual investment to the system.

3 METHODS

Method is to analize an operational principle of the exhaust air-source heat pump. How does it work, what kind of devices are included. Then to design air flow rates of the ventilation system. After designs to calculate heat losses through the envelopes. This will show the heat demand of the building. To compensate needed amount of the heat calculations of the heat produced by exhaust-air source heat pump will be done. When the heat produced is known, it is possible to calculate annual electricity energy consumption and annual costs of the system.

3.1 Description of the building

The residential house will be built in countryside of Mikkeli. In the weather zone 2. More initial data will be shown in chapter 5 according to refference /1./ This house made of five shipping containers, where dimensions are 12192x2440x2920 mm. Heated area of a building is 143,42 m^2. All containers will be covered by sandwich panels. It is shown in figure 1. Roof of the house is sloped. The side of the building with most of the windows will be orientated to South side to increase the inflow of solar.

;

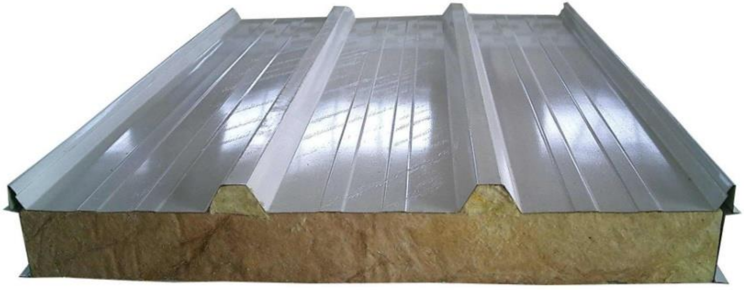


FIGURE 1. Sandwich panel

Design indoor air temperatures for bed rooms, diving and living room, corridor, cloak room, utility and technical room is T_s = 21˚C. For toilets, shower and sauna is T_s = 22˚C. U – values are chosen according to National Building Code of Finland. Walls, floors U=0,17 W/m^2K, roof U=0,09 W/m^2K, windows and doors U=1,1 W/m^2K. Sum of the supply air flow rate is +53 l/s, an exhaust air flow rate is -65 l/s. /2./

4 BASICS OF THE HEAT PUMP

There are two main types of heat pumps: geothermal heat pump (GHP) and exhaust air-source heat pump /3/. This kind of devices can be found at our homes, for example a fridge. The operation of the fridge is based on a heat pump.

A heat pump has four main parts: condenser, compressor, evaporator and expansion valve. All parts are connected and has own processes, as seen in figure 2.

- The evaporator has a refrigerant inside, which is colder than the heat source (lake water, ground, air), which maintains between 10 – 15 ℃ /2/. This causes the heat source to move towards the refrigerant, where it then evaporates.
- This vapour moves to the compressor and reaches a higher temperature and pressure.
- The hot vapour enters the condenser and gives off heat as it condenses.
- The refrigerant in liquid state moves to the expansion valve, temperature drops and pressure as well, and this liquid returns to the evaporator to begin the cycle again. /4./

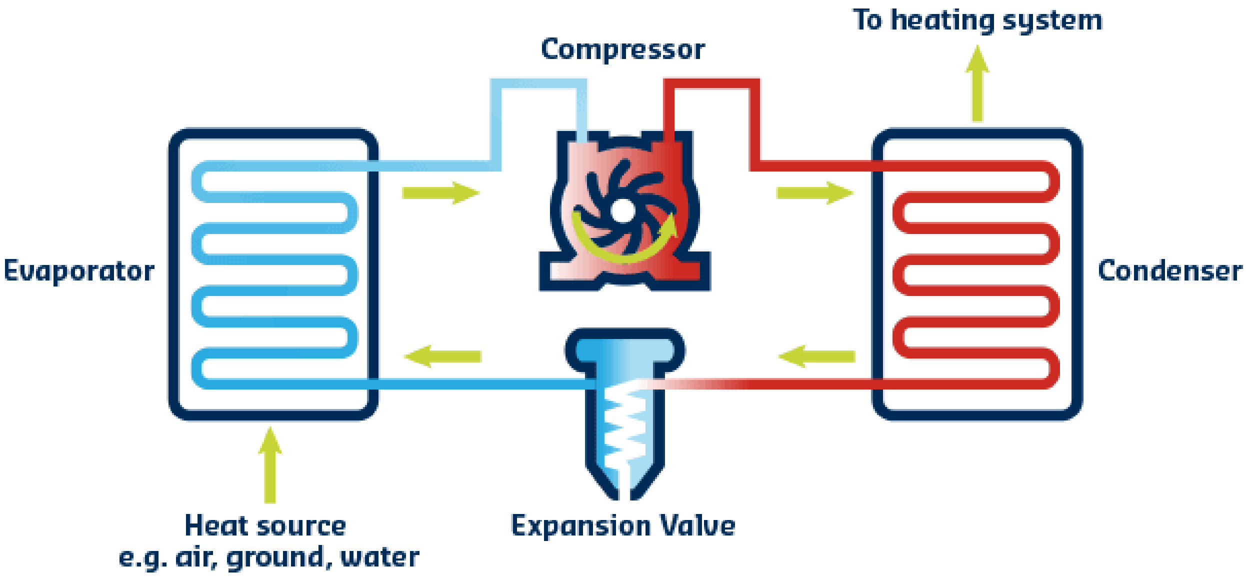


FIGURE 2. Principle of the operation of heat pump /4/

4.1 Types of the heat pump systems

To heat a building with the heat pump, a heat source is required and to cool down a building, a cold source is required as well. The source is ground, lake water and air. Moreover there are different ways to get energy from these sources.

Horizontal closed loop system

Is used when house has enough land area to place pipelines in horizontal position. These pipelines have length from 30 m to 130 m. An example of horizontal closes loop pipelines are shown in figure 3. /5./

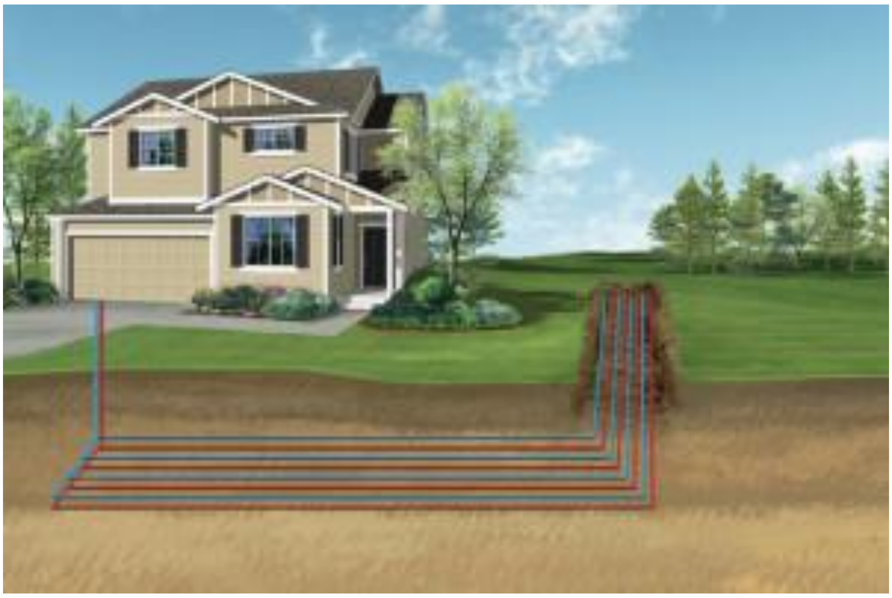


FIGURE 3. Horizontal closed loop system /5/

Vertical closed loop

Is the most common system, because of a cheaper way to get required amount of the energy /5./ As it is mentioned earlier, heat source is needed. This heat source is a vertical boreholes. These holes have a diameter of approximately 100 mm and can be drilled with 3 m spacing. The depth of these pipelines without connection to a building is from 45 m to 120 m. Pipes are connected with U-bend at the bottom to form loop. At the top pipelines are connected to the horizontal ones and continue to the building, where they are connected to heat pump. An example is shown in figure 4.

FIGURE 4. Vertical closed loop system /5/

Lake closed loop system

When it is possible to use a pond or a lake beside of the building, then it is the best to choose exactly this type of system for pipelines. From the building to water, pipelines are in a horizontal position. To prevent freezing at least in the 2,5 m depth under the water‘s surface pipes are coiled into circles. Basically they are placed near the ground, because it matches minimum volume, depth and quality. Lake closed loop system is shown in figure 5. /5./

FIGURE 5. Lake closed loop system /5/

4.2 Exhaust air-source heat pump

This type of heat pump is used in a mechanical ventilation system which connects exhaust and supply ducts. In the exhaust air duct, there is an evaporator, which takes heat by refrigerant and transfers this heat to supply air duct. Here is the condenser, it heats up coming outdoors air. This process shown in figure 6.

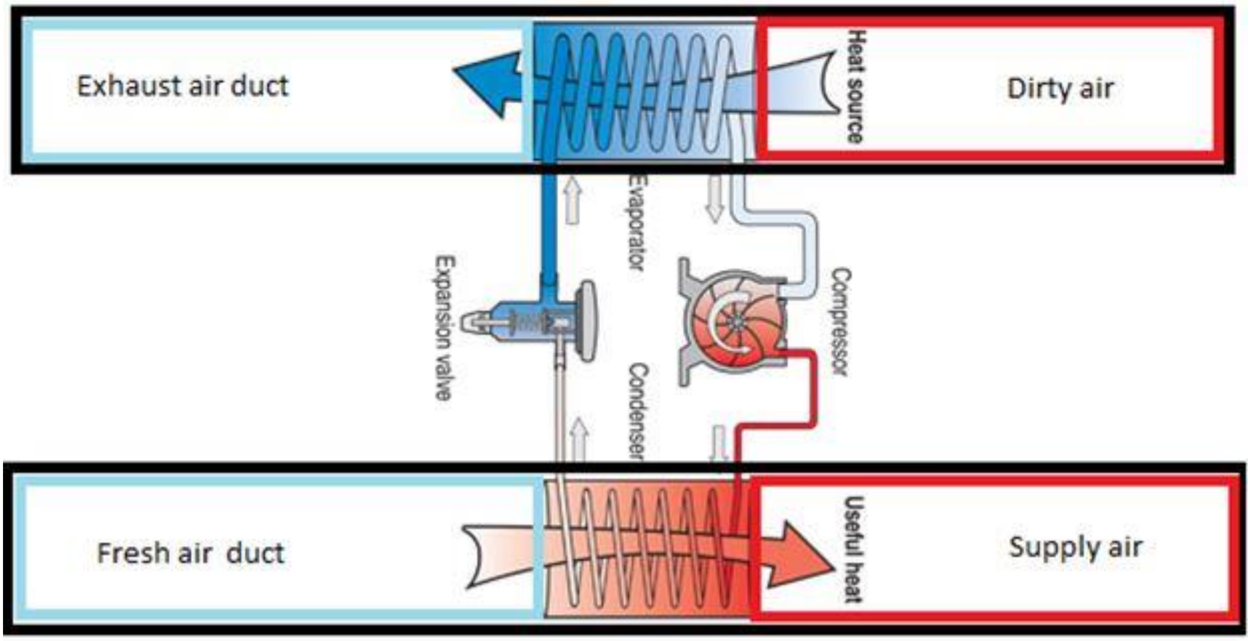


FIGURE 6. Exhaust air-source heat pump

In figure 6. is an example of exhaust air-source heat pump in mechanical ventilation system. Here dirty air is sucked out from the apartments, building. This air consists the heat. This heat is removed from an air by the refrigerant in evaporator. Compressor is used to move heat from an evaporator to the condenser. After compressor temperature and pressure of the refrigerant increases and enters condenser. Here comes fresh air and has to be heated up. This needed heat produces condenser. When the heat is transfered to the fresh air, the refrigerant is cooled down. Then it is moving back to the evaporator. Expansion valve decreases the pressure and temperature of a refrigerant. The cycle is done. Refrigerant repeats the cycle.

4.3 Geothermal ventilation

The temperature of the earth‘s surface remains constant all the year round. The ground temperature at 1,5-3,2m depth ranges from +5 up to +7 ℃ in winter and +10 up to 12 ℃ in summer. This system needs 30 – 40 meters of underground ducting. These pipelines can be placed in a straight line, in a grid pattern or around the perimeter of the house. Geothermal ventilation shown in figure 7. On the top of a picture is shown summer case. When outdoors air temperature is higher than indoors air temperature. By passing underground ducts outdoors air temperature will be decreased. In this way air is pre-cooled for supply to the building. On the bottom of a picture there is a winter time case. Where outdoors air temperature is lower than indoors air temperature. By passing underground ducts outdoors air temperature will be pre-heated and ready for mechanical ventilation system.

FIGURE 7. Geothermal ventilation /6/

4.4 NIBE F470

Chosen an exhaust air-source heat pump system is a F470 of the Swedish manufacturer NIBE. NIBE F470 produce part of the required heat for a building (hot tap water, heating, supply air). The type of a refrigerant in exhaust air-source heat pump is R290 (propane). /7./

This system looks like a fridge, but it is not. It is a box (600x616x2100mm), which is used to heat water for heating, ventilation system and hot tap water purposes. It contains eight main parts, where all processes are going.

Operation process of NIBE F470

Main parts of NIBE F470 are explained in figure 8. Exhaust air-source heat pump takes heat from exhaust air duct. There is an evaporator, where the refrigerant evaporates, because of low boiling temperature of the refrigerant. Refrigerant in vapour phase enters compressor. Compressor increases pressure and temperature of the refrigerant. Refrigerant enters the condenser, condensates, changes state from vapour to liquid and heats up a storage tank, which contains water used for hot tap water and heating purposes. Then the refrigerant goes to expansion valve, where the pressure and temperature are reduced. The refrigerant has now completed cycle and returns to the evaporator to repeat cycle. After exhaust air-source heat pump process, hot water in storage tank is distributed to hot water taps (shower, faucets, etc.), heating system and to heat up supply air. /7./

To increase customer‘s comfort level NIBE F470 has an automation system. Display where it is possible to change temperatures in supply air, hot tap water, heating system. It can turn off heating system if it is not in use. There are apps for phone (only for Android operating system), where it can control the system during customer‘s holidays or while the customer at work. Immersion heater is used to heat up the water during cold conditions, when the temperature is below -15℃ and compressor can not produce needed heat demand. /7./

Parts of the NIBE F470

Each part of this machine has its own operation. Outdoors air duct + supply fan (1) sucks in preheated by the geothermal heater outdoors air and supplies to the building. Exhaust air duct + extract fan (2) sucks out used air from the building and extracts outside. The condenser (3), here refrigerant condenses (changes phase from vapour to liquid) and transfers the heat to heat up a water in the storage tank (5). In the evaporator (4) refrigerant absorbs a heat from the exhaust air duct (exhaust temperature 22 ℃, extract temperature 0 ℃, absorbed temperature of the refrigerant 10℃). The storage tank (5) holds 240 litres of hot water for distribution to faucets, showers, heating system and supply air baterry (14). Compressor (6) compresses refrigerant, increases pressure and temperature (from 10 ℃ to 80 ℃). In the expansion valve (7) pressure and temperature of a refrigerant decreases, refrigerant changes a phase from a liquid to a mixture of liquid and vapour. Circulation pump (8) circulates a hot water for heating and supply air battery (14). Heating return pipe (9) returns used water from supply air battery (14) and heating systems (at 45 ℃ temperature). Docking connection (10) is a connection for other heat sources to the heat pump. Hot water pipe (11) is a supply pipe for the hot tap water. Cold water pipe (12) is used to supply cold water to the storage tank (5), where a cold water is heated up. Heating supply pipe (13) supplies hot water (at 55℃ temperature) to heating system. Supply air battery (14) transfers a heat received from the storage tank (5) to supply air duct. The immersion heater (15) is used to heat up water in a storage tank (5), when it is not enough received heat from exhaust air-source heat pump.

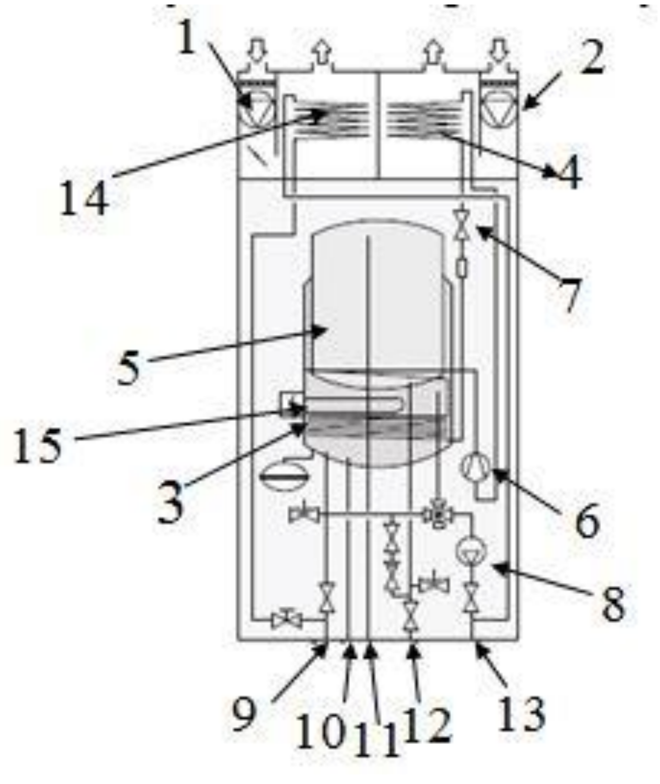


FIGURE 8. Main parts of NIBE F470 (1 - outdoors air duct + supply fan, 2 - exhaust air duct + extract fan, 3 – condenser, 4 – evaporator, 5 – storage tank, 6 – compressor, 7 – expansion valve, 8 – circulation pump, 9 – heating return pipe, 10 – docking connection, 11 – hot water pipe, 12 – cold water pipe, 13 – heating supply pipe, 14 – supply air battery, 15 – immersion heater /7./

5 HEAT LOSS CALCULATIONS

5.1 Heat loss of building envelopes

Heat loss due to transmission through the building envelope is the heat loss through the all construction elements – walls, roof, floor, windows, and doors. During these calculations the heat loss of conduction through internal walls to colder spaces should be considered. Calculation should be done according to National Building Code. The heat loss due to heat transmission through the envelopes can be calculated from equation 1.

$$\Phi_{en} = \sum \Phi_{el} + \sum \Phi_{\Psi} \tag{1}$$

Where Φ_{el} is heat loss of the structure of envelope elements, Φ_{Ψ} – heat loss of the thermal bridges.

5.2 Heat losses through construction elements

The heat losses through the construction elements are calculated by summing all heat losses through different building construction elements. The heat loss through the construction elements can be calculated by using the equation /2/

$$\Phi_{el} = U \cdot A \cdot \Delta t \tag{2}$$

U is heat transfer coefficient of the construction element, A area of the element, Δt – indoor and outdoor dimensioning temperature difference.

The indoor and outdoor dimensioning temperature difference can be calculated by following equation 3.

$$\Delta t = T_S - T_{u,dim} \tag{3}$$

Where T_S design indoor air temperature, $T_{u,dim}$ dimensioning outdoor air temperature.

Calculation example of heat loss due to envelopes elements in dining and living room:

Heat loss due to building envelope, which are oriented to the East side:

$\Phi_{\text{el, wall , dining room}}$ = 0,17·18,28·(21 – (- 29)) = 155,38W;

Heat loss due to building envelope, which are oriented to the South side:

$\Phi_{\text{el, wall , dining room}}$ = 0,17·9,56·(21 – (- 29)) = 81,26W;

$\Phi_{\text{el, windows , dining room}}$ = 1,1·2,64·(21– (- 29)) = 72,6 W;

Heat loss due to building envelope, which are oriented to the West side:

$\Phi_{\text{el, wall , dining room}}$ = 0,17·16,96 ·(21 – (- 29)) = 144,16 W;

$\Phi_{\text{el, windows , dining room}}$ = 1,1·1,32·(21 – (- 29)) = 145,2W;

Heat loss due to floor:

$\Phi_{\text{el, floor , dining room}}$ = 0,17·35,7·(21 - 4,6)) = 99,53 W;

Total heat losses due to building envelopes in dining and living room:

$\sum \Phi_{\text{el, dining room}}$ = 155,38+81,26 +144,16 +72,6 +145,2+ 99,53= 698,13 W

Other results of calculated heat losses due to building envelopes are shown in the table 1.

TABLE 1. Calculations of heat loss due to envelopes elements.

Room	Envelope	Orientation	U, W/m^{2}K	Area, m^2	Δt, °C	Φ_{el}, W
Dining and living room	Wall	East	0,17	18,28	50	155,38
	Wall	South	0,17	9,56	50	81,26
	Wall	West	0,17	16,96	50	144,16
	Floor		0,17	35,7	16,4	99,53
	Window	West	1,1	2,64	50	145,20
	Window	South	1,1	1,32	50	72,60
Cloak room	Wall	West	0,17	10,1	50	85,85
	Wall	North	0,17	6,1	50	51,85
	Doors		1,1	2,1	50	115,50
	Floor		0,17	10,23	16,4	28,52
WC1	Floor		0,17	1,66	17,4	4,91
Utility room	Wall	East	0,17	10,1	50	85,85
	Wall	North	0,17	5,62	50	47,77
	Doors		1,1	2,1	50	115,50
	Window	North	1,1	0,48	50	26,40
	Floor		0,17	11,47	16,4	31,98
Corridor	Wall	South	0,17	5,86	50	49,81
	Wall	North	0,17	8,615	50	73,23
	Window		1,1	0,48	50	26,40
	Ceiling		0,09	22,35	50	100,58
	Doors		1,1	1,89	50	103,95
WC2	Ceiling		0,09	2,04	51	9,36
Shower	Wall	South	0,17	4,65	51	40,32
	Window		1,1	0,6	51	33,66
	Ceiling		0,09	5,1	51	23,41
Sauna	Wall	South	0,17	5,6525	51	49,01
	Wall	West	0,17	5,74	51	49,77
	Window		1,1	0,36	51	20,20
	Ceiling		0,09	5,49	51	25,20
Bed room 1	Wall	West	0,17	9,56	50	81,26
	Wall	North	0,17	9,0525	50	76,95
	Ceiling		0,09	17,6	50	79,20
	Window	West	1,1	2,64	50	145,20
Bed room 2	Wall	North	0,17	10,535	50	89,55
	Wall	East	0,17	6,1	50	51,85
	Window	North	1,1	1,32	50	72,60
	Ceiling		0,09	10,6	50	47,70
Bed room 3	Wall	East	0,17	4,78	50	40,63
	Ceiling		0,09	10,6	50	47,70
	Window	East	1,1	1,32	50	72,60
Bed room 4	Wall	East	0,17	6,1	50	51,85
	Wall	South	0,17	10,535	50	89,55
	Window	South	1,1	1,32	50	72,60
	Ceiling		0,09	10,6	50	47,70
					$\Sigma\Phi_{el}$	2964,071

Total heat loss of all elements in the investigated one family building:

$\sum \Phi_{el} = 2964{,}07$ W.

5.3 Heat losses through thermal bridges

Thermal bridges occurs when there is a gap between materials and structural surfaces. The main thermal bridges found at the junctions of facings and floors, facings and walls, facings and ceilings, facings and low floors. The heat loss due to thermal bridges can be calculated by following equation 4.

$$\Phi_{\Psi} = \Psi \cdot l \cdot \Delta t \tag{4}$$

Where Ψ thermal bridge heat transfer coefficient, this coefficient took as low as possible according to D5, because of the good insulated wall construction /8/, l *is a* length of the element perpendicular to the heat flow.

Calculation of heat loss coefficient through thermal bridges in a dining and living room:

Heat loss through thermal bridges, which are oriented to the East side:

$\Phi_{\Psi, \text{dining room floor}} = 01 \cdot 7{,}312 \cdot (21 - (-29)) = 36{,}56$ W;

$\Phi_{\Psi, \text{dining room ceiling}} = 0{,}04 \cdot 7{,}312 \cdot (21 - (-29)) = 14{,}62$ W;

$\Phi_{\Psi, \text{dining room window}} = 0{,}15 \cdot 9{,}2 \cdot (21 - (-29)) = 69$ W;

Heat loss through thermal bridges, which are oriented to the South side:

$\Phi_{\Psi, \text{dining room floor}} = 0{,}1 \cdot 4{,}88 \cdot (21 - (-29)) = 24{,}4$ W;

$\Phi_{\Psi, \text{dining room ceiling}} = 0{,}04 \cdot 4{,}88 \cdot (21 - (-29)) = 9{,}76$ W;

$\Phi_{\Psi, \text{dining room corner}} = 0{,}06 \cdot 5 \cdot (21 - (-29)) = 15$W;

Heat loss through thermal bridges, which are oriented to the West side:

$\Phi_{\Psi,\text{ dining room floor}} = 0{,}1 \cdot 7{,}312 \cdot (21 - (-29)) = 36{,}56$ W;

$\Phi_{\Psi,\text{ dining room ceiling}} = 0{,}04 \cdot 7{,}312 \cdot (21 - (-29)) = 14{,}62$ W;

$\Phi_{\Psi,\text{ dining room window}} = 0{,}15 \cdot 4{,}6 \cdot (21 - (-29)) = 34{,}5$W;

Total heat loss through thermal bridges in dining and living room:

$\sum \Phi_{\Psi,\text{ dining room}} = 87{,}74 + 58{,}56 + 87{,}74 + 65{,}81 + 43{,}92 + 65{,}81 + 69 + 34{,}5 + 15 = 528{,}08$W.

Other results of heat loss coefficients through thermal bridges represented in table 2.

TABLE 2. Calculations of the heat loss due to thermal brigdes.

Room	Element	Orientation	Ψ, (W/mK)	l, m	Δt, °C	$\Phi_{\text{thermal bridges}}$, W
Diving and living room	Floor	East	0,1	7,312	50	36,56
	Floor	South	0,1	4,88	50	24,4
	Floor	West	0,1	7,312	50	36,56
	Ceiling	East	0,04	7,312	50	14,624
	Ceiling	South	0,04	4,88	50	9,76
	Ceiling	West	0,04	7,312	50	14,624
	Window	South	0,15	9,2	50	69
	Window	West	0,15	4,6	50	34,5
	Corner	South	0,06	5	50	15
WC1	Floor		0,1	5,2	51	26,52
Cloak room	Floor	West	0,1	4,88	50	24,4
	Floor	North	0,1	2,44	50	12,2
	Ceiling	West	0,04	4,88	50	9,76
	Ceiling	North	0,04	2,44	50	4,88
	Doors	West	0,15	6,2	50	46,5
	Corner	North	0,06	2,5	50	7,5
Utility and technical room	Floor	East	0,1	4,88	50	24,4
	Floor	North	0,1	2,44	50	12,2
	Ceiling	East	0,04	4,88	50	9,76
	Ceiling	North	0,04	2,44	50	4,88
	Window	North	0,15	2,8	50	21
	Doors	East	0,15	6,2	50	46,5
	Corner	North	0,06	2,5	50	7,5
Corridor	Floor	North	0,1	3,75	50	18,75
	Floor	South	0,1	3,1	50	15,5
	Ceiling	North	0,04	3,75	50	7,5
	Ceiling	South	0,04	3,1	50	6,2
	Window	North	0,15	2,8	50	21
	Doors	South	0,15	6	50	45

Continue of **TABLE 2.**

WC2	Ceiling		0,04	5,8	51	11,832
Shower	Floor	South	0,1	2,1	51	10,71
	Ceiling	South	0,04	2,1	51	4,284
	Window	South	0,15	3,2	51	24,48
Sauna	Floor	South	0,1	2,26	51	11,526
	Floor	West	0,1	2,44	51	12,444
	Ceiling	South	0,04	2,26	51	4,6104
	Ceiling	West	0,04	2,44	51	4,9776
	Window	West	0,15	2,4	51	18,36
	Corner		0,06	2,5	51	7,65
Bed room 1	Floor	West	0,1	4,88	50	24,4
	Floor	North	0,1	3,621	50	18,105
	Ceiling	West	0,04	4,88	50	9,76
	Ceiling	North	0,04	3,621	50	7,242
	Window	West	0,15	9,2	50	69
	Corner	South	0,06	2,5	50	7,5
Bed room 2	Floor	North	0,1	4,742	50	23,71
	Floor	East	0,1	2,4	50	12
	Ceiling	North	0,04	4,742	50	9,484
	Ceiling	East	0,04	2,4	50	4,8
	Window	North	0,15	4,6	50	34,5
	Corner	East	0,06	2,5	50	7,5
Bed room 3	Floor	East	0,1	2,44	50	12,2
	Ceiling	East	0,04	2,44	50	4,88
	Window	East	0,15	4,6	50	34,5
Bed room 4	Floor	East	0,1	2,44	50	12,2
	Floor	South	0,1	4,742	50	23,71
	Ceiling	East	0,04	2,44	50	4,88
	Ceiling	South	0,04	4,742	50	9,484
	Window	South	0,15	4,6	50	34,5
	Corner	East	0,06	2,5	50	7,5
					ΣΦ	1109,707

The total heat loss through thermal bridges in the building:

$\sum \Phi\ \psi = 1109{,}71$ W.

The total heat loss coefficient of investigated one family house due to heat transmission through the envelopes equation 1. is equal to:

$\Phi_{en} = \sum \Phi_{el} + \sum \Phi_{\psi} = 2964{,}07 + 2212{,}98 = 5177{,}05$ W.

5.4 Air flows heated by the heat emitters

Air flows which enters the room has lower temperature than the room has. To avoid heat losses, the entered air has to be heated up. Air flows heated by the heat emitters can be calculated by following equation 5.

$$\Phi_{air} = \sum \Phi_{leakage\ air} + \sum \Phi_{supply\ air} + \sum \Phi_{make\text{-}up\ air} \qquad (5)$$

Where $\Phi_{heated\ leak\ air}$ heated leakage air by heat emitters, $\Phi_{supply\ air}$ heat demand of the ventilation in the room of supply air, $\Phi_{make\ up\ air}$ heat demand of the ventilation in the room of make – up air.

In the investigated building, the mechanical balanced ventilation is installed, so there is no heat demand due to make – up air.

$\sum \Phi_{make\text{-}up\ air} = 0$.

In this case an equation of ventilation heat demand becomes simpler in equation 6.

$$\Phi_{air} = \sum \Phi_{leakage\ air} + \sum \Phi_{supply\ air} \qquad (6)$$

From equation 6. Make-up air is erased and is not taken into account.

5.5 Heat demand of leakage air

Heat demand of the heated leakage air can be calculated by equation /7/

$$\Phi_{leakage\ air} = c_{p\ air} \cdot \rho_{air} \cdot q_{v,\ leakage\ air} \cdot (T_s - T_{u,dim},) \qquad (7)$$

$\Phi_{leak\ air}$ - heat demand of leakage air, c_{pair} – specific heat capacity of air, 1000 J/kgK, ρ_{air} – density of air, 1,2 kg/m^3, $q_{v,\ leakage\ air}$ - leakage air flow rate, T_s – indoor temperature, $T_{u,\ dim}$ – dimensioning outdoor temperature.

Calculation of leakage air flow rate is in equation 8.

$$q_{\text{v, leakage air}} = \frac{q_{50}}{3600 \cdot x} \cdot A_{envelope} \tag{8}$$

Where $q_{\text{v, leakage air}}$ - leakage air flow rate, q_{50} - leakage air value, $A_{envelope}$- area of building envelope base floor included, x– factor, 3600 – factor for changing units from m^3/h to m^3/s.

The leakage air flow rate for dining and living room:

$$q_{\text{v, leakage air, dining room}} = \frac{2}{3600 \cdot 24} \cdot 84{,}46 = 0{,}001955\ m^3/s.$$

All results of leakage air flow rates are represented table 3. Leakage air value is 2 $m^3/h{\cdot}m^2$. X factor is 24, because of 2 storeys building. $A_{envelope}$ is area of the envelopes. $q_{\text{v, leakage air, dining room}}$ is a leakage air flow rate.

TABLE 3. The leakage air flow rates of the rooms.

Room	q50, $m^3/h{\cdot}m^2$		x	A_{envelope}, m^2	$q_{\text{v, leakage air}}$, m^3/s
Dining and living room	2	3600	24	84,46	0,001955093
Cloak room	2	3600	24	28,53	0,000660417
WC1	2	3600	24	1,66	3,84259E-05
Utility and technical room	2	3600	24	35,87	0,000830324
Corridor	2	3600	24	37,925	0,000877894
Shower	2	3600	24	10,35	0,000239583
Sauna	2	3600	24	17,2425	0,000399132
Bed room 1	2	3600	24	38,8525	0,000899363
Bed room 2	2	3600	24	28,555	0,000660995
Bed room 3	2	3600	24	16,7	0,000386574
Bed room 4	2	3600	24	28,555	0,000660995

Heat demand of leakage air heating in dining and living room by equation 7.

$$\Phi_{\text{leakage air, dining room}} = 1000 \cdot 1{,}2 \cdot 0{,}001955 \cdot (\,21-(-29)\,) = 117{,}31\ W.$$

Other results of heat loss due to leakage air are presented table 4. Where $\Phi_{\text{leakage air}}$ is a leakage air heat demand.

TABLE 4. The heat demand due to leakage air heating.

Room	ρ, kg/m^3	cp, J/kgK	$q_{v,\ leakage\ air}$, m^3/s	Δt, °C	$\Phi_{leakage\ air}$, W
Dining and living room	1,2	1000	0,001955093	50	117,31
Cloak room	1,2	1000	0,000660417	50	39,63
WC1	1,2	1000	3,84259E-05	51	2,35
Utility and technical room	1,2	1000	0,000830324	50	49,82
Corridor	1,2	1000	0,000877894	50	52,67
Shower	1,2	1000	0,000239583	51	14,66
Sauna	1,2	1000	0,000399132	51	24,43
Bed room 1	1,2	1000	0,000899363	50	53,96
Bed room 2	1,2	1000	0,000660995	50	39,66
Bed room 3	1,2	1000	0,000386574	50	23,19
Bed room 4	1,2	1000	0,000660995	50	39,66
				$\Sigma\Phi$	457,34

The total heat demand of the leakage air:

$\sum \Phi_{leakage\ air} = 457{,}34$ W.

5.6 Heat demand of the ventilation of supply air

Heat loss occurs, when the entered air has lower temperature than the room. Usually supply air has lower temperature than the room. This supplied air has to be heated up. Heat loss of the ventilation in the room of supply air can be calculated by following expression /9/.

$$\Phi_{supply\ air} = c_{pi} \cdot \rho_{i} \cdot q_{v,\ supply\ air} \cdot (Ts - Tsupply\ air) \qquad (9)$$

Where $\Phi_{supply\ air}$ - heat demand of supply air, $c_{p\ air}$ – specific heat capacity of air, 1000 J/kgK, ρ_{air} – density of air, 1,2 kg/m^3, $q_{v,\ supply\ air}$ - supply air flow rate, T_s – indoor temperature, $T_{supply\ air}$– supply air temperature.

Exhaust and supply air flow rates are shown in table 5. These air flow rates were designed according to National Building Code.

TABLE 5. The air flow rates of supply and exhaust air in the rooms.

Room	Supply air, m^3/s	Exhaust air, m^3/s
Dining and living room	0,014	-
Cloak room	0,004	-
WC1	-	-0,02
Utility and technical room	0,005	-0,008
Corridor	0,009	-
Shower	-	-0,01
Sauna	0,002	-0,012
WC2	-	-0,015
Bed room 1	0,007	-
Bed room 2	0,004	-
Bed room 3	0,004	-
Bed room 4	0,004	-
∑	**0,053**	**-0,065**

Heat demand of the ventilation in the room of supply air in dining and living room by equation 9.

$$\Phi_{\mathit{supplt\ air,\ dining}}\ \mathrm{room} = 1000 \cdot 1{,}2 \cdot 0{,}014 \cdot (21 - 18) = 50{,}4\ \mathrm{W}$$

Other results heat demand of ventilation in the rooms of supply air are represented table 6. Temperature of supply air is 18 °C.

TABLE6. The heat demand of ventilation in the rooms of supply air.

Room	ρ, kg/m³	cp, J/kgK	$q_{v,\ supply\ air}$, m³/s	t_s, °C	Δt, °C	$\Phi_{sup.\ air}$, W
Dining and living room	1,2	1000	0,014	18	3	50,4
Cloak room	1,2	1000	0,004	18	3	14,4
WC1	1,2	1000	0	18	4	0
Utility and technical room	1,2	1000	0,005	18	3	18
Corridor	1,2	1000	0,009	18	3	32,4
WC2	1,2	1000	0	18	3	0
Shower	1,2	1000	0	18	4	0
Sauna	1,2	1000	0,002	18	4	9,6
Bed room 1	1,2	1000	0,007	18	3	25,2
Bed room 2	1,2	1000	0,004	18	3	14,4
Bed room 3	1,2	1000	0,004	18	3	14,4
Bed room 4	1,2	1000	0,004	18	3	14,4
					ΣΦ	193,2

The total heat demand of the ventilation of the supply air in the rooms:

$\sum \Phi_{\text{supply air}} = 193{,}2$ W.

5.7 The total heat demand for each room or space

The total heat demand of the building consists of heat loss due to conduction through building envelopes and the heat demand of ventilation. It can be expressed by this equation /10/:

$$\Phi_{house} = \Phi_{el} + \Phi_{\psi} + \Phi_{leakage\ air} + \Phi_{supply\ air} \tag{10}$$

The total heat demand for dining and living room:

$\Phi_{dining\ room} = 698{,}13 + 528{,}08 + 117{,}31 + 50{,}4 = 1393{,}92$W

Other results of total heat demand of separate building room or space are represented table 7.

TABLE 7. The total heat demand of the rooms.

Room	Φ_{el}, W	$\Phi_{\text{thermal bridges}}$, W	$\Phi_{\text{leakage air}}$, W	$\Phi_{\text{sup. air}}$, W	$\Phi_{\text{room total}}$, W
Dining and living room	698,132	255,028	117,31	50,4	1120,87
Cloak room	281,721	105,24	39,63	14,4	440,99
WC1	4,91028	26,52	2,35	0	33,78
Utility and technical room	307,498	126,24	49,82	18	501,56
Corridor	353,963	113,95	52,67	32,4	552,99
WC2	9,3636	11,832	0	0	21,20
Shower	97,3845	39,474	14,66	0	151,52
Sauna	144,168	59,568	24,43	9,6	237,76
Bed room 1	382,606	136,007	53,96	25,2	597,78
Bed room 2	261,698	91,994	39,66	14,4	407,75
Bed room 3	160,93	51,58	23,19	14,4	250,10
Bed room 4	261,698	92,274	39,66	14,4	408,03
	2964,07	1109,71	457,34	193,20	4724,32
					Φ_{house}, W

The total heat demand of this one family building:

$\sum \Phi_{\text{House}} = 4724{,}32\ \text{W} \approx 4{,}72$ kW.

6 ANNUAL ELECTRICITY ENERGY CONSUMPTION AND ANNUAL COSTS CALCULATIONS

In this chapter calculations of electricity energy consumption of all parts of NIBE F470 will be done. It is circulation pump, supply and exhaust air fans, immersion heater and a compressor.

6.1 Annual energy consumption calculations of circulation pump

Circulation pump for heating

When the total heat demand is calculated for the heating system, it is possible to calculate what is the water flow needed for heating system. To calculate water flow for heating system is expressed in equation 11.

$$q_v = \frac{\Phi_{house}}{\rho_{water} \cdot c_{p_{water}} \cdot (\Delta t)} \tag{11}$$

Where q_v is water flow, Φ_{House} total heat demand of the building, W, $c_{p\ water}$ – specific heat capacity of water, 4,2 kJ/kgK, ρ_{water} – density of water, 1000 kg/m^3, Δt is the temperature difference of supply and return in heating system, K.

Water flow needed for heating system:

$$q_v = \frac{4724}{1000\ \cdot 4{,}2\ \cdot (55 - (45))} = 0{,}11\ dm^3/s$$

Circulation pump for supply air coil heating

To calculate circulation pump water flow to supply air coil, capacity of the supply air coil is needed. Capacity of the supply air coil, when supply and outdoors temperatures of air are -29/+18 ℃, equation 12 is used:

$$Q_{coil} = \rho_{air} \cdot c_{p_{air}} \cdot q_{v_{supply}} \cdot \left(t_{supply} + 7 - t_u\right) \tag{12}$$

Where Q_{coil} is capacity of the coil, ρ_{air} density of air, 1,2 kg/m^3, $c_{p_{air}}$ specific heat capacity of air, 1 kJ/kgK, q_v supply air flow, t_{supply} temperature of supply air, t_u dimensioning outdoors air temperature, -7 is how much temperature increases after geothermal ventilation ducts.

According to equation /12/ capacity of the supply air coil is:

$$Q_{sup.coil} = 1{,}2 \cdot 1 \cdot 0{,}053 \cdot (18 - (-29) - 7) = 2{,}54\ kW$$

When capacity of the coil is calculated, to find out a water flow to supply air coil by equation 13.

$$q_{v_{water\ \mathrm{sup}.coil}} = \frac{Q_{sup.coil}}{\rho_{water} \cdot c_{p_{water}} \cdot \left(t_{supply} - t_{return}\right)} \tag{13}$$

Where Q_{coil} is capacity of the coil, ρ_{water} density of water, 1000kg/m^3, $c_{p_{water}}$ specific heat capacity of water, 4,2 kJ/kgK, $q_{v_{water\ \mathrm{sup}.coil}}$ water flow, t_{supply} temperature of supply water to supply air coil, t_{return} temperature of return water from supply air coil. Water flow is needed to supply air coil by equation 13.

$$q_{v_{water\ \mathrm{sup}.coil}} = \frac{2{,}54}{1 \cdot 4{,}2 \cdot (55 - 45)} = 0{,}06\ dm^3/s$$

All of the results are shown in table 8. Where are the degree days temperatures, duration in percents and in hours per year of exact temperature . Σϕheat demand is a heat demand for heating purposes. Σϕventilation+7 is a heat demand for supply air coil. Underground ducts pre-heating is included as +7 ℃. Water flow rates for heating and supply air coil is according to heat demand by equation 13. Water flow of the circulation pump is a sum of water flow of heating system and supply air coil.

TABLE 8. Data of capacity, flow of the supply air coil, flow of the heating system.

t_{out}, ˚C	Duration, %	Hours per year, h	Σϕheat demand, kW	Σϕventilation+7, kW	$\Sigma\Phi_{total}$, kW	$q_{v\ vent.}$, dm^3/s	$q_{v\ heating.}$, dm^3/s	$q_{v\ circ.\ pump}$, dm^3/s
-29	0,377	33,03	4,73	2,54	7,27	0,06	0,11	0,17
-20	3,368	262,01	3,93	1,97	5,90	0,05	0,09	0,14
-15	7,74	382,99	3,49	1,65	5,14	0,04	0,08	0,12
-10	11,95	368,80	3,06	1,34	4,40	0,03	0,07	0,10
0	38,18	2297,75	2,19	0,70	2,89	0,02	0,05	0,07
5	59,39	1858,00	1,76	0,38	2,14	0,01	0,04	0,05
10	70,88	1006,52	1,32	0,06	1,38	0,0015	0,03	0,0315
12	76,39	482,68	1,15	0,00	1,15	0,00	0,03	0,03

The annual electricity energy consumption of circulation pump

When all of the flows are known, it is possible to calculate annual electricity energy consumption of the circulation pump. The chart of circulation pump and chosen step one is shown in figure 9. On the x axis there is a needed water flow of circulation pump. On the y axis it is power output according to needed water flow.

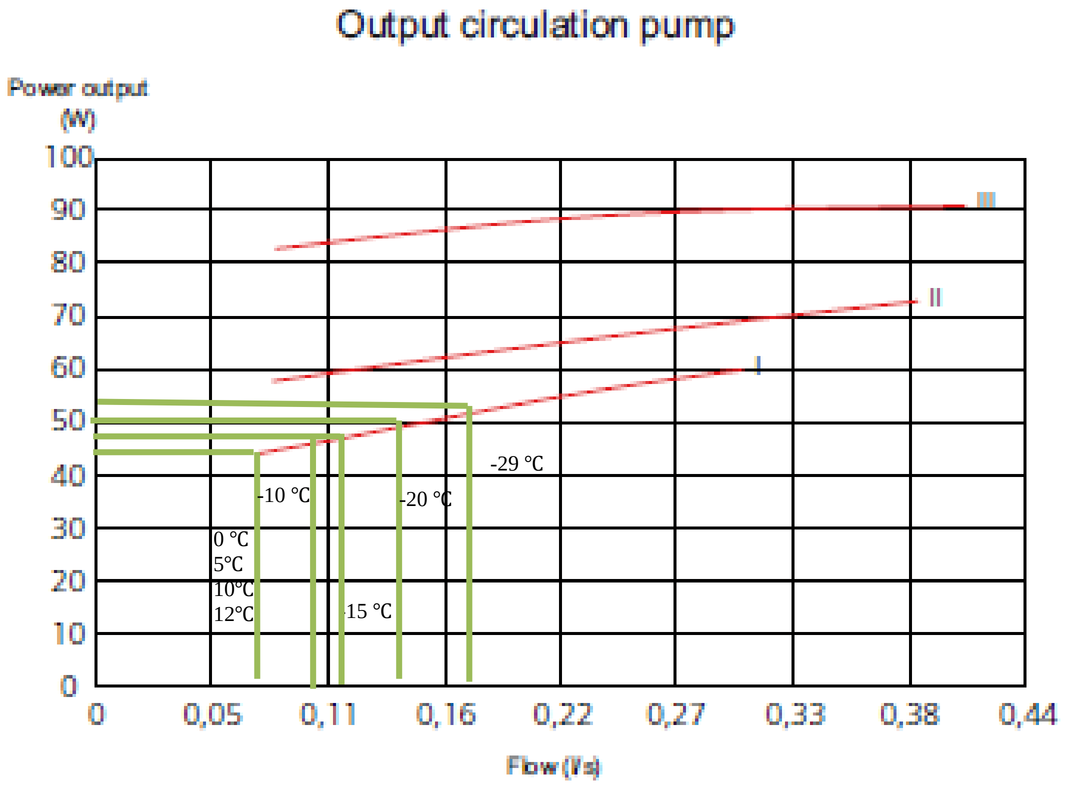


FIGURE 9. Chart of the circulation pump /7/

To calculate annual electricity energy consumption, equation 14 is used:

$$E = P \cdot t \tag{14}$$

Where E is electricity energy consumption, kWh, P power of the device, kW, t time period in hours, h.

Annual electricity energy consumption of the circulation pump:

$$E = 0{,}053 \cdot 33{,}03 = 1{,}75\ kWh$$

Power output and electricity energy consumption of the circulation pump is shown in table 9. There are results according to exact outdoors air temperature. When the temperature decreases, the water flow through circulation pump decreases also.

TABLE 9. Electricity energy consumption of the circulation pump according to outdoors air temperature.

$q_{v\ circ\ pump}$, dm^3/s	Working hours,h	Power output, W	Electricity energy consumption, kWh
0,17	33,03	53	1,75
0,14	262,01	50	13,10
0,12	382,99	47	18,00
0,10	368,80	46	16,96
0,07	2297,75	45	103,40
0,05	1858,00	45	83,61
0,0315	1006,52	45	45,29
0,03	482,68	45	21,72

The annual electricity energy consumption of circulation pump is 303,83 kWh. It is working 6691,78 hours per year.

6.2 The annual electricity energy consumption of a ventilation fan calculations

Supply air fan

When supply air flow rate is +53 l/s. According to figure 10. fan power output is 67W = 0,067 kW and it works at 70% of a maximum power. Fan works 8760h per year. To calculate annual electricity energy consumption of a supply air fan, equation 14 is used:

$$E = 0{,}067 \cdot 8760 = 586{,}92\ kWh$$

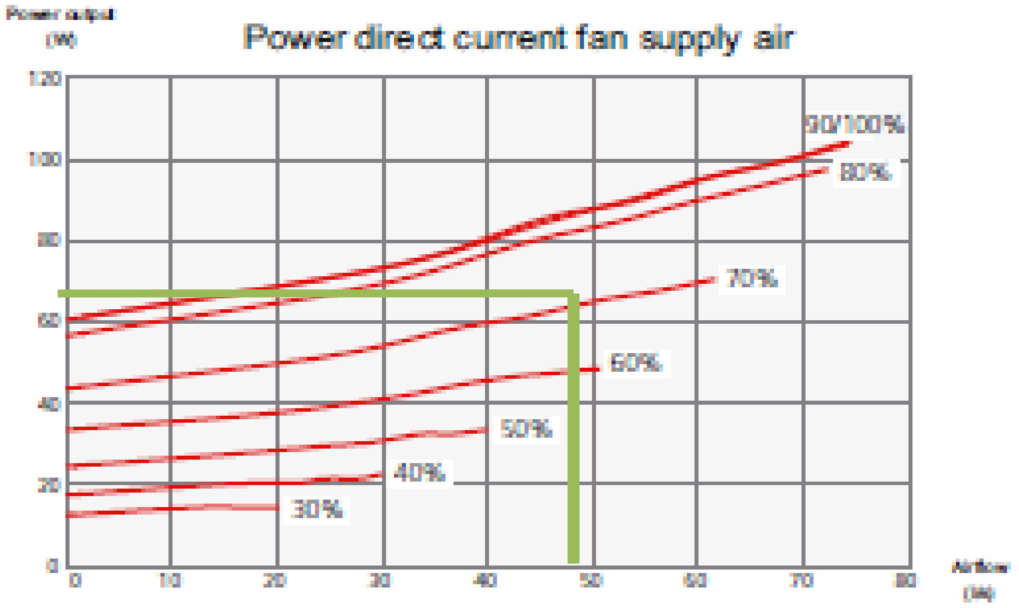


FIGURE 10. Chart of the supply air fan /7/

Exhaust air fan

Exhaust air fan sucks out -65 l/s. In figure 11. it works at 70% of the maximum power of a fan. Power output is 80W = 0,08 kW. Working time is 24h per day. According to equation 14 annual electricity energy consumption is:

$$E = 0,08 \cdot 8760 = 700,80 kWh$$

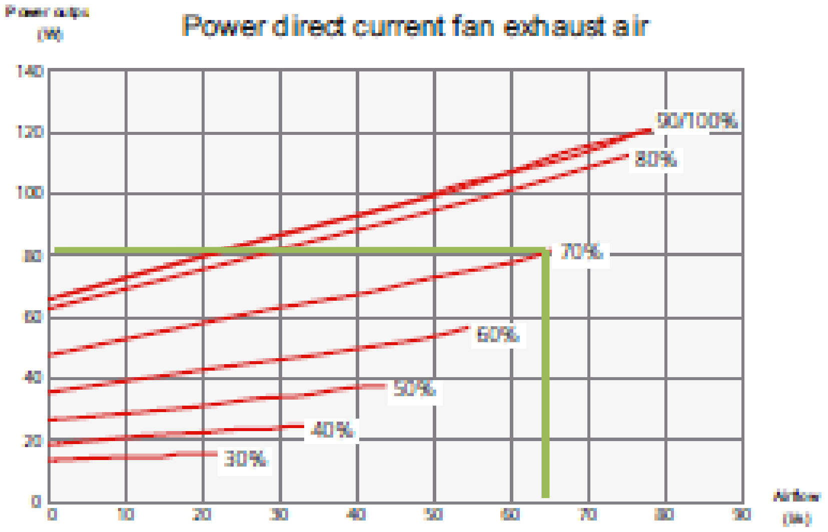


FIGURE 11. Chart of the exhaust air fan /7/

6.3 The annual electricity energy consumption of compressor and immersion heater

In this chapter are calculated how much electricity energy consumes immersion heater and compressor. These calculations should be according degree days, to find out how many hours per year compressor and immersion heater works.

To calculate annual heat demand of this building, eight different temperatures and duration of these temperatures during the year from degree days table were taken. These different temperatures creates interval between dimensioning outdoors temperature and temperature, when heating is not needed anymore. They are expressed in table 8.

According to chapter **5.** calculations $\Sigma\phi_{\text{heat demand}}$ is calculated for each of degree days outdoors temperature. $\Sigma\phi_{\text{ventilation+7}}$ calculated according to equation 12 to exact outdoors air temperature. To find out how much heating energy NIBE F470 should produce equation 15 is used:

$$\Sigma\Phi_{\text{total}} = \Sigma\phi_{\text{heat demand}} + \Sigma\phi_{\text{ventilation+7}} \tag{15}$$

Then total needed heat energy is:

$$\Sigma\Phi_{\text{total}} = 4{,}73 + 2{,}54 = 7{,}27\ kW$$

Needed water flow to supply air battery is calculated by equation 12 and to heating system by equation 11. To calculate how much energy $\mathbf{\Phi_1}$ exhaust air-source heat pump can produce from exhaust air we need mass flow q_m in the evaporator/16/:

$$q_m = q_v \cdot \rho_{air} \tag{16}$$

Where q_m is mass flow in the evaporator, q_v volume flow of the exhaust air, ρ_{air} densinty of the air. By equation mass flow of refrigerant in heat pump is:

$$q_m = 0{,}065 \cdot 1{,}2 = 0{,}078\ kg/s$$

To calculate how much energy is taken in the evaporator, enthalpy difference of the exhaust and extract air is needed. As it was mentioned in chapter 4.2, the dirty air the temperature is +21 ℃. Exhaust air temperature is +1℃ /7/. Enthalpy difference is found out from figure 12.

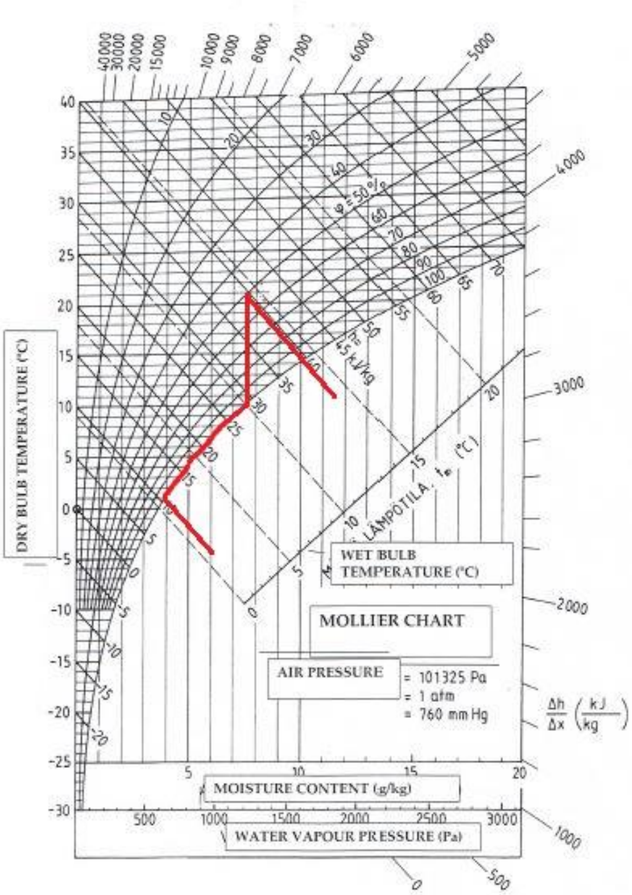


FIGURE 12. Mollier chart to find out enthalpy difference

Enthalpy difference is calculated by equation 17.

$$\Delta h = h_1 - h_2 \qquad (17)$$

Where Δh is enthalpy difference, h_1 enthalpy of the air at +21 ℃, h_2 enthalpy of the air at +1 ℃

Calculated enthalpy difference by equation 17.

$$\Delta h = 39 - 11 = 28\ kJ/kg$$

Energy capacity taken into the evaporator 18.

$$\emptyset_2 = \Delta h \cdot q_m \qquad (18)$$

Where $\emptyset_2$ is amount of the energy taken in an evaporator, Δh enthalpy difference, q_m mass flow of the air.

This amount of energy taken in an evaporator by equation 18 is:

$$\emptyset_2 = 0{,}078 \cdot 28 = 2{,}18\ kW$$

According to technical data of NIBE F470, compressor power output is 0,65 kW /7/. According to equation 19. Amount of produced energy of an exhaust air-source heat pump is:

$$\emptyset_1 = \emptyset_2 + P_{compressor} \tag{19}$$

Where $\emptyset_1$ is a amount of energy produced by a heat pump, $\emptyset_2$ is amount of the energy taken in an evaporator, $P_{compressor}$ is a power output of a compressor.

Energy amount produced by the compressor:

$$\emptyset_1 = 2{,}18 + 0{,}65 = 2{,}83\ kW$$

Amount of the energy compensated by a compressor is needed to calculate how many hours per year works compressor and how many hours works immersion heater, it is calculated by equation 20.

$$\Delta\Sigma\Phi_{\text{total - }\Phi1} = \Sigma\Phi_{\text{total}} - \emptyset_1 \tag{20}$$

Needed to produce amount of energy by immersion heater:

$$\Delta\Sigma\Phi_{\text{total - }\Phi1} = 7{,}27 - 2{,}83 = 4{,}44kW$$

The electricity energy consumption of the immersion heater by equation 21.

$$E_{immersion\ heater} = \Delta\Sigma\emptyset_{\text{total}-\ \emptyset_1} \cdot \text{t} \tag{21}$$

Where $E_{immersion\ heater}$ annual electricity energy consumption of the immersion heater, $\Delta\Sigma\emptyset_{\text{total}-\ \emptyset_1}$ annual electricity energy consumption, when compressor compensates 2,83 kW, t is the time.

Example of the electricity energy consumption of the immersion heater at -29 ℃ by equation 21.

$$E_{immersion\ heater} = 4{,}44 \cdot 33{,}03 = 146{,}76\ kWh$$

For the compressor equation 21 changes to:

$$E_{compressor} = \emptyset_1 \cdot \text{t}$$

Where $E_{compressor}$ is annual electricity energy consumption of the compressor, $\emptyset_1$ amount of the energy which compressor produces, t is the time.

Example of electricity energy consumption of the compressor at -29 °C:

$$E_{compressor} = 0{,}65 \cdot 33{,}03 = 21{,}47 \text{ kWh}$$

All the results are presented in table 10. This table is continue of table 8. Here is electricity energy consumption of immersion heater and compressor. Under the bolded line compressor does not work anymore.

TABLE 10. The annual electricity energy consumption of compressor and immersion heater.

t_{out}, ˚C	Duration, %	Hours per year, h	Σϕheat demand, kW	Σϕventilation+7, kW	$\Sigma\Phi_{total}$, kW	$q_{v\ vent.}$, dm³/s	$q_{v\ heating.}$, dm³/s	$\Delta\Sigma\Phi_{total-\Phi1}$, kW	Φ1	Compressor heater Electricity energy consumption, kWh	Immersion heater electricity energy consumption, kWh
-29	0,377	33,03	4,73	2,54	7,27	0,06	0,11	4,44	2,83	21,47	146,76
-20	3,368	262,01	3,93	1,97	5,90	0,05	0,09	3,07	2,83	170,31	804,79
-15	7,74	382,99	3,49	1,65	5,14	0,04	0,08	2,31	2,83	248,94	886,08
-10	11,95	368,80	3,06	1,34	4,40	0,03	0,07	1,57	2,83	239,72	577,39
0	38,18	2297,75	2,19	0,70	2,89	0,02	0,05	0,06	2,83	1493,54	136,95
5	59,39	1858,00	1,76	0,38	2,14	0,01	0,04	-	2,83	1207,70	-
10	70,88	1006,52	1,32	0,06	1,38	0,0015	0,03	-	2,83	654,24	-
12	76,39	482,68	1,15	0,00	1,15	0,00	0,03	-	2,83	313,74	-

In TABLE 10. at the +5 °C temperature compressor can produce needed amount of the energy by it‘s own and immersion heater is not needed anymore. This point is shown in figure 13.

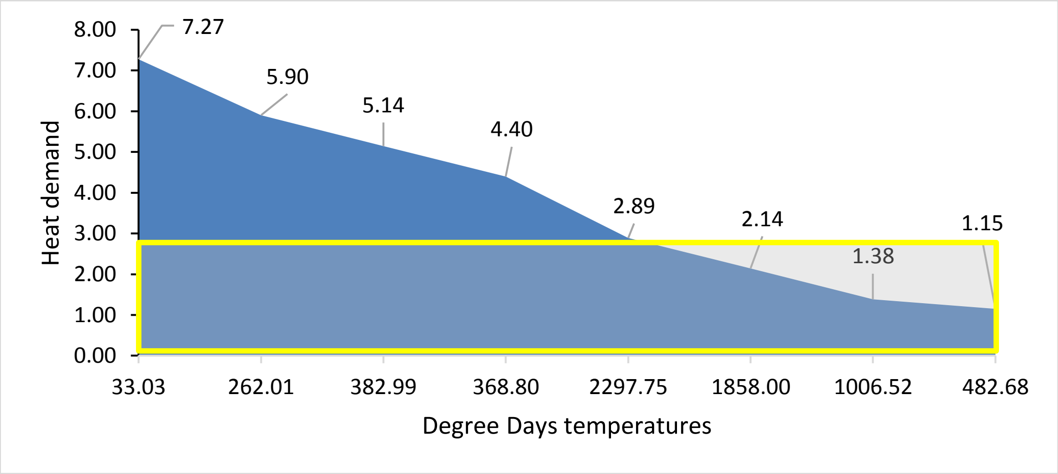


FIGURE 13. Needed amount of the energy compensated by a compressor

In this figure is shown amount of energy compensated by compressor. The square shows area of produced energy by compressor Above the square needed energy should be produced by immersion heater.

To calculate total annual electricity energy consumption of the compressor and immersion heater consumed energy is sumed up. To calculate the annual working hours for each of device equation 14 is used:

$$t_{immersion\ heater} = \frac{2551{,}97}{10{,}25} = 248{,}97\ h$$

$$t_{compressor} = \frac{4349{,}65}{0{,}65} = 6691{,}76\ h$$

All of the results are shown in table 11.

TABLE 11. Total annual electricity energy consumption, working hours of immersion heater and compressor.

	Electricity energy consumption, kWh	Working hours, h
Immersion heater	2551,97	248,97
Compressor	4349,65	6691,76

Here is a annual electricity energy consumption and working hours per year of the immersion heater and compressor.

6.4 The annual costs of NIBE F470 exhaust air – source heat pump

When the total annual electricity energy consumption of every device in NIBE F470 is known, it is possible to calculate annual costs of the system. Annual costs of the machine is calculated by equation 22 according to Finnish electricity price in the Eastern Finland, when annual consumption is 10 000 kWh/ year /9/:

$$Costs = 0{,}0634\,\frac{€}{\mathrm{kWh}} \cdot \mathrm{E_{device}} \tag{22}$$

Where $0{,}0634\frac{€}{\mathrm{kWh}}$ is a 20.1.2015 Finnish electricity price, $\mathrm{E_{device}}$ is power output of the device.

A calculations example of an annual costs of the supply air fan by equation 22.

$$Costs = 0{,}0634\,\frac{€}{\mathrm{kWh}} \cdot 586{,}92 = 37{,}21\ €$$

Annual costs of the NIBE F470 exhaust air – source heat pump is the sum of costs of the all devices. table 12 shows all of results. There is power output of the devices. Working hours per year. Annual electricity energy consumption and annual costs of the devices.

TABLE 12. Annual costs to NIBE F470 exhaust air-source heat pump.

	Power, kW	Working hours, h	Annual electricity energy consumption, kWh	Annual costs, €	Sum of the annual investment to the system, €
Supply fan	0,067	8760	586,92	37,21	538,47
Exhaust fan	0,08	8760	700,80	44,43	
Circulation pump	-	6691,76	303,84	19,26	
Compressor	2,05	6691,76	4349,65	275,77	
Immersion heater	10,25	520,09	5330,93	161,79	

Annual costs of NIBE F470 of electricity energy consumption is 538,47 **€**.

7 ANNUAL ELECTRICITY ENERGY CONSUMPTION CALCULATIONS OF SECOND CASE AND COMPARISON OF THE TWO CASES

In this chapter will be calculated annual electricity energy consumption and annual costs of the second case, when exhaust air flow rate is -28 l/s. Then second case will be compared with first case, when exhaust air flow rate is -65 l/s. In the end the better case will be found out.

7.1 Calculations of the electricity energy consumption of a second case

In this chapter two the same buildings will be compared, but with different air flow rates. In first case (case 1) it is maximum air flow rate, in second case (case 2) it is minimum air flow rate. This comparison will show how does the annual costs changes according to air flow rate in the building.

Case 2 has lower air flow rate. Supply air flow rate is 22 l/s, exhaust air flow rate -28 l/s. It is minimum air flow rate which NIBE F470 exhaust air-source heat pump can operate.

In this chapter calculations are from chapters **5., 6.1., 6.2.** and **6.3., 6.4.**

By using of chapters **5, 6.3.** annual electricity consumption of the immersion heater and compressor are calculated, it is shown in table 13.

TABLE 13. The annual electricity energy consumption of compressor and immersion heater in second case.

t_{out}, ˚C	Duration, %	Hours per year, h	Σϕheat demand, kW	Σϕventilation+7, kW	$\Sigma\Phi_{total}$, kW	$q_{v\ vent.}$, dm³/s	$q_{v\ heating.}$, dm³/s	$\Delta\Sigma\Phi_{total-\Phi 1}$, kW	Φ1	Compressor heater Electricity energy consumption	Immersion heater Electricity energy consumption kwh
-29	0,377	33,03	4,62	1,06	5,68	0,03	0,11	4,09	1,59	21,47	134,94
-20	3,368	262,01	3,82	0,82	4,64	0,02	0,09	3,05	1,59	170,31	798,72
-15	7,74	382,99	3,39	0,69	4,08	0,02	0,08	2,49	1,59	248,94	952,26
-10	11,95	368,80	2,95	0,55	3,50	0,01	0,07	1,91	1,59	239,72	706,02
0	38,18	2297,75	2,08	0,29	2,37	0,01	0,05	0,78	1,59	1493,54	1793,16
5	59,39	1858,00	1,65	0,16	1,81	0,0038	0,04	0,22	1,59	1207,70	405,79
10	70,88	1006,52	1,21	0,03	1,24	0,0006	0,03	-	1,59	654,24	-
12	76,39	482,68	1,04	0,00	1,04	0,00	0,02	-	1,59	313,74	-

In this table shown electricity energy consumption according to exact outdoors air temperature. Under the bolded line immersion does not work anymore, needed amount of energy can be compensated by compressor.

To see how much energy compressor compensates we can find in figure 14.

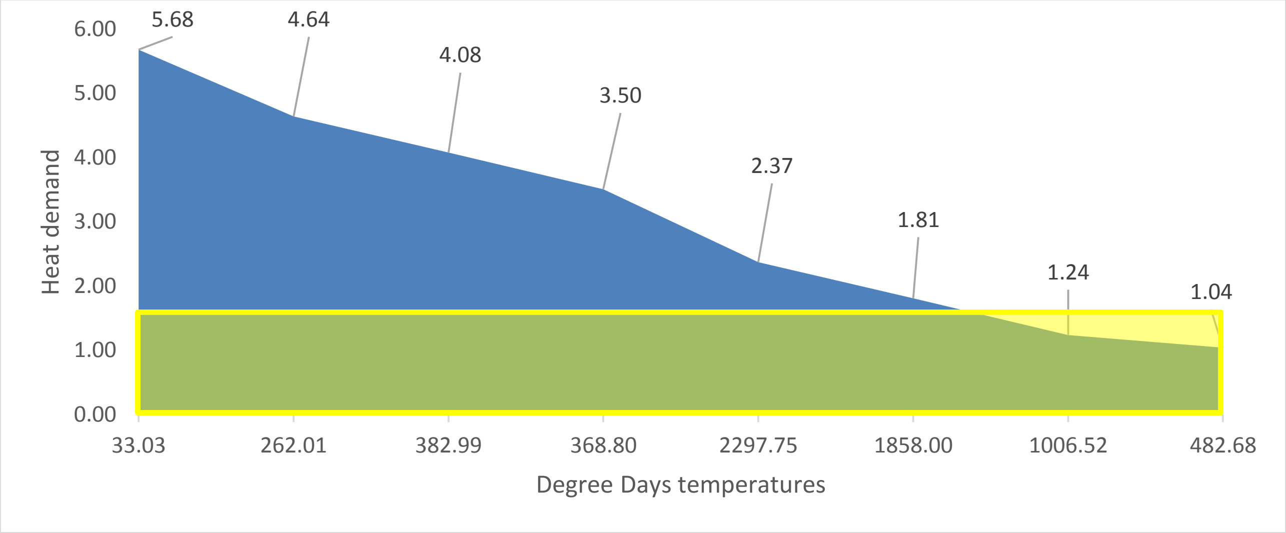


FIGURE 14. Needed amount of the energy compensated by a compressor

Annual electricity energy consumption and annual costs of every device in NIBE F470 of second case is shown in table 14. In the table all results are presented as in table 13.

TABLE 14. Annual costs to NIBE F470 exhaust air-source heat pump.

	Power, kW	Working hours, h	Annual electricity energy consumption, kWh	Costs	Sum of the annual investment to the system, €
sup fan	0,032	8760	280,32	17,77	628,28
exhaust fan	0,021	8760	183,96	11,66	
pump	-	6691,76	305,01	19,34	
Compressor	1,59	6691,76	4349,65	275,77	
Immersion heater	10,25	467,40	4790,89	303,74	

Annual costs of NIBE F470 of electricity energy consumption is 628,28 €.

7.2 Comparison of the two cases

When the annual electricity energy consumption and annual costs of the cases are known, it is possible to compare these two cases. First it is compared the total heat demand of the building according to exact outdoors air temperature. It is shown in figure 15. Blue column is a case 1 and brown column is a case 2.

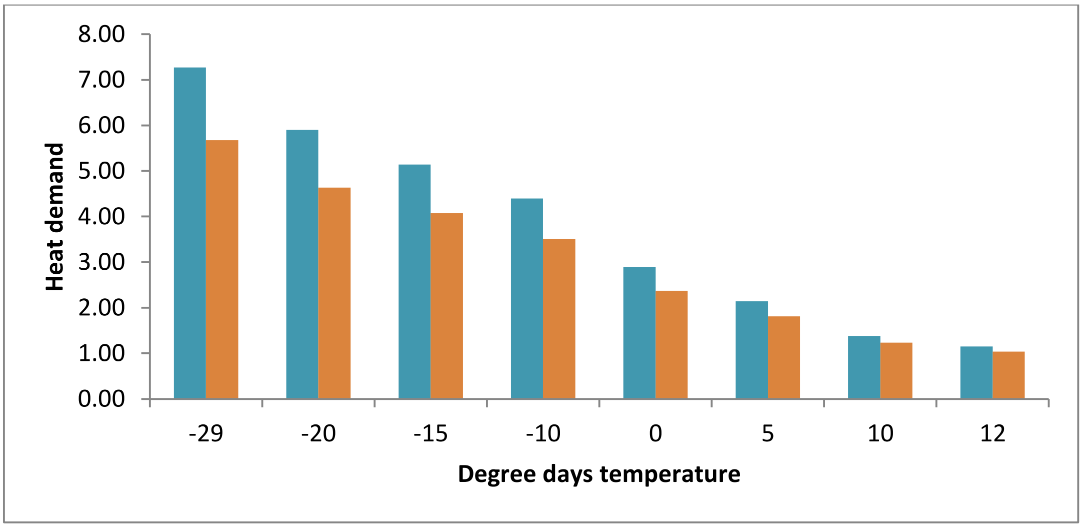


FIGURE 15. Heat demands in the case 1 and the case 2

Here could be noticed that heat demand for heating purposes is higher in case 1. It is because of lower supply air flow rate in case 2. It is 2,3 times lower than in case 1, this means 2,3 times lower heat demand for supply air battery.

Capacity of the produced heat by compressor should be lower, because of the lower air flow rate in case 2. This difference we can see in figure 16. Blue column is case 1, red column is case 2.

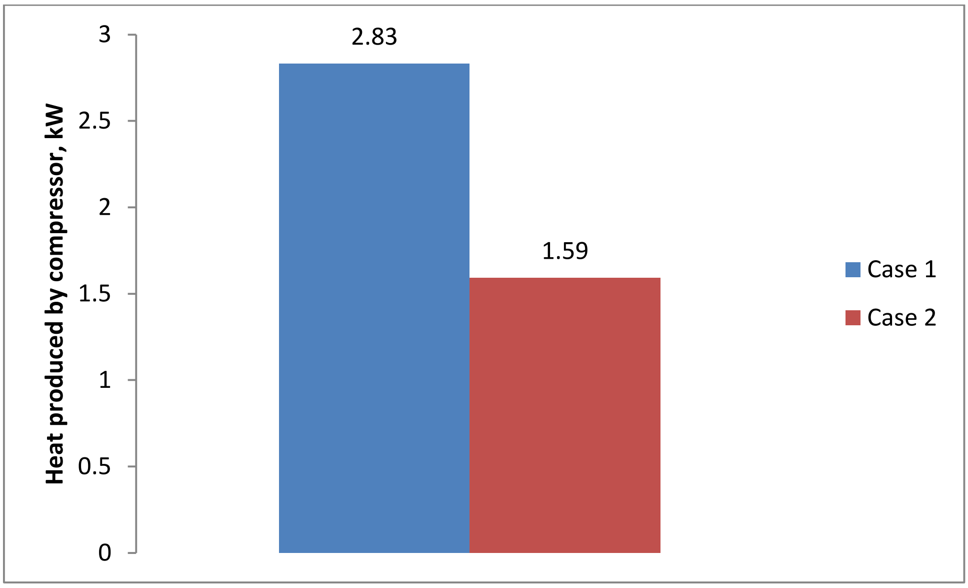


FIGURE 16. Heat produced by compressor in the case 1 and the case 2

The difference between heat produced by compressor is 1,24 kW. It means more working hours of immersion heater.

There is a difference between produced heat energy by a compressor. It means there should be difference between working hours of immersion heater and compressor. In case 2 compressor produces less heat energy, immersion heater should work more hours to compensate needed amount of energy. Difference is 218,43 more hours in case 2. This could be seen in figure 17.

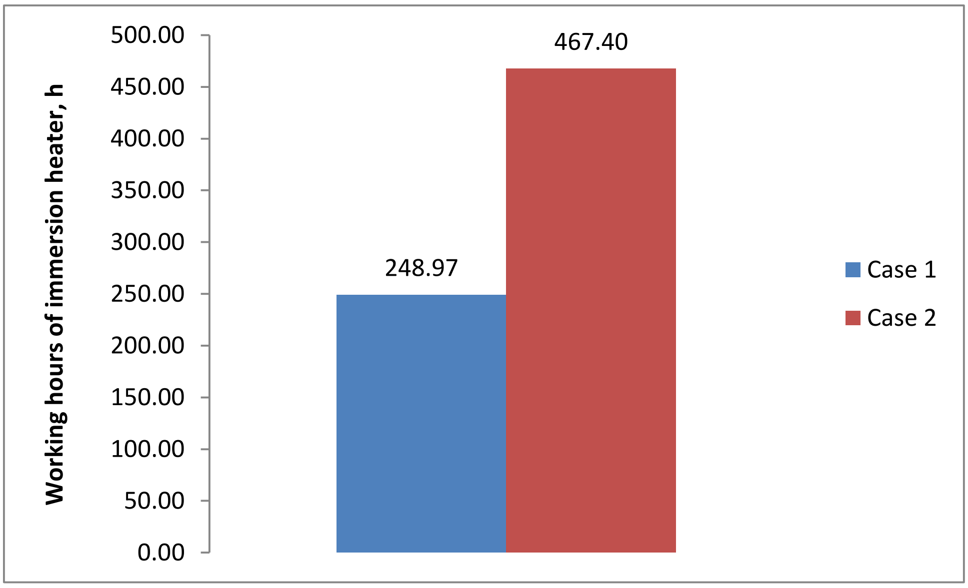


FIGURE 17. Working hours of immersion heater in the case 1 and the case 2

Working hours of the compressor is the same, because compressor is the same. This difference is shown in figure 18.

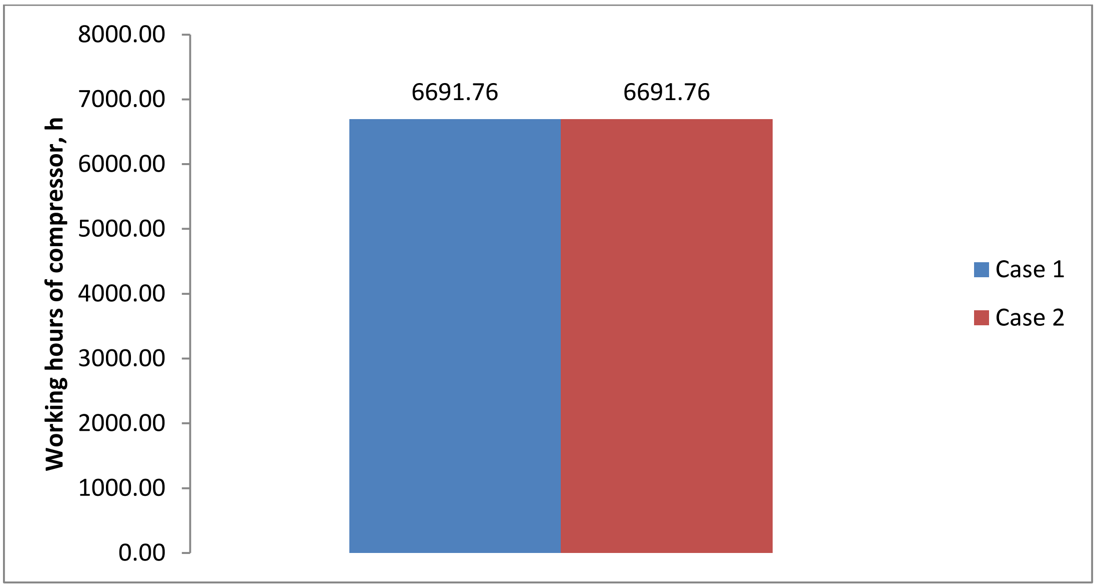


FIGURE 18. Working hours of compressor in the case 1 and the case 2

When there is a difference between working hours of each device, there should be difference of total electricity energy consumption. This difference shown in figure 19.

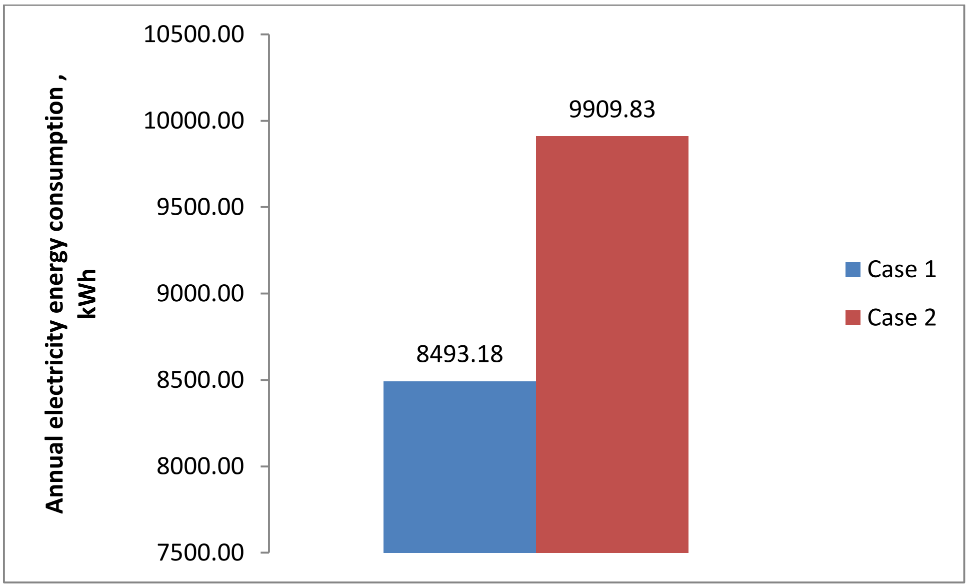


FIGURE 19. Annual electricity energy consumption of the case 1 and the case 2

Case 2 annual electricity energy consumption is 1416,65 kWh more than in case 1. This is because of lower air flow rate in case 2. Compressor produces less heat energy and immersion heater has to compensate this difference.

When annual electricity energy consumption is known, comparison of annual costs of NIBE F470 exhaust air-source heat pump could be done. This difference between the case 1 and the case 2 could be seen in figure 20.

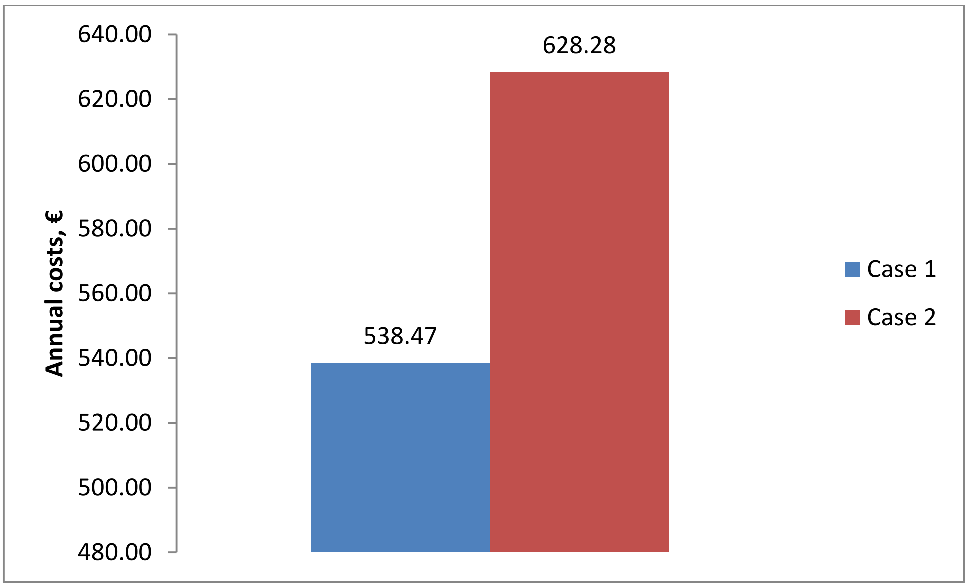


FIGURE 20. Annual costs of the NIBE F470 exhaust air-source heat pump in a case 1 and a case 2

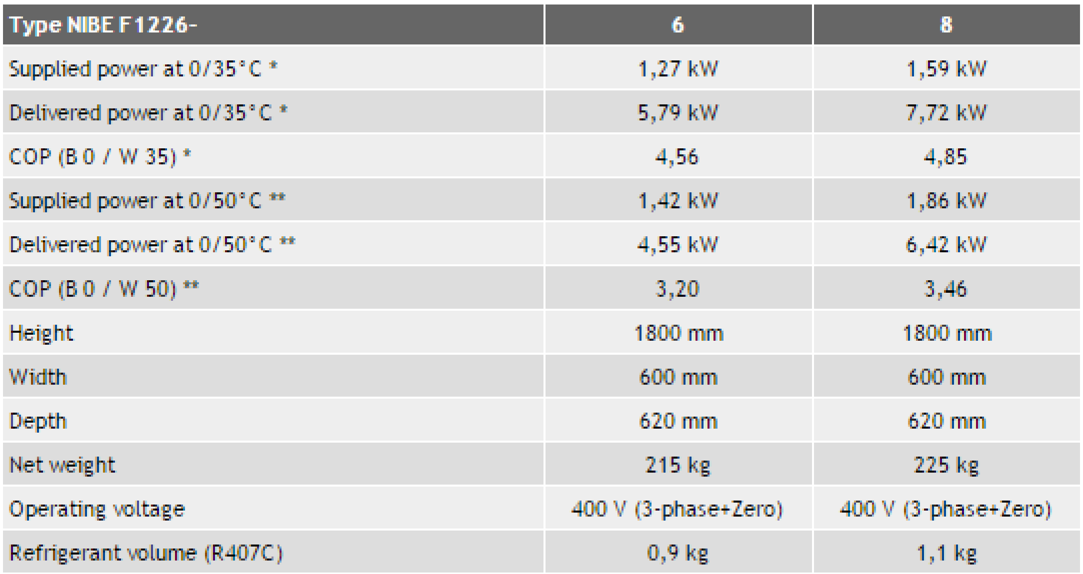
Difference between the case 1 and the case 2 annual costs is 89,81 €. When there are minimum air flow rates of NIBE F470 the annual investment to the system is higher. As it was mensioned earlier, this difference is because of the more working hours of an immersion heater.

8 CALCULATIONS AND COMPARISON OF GROUND SOURCE HEAT PUMP AND EXHAUST AIR-SOURCE HEAT PUMP

Selected ground source heat pump is NIBE F1126. In this chapter there will be compared two different heat pumps. An exhaust air-source heat pump and the ground source heat pump. All of the calculations will be made according to **5**, **6.1**, **6.2**, **6.3**, **6.4** chapters.

Calculations of the ground source heat pump

According to technical data of NIBE F1126 all of the needed information for calculations is shown in figure 21.



Type NIBE F1226-	6	8
Supplied power at 0/35°C *	1,27 kW	1,59 kW
Delivered power at 0/35°C *	5,79 kW	7,72 kW
COP (B 0 / W 35) *	4,56	4,85
Supplied power at 0/50°C **	1,42 kW	1,86 kW
Delivered power at 0/50°C **	4,55 kW	6,42 kW
COP (B 0 / W 50) **	3,20	3,46
Height	1800 mm	1800 mm
Width	600 mm	600 mm
Depth	620 mm	620 mm
Net weight	215 kg	225 kg
Operating voltage	400 V (3-phase+Zero)	400 V (3-phase+Zero)
Refrigerant volume (R407C)	0,9 kg	1,1 kg

FIGURE 21. Initial data of NIBE F1126 /10/

Here is a supplied and delivered power and COP at 0/50 ℃ at 8 kW heat pump. There is an option to attach immersion heater, in this case it is 7 kW immersion heater. It is possible to calculate power output of compresssor by using equation 23.

$$P_{compr.} = \frac{COP}{\Phi_2+1} \tag{23}$$

Where $P_{compr.}$ is power output of compressor, COP is a coefficient of performance of the heat pump, Φ_2 is a amount of the energy taken in to the evaporator. Then the power output of the compressor:

$$P_{compr.} = \frac{3,46}{1,86+1} = 1,21\ kW$$

Annual electricity energy consumption of the compressor and immersion heater is shown in table 15.

TABLE 15. The annual electricity energy consumption of compressor and immersion heater in ground source heat pump.

t_{out}, °C	Duration, %	Hours per year, h	Σϕheat demand, kW	Σϕventilation+7, kW	$\Sigma\Phi_{total}$, kW	$q_{v\ vent.}$, dm^3/s	$q_{v\ heating.}$, dm^3/s	$\Delta\Sigma\Phi_{total-\Phi1}$, kW	Φ1	Compressor heater Electricity energy consumption, kWh	Immersion heater electricity energy consumption, kWh	Annual electricity energy consumption, kWh	Annual Investment	Working hours, h
-29	0,377	33,03	4,73	2,54	7,27	0,06	0,11	0,85	6,42	39,63	28,20	8030,12	509,11	6691,76
-20	3,368	262,01	3,93	1,97	5,90	0,05	0,09	-	6,42	314,41	-			
-15	7,74	382,99	3,49	1,65	5,14	0,04	0,08	-	6,42	459,58	-			
-10	11,95	368,80	3,06	1,34	4,40	0,03	0,07	-	6,42	442,56	-			
0	38,18	2297,75	2,19	0,70	2,89	0,02	0,05	-	6,42	2757,30	-	28,20	1,79	4,03
5	59,39	1858,00	1,76	0,38	2,14	0,01	0,04	-	6,42	2229,60	-			
10	70,88	1006,52	1,32	0,06	1,38	0,00	0,03	-	6,42	1207,83	-			
12	76,39	482,68	1,15	0,00	1,15	0,00	0,03	-	6,42	579,21	-			

Here is a Φ_1 produced energy of ground source heat pump /9/. $\Delta\Sigma\Phi_{total-\Phi1}$ is a needed energy to compensate and produce by a immersion heater. In the column Annual electricity energy consumption in the upper row is a consumption of the compressor and in the second row is consumption of the immersion heater.

In the ground source heat pump the supply and exhaust air fans, circulation pump are the same as in the exhaust air-source heat pump. The annual electricity energy consumption, working hours and annual costs of the ground source heat pump is shown in table 16.

TABLE 16. The annual electricity energy consumption, working hours and annual costs of the ground source heat pump

	Power, kW	Working hours, h	Annual electricity energy consumption, kWh	costs	Sum of the annual investment to the system, €
sup fan	0,067	8760	586,92	37,21	611,80
exhaust fan	0,08	8760	700,80	44,43	
pump		6691,76	303,84	19,26	
Compressor	1,20	6691,76	8030,12	509,11	
Immersion heater	7,00	4,03	28,20	1,79	

The annual costs of the ground source heat pump is 611,80 €.

Comparison of ground source heat pump and exhaust air-source heat pump

In this chapter there will be compared two different types of heat pumps. To find out which system is more economically efficient, consumes less electricity energy consumption. The last question is how many years is needed to get money back, if ground source heat pump is changed to exhaust air-source heat pump.

The difference between annual electricity energy consumption is shown in figure 22.

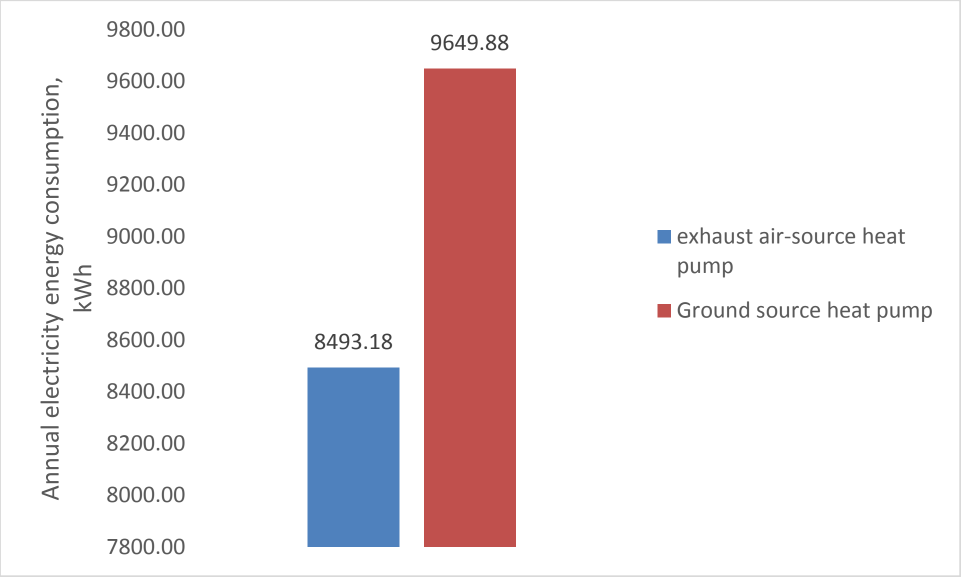


Figure 22. Difference of the annual electricity energy consumption of the exhaust air-source heat pump and ground source heat pump

The difference is 1156,70 kWh. The difference is because of less energy consumed by a compressor. In exhaust air-source heat pump produces 2,83 kW. In ground source heat pump compressor produces 6,42 kW. In ground source heat pump the compressor has higher power ouput and consumes more electricity energy.

The annual costs of the systems is shown in figure 23. The difference is 73,33 € per year.

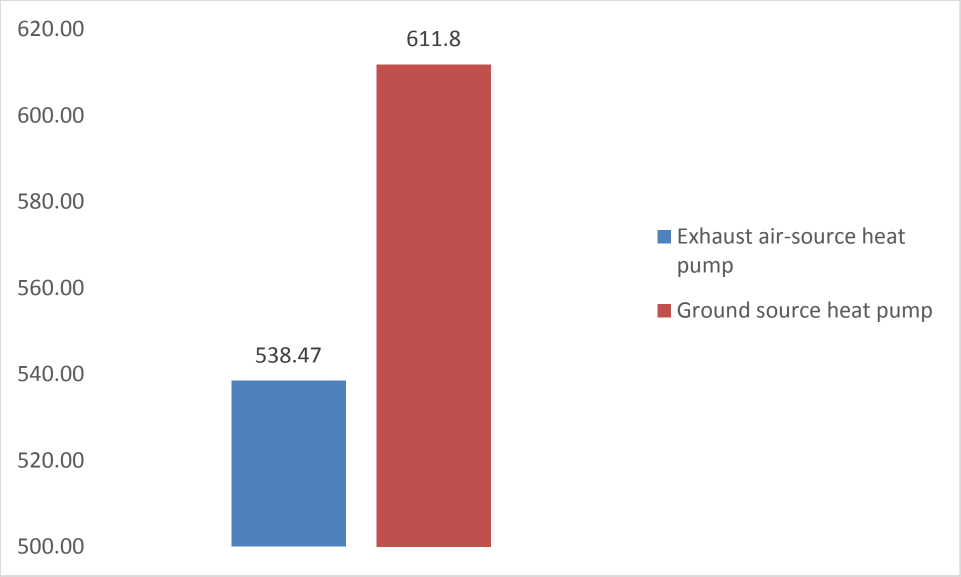


Figure 23. Difference of the annual investments of the exhaust air-source heat pump and ground source heat pump

Exhaust air-source heat pump has lower annual costs per year. If ground source heat pump is changed to exhaust air-source heat pump there is a profit. Then it is possible to calculate pay back time of the ground source heat pump. Let's say that these two heat pumps costs the same price, it is 5000 €. The pay back time will be:

$$Pay\ back\ time = \frac{5000\ \text{€}}{73{,}33\ \text{€/year}} = 68{,}18\ year$$

The pay back time is 68,18 years. It is bad idea to change ground source heat pump to exhaust air-source heat pump. The pay back time is too long.

9 CONCLUSION

NIBE F470 exhaust air-source heat pump has been chosen. The total annual electricity energy consumption of the system is 8493 kWh, the annual costs 539 €. Compressor consumes 51% of the total electricity energy consumption 4350 kWh and it works 6692 hours per year. Power of the produced heat of a compressor is 2,83 kW. Immersion heater consumes 2552 kWh, it is 30 % of the total annual electricity energy consumption. It works 249 hours per year. Power of the produced heat is 10,25 kW. Circulation pump, supply air fan, exhaust air fan consumes 19 % of the total annual electricity energy consumption, it is 1592 kWh.

Comparing two case, when case 2 has 2,3 times lower supply and exhaust air flow rates, the difference between the total annual electricity energy consumption is 1417 kWh higher in case 2. Difference between annual costs is 90 €. In the case 2 compressor in a heat pump produces less heat, it is 1,59 kW, when in case 1 compressor produces 2,83 kW heat. Compressor in these 2 cases works the same amount of the hours. Difference between produced heat energy by a compressor is 1,24 kW. Because of lower heat production of compressor in case 2, immersion heater has to compensate this difference. In case 2, immersion heater works 219 hours more than in case 1 and consumes more 2239 kWh total annual electricity energy.

Despite higher air flow rates in case 1, it is more financially reasonable to have maximum air flow rates of the NIBE F470. As it was mentioned in case 2 annual costs are 90 € higher than in case 1. The lower exhaust air flow rate, the less heat energy system produces by using a compressor. This difference has to be compensated by a immersion heater. This is why in case 2 immersion heater works more hours and case 2 has higher annual costs. All in all, case 1 is better than case 2, higher air flow rate, higher level of the comfort in the building.

Comparing exhaust air-source heat pump and ground source heat pump the difference between annual electricity energy consumption is 1157 higher in ground source heat pump. This difference because of less energy consumed by a compressor in exhaust air-source heat pump. The difference between annual costs is a 74 €/year profit to have exhaust air-source heat pump instead of ground source heat pump. If these two different heat pumps would cost the same price and ground source heat pump is changed to exhaust air-source heat pump, the pay back time is 68,18 years. To sum up, it is a bad idea to change the ground source heat pump to the exhaust air-source heat pump. The better choice is to leave and do not replace ground source heat pump, because of too long pay back time.

REFERENCES

1. National Building Code of Finland. Part D5. Calculation of power and energy needs for heating of buildings. Ministry of the Environment, Department of the Built Environment.
2. National Building Code of Finland D3. Energy efficiency of Buildings, regulations and guidelines 2012. Ministry of the Environment, Department of the Built Environment.
3. National Renewable Energy Laboratory. June 2011. Air-source heat pumps. www.nrel.gov/docs/fy01osti/28037.pdf. Last updated 09/20/2013 20:13:48, referred 09/20/2013 20:13:48;
4. Mark Group. No years of publishment. Heat pumps. www.markgroup.co.uk/homeowners/heating/heat-pumps. Last updated 10/12/2014 19:03:05, referred 10/12/2014 19:03:05
5. Moses Drilling Company. No years of publishment. Types of systems. http://www.mosesdrilling.com/types-of-systems/. Last updated 10/12/2014 19:34:51, referred 10/12/2014 19:34:51
6. Vents. No years of publishment. Geothermal ventilation systems. http://www.ventilation-system.com/cat/energy-saving-geo/. Last updated 11/16/2014 21:00:13, referred 11/16/2014 21:00:13;
7. NIBE. No years of publishment. Product NIBE F470. http://www.nibe.eu/Domestic-heatingcooling/Exhaust-air-heat-pumps/Product-range/NIBE-F470/. Last updated 10/12/2014 20:24:41, referred 10/12/2014 20:24:41;

8. Aki Valkeapää, Martti Veuro. 2013. Introduction and principles of design, heat loss calculations. Mikkeli University of Applied Sciences.

9. Sahkonhinta. Energiavirasto. 2015. Finnish electricity price. http://www.sahkonhinta.fi/summariesandgraphs. Last updated 20/01/2015 15:34:26, referre: 20/01/2015 15:34:26;

10. NIBE. No years of publishment. Product NIBE F1126. http://www.nibe.eu/Domestic-heatingcooling/Ground-source-heat-pumps/Product-range/NIBE-F1126/. Last updated undefined, referred undefined;

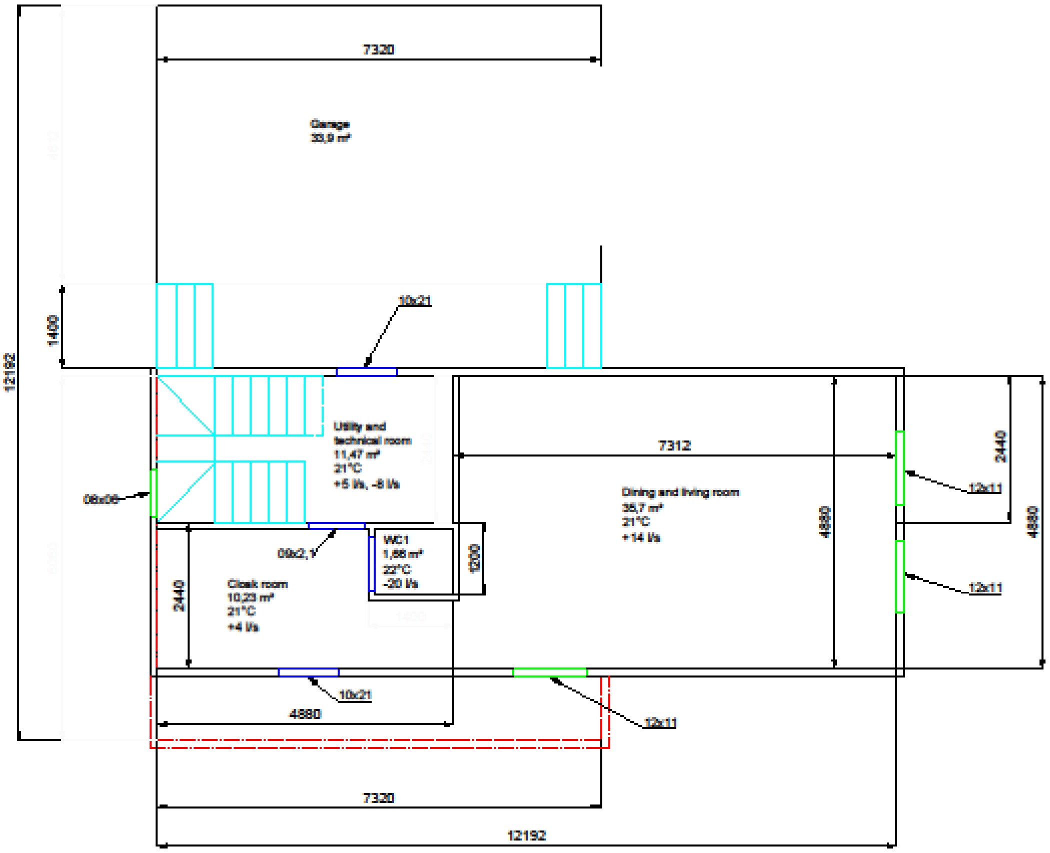


Figure 24. Plan of the first floor of the building

APPENDIX 2

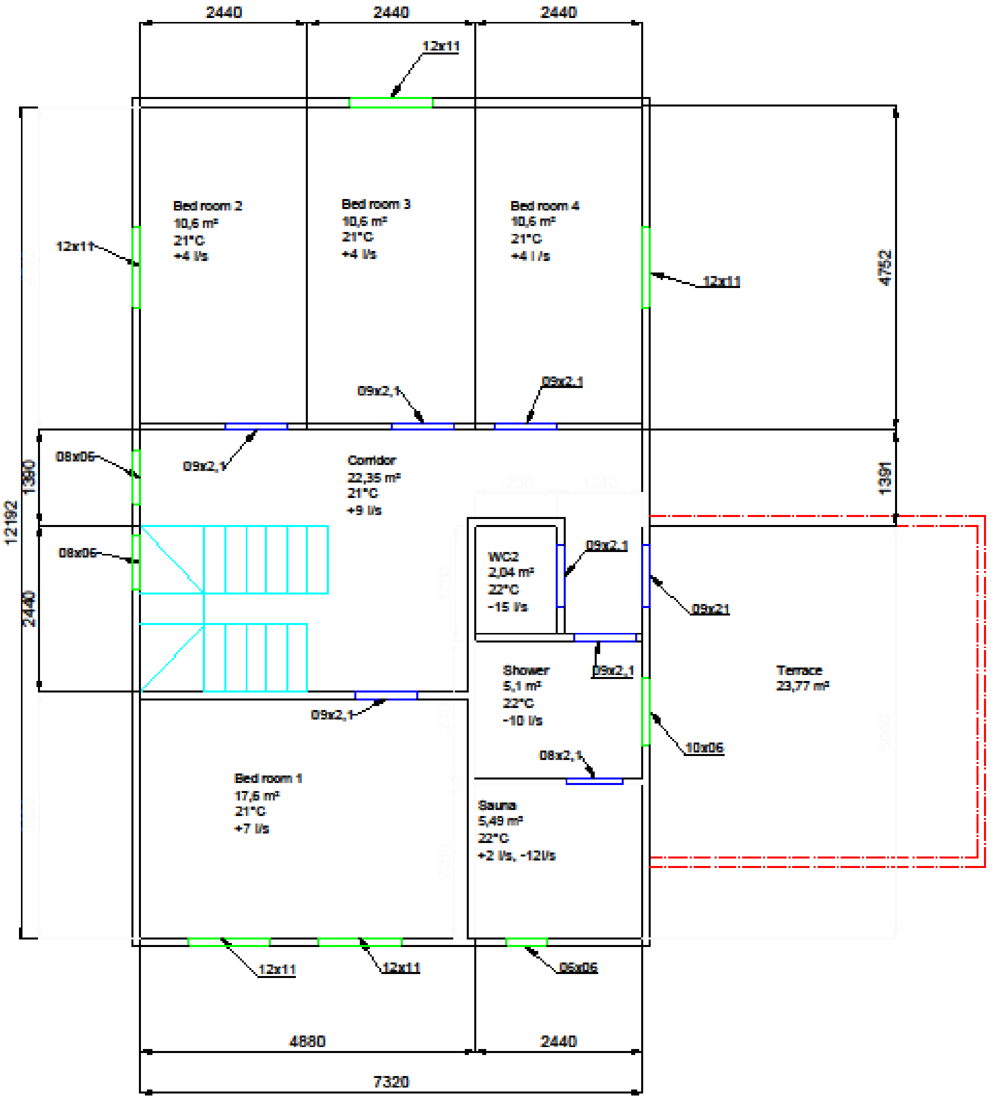


Figure 25. Plan of the second floor of the building