



The use of solar collector for heating and electricity for a single family house

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ERASMUS PROJECT

[The use of solar collector for heating and electricity for a single family house]

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Abstract

The presented work is related to the use of solar energy for the needs of heating and electricity for a single house located in Poland. Electricity will be provided by energy conversion in the turbine by means of Organic Rankine Cycle (ORC), in which the operating medium (water heated in solar collector) is heating refrigerator in the heating exchanger.

The solar installation is integrated with heat accumulator and wood boiler, which is used in the situation that collector is not enough to fill requirements of thermal comfort. There are chosen also all the necessary components of the system.

In the work is also performed the economic assessment, by F chart method, to evaluate the profitability of the project, taking into total costs and savings.

Keywords

F-chart method, solar system, Organic Rankine Cycle (ORC), renewable energy sources,

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List of Symbols and Abbreviations

ECTS	European Credits Transfer System
EU	European Union
A	Area
A_c	Area of the collector
b_u	Temperature reduction factor
C_p	Specific heat of water
C_e	Cost of equipment
C_M	Cost of maintenance
C_A	Cost per unit area of collector
D	The diffuse radiation
D_L	Length of the day
e_i	The shielding factor
f	Solar fraction
f_v	Temperature reduction factor
F	Fin efficiency factor
F_R	Collector heat removal factor
F'_R	Collector heat exchanger factor
G	Irradiance
G_{SC}	Solar constant
g	Gravitational constant
h	Enthalpy
H	Daily irradiation
H_o	The total solar radiation
i	The discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk)
l	Hourly irradiation
I_o	The initial investment
K_T	Daily clearness index
L	Longitude, The albedo radiation intensity

\dot{m}	Mass flow rate
N_p	Payback period
N_h	Water partition coefficient of uniformity
n_{\min}	The minimum multiplicity of air exchange, h^{-1}
n_{50}	the multiplicity of air exchange, h^{-1}
Q_{DHW}	Daily energy consumption of domestic heat water in the building
q_{DHW}	Daily water flow rate
R	Ratio of total radiation on a tilted plane to that on the plane of measurement (usually horizontal), heat transfer resistance
R_A	Annual cash flow
R_t	The net cash flow
S^d	The direct radiation
t, T	Temperature, time of the cash flow
U	Number of householders
U_L	Collector overall heat loss coefficient
W	Power
V	Volume, consumption of water
X	Dimensionless collector loss ratio
Y	Dimensionless absorbed energy ratio

GREEK SYMBOLS

α	Absorptance
β	The slope of the solar collector
ε_i	Correction factor related to air velocity depending of location of heated space
δ	Declination of the Sun, thickness
Φ	Latitude
ω_s	Sunset hour angle
Φ_{DHW}	Heat power needed for domestic hot water
ρ	the viscosity of the water
λ	Thermal conductivity of the material
τ	Coefficient of transimition

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1. **INTRODUCTION**

The problem

Methods

1. Introduction

This work was carried out based on an ERASMUS PROJECT in order to get 20ECTS in the academic year of 2015/2016, first semester.

1.1. The Problem

The main point of this work is to conduct the technical and economic assessment of the using water solar collectors for needs of heat and electricity consumed in a single house in Poland. House is located in Wrocław, big city in the west of Poland, (II climatic zone). The operating medium from the solar collectors in the next part of process is heating refrigerant in Organic Rankine Cycle that produce electricity and heat in condenser. The system does not need batteries since it must be connected with the grid. The thermo-accumulator is a condition of f-chart method. It is also necessary to predict an auxiliary system (e.g. cooling tower) to complete condensation of the refrigerant in the ORC.

The work was divided into several tasks such as:

- Analysis of the energy consumption in a typical polish single house (both heating and electricity),
- Choose a refrigerant in ORC (comparison of refrigerants was carried out base on Coolpack program),
- Sizing the solar installation for using the solar fraction (using F- chart method),
- Selection of all necessary components,
- Economic analysis and feasibility of the project.

1.2. Methods

The strategy to prepare the final project described in subchapter 1.1 consistent on weekly appointments with the Professor Leonardo Silva Ribeiro. During these meetings the progress of work was consulted. Every week new part of project were prepared, mainly calculations and figures. The all existing problems were discussed to find the most optimal solution. The most important assumptions of the work were established in accordance with Professor's advices. Preparing of theoretical part and choice of main components was planned as a last stage of project. The function of professor was systematically giving guidelines and support on each

phase of project development. During preparing of this work used materials mentioned in internet like presentation, catalogues, scientific publication, the legal standards, websites (for example website related to meteorological data from Poland) and books, English and Polish, as well. All bibliography used in project was listed in the end of this report. The main work tools were programs Coolpack, Autocad and Microsoft Office.

2. BACKGROUND

Analysis of the energy consumption in single house in Poland

Selection of a refrigerant

Sizing the installation

As will be shown in later sections, the variables X and Y are used to determine f_i , the monthly fraction of the load supplied by solar energy. The energy contribution for the month is the product of f_i and the monthly heating and hot-water load L_i . The fraction of the annual heating load supplied by solar energy F is the sum of the monthly solar energy contributions divided by the annual load:

$$F = \frac{\sum f_i \cdot L_{ij}}{\sum L_i} \quad 1.$$

For the analyzed solar system the fraction f of the monthly total load supplied by the solar space and water heating system is given as a function of X and Y in Figure 20.3.1.

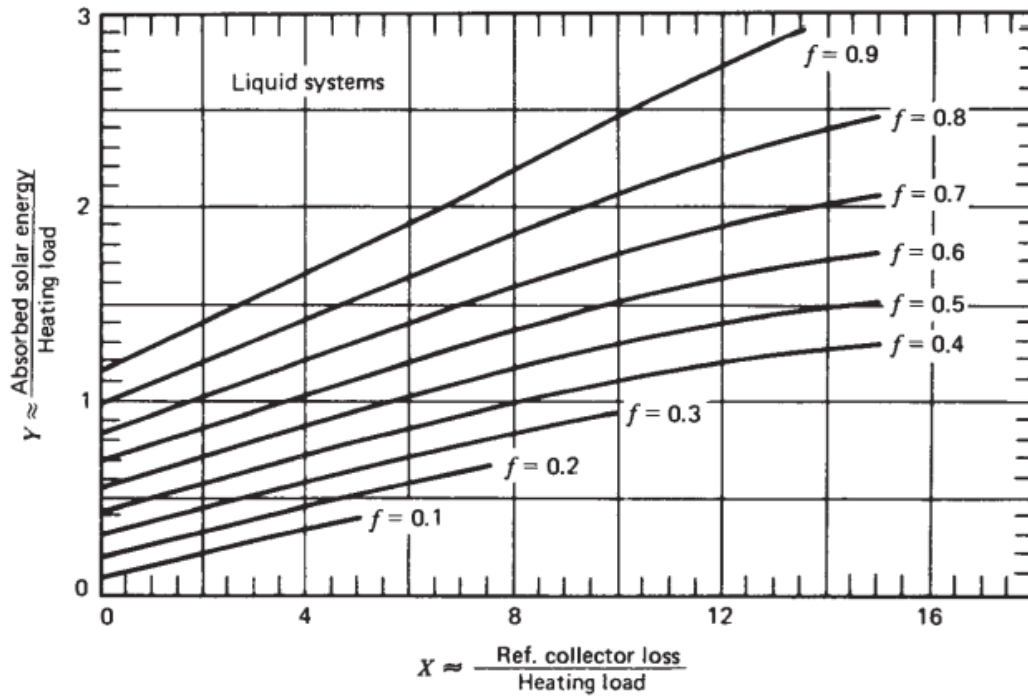


Fig. 6 The f -Chart for systems using liquid heat transfer and storage media. From Beckman et al. (1977). [2]

To determine the economic optimum collector area, the annual load fraction corresponding to several different collector areas must be determined. The annual load fraction is then plotted as a function of collector area, as shown in **Fig. 7**. The information in this figure can then be used for economic calculations. For liquid systems, f -chart calculations can be modified to estimate changes in long-term performance due to changes in storage tank capacity and load heat exchanger characteristics.

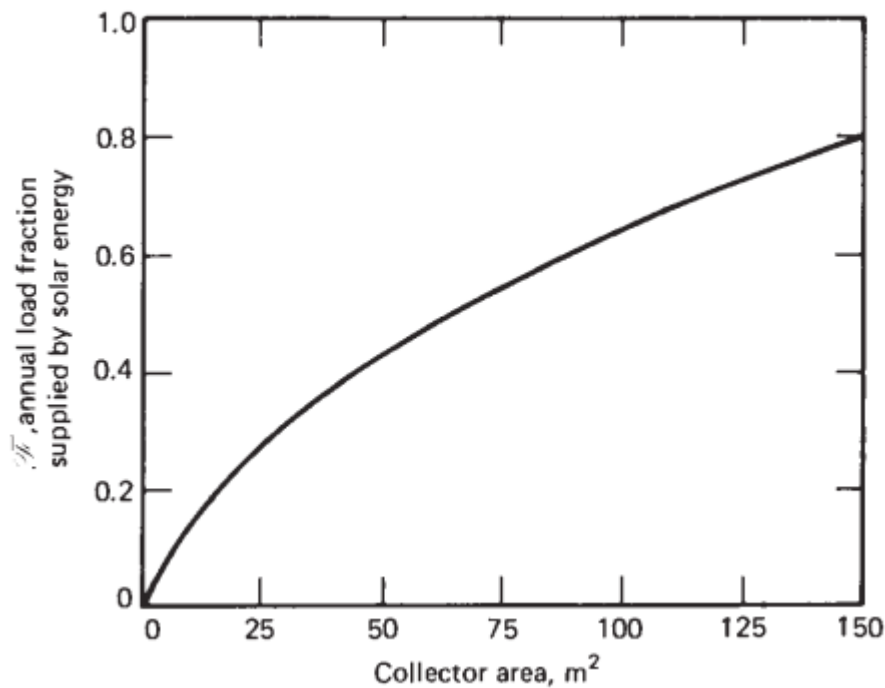


Fig. 7 Annual load fraction versus collector area. [2]

The f-chart was developed for a standard storage capacity of 75 liters of stored water per square meter of collector area and in this work this volume of water was used.

As the heat exchanger used to heat the building air is reduced in size, the storage tank temperature must increase to supply the same amount of heat, resulting in higher collector temperatures and reduced collector output. A measure of the size of the heat exchanger needed for a specific building is provided by the dimensionless parameter $\varepsilon_L C_{min}/(UA)_h$ where ε_L is the effectiveness of the water-air load heat exchanger, C_{min} is the minimum fluid capacitance rate (mass flow rate times the specific heat of the fluid) in the load heat exchanger and is generally that of the air, and $(UA)_h$ is the overall energy loss coefficient–area product for the building used in the degree-day space-heating load model.

Selection of all necessary components

Economic analysis

2. Background

As mentioned above the main point of work is to conduct the technical and economic analysis of using a solar system for the need of electricity and heat in a typical Polish single house.

The installation is presented below on the drawing.

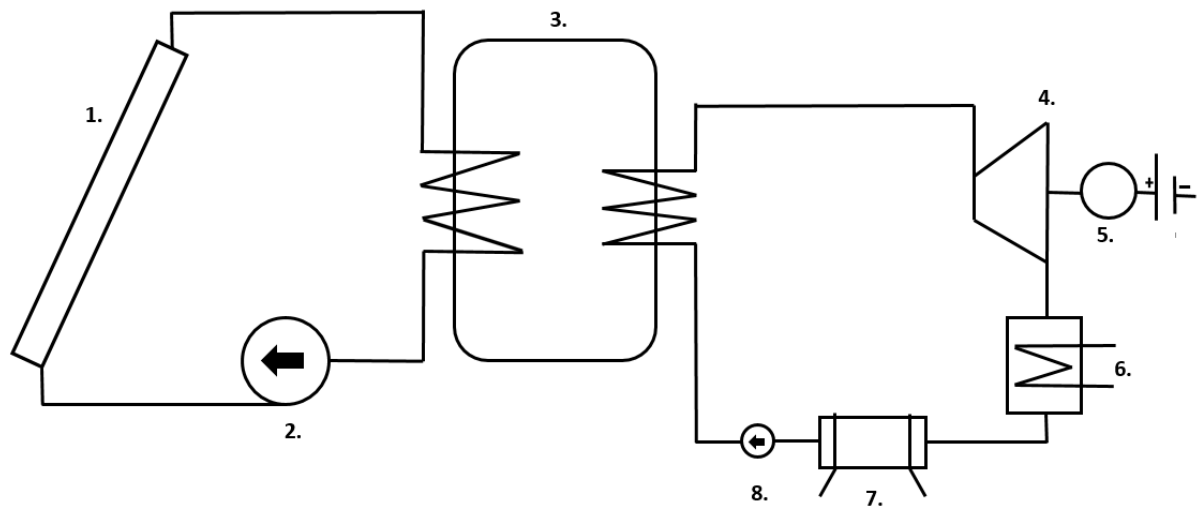


Fig. 1 Schema of the installations. 1. Solar collector; 2. Water pump; 3. Water tank; 4. Turbine; 5. Generator; 6. Condenser; 7. Cooling tower; 8. Refrigerant pump.

This installation is divided into two circuits. First (on the left) is the solar system, where the operating medium is water. The second system (on the right) is called the Organic Rankin Cycle (ORC), which allows the use of renewable energy sources (for example, solar energy like in this work) to produce electricity power. The operating medium in the ORC is a low-boiling fluid. The ORC consists of several processes (Fig. 2): 1-2 isentropic expansion of saturated steam, 2-3 isobaric condensation, 3-4 liquid compression and 4-1 isobaric heating and evaporation.

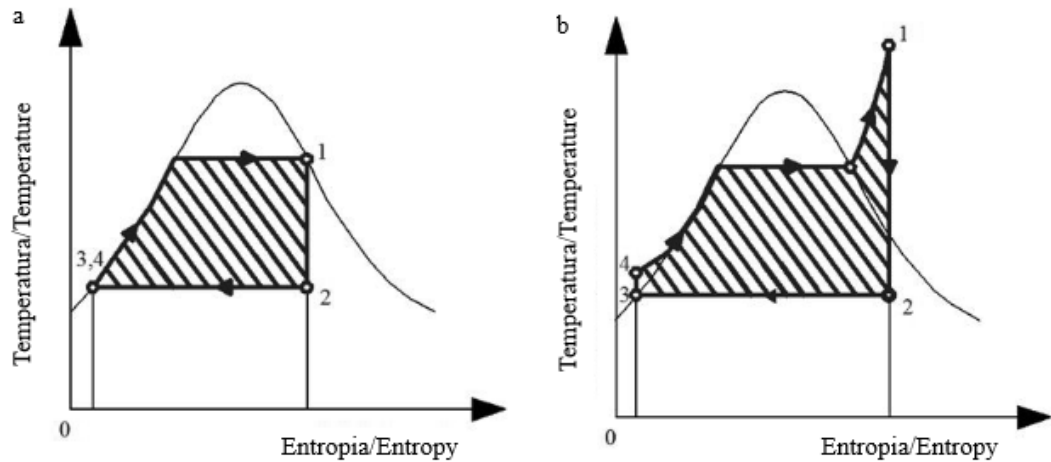


Fig. 2 The Clausius-Rankine cycle in thermodynamic Belpaire system of coordinates (absolute temperature – entropy): a – for wet saturated steam, b – for superheated steam [1]

2.1. Analysis of the energy consumption in single house in Poland

The first part of project was to assess energy consumption in a single house. For this purpose the typical design of a single house was chosen. All layers and the thickness of them have been established. Next stage was calculate all heat losses by walls, doors, windows, floors, roofs and also by ventilation air (to provide fresh air). All drawings, equation and calculation will be presented in the next chapter. All calculations in this part were conducted base on the Polish Standard PN – EN 12831 (standard concern the method of calculating the design heat load).

2.2. Selection of a refrigerant

Selection of the appropriate refrigerant plays an important role in the application of ORC among other things to achieve high level of the energy efficiency. There are three types of organic factors, which can realize the Organic Rankin Cycle: wet factor, dry factor and isentropic factor. These sample organic working mediums were presented on the Fig. 3.

Choosing of the right organic liquid is related with thermodynamic and physics. Some important properties of such fluids are:

- Isentropic steam evaporation curve,
- Low freezing point,
- High temperature stability,
- High density and heat of vaporization,
- Low environment impact,
- Safety
- Low cost.

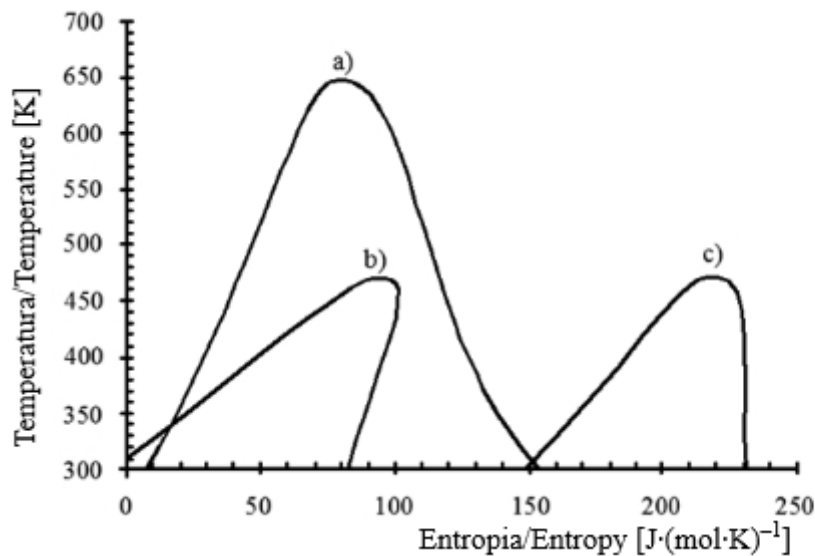


Fig. 3 Three types of organic working medium in thermodynamic system of coordinates T-s (temperature – entropy): a – wet fluid – water, b – dry fluid – pentane, c – isentropic fluid – R11, (Chen et al. 2010)

In the next chapter the comparison of a few refrigerants was conducted to select the fluid which will have the best properties in analyzed process.

2.3. Sizing the installation by the method of solar fraction

2.3.1. Concepts related to solar energy

The solar energy which a solar collector receives from the Sun has to be estimated to conduct all necessary calculations. The power of solar radiation on Earth is around $8 \cdot 10^{16}$ W. The Sun has $1,39 \cdot 10^9$ m of diameter and distance from our planet is $1,5 \cdot 10^8$ km. The Sun is considered as black body and the estimated surface temperature is 5775 K. The used equations will be presented in the next chapter of this work.

The thermal radiation is independent on the surrounding environment so energy transport in vacuum is possible. Solar radiation has spectral distribution as shown in **Fig. 4** with the range of wavelengths ranging essentially between the values 0.2 and 3 μm .

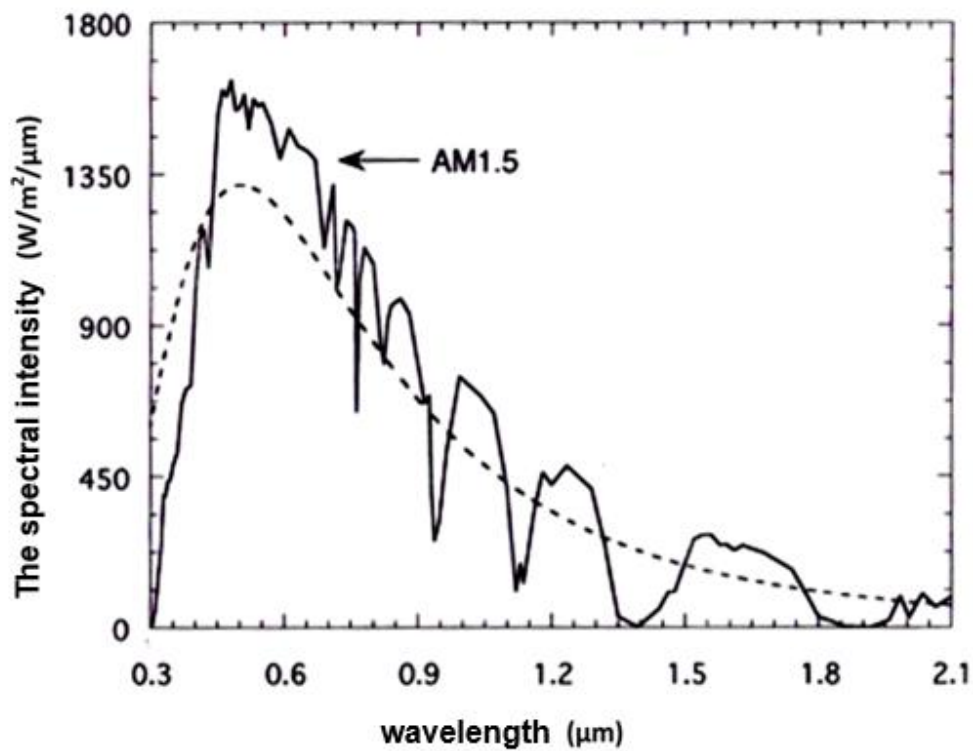


Fig. 4 Spectral diagram of the solar radiation. I

Below are listed all equation needed to make necessary calculations.

- The average constant solar

$$G_{SC} = 1367 \left(1 + 0,33 \cos \left(\frac{360 n}{365} \right) \right), \frac{W}{m^2} \quad 2.$$

- Declination of the Sun

$$\delta = 23,45 \sin \left(360 \frac{284 + n}{365} \right) \quad 3.$$

- Day length

$$D_L = \frac{2}{15 \arccos(-\tan \delta \tan \phi)}, h \quad 4.$$

- Extraterrestrial solar radiation for horizontal surface on the soil

$$G = S + D \quad 5.$$

- Irradiation of the surface on the soil

$$I = S + D + L \quad 6.$$

- The total solar radiation on the edge of atmosphere

$$H_0 = \frac{24 \cdot 3600}{\pi} \left(1 + 0,33 \cos \left(\frac{360n}{365} \right) \right) \cdot \left(\cos(\phi) \cos(\delta) \sin(\omega_s) + \frac{\pi \omega_s}{180} \sin \phi \sin \delta \right) \quad 7.$$

- Sunset hour angle

$$\omega_s = \arccos(-\tan \phi \tan \delta) \quad 8.$$

- The average clearness index

$$K_T = \frac{H}{H_0} \quad 9.$$

System was planned for the single house building in Poland, in Wrocław (the city is located in second climate zone as shown on the **Fig. 5**)

2.3.2. The climate zone i design temperatures in Poland

The design outside and inside temperatures of the air were listed below in the **Tab. 1**. The values of these temperatures will be needed in the next chapter to calculate the thermal losses through walls, windows, doors, floors, roofs and ventilation.

Tab. 1 The design and average annual temperatures. [II]

The climate zone	The design outside temperature, °C	The average annual outside temperature, °C
I	-16	7,7
II	-18	7,9
III	-20	7,6
IV	-22	6,9
V	-24	5,5



Fig. 5 The climate zone in Poland. [II]

2.3.3. The F-chart method

[2] The ϕ -f chart method is a simulation technique used in solar energy systems for heating and cooling. This method is particularly useful for sizing system components. The difficulty of sizing systems components lies in the fact that these systems are influenced both by predictable data (e.g. collectors, storage tanks, ...) and unpredictable data such as weather data. This method is particularly useful in the simulation of absorption refrigerators, industrial process heating, and space heating systems where the thermodynamics cycle efficiency is independent of the heat supply temperature.

In the report is presented the algorithm for thermal calculation and the analysis of the effects of installation with solar collectors using f-chart method. The presented algorithm and the basic version of the f-chart method were supported by calculation for the selected solar installation (**Błąd! Nie można odnaleźć źródła odwołania.**). This system is used to power control of heat and electricity for the needs of single-family building. Calculations were carried out for the installation with flat-plate collectors. Selection of such collectors was determined by their popularity and precisely defined surface.

Detailed simulations of these system have been used to develop correlations between dimensionless variables and f , the monthly fraction of loads carried by solar energy. The two dimensionless groups are:

$$X = \frac{A_c F'_R U_L (T_{ref} - \bar{T}_a) \Delta t}{L} \quad 10.$$

$$Y = \frac{A_c F'_R (\bar{\tau}\alpha) \bar{H}_T N}{L} \quad 11.$$

As will be shown in later sections, the variables X and Y are used to determine f_i , the monthly fraction of the load supplied by solar energy. The energy contribution for the month is the product of f_i and the monthly heating and hot-water load L_i . The fraction of the annual heating load supplied by solar energy F is the sum of the monthly solar energy contributions divided by the annual load:

$$F = \frac{\sum f \cdot L_{i1}}{\sum L_i} \quad 12.$$

For the analyzed solar system the fraction f of the monthly total load supplied by the solar space and water heating system is given as a function of X and Y in Figure 20.3.1.

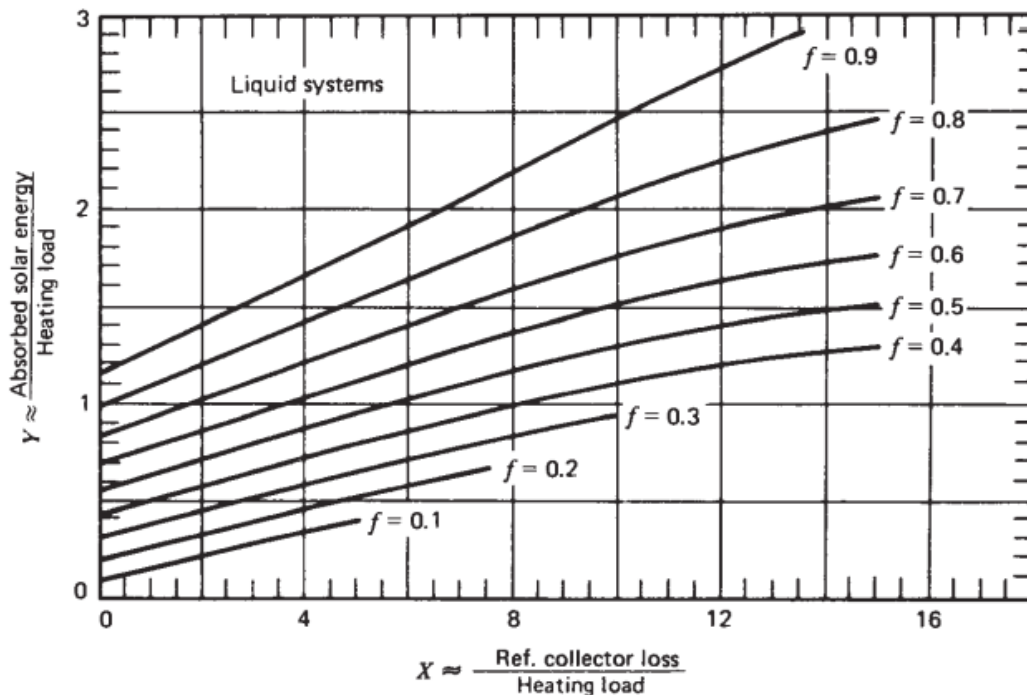


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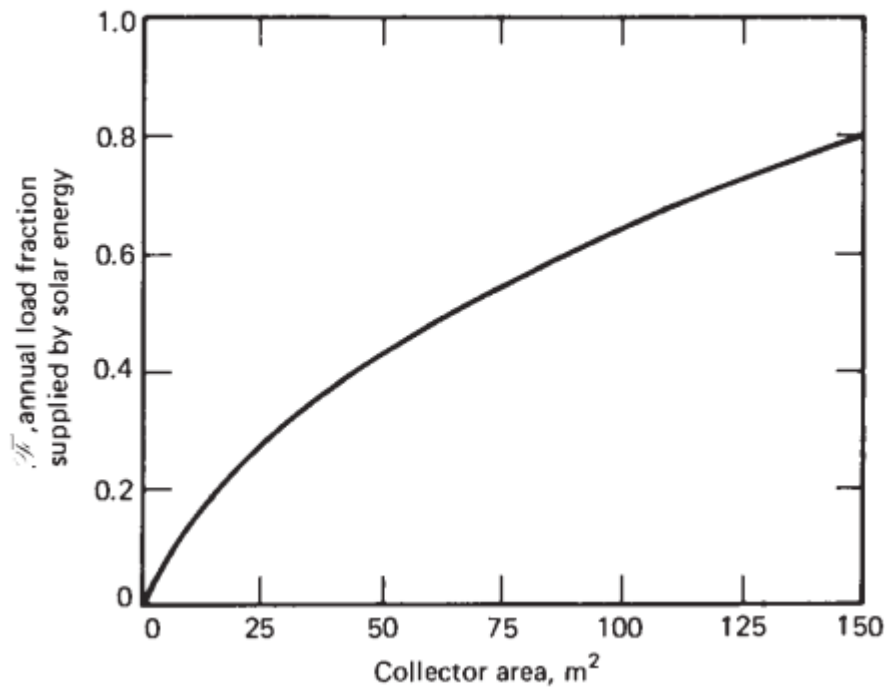


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2.4. Selection of all necessary components

All necessary equipment was selected based on companies catalogues available in the internet. The selection criteria were economic substance, technical characteristic, energy efficiency. All selected equipments is listened in the next chapter.

2.5. Economic analysis

The work will also contain an economic analysis to estimate profitability of this idea. Every project should bring economic and social advantages as well. All investors, entrepreneurs and normal families as well, want to know cost and savings of selected installation. There are a few certain criteria for making a decision such as the net present value NPV, the internal rate of return (IRR), the payback period etc.

2.5.1. The net present value (NPV)

The NPV function is defined as the sum of the present values (PVs) of incoming and outgoing cash flows over a period of time. Due to the changes in the exchange of money value, currencies can have different values every day. The NPV calculates the current value of each series of cash flows and adds them to get the net present value.

$$NPV(i, N) = \sum_{t=0}^N \frac{R_t}{(1+i)^t} - I_0 \quad 13.$$

Where:

t- the time of the cash flow

i-the discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk)

R_t- the net cash flow

I₀- the initial investment

According to this assessment criterion when $NPV > 0$, the investment has merit and could be implemented.

2.5.2. Internal rate of return (IRR)

The internal rate of return (IRR) is the method of evaluating the economic efficiency of investments, as well as financial ratio determined on the basis of this method. The calculating the IRR value consist on calculating the specific value of the discount rate (i) as shown on the below equation:

$$N \sum_{t=0}^N \frac{R_t}{(1+i)^t} - I_0 = 0 \quad 14.$$

The internal rate of return (IRR) of an investment can be:

- **larger** than the rate of weighted average cost of capital (rate) and it means that investment is economically interesting,
- **equal** the rate of weighted average costs, in this case is economically neutral,
- **less** than the rate of weighted average cost, in this situation investment is not profitable

2.5.3. The payback period

The payback period is the period of time required to recover the funds expended in an investment, or to reach the break-even point.

$$N_p = \frac{C}{R_A} \quad 15.$$

Where:

C- Cost of the project

R_A- Annual cash inflows

To use all listened above equation the cost of investment must be known. In the next chapter there will be listened all cost of installation, necessary equipment etc.

3. *DEVELOPMENT*

Analysis of the energy consumption in single house in Poland *Błąd! Nie można odnaleźć źródła odwołania.*

Selection of the refrigerant

Sizing of the installation by the method of solar fraction

Selection of the main components of system

Economic analysis

3. Development

As mentioned above report is related to using the solar system for the needs of heat and electricity in the single family house located in Poland. The schema of the system was shown on the Fig. 1.

3.1. Analysis of the energy consumption in single house in Poland

3.1.1. Description of the building

First think, which has to be conduct, is calculating the thermal load of the chosen building. For the needs of this project the single family house was chosen based on the construction project, which was announced on the polish website www.murator.dom. [III]

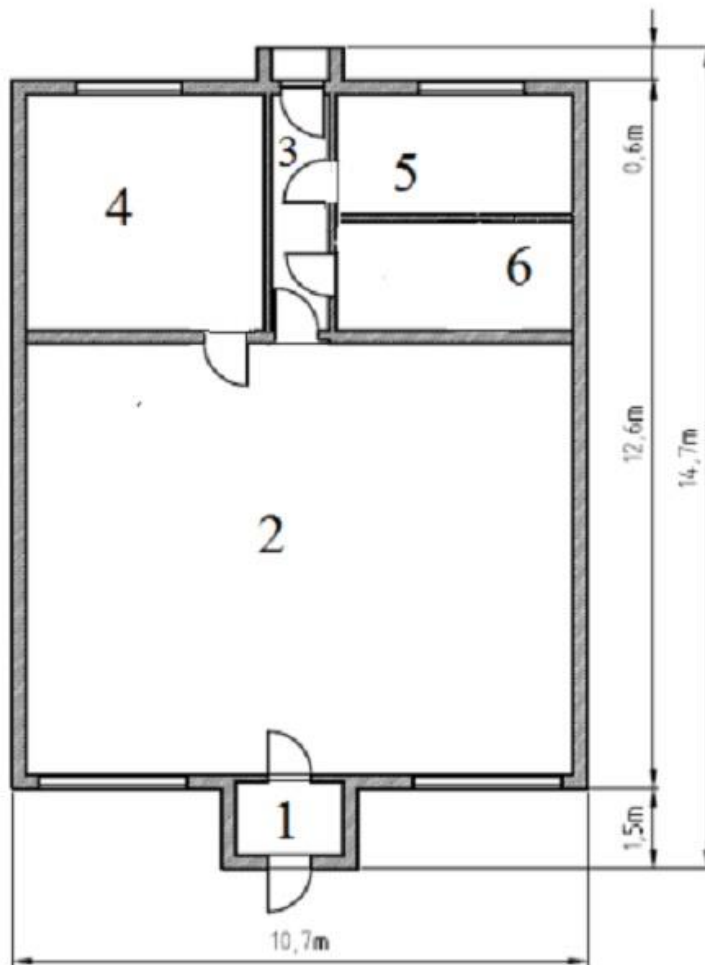


Draw. 1 Visualization of construction project of the house. [III]

To calculate the thermal load of this building it is necessary to define layers of the building partitions. Below the floor plan, made in Autocad Program base on construction project from the website [III] was presented. On this floor plan, size and layout of the premises were shown.

Tab. 2 The surface of the rooms in the selected building [III]

1.	Vestibule	2,8 m ²
2.	Living room with the kitchen	79,2 m ²
3.	Corridor	4,9 m ²
4.	Bedroom 1	14,7 m ²
5.	Bedroom 2	7,8 m ²
6.	Bathroom	5,7 m ²



Draw. 2 The floor plan of the selected single family house. [III]

3.1.2. Heat losses by the partitions

To calculate heat losses in the building it is necessary to define the layers of partitions, thickness of these layers and conductivity as well. These data are needed to know a value of total heat transfer coefficients, which will be used in the following equation of the heat losses

$$Q = A \cdot U \cdot \Delta T \cdot b_u \quad 16.$$

Where:

A- area of the partition, m^2

U- total heat transfer coefficient, $\frac{W}{m^2K}$

ΔT - difference of the temperatures between the analyzed surroundings, $^{\circ}C$

b_u - temperature reduction factor

Tab. 3 Description of layers of the building partitions.

Layer	δ, m	$\lambda, \frac{W}{mK}$
OUTSIDE WALLS		
Thin layer plaster	0,02	0,800
Aerated concrete	0,24	0,140
Styrofoam	0,20	0,043
CEILLINGS		
Mineral wool	0,150	0,031
Reinforced concrete plate	0,140	0,160
Steel sheet tile	0,007	0,022
FLOOR		
Concrete	0,100	0,140
Styrofoam	0,050	0,043
Concrete screed	0,050	1,200
Sand bed	0,200	0,400
Pope	0,002	0,180
Wooden panels	0,010	0,1800

To calculate heat losses by barrier construction the thermal resistance of surface must be known. In all constructions of walls there are *layers*, as said above, of different thicknesses made from different materials and with different types of construction. All these layers have a physical resistance to the heat transfer between the environment inside and outside. This resistance depends on the thermal conductivity of the material and layer thickness. In addition to the strength of the solid material to heat transfer there is also a resistance between the indoor air and the inner face of the wall and between the outdoor air and the outer face of the wall. All these thermal resistances must be accounted to calculate the overall thermal resistance.

Tab. 4 Thermal resistance between the indoor and outdoor [IV].

Thermal resistance, $\frac{m^2K}{W}$	Direction of heat transfer		
	→	↑	↓
R_I (inside)	0,13	0,1	0,17
R_O (outside)	0,04	0,04	0,04

Knowing the thickness and the conductivity of the layers it is possible to calculate the thermal resistance of the layer and after that the total heat transfer coefficient of particular barrier construction. The equation defining thermal resistance of the material (layer) is:

$$R_{\text{coni}} = \frac{\delta_i}{\lambda_i} \quad 17.$$

The mathematical relation allowing to calculate the total heat transfer coefficient is:

$$U = \frac{1}{R_I + R_{\text{con}} + R_O} \quad 18.$$

U – The overall heat transfer coefficient,

R_I– Thermal convective resistance (inside), $\frac{m^2K}{W}$

R_{con} - Resistance related to the thermal conductivity in the surrounding, $\frac{m^2K}{W}$

R_O – Thermal convective resistance (outside), $\frac{m^2K}{W}$

Tab. 5 The total heat transfer coefficient for windows and doors.

WINDOWS		
Triple glazing, float glass with low emission shell	U	1,3 $\frac{W}{m^2K}$
DOORS		
Dry wood	U	2,6 $\frac{W}{m^2K}$

In **Tab. 6** table there are presented calculations of the heat transfer coefficient and heat thermal load depending on the partition. For the II climate zone in Poland the outside design temperature, like it was said in the previous chapter, is -18°C . The temperature, which should be in the internal rooms designed for the regular stay of people, who do not pursue an activity continuously, is at least 20°C (base on the Polish Standard PN-EN 12831 [V]). For needs of this project the assumed temperature inside the building to provide the thermal comfort for the householders is 21°C . The heating thermal load was calculated taking into account the worst possible situation in terms of energy, that is, considering to be off the equipment, no person releasing heat and no gain from solar radiation.

Tab. 6 Heat losses calculation for the individual partitions in Winter.

OUTSIDE WALLS							
A, m ²	145,13	b _u	1	$U \frac{W}{m^2K}$	0,85	Q _{pow} , kW	1,80
CEILLINGS							
A, m ²	120,8	b _u	0,9	$U \frac{W}{m^2K}$	0,22	Q _{pc} , kW	0,93
FLOOR							
A, m ²	115,1	b _u	0,6	$U \frac{W}{m^2K}$	0,38	Q _{pf} , kW	0,70
WINDOWS							
A, m ²	17,7	b _u	1	$U \frac{W}{m^2K}$	1,3	Q _{pw} , kW	0,91
DOORS							
A, m ²	4,2	b _u	1	$U \frac{W}{m^2K}$	2,6	Q _{pd} , kW	0,43
Together				4,13 kW			

3.1.3. Heat losses by ventilation

In construction the greatest heat losses arise from the need to ensure adequate quality of internal air by ventilation. In the case of the analyzed building the ventilation efficiency was assumed to 70%. To calculate the losses by ventilation the following equations were used:

$$\dot{V}_i = \dot{V}_{inf} + \dot{V}_{su} \cdot f_v + \dot{V}_{mech,inf} \quad 19.$$

$$T_n = T_e + \phi(T_i - T_e) \quad 20.$$

$$V_{min} = V_s n_{min} \quad 21.$$

$$f_v = \frac{T_i - T_n}{T_i - T_e} = 1 - \phi \quad 22.$$

$$\dot{V}_{inf} = 2Vn_{50}e_i\varepsilon_i \quad 23.$$

$$Q_{ve} = \rho\dot{V}_i C_p (T_i - T_e) \quad 24.$$

Where:

V - the cubic capacity of heated space, m^3

\dot{V}_{inf} - the infiltrating air to the heated space, (m^3/s)

V_s - the volume of the air supplied to the heated space, $m^3(m^3/s)$

V_{min} - the minimum volume of air flow, (m^3/s)

$\dot{V}_{mech,inf}$ - the excess of air flow discharged from heated space, (m^3/s)

f_v - temperature reduction factor

n_{min} - the minimum multiplicity of air exchange, h^{-1}

T_n - temperature of the air supplied to the heated space, $^{\circ}C$

n_{50} - the multiplicity of air exchange, h^{-1}

e_i - the shielding factor

ε_i - correction factor related to air velocity depending on location of heated space.

Tab. 7 All data necessary to calculate heat losses by ventilation [VI].

ε_i	1	ρ	1,2
e_i	0,02	\dot{V}_{inf}	41,4
n_{50}	3	\dot{V}_{su}	40
$\phi, \%$	60	$\dot{V}_{mech,inf}$	0
f_v	0,4	C_p	1006,1
T_n	5,4	Q_{ve}	2643,7
V_{min}	50	V	345,3
n	0,5	\dot{V}_i	57,4

$$Q_{ve} = 2,71 \text{ kW}$$

All heat losses, by barrier construction and by ventilation as well are **6,84 kW**.

3.1.4. The demand of domestic hot water

It is necessary also to calculate the demand of domestic hot water. It was assumed that in the house live 4 people. The domestic hot water is needed in the bathroom to take a bath and in the kitchen in the sink (for example to wash the dishes). The assumed daily water consumption per person is $0,008 \text{ m}^3$ like listened below.

To calculate power and energy which is needed for hot domestic water there were used the following formulas [VII]:

$$Q_{\text{DHW}} = C_p \cdot \rho \cdot V \cdot (t_H - t_C) \cdot 10^6 [\text{GJ}] \quad 25.$$

$$\Phi_{\text{DHW}} = V_{\text{ave}} \cdot q_{\text{DHW}} \cdot N_h \cdot 277,7 \quad 26.$$

$$N_h = 9,32 \cdot U^{-0,244} \quad 27.$$

$$V_{\text{ave}} = \frac{V_{\text{day}}}{18} \quad 28.$$

Tab. 8 Data necessary to calculate hot domestic water demand.

U	4
V	$0,008 \text{ m}^3$
V_{day}	$0,02 \text{ m}^3$
V_{ave}	$0,0011 \text{ m}^3$
t_H	55°C
t_C	10°C
C_p	$4,19 \frac{\text{kJ}}{\text{kg}}$
ρ	$997 \frac{\text{kg}}{\text{m}^3}$
Energy consumption for heating of 1 m³ of water	$0,189 \frac{\text{GJ}}{\text{m}^3}$
Q_{DHW}	$0,04 \frac{\text{GJ}}{\text{day}}$
N_h	6,65
Φ_{DHW}	0,1 kW

Where:

t_H-the temperature of hot water, °C

t_C- the temperature of cold water, °C

C_p- the specific heat of water, $\frac{\text{kJ}}{\text{kg}}$

V- Daily water consumption per person

ρ - the density of the water, $\frac{kg}{m^3}$

U - number of persons in the house

Q_{DHW} - Daily energy consumption of domestic heat water in the building

Φ_{DHW} - heat power needed for domestic hot water

q_{DHW} - daily water flow rate

N_h - Water partition coefficient of uniformity

V_{ave} - Average hourly consumption of domestic hot water in the building

V_{day} - Daily Consumption of hot domestic water in the building

3.1.5. The demand of electricity

For the calculation was considered for a typical M3 house, which consists of: two bedrooms, a bathroom, a living room with the kitchen, vestibule and corridor. It was considered a set of appliances and equipment used in each sections of the house. To determine the energy consumed monthly by certain equipment in Wh (or kWh), the operating time was multiplied by the power of the selected equipment. The monthly cost spent on energy was determined by multiplying the total energy consumed by all devices in kWh by the unit cost of kWh, which is indicated with a value 0, 54 PLN/ kWh.

For the typical house in Poland the electricity demand is about 10-12 kW or even more when in the flat there is electricity oven or electricity heating installation. This value is correct only in the situation when all of devices used in the house are working simultaneously. Usually the devices and equipment in house do not work together in the same time, so it is possible to assume smaller electricity demand.

In the **Tab. 9** there are listed all electricity devices and light equipment used in house depending on the room type. The column contains information about the power of each device, operating time during day f. There were also calculated power consumption per day and month price for electricity usage.

The Summer electrical needs are different from the Winter demand. In the following table there are presented the electrical needs for both these seasons for each of the divisions of the house, being presented in the order total monthly consumption of electricity in Winter and in Summer as well.

Tab. 9 The electricity demand in assumed house for Winter and Summer.

Room	Devices	Power	Operation time/ day		Power consumption kWh/day		Price, PLN/ month	
			Winter	Summer	Winter	Summer	Winter	Summer
Vestibule	Heating installations	15000W	12h	5h	3,00	1,25	46,80 zł	19,50 zł
	2 bulbs	55 W	14h	4h	0,77	0,44	12,01 zł	6,86 zł
Living room with kitchen	Coffee express	500W	1h	1h	0,17	0,17	2,57 zł	2,57 zł
	TV	310W	5h	4h	0,03	1,24	0,40 zł	19,34 zł
	Oven	3500W	1,5h	1h	5,25	3,50	54,60 zł	54,60 zł
	5 bulbs	55 W	14h	4h	3,85	0,88	29,80 zł	29,80 zł
	Dishwasher	1,49 kWh per washing	5 washings per week		7,45	7,45	60,06 zł	60,06 zł
	Water heater	2000W	10 min	10 min	0,33	0,33	5,20 zł	5,20 zł
	Microwave	900 W	20 min	30 min	0,30	0,45	4,68 zł	7,02 zł
	Fridge	2000W	24h	24h	0,74	0,74	11,54 zł	11,54 zł
Corridor	2 bulbs	55W	14h	4h	1,54	0,44	24,02 zł	6,86 zł
Bedroom 1	2 bulbs	55W	14h	4h	1,54	0,44	24,02 zł	6,86 zł
	Computer	250	6h	6h	1,50	1,50	23,40 zł	23,40 zł
Bedroom 2	3 bulbs	55W	14h	4h	2,31	0,66	36,04 zł	10,30 zł
	TV	210	3h	3h	0,63	0,63	9,83 zł	9,83 zł
Bathroom	Ventilator	20W	10h	10h	0,20	0,20	3,12 zł	3,12 zł
	2 bulbs	55W	14h	4h	1,54	0,44	24,02 zł	6,86 zł
	Washing machine	0,95kWh /washing	2 washings/per week		0,28	0,28	1,12	1,12 zł
Together					29,67	21,04	358,94 zł	224,23 zł

3.1.6. Summary of the heat and power consumption in the selected house

There were conducted above all necessary calculations to know thermal and electricity load of selected building. The summary is presented in the following table.

Tab. 10 Summary of the heat and electricity demand.

	Summer		Winter	
	kW	MJ/ month	kW	MJ/ month
Electricity	0,9	2272,3	1,25	3240,2
Heat	0,1	259,2	6,94	17936,6

3.2. Selection of the refrigerant

In the Chapter 2 are described desirable properties of refrigerant. In this chapter there was conducted a comparison analysis of the three type of refrigerants, in line with the European standards:

- R134a
- R507a
- R290.

It is presented below T-S (temperature-entropy) diagram of fluid heating cycle. On the diagram are shown 4 main processes:

- **1-2** The isentropic process in which pressure is increasing
- **2-3** The isobaric heating of the operating medium passing from the liquid to the state of superheated steam in which enthalpy is increasing
- **3-4** Process in which there is an enthalpy decrease of the steam passing through the turbine. In the turbine the refrigerant undergoes an ideally isentropic expansion that drives the turbine and consequently there is the production of electricity in generator;
- **4-1** The operating medium exits to the turbine at vapor state, so it is required to cool the working fluid in a condenser.

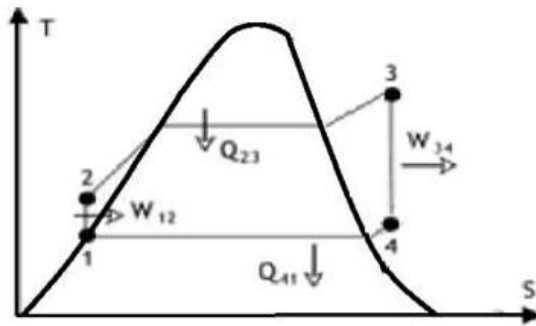


Fig. 8 T-S Diagram of fluid heating cycle

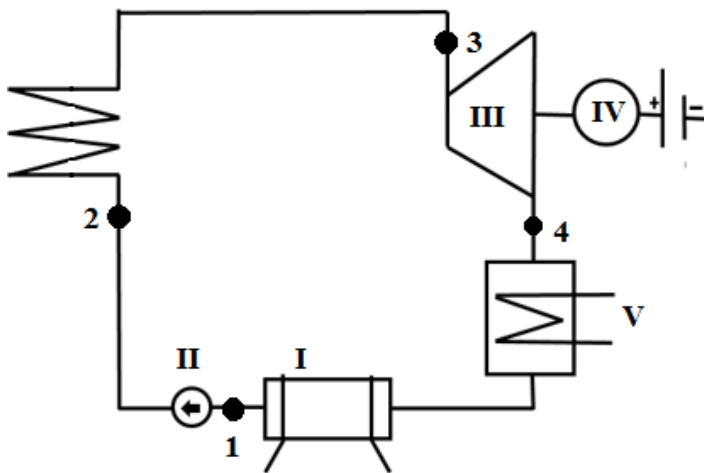


Fig. 9 Schema of refrigerant heating cycle. I – cooling tower, II – circulation pump of refrigerant III- turbine, IV – generator, V- condenser

To conduct all calculations the temperature of higher and lower source must be assumed. The analysis was conducted for three values of the temperature of higher source (water in the solar collector) and one temperature of the lower source (refrigerant in ORC installation). The assumed temperatures are presented in the following table:

Tab. 11 The temperatures of higher and lower source.

Temperature of higher source, °C	50	65	80
Temperature of lower source, °C	34		

These temperatures were chosen because the refrigerant can easily reach 50-80°C at the collector; and the temperature in the condenser was chosen in order to be possible to heat the house during the condensing process (required temperature was set above as 21°C). All parameters of refrigerants were read from the program Coolpack [VIII], which is a special program with collection of simulation models for refrigeration systems. The models

each have a specific purpose e.g. cycle analysis, dimensioning of main components, energy analysis and -optimization.

The following equations were used in the analysis of refrigerants:

$$m_{\text{ref}} = \frac{N_e}{\eta_{\text{tur}}\eta_{\text{gen}}(h_4 - h_3)} \quad 29.$$

$$W_{3-4} = \eta_{\text{tur}}(h_4 - h_3) \quad 30.$$

$$Q_{2-3} = m_{\text{ref}}(h_3 - h_2) \quad 31.$$

$$Q_{1-4} = m_{\text{ref}}(h_4 - h_1) \quad 32.$$

$$m_{\text{water}} = \frac{Q_{2-3}}{C_p\Delta T} \quad 33.$$

Where:

m_{ref} - the mass flow of refrigerant, $\frac{kg}{s}$

N_e - electricity power, kW

η_{tur} - energy efficiency of the turbine

η_{gen} - energy efficiency of the generator

W_{3-4} - The power produced in the turbine into a mass flow of refrigerant, kW

Q_{2-3} - The input power of the cycle, which has to be provided by solar collector, kW

Q_{1-4} - The heat power of condenser, kW

m_{water} - The mass flow of water in solar collector system, $\frac{kg}{s}$

h_4, h_3, h_2, h_1 - The value of enthalpy of refrigerants depending on the point on the figure, $\frac{kJ}{kg}$

The assumed value of energy efficiency of the turbine, the energy efficiency of the generator and the electricity power produced by generator are presented in the following table:

Tab. 12 The assumed values necessary for calculations.

η_{tur}	70%
η_{gen}	90%
$N_{e(\text{winter,summer})}$	1,5 kW; 0,9 kW

The tables with all of the necessary properties of refrigerants depending on the temperature of higher source are presented below. Like it was said before, the properties were read from the program Coolpack. The T-S diagrams of selected refrigerants are attached in the Appendix 1.

Tab. 13 The refrigerant properties for the temperature of lower and higher source, respectively 34°C and 50°C.

Points	Temperature, K	Enthalpy $\frac{kJ}{kg}$	Entropy $\frac{kJ}{kgK}$	Pressure, MPa
R134a				
1	307	247,7	1163,6	8,6
2	309	247,7	1163,63	13,2
3	333	435,2	1744,63	13,2
4	317	426,7	1744,63	8,6
R507				
1	307	244,0	1148,4	16,2
2	309	244,0	1148,4	23,8
3	329	386,5	1587,4	23,8
4	311	378,9	1587,4	16,2
R290				
1	307	291,1	1308,5	11,9
2	309	291,1	1308,5	17,2
3	330	637,4	2378,2	17,2
4	312	619,7	2378,2	11,9

Tab. 14 The refrigerant analysis for the temperature of lower and higher source, respectively 34°C and 65°C.

Points	Temperature, K	Enthalpy $\frac{kJ}{kg}$	Entropy $\frac{kJ}{kgK}$	Pressure, MPa
R134a				
1	307	247,7	1163,6	8,6
2	309	247,7	1163,63	18,9
3	343	435,3	1721,5	18,9
4	311	413,8	1721,5	8,6
R507				
1	307	244,0	1148,4	16,2
2	309	244,0	1148,4	33,3
3	354	399,1	1606,6	33,3
4	317	384,9	1606,6	16,2
R290				
1	307	291,1	1308,5	11,9
2	309	291,1	1308,5	23,4
3	362	692,7	2494,2	23,4
4	331	657,6	2494,2	11,9

Tab. 15 The refrigerant analysis for the temperature of lower and higher source, respectively 34°C and 80°C.

Points	Temperature, K	Enthalpy $\frac{kJ}{kg}$	Entropy $\frac{kJ}{kgK}$	Pressure, MPa
R134a				
1	307	247,7	1163,6	8,6
2	309	247,7	1163,6	26,3
3	365	449,8	1743,8	26,3
4	317	426,3	1743,8	8,6
R507				
1	307	244,0	1148,4	16,2
2	309	244,0	1148,4	
3	-	-	-	-
4	-	-	-	16,2
R290				
1	307	291,1	1308,5	11,9
2	309	291,1	1308,5	31,5
3	366	672,9	2400,6	31,5
4	316	627,2	2400,6	11,9

Based on the values included in the tables above were calculated the mass flow of refrigerant in the ORC cycle, mass flow of water in solar collector, input power of cycle (power which has to be provided by solar collector), power of the generator and also power of condenser. The results of these calculations are presented in the following table:

Tab. 16 Comparison of the three types of refrigerants (Winter).

	R 134a	R507	R290
50°C			
$m_{ref}, \frac{kg}{s}$	0,28	0,31	0,13
W_{3-4}	1,67	1,67	1,67
Q_{2-3}	52,52	44,64	46,58
Q_{1-4}	50,14	42,26	44,20
65°C			
$m_{ref}, \frac{kg}{s}$	0,11	0,17	0,07
W_{3-4}, kW	1,67	1,67	1,67
Q_{2-3}, kW	20,78	26,01	27,24
Q_{1-4}, kW	18,39	23,63	24,86
80°C			
$m_{ref}, \frac{kg}{s}$	0,10	-	0,05
W_{3-4}, kW	1,67	-	1,67
Q_{2-3}, kW	20,48	-	19,89
Q_{1-4}, kW	18,10	-	17,51

Based on the analysis above, the best refrigerant for the system designed in this work is R134a.

Tab. 17 The calculated values for the chosen refrigerant R134a for three differences of the temperatures for the Winter season.

T, °C	50	65	80
$W_{3-4, \text{summ}}$ kW	1,0	1,0	1,0
$Q_{2-3, \text{summ}}$ kW	31,5	12,3	12,5
$Q_{1-4, \text{summ}}$ kW	30,1	10,9	11,0
$W_{3-4, \text{wint}}$ kW	1,7	1,7	1,7
$Q_{2-3, \text{wint}}$ kW	52,5	20,8	20,4
$Q_{1-4, \text{wint}}$ kW	50,1	18,4	18,1

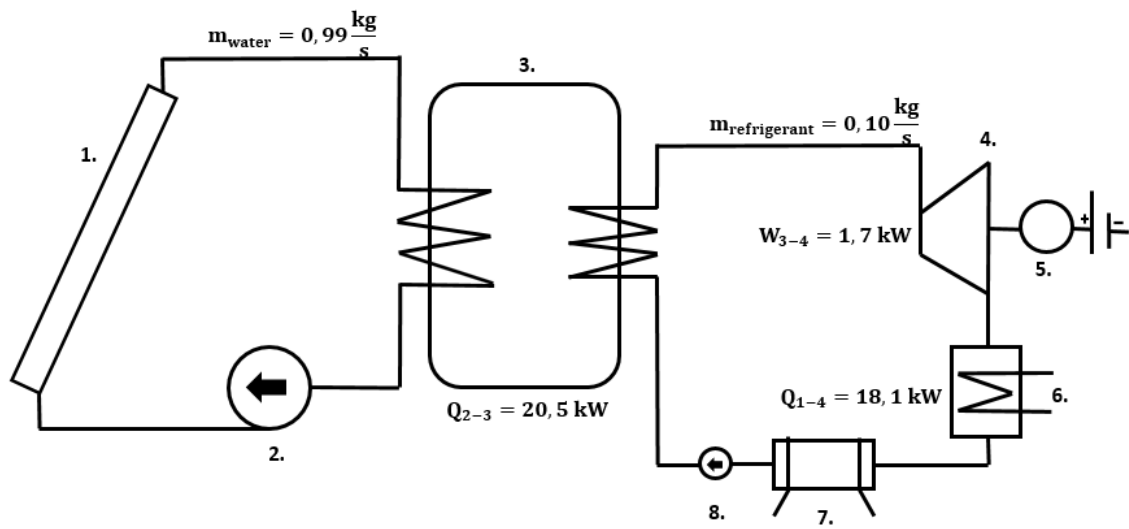
Tab. 18 Thermal load of solar installation for the 3 difference of the temperatures, for Summer and Winter as well.

T, °C	50	65	80
$m_{\text{water, wint}}$, $\frac{\text{kg}}{\text{s}}$	2,51	0,98	0,99
$m_{\text{water, summ}}$, $\frac{\text{kg}}{\text{s}}$	1,50	0,59	0,59
$m_{\text{ref, wint}}$, $\frac{\text{kg}}{\text{s}}$	0,28	0,11	0,10
$m_{\text{ref, summ}}$, $\frac{\text{kg}}{\text{s}}$	0,17	0,06	0,07
$Q_{1-4, \text{summer}}$ MJ	727792,9	262656,0	266996,1
$Q_{2-3, \text{summer}}$ MJ	81680,7	31844,6	32309,6
$Q_{1-4, \text{winter}}$ MJ	129963,0	46902,9	47677,9
$Q_{2-3, \text{winter}}$ MJ	136134,5	53074,3	53849,3

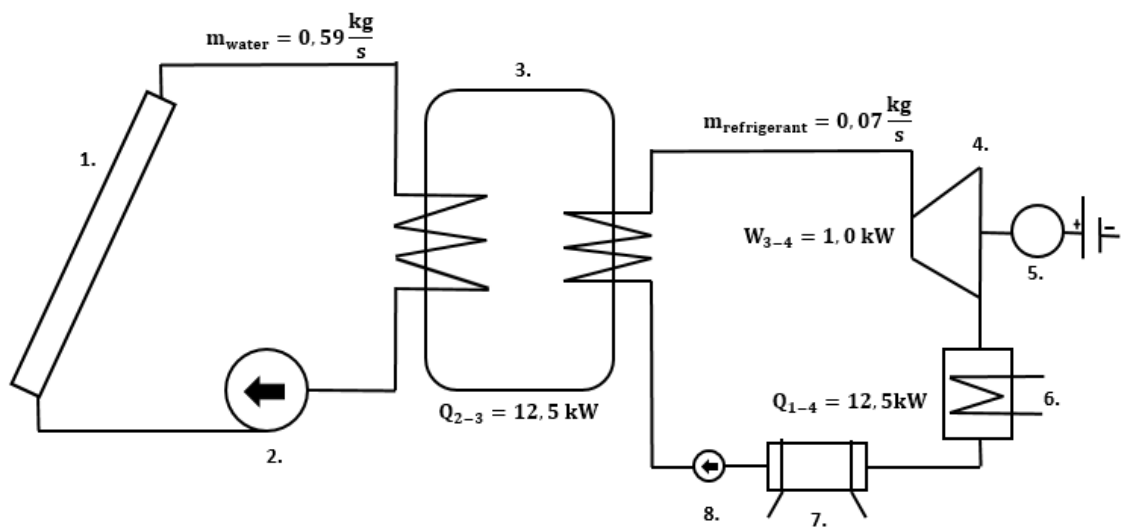
The Winter season is assumed from November to March, and Summer season from April to October. The chosen difference of temperature is 34°C and 80°C.

In the **Tab. 18** are presented results of calculations of thermal load for Winter and Summer as well. The flow mass of refrigerants in the Organic Rankine Cycle was calculated knowing electricity demand for these two seasons. The value of Q_{1-4} is the value of heat wasted in condenser, which can be used for the heating needs of the building.

On the next page the calculated result are shown on the schematic drawing of the installations. In both of these samples for Summer and Winter season as well, the value of Q_{2-3} is value of heat, which has to be provided by operating medium in solar collector (thermal load of solar collector) in order to transfer heat to refrigerant in the next part of process.



Draw. 3 Schema of the installation in Winter.



Draw. 4 Schema of the installation in Summer.

3.3. Sizing of the installation by the method of solar fraction

The systematic of F-chart method was described in the Sub chapter 2.3. In this chapter the results of using the solar fraction method are presented. To apply the method of solar fraction the installation has to be considered as a thermodynamic system, in this report 3-rooms house connected to an installation of solar collectors. The values, which must be known to use the f-chart method are monthly energy needs/thermal loads. The solar fraction can be set monthly or annually. It is the energy captured monthly/ yearly or monthly/annual heat load.

3.3.1. The calculation of solar fraction

To set the incoming solar radiation it is necessary to define the location. The installation is located in Wrocław, south-west part of Poland, where the latitude is 51°. The calculations were made based on the theory and in the formulas set out in chapter 2.3 . First it was calculated the amount of radiation that the solar collector receives – this part is converted into thermal energy or the amount of solar energy that actually contributes to energy system needs.

To calculate the solar fraction the following parameters must be assumed:

- Location – Wrocław, Poland
- Latitude - 51°
- The slope of solar collector $\beta = 35^\circ$
- Ratio of collector heat exchanger and removal factor $\frac{F'_R}{F_R} = 0,97$
- $F_R U = 7,84 \frac{W}{m^2K}$
- $F_R (\tau\alpha)_n = 0,81$
- Global coefficient of collector losses $U = 5,77 \frac{W}{m^2K}$
- $\rho = 0,1$

The calculation of the amount of radiation the collector receives was the starting point for calculating the solar fraction. All calculations were made in a spreadsheet (Annex II, CD). The solar radiation is related to the location of collector (N, E, S W) and the slope of the collector.

The following equations were used:

- The direct radiation:

$$S^d = \left(1 - \frac{D_H}{G_H}\right) \cdot R_s \cdot G_H \quad 34.$$

- The diffuse radiation

$$D = \left(\frac{D_H}{G_H}\right) \cdot \frac{(1 + \cos\beta)}{2} \cdot G_H \quad 35.$$

- The albedo radiation intensity

$$L = \rho \cdot \frac{(1 + \cos\beta)}{2} \cdot G_H \quad 36.$$

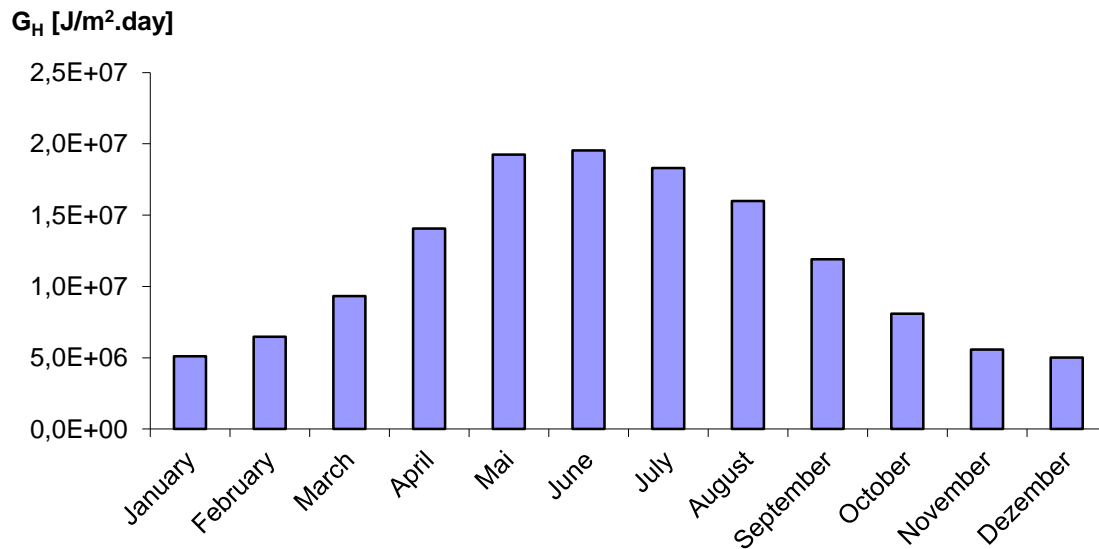


Fig. 10 The monthly diagram of global radiation for the city of Wrocław, based on [IX].

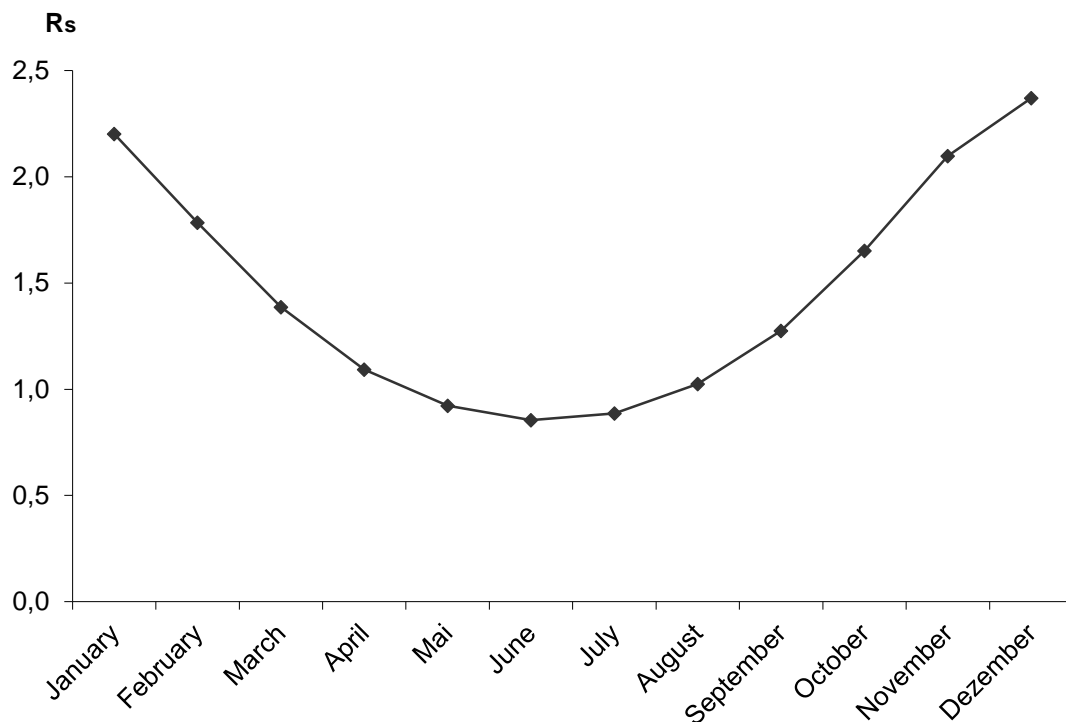


Fig. 11 Graphic relation of the ratio of direct irradiation on a sloping surface in relation to the ground and direct radiation incident at the same surface resting on the ground.

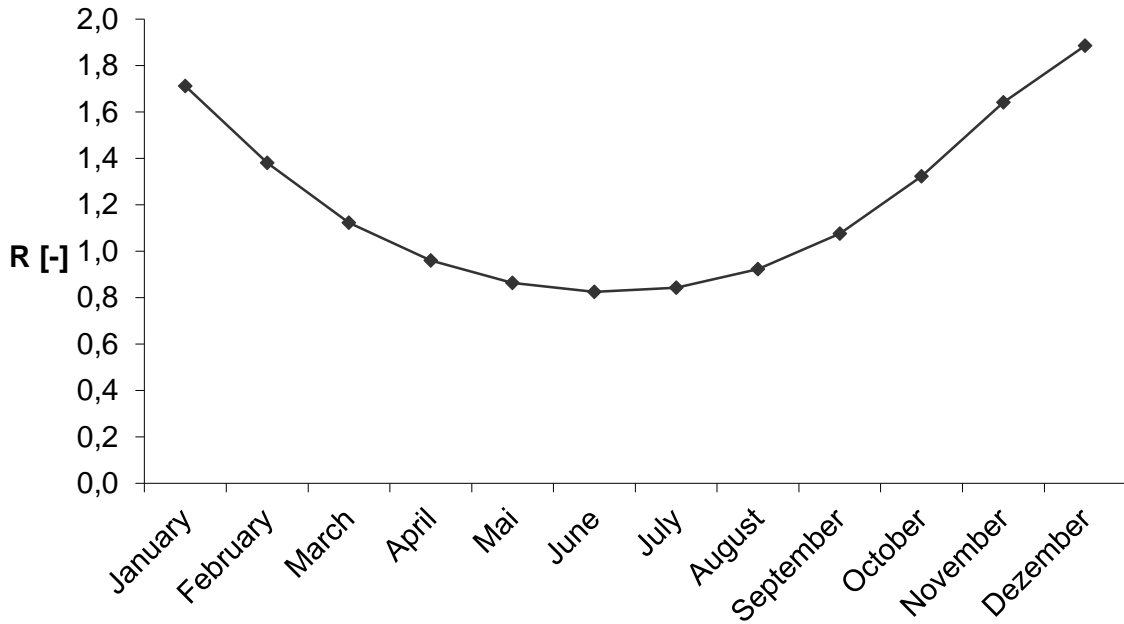


Fig. 12 Monthly average daily value of ratio of radiation on a sloping surface relative to the ground and the radiation incident on the same surface resting on the floor.

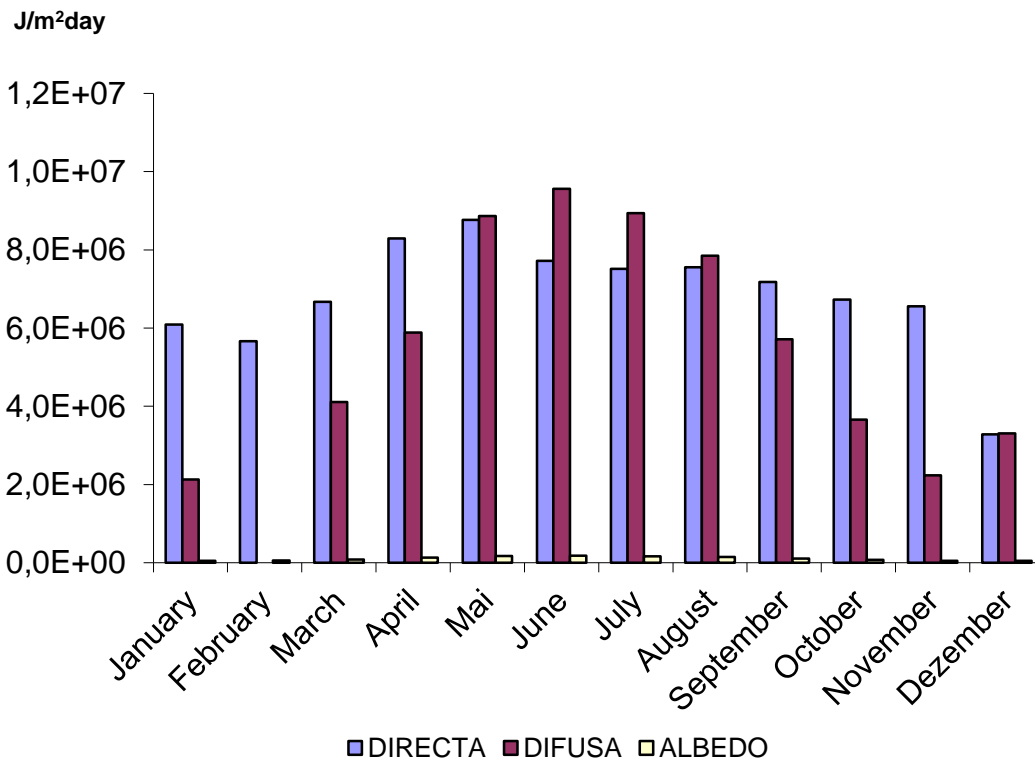


Fig. 13 Chart of the direct and diffuse radiation and albedo of the city of Wrocław.

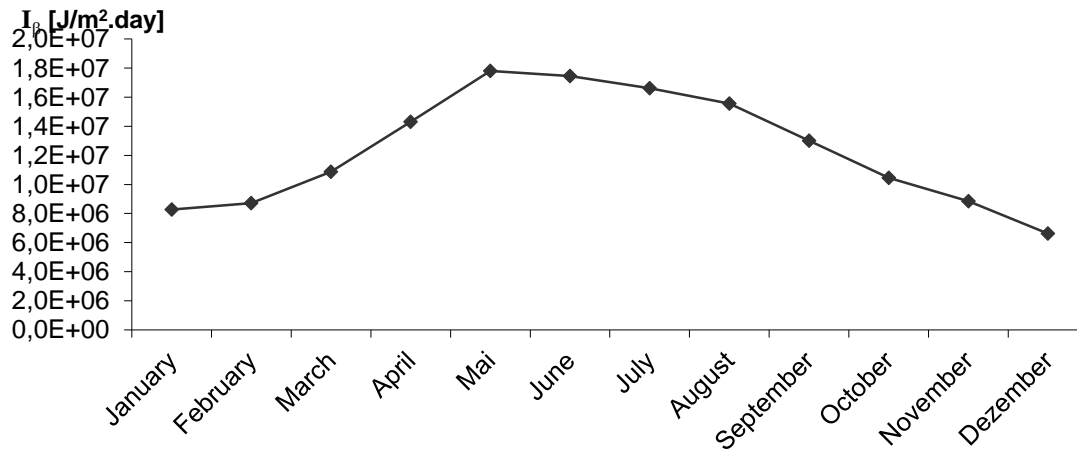


Fig. 14 The diagram of irradiation for the city of Wrocław.

Solar collectors cover glass with a transferability τ and an absorber plate with an absorption coefficient α . The assumed values are $\tau_n = 0,88$ and $\alpha_n = 0,94$. To determine τ and α the first step is to calculate monthly journal angle of the direct solar radiation i . The figure below is containing the i curves for each month of the year. The value of i in correlation to $|\phi - \beta|$ was found using this figure.

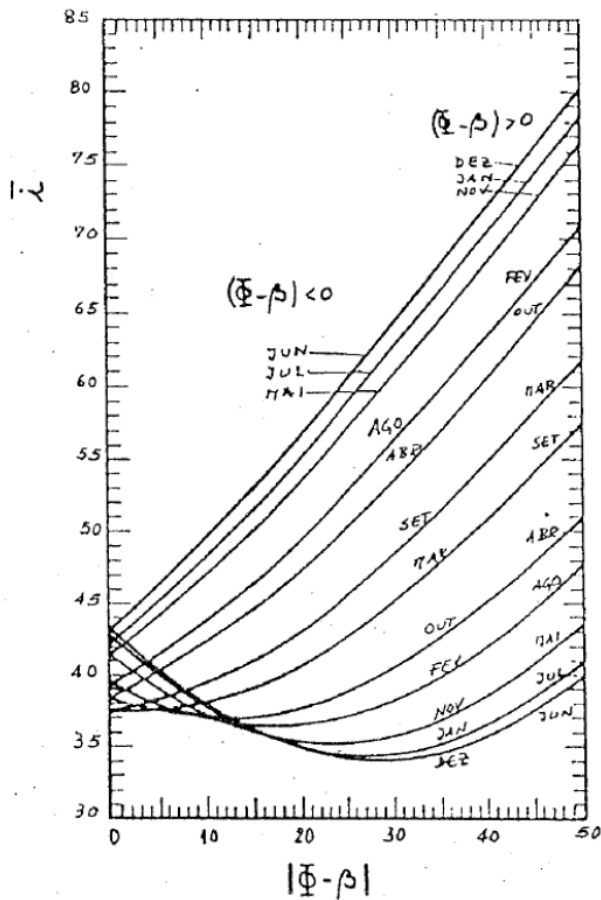


Fig. 15 The average monthly angle of daily incidence of solar radiation.

In the Appendix 2 on the CD there are presented calculated values of i for every month of the year, values of $\frac{(\tau\alpha)_s}{(\tau\alpha)_n}, \frac{\alpha}{\alpha_n}, \frac{D_h}{G_h}, \frac{R_s}{R}$.

The using equation to calculate all necessary values are presented below:

$$\frac{(\tau\alpha)_s}{(\tau\alpha)_n} = \left(1 - \frac{D_h}{G_h}\right) \cdot \frac{R_s}{R} \cdot \frac{\alpha}{\alpha_n} \cdot \frac{\tau}{\tau_n} \quad 37.$$

$$\frac{(\tau\alpha)_D}{(\tau\alpha)_n} = \frac{1}{\frac{D_h}{G_h} \cdot \left(\frac{1 + \cos\beta}{2}\right)} \cdot \frac{\alpha}{\alpha_n} (60^\circ) \cdot \frac{\tau}{\tau_n} (60^\circ) \quad 38.$$

$$\frac{(\tau\alpha)_L}{(\tau\alpha)_n} = \left(\frac{D_h}{G_h}\right) \cdot \left(\frac{1 + \cos\beta}{2}\right) \cdot \frac{\alpha}{\alpha_n} (60^\circ) \cdot \frac{\tau}{\tau_n} (60^\circ) \quad 39.$$

$$\frac{(\tau\alpha)}{(\tau\alpha)_n} = \frac{(\tau\alpha)_s}{(\tau\alpha)_n} + \frac{(\tau\alpha)_D}{(\tau\alpha)_n} + \frac{(\tau\alpha)_L}{(\tau\alpha)_n} \quad 40.$$

$$I_\beta(\tau\alpha) = \frac{(\tau\alpha)}{(\tau\alpha)_n} \cdot I_\beta \cdot 0,88 \cdot 0,94 \quad 41.$$

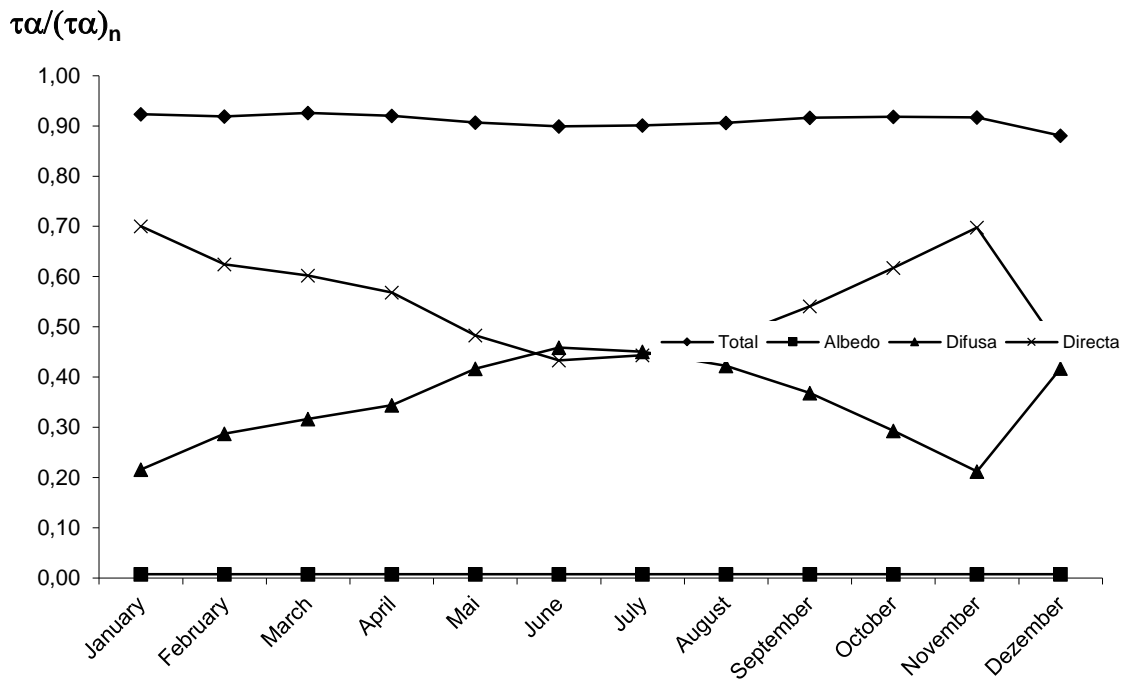


Fig. 16 Monthly average daily values of $\frac{(\tau\alpha)}{(\tau\alpha)_n}, \frac{(\tau\alpha)_s}{(\tau\alpha)_n}, \frac{(\tau\alpha)_D}{(\tau\alpha)_n}, \frac{(\tau\alpha)_L}{(\tau\alpha)_n}$.

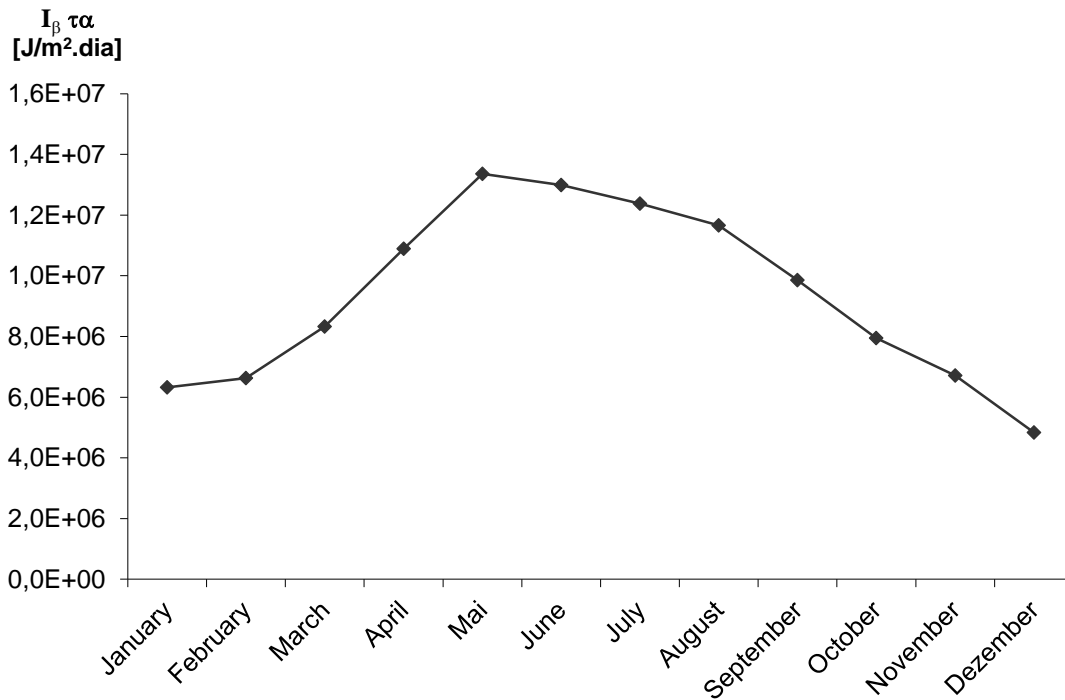


Fig. 17 $I_{\beta}(\tau\alpha)$ for the city of Wrocław.

The next step is the calculations of solar fraction. The values of solar fraction is obtained by the following equation, which depends on two parameters X and Y, which are calculated by Formulas (9) and (10).

$$f = 0,29Y - 0,065X - 0,245Y^2 + 0,0018X^2 + 0,0215Y^3 \quad 42.$$

The value of $Q_{2-3} = Q_{CT}$, which is the value corresponding to thermal installation needs (thermal load) of the solar collector is necessary to calculate solar fraction. The design of the system will be made by varying the solar collector area. The system will obtain different fractions for different areas. The area of variation was 10 m² up to a maximum value of collector area of 80 m². The best collector area will be chosen in the next chapter.

The relation of solar fraction and collector area is shown on the figure above. As we increase the area, the solar fraction tends to 1. When $f = 1$ energy collected by collectors match all your energy needs, but the higher the of collector area, the higher the cost of installation. All calculation related with solar fraction are included in Annex 2.

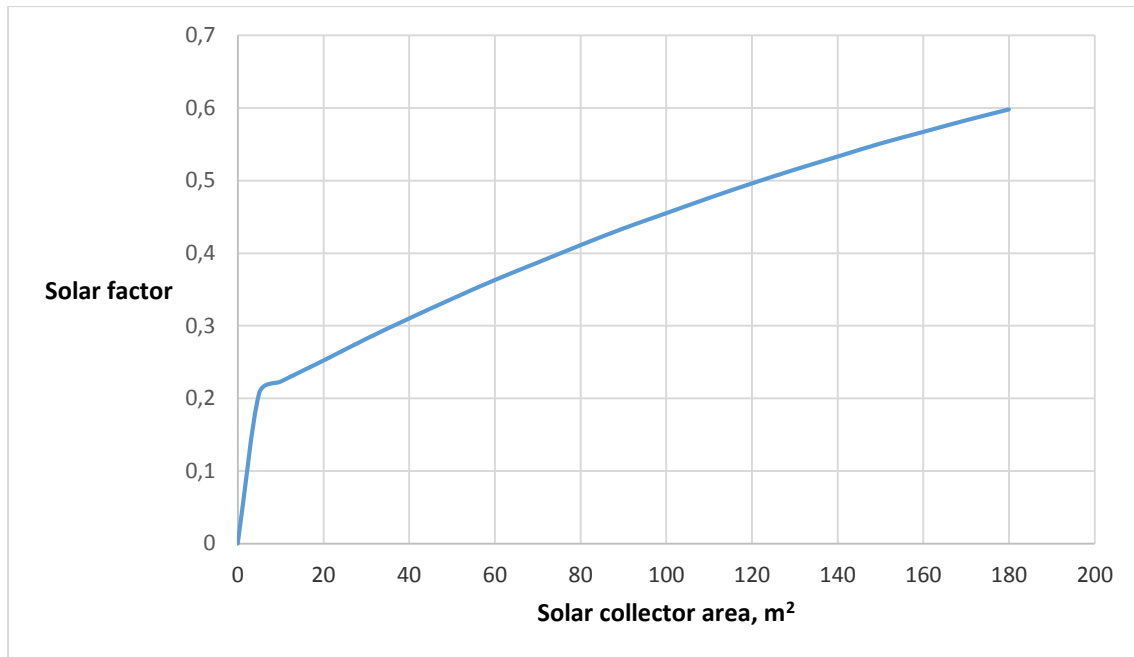


Fig. 18 Values of solar fraction depending on the solar collector area based on tables included in Annex II.

3.4. Selection of the main components of system

The data sheets of selected components are included in the Annex II.

3.4.1. The solar collector

The selected solar collector is TISUN FM- S 2.0. [XVIII]. The technical characteristic of this collector are:

- Type - flat module plate collector
- Installation and assembly - The angle of inclination from 15 ° to 70 °
- Allowable load - max. 300 $\frac{\text{kg}}{\text{m}^2}$
- Frame - aluminum frame in graphite (RAL7016) powder affixed, the rear wall of aluminum
- Absorber - aluminum absorber with highly selective PVD coating, meandering copper tubes, laser welded
- Connectors - 4/copper tubes, 18 x 0.8 mm
- Coverage - Prismatic solar glass with a thickness of 4 mm (high energy transmission factor)

The price of one collector is **1290 PLN**. Set fixing one collector on the roof costs **425 PLN**.

3.4.2. Thermo accumulator

For needs of analyzed system the thermoaccumulator of the brand Velis 80L EU 3700421 Ariston was selected [XVI]. The technical properties of this devices are listened below:

Installation : horizontal/ vertical

- Capacity – 80 l
- Power – 1,5 kW
- The maximum operating temperature- 80°C
- Daily energy loss (at 60°C)-0,93 kWh/24h
- Maximum operating pressure- 8 bar
- Protection – IPX4.

The cost of this thermo accumulator is **809 PLN**.

3.4.2. Wood boiler

Wood boiler are used in heating systems, as well as for domestic hot water systems. In the situation when the solar installation will not be enough to meet the needs of heat and electricity demand of the house, the gas boiler will start operate. The selected boiler is HT Baisc 11 [XVII]. The price of selected boiler is **2488 PLN**. To this price must be add costs of necessary equipment, around **2000 PLN**.

3.4.3. Water and refrigerant circulation pump

The selected water circulation pump is the pump of type 25/60-180 IBO [XIV]. The main advantages of this pump:

- low energy consumption;
- quiet operation;
- easy installation and commissioning;
- convenience.

The cost of selected model is 130 PLN/ pump, the total price **260 PLN**.

3.4.4. Cooling tower

After leaving the turbine, the refrigerant must pass through a heat exchanger which transfers heat to home and subsequently by coil positioned within the cooling tower. The condensation of refrigerant should be complete after the refrigerant passing through the heat exchanger and serpentine. The cooling tower works so that the refrigerant passes within a coil and the back coil will flow saturated with moisture, at the temperature of the bulb wet. The cooling tower will have to dissipate a maximum to a power atmosphere maximum heat of 18,1kW.

The chosen cooling tower is the model T25, company CTS Cooling Tower Systems [X]. The drawings of selected cooling tower is attached as a Appendix 3. The cost of this is 1257 \$ (1\$=4,13 PLN - dollars exchange rate from 26.01.2015) so the total price in polish currency is **5192 PLN.**

3.4.5. Float steam trap

At the exit of the serpentine cooling tower must be a steam trap, such as those that exist in steam, to ensure full condensation of the refrigerant to output of the cooling tower. A float valve is the best choice because it does not allow the steam output and allows a constant output of condensate is often used to hold the vapor in the output of heating appliances. The chosen float steam trap is F32, brand Stim Bytom. The price of float steam trap is **365 PLN.** [XXII]

3.4.6. Batteries to store electrical energy (not mandatory as explained before)

To select adequate batteries storing electrical energy the power consumed daily should be known. This value is determined by multiplying the value of 1,25 kW in Tab. 10, over 15% of this value, corresponding to losses in the inverter, which is 1,44 kW.

It assumed a value of autonomy of 3 hours, multiplied by 1,44 kW gives 4,32 kWh. Dividing 4,32 kWh per 12V corresponding to the voltage value in the database batteries, has 360 Ah, what mean that the battery bank capacity must be equal or greater than 360 Ah.

The selected battery pack has the following characteristics:

- Stationary;
- Company FIAMM Motive Power [XII]
- Made up of 6 blocks of 2V each;
- Capacity of 400 Ah;

The price of all batteries is **3500 PLN.**

3.4.7. Power inverter

The inverter converts alternating current to charge the batteries and continues in alternating, which will be used for feeding the house equipment. It makes up the design of the inverter by comparing the electricity consumption of house with Wh actual capacity of the drive (capacity in W x FP). The drive must have higher capacity consumption. The house has an average fuel consumption in a day, the month of Winter 1,25 kW, so the charger / inverter must be a power or higher energy and inputs and outputs 12 V and 220 V. The selected power inverter is PRO P313D31122 ARTEL. The price of it is **495 PLN.** [XXI]

3.4.8. Charge regulator

The charge regulator is a component used in autonomous systems to manage and control the charge and discharge process of the battery bank. Functions of the charge controller:

- Applicable to various types of batteries;
- MPPT function, Maximum Power Point Tracker, function of detecting the maximum point
- Panel power and deliver it by this maximum power in the battery voltage,
- Thereby providing a substantial increase in system performance;
- Microprocessor pulse-width modulation controller (PWM) charge;
- Temperature sensor for compensation of battery charging;
- Overload protection (automatic restoration);
- Discharge protection (automatic restoration);
- Short circuit protection (automatic restoration):
- Thunder protection;
- Protection against reverse discharge.

To calculate the current of the charge regulator the electricity power (including possible inverter losses) 1,44 kW must be multiplying by voltage of batteries (12 V), what gives 120 A. In the analyzed system it is necessary to use two charge regulator. The selected device is the charge regulator of brand VOLT Polska 60 A. The price of is **656 PLN**.

3.4.9. Turbine/ Generator

During the research it must be found a turbine that uses a refrigerant as the working medium. The power of this system is 1,7 kW. The selected turbine generator is ORC IT10 brand RENCRAFT. In the Annex 4 there is information on main characteristics of the turbine and generator. [XI].The cost of it is **3200 PLN**.

3.4. Economic analysis

For investors there are very important economic and social advantages as well. One of the key information is the payback period. There are the certain criteria for making a decision such as NPV, IRR and mentioned earlier period time. These criteria were described in the chapter 2.5. In this chapter it will be defined area collectors, by the results of investment evaluation criteria. The larger area of collectors means greater energy produced but the installation and hence increase of the costs. All calculation related to economic analysis are included in Annex 5 on the CD.

3.5.1. Cost of the installation

Tab. 19 Costs of the installation components.

Component	Price, PLN
Kit hydraulic connections for thermal solar collectors, with isolated connections, plugs, cable glands etc.	420
Cooling tower	5192
Float steam trap	365
Thermo accumulator	809
Gas boiler	4488
Circulation pump 2x	260
Batteries to store electrical energy	3500
Power inverter	495
Charge regulator	656
Turbine / generator	3200
Water-glycol solution for thermal solar collector filler, for working temperature of -28°C to + 200°C	50
Brass ball valve nickel	40
Special safety valve for solar thermal applications for a maximum temperature of 130 ° C	155
TOGETHER	19630

The cost of solar collector is the variable cost because it depends on the collector area and number of the solar modules, what will be defined in the next part of this chapter. This cost of one collector together with assembly is **1790 PLN**.

Tab. 20 The maintenance costs of the components

Annual cost of solar collector maintenance	600
Annual maintenance cost for the boiler	350
Annual maintenance cost for the generator circuit	700
TOGETHER	1650 PLN

In calculating the investment, the total cost of the installation is composed of variable cost which is related to the area of solar collectors and a fixed cost that is related to the basic elements of an installation. Investment values were obtained by formula:

$$INV = A \cdot C_v + C_e \quad 43.$$

Tab. 21 Composition of investment variables.

INV	The cost of investment	
C_V	The variable cost of installation (1m ²)	895 PLN
C_e	Cost of the components	19630 PLN
C_M	Cost of maintenance	1650 PLN
CW	Price per kWh	0,54 PLN/kWh [XIX]

3.5.2. Installation sizing by economic criteria

The area of solar collectors in the facility will be determined by the best results of the criteria evaluation of investments. For evaluation criteria investments set up a rate of weighted average cost of capital life of solar thermal system and an inflation rate according to the conducted survey. The value of the rate of weighted average cost and the number of years of life were set to determining the NPV and IRR. An inflation rate was also considered in view of the increasing the cost of energy and maintenance services.

Tab. 22 The necessary information to sizing installation by economic criteria.

The weighted average cost of capital rate	The number of years of useful life of the solar system	The annual inflation rate
5%	20	2,4%

There will be considered 3 types of the auxiliary system :

- Gas boiler
- Coal boiler
- Wood boiler

The auxiliary system will become operation in the situation that the solar system cannot supply enough power. The table below contains necessary information to calculate cost of the fuel in every sample:

Tab. 23 Description of fuels in the auxiliary system [XV], [XX]

Fuel type	Price	Calorific value
Gas	1,5 PLN/m ³	10,29 kWh/m ³
Wood	240 PLN/m ³	3300 kWh/m ³
Coal	740 PLN/ton	8 kWh/kg

The wood is sold in the block of volume of $1m^3$, that mean that in this volume is not full $1m^3$ of wood, but unit called 1 mp. To have $1m^3$ of wood, the 1mp must be multiplying by 1,4. In the Tavle below there were conducted data for full $1m^3$ of wood,

The calculation made for the cost the auxiliary system is using the following equation:

$$Cost_{aux.sys} = (1 - f) \cdot Q_{CTannual(in kWh)} \cdot Price \quad 44.$$

The annual revenues were obtained as indicated by the following formula:

$$Rev = Sav - Cost_{aux.sys} - CM \quad 45.$$

In the obtained annual revenues took into account the saving of using solar energy system, the cost of the auxiliary system and the cost of the annual maintenance of the system.

In the following table there were made a calculation related to cost of investment, annual cost of the auxiliary system, annual energy savings, annual revenue for each corresponding area. The calculations were performed based on the equations (42), (43), (44) and (45).

The following equation was used to calculate savings of the energy and heat:

$$Elec = 9261kWh \cdot 0,54 \frac{PLN}{kWh} \quad 46.$$

$$Heat = \left(145600kWh : 3300 \frac{kWh}{m^3} \right) \cdot 240PLN \quad 47.$$

Tab. 24 Information necessary to calculate cost of solar system.

Area of collector, m^2	Cost of investment, PLN	Energy which will be provided by solar system, GJ	Energy which must be provided by auxiliary system, kWh	Cost of auxiliary system (gas), PLN	Cost of auxiliary system (wood), PLN	Cost of auxiliary system (coal), PLN
0	0	0,0	145600,0	21224,5	13468,0	11457,0
10	28580	115,8	113190,0	16500,0	10470,1	8906,8
20	37530	131,5	108777,2	15856,7	10061,9	8559,5
30	46480	146,7	104535,2	15238,4	9669,5	8225,7
40	55430	161,2	100461,2	14644,5	9292,7	7905,1
50	64380	175,2	96549,6	14074,3	8930,8	7597,3
60	73330	188,6	92797,6	13527,3	8583,8	7302,1
70	82280	201,4	89199,6	13002,9	8251,0	7019,0
80	91230	213,8	85750,0	12500,0	7931,9	6747,5
90	100180	225,6	82446,0	12018,4	7626,3	6487,6
100	109130	236,8	79284,8	11557,6	7333,8	6238,8
110	118080	247,7	76258,0	11116,3	7053,9	6000,6
120	127030	258,0	73362,8	10694,3	6786,1	5772,8
130	135980	267,9	70599,2	10291,4	6530,4	5555,3
140	144930	277,3	67956,0	9906,1	6285,9	5347,4
150	153880	286,3	65433,2	9538,4	6052,6	5148,8
160	162830	294,9	63025,2	9187,3	5829,8	4959,4
170	171780	303,1	60726,4	8852,2	5617,2	4778,5
180	180730	311,0	58534,0	8532,7	5414,4	4606,0

In the following table will be presented information about how much would cost heat and electricity gained because of solar system depending on the solar collector area and savings/losses achieved thanks this solution.

Savings of heat was calculated assuming that heat is provided by wood boiler and the electricity is bought from the national grid.

The revenues gained by investor were calculated by subtracting cost of auxiliary system and cost of annual maintenance from the savings gaining because of using solar system.

Tab. 25 Savings of energy and revenues of usage the solar system.

Area of collector, m^2	Savings gained from the heat provided by the solar system, PLN	Savings gained from the electricity provided by the solar system, PLN	Savings together, PLN	Revenues, PLN
0	2423,6	5003,2	0	-13107,0
10			7426,81	-3129,9
20			7426,81	-2782,7
30			7426,81	-2448,9
40			7426,81	-2128,3
50			7426,81	-1820,5
60			7426,81	-1525,3
70			7426,81	-1242,2
80			7426,81	-970,7
90			7426,81	-710,7
100			7426,81	-462,0
110			7426,81	-223,8
120			7426,81	4,0
130			7426,81	221,5
140			7426,81	429,5
150			7426,81	628,0
160			7426,81	817,5
170			7426,81	998,3
180			7426,81	1170,9

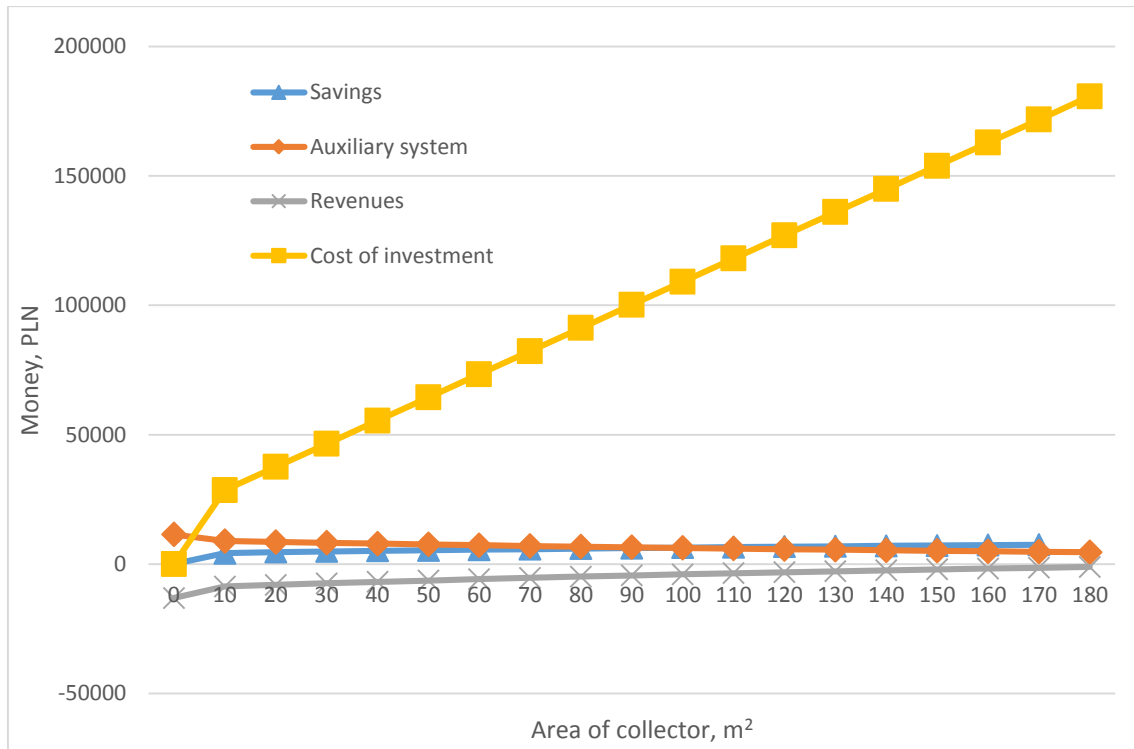


Fig. 19 Graphic presentation of investment costs, annual energy savings and the cost of auxiliary system.

The figure presented above shows that using of this system is unprofitable. The solar fraction in the best sample for the biggest solar collector area (180 m²) is 0,598, what means that the solar collector can provide about 60% of energy demand of the Organic Rankine Cycle. The rest must be provided by auxiliary system (the cheapest option was using the wood boiler). The most of the profits was gained because of electricity. In case of surplus it is possible to sell electricity to the national grid. The heat cannot be sold, so it will be wasted in the cooling tower. For assumed areas of collector investor cannot gain any benefits, because difference between savings and cost of auxiliary system and cost of maintenance is cons.

3.5.3. Net present value, payback period and internal rate of return

Below there were conducted calculation of NPV and IRR values. For the format of the IRR and NPV calculations took into account the annual revenues, the annual inflation rate, the number of years of useful life of the solar system from **Tab. 24**. The values of NPV and IRR were calculated using formulas in Program Microsoft Excel 2013.

Tab. 26 Values of NPV and IRR.

Area of solar collector, m^2	NPV, PLN	IRR, %
10	-174 259,8	0%
20	-91 178,8	0%
30	-93 184,1	0%
40	-95 458,1	0%
50	-97 996,6	0%
60	-100 790,6	0%
70	-103 835,8	0%
80	-107 123,4	0%
90	-110 644,5	0%
100	-114 394,8	0%
110	-118 369,8	0%
120	-122 556,3	0%
130	-126 949,9	-22%
140	-131 550,6	-19%
150	-136 340,9	-17%
160	-141 320,5	-16%
170	-146 480,9	-15%
180	-151 813,1	-15%

In the first chapter it was said that if the value of NPV is less than 0 the investment is not financially viable. Investment start to show profits when the area of collector is 130 m^2 and more but these revenues are not enough to cover cost of the investment during the period of the viability of the system. The implementation of this system for the polish wheatear conditions is not good idea because solar system is not enough to provide all necessary energy. Comparing the values of solar factor in Poland in Portugal it can be noticed that for the same solar collector area the value of f is much bigger and provide almost the necessary energy.

4. CONCLUDING REMARKS

4. Concluding remarks

The main objective of this work was conducting technical and economic analysis and calculation related to usage of solar system for the needs of heating and electricity in the single family house in Poland. The solution was to use two cooperating circuits- first with solar collector, which will provide hot water functioned as a heat source for the second system- Organic Rankine Cycle. For this purpose there were conducted several calculation like thermal load and electricity demand of the building, selection of the best refrigerant for ORC, calculation of solar fraction, choice of all necessary components and economic analysis of profitability of usage this solution under these conditions.

This report allows to admit that proposed solution is not suitable for Polish weather conditions. The value of solar fraction in the best sample, that the collector area is 180 m², is 0,6 what means that solar system can provide 60% of Organic Rankine Cycle heat demand. The rest of needs must be provided by auxiliary system (for the needs of auxiliary system the wood boiler was chosen, because it was the cheapest option). The usage of this system starts to give the profits when the solar collector area is 130m² and more, but the cost of investment are very high. Ultimately the investment is not financially viable. The calculation of economic criteria also showed that implementation of this investment is not economically justified. Net present value is less than 0 and the internal rate of return is negative.

However, unprofitability of usage this system in Poland does not mean that this system is not good solution. It can be implement in the countries when the solar radiation is high and relatively balanced throughout all year. Portugal and Spain are two of them. In the warm countries this system can be profitable also for the smaller areas of solar collector which translates into lower investment costs.

If it comes about concluding remarks related to preparing this presentation on the ISEP Master Degree in Mechanical Engineering, under the guidance of Professor Leonardo Silva Ribeiro, it was really pleasure to be a student of Professor and have possibility to conduct part of the studies in Portugal. Portugal is really beautiful country and here there are a lot of places very worth to visit. Porto is one of the most beautiful city, which I have ever seen. I am totally impressed with the architecture, azulejos, Ribeira, food and weather of Porto and all Portugal. I am very happy that I could spend here one semester, achieve new experience, improve language skills, meet new amazing people and visit incredibly beautiful places.

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5. Bibliography and others sources of information

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6. *APPENDIXES*

6. Appendixes

- 1) **Appendix 1** The log(p)- diagrams of selected refrigerants.
- 2) **Anexo 2** The data sheet of selected components.
- 3) **Anexo 3** The tables related to calculation of total and direc intensity of solar radiation. Spreadsheet on CD.
- 4) **Anexo 4** The tables related to calculation of solar fraction. Spreadsheet on CD.
- 5) **Anexo 5** The tables related to calculation of economic analysis. Spreadsheed on CD.

APPENDIX 1

The log(p)-h diagrams of selected refrigerants

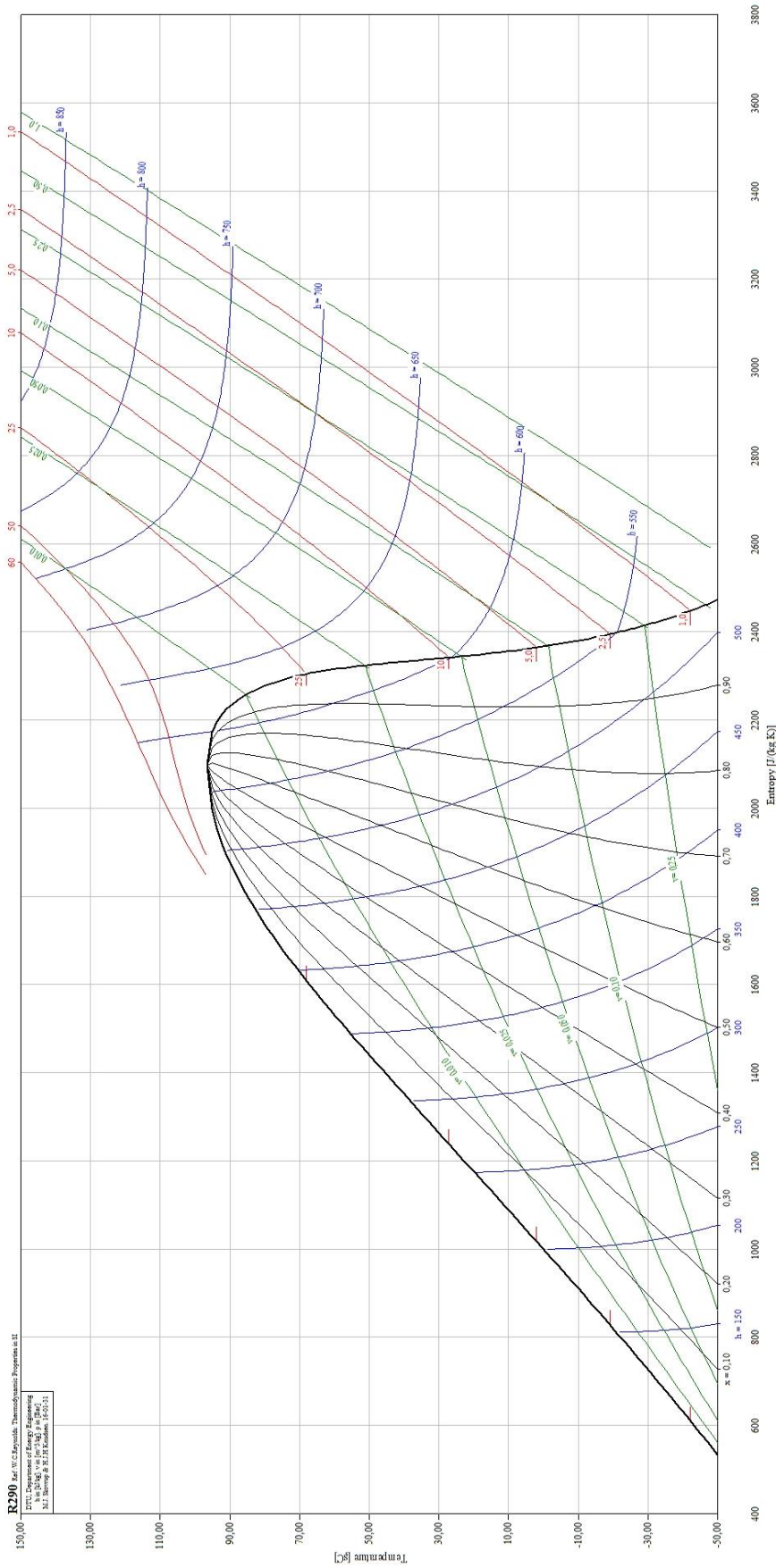


Fig. 21 Diagram TS for refrigerant R290.

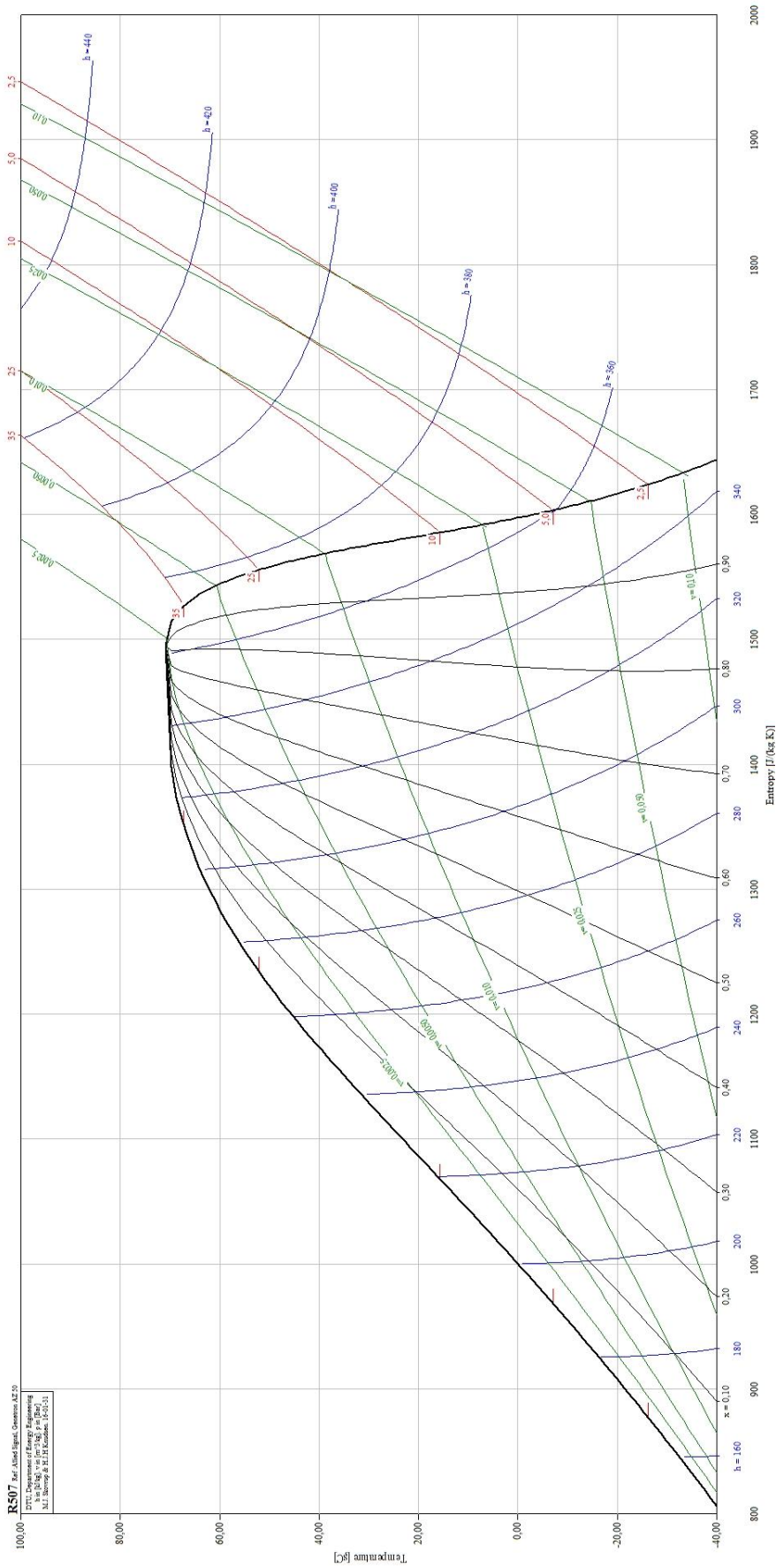


Fig. 22 Diagram TS for refrigerant R507.

ANEXO 2

Data sheets of selected components

Specyfikacja techniczna:

Szerokość - 1180 mm

Wysokość - 2160 mm

Głębokość - 90 mm

Masa - 47 kg

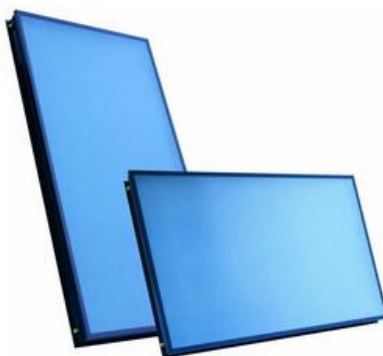
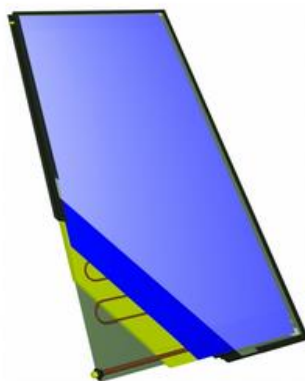

Powierzchnia brutto -2,55 m²Powierzchnia absorbera-2,36 m²**Opis produktu****Typ** - Płaski kolektor modułowy**Instalacja i montaż** - Kąt nachylenia kolektora od 15° do 70°**Dopuszczalne obciążenie** - max. 300 kg/m²**Rama** - Aluminiowa rama w kolorze grafitowym (RAL7016) nanoszonym proszkowo, tylna ściana z aluminium**Absorber** - Aluminiowy absorber z wysokoselektywną powłoką PVD, miedziane meandryczne rurki, spawane laserowo**Złącza** - 4/ miedziane rurki, 18 x 0,8 mm**Pokrycie** - Pryzmatyczne szkło solarne o grubości 4 mm (wysoki współczynnik przepuszczalności energetycznej)

Fig. 23 Data sheets of solar collector.[XVIII]

Kotły zasypowe - nowa linia HT



HT BASIC 7 - 35 kW - kotły do tradycyjnego spalania węgla i drewna

Nazwa	Moc nominalna	Zakres mocy	Powierzchnia ogrzewana*	Cena netto	Cena brutto
HT BASIC 7	7	2 - 7	20 - 70	1 908,00 zł	2 346,84 zł
HT BASIC 11	11	3 - 11	30 - 110	2 198,00 zł	2 703,54 zł
HT BASIC 15	15	5 - 15	50 - 150	2 661,00 zł	3 273,03 zł
HT BASIC 20	20	6 - 20	60 - 200	2 938,00 zł	3 613,74 zł
HT BASIC 25	25	8 - 25	80 - 250	3 238,00 zł	3 982,74 zł
HT BASIC 30	30	9 - 30	90 - 300	3 702,00 zł	4 553,46 zł
HT BASIC 35	35	11 - 35	110 - 350	4 164,00 zł	5 121,72 zł

Paliwo podstawowe: Węgiel
 Paliwo zastępcze: Drewno opałowe, Brykiet

Fig. 24 The data sheet of wood boiler. [XVII]

**Dane techniczne**

- Rodzaje instalacji: 1-fazowa, 2-fazowa, 3-fazowa
- Wejście prądowe AC: 0-1A, 0-2A albo 0-5A,
- Wejście napięciowe AC : 0-100V, 0-220V, 0-380V, 0-500V albo 0-600V
- Możliwość zwiększenia zakresu pomiaru prądu / napięcia przy współpracy z przekładnikami CT / VT
- Wejście temperaturowe: Cu50, Pt150, Cu100 lub Pt100
- Wyjścia analogowe : 4-20mA, 0-20mA, 0-10mA, 0-1mA, 0-1V, 0-5V albo 0-10V (+ inne wyjścia w zależności od typu przetwornika - patrz karta typu)
- Zasilanie: 24-80V AC/DC albo 85-265V AC/DC (+dodat. opcja dla typów PRO U i PRO I - patrz karta typu)
- Możliwe definicje użytkownika
- Dokładności: Klasa 0,2 albo Klasa 0,5

Pozostałe parametry

- Środowisko pracy: -10-50°C, RH < 90%
- Składowanie: -40-85°C, RH < 90%
- Obudowa: poliwęglan (PC)
- Wymiary: zależne od typu

Seria PRO to przetworniki przemysłowe przetwarzające w czasie rzeczywistym takie parametry jak U, I, PF, Hz, P, Q, S, Temp. na sygnały analogowe wyjściowe. Przetworniki dostarczane są zgodnie z konfiguracją ustaloną przez użytkownika na podstawie odpowiedniego arkusza zamówień.

Właściwości

- Zaprojektowane i testowane zg z IEC668
- Duża przeciążalność
- Wysoka niezawodność
- Montaż na szynie DIN

Typy przetworników

- PRO I31/I33 przetworniki prądu AC
 - PRO U31/U33 przetworniki napięcia AC
 - PRO F31 przetworniki częstotliwości AC
 - PRO L31/L33 przetworniki wsp. mocy PF i kąta fazowego
 - PRO P31/Q31 przetworniki mocy czynnej P albo bierniej Q
 - PRO PD32/QD32 przetworniki energii czynnej i bierniej
 - PRO S32 przetworniki mocy czynnej i bierniej P/Q
 - PRO DI31/DU31 przetworniki prądu DC albo napięcia DC
 - PRO T31 przetwornik temperatury
- (Szczegółowe dane odnośnie konfiguracji i wyboru opcji dostępne na kartach katalogowych poszczególnych typów)

Fig. 25 Data sheet of power inverter. [XXI]



Charakterystyka produktu :

- ekskluzywny design
- system shower-ready
- funkcja ECO EVO (powtarza sposób wykorzystania ciepłej wody - oszczędność wody do 14 %)
- dwie anody magnezowe
- możliwość instalacji pionowej lub poziomej
- izolacja z grubej pianki poliuretanowej
- wyświetlacz LED
- produkt testowany aby spełnić najwyższe wymagania

Dane techniczne:

- Montaż : poziomy/pionowy
- Pojemność: 80l
- Moc: 1,5kW
- Maksymalna temperatura robocza: 80°C
- Dobowe straty energii (przy 60°C): 0,93 kWh/24h
- Maksymalne ciśnienie robocze: 8 bar
- Stopień ochrony IP: IPX4

Fig. 26 Data sheet of thermoacumulator.XVI

PARAMETRY TECHNICZNE

- Napięcie znamionowe 12V/24V (automatycznie przełączane w zależności od podłączonego akumulatora)
- Typ ładowania PWM
- Chroni akumulator przed głębokim rozładowaniem
- Zabezpiecza akumulator przed przeladowaniem
- Zabezpiecza akumulator przed rozładowaniem przez panel słoneczny w nocy
- Wskaźnik poziomu naładowania akumulatora
- Wskaźnik ładowania przez baterie słoneczną
- Maksymalny prąd ładowania 60A
- Wielkość 18,8 x 13 x 6,2 cm
- Waga netto 700g



Fig. 27 Data sheet of charge regulator. [XIII]



2V 5PzS 400

Cena netto: 473,37 zł

Cena brutto: 582,23 zł

Dostępność: na zamówienie, dostawa około 3 tygodnie (zapytaj o Express 3-5 dni rob.)

ILOŚĆ:

DODAJ DO ZAMÓWIENIA >>

- Dodaj do schowka
- Dodaj do porównania

Parametry	Ogniwa	
Napięcie:	2V	Szerszy bok (mm): 198
Pojemność (Ah):	400	Węższy bok (mm): 101
Waga ogniów (kg):	22,6	Wys. bez korka (mm): 405

Fig. 28 Data sheet of batteries. [XII]

Dane techniczne:

Ciężar: 3,1 kg

Przyłącza: 1 1/2 (5/4) cala

Wymiary gwintu przyłączeniowego: 47,5 mm (mierzone na zewnątrz gwintu)

Maksymalna temperatura wody: 110 °C

Maksymalna temperatura otoczenia: 55 °C

Maksymalne ciśnienie robocze: 10 bar

Korpus pompy: 180 mm (długość montażowa)

Ilość biegów: 3 Podnoszenie słupa wody: 6 m

Napięcie znamionowe: 220-240 V / 50 Hz

Głośność: 45db

Prąd znamionowy: 0,4 A

Moc maksymalna na poszczególnych biegach: I - 46 W, II - 67 W, III - 93 W

Gwarancja 2 lata



Fig. 29 Data sheet of circulating pump. [XIV]



▶ ORC IT10

- ▶ Moc elektryczna netto (dla czynnika R245fa Genetron) ▶ 10 kW
- ▶ Generator (wyposażenie dodatkowe) na wspólnym wale, 1,800 / 3,600 obr / min ▶ opcjonalnie DC lub AC 50/60hz
- ▶ Przepływ przez parownik ▶ 83 l/min, temperatura zasilania ▶ 90 °C, spadek temperatury za parownikiem ▶ 15 °C
- ▶ Przepływ przez skraplacz ▶ 166 l/min, temperatura chłodzenia ▶ 15 °C, wzrost temperatury za skraplaczem ▶ 15 °C
- ▶ Wymiary
Długość ▶ 1220 mm
Szerokość ▶ 610 mm
Wysokość ▶ 1220 mm
- ▶ Masa w stanie suchym ▶ ca 200 kg

[Karta informacyjna produktu](#)

Fig. 30 Data sheet of turbogenerator ORC. [XI]

Specifications (Continued)



HOT WATER DISTRIBUTION SYSTEM:

The PVC hot water distribution system consisting of sprinkler arms and aluminum or stainless steel sprinkler head, as specified, to deliver incoming water by pump water pressure through a single water inlet connection ensuring even distribution over the wet deck surface.

COLD WATER BASINS AND ACCESSORIES:

The (FRP) cold water basin shall be watertight and include a brass float operated mechanical make-up valve. From the lip of the cold water basin to the bottom edge of the casing section shall be enclosed by a polyvinyl chloride (PVC) screen to prevent debris from entering the cold water basin and water splash out.

SCOPE OF WORK IF REQUIRED:

By owner/contractor... The cooling tower manufacturer shall be responsible for the design, fabrication, and delivery of materials to the work site, and for the erection of the tower on supporting piers or grilleage furnished by owner/contractor.

ACCESSORIES:

Listed in the Cooling Tower Systems catalog it includes all Stainless Steel components hardware vibration cut-out switches, variable speed drives, remote sump tanks, cold water basin heaters and controls, water pumps, and plate heat exchangers.

WARRANTY:

- (1) The manufacturers shall warrant the fiberglass basin and casings for ten (10) years.
- (2) (2) Wet Deck Polyvinyl Chloride (PVC) for two (2) years.
- (3) Fan Motor for one (1) year.
- (4) Extended Warranties are available upon request, for an additional fee.



Fig. 31 Data sheet of cooling tower. [X]

UNIERSALNY ODWADNIACZ Z PŁYWAKIEM SWOBODNYM I ODPOWIETRZNIKIEM TERMICZNYM

Zalety

Odwadniacz łatwo-wymienny z kołnierzem dwu śrubowym przeznaczony do odwadniania rurociągów, parogrzemek i małych urządzeń wymiennikowych itp.

1. Specjalny konektor kołnierzowy z dwoma śrubami mocującymi zapewnia bardzo szybko wymianę odwadniacza
 2. Konektor obrotowy pozwala na ustawienie odwadniacza niezależnie od układu rurociągu.
 3. Unikalna konstrukcja z pływakiem swobodnym eliminuje miejscowe zużycie zapewniając ługi czas pracy.
 4. Trzypunktowy system podparcia kuli zapewnia perfekcyjną szczelność ,nawet przy bardzo małych przepływach
 5. Odwadniacz posiada odpowietrznik bimetaliczny dla szybkiego rozruchu
1. Wbudowane dwa filtry o dużej powierzchni wydłużają okres bezawaryjnej pracy.



Specyfikacja

Model	FS3		
Typ przyłącza	Gwintowe	Spawane	Kołnierzowe
Wymiar	1/2", 3/4", 1"	DN15, 20, 25	
Nr kryza	5, 10, 21		
Maksymalne ciśnienie pracy [barg] PMO	5, 10, 21		
Maksymalna różnica ciśnień [bar] ΔPMX	5, 10, 21		
Maksymalna temperatura pracy [°C] TMO	350		

PARAMETRY PROJEKTOWE KORPUSU (NIE PARAMETRY PRACY) :

Maksymalne dopuszczalne ciśnienie [barg] PMA : 21
Maksymalne dopuszczalna temperatura [°C] TM : 350

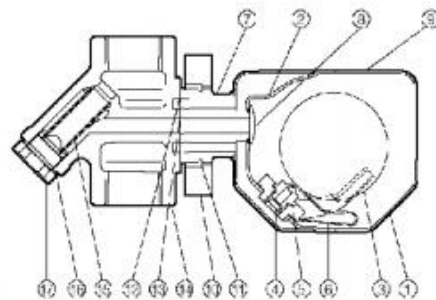
UWAGA

Aby uniknąć nieprawidłowej pracy, wypadków oraz poważnych zranień, NIE WOLNO stosować tego urządzenia poza warunkami pracy podanymi w tabeli. Lokalne regulacje mogą być bardziej restrykcyjne

NR	Opis	Materiał	DIN *	ASTM/AISI *
1 T	Korpus odwadniacza	Stal kwas. SUS316L	1.4404	AISI316L
2 T	Wewnętrzna pokrywa	Stal kwas. SUS316L	1.4404	AISI316L
3 T	Pływak	Stal kwas. SUS316L	1.4404	AISI316L
4 T	Kryza	Stal kwas. SUS316L	1.4404	AISI316L
5 T	Prowadzenie pływaka	Stal kwas. SUS316L	1.4404	AISI316L
6 T	Pasek bimetalu	Bimetal	----	---
7 T	Łącze konektora	Stal kwas. SUS304	1.4301	AISI304
8 T	Siatka filtra	Stal kwas. SUS304	1.4301	AISI304
9 T	Tabliczka	Stal kwas. SUS304	1.4301	AISI304
10 T	Kołnierz konektora	Stal węglowa A105	1.0460	A105
11 T	Pierścień	Stal węglowa SWRH57	1.0535	AISI1055
12 MT	Uszczelka zewnętrzna konektora	Stal kwas./Grafit SUS304	1.4301	AISI304
13 MT	Uszczelka wewnętrzna konektora	Stal kwas./Grafit SUS304	1.4301	AISI304
14	Korpus konektora	Stal kwas. SCS13A	1.4312	A351 Gr. CF8
15	Siatka filtra zewnętrzna	Stal kwas. SUS430	1.4016	AISI430
16 M	Uszczelka korka	Stal kwas. SUS316L	1.4404	AISI316L
17	Korek filtra	Stal kwas. SUS303	1.4305	AISI303
18 T	Śruba konektora	Stop SNB7	1.7225	A193 Gr. B7
19	Kołnierz	Stal kwas. / Stal kwas. SCS13A / SUS304	1.4312 / 4301	A351 Gr. CF8 / AISI304

* Materiał równoważny , ** - Pokazano na odwrocie , *** Pokazano na odwrocie, kształt oraz materiał zależą od konfiguracji kołnierza

Dostępne zestawy naprawcze , M – Obsługowy , T – Odwadniacz S3



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Fig. 32 Data sheet of flow trap. [XXII]

ANEXO 3

Tables related to calculation of total and direct intensity of solar radiation. Spreadsheet on CD.

ANEXO 4

Tables related to calculation of solar fraction. Spreadsheet on CD

ANEXO 5

Tables related to calculation of economic analysis. Spreadsheet on CD