POLITECHNIKA GDAŃSKA

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RENEWABLE ENERGY SOURCES LABORATORY

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# LABORATORY INSTRUCTION NO. 7-PC

# HEAT PUMP

**1. Purpose & range of the exercise**

The exercise aims to familiarize students with the following topics:

• Principle of an air-air heat pump operation.

• Principle of an air-water heat pump operation.

• Calculating the heat flux value in the bottom & top heat source, as well as heat pump performance.

• Calculating the heat flux value absorbed by water in an air-water heat pump.

## 2. Scope of exercise

The principle of a heat pump operation is receiving heat Qd from the so-called bottom source (low temperature: -15°C to +30°C) and transferring heat $Q_g$ to the top source (high temperature: central heating & domestic hot water) This process is carried out through the use of an electric-powered compressor L (Fig.1.).

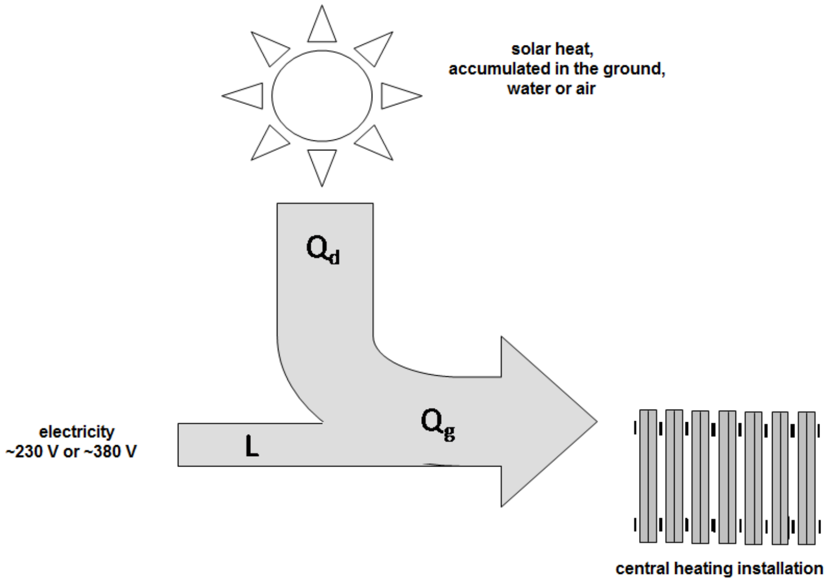



**Fig. 1.** Principle of heat pump operation

In practical terminology, $Q_d$ is the heat pump's cooling effect, $Q_g$ is the heat pump's heating effect. In heat pump systems, it is possible to utilize the hotter top source (e.g. heating purposes), as well as the cooler bottom source (e.g. in air conditioning or refrigeration). Based on its purpose, a heat pump should be selected considering either its heating effect or its cooling effect.

In practical use, the following types of bottom heat sources are utilized:

- Horizontal heat exchanger - PE pipes laid down horizontally underground. Inside the pipes, a non-freezing liquid is pumped, the temperature of which is lower than the ground's temperature. The liquid extracts heat from the ground and transfers is to the heat pump.
- Vertical ground heat exchanger - similar to its horizontal counterpart, but the pipes are laid down vertically. As with the horizontal exchanger, a non-freezing liquid flows inside the pipes in a closed loop. It covers a smaller area than a horizontal exchanger.
- Double well system - water is pumped from one well and, after flowing through the heat pump, cooled down and discharged into the second well.
- Refrigeration processes (cold storage chambers, production of iced water, air conditioning).
- Air. Best results are obtained when utilizing constant temperature air, e.g. from vent systems.

Basic installation elements include (Fig.2):

- evaporator (bottom source heat exchanger),
- condenser (top source heat exchanger),
- compressor,
- expansion valve.

Top heat source is most commonly water utilized in central heating installations. Target temperature for a heat pump is up to 100°C (a heat pump reaches maximum performance when top heat source temperatures are lower, practically within the range 35÷55°C). The bottom heat source is a probe (underground heat exchanger). Based on deposition depth, probes are divided into: surface heat probes, high depth heat probes. Surface heat probes are placed horizontally on a small depth, or vertically and are known as ground collectors.

**Table 1.** Selecting horizontal & vertical surface collectors

| Characteristic | Horizontal collectors | Vertical collectors |
|---|---|---|
| Depth [m] | 1÷2 | 150÷200 |
| Pipe length unit [m/kW] | 28÷50 | 15÷32 |
| Typical pipe diameters | ¼" ÷2" | ¾ " ÷2" |

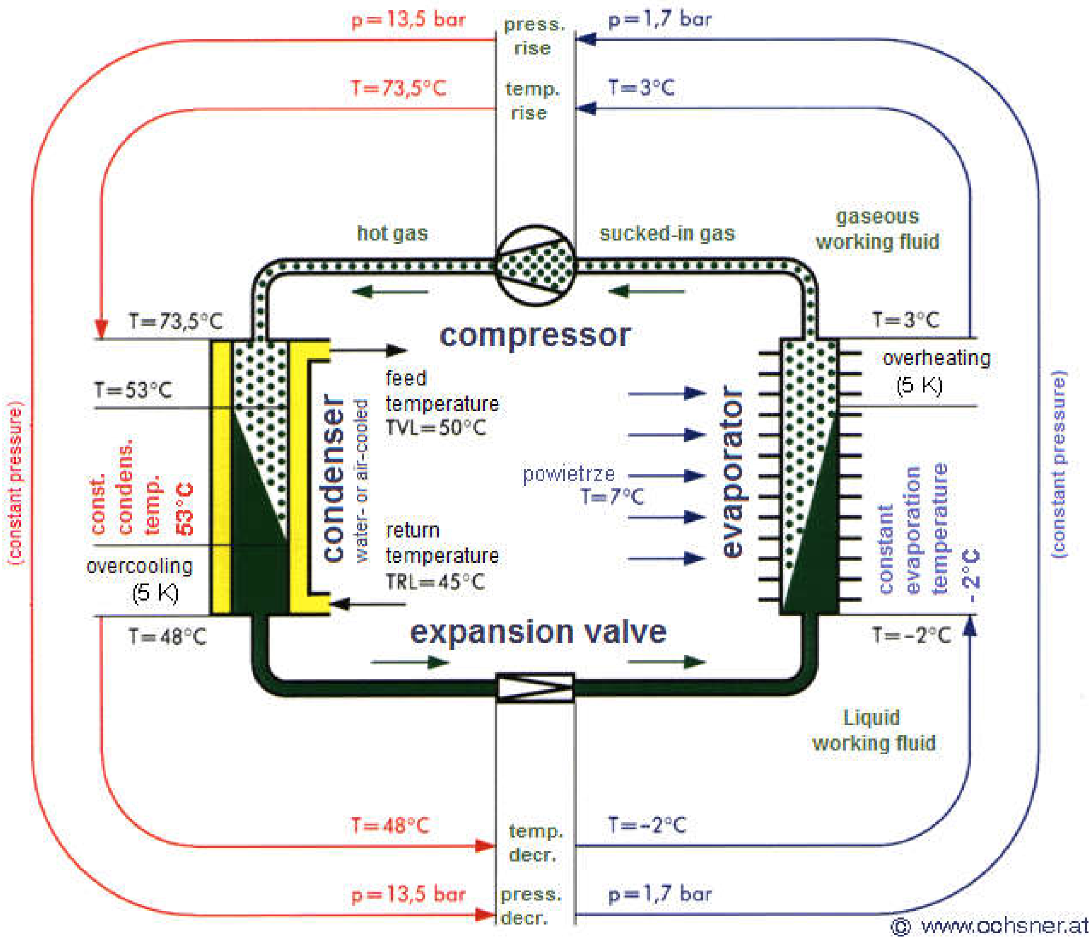


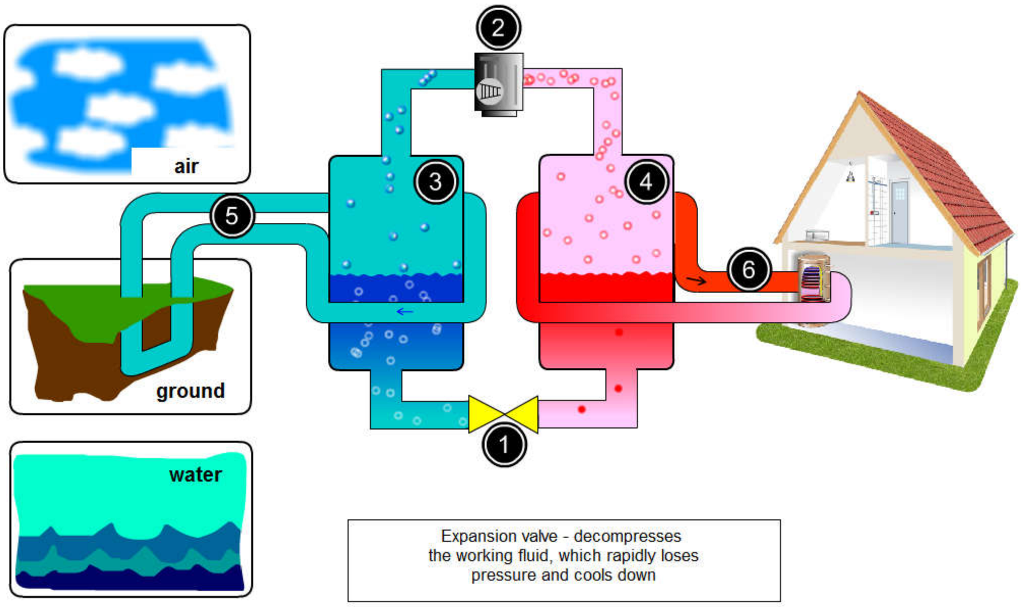

**Fig. 2.** Heat pump scheme

Brine (25÷30%) or refrigerating agents are utilized within the probes. Because water temperature at the pump's outlet should not exceed 55°C, the most appropriate is a low-temperature heating system, such as floor heating. This type of heating allows for thermal comfort, feeding the system with a working medium heated to 30÷40°C.

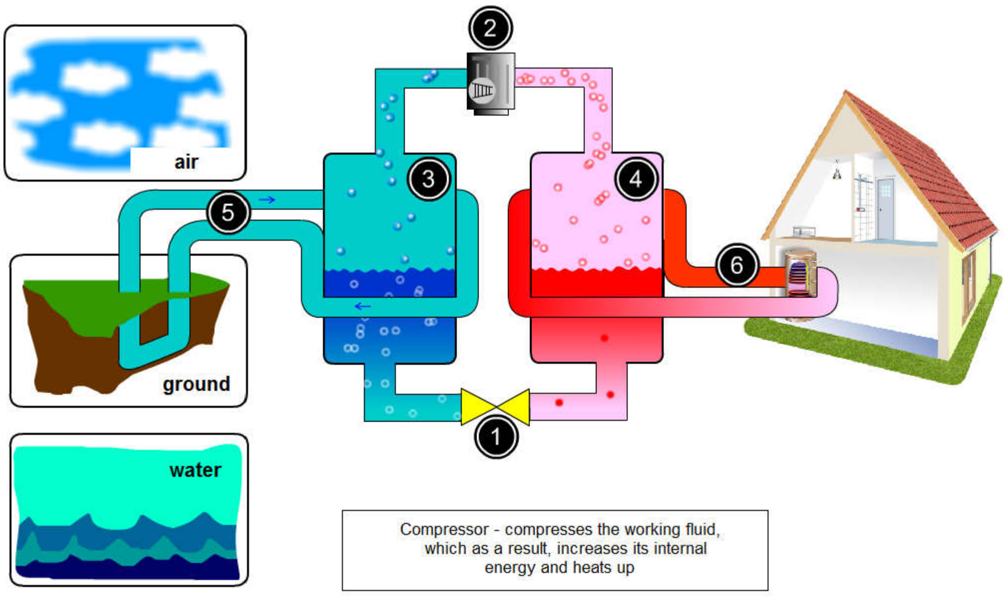
Deep wells enable heat extraction from groundwater. As opposed to vertical & horizontal collectors (which operate in a closed loop), this system creates an open loop.
In case of the aforementioned system, the depth of pipes is crucial, because of the bottom source's temperature (which is the ground). In deeper layers - below 20 meters - energy is accumulated from the Earth's crust as well as solar radiation. At a depth of approx. 10 meters, temperature is constant and - for intermediate climate zones - approx. 10 degrees Celsius. At a depth of approx. 1.5 - 2 meters, temperature changes sinusoidally within the range of 6 - 15 degrees.
Linking floor heating & wall heating is the most effective way of heating a modern, energy-saving house.
The energetic effect of a heat pump is described by its Coefficient of Performance (*COP*):

$$\varepsilon = \frac{\dot{Q}_g}{|N_e|} > 1,$$

where $\dot{Q}_g$ is heat flux transferred to the heated body,
whereas $N_e$ is power supplied to the pump.
A heat pump system with a description of its elements and their function is shown in Fig. 3. points 1÷6.




**1.**

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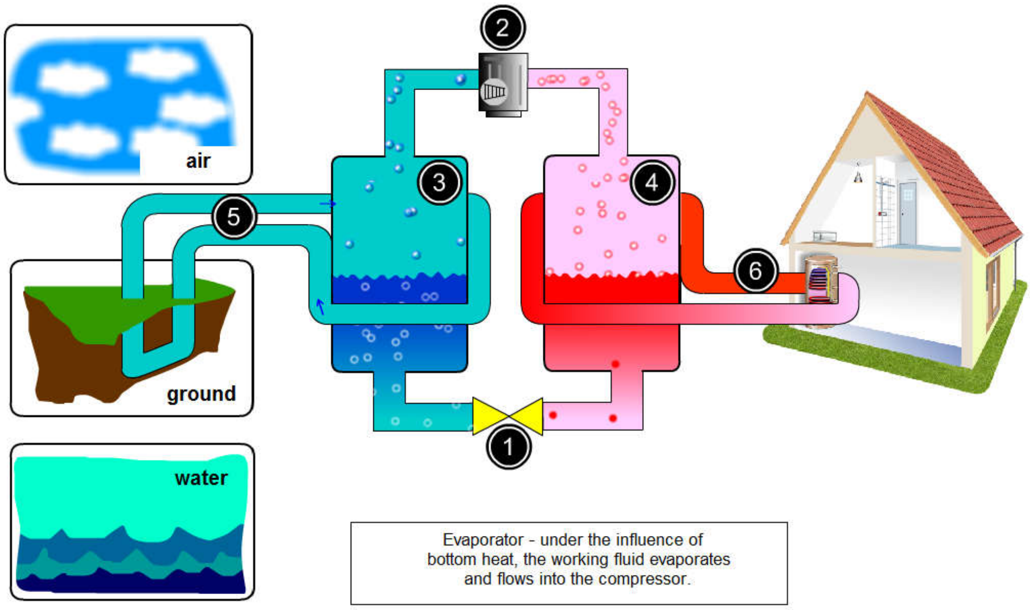
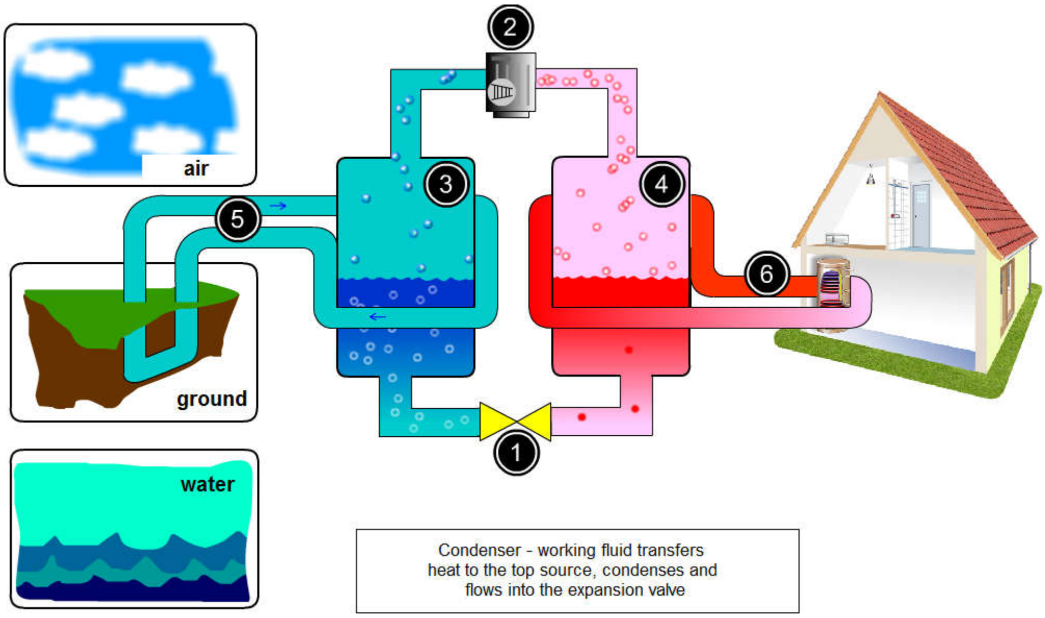

air
ground
water
2
3
4
5
6
1
Evaporator - under the influence of bottom heat, the working fluid evaporates and flows into the compressor.

3.


air
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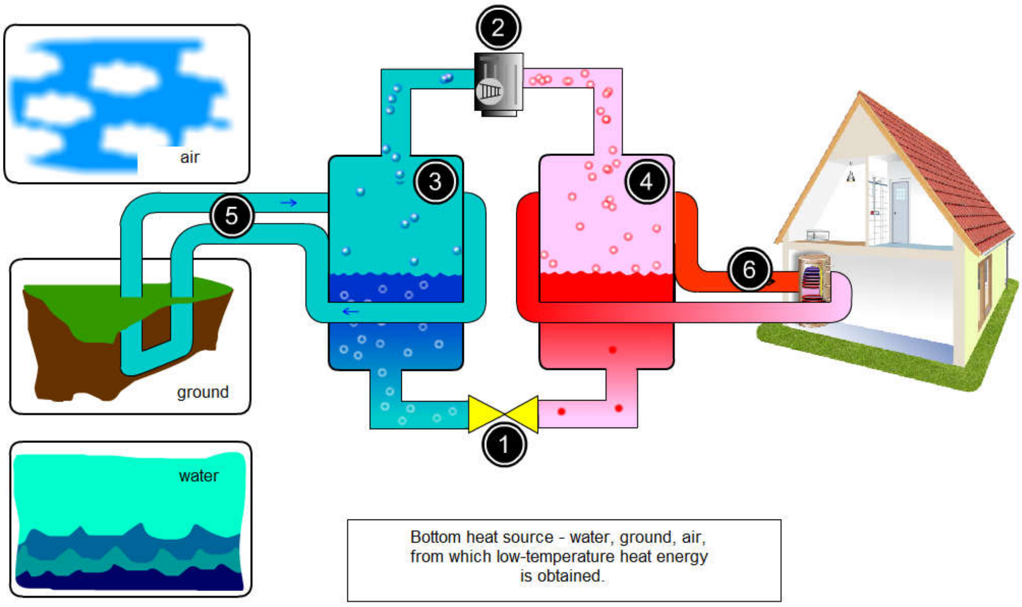
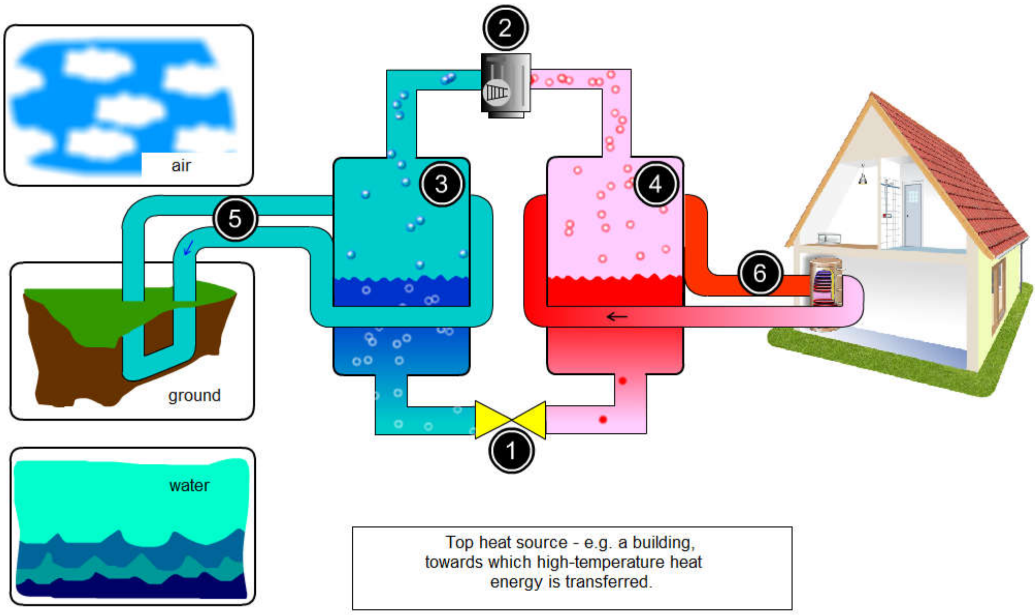
Condenser - working fluid transfers heat to the top source, condenses and flows into the expansion valve

4.




**5.**




**6.**

**Fig. 3.** Heat pump system with a description of its elements and their function 1 - expansion valve, 2 - compressor, 3 - evaporator, 4 - condenser, 5 - bottom heat source, 6 - top heat source

**Set of experiments for the study:**

A. Calculating the heat flux value and pump performance for an air-air heat pump.

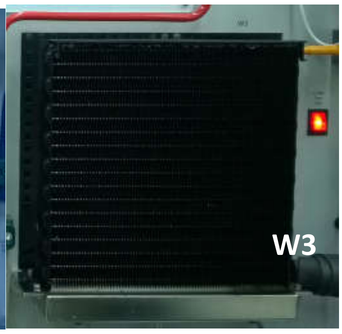
B. Calculating the heat flux value, performance and heat flux absorbed by water in an air-water heat pump.

## 3. Description of the experimental station

The purpose of the refrigerating system and the heating pump is transferring heat from low temperature level to high temperature level. According to the laws of thermodynamics, this process cannot occur without work input. The difference between a heat pump and a refrigerating system is that in a refrigerating system, the cold end is utilized (evaporator), while in a heat pump - the hot end (condenser). Thermodynamic cycles are identical.

### 3A. Heat Exchangers

The device is a fully-functional refrigerating system/heat pump. System allows for utilizing and comparing different evaporators and condensers. The system is equipped with 4 heat exchangers:
• 3 air-cooled exchangers;




• 1 water-cooled exchanger (W4).


The water-cooled heat exchanger (W4) may work as a condenser and an evaporator. This feature also refers to one of the air-cooled exchangers (W3).

### 3B. Compressor

The system is equipped with a hermetic piston compressor. The engine and the compressor are placed in a tightly sealed & welded metal casing. The engine is cooled with sucked-in refrigerating medium vapor. The compressor in this case is suction-cooled. Engine speed for this compressor is approx. 2900 RPM at 50 Hz electric installation frequency. The compressor's work temperature limit is 120°C.

### 3C. Thermal expansion valves (TEV)

The purpose of an expansion valve is decompressing the refrigerating agent and maintaining constant overheating value in the evaporator's outlet. Every heat exchanger is equipped with its own expansion valve, which gives a total of 4 expansion valves within the whole system. Overheating the refrigerating medium can be regulated with the valve's adjustment bolt.

### 3D. Control elements

The installation can be configured in 19 different work modes, which allows us to analyze several common utilization scenarios. The examples include factors influencing the operational behavior of the heat pump. The system is equipped with a large number of measuring devices, allowing for qualitative and quantitative analysis of the heat exchange process.

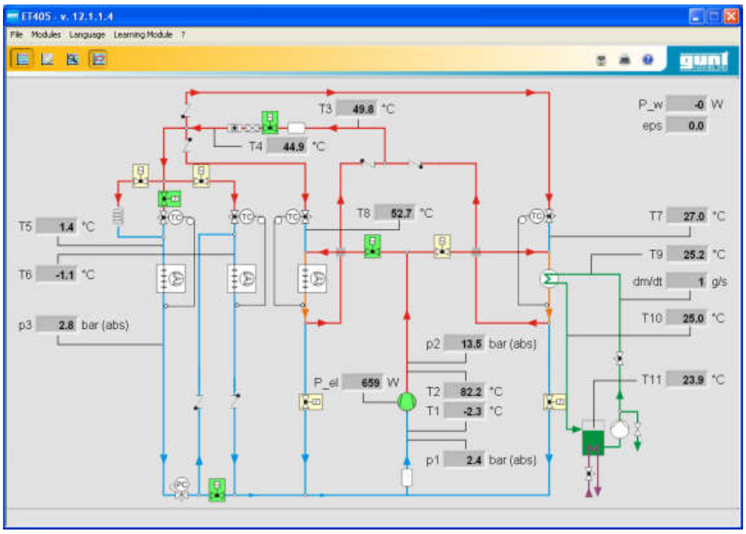
**Table 2.** Work modes for evaporators of the refrigerating unit W1& W2.

| Switch position | Work mode | V1 | V2 | V3 | V4 |
|---|---|---|---|---|---|
| **1** | No evaporator | 0 | 0 | 0 | 0 |
| **2** | Standard refrigerating W1 | 0 | 1 | 1 | 0 |
| **3** | Freezing W2 | 0 | 0 | 0 | 1 |
| **4** | Parallel mode: W1 & W2 with expansion valve | 0 | 1 | 1 | 1 |
| **5** | Parallel mode: W1 & W2 with a capillary | 1 | 0 | 0 | 0 |

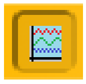
**Table 3.** Work modes for heat exchangers W3 & W4.

| Switch position | Work mode work | V5 | V6 | V7 | V8 | V9 |
|---|---|---|---|---|---|---|
| **1** | No W4, air-cooled condenser W3 | 1 | 0 | 0 | 0 | 1 |
| **2** | Cold water W4, air-cooled condenser W3 | 1 | 0 | 0 | 1 | 1 |
| **3** | Hot water W4, air-cooled condenser W3 | 0 | 1 | 1 | 0 | 1 |
| **4** | Hot water W4, no W3 | 0 | 1 | 0 | 0 | 1 |

### 3E. Software

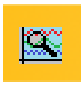


Software is utilized to record the results, observe the graphs and control process conditions. Icons for switching software functions:



**Graph of temperature & pressure change in time**

**Data recorder**



**Data browser**

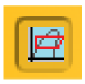


**Diagram log *p-h***

## 4. The course of exercise

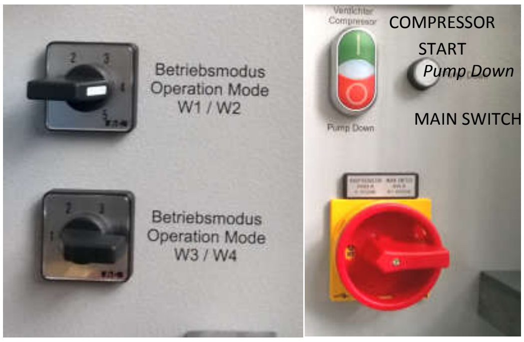
### A. Calculating the heat flux value and pump performance for an air-air heat pump.

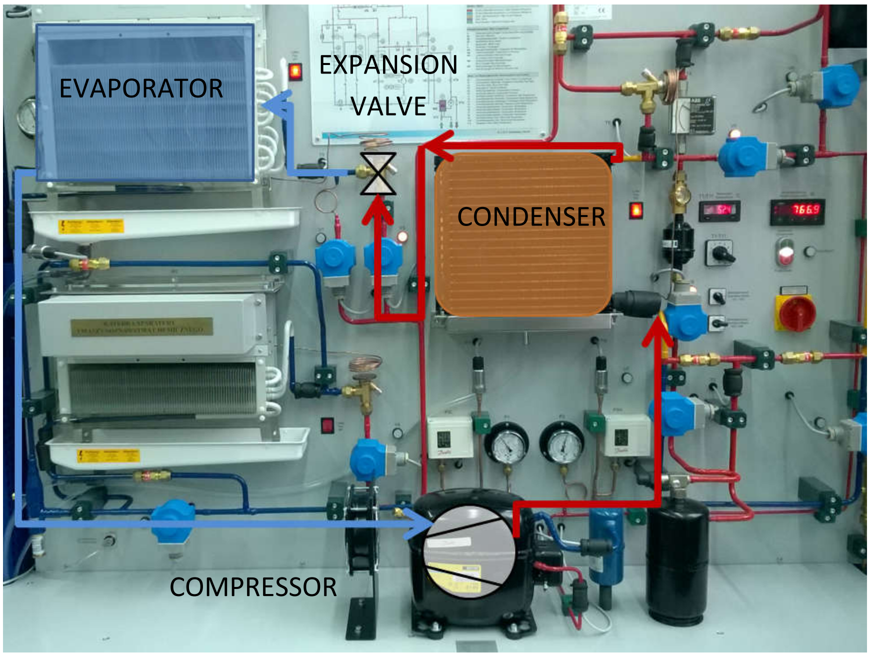
**A1. Turn on the system with the main switch.**

A2.Enable the fan in the **W1** evaporator and **W3** condenser. Then set the switch**W1/W2** in position **2**, and switch **W3/W4** in position **1**.

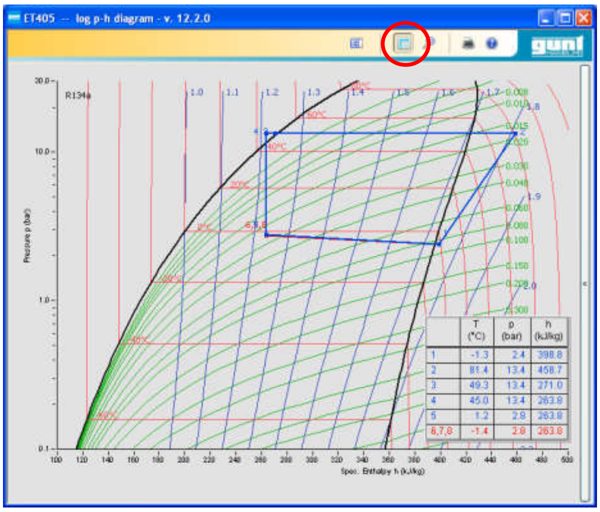
**A3. Enable the compressor.**

A4. After setting the switches, begin the measurement.




**After an equilibrium is achieved (compressor inlet pressure remains constant)switch to Diagram log *p-h* tab and open the data table.**



A5. Note all the values necessary to create a log *p-h* graph and to conduct the calculations (Table 1).

A6. Use the flow meter (**F1**) to read the volumetric medium flow rate $(\dot{V}_R)$.


**A7. Press the *Pump Down* switch and wait until the refrigerating agent is pumped out of the system**

A8. Calculate the value of bottom source heat flux($\dot{Q}_d$), as a product of the refrigerating agent's mass flow rate and the enthalpy difference on the evaporator.

$$\dot{Q}_d = (h_2 - h_4) \cdot \dot{m}_R$$

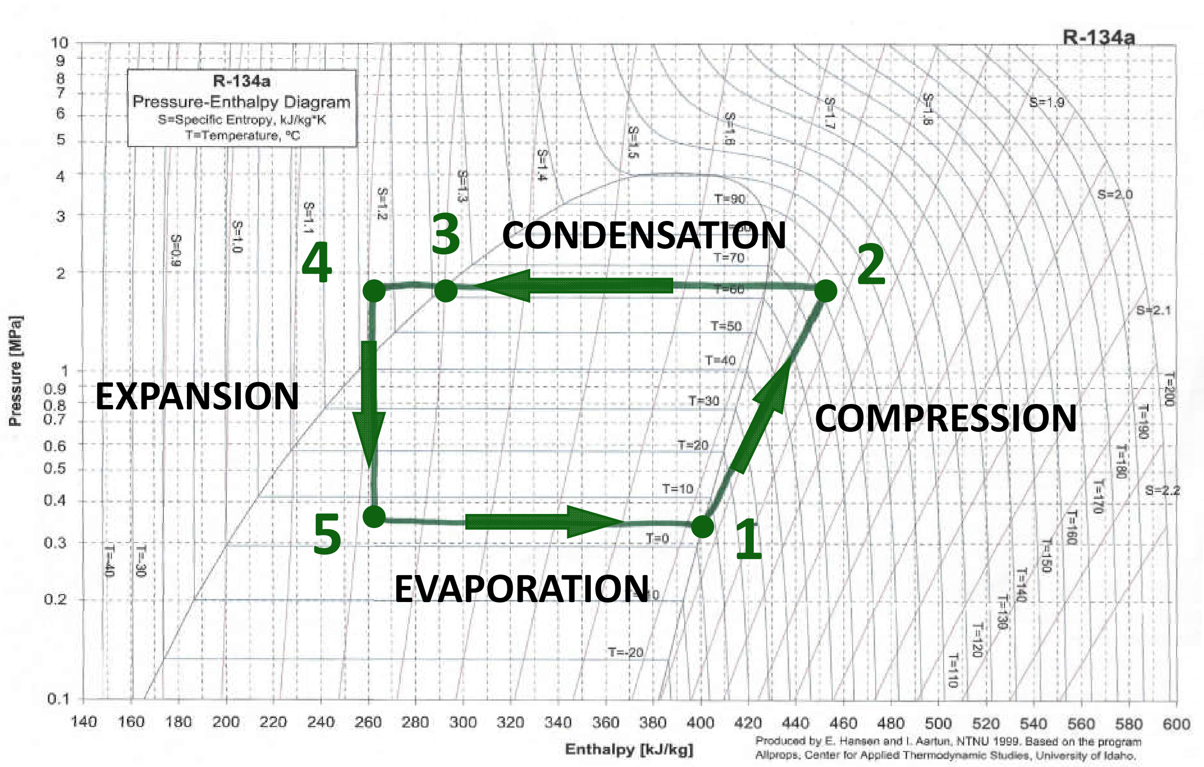
Top source heat flux ($\dot{Q}_g$)as a product of the refrigerating agent's mass flow rate ($\dot{m_r}$)and the enthalpy difference on the condenser, assuming that density is constant and $\rho_R$=1.12 kg/L.

$$\dot{Q}_g = (h_1 - h_5) \cdot \dot{m}_R$$
$$\dot{m}_R = \rho_R \cdot \dot{V}_R$$

Calculate the performance of the system's heat pump ($\varepsilon_{RS}$)as a quotient of heat flux from the top source to the power consumed by the compressor($P_{el}$).

$$\varepsilon_{RS} = \frac{\dot{Q}_g}{P_{el}}$$

A9. Draw the points 1-5 on the diagram attached to this instruction manual.




**A thermodynamic process is a set of consecutive transitions:**

1-2 – compressing the working fluid in the compressor;
2-3,4 – extracting heat from the bottom source (working fluid evaporation);
4-5 – working fluid decompression in the expansion valve;
5-1 – transferring heat to the top source (working fluid condensation).

**B. Calculating the heat flux value, performance and heat flux absorbed by water in an air-water heat pump.**

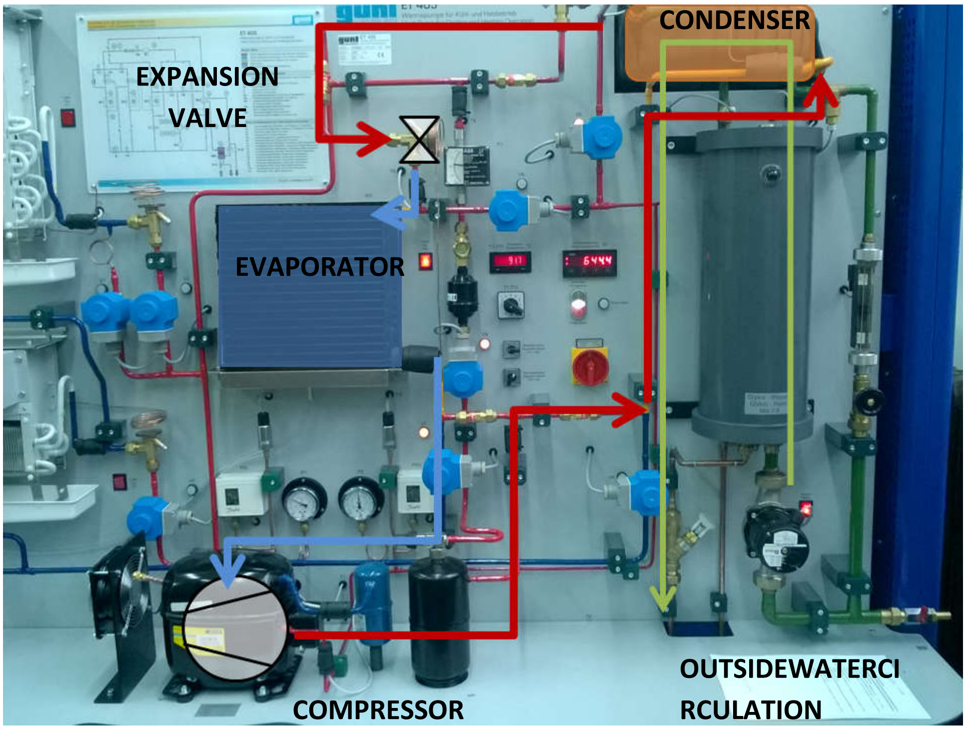

**B1. Turn on the system with the main switch.**

B2.Enable the fan in the **W3** evaporator. Then set the **W1/W2** switch in position **1**, and the **W3/W4** switch in position**3**.

**B3. Enable the pump.**

B4. Set the water flow rate through the heat exchanger (**V10**) $(\dot{m}_W)$to 30 g/s, and the outside circulation water flow rate to 8 L/min on the control valve (**V11**).

**B5. Enable the compressor.**




B6. After setting the switches, begin the measurement.

B7. After an equilibrium is achieved (compressor inlet pressure remains constant) note all the values necessary to create a log *p-h* graph and to conduct the calculations (Table 2). Use the flow meter (**F1**) to read the volumetric medium flow rate, as during exercise A.

**B8. Press the Pump Down switch and wait until the refrigerating agent is pumped out of the system.**

B9. Calculate the value of top source heat flux, as a product of the refrigerating agent's mass flow rate and the enthalpy difference on the condenser, assuming that density is constant and $\rho_R$=1.12 kg/dm$^3$

$$\dot{Q}_g = (h_1 - h_5) \cdot \dot{m}_R$$
$$\dot{m}_R = \rho_R \cdot \dot{V}_R$$

Also calculate the performance of heat pump in the system as a quotient of heat flux from the top source to the power consumed by the compressor.

$$\varepsilon_{RS} = \frac{\dot{Q}_g}{P_{el}}$$

Finally, calculate the amount of heat absorbed by water($\dot{Q_{C_W}}$) in the presented air-water system, as a product of water mass flow rate($\dot{m_W}$), water's specific heat ($C_{p_W}$)and temperature differenceon the water exchanger($\Delta T_W$).

$$\dot{Q_{C_W}} = \Delta T_W \cdot \dot{m_W} \cdot C_{p_W}$$

B10. Draw the points 1-5 on the diagram attached to this instruction manual, as in exercise A.

## 5. Literature:


[1] Ewa Klugmann-Radziemska, Odnawialne źródła energii - przykłady obliczeniowe, Wydanie V, Wydawnictwo Politechniki Gdańskiej 2015

[2] ET 405 Heat Pump for Cooling and Heating Operation, G.U.N.T. Gerätebau, Barsbüttel, Germany 2015