MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF
KAZAKHSTAN

СӘТБАЕВ УНИВЕРСИТЕТІ | SATBAYEV UNIVERSITY

School of Industrial Automation and Digitalization
Department of Industrial Engineering

Zholdybaev A.A.

The study of efficient modes of heat generation and distribution of a hybrid heat supply
system based on a gas boiler and a heat pump
**DIPLOMA PROJECT**

5B071200 – Mechanical Engineering

Almaty 2020

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School of Industrial Automation and Digitalization
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APPROVED FOR DEFENSE
Head of Institute of Cybernetics
and Information Technology
N. Seilova
Head of Department of Applied Mechanics
and Engineering Graphics
A. Kaltayev

_____  _____

**DIPLOMA PROJECT**

Topic: "The study of efficient modes of heat generation and distribution of a hybrid heat
supply system based on a gas boiler and a heat"

5B071200 – Mechanical Engineering

Performed by:                                A. Zholdybaev

Scientific adviser
PhD, tutor

_____ Ye. Belyayev
"___" _____2020

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School of Industrial Automation and Digitalization
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5B071200 – Mechanical Engineering

**CONFIRM**

Head of Institute of
Cybernetics and Information Technology
N. Seilova
Head of Department of Applied Mechanics
and Engineering Graphics
A. Kaltayev

_____

**TASK**
**for completing the diploma project**
For student: A. Zholdybaev

Topic: "The study of efficient modes of heat generation and distribution of a hybrid heat supply system based on a gas boiler and a heat"

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

Deadline for completion the work *"3" June 2020*

Initial data for the diploma project: Weather data

Summary of the diploma project:

a)    *Theoretical information;*

b)    *The analysis of the refrigerant and the system;*

c)    *The analysis of the house*

d)    *Manual calculation*

e)    *The simulation in TRNSYS and analysis of the results.*

List of graphic material: *presented 20 slides of presentation of the diploma project*

Recommended main literature:

1. *Ashrae B. Commercial/Institutional Ground-Source Heat Pumps Engineering Manual. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers. 1995.*

StrikePlagiarism.com

**НАЗВАНИЕ:**
The study of efficient modes of heat generation and distribution of a hybrid heat supply system based on a gas boiler and a heat pump

**АВТОР:**
Zholdybaev A.A

**НАУЧНЫЙ РУКОВОДИТЕЛЬ:**
Ержан Беляев

**ПОДРАЗДЕЛЕНИЕ:**
ИКиИТ

**ДАТА ЗАГРУЗКИ ДОКУМЕНТА:**
2020-06-01 12:29:20

**ЧИСЛО ПРОВЕРОК ДОКУМЕНТА:** (i)
1

**ПРОПУЩЕННЫЕ ВЕБ-СТРАНИЦЫ:** (i)

## ■ Уровень заимствований

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

**3,07%** КП1 (i)

% комбинаций из 5 слов, найденный во всех доступных источниках, кроме БЮА

**0,85%** КП2 (i)

% комбинации 25 -слов, найденных во всех доступных источниках, кроме БЮА

**0,00%** КЦ (i)

% найденных слов в тексте, помеченных как цитаты

| 25 | 3161 | 19922 |
|---|---|---|
| Длина фразы для коэффициента подобия 2 | Количество слов | Количество символов |

## ■ 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 | 0 | показать в тексте |
| Использование символов из другого алфавита - может указывать на способ обойти систему, поэтому следует установить их использование. | | |
| Интервалы | 0 | показать в тексте |
| Количество увеличенного расстояния между буквами (просим определить является ли расстояние имитацией пробела, так как исходно слова могут быть написаны слитно). | | |
| Микропробелы | 0 | показать в тексте |
| Количество пробелов с нулевым размером - необходимо проверить влияют ли они на неправильное разделение слов в тексте. | | |
| Белые знаки | 0 | показать в тексте |
| Количество символов, выделенных белым цветом, пожалуйста, проверьте не используются ли белые символы вместо пробела, соединяя слова (в отчете подобия система изменяет автоматически цвет буке в черный, чтобы их сделать видимыми). | | |

## ■ Заимствования по списку источников

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 повторяющимися короткими фразами, разбросанными в документе (совпадающие сходства), многочисленными короткими фразами расположенные рядом друг с другом (парафразирование) или обширными фрагментами без указания источника ("криптоцитаты").

### 10 самых длинных фраз (3,07 %)
Десять самых длинных фрагментов найденых во всех доступных ресурсах.

| ПОРЯДКОВЫЙ НОМЕР | НАЗВАНИЕ И АДРЕС ИСТОЧНИКА URL (НАЗВАНИЕ БАЗЫ) | АВТОР | КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ | |
|---|---|---|---|---|
| 1 | An experimental investigation on ground heat flow balance issue for a GCHP ( - Paperity ) | Xue, Qin, An, Erming,Chen, Jiufa, Zheng, Hongqi, Qiao, Weilai; | 27 | 0,85 % |
| 2 | Single-Component Optimal Heat Exchanger Effectiveness Using Specific Exergy Costs And Revenues ( - Paperity ) | David Paulus, Jr.; | 16 | 0,51 % |
| 3 | https://core.ac.uk/display/82776322 | | 13 | 0,41 % |
| 4 | https://www.gronkirke.dk/heat-pump/ | | 12 | 0,38 % |
| 5 | https://www.netpicks.com/supertrend-indicator/ | | 7 | 0,22 % |
| 6 | https://www.netpicks.com/supertrend-indicator/ | | 6 | 0,19 % |
| 7 | https://www.bib.irb.hr/704813 | | 6 | 0,19 % |
| 8 | https://www.gronkirke.dk/heat-pump/ | | 5 | 0,16 % |

| 9 | https://www.netpicks.com/supertrend-indicator/ | | 5 | 0,16 % |

## из базы данных RefBooks (1,36 %)

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* | | | |
| 1 | An experimental investigation on ground heat flow balance issue for a GCHP | ( Xue, Qin, An, Erming,Chen, Jiufa, Zheng, Hongqi, Qiao, Weilai; ) | 27 (1) | 0,85 % |
| 2 | Single-Component Optimal Heat Exchanger Effectiveness Using Specific Exergy Costs And Revenues | (David Paulus, Jr.; ) | 16 (1) | 0,51 % |

## из домашней базы данных (0,00 %)

Все фрагменты найдены в базе данных вашего университета.

| ПОРЯДКОВЫЙ НОМЕР | НАЗВАНИЕ | АВТОР | ДАТА ИНДЕКСАЦИИ | ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ) |
|---|---|---|---|---|

ЗАИМСТВОВАНИЙ НЕ НАЙДЕНО

## из программы обмена базами данных (0,00 %)

Все фрагменты найдены в базе данных других университетов.

| ПОРЯДКОВЫЙ НОМЕР | НАЗВАНИЕ НАЗВАНИЕ БАЗЫ ДАННЫХ | АВТОР | ДАТА ИНДЕКСАЦИИ | КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (КОЛИЧЕСТВО ФРАГМЕНТОВ) |
|---|---|---|---|---|

ЗАИМСТВОВАНИЙ НЕ НАЙДЕНО

## из интернета (1,71 %)

Все фрагменты найдены в глобальных интернет-ресурсах открытого доступа.

| ПОРЯДКОВЫЙ НОМЕР | ИСТОЧНИК URL | ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ) | |
|---|---|---|---|
| 1 | https://www.netpicks.com/supertrend-indicator/ | 18 (3) | 0,57 % |
| 2 | https://www.gronkirke.dk/heat-pump/ | 17 (2) | 0,54 % |
| 3 | https://core.ac.uk/display/82776322 | 13 (1) | 0,41 % |
| 4 | https://www.bib.irb.hr/704813 | 6 (1) | 0,19 % |

# ANNOTATION

The main task of this work is to study and simulate the hybrid heating system consisting of air source heat pump and gas boiler.

The necessary simulation was created, including the graphs and calculations based on it. The simulation was created in TRNSYS simulation software in order to show the advantages of such systems over classic transient systems.

The results had shown that the hybrid system was able to perform effectively at different temperatures due to the energy efficiency of heat pumps.


# АННОТАЦИЯ

Основной задачей данной работы является изучение и моделирование гибридной системы отопления, состоящей из воздушного теплового насоса и газового котла.

Была создана необходимая симуляция, включая графики и расчеты на ее основе. Моделирование было создано в программном обеспечении TRNSYS для демонстрации преимуществ таких систем по сравнению с классическими переходными системами.

Результаты показали, что гибридная система способна эффективно работать при различных температурах благодаря энергоэффективности тепловых насосов.


# АҢДАТПА

Бұл жұмыстың негізгі міндеті ауа көзінің жылу сорғысы мен газ қазандығынан тұратын гибридті жылу жүйесін зерттеу және модельдеу болып табылады.

Қажетті модельдеу құрылды, соның ішінде графиктер мен есептеулер. Модельдеу мұндай жүйелердің классикалық өтпелі жүйелерден артықшылықтарын көрсету үшін TRNSYS модельдеу бағдарламалық жасақтамасында жасалды.

Нәтижелер гибридтік жүйе жылу сорғыларының энергия тиімділігі арқасында әр түрлі температурада тиімді жұмыс істей алатындығын көрсетті.

# CONTENT

# 1. INTRODUCTION

Air pollution is one of the most critical problems that we are facing at present. Heating of buildings and various facilities represent the main part of energy consumption. There are various ways to solve this problem. For example, the most popular type is water heating and air heating. Water heating is based on using the water containing some energy in the form of heat. The water containing some energy flows through pipes and heats a space with the help of radiators. The water might get heated using the Gas water heaters or electric water heaters. Another type is convection or air heaters. The working principle is based on the air passing through the element of convector. The warmer air raises to the top, so the cooler one goes down which create an air circulation. But the main problem with the current heating systems is the emission of $CO_2$ and energy efficiency. Therefore, we will be using hybrid heating system consisting of gas boiler and air-to-water heat pump.

First of all, the main problem with the current air-to-water heat pumps is a low efficiency at low temperatures. The main cause of this problem is the chemical properties of cooling liquid which operates inside such pumps. The next problem is connected with the geographical position. To be precise, in order to build these systems in various places, we must consider the local climate and temperature variations. Thus, adapting and attuning the system is crucial.

Nevertheless, the importance of such systems is undeniable due to the greenhouse emissions and inefficient usage of natural resources. Therefore, in this diploma work we will simulate and perform the hybrid system consisting of gas boiler and air to water heat pump.

## 2. HEAT PUMPS

### 2.1 Air-to-water heat pump

An air to water heat pump utilizes the energy inside an ambient air by absorbing it and transferring to heating liquid (such as water) in order to heat some facility of building.

The main idea behind the working principle of air source heat pump is that the air contains some amount of energy at temperatures higher than absolute zero. So the heat pump just transfers it from one place to another. Moreover, any air conditioning systems rely on refrigerant's pressure-temperature relationship. Whether it evaporates or boils, it absorbs energy in any case. These refrigerants are special liquids which operate in heating-refrigeration cycle and undergo a phase transition. Due to such transitions, the refrigerant emits or absorbs energy depending on scenario. The common examples are: Chlorofluorocarbons (R12), Hydrochlorofluorocarbons (R22), Hydrofluorocarbons (R410, R134).
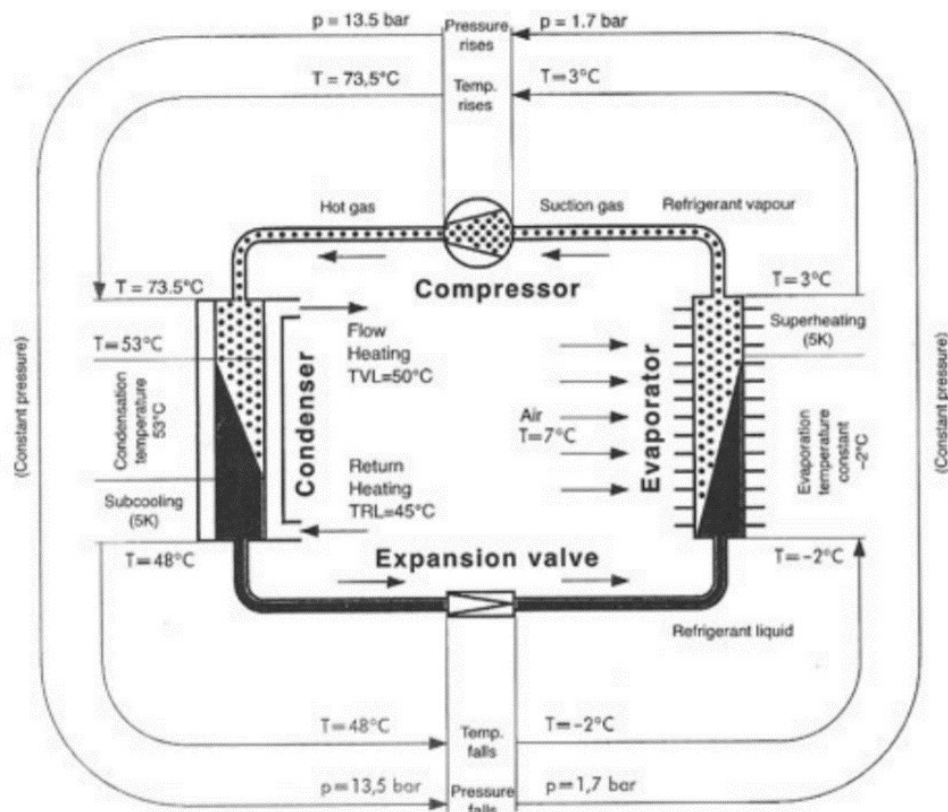


Image - 1 An example of working cycle of a heat pump

## 2.2 Coefficient of performance

The measurement is performed using COP. The average range of COP is from 2.5 to 3.5 meaning that the heat pump can deliver 2.5-3.5 times the energy consumed to its operation. The main advantage of air source heat pump compared to ground or water so is that the system installation is easy. This leads to lower installation and operational costs.

Air to air water heat pumps operate in 2 modes. These are summer and winter modes. In summer mode, compressor receives refrigerant at low temperature and pressure. Then, it increases its pressure and loads the refrigerant to high pressure side of heat pump. After it passes to condenser, an ambient air with the help of fan absorb energy from refrigerant and turn it to liquid (condensation process). The liquid refrigerant bypasses through expansion valve (which restricts the flow) and decrease the pressure of liquid making it to evaporate. An evaporated refrigerant absorbs the heat from indoor space, thus cooling it. After, the refrigerant goes to compressor the process is repeated.

The working principle of air to water heat pump in steps:
1. Liquid refrigerant absorbs energy from ambient air, thus evaporating (in evaporator, or outdoor unit)
2. It passes through compressor where the temperature and pressure is increased.
3. The hot gaseous refrigerant passes its energy to indoor liquid (for example: water of central heating system) and condensates turning itself to liquid refrigerant.
4. Then it passes through expansion valve decreasing its temperature.
5. The process is repeated.

## 2.3 Gas boiler

A typical boiler uses fuel source in order to heat up some facility. These might be electricity or fuel. The modern ones have a special thermostat which controls the heating of water which is supplied to the building. In our case, we'll be using gas as a source of energy to heat the water. It'll operate at low temperature, thus supplying the part of heating loads.
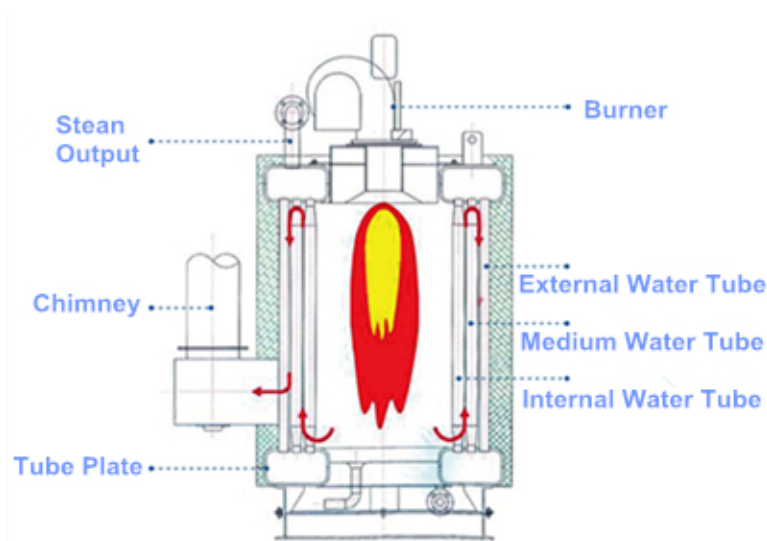
Image – 2 Structure of vertical gas boiler

## 2.4 Hybrid system

A hybrid system will provide heating loads whole year providing the house with the necessary amount of heat. The heat pump will operate mainly at high temperatures, whereas gas boiler will supply heating loads at lower temperatures, where the air-to-water heat pump is inefficient. Typically, inefficient working temperature of a heat pump varies up to -3° C to -6° C.

A special thermostat will be present in the system to control heating loads throughout the year. These are: heating temperature thermostat and hot water temperature thermostat

The main problem with such systems, is that the hybrid systems require a lot of calculations regarding the various factors such as weather data, coefficients and detailed information about the facility. In order to get the precise and detailed information about the heating loads of specific room, the hand calculations must be present. This allows us to compare the results of manual calculations and the results of TRNSYS simulation.

The flexibility of TRNSYS allows to run a simulation consisting of several elements at ease with the help of components that will be included in it. These are: weather data, integrator and plotter.

# 3. The selection and calculation of refrigerant

In our we case, it'll be reasonable to select the most eco- friendly refrigerant with minimum level of CO2 emissions. In our case, we'll be using refrigerant R134a(tetrafluoroethane). This type of refrigerant is considered safe amongst the others due to its chemical structure. It doesn't contain bromine and chlorine as well as doesn't smell and color. This refrigerant is non-toxic. The following table shows the physical properties:

Table 1 – Physical properties of R134a

| Parameter | Unit | R134 |
|-----------|------|------|
| Chemical formula | ~ | CF3CFH2 |
| Boiling temperature | °C | -26.1 |
| Critical temperature | °C | 101.1 |
| Critical pressure | MPA | 4.067 |
| Ozone Depletion Potential(ODP) | ~ | 0 |
| Global warming potential | ~ | 1300 |

In order to define the efficiency of heat pump which utilizes this refrigerant, we must find the specific COP of heat pump for it and find the evaporated, compressed, condensated amount of energy vapor-compression cycle. Such results will be obtained using the Energy Equation Solver. The code for solving this problem in Energy Equation solver is described below:

```
$UnitSystem SI MASS DEG PA K J
$Tabstops 0,2 0,4 0,6 0,8 1,0

"!Basic model of a vapor compression heat pump"

"!Operating conditions & system parameters"
T_amb      = converttemp('C'; 'K'; -5[C])
T_del      = converttemp('C'; 'K'; 35[C])
F$         = 'R134a'
Q_cond     = 25000 [W]

"!Placeholder guesses"
//m[1]      = 0.1 [kg/s]


"!System performance parameters"
Sup_evap   = 5 [K]
CAT_evap   = 10 [K] "Closest approach temperature to the ambient"
Sub_cond   = 5 [K]
CAT_cond   = 10 [K]
T[3]       = T_del + CAT_cond
eta_comp   = 0,7

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

"!(2) Compressor outlet / condenser inlet"
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])
W_comp     = m[2]*(h_s[2] - h[1])/eta_comp
W_comp     = m[2]*(h[2] - h[1])
T[2]       = temperature(F$; h=h[2]; P=P[2])
s[2]       = entropy(F$; h=h[2]; P=P[2])


"!(3) Condenser outlet / expansion valve inlet"
m[3]       = m[2]
P[3]       = P[2]
h[3]       = enthalpy(F$; T=T[3]; P=P[3])
s[3]       = entropy(F$; T=T[3]; P=P[3])
Q_cond     = m[3]*(h[2] - h[3])


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

COP_heat   = Q_cond/W_comp
```

Image - 3 Programming code of Energy
equation solver for vapor-compression
cycle


Considering the results of the calculation, the coefficient of performance is 2.8. In the process of functioning the compressor consumer electrical energy. The coefficient of performance was found and can be described with the following formula:

$$COP = \frac{Q_{consumed}}{A} = \frac{Q_{in} \cdot k}{A} \tag{1}$$

Where COP – coefficient of performance

$Q_{consumed}$ – amount of consumed heat

k – coefficient of effective work

A – work done by pump

Unit Settings: SI K Pa J mass deg

CAT$_{cond}$ = 10 [K]      CAT$_{evap}$ = 10 [K]      COP$_{heat}$ = 2,799      η$_{comp}$ = 0,7      F$ = 'R134a'

Q$_{cond}$ = 25000 [W]      Q$_{evap}$ = 16069 [J/s]      Sub$_{cond}$ = 5 [K]      Sup$_{evap}$ = 5 [K]      T$_{amb}$ = 268,2 [K] {-5 [C]}

T$_{del}$ = 308,2 [K] {35 [C]}      W$_{comp}$ = 8931 [W]


Click on this line to see the array variables in the Arrays Table window


No unit problems were detected.


Calculation time = 62 ms

| Sort | $m_i$ [kg/s] | $P_i$ [Pa] | $T_i$ [K] {[C]} | $h_i$ [J/kg] | $s_i$ [J/kg-K] | $h_{S,i}$ [J/kg] | $x_i$ |
|------|------|------|------|------|------|------|------|
| [1] | 0,1268 | 132820 | 258,2 {-15} | 242482 | 961,6 | | |
| [2] | 0,1268 | 1,319E+06 | 356,2 {83,04} | 312919 | 1023 | 291788 | |
| [3] | 0,1268 | 1,319E+06 | 318,2 {45} | 115751 | 417,7 | | |
| [4] | 0,1268 | 132820 | 253,2 {-20} | 115751 | 461,2 | | 0,4239 |

Image – 4 Results of calculation


     The image above represents the amount of mass, pressure, temperature, enthalpy, entropy, and quality of refrigerant. As the results show, the quality of refrigerant doesn't exceed 0.43. The results are satisfactory.

## 4. INPUT DATA AND SIMULATION

### 4.1 Simulation preparation

The input data for each element represent the data which it takes and gives an output data. Thus, working as a function which helps us to modify the information about the system and obtain the precise results. It can be specified in pop up window of each element by double clicking on it. Each one has specific sets of input data and its behavior varies depending on following connections. It's important to be aware of the properties of each elements and devices in order to avoid errors. All of the input data which was used in this work is shown in images below:

| | | Name | Value | Unit |
|---|---|---|---|---|
| 1 | | Return Air Temperature | 20.0 | C |
| 2 | | Return Air Humidity Ratio | 0.008 | - |
| 3 | | Return Air % Relative Humidity | 50.0 | - |
| 4 | | Return Air Flow Rate | 0. | kg/hr |
| 5 | | Inlet Pressure | 1. | atm |
| 6 | | Fan Pressure Rise | 0. | atm |
| 7 | | Outside Air Temperature | 20.0 | C |
| 8 | | Outside Air Humidity Ratio | 0.005 | - |
| 9 | | Outside Air % Relative Humidity | 50.0 | % (base 100) |
| 10 | | Ambient (Sink) Temperature | 20.0 | C |

Image - 5 Air to water heat pump

| | | Name | Value | Unit |
|---|---|---|---|---|
| 1 | | Flow rate at inlet 1 | 0.0 | kg/hr |
| 2 | | Flow rate at outlet 1 | 0.0 | kg/hr |
| 3 | | Flow rate at inlet 2 | 0.0 | kg/hr |
| 4 | | Flow rate at outlet 2 | -2 | kg/hr |
| 5 | | Temperature at inlet 1 | 20.0 | C |
| 6 | | Temperature at inlet 2 | 20.0 | C |
| 7 | | Environment temperature | 22.0 | C |
| 8 | | Control signal for element 1 | 1.0 | - |
| 9 | | Control signal for element 2 | 1.0 | - |
| 10 | | Flow rate for heat exchanger | 0.0 | kg/hr |

Image 6 – Hot water tank

| | | Name | Value | Unit | More | Macro |
|---|---|---|---|---|---|---|
| 1 | | Building loss coefficient | 5 | kJ/hr.m^2.K | More... | ☑ |
| 2 | | Building capacitance | 1000.0 | kJ/K | More... | ☑ |
| 3 | | Specific heat of building air | 1.006 | kJ/kg.K | More... | ☑ |
| 4 | | Density of building air | 1.2 | kg/m^3 | More... | ☑ |
| 5 | | Building surface area | 77.9 | m^2 | More... | ☑ |
| 6 | | Building volume | 233.7 | m^3 | More... | ☑ |
| 7 | | Humidity ratio multiplier | 10 | - | More... | ☑ |
| 8 | | Initial temperature | 18 | C | More... | ☑ |

Image 7 – Simulated House

| | | | | |
|---|---|---|---|---|
| 1 | | Flow rate at inlet 1 | 0.0 | kg/hr |
| 2 | | Flow rate at outlet 1 | 0.0 | kg/hr |
| 3 | | Flow rate at inlet 2 | 0.0 | kg/hr |
| 4 | | Flow rate at outlet 2 | -2 | kg/hr |
| 5 | | Temperature at inlet 1 | 20.0 | C |
| 6 | | Temperature at inlet 2 | 20.0 | C |
| 7 | | Environment temperature | 22.0 | C |
| 8 | | Control signal for element 1 | 1.0 | - |
| 9 | | Control signal for element 2 | 1.0 | - |
| 10 | | Flow rate for heat exchanger | 0.0 | kg/hr |

Image - 8 Hot water temperature
thermostat:

| | | Name | Value | Unit |
|---|---|---|---|---|
| 1 | | Monitoring temperature | 20.0 | C |
| 2 | | Heating setpoint | 22 | C |
| 3 | | Cooling setpoint | 24.0 | C |

Image – 9 Heating temperature
Thermostat

| | | Name | Value | Unit |
|---|---|---|---|---|
| 1 | | File Type | 6 | - |
| 2 | | Logical unit | **50** | - |
| 3 | | Tilted Surface Radiation Mode | 5 | - |
| 4 | | Ground reflectance - no snow | 0.2 | - |
| 5 | | Ground reflectance - snow cover | 0.7 | - |
| 6 | | Number of surfaces | 1 | - |
| 7 | | Tracking mode | 1 | - |
| 8 | | Slope of surface | 0.0 | degrees |
| 9 | | Azimuth of surface | 0 | degrees |

Image – 10 Weather data:

| | | Name | Value | Unit |
|---|---|---|---|---|
| 1 | | Inlet fluid temperature | 20 | C |
| 2 | | Inlet fluid flow rate | 0 | kg/hr |
| 3 | | Control signal | 1 | - |
| 4 | | Overall pump efficiency | 0.6 | - |
| 5 | | Motor efficiency | 0.9 | - |

Image – 11 Network pump:

| | | Name | Value | Unit |
|---|---|---|---|---|
| 1 | | Room Temperature | 18 | C |
| 2 | | Room Air Pressure | 1 | atm |
| 3 | | Inlet Water Temperature | 40 | C |
| 4 | | Water Flowrate | 0 | kg/hr |

Image – 12 Radiator:

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## 4.2 Simulation process

The simulation will be created in TRNSYS Simulation Studio. The following elements will be included:
- Air-to-water heat pump;
- Hot water tank;
- Simulated house;
- Hot water temperature thermostat;
- Heating temperature thermostat;
- Weather data;
- Plotter;
- Forcing function;
- Heating network pump;
- COP Plotter;
- Temperature/energy plotter;
- Radiator.

An air-to-water heat pump utilizes outdoor air temperature to boil refrigerant which will be passed to indoor unit. We will be using this element only in heating mode so the gas boiler is already included in it.

Hot water tank will store the hot water which will be passed to the following pumps and radiators. It consists of two inlet/outlets passing the hot/cold water to the system.

Simulated house represents the house which we're aiming to heat. It's basically a single zone structure which serves as a substitute to a complex facility model. This element is responsible for heating load estimation coming to our simulating system.

Hot water temperature thermostat is a simple thermostat providing an output as an on/off function which measures a hot water temperature

Heating temperature thermostat provides an output as an on/off function which measures a heating temperature

Weather data is an element which is responsible for providing various inputs. In our case, we will be utilizing dry bulb temperature and humidity ratio.

Plotter is an element responsible for creating graphs and plots. The flexibility of such element allows the user to change and define various variables

Transient simulations require a graphics with repeated patterns. The forcing function creates such plots using the discrete data points. The continuation and length of function with repeating pattern depends on specified time value.

Network pump is a simple element representing the basic pump which transfers the liquid through the network

Coefficient of performance(COP) is the ratio of produced heat to consumed amount of electricity. In order to show the efficiency of heat pump, we utilize COP Plotter.

Temperature/energy plotter is a plotter which plots temperature and amount of produced energy via corresponding graphs in a special window.

Radiator is required to simulate the heating device which is utilized in every building or house. The main input data will include: Room temperature, Inlet water temperature, inlet water flowrate. The output data is the following: heat transfer rate, water outlet temperature, water flowrate.

All of the elements mentioned above must be specified and the variables must be connected correctly in order to avoid potential errors. Once, the variables are connected it's important to specify simulation run time, simulation step, weather data, and various temperatures. These are: dry bulb temperature, latitude, tilted surface radiation mode, ground reflectance, azimuth of surface.

## 4.3 Heating loads calculation

In order to heat the house, the system must satisfy two conditions. The first condition states, that the transient system must supply the necessary amount of energy required to maintain the stable temperature inside the facility. The optimal room temperature throughout the season must maintain at +20 C. The standards regarding the required microclimate is described by GOST 30494-96.

Table - 1 Required microclimate

| Room type | Air temperature, C | Relative Humidity, % | The speed of air, m/s |
|---|---|---|---|
| Living Room | 20-22 | 45-30 | 0.15 |
| Kitchen | 19-21 | 45-30 | 0.15 |
| Restroom | 19-21 | ~ | 0.15 |
| Bathroom | 24-26 | ~ | 0.15 |
| Resting and studying room | 20-22 | 45-30 | 0.15 |

The compensation of heat loss is described by second condition. It occurs even in most ideal situation in any system in various amounts, so the main task is to minimize heat losses. The standard amount of heat loss is described in the table below:

Table – 2 Standart amount of heat loss

| Element of the house | Approximate loss of heat, % |
|---|---|
| foundation, floors on the ground or over unheated rooms | 5-10 |
| poorly insulated construction joints | 5-10 |
| water supply, gas pipes, power cables | Up to 5 |
| Outer walls depending on thermal insulation | 20-30 |
| Windows and outer doors | 20-30 |
| Roof | Up to 20 |
| Ventilation and chimney | Up to 30 |

The scheme of the house plays major role in identifying heating loads and losses. Therefore, in following image the number of rooms and detailed sizes are present. Each space and room is labeled with a number.
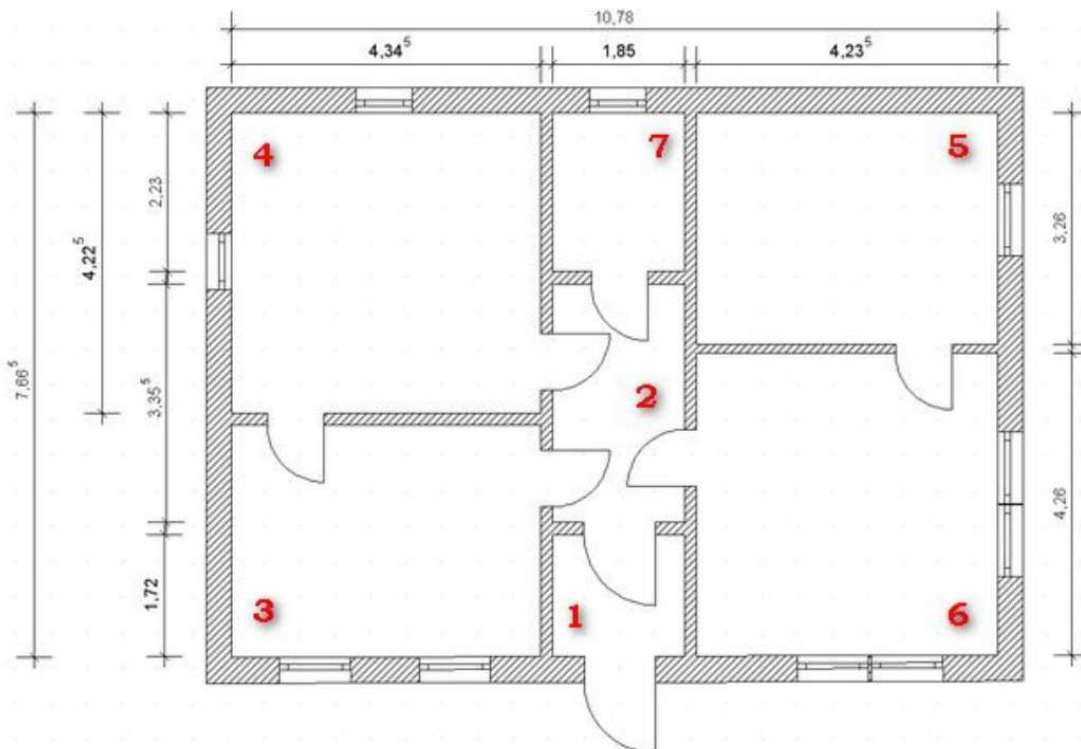


Image – 13 The scheme of the house

The formula for calculating overall heating load is:

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$$Q = \sum_{n=1}^{7}(S_n \cdot 100) \cdot a_n \cdot b_n \cdot c_n \cdot d_n \cdot e_n \cdot f_n \cdot g_n \cdot h_n \cdot i_n \cdot j_n \cdot k_n \cdot l_n \cdot m_n \qquad (2)$$

Where Q - amount of heat

S - area of room

a - considers the amount of outer windows

b - the location of outer walls relative to the cardinal points

d - considers the geographical location of house

e - which considers the amount of thermal insulation of walls

f - coefficient regarding the height of walls

g - the type of floor or room located under the ceiling

h - considers the type of floor or room located over the ceiling

i - coefficient which takes into account the type of windows

j - correction factor which takes into account the total area of glazing

k - coefficient which takes into account the presence of the front door

l - coefficient of adjustments of the scheme of the connection of radiators

m - coefficient of the possible location of the location of radiators.

Table - 3The results of the calculations for each room is shown below:

| Room type, area, height of ceiling, floor insulation | Number of outer walls, their location relative to cardinal points, insulation degree of the walls | Number, type, size of windows | Precense of entrance doors, | Required heating power(Taking into account the 10% reserve power) |
|---|---|---|---|---|
| 1.Hallway. 3.2 $m^2$, ceiling 3 m, insulated floor, insulated attic | 1, South, medium insulation, | None | 1 | 0.52 kWt |
| 2.Hall. 6 $m^2$, ceiling 3 m, insulated floor, insulated attic | none | none | None | 0.59 kWt |
| 3.Kitchen, 15 $m^2$, ceiling 3 m, Well insulated floor, insulated attic | 2, Southwest, medium insulation, downwind | 2, double-glazed window, 1200x900 mm | None | 2.1 kWt |
| 4.Children's room. 17.9 $m^2$, ceiling 3 m, well insulated floor, insulated attic | 2, Northwest, high insulation, upwind | 2, double-glazed window, 1400x1000 mm | None | 2.7 kWt |
| 5.Bedroom. 14 $m^2$, ceiling 3 m, well | 2, North, East. High insulation, upwind | 1, double-glazed window, 1400x1000 mm | None | 1.8 kWt |

| | | | | |
|---|---|---|---|---|
| insulated floor, insulated attic | | | | |
| 6.Guest's room. 17,9 $m^2$, ceiling 3 m, well insulated floor, insulated attic | 2, East, South, high insulation, parallel to wind direction | 4, double-glazed window, 1500x1200 mm | None | 2.6 kWt |
| 7.Bathroom,Restroom. 3.9 $m^2$, ceiling 2.9 m, well insulated floor, insulated attic | 1, North, High insulation, upwind | 1, double glazed wooden frame, 400x500 | None | 0.6 kWt |

Thus, the overall required heating loads is:
$$Q = 0.52 + 0.59 + 2.1 + 2.7 + 1.8 + 2.6 + 0.6 = 1.1 \cdot (10.91) = 12 \, kWt \quad (3)$$


## 4.4 TRNSYS Simulation

The simulation process starts from defining the elements as well as auxiliary components (Forcing Function, Plotters, Weather Data, Network Pumps)
The core elements of a simulation are:
- Type 119b gas auxiliary air source heat pump;
- Simulated house with area of 77.9 $m^3$;
- Type 60c Hot water tank with the volume of 0.3 $m^3$;
- Type 15-1 Weather Data (Kazakhstan, Aktobe);
- Type1231 Radiator;
- Type 166 Heating thermostat;
- Type 166 Hot water thermostat;
- Type 114 Heat Pump network pump;
- Type 65d COP plotter;
- Type 65d Temperature/energy plotter;
- Type 14b Time-dependent forcing function;


The next step in creating the simulation, consist of:
- specifying the weather data;
- identifying variables;
- setting the variables;
- setting input data;
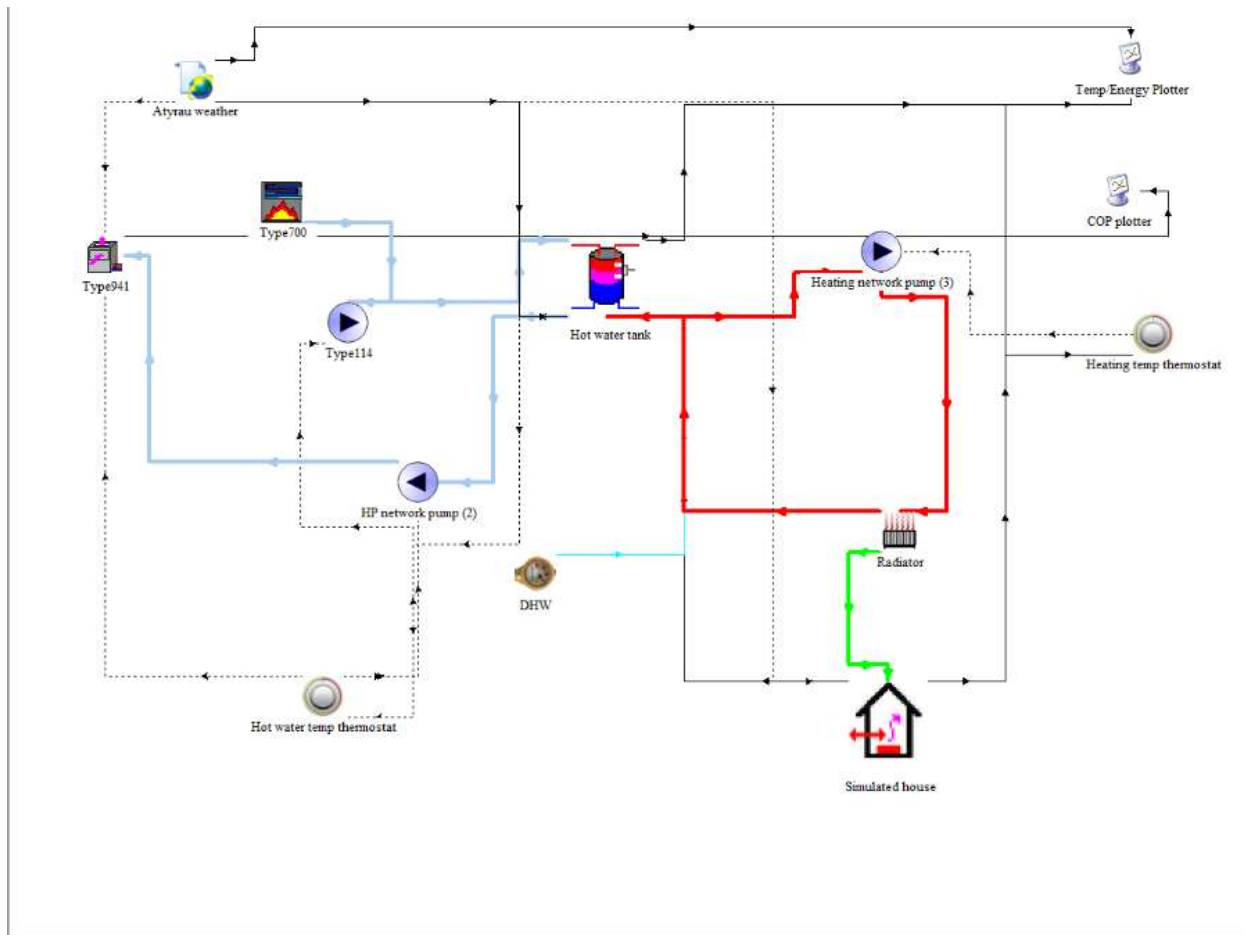- checking output;
- setting graph variables

Image – 14 The simulation of transient system

The mentioned scheme represents the general view for the system. The heat pump and integrated gas boiler serves as a core of the transient system. The pump pumps the heat from the heated refrigerant to the water where it's distributed through the system. The radiator takes the water from the water tank and distributes the heat through the room. COP and temperature/energy plotters plots the graphs of the variables whereas hot water temperature thermostat and heating temperature thermostat controls the house heating and water heating cycles of the system.

## 5. RESULTS

The results of simulation show that the transient system is capable of heating the given household. Moreover, given the additional 10% heating loads are easily capable of compensating heating losses through the conduction and convection which were specified in the corresponding element of TRNSYS.

The comparison of manual calculation and the results of TRNSYS simulation software shows, that the difference between the final results of calculations are negligible and the feasibility and accuracy of the software is proven.

The results of simulation in graphs are in application.

# CONCLUSION

The results of simulation show that the transient system is capable of heating the given household. Moreover, given the additional 10% heating loads are easily capable of compensating heating losses through the conduction and convection.

Manual calculation was made in order to strengthen and support the obtained results.

TRNSYS simulation software had shown that its capable of simulating and giving the precise results, thanks to the flexible and powerful interface and mathematical bias of the software.

Given the input data of all elements and weather, the possibility of integrating with testing and simulating of such system is possible.

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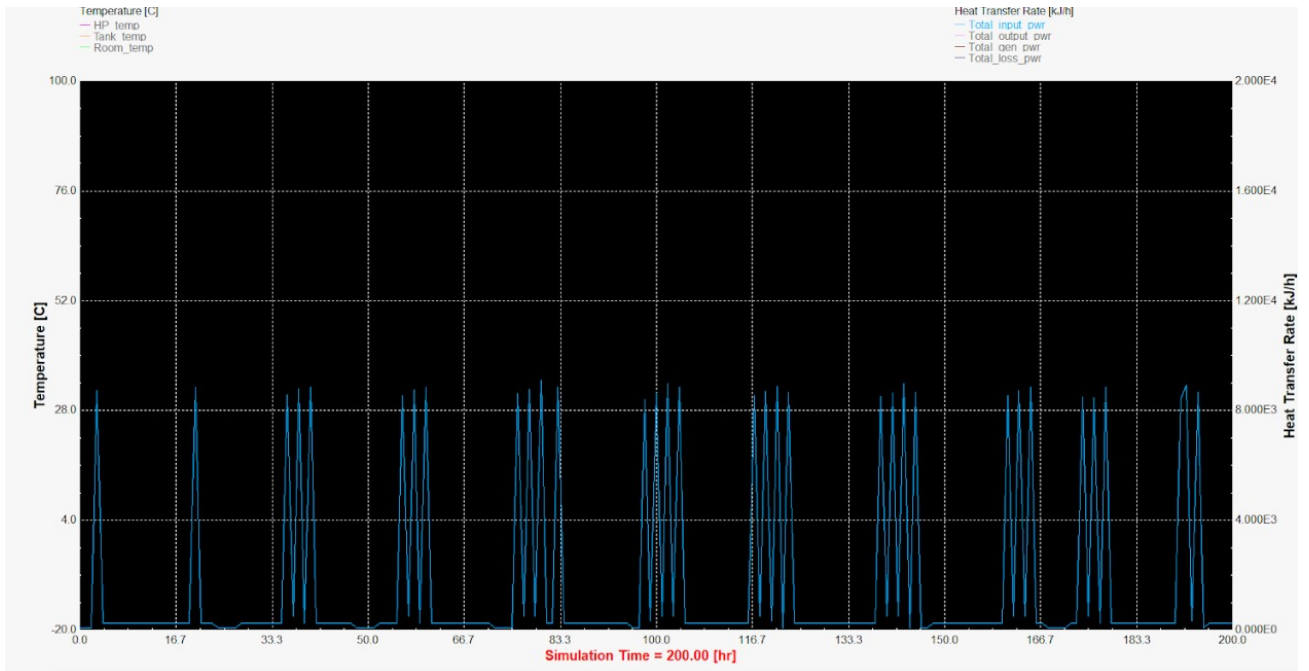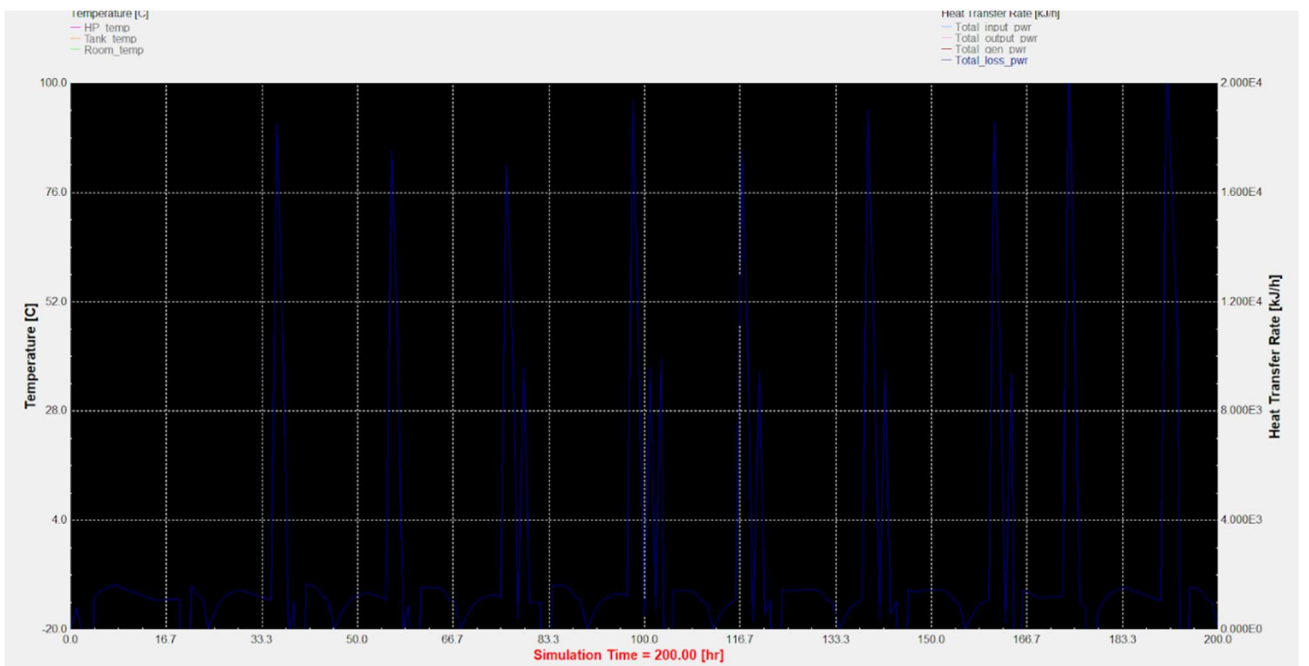
## APPLICATIONS



Image - 12 Total power input



Image – 13 Power loss graph