MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

Satbayev University

Institute of Cybernetics and Information Technology

Department of Applied Mechanics and Engineering Graphics

APPROVED BY
The heat of the department of AMaEG,
A. Kaltayev

“____“ _____2020y.

GRADUATE WORK

On the topic: “Study of efficient heat exchange between air-to-water heat pump and a heat storage tank; configuration optimization”

5B071200 – Mechanical Engineering

Performed by Arystanbekov Ch. M.

Scientific advisor PhD, tutor

_______________Ye. Belyayev

“_____” __________ 2020y.

Almaty 2020

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КАЗ ҰТУ

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НАЗВАНИЕ:
STUDY OF EFFICIENT HEAT EXCHANGE BETWEEN AIR-TO-WATER HEAT PUMP AND A HEAT STORAGE TANK; CONFIGURATION OPTIMIZATION

АВТОР:
Arystanbekov Ch. M.

НАУЧНЫЙ РУКОВОДИТЕЛЬ:
Ержан Беляев

ПОДРАЗДЕЛЕНИЕ:
ИКиИТ

ДАТА ЗАГРУЗКИ ДОКУМЕНТА:
2020-06-01 12:39:10

ЧИСЛО ПРОВЕРОК ДОКУМЕНТА:
1

ПРОПУЩЕННЫЕ ВЕБ-СТРАНИЦЫ:

Уровень заимствований

Обратите внимание!Высокие значения коэффициентов не означают плагиат. Отчет должен быть проанализирован экспертом.

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25	5148	31027
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Предупреждение и сигналы тревоги

В этом разделе вы найдете информацию, касающуюся манипуляций в тексте, с целью изменить результаты проверки. Для того, кто оценивает работу на бумажном носителе или в электронном формате, манипуляции могут быть невидимы (может быть также целенаправленное вписывание ошибок). Следует оценить, являются ли изменения преднамеренными или нет.

Замена букв Использование символов из другого алфавита - может указывать на способ обойти систему, поэтому следует установить их использование.	0	показать в тексте
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Просмотрите список и проанализируйте, в особенности, те фрагменты, которые превышают КП №2 (выделенные жирным шрифтом). Используйте ссылку «Обозначить фрагмент» и посмотрите, являются ли выделенные фрагменты повтояющимися короткими фразами, разбросанными в документе (совпадающие сходства), многочисленными короткими фразами расположенные рядом друг с другом (парафразирование) или обширными фрагментами без указания источника ("криптоцитаты").

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ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ И АДРЕС ИСТОЧНИКА URL (НАЗВАНИЕ БАЗЫ)	АВТОР	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ

6	Thermal analysis of SUS 304 stainless steel using ethylene glycol/nanocellulose-based nanofluid coolant (- Paperity - abstrakty)	Lingenthiran, M. M. Rahman,K. Kadirgama, D. Ramasamy, K. Anamalai, M. Samykano, K. Ramachandran, A. Kottasamy;	8	0,16 %
7	Thermal analysis of SUS 304 stainless steel using ethylene glycol/nanocellulose-based nanofluid coolant (- Paperity - abstrakty)	Lingenthiran, M. M. Rahman,K. Kadirgama, D. Ramasamy, K. Anamalai, M. Samykano, K. Ramachandran, A. Kottasamy;	8	0,16 %
8	Thermal analysis of SUS 304 stainless steel using ethylene glycol/nanocellulose-based nanofluid coolant (- Paperity - abstrakty)	Lingenthiran, M. M. Rahman,K. Kadirgama, D. Ramasamy, K. Anamalai, M. Samykano, K. Ramachandran, A. Kottasamy;	7	0,14 %
9	https://www.sciencedirect.com/topics/engineering/conduction-heat-transfer		7	0,14 %

из базы данных RefBooks (0,45 %)

Все фрагменты найдены в базе данных RefBooks, которая содержит более 3 миллионов текстов от редакторов и авторов.

ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ	АВТОР	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (КОЛИЧЕСТВО ФРАГМЕНТОВ)	
		Источник: Paperity - abstrakty		
1	Thermal analysis of SUS 304 stainless steel using ethylene glycol/nanocellulose-based nanofluid coolant	(Lingenthiran, M. M. Rahman,K. Kadirgama, D. Ramasamy, K. Anamalai, M. Samykano, K. Ramachandran, A. Kottasamy;)	23 (3)	0,45 %

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ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ	АВТОР	ДАТА ИНДЕКСАЦИИ	ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)

ЗАИМСТВОВАНИЙ НЕ НАЙДЕНО

из программы обмена базами данных (0,00 %)

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ПОРЯДКОВЫЙ НОМЕР	ИСТОЧНИК URL	ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)	
1	https://pastebin.com/KG6BJTPS	221 (1)	4,29 %
2	https://saryiagash.satu.kz/Alternativnye-istochniki-otopleniya.html	33 (3)	0,64 %
3	https://community.ptc.com/sejnu66972/attachments/sejnu66972/PTCMathcad/173365/1/1.1%20Heat%20Conduction%20in%20Multilayered%20Walls.pdf	21 (1)	0,41 %
4	https://www.sciencedirect.com/topics/engineering/conduction-heat-transfer	7 (1)	0,14 %

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Satbayev University

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Department of Applied Mechanics and Engineering Graphics

5B071200 – Mechanical Engineering

CONFIRM

The head of the

Department of Applied Mechanics

and Engineering Graphics

Prof. A. Kaltayev

TASK

for completing the diploma project

For student: Arystanbekov Ch. M.

Topic: "Study of efficient heat exchange between air-to-water heat pump and heat storage tank; configuration optimization"

Approved *by the order of university rector №762-b from "27" January 2020*

Deadline for completion the work *"24" May 2020*

Initial data for the diploma project:

Summary of the diploma project:

a) *2D model of a building, calculation the heat loss of the building;*
b) *Comparing different types of heat sources;*
c) *Constructing actual heating system in TRNSYS, analysis on output.*

List of graphic material: images - 13

Recommended main literature:

1. Antonio Briganti. Heat pumps in the living spaces.// ABOK, 2001, #5,6.

2. Porocenko V. P., Radchenko V. A. Coefficient of performance of a Heat pumps. 1988, #8.

THE SCHEDULE

For the graduate work preparation

Name of sections, list of issues being developed	Submission deadlines to the scientific adviser	Notes
Theoretical part	8.03.2020	Task completed
Calculating part	15.03.2020	Task completed
Modeling part	03.04.2020	Task completed
Analyzing part	16.04.2020	Task completed

Signatures

Of consultants and standard controller for the completed diploma work, indicating the relevant sections of the work (project).

The section titles	Consultant name (academic degree, title)	Date	Signature
Theoretical part	PhD, Belyayev Y. K.	9.03.2020	
Calculation part	PhD, Belyayev Y. K.	16.03.2020	
Modeling part	PhD, Belyayev Y. K.	04.04.2020	
Analyzing part	PhD, Belyayev Y. K.	17.04.2020	
Normcontrol	PhD, Belyayev Y. K.	22.05.2020	

Scientific adviser ________________ PhD, Ye. Belyayev

Signature

The task was completed by student: ________________ Ch. Arystanbekov

Signature

Date: "22" May 2020

АҢДАТПА

Дипломдық жұмыс жылу сорғы технологиясын зерттеудің өзекті тақырыбына арналған.

Жылу сорғыларындағы процестер сипатталған. Жылу сорғыларының әртүрлі түрлері арасында дәл салыстыру жасалды, мұндай технологиялардың артықшылықтары мен кемшіліктері анықталды. Сондай-ақ, жұмыс сұйықтығының негізгі түрлері (салқындатқыш) сипатталды. Ауа-су типтегі жылу сорғысы есептеліп, негізгі сипаттамалары есептелді.

АННОТАЦИЯ

Дипломная работа посвящена актуальной теме исследования технологии тепловых насосов.

Были описаны процессы, протекающие в тепловых насосах. Проведено тщательное сравнение между разными видами тепловых насосов, выявлены достоинства и недостатки таких технологий. Также, были разобраны основные виды рабочего тела(хладагент). Был проведен расчет теплового насоса вида воздух-вода, рассчитаны основные характеристики.

ABSTRACT

The work is devoted to the relevant topic of investigating of heat pump technology.

Processes in heat pumps have been described. An accurate comparison between different types of heat pumps was made; the advantages and disadvantages of such technologies were revealed. Also, the main types of working fluid (refrigerant) were described. A heat pump of the air-water type was calculated, and the main characteristics were determined.

Content

INTRODUCTION

The heat pump is an invention that belongs to Lord Kelvin, thermodynamically identical to the refrigerator. The fundamental difference between the heat pump and refrigerator is that it does an exact opposite. Refrigerator and air conditioners are used to make space cooler, whereas a heat pump to make it warmer.

For the last decades, it is been noticed that interest in this type of heating system is increased in all well-developed countries. This tendency is observed due to some solved problems that occurred in the second half of the XX century. Unlike the other energy sources heat pumps meet almost all the requirements of modern society. Such as environmental-friendliness, profitability, durability, and safety.

Heat pumps have their relevance particularly in such polluted cities as Almaty. As it does not use any fuels and therefore no harmful gases such as CO, CO2, NOx, SO2 that affect on human body and environment are released into the atmosphere. Moreover, the heat pump uses energy more effectively than the boilers that burn organic fuels and use electric energy. Low electric-energy-consuming is achieved by the high coefficient of performance of the system and allows to get 3-5 kW heat energy for every 1 kW spent electric energy.

Heat pumps are fireproof and there are no explosions. There is no fuel, no open fire, no dangerous gases or compounds. There is no part of the heat pump that heats enough to cause a fire. There is nothing to explode in this construction. Stopping the process in a device does not lead to its breaking or freezing. In fact, a heat pump is not more dangerous than a simple refrigerator.

An exploitation period of heat pumps is longer than traditional heat sources. Heat pumps can serve from 20 to 30 years. Then, if the parts that need to be changed are replaced heat pump continues serving another 20-30 years.

However, there are several significant disadvantages of such energy sources as heat pumps. Its cost, space that it needs to be installed in, and a noise. Heat pumps are more expensive than the gaseous or electric heating systems. It is the main problem of heat pumps. Of course, it must be noticed that the payback period of heat pumps reaches 4-6 years, on average. Besides, it requires a decent amount of space. For example, heat pumps produced by the “NIBE” company need 4-6 m^2 for a steam shop and 2-3 times bigger area than a heated one for the horizontal collector.

1 Basics of heat pumps

1.1 Working principle

As was already mentioned the working principle of the heat pump is identical to the refrigerator. In refrigerator freezer(evaporator) retrieves heat from food. This heat is released from a radiator(condenser) to the surrounding room. In the same way heat pump derives low potential heat from a natural source (water, ground, air), and consuming some amount of electric energy for its work transforms energy with low potential to the energy with average potential which is applicable for the consumers.

1.2 Classification of heat pumps

There are many variations in the classification of heat pumps. Depending on the state of aggregation of renewable low-temperature sources of energy and heated substance heat pumps are divided into water-to-water, air-to-water, air-to-air, water-to-air. Depending on compressor equipment is divided into spiral, piston, helical. Depending on drive motor – electric drive and heat-driven. Depending on working fluid(refrigerant) – low-temperature, average-temperature, high-temperature. Depending on operating functions – heat pumps are only for heating and heat pumps for heating or cooling.

1.3 Work description

On an image 1 the fundamental scheme of an air-to-water heat pump is given. The state of working fluid after processes that take place in the main parts of the heat pump are marked with corresponding numbers. In contradistinction to the vapor compression refrigerator the air-to-water heat pump has an extra part which is sub-cooler (SC). It is used to cool the liquid refrigerant. The heat pump works in a next way: air flows through the annulus, where it cools due to boiling (evaporation) of working fluid (refrigerant) in a pipe. Vapors from an evaporator (E) are constantly sucked by a compressor (C). Going through the heat exchanger (HE) vapors are heated because of heat exchanging with passing through the pipes liquid refrigerant. Compressor (C) compresses heat vapors of refrigerant up to the condensation pressure and directs it to the annulus of the condenser (CD). Cool water is supplied to the pipes of the condenser. On an external surface of pipes in the annulus of condenser vapors of refrigerant are cooled and condensed, turn to the liquid which then passes to the sub-cooler where it cools due to heat-exchanging with supplied cool water. Then cool refrigerant flows via heat-exchanger and cools even more as a due to heat exchanging with refrigerant vapors. It is then throttled in an expansion valve (EV) decreasing pressure and, consequently, the temperature in the evaporator. Obtained vapor-liquid mix boils (evaporates) in an evaporator, getting heat from the air. These vapors of refrigerant are sucked by the compressor, the cycle closes.

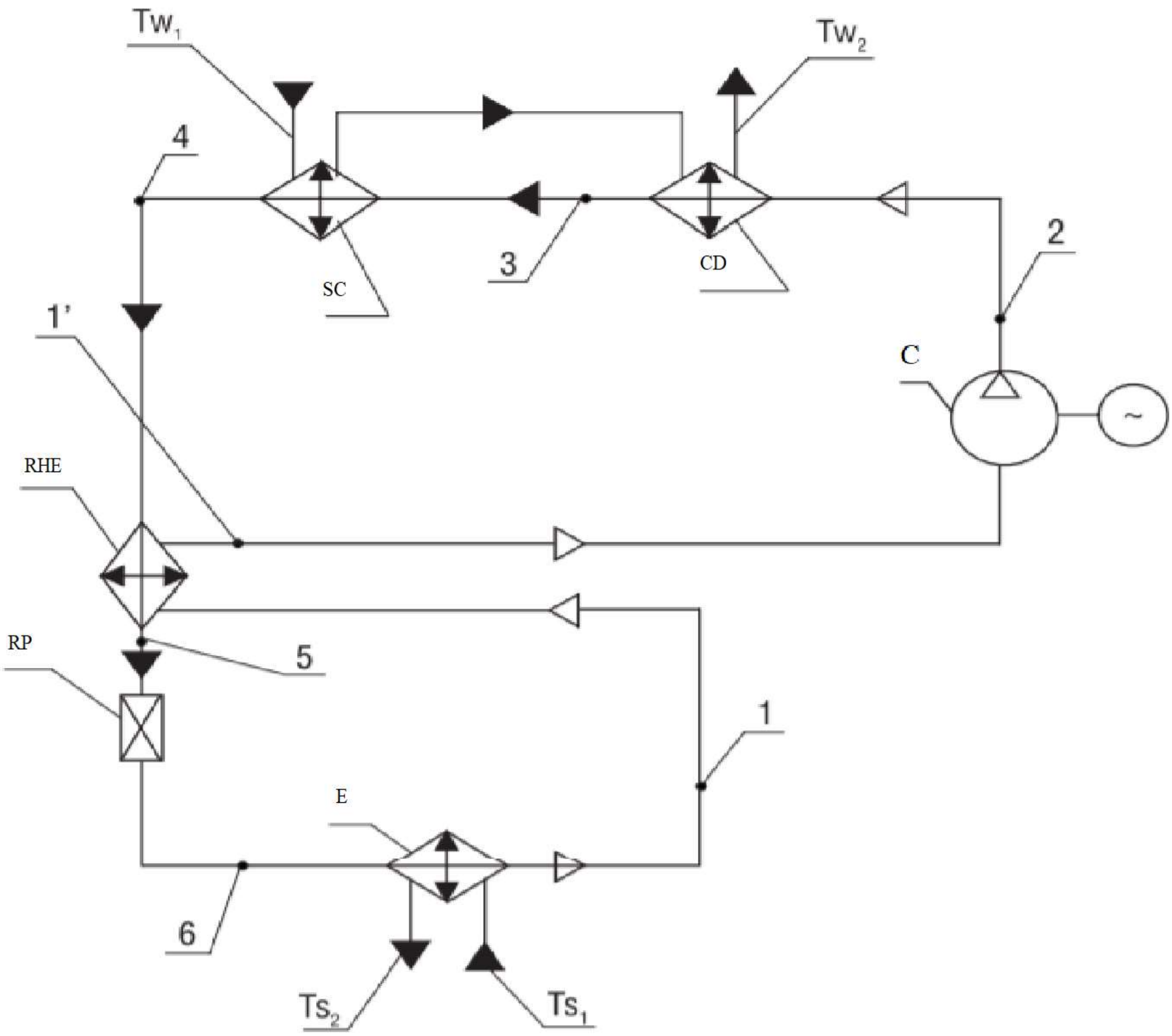


Image 1 - C – compressor; CD – condenser; SC – sub-cooler; RHE – heat exchanger; EV – expansion valve; E – evaporator; Ts1 and Ts2 – the temperature of air from outside; Tw1 and Tw2 – the temperature of heated water.

1.4 The energy efficiency of heat pumps

1.4.1 Coefficient of performance

As was noticed, the heat pump works as a basic refrigerator. It implements reverse thermodynamical cycle, transferring heat from less warm substance to warmer fluid using primary electric energy. The relevance of gained heat energy by a consumer to the spent energy determines the efficiency of the heat pump and called the coefficient of performance:

$$\varphi = (Q_{sc} + Q_{cd})/Q_c, \tag{1.1}$$

where $Q_{sc}+Q_{cd}$ – heat, received by a consumer from sub-cooler and condenser;
Q_c – energy spent on compressor drive.

For example, if the coefficient of performance is equal to 3, the consumed electric energy is three times less than the produced heat energy by a heat pump.

1.4.2 Comparison with traditional heat sources

To compare the heat pump with traditional heat sources such as coal, gas, electric boilers we need to know: dimensions of a building, the number of windows(and their dimensions), the material that the walls are made of, the material that the floors are made of, the material that windows are made of, the thickness of the walls(windows, floor), the temperature outside and inside, the floor of a room.

For these calculations, the real building (image A3) with the following characteristics was taken. Input parameters:

- 1-stage house;
- Ceiling hight, h = 2.75 m;
- Dimensions of the outer walls, width = 10 m, length = 10 m;
- Number of the windows = 6, Number of small windows = 1;
- Dimensions of one window, width = 1 m, height = 1.6 m;
- Dimensions of a small window, width = 0.4 m, height = 1.6 m;
- The material of windows: single chamber double-glazed window;
- The material and thickness of the walls: foam blocks, 0.3 m;
- Silicate brickwork, 0.12 m;
- Plastered with cement-sand mortar, 0.03m;
- The material of the floors: wood;
- Inside maintained temperature T_{inside} = 20ºC;
- Outside temperature $T_{outside}$ = -10ºC;

Area calculations:

Area of the outer walls(without windows):

$$S_{walls} = 10*2.8*4 – (6*1*1.6 + 0.4*1.6) = 101.76 m^2;$$

Area of the windows:

$$S_{windows} = 6*1*1.6 + 1.4*1.6 = 10.24 m^2;$$

Area of the floor:

$$S_{floor} = 10*10 = 100 m^2;$$

Area of the ceiling:

$$S_{ceiling} = 10*10 = 100 m^2;$$

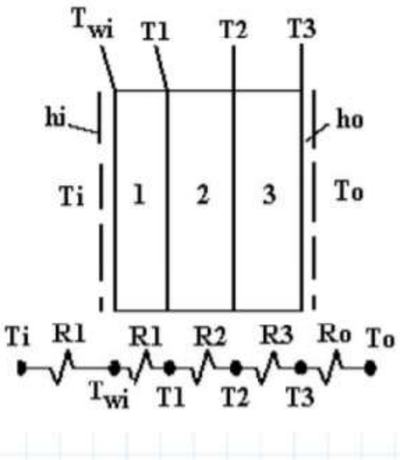


Image 2 – multiple layers wall and thermal network

1. Heat losses through the Walls:

h_i = 9 W/m^2*K – interior heat transfer coefficient(convection);
h_o = 20 W/m^2*K – exterior heat transfer coefficint(convection);
A = 101.76 m^2 – surface area;
X_1 = 0.12 m – thickness of Silicate bricks layer;
k_1 = 0.87 W/m*K – thermal conductivity of Silicate brick;
X_2 = 0.3 m – thickness of Foam blocks layer;
k_2 = 0.37 W/m*K – thermal conductivity of Foam blocks;
X_3 = 0.03 m – thickness of cement-sand mortar layer;
k_3 = 0.93 W/m*K – thermal conductivity of cement-sand mortar;

Interior thermal resistance(convection):

$$R_i = 1/h_i*A; \tag{1.2}$$

Exterior thermal resistance(convection):

$$R_o = 1/h_o*A; \tag{1.3}$$

The thermal resistance of wall layer j :

$$R_j = X_j/k_j*A, \qquad j=1,..3; \tag{1.4}$$

The total resistance of the wall:

$$R_{tot} = R_i + R_o + \sum R; \tag{1.5}$$

Calculating all the values:

$$R_i = 0.001 \text{ K/W};$$
$$R_o = 0.0005 \text{ K/W};$$
$$R_1 = 0.0013 \text{ K/W};$$
$$R_2 = 0.008 \text{ K/W};$$
$$R_3 = 0.00031 \text{ K/W};$$
$$R_{tot} = 0.011 \text{ K/W};$$

Heat amount from inside(T_i) to outside(T_o):

$$Q = (T_i – T_o)/R_{tot} = (20-(-10))/0.011 = 2727 \text{ W};$$

2. Heat losses through the windows:

k = 2.9 W/m*K – thermal conductivity of single chamber double-glazed window;
X = 0.024 m – thickness of a window;
A = 10.24 m^2 – surface area of the windows;
Thermal resistance of windows:

$$R = 0.024/0.07*10.24 = 0.033 \text{ K/W};$$

Heat loss:

$$Q = 30/0.033 = 909 \text{ W};$$

3. Heat losses through the floor.

The building is located on a ground, therefore:
X = 1 m – thickness of insulation layer(concrete);
k = 2.1 W/m*K – thermal conductivity of insulation layer(concrete);
A = 100 m^2 – floor area;
Thermal resistance:

$$R = X/k*A = 0.0047 \text{ K/W};$$

Heat loss:

$$Q = 30/0.0047 = 640 \text{ W};$$

4. Heat losses through the ceiling:

k_1 = 0.19 W/m*K – thermal conductivity of the first layer(chipboard);
X_1 = 0.001 m – thickness of the first layer(chipboard);
k_2 = 0.07 W/m*K – thermal conductivity of the second layer(glass wool);
X_2 = 0.1 m – thickness of the second layer(glass wool);
A = 100 m^2;

Thermal resistance of layers:

$$R_1 = X_1/ k_1*A = 0.00005 \text{ K/W};$$
$$R_2 = X_2/k_2*A = 0.014 \text{ K/W};$$
$$R_{tot} = 0.01405 \text{ K/W};$$

Heat loss:

$$Q = 30/0.01405 = 2135.23 \text{ W};$$

5. Total heat loss:

$$Q_{tot} = 6411 \text{ W} = 6.411\text{kW};$$

To compensate for these heat losses and maintain a stable temperature inside the building at 20ºC “GREE-8: VERSATI II GRS-CQ8Pd (R410A)” heat pump was chosen. The characteristics of this heat pump:

- Heating performance(radiator), Q = 8500 W;
- Electric power consumption, Q_e = 2100 W;
- Coefficient of performance, COP = 3;
- The maximum temperature of heated water at outlet, T_{w2} = 80ºC;
- Amount of noise, 55 dB;
- Heated area, A = 100 m^2;

- Price – 1,700,000 tg;

As a comparison, the other types of heat sources such as coal, gas, electric boilers are taken. The main characteristics are given in table A1.

The heating season in Almaty lasts for 183 days (from October 15 until April 15) which is 4392 hours. Considering that for the calculations above the average-minimum temperature in Almaty(-10ºC) was taken, almost every other day in Almaty during winter is warmer, that is why the heating system only works half its power.

Therefore, the consumed energy throughout heating season:

$$6.411*183*24/2 = 14078.5 \text{ kWh}$$

Consumed energy by every heating system, considering efficiency:

1. Heat pump, COP = 3, which means consumed energy must be 3 times less than produced heat. 14078/4 = 3519 kWh;
2. Coal boiler, 14078.5*100/70 = 20112.14 kWh;
3. Gas boiler, 14078.5*100/92.9 = 15154.4 kWh;
4. Electric boiler, 14078.5*100/98 = 14365.3 kWh;

Table 2 – energy consumption and useful energy throughout the heating season

Heating source	Energy consumption, kW*h	Useful energy produced by the heat source, kW*h
1. Heating pump	3519.5	14078.5
2. Coal boiler	20112.14	14078.5
3. Gas boiler	15154.4	14078.5
4. Electric boiler	14365.3	14078.5

1.5 Economic efficiency of heat pumps

Reduction of expenses on a heating and hot water supply, decreasing dependence on an import of organic fuel in many regions that do not have their fuel source is a very topical issue. The heat pump could be used if the cost of saved fuel(energy) throughout 2-4 years exceeds or equals the annual expenses(capital expenditures, maintenance, and repair) which usually higher for a heat pump as it is more expensive.

In this section economic efficiency of heat pump “GREE-8: VERSATI II GRS-CQ8Pd (R410A)” is compared to the other heat sources (coal, gas, electric boilers).

The average cost of electricity including VAT in Almaty is 17 tg per kW*h. As it was calculated, the heat pump consumes 3519.5 kW*h electric energy throughout the heating season.

Thus, the general costs of electric energy consumed by the heat pump:

$$17*3519.5 = 60{,}000 \text{ tg;}$$

To calculate the costs of the consumed coal, we need its calorific value. On average, coal has calorific value q = 13000kJ/kg. The mass of consumed coal can be found:

$$m = Q/q, \tag{1.6}$$

where Q – consumed energy, kJ;

Consumed energy of the coal boiler “Dobrynya NG 10” can be found in kJ:

$$Q = 20112.14*3600 = 72403714 \text{ kJ};$$

Then the mass of coal:

$$m = 72403714/13000 = 5570 \text{ kg} = 5.5\text{t};$$

The price of coal per ton is 17000 tg (including delivery). Therefore, the total costs of coal per heating season:

$$5.5*17000 = 93500 \text{ tg};$$

The volume of consumed gas during the heating season can be found:

$$V = Q/q, \tag{1.7}$$

where Q – consumed energy,

q – calorific value of a gas, 9.2 kW/m^3;

Therefore,

$$V = 15154.4/9.2 = 1647.17 \text{ m}^3;$$

Knowing the price for each m^3(30 tg):

$$1647.17\text{m}^3*30\text{tg/m}^3 = 49{,}500 \text{ tg};$$

The costs of consumed electric energy by the electric boiler can be found:

$$14365\text{kWh}*17\text{tg/kWh} = 244{,}200 \text{ tg};$$

Table 3 – costs of various heating systems throughout the heating season

Heating system	Costs
1. Heat pump	60,000 tg
1. Coal boiler	93,500 tg
2. Gas boiler	49,500 tg
3. Electric boiler	244,200 tg

Payback period of heat pump:

Coal boiler: (1,500,000-181,000)/(93,500-60,000) = 39 years;

Gas boiler: (1,500,000-220,000)/(49,500-60,000) = -122 years;

Electric boiler: (1,500,000-41,000)/(244,200-60,000) = 8 years.

It can be noticed that the heat pump does not have a payback period compared to the gas boiler. The graph of costs is given in image A2.

1.6 Environmental impact of heat pumps

The environmental impact of heat pumps compared to the traditional heat sources based on an organic fluid is determined by energy efficiency, i.e. saving fuels by using heat pumps with the same amount of produced heat energy.

Table 1 – the amount of burned fuel by all the fuel-based power stations in Kazakhstan (in tons)

Consumed fuel	2009 y.	2010 y.	2011y.	2012 y.
Coal	2,779,658	6,009,109	6,677,558	6,999,479,5
Fuel oil	29,114	56,783	58,601	81,776
Gas	559,160	609,361	609,832	599,720
Diesel fuel	13,634	19,987	21,499	23,036
Petrol	3,888	4,585	4,712	6,146

Heat pumps with the coefficient of performance $\varphi = 3$ have almost twice fewer emissions of nitric oxide, sulfur oxide, and carbon dioxide. More than one and a half times less in case of working on fuel oil. 30% less in the case of working on gas.

Comparing to the electric boiler which receives electric energy from thermal power station (TPS) the heat pump which also gets electric energy for its drive from TPS has three times fewer emissions. If the coefficient of performance increases twice, from $\varphi=3$ to $\varphi=6$ the emissions decreases twice as well. In an image 2 relative emission reduction of greenhouse gases such as CO2 with the different coefficient of performance of heat pumps is given. Modern air-to-water COP = 3-4.

According to the image 2, for instance, a heat pump with COP = 2.75 emits 35% less CO2 into the atmosphere than the gas boilers with 90% efficiency.

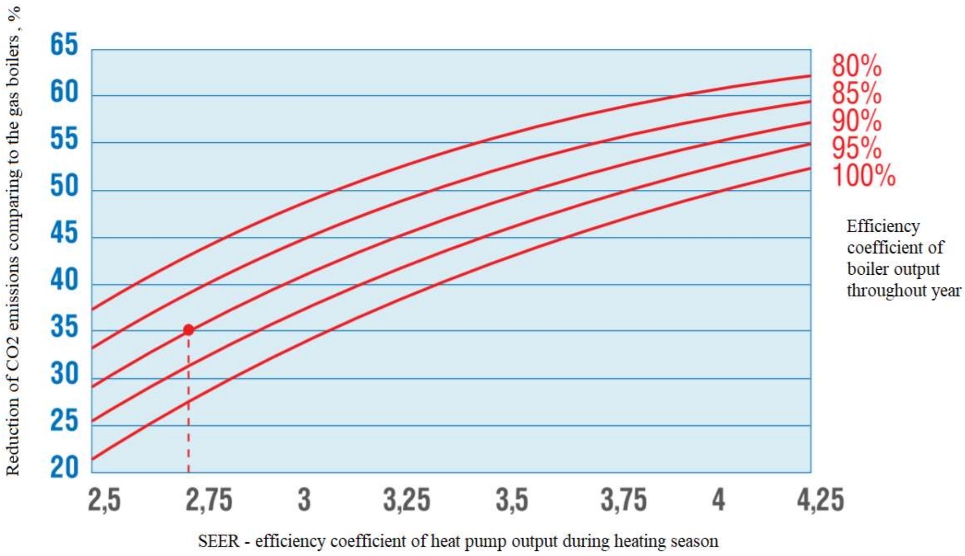


Image 2 - CO2 emissions difference between electric-driven heat pumps with the gas boilers

1.7 Renewable sources of low-potential heat

Thermal, economic, and energetic characteristics of the heat pump mostly depend on a heat source(air, ground, water). The ideal heat source must maintain a stable temperature throughout the heating season, be renewable and abundant. It does not have to be carrozially active, polluting and it must have good thermophysical characteristics. In table 2 the thermal indicator of some most spread heat sources is given.

Table 2 – temperature range of different heat sources.

Heat source	Temperature Range
Outside air	-10/+15
Groundwater	>10
Lake water	0/10
River water	0/10
Seawater	3/8
Ground	0/10
Subsoil water	4/10
Geothermal water	20/50

1.7.1 Air

Outside air, being completely free is the most preferable heat source. However, heat pumps that use air as a heat soruce have some seasonal load factor decreasing on 10-30% comparing to the water-to-water heat pumps. This is explained by the next circumstances:

1) Quick decrease of power and output of heat pump with dropping of the outside temperature.

2) A relatively large difference between condensation and evaporation temperature during winter when the outside temperature reaches its minimum.
3) Energy consumption for a defrosting of evaporator which is blown by air and for a work of fans.

In the humid clime conditions on a surface of the evaporator in a temperature range 0-6ºC the frost is obtained which can affect on productivity of the heat pump. Frost hinders air flowing. Heat transfer deteriorates which consequently causes the dropping of refrigerant evaporation temperature. Dropping of evaporation temperature makes things even worse causing more frosting until the processes in the aggregate are stopped. To defrost the system additional electric energy is consumed which decreases the coefficient of performance φ.

1.7.2 Water

Water-to-water heat pumps use the heat of subsoil(ground) water, open water such as lakes, rivers, or lakes. Groundwater can be found almost anywhere they have quite a stable temperature throughout the whole year(from 7 to 12ºC). In image 3, the water-to-water system for a private house is shown.

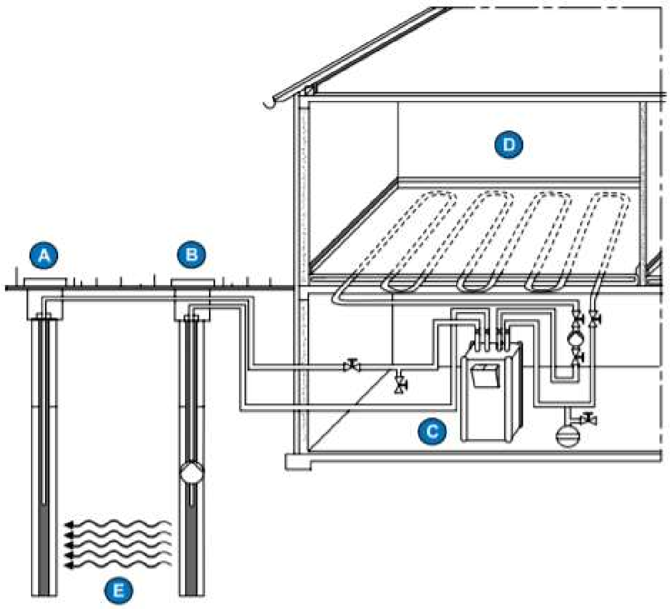


Image 3 - Heating system with a water-to-water heating pump. A – receiving well, B – supplying well, C – heat pump, D – floor heating system, E – groundwater movement direction.

Comparing to other heat sources groundwater has the smallest difference between temperatures($T_c - T_e$), therefore it has a higher conversion coefficient φ.

Table 3 – Comparison in value of φ between different types of heating systems.

Heating system type and temperature of heated water, ºC	Value of φ
Traditional radiator systems (60-50)	2.5
Floor heating system (35-30)	4.0
Convection ventilation (45-35)	3.5

The main disadvantage of groundwater heat pumps is very high costs for the arrangement of wells. Besides, depending on the quality of groundwater additional corrosion protection must be installed.

River and Lake waters are theoretically very appealing heat sources. However, they have one significant disadvantage: excessively low temperature during winter(it can reach slightly more or even equal to 0°C). That is why very important to pay attention to the freezing preventing system during designing.

Seawater is a great heat source and used in medium and large systems. At a depth from 25 to 50 meters seawater has a stable temperature from 5 to 8°C and problems with freezing do not occur in this case.

1.7.3 Ground

Heat pumps that use the ground as a low-temperature heat source are mostly applied in a big commercial and administrative buildings. Ground as well as groundwater has a relatively stable temperature throughout the year, which provides high coefficient of performance φ.

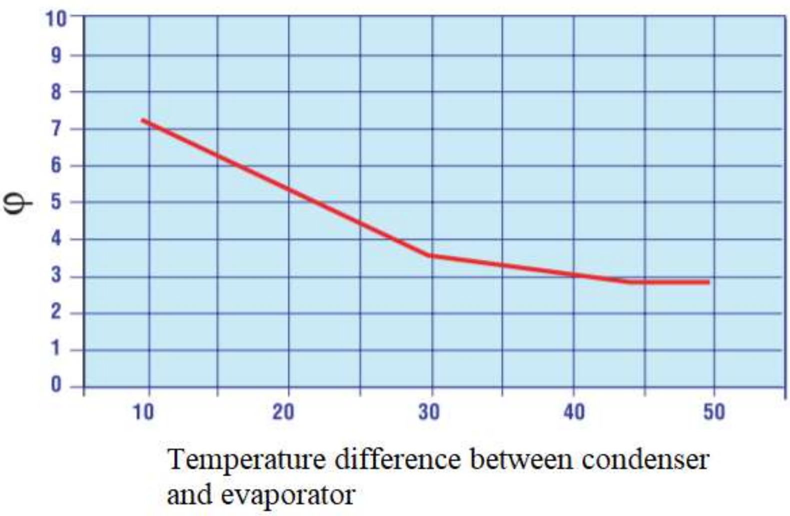


Image 4 - The dependence of conversion coefficient φ on a temperature difference between condenser and evaporator in a ground heat pump.

Heat is taken through pipes – ground heat exchangers, which can be laid in a ground horizontally, spiral, or vertically.

In-ground heat pumps can be applied:

1) Direct expansion system with the cooling liquid, evaporating during circulating through the contour of the pipeline.
2) Systems with the brine fluid pumped through the contour of the pipeline.

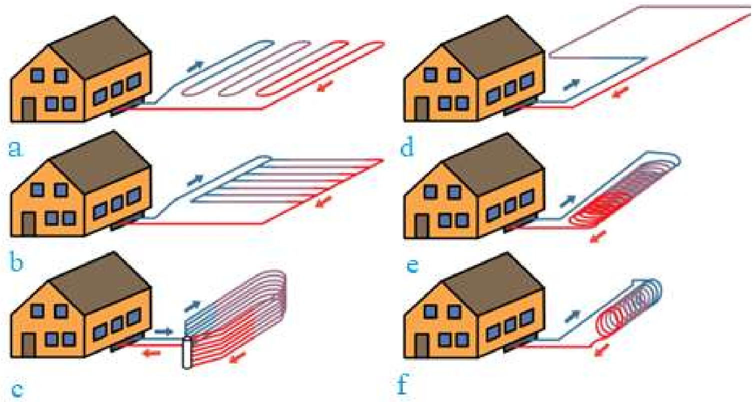


Image 5 - The types of horizontal ground heat pumps. a – heat exchanger with the pipes connected in series, b – heat exchanger with the parallel connection, c – heat exchanger laid in a trench, d – heat exchanger in a loop form, e – spiral heat exchanger located horizontally, f – spiral heat exchanger located vertically.

In heat pumps with the horizontal heat exchangers the process of heat absorption goes with the help of large areas of plastic pipes. Plastic pipes made of polyethylene are laid in the ground at a depth of 1.2-1.5 meters, depending on a cross-section of pipe, at a distance of 0.5-0.7 meters from each other. The length of the pipeline must not exceed 100 meters due to losses of pressure and additional required power for a pump.

Brine liquid circulates through the plastic pipes with the help of a pump absorbing heat from the ground and transferring it to the refrigerant. This heat is then transformed into higher-potential temperature to heat indoor space. Pipeline laid in the ground does not affect any plants planted above them. However it is recommended not to plant plants with long roots.

Ground heat is an accumulated heat from the sun, which transfers to the ground through the sun rays, heat passing from air or precipitation. The heat from the lower layers of the earth(15-20m) is formed by the bowels of the earth and does not depend on climate change.

The amount of useful energy and required of the heat exchanging area depends on the properties of ground and climate. Thermal properties such as heat capacity thermal conductivity are very dependent on soil composition and soil conditions. The more ground saturated with water and the fewer pores with air the better thermal storage and thermal conductivity of the soil.

Table 4. Heat flux distribution for the different types of soil.

Type of soil	q_e, W/m^2
Dry sand	q_e = 10-15
Damp sand	q_e = 15-20
Dry clayey	q_e = 20-25
Damp clayey	q_e = 25-30
Aquiferous layer	q_e = 30-35

In regions with a high population density, it is recommended to install vertical heat exchangers. Usually, these heat exchangers are made of polyethylene pipes. Most often four pipes are installed in one well(image 6). All the room between pipes and ground is filled with material that has high thermal conductivity(bentonite). Brine liquid flows down through the pipes and comes back to the distributor.

Heat exchangers are installed to the depth from 50m up to 200m. Experience shows that heat flux distribution fluctuates between 20 and 100 Watt per one meter of heat exchangers(table 5).

Table 5 – Heat flux distribution of different layers of ground, W/m

Dry sand	$q_e = 20$
Damp sand	$q_e = 40$
Damp rocky ground	$q_e = 60$
Aquifers	$q_e = 80\text{-}100$

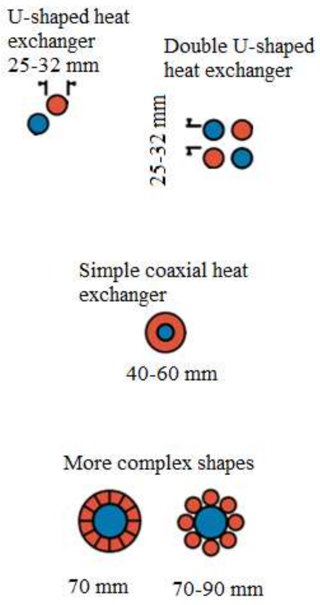


Image 6 - Cross-section of different types of vertical ground heat exchangers

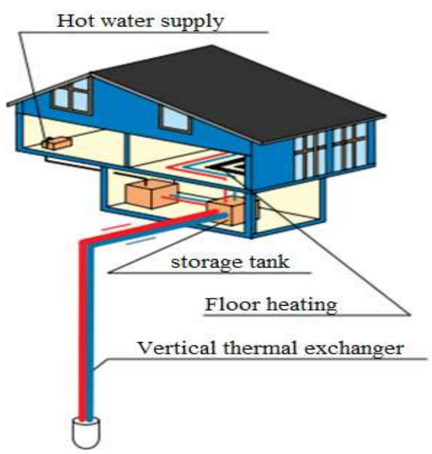


Image 7 – Heating system with vertical thermal exchanger

1.8 Working fluid(refrigerant)

Refrigerant depending on the classification of heat pumps and refrigerators are divided into:

1) Low pressure or high boiling temperature(boiling temperature above t_s above -10ºC) are used in high-temperature heat pumps.
2) Medium pressure (t_s from -10 to 60ºC) are used in medium-temperature heat pumps.
3) High pressure or low boiling (t_s bellow -60ºC).

In the heat pumps the boiling pressure as well as in refrigerators depends on the temperature of heat source, and condensation pressure depends on the temperature of a heated fluid(water). In a high-temperature heat pump condensation temperature (t_c) equals or lower than 100ºC.

Table 6 – different types of refrigerants used at the different temperatures in the heat pump.

The temperature in a heat pump	Types of refrigerant
80-100º	$R142_b$, R124, R236, R744
55-80º	$R134_a$, $R152_a$
<55º	R22, $R407_c$

2 Experimental part

2.1 Briefly about Transient System Simulation Tool (TRNSYS)

TRNSYS (pronounced 'tran-sis') is an extremely flexible graphically based software environment used to simulate the behavior of transient systems. While the vast majority of simulations are focused on assessing the performance of thermal and electrical energy systems, TRNSYS can equally well be used to model other dynamic systems such as traffic flow, or biological processes.

TRNSYS is made up of two parts. The first is an engine (called the kernel) that reads and processes the input file, iteratively solves the system, determines convergence, and plots system variables. The kernel also provides utilities that (among other things) determine thermophysical properties, invert matrices, perform linear regressions, and interpolate external data files. The second part of TRNSYS is an extensive library of components, each of which models the performance of one part of the system. The standard library includes approximately 150 models ranging from pumps to multizone buildings, wind turbines to electrolyzers, weather data processors to economics routines, and basic HVAC equipment to cutting edge emerging technologies. Models are constructed in such a way that users can modify existing components or write their own, extending the capabilities of the environment.

After 35 years of commercial availability, TRNSYS continues to be a flexible, component-based software package that accommodates the ever-changing needs of both researchers and practitioners in the energy simulation community.

2.2 Air-to-water heat pump heating system simulation in TRNSYS

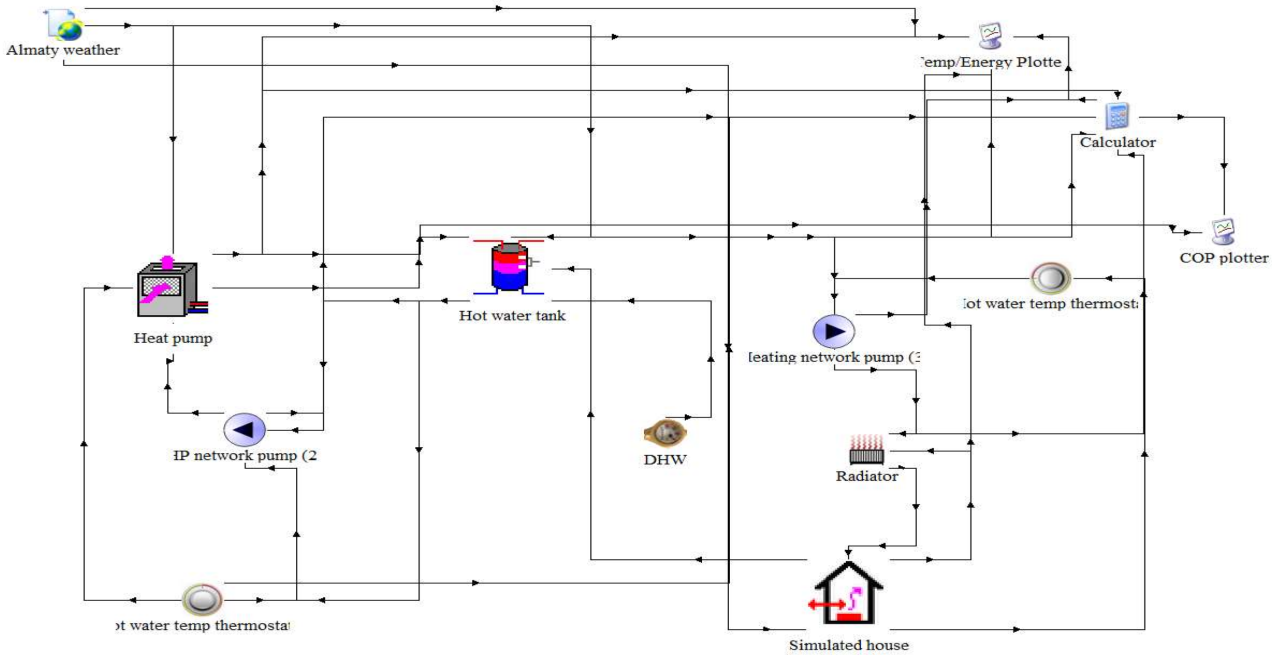


Image 8 – heating system simulation

The heating system was simulated in TRNSYS (image 8). Corresponding parameters were entered (Almaty weather, heat pump parameters, simulated house, hot tank). Calculator calculates the values (COP, temperature, consumed and produced energy). COP plotter and Temperature/Energy plotter plot the graphs of the system (image 9). The results are given in attachment B (image B1, image B2, image B3, image B4).

The maximum temperature of water at the heat pump reaches 100ºC. Then it drops to minimum 48ºC and raises again. Average ambient air temperature is -7.5ºC (for Almaty climate). Average room temperature is 22ºC.

To determine the COP of the system Engineering Equation Solver (EES) program was used. Program code in EES:

```
T_amb = converttemp('C', 'K', -7.5[C])
T_del = converttemp('C', 'K', 22[C])                 Operating and
F$ = 'R134a'                                          basic parameters
Q_cond = 8500 [W]

m[1] = 0.1 kg/s
Sup_evap = 5 [K]
CAT_evap = 10 [K]                                     System performance
Sub_cond = 5 [K]                                      parameters
CAT_cond = 10 [K]
T[3] = T_del + CAT_cond
eta_comp = 0.7

T[1] = T_amb – CAT_evap
P[1] = p_sat(F$, T=T[1]-Sup_evap)                     Evaporator outlet/
h[1] = enthalpy(F$; T=T[1];P=P[1])                    Compressor inlet
s[1] = entropy(F$; T[1]; P=P[1])

m[2] = m[1]
P[2] = p_sat(F$;T=T[3]+Sub_cond)
h_s[2] = enthalpy(F$; P=P[2]; s=s[1])                 Compressor outlet/
W_comp = m[2]*(h_s[2]-h[1])/eta_comp                  condenser inlet
W_comp = m[2]*(h_s[2]-h[1])
T[2] = temperature(F$; h=h[2]; P=P[2])
s[2] = entropy(F$; h=h[2]; P=P[2])

m[3] = m[2]
P[3] = P[2]
h[3] = enthalpy(F$; T=T[3]; P[3])                     Condenser outlet/
```

```
s[3] = entropy(F$; T=T[3]; P[3])                    Expansion valve inlet
Q_cond = m[3]*(h[2]-h[3])

m[4] = m[3]
h[4] = h[3]
P[4] = P[1]
s[4] = entropy(F$; h=h[4]; P=P[4]                    Expansion valve outlet/
T[4] = temperature(F$; h=h[4]; P=P[4])                Evaporator inlet
x[4] = quality(F$; h=h[4]; P=P[4])
Q_evap = m[4]*(h[1]-h[4])

COP_heat = Q_cond/W_comp
```

The results:

W_{comp} = 2100 W;
COP_{heat} = 4.04;

Table 7 – the achieved results from EES

m_i, kg/s	P_i, Pa	T_i, K	h_i, J/kg	s_i, J/kg-K
0.1	132820	258.2	242482	961
0.1	1.3E+06	356.2	312919	1023
0.1	1.3E+06	318.2	115751	417.7
0.1	132820	253.2	115751	461.2

List of abbreviations

1. COP – coefficient of performance
2. HP – Heat pump
3. TPS – Thermal power station
4. VAT – Value-added tax
5. LPH – low-potential heat
6. HPH – high-potential heat
7. AWHP – air-to-water heat pump
8. WWHP – water-to-water heat pump
9. GWHP – ground-to-water heat pump
10. WF – working fluid
11. CD – condenser
12. EES – engineering equation solver

CONCLUSION

Heat pumps, despite higher primary capital investments, take the market from traditional boilers for economic reasons – because of lower operating costs. For the first time, the energy policy of human development is associated with a decrease, and not increase energy consumption. The widespread use of the heat pump in the world is promoted by rising energy prices, energy efficiency laws, environmental laws, requirements for reducing greenhouse gas emissions. Companies selling efficient and environmentally friendly clean heat pump installations, enjoy tax benefits. Organizations and homeowners who purchase this equipment receive subsidies, preferential loans.

The widespread adoption of the heat pump is technology is being held back by price distortions. Thermal and electric energy, lack of necessary regulatory framework and investment climate, and most importantly due to the lack of state support and regional authorities implementing this innovative technology.

Attachment A

Table A1 – main characteristics of heating systems

Heat source	Model	Heating performance, kW(max)	Efficiency	Price, tg	Made in
1. Heat pump	GREE-8: VERSATI II GRS-CQ8Pd (R410A)	8.5	COP = 4	1,500,000	China
2. Coal boiler	Dobrynya NG 10	10	70%	181,000	Russia
3. Gas boiler	BAXI ECO4S 10F	10	92.9%	220,000	Italy
4. Electric boiler	ЭВН-К-9Э1	9	98%	41,000	Kazakhstan

Image A2 - costs graph throughout years, green – heat pump, blue – coal boiler, red – gas boiler, orange – electric boiler.

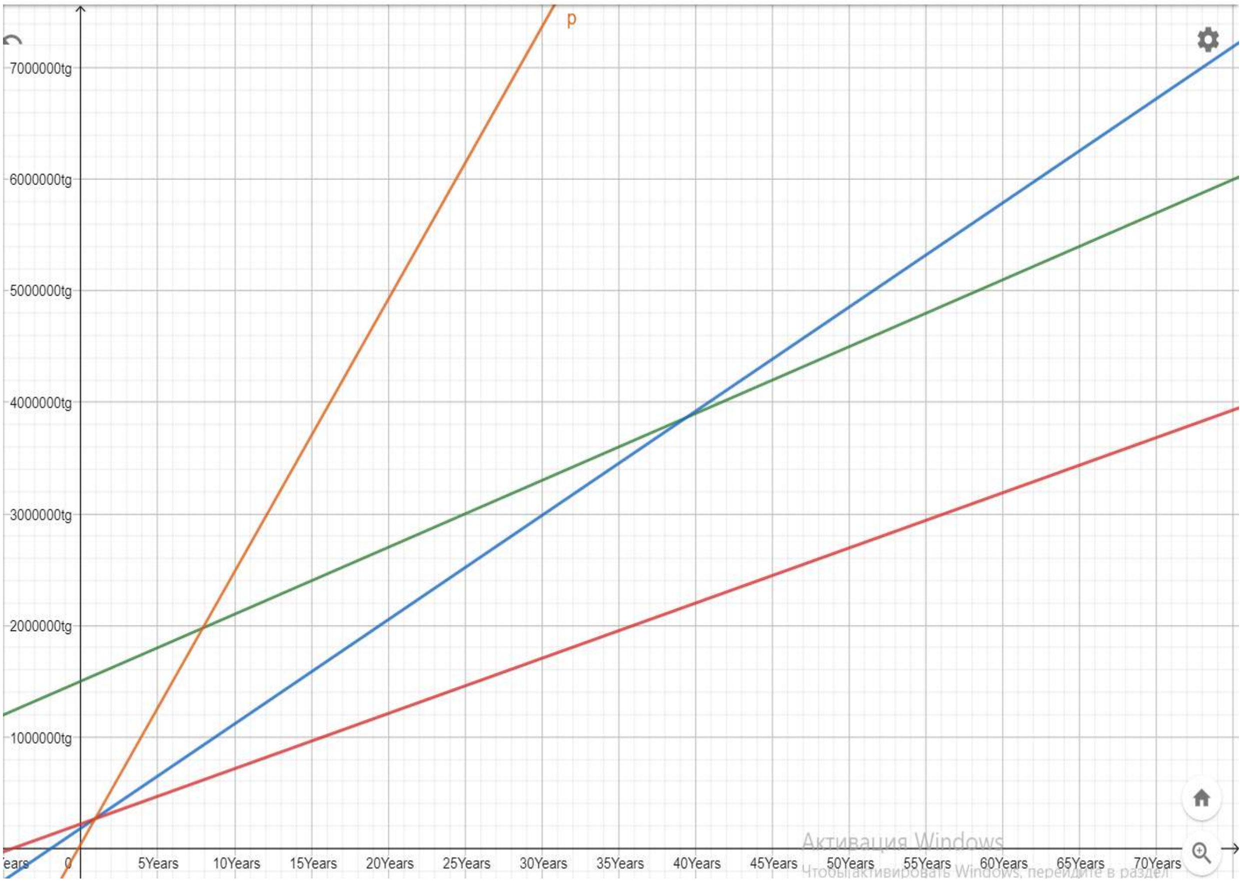
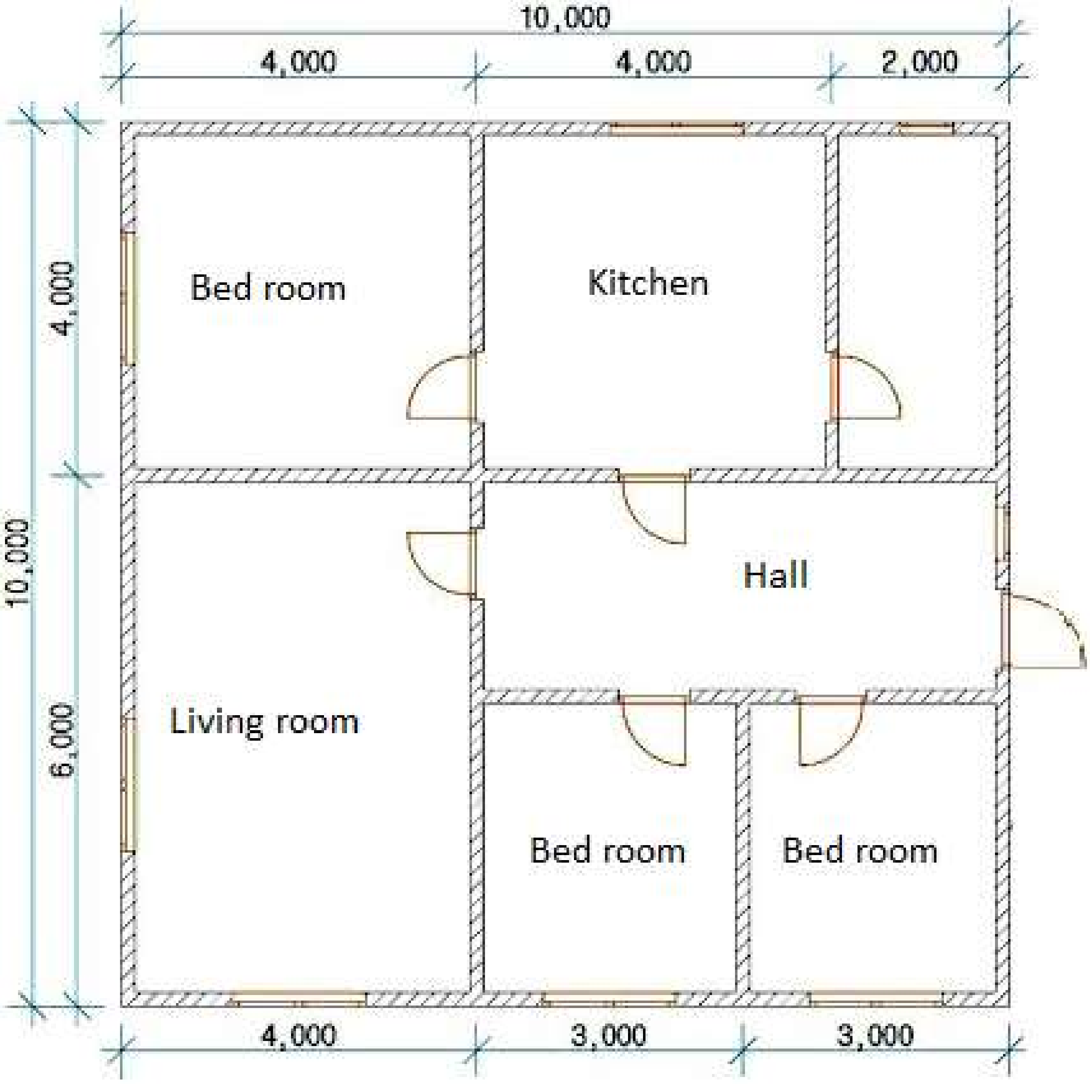


Image A3 – building drawing



Attachment B

Image B1 – temperature of hot water tank

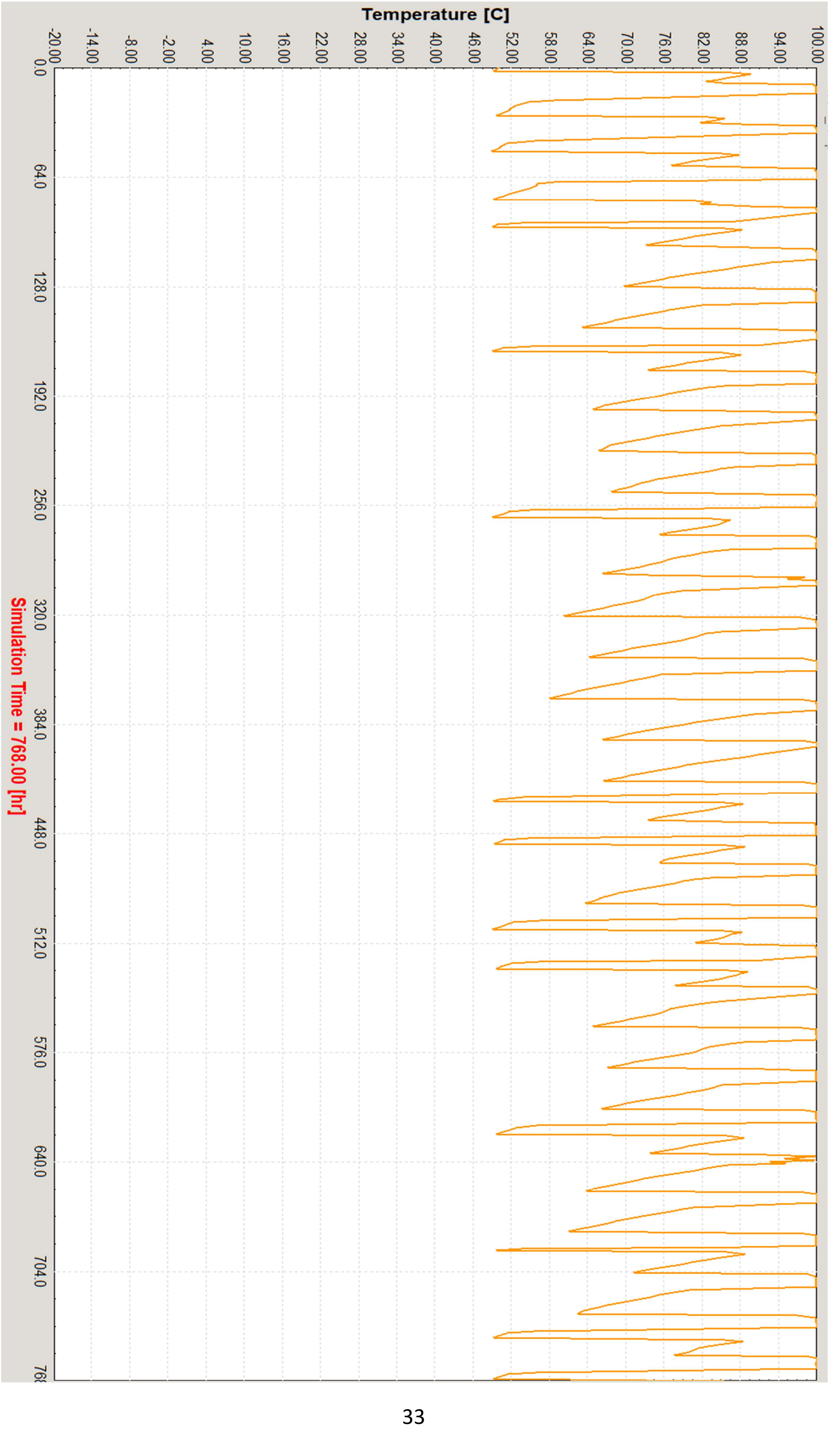


Image B2 – room temperature (inside the building)

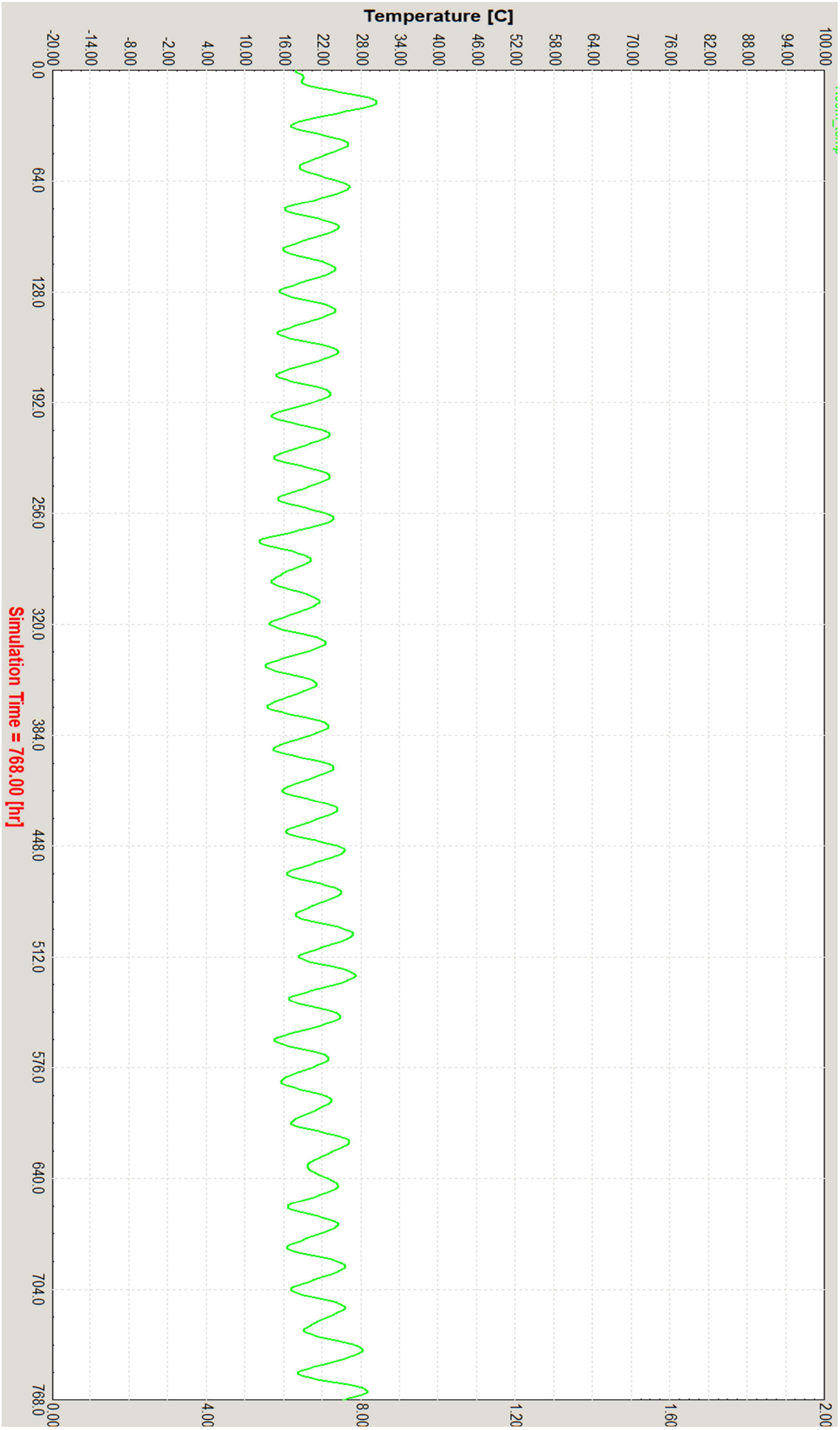
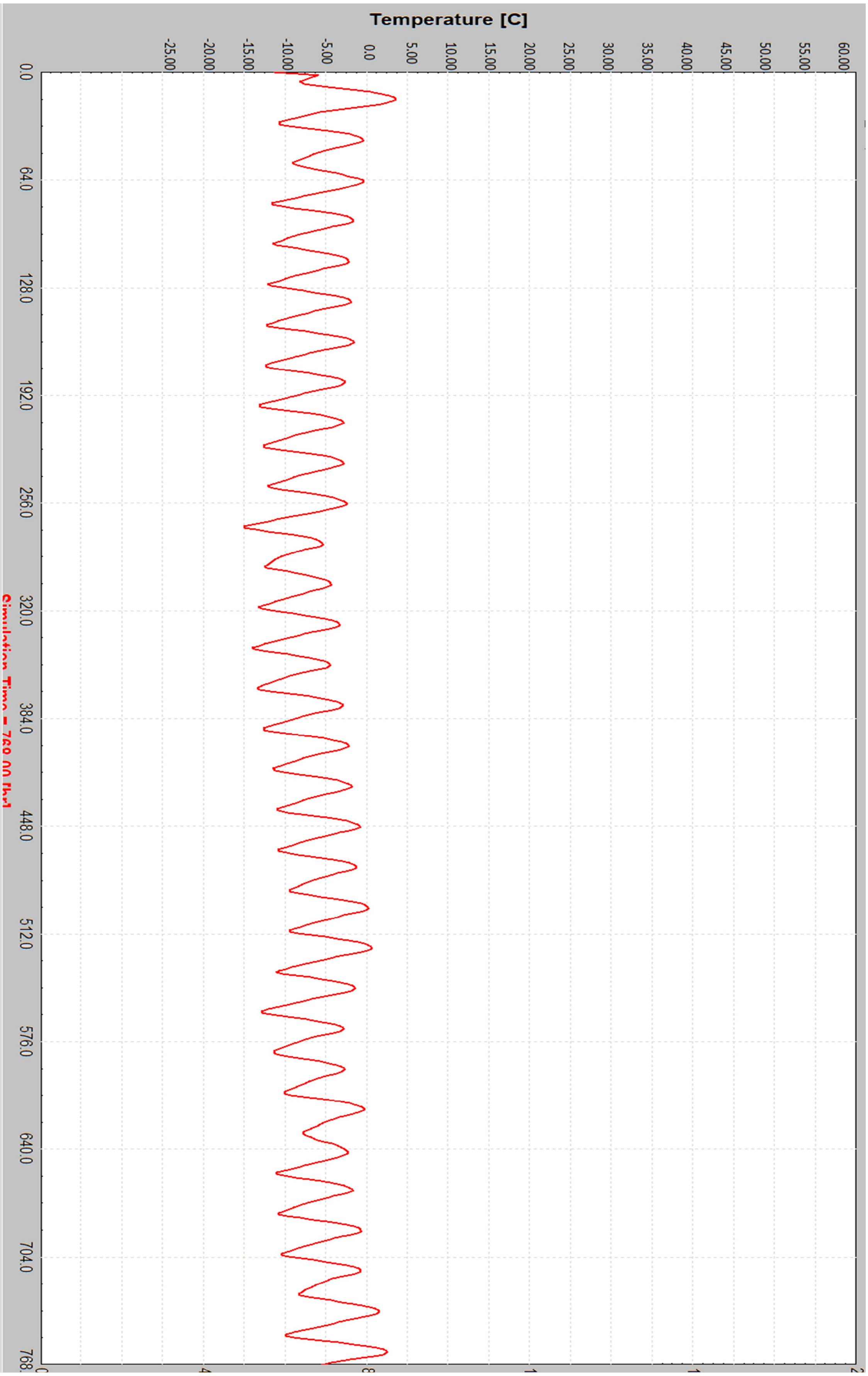


Image B3 – ambient temperature



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