Spotkaniu Klastrów Ekoenergetycznych

Bałtycki Klaster Ekoenergetyczny

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Ejection systems new approach for solar air-conditioning

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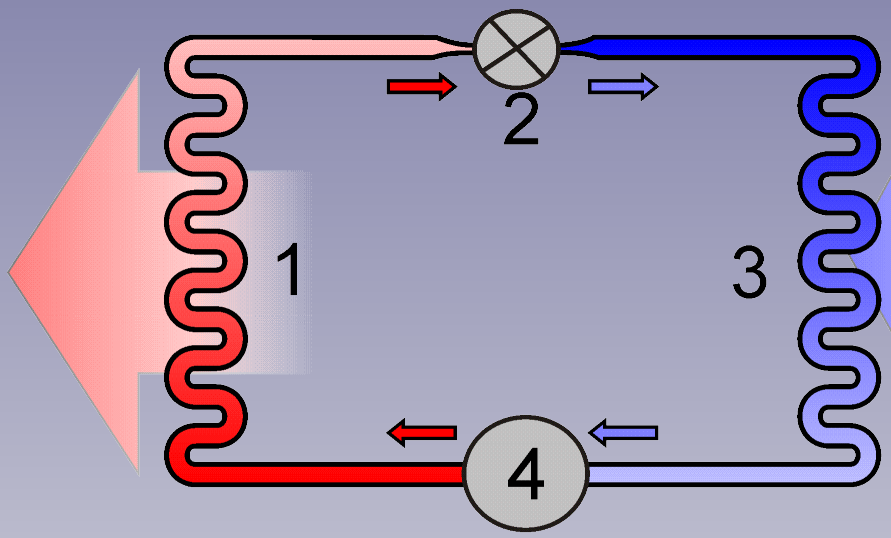
Plan of presenttion

- Introduction: solar RAC
- Concept of application of ejection systems
- Solar ejection AC systems
- Solar-based polygeneration unit
- CCHP system in large scale
- Remarks concerning working fluids and environmental impact measures
- Conclusions

1. Introduction: solar RAC

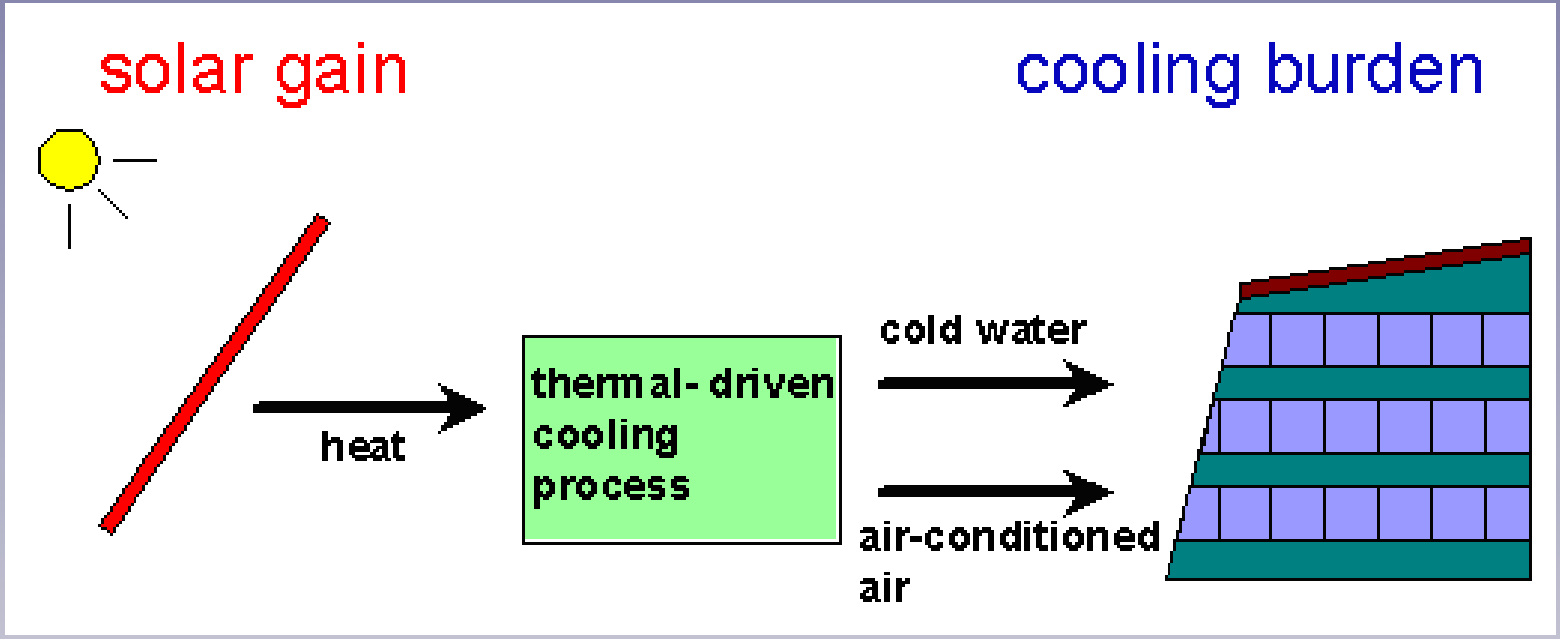


Compression RAC (classic approach):

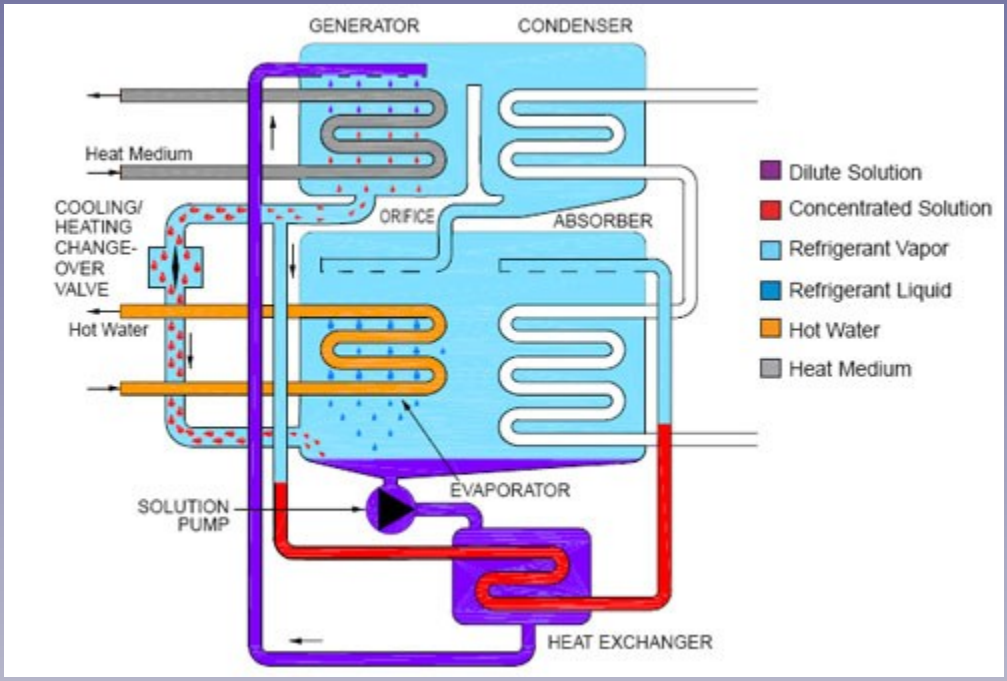
- electric energy driven systems;
- synthetic fluids are used (high GWP);
- large energy consumption;
- the environment benefits

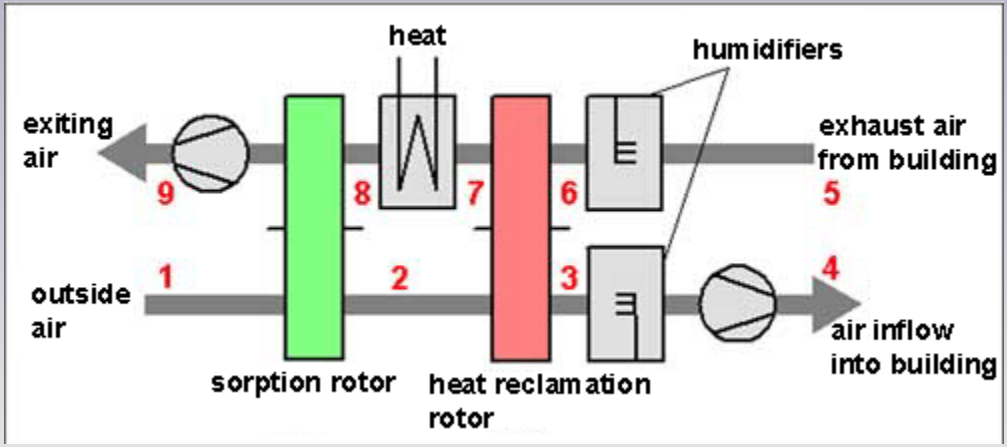
depend on the power plant efficiency .

Solar based thermal driven cycles for RAC

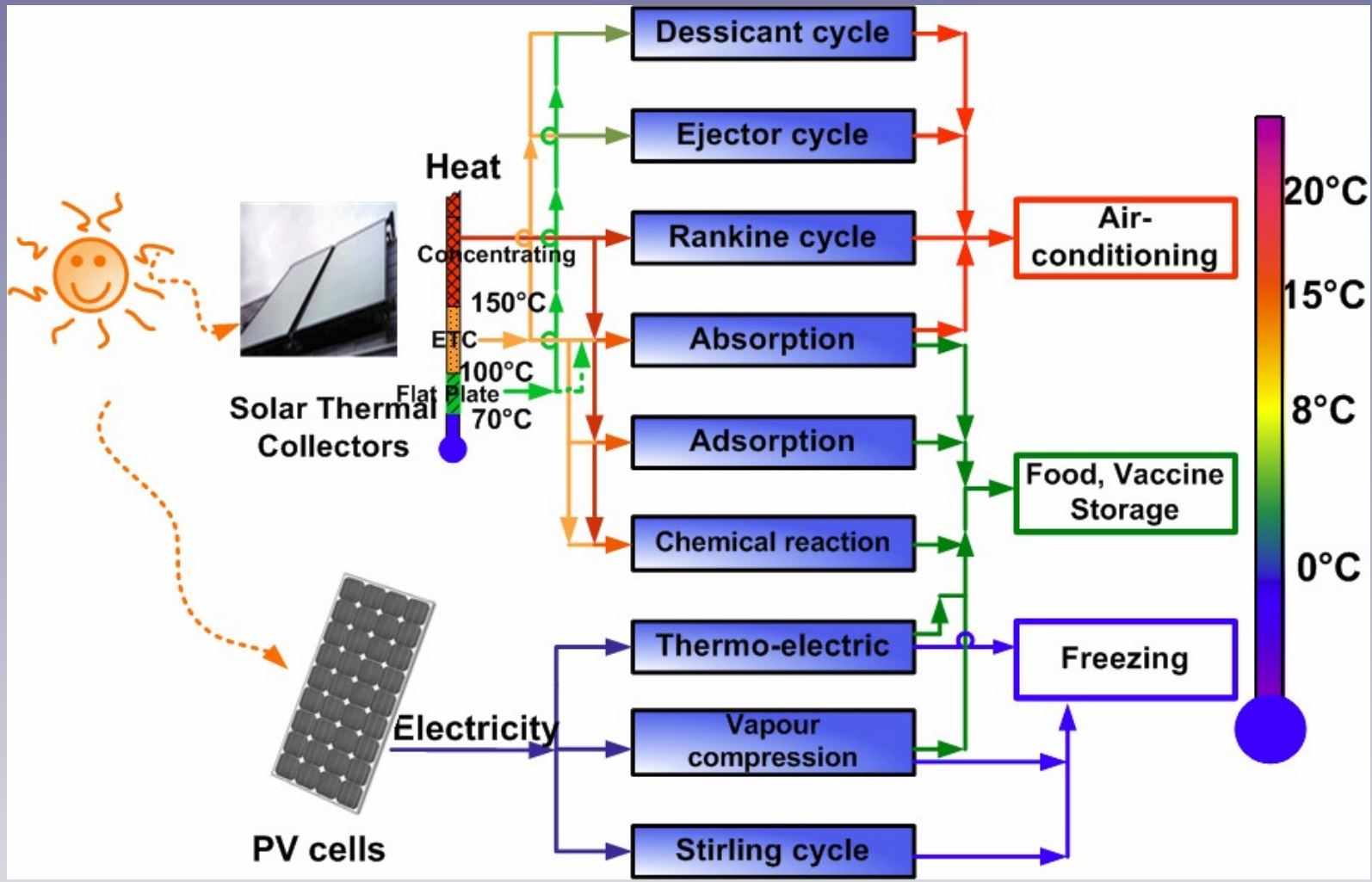


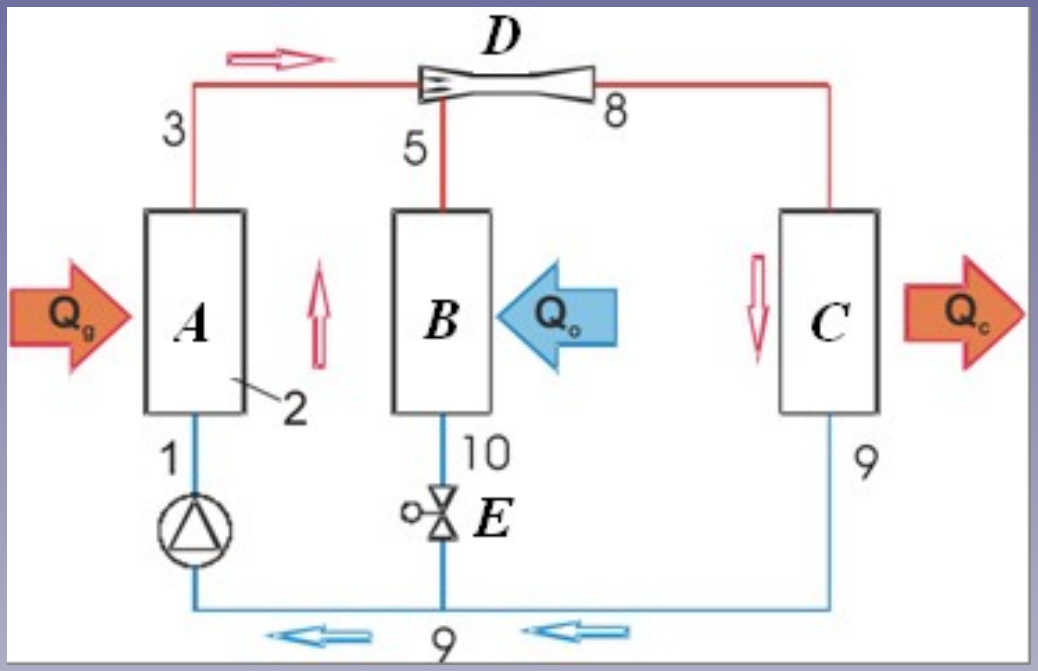
Typical soprtion systems: absorption or adsorption

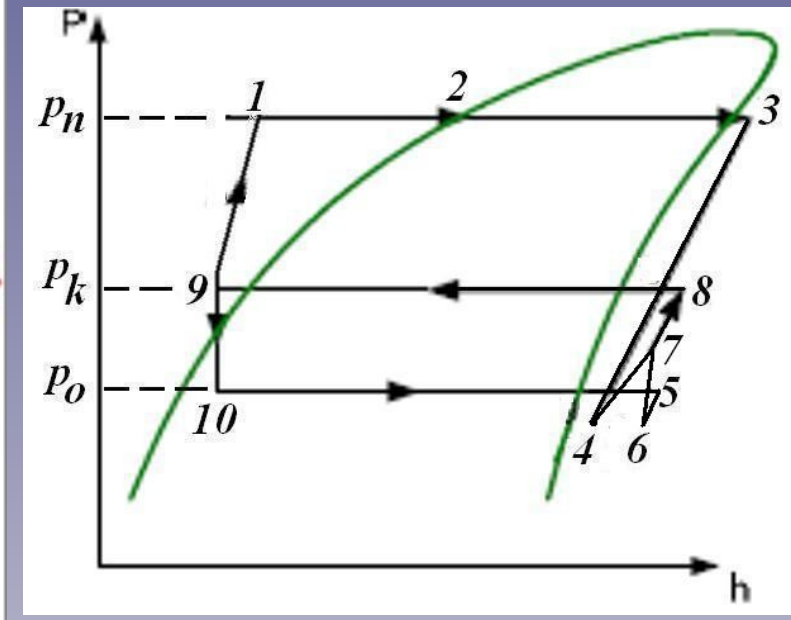


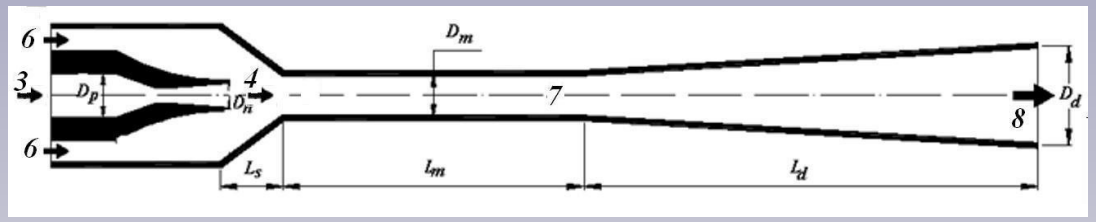


2. Ejection cooling systems



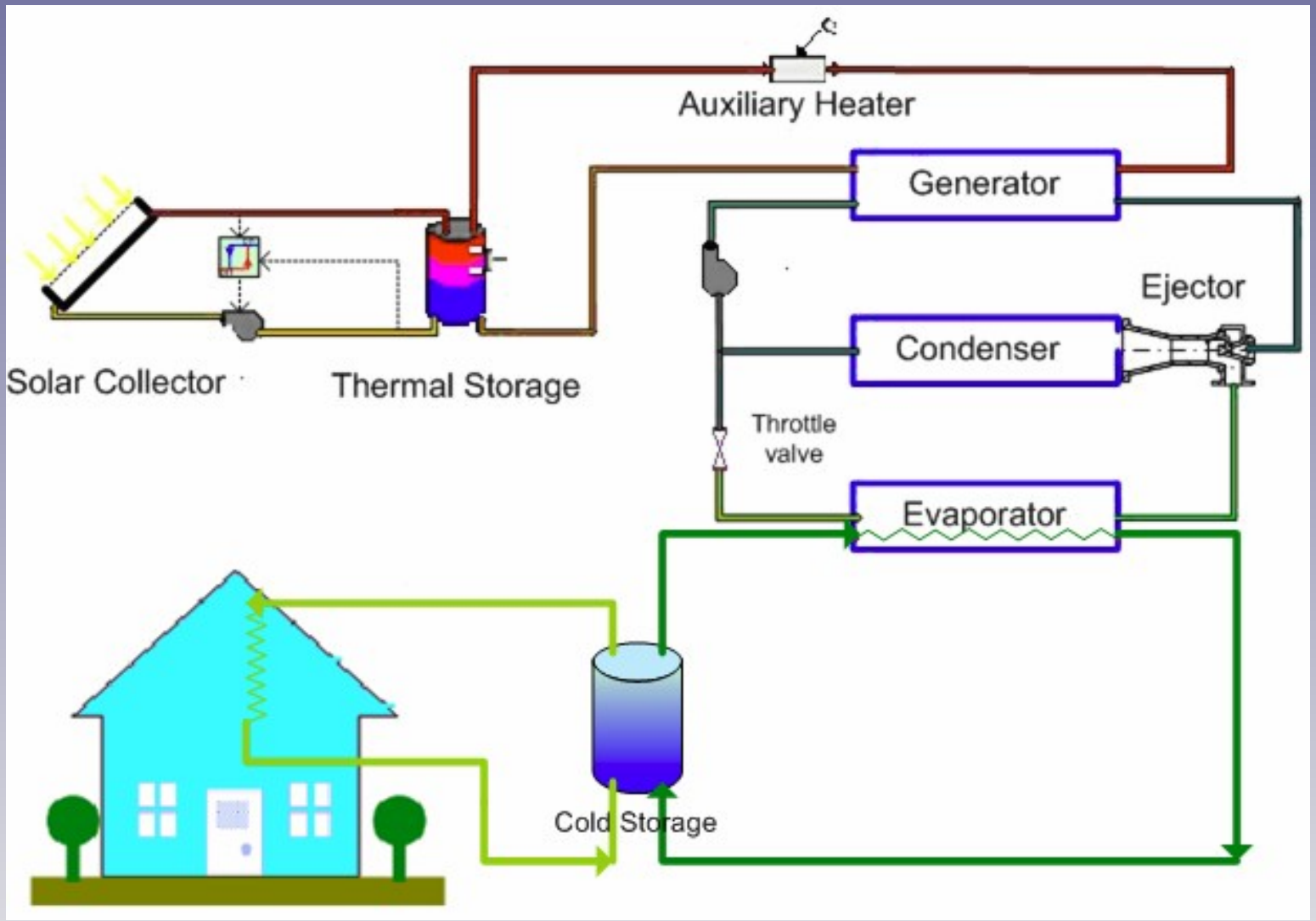


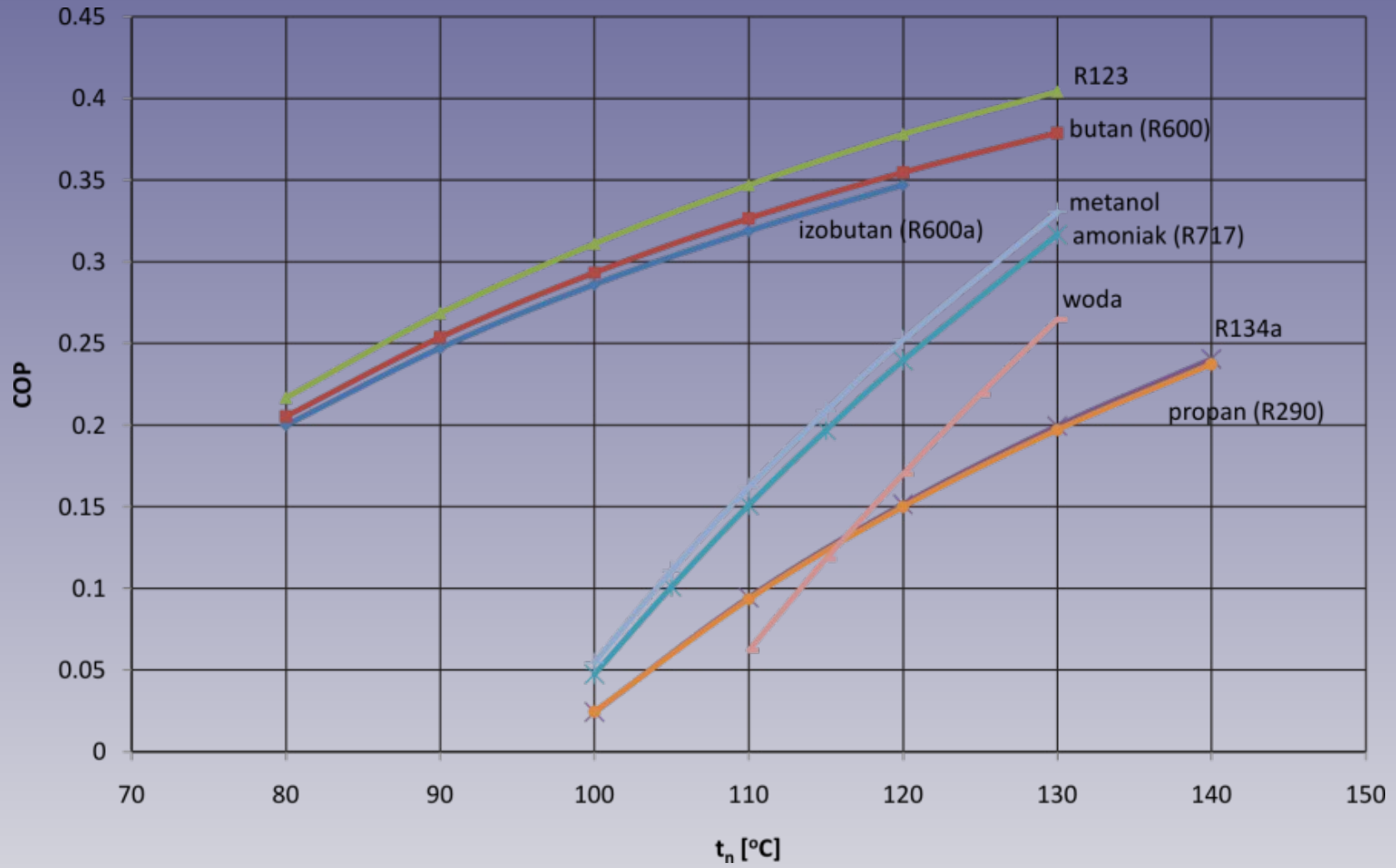


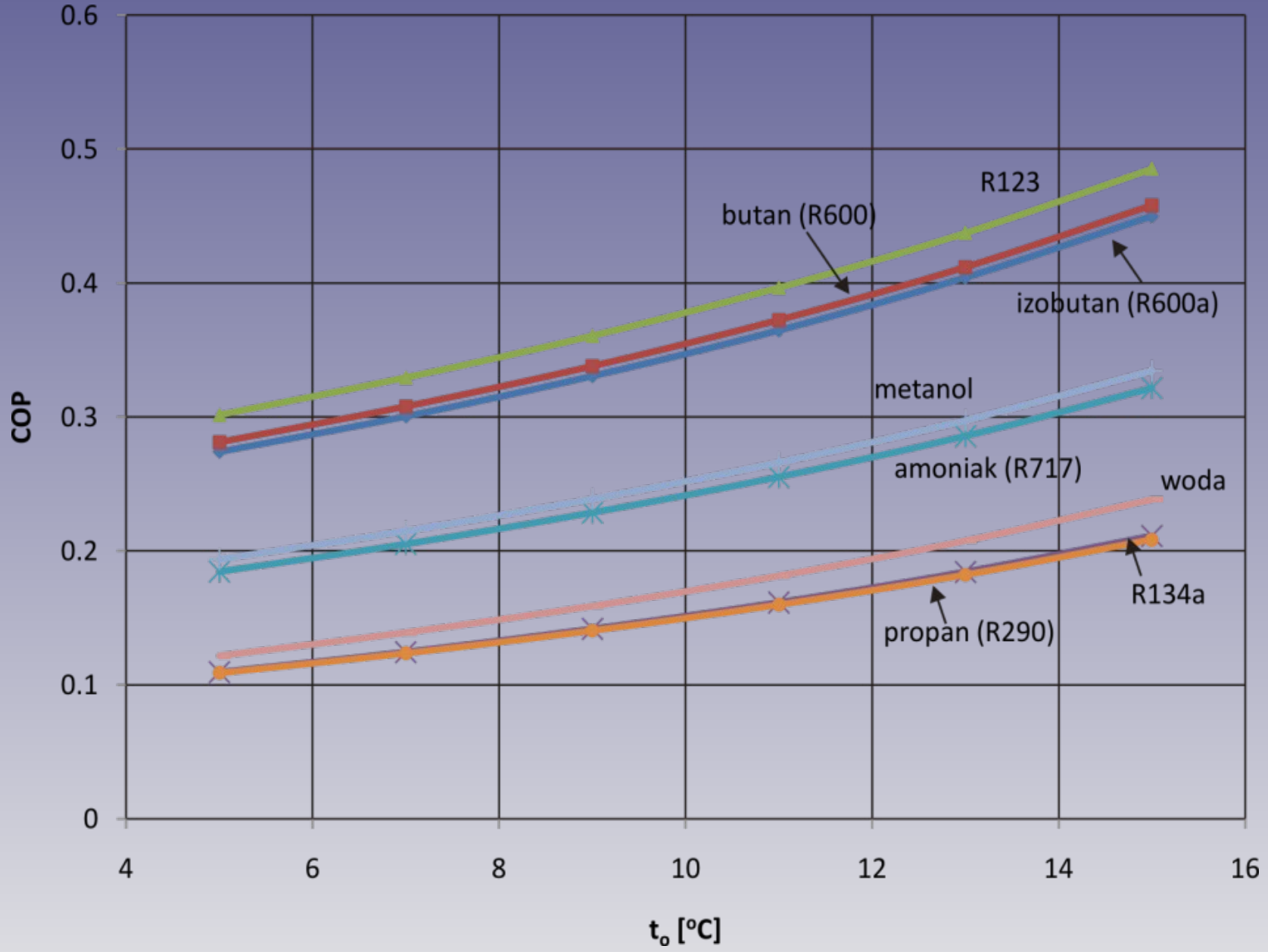


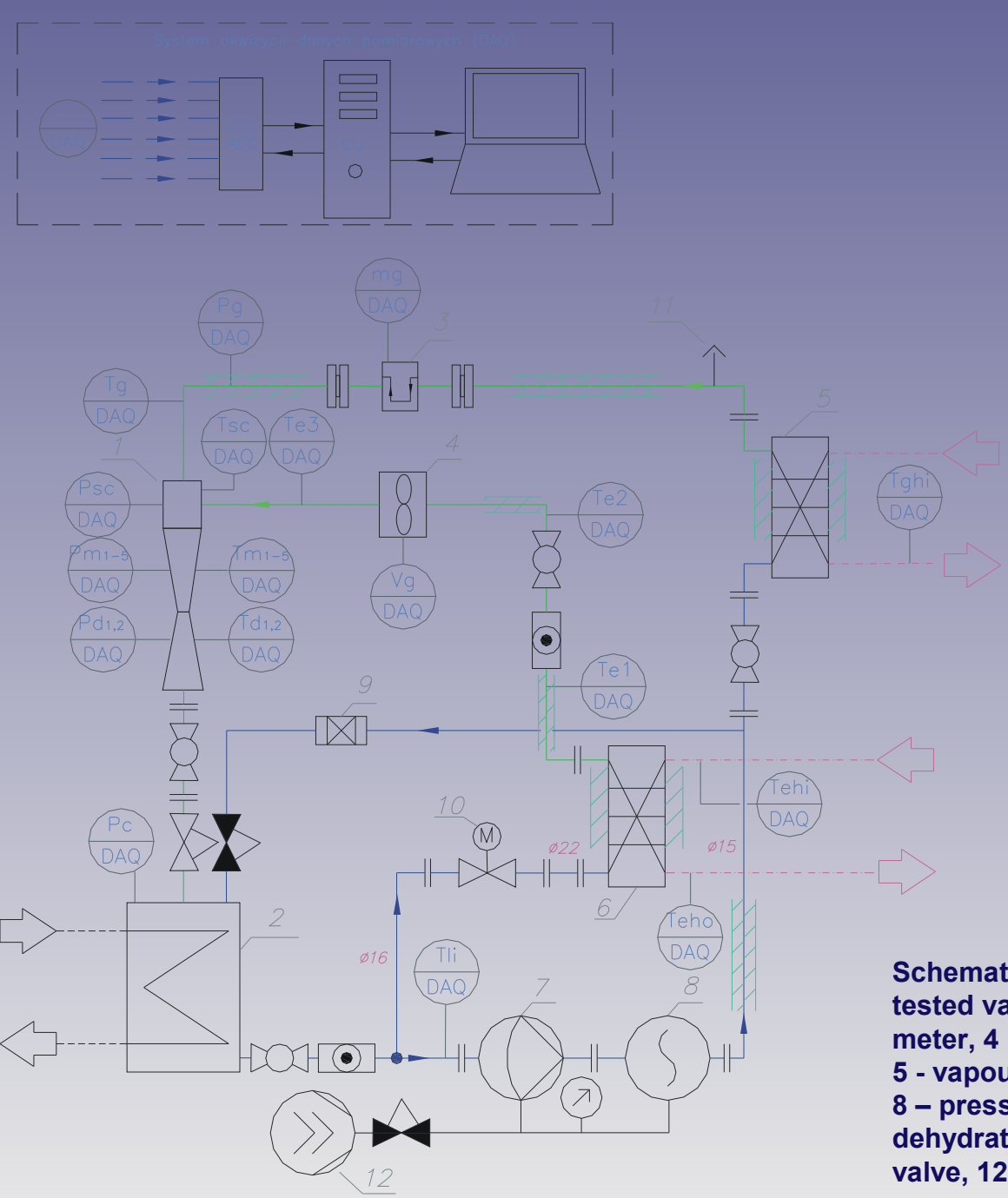
Schematic diagram of ejection solar air-conditioning system

3. Solar AC systems



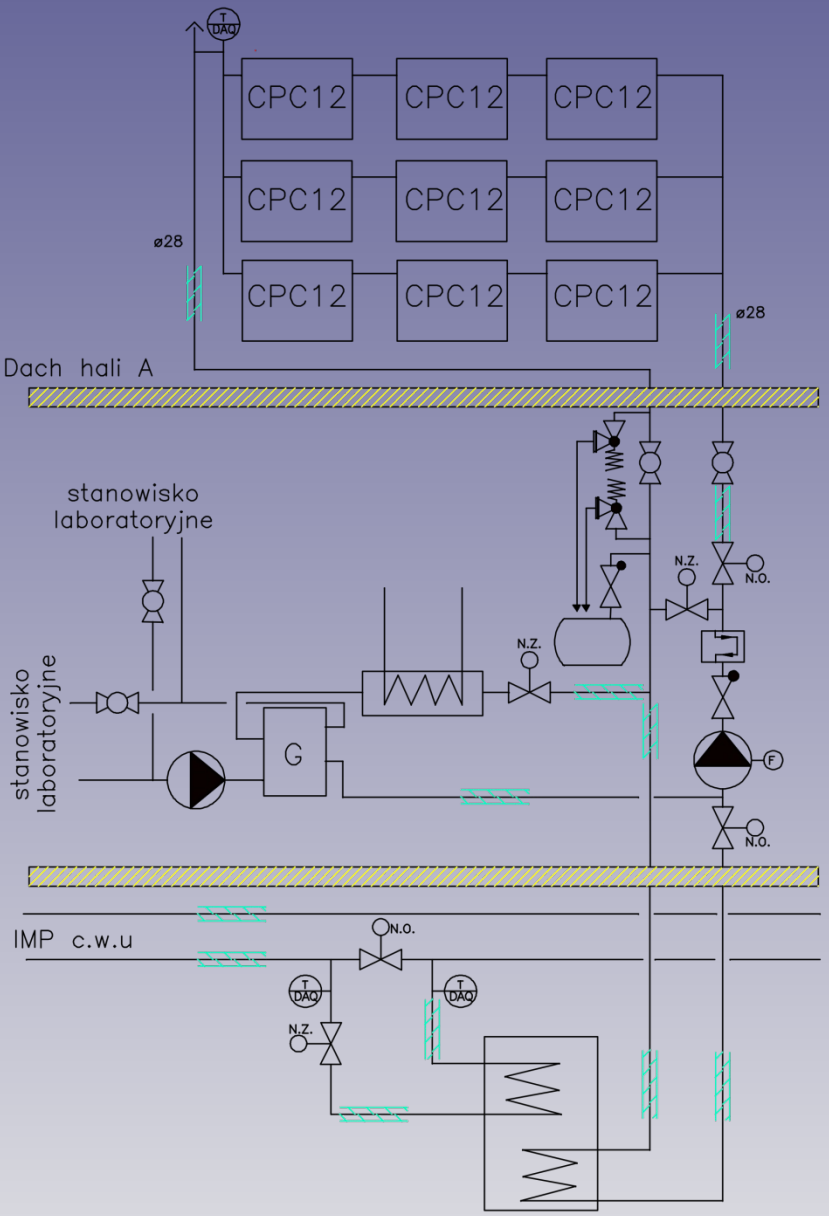

0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
COP
70
80
90
100
110
120
130
140
150
t_n [°C]
R123
butan (R600)
izobutan (R600a)
metanol
amoniak (R717)
woda
R134a
propan (R290)


0.6
0.5
0.4
0.3
0.2
0.1
0
COP
4
6
8
10
12
14
16
t_o [°C]
R123
butan (R600)
izobutan (R600a)
metanol
amoniak (R717)
woda
R134a
propan (R290)

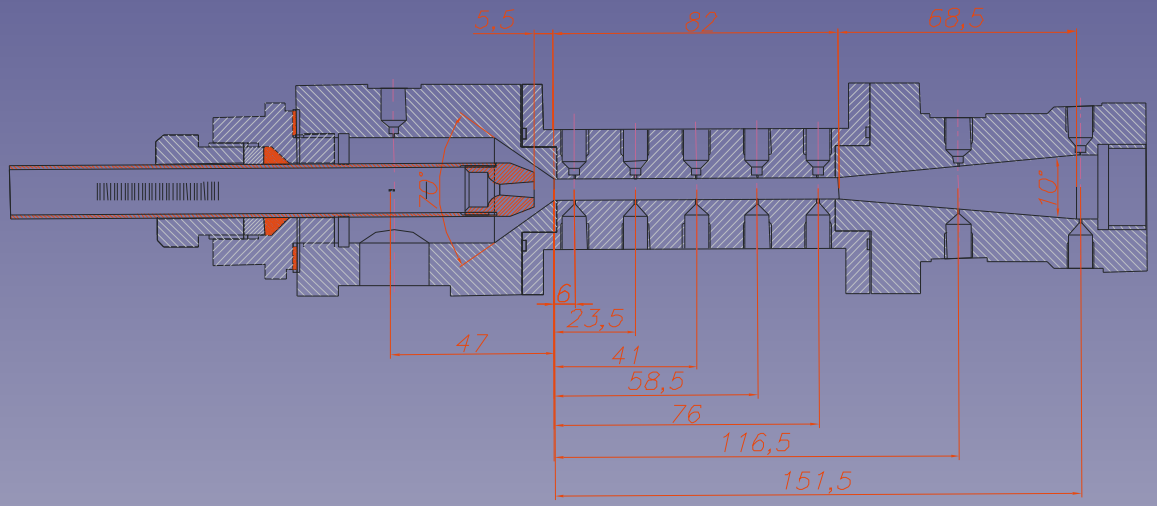


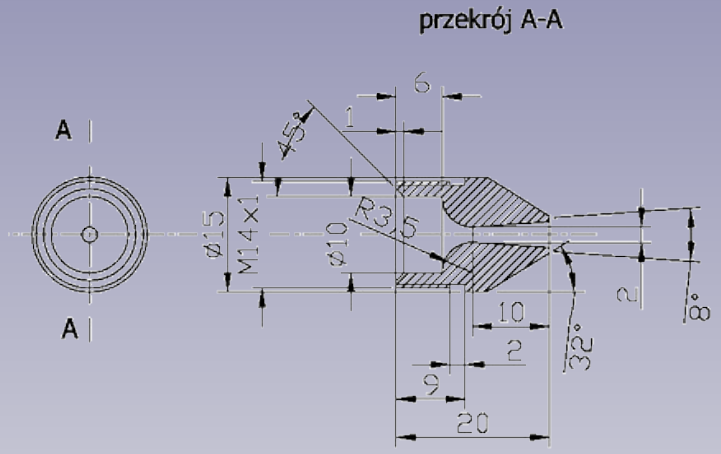
Schematic diagram of the ejector testing stand: 1 – tested vapour ejector , 2 - condenser, 3 - mass flow-meter, 4 - volumetric flow-meter, 5 - vapour generator, 6 - evaporator, 7 - diaphragm pump, 8 – pressure dumper, 9 – mechanical filter and dehydrator, 10 - electronic control valve, 11 – purging valve, 12 – air compressor.

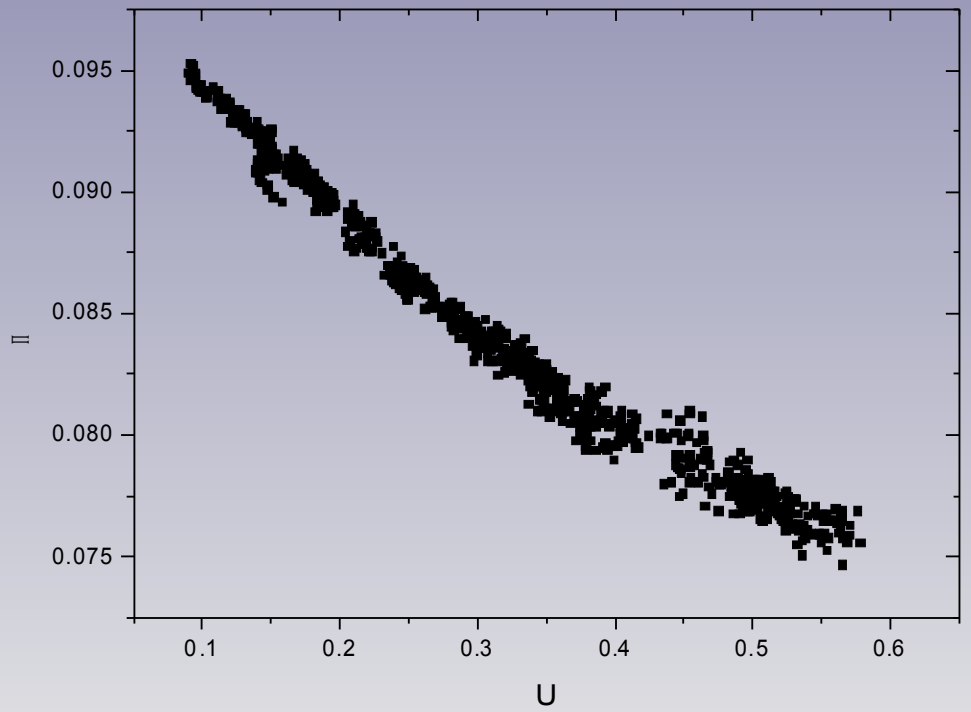
Photograph of testing stand



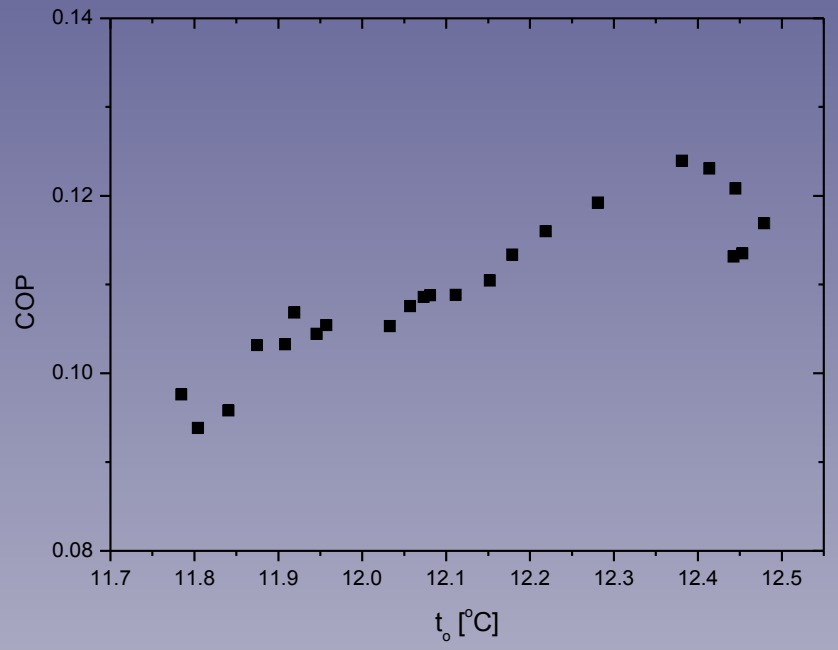
Solar collectors (18 kW, 180 °C)



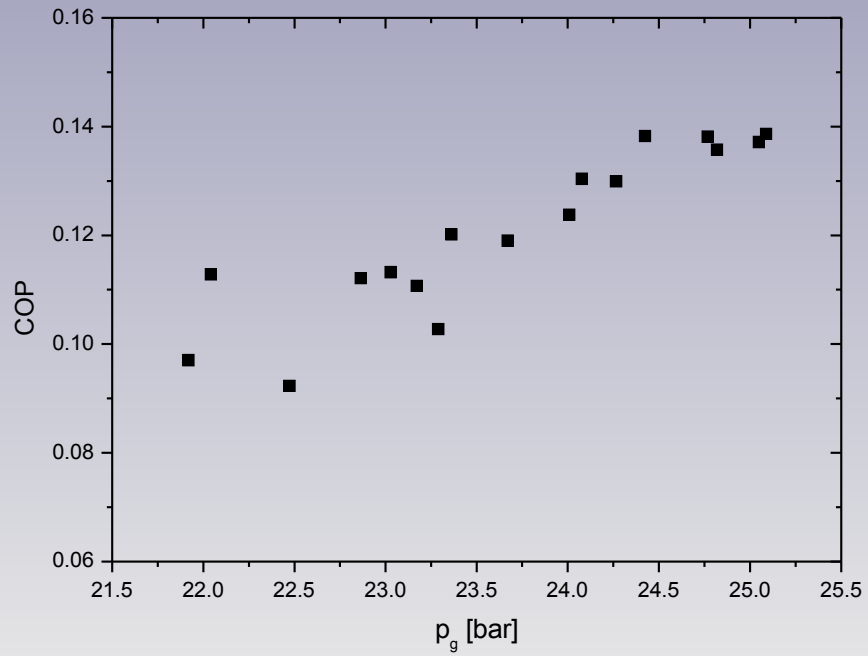




The exemplary results: dependence of the compression ratio Π versus the mass entrainment ratio U for the following operating conditions: generator pressure p_n = 4.68 bar, condenser pressure p_k = 1.26 bar, evaporator pressure p_o = 0.86 bar, mass flow rate of the motive vapour 329 kg/h.

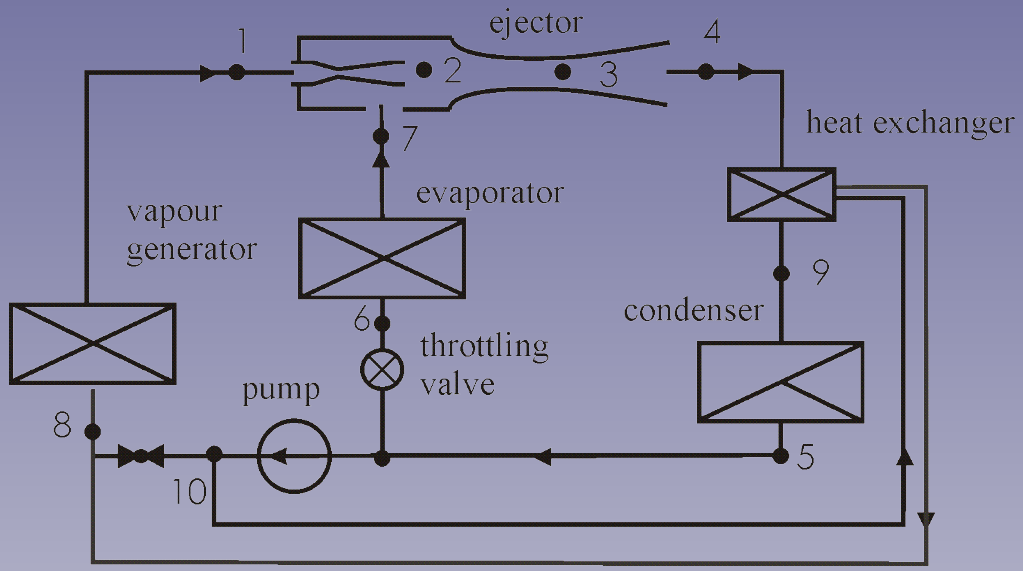


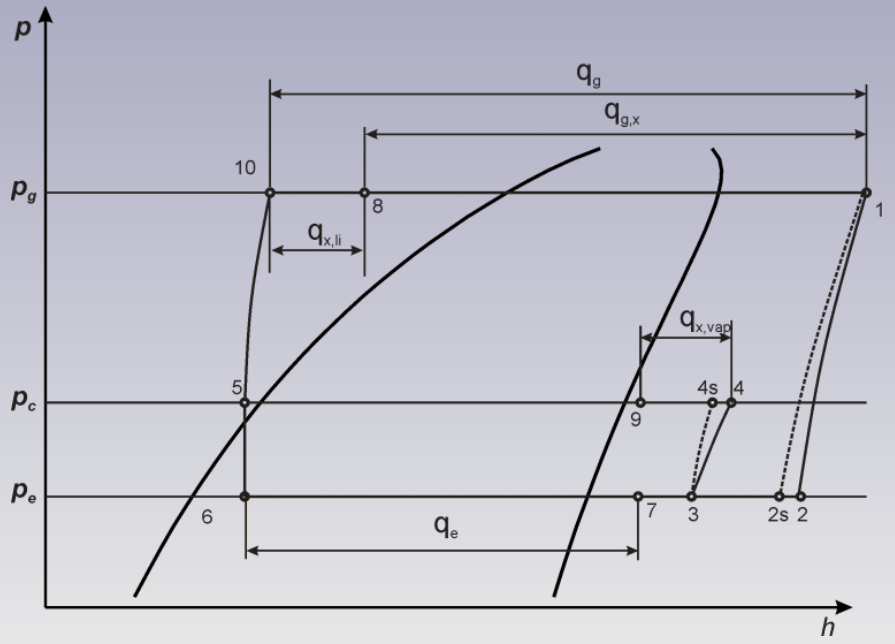
COP vs. evaporation temperature for constant condensation pressure p_c = 11.4 bar and constant motive enthalpy difference $\Delta h = h_g - h_o$ = 24.95 kJ/kg

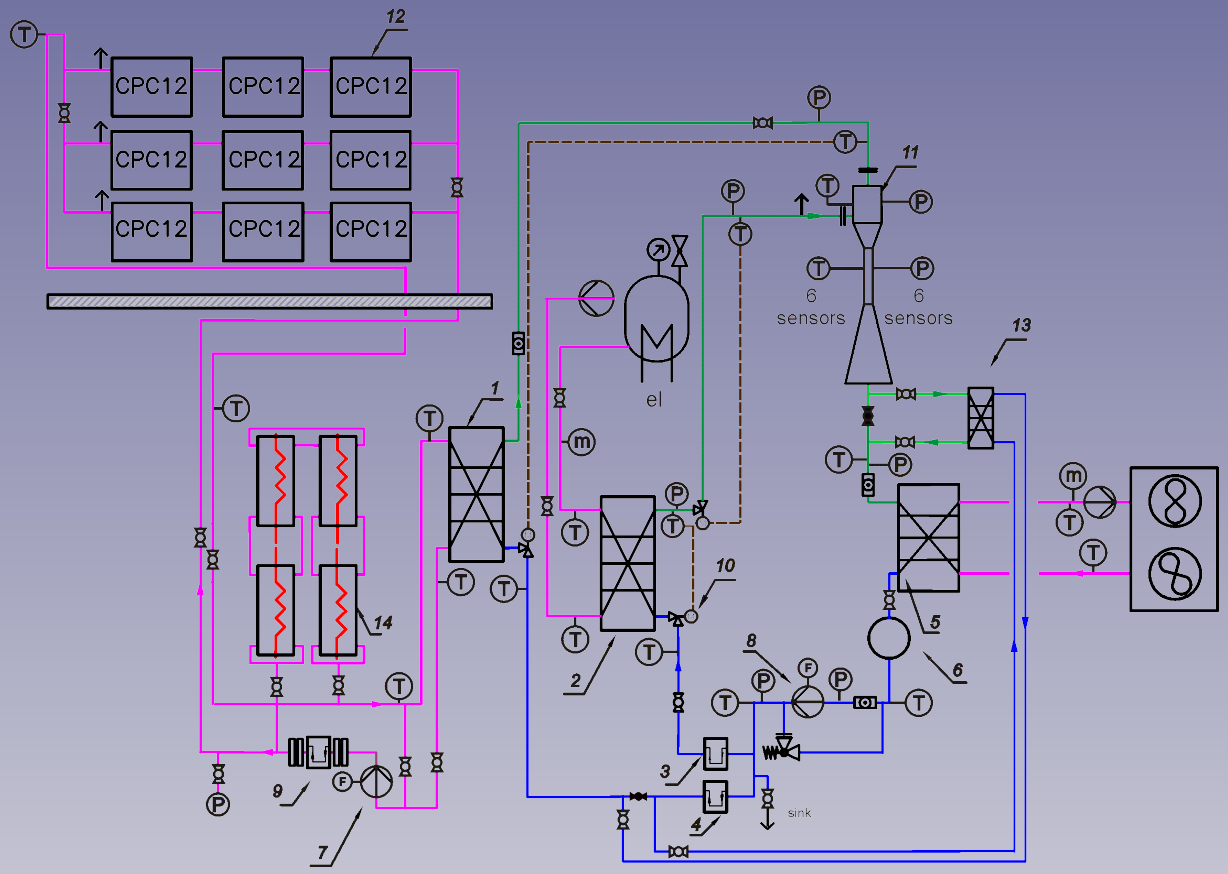


COP vs. motive pressure p_g for constant condensation pressure p_c = 11.21 bar and various evaporation pressure

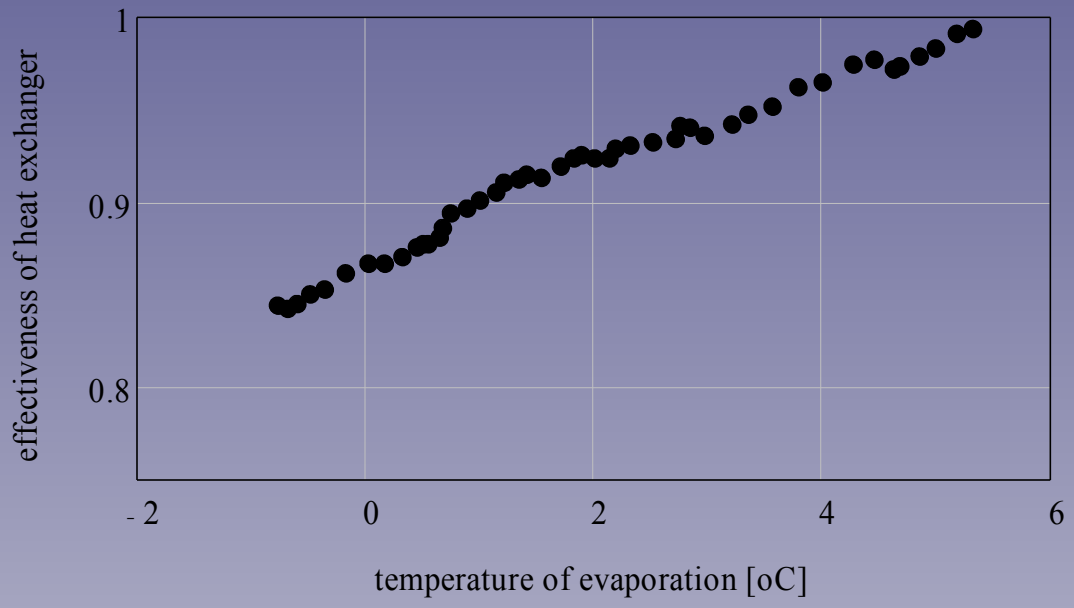
Improving of COP of ejection system by means of hot internal heat exchanger

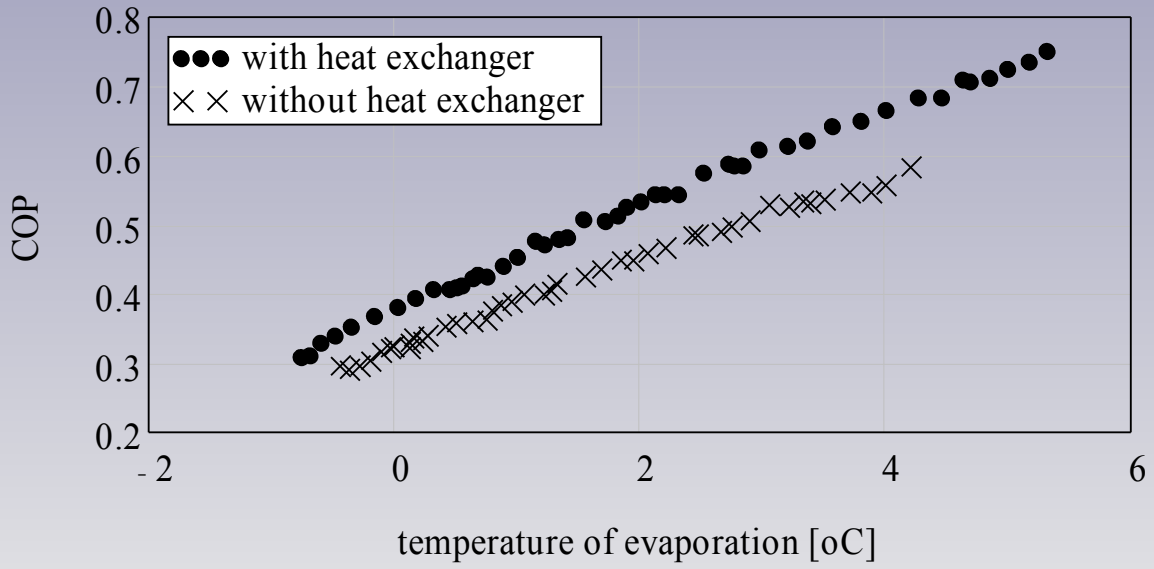




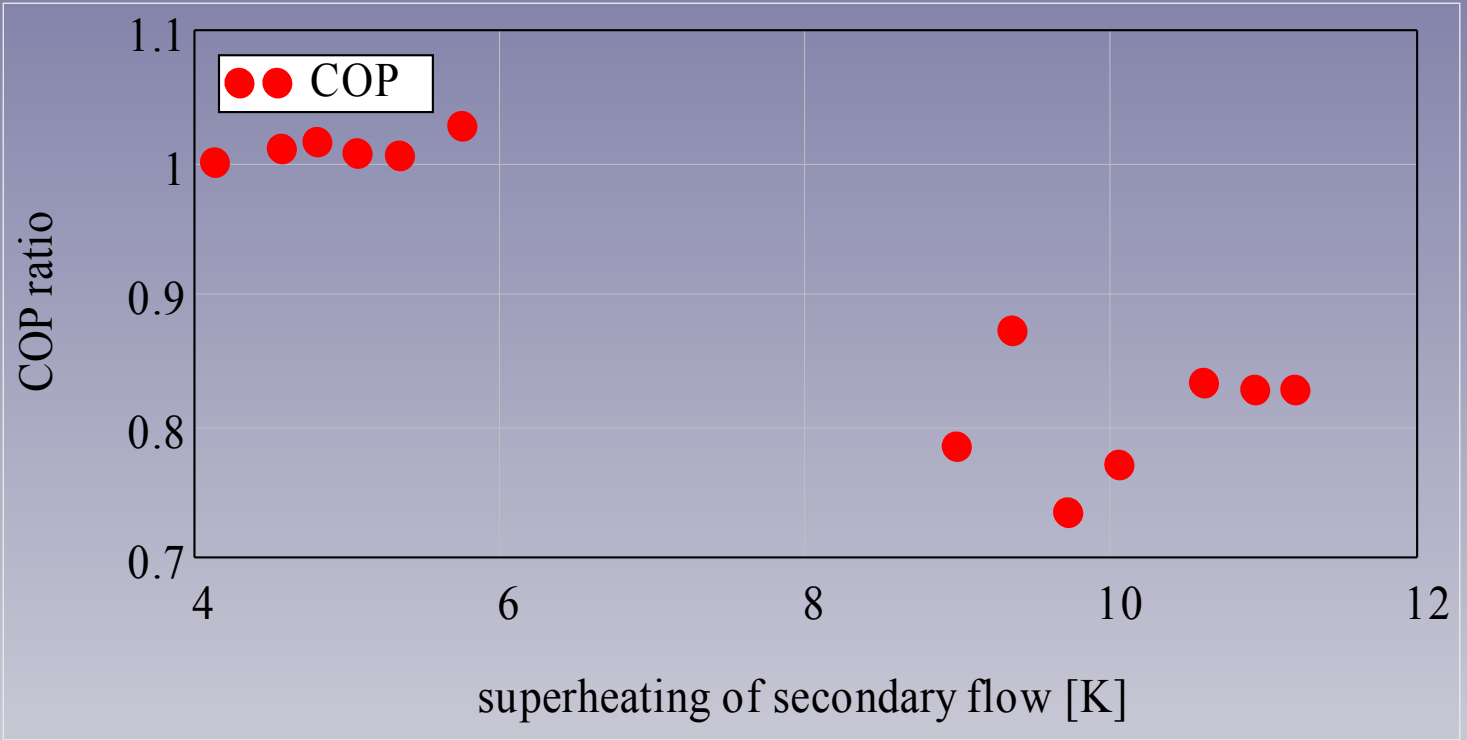


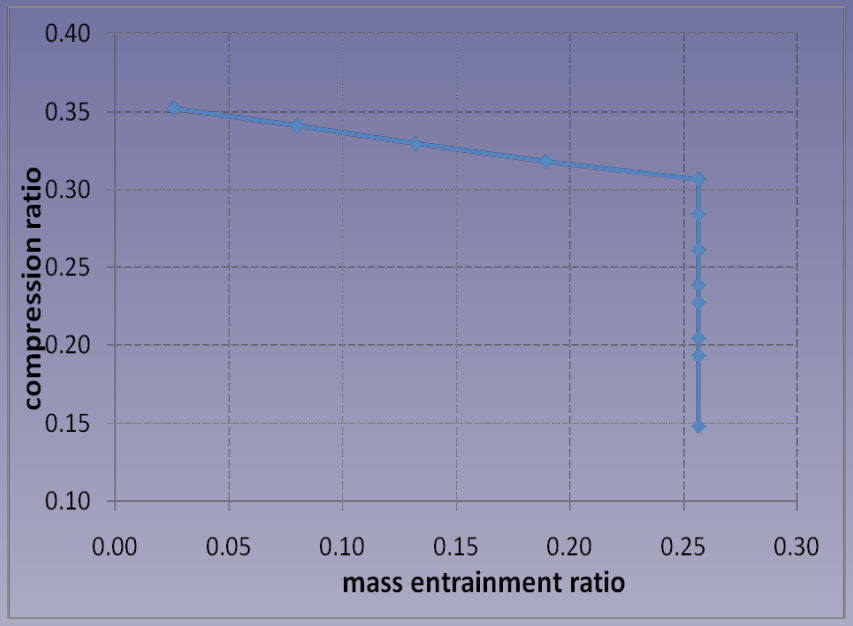
Schematic diagram of testing stand, *1* – vapour generator, *2* – evaporator, 3 – secondary fluid mass flowmeter, 4- primary fluid mass flowmeter, 5 – condenser, 6 – liquid refrigerant storage, 7 - glycol pump, 8 - refrigerant pump, 9 - glycol mass flowmeter, 10 – throttling valve, 11 – ejector, 12 – solar collectors, 13 – internal heat exchanger, 14 – electric heater


effectiveness of heat exchanger
1
0.9
0.8
- 2
0
2
4
6
temperature of evaporation [oC]

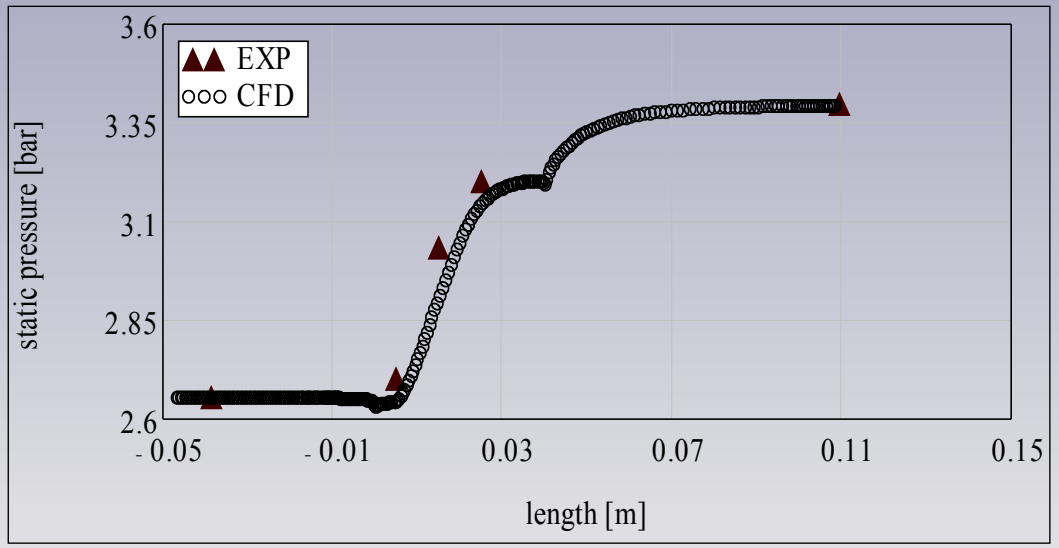

COP
0.8
0.7
0.6
0.5
0.4
0.3
0.2
with heat exchanger
without heat exchanger
- 2
0
2
4
6
temperature of evaporation [oC]

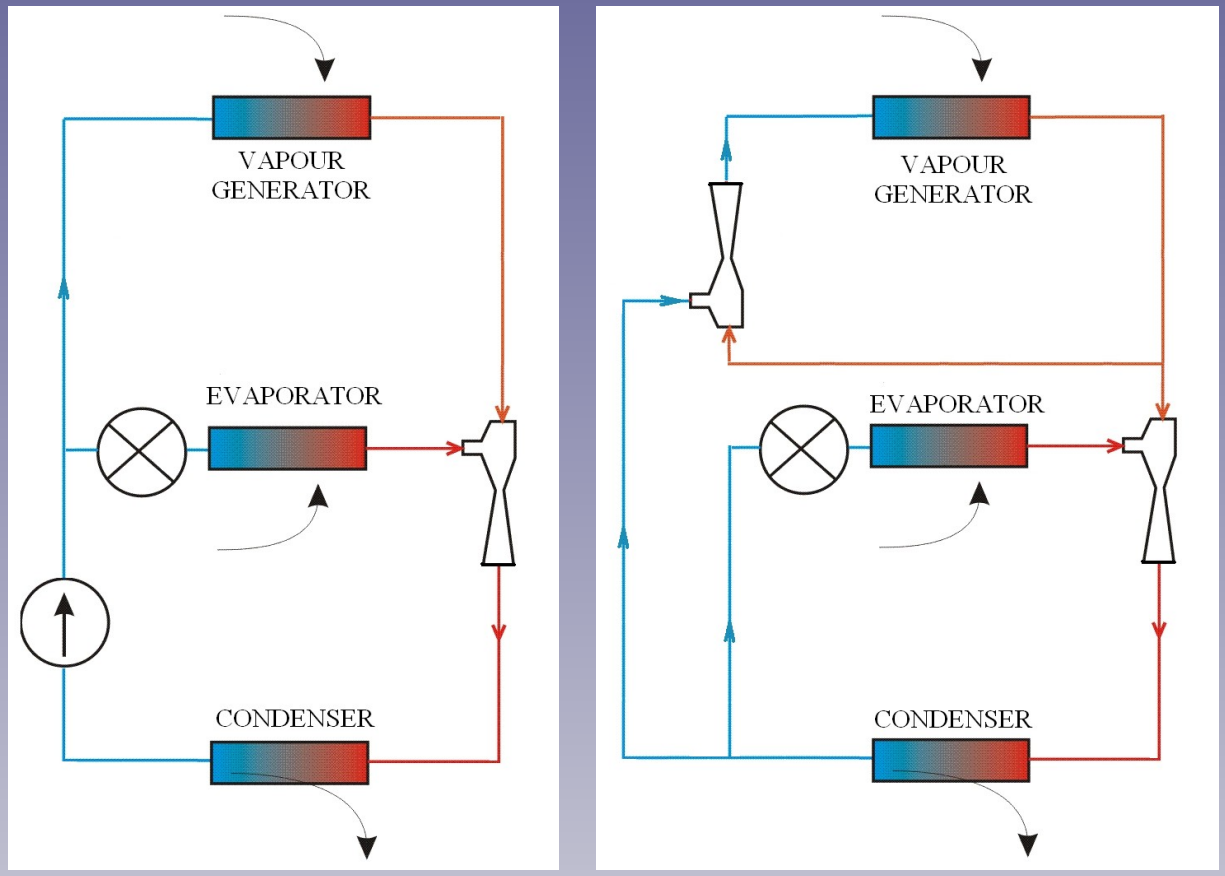
Effect of superheating of the secondary flow





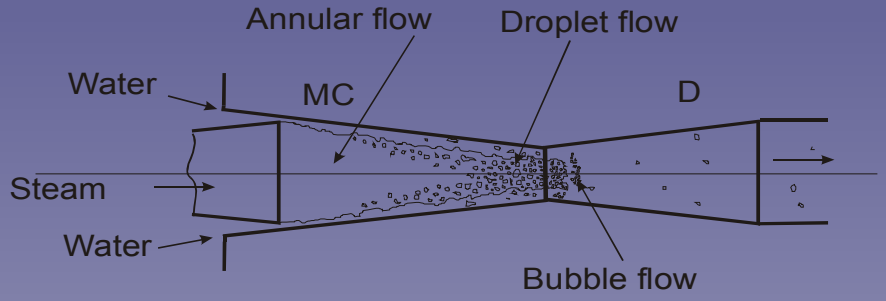
CFD modelling of the ejector under on-design and off-design conditions (for isobutane)



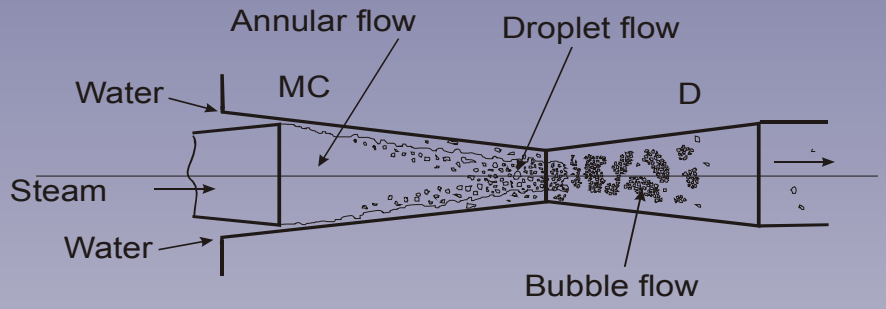


Ejection refrigeration cycle:
a) classic with mechanical liquid pump;
b) fully thermal driven cycle with vapour-liquid injector

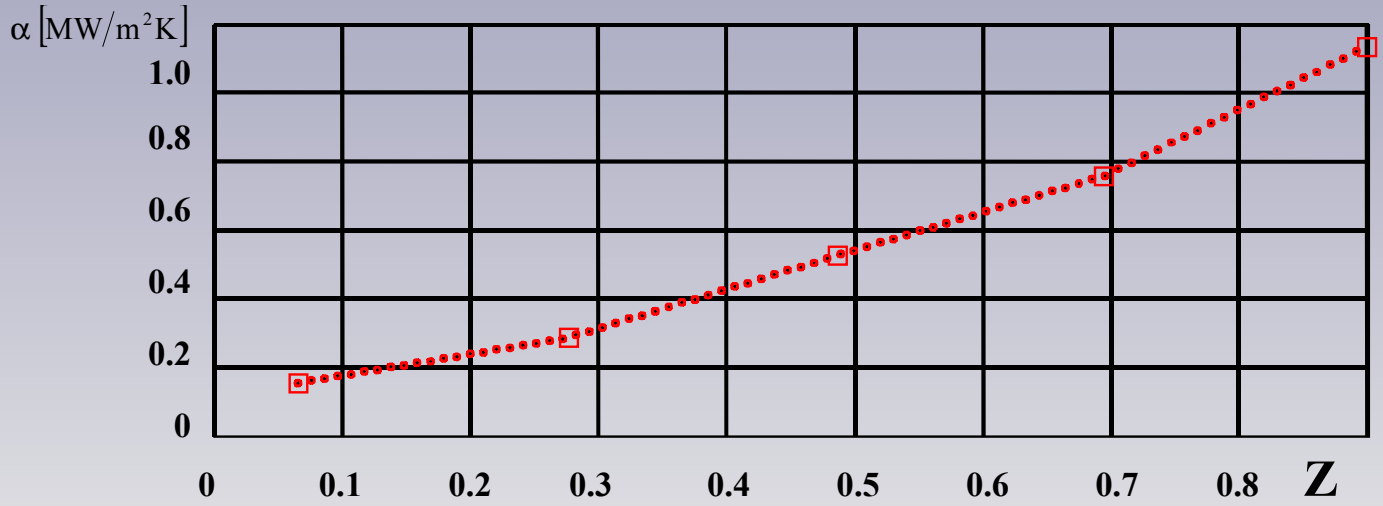
Investigation of steam-water ejection pump



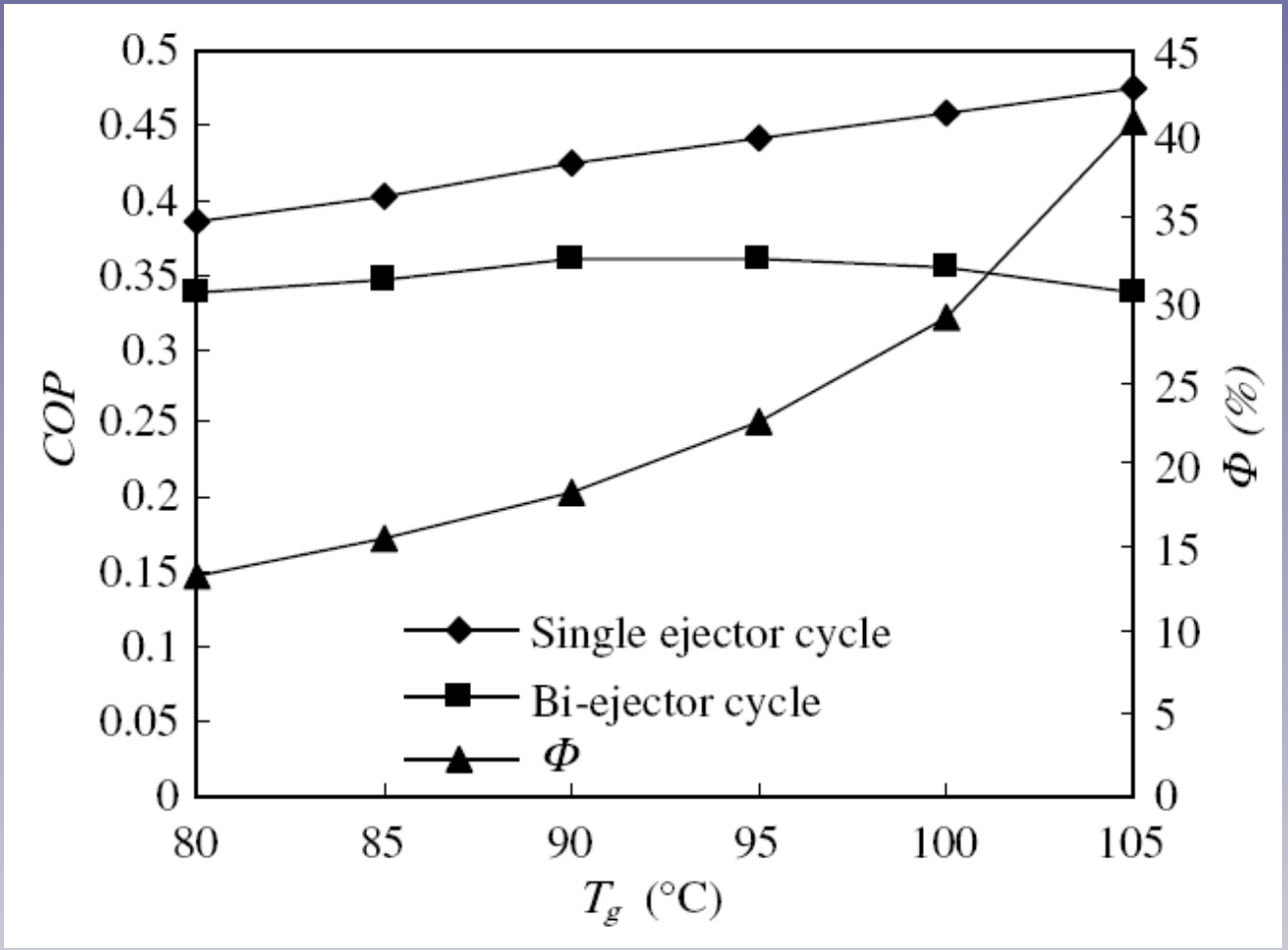
a) High back pressure.



b) Low back pressure.

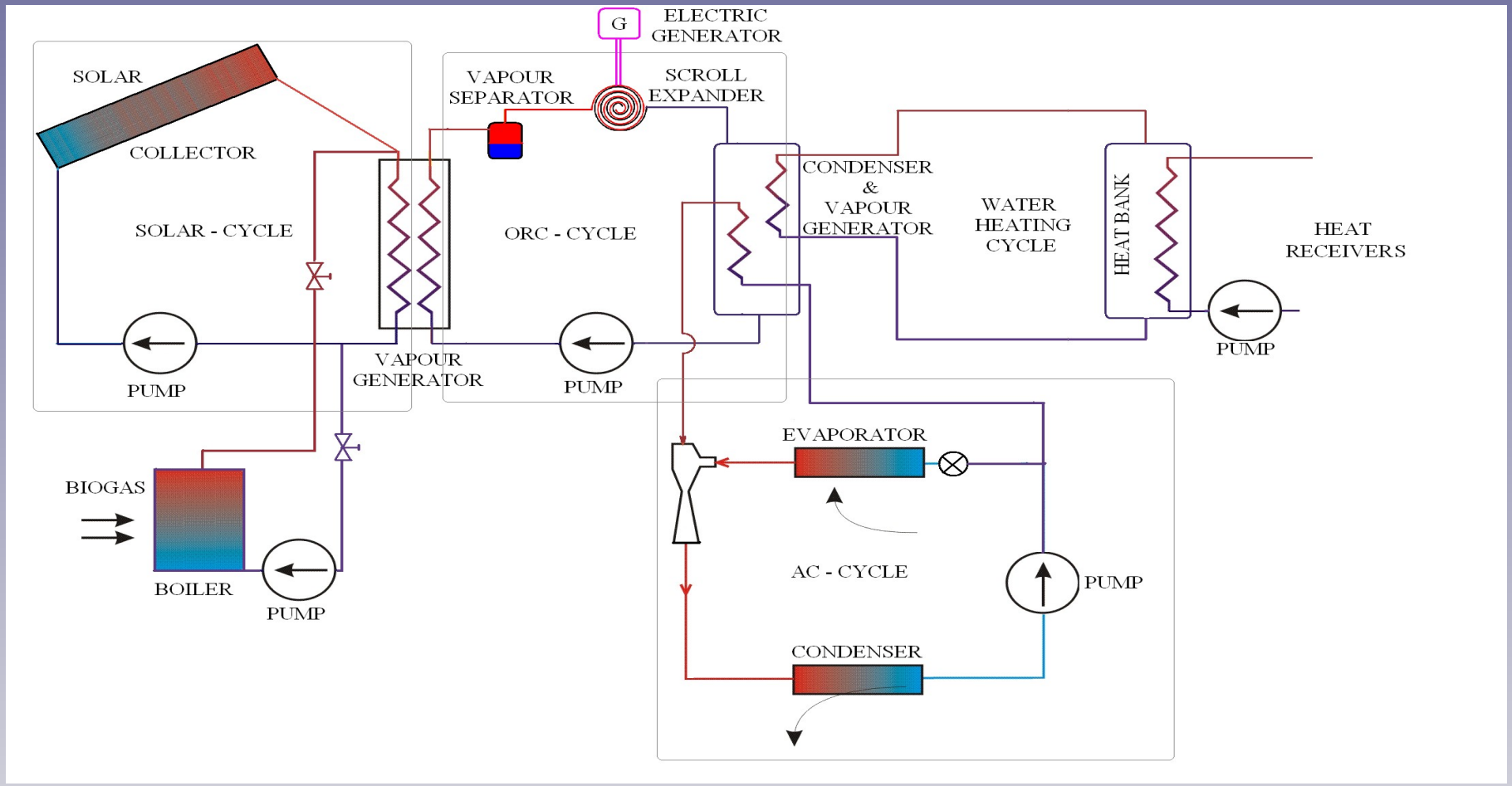


Exemplary distribution of local heat transfer coefficient in the mixing chamber at g = 0.50 mm; $\dot{m}_{li}/\dot{m}_{vi}$ = 24.46; Z = z/L_{MC} , L_{MC} – mixing chamber length.

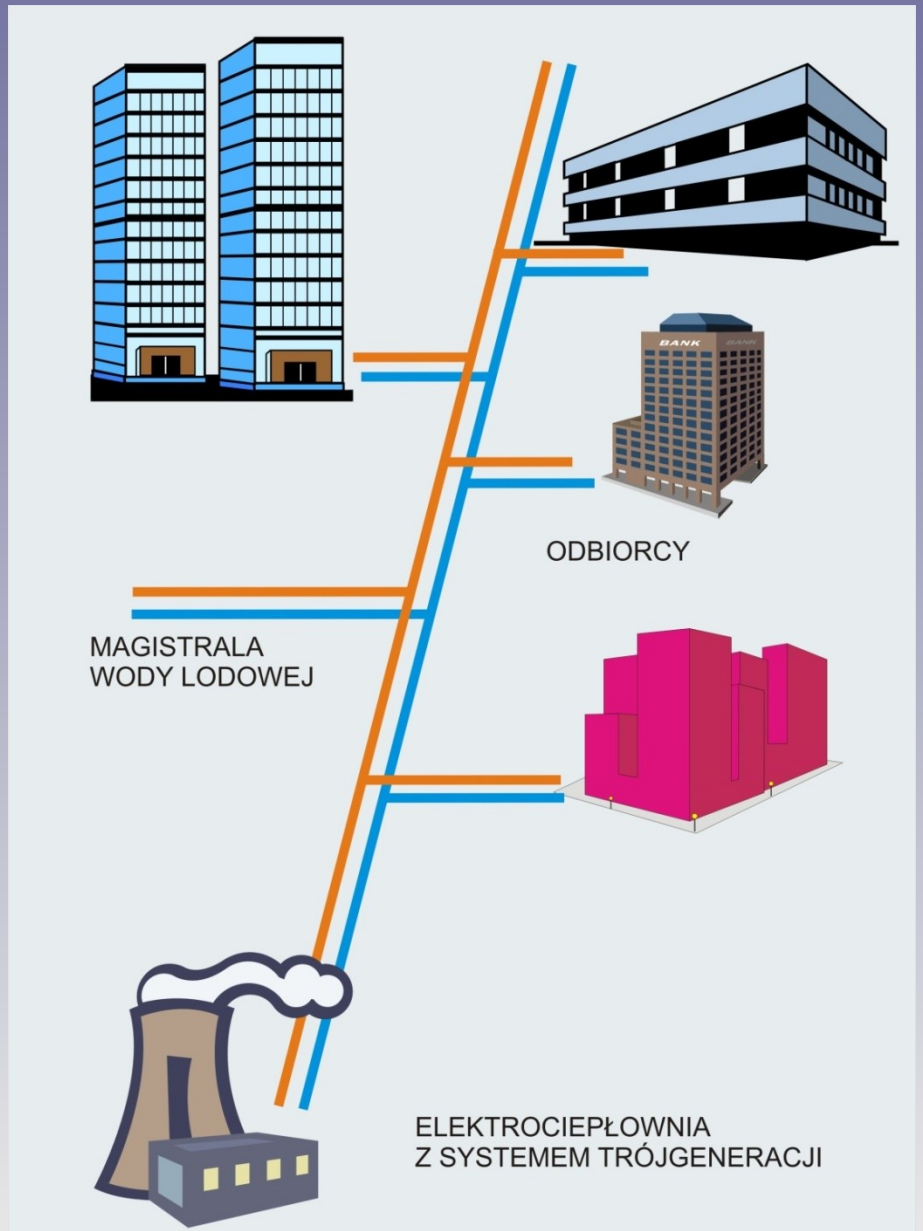


COP vs. generator temperature for single, and bi-ejector cycle and mtove vapour consumption ratio for jet pump

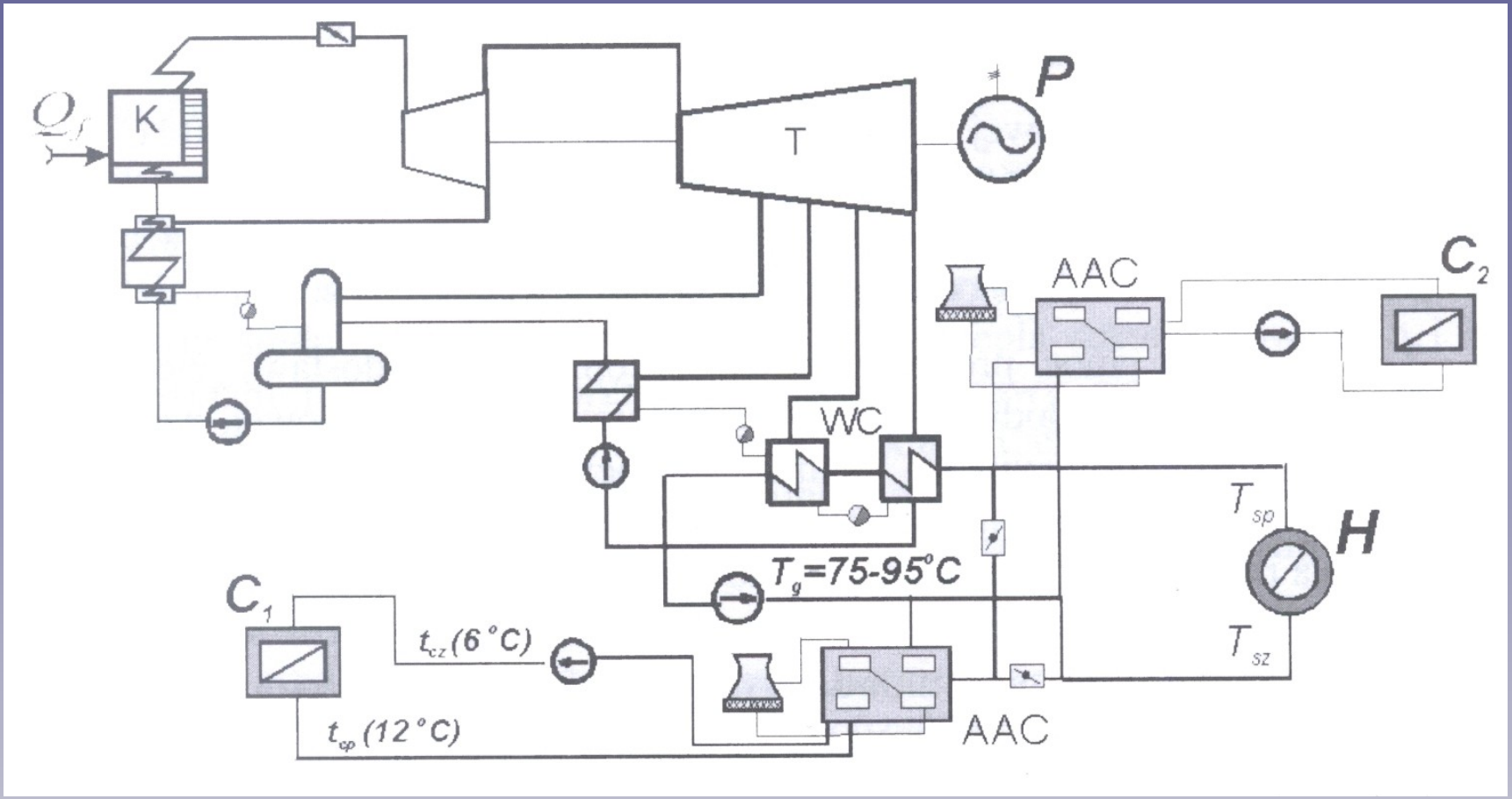
4. Solar based polygeneration unit



5. CCHP system in large scale

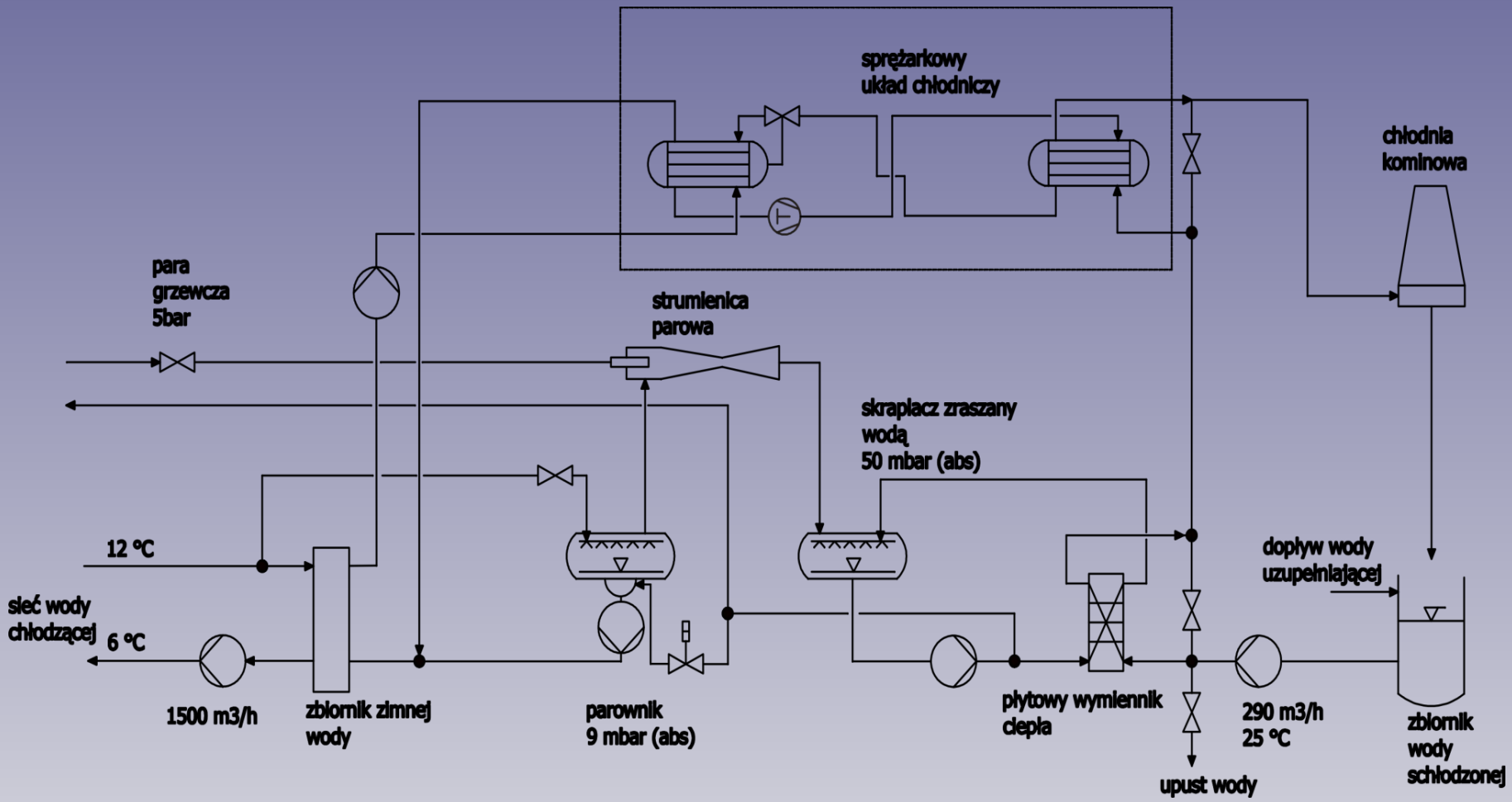


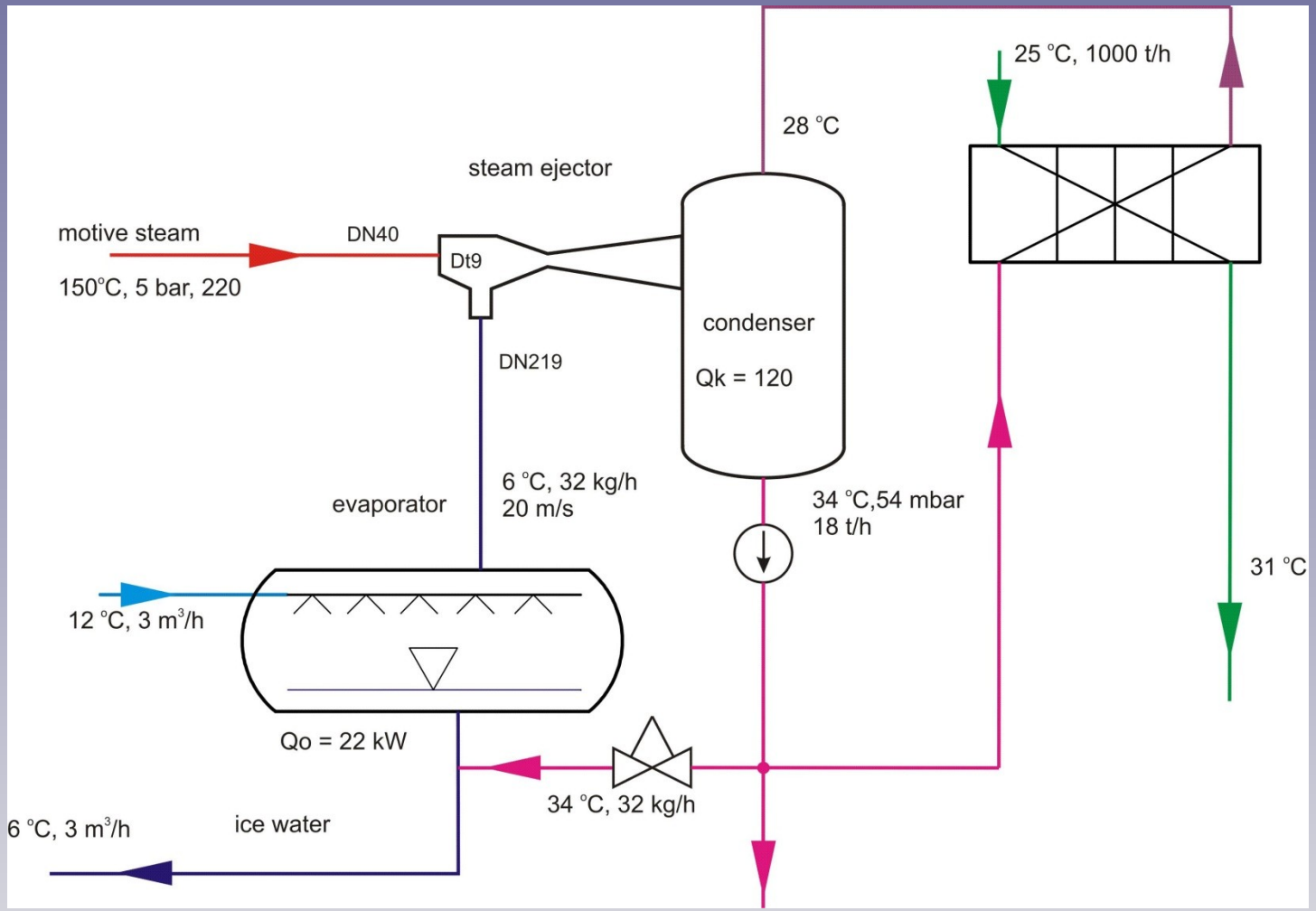
District cooling system – cold water is produced in central CCHP plant

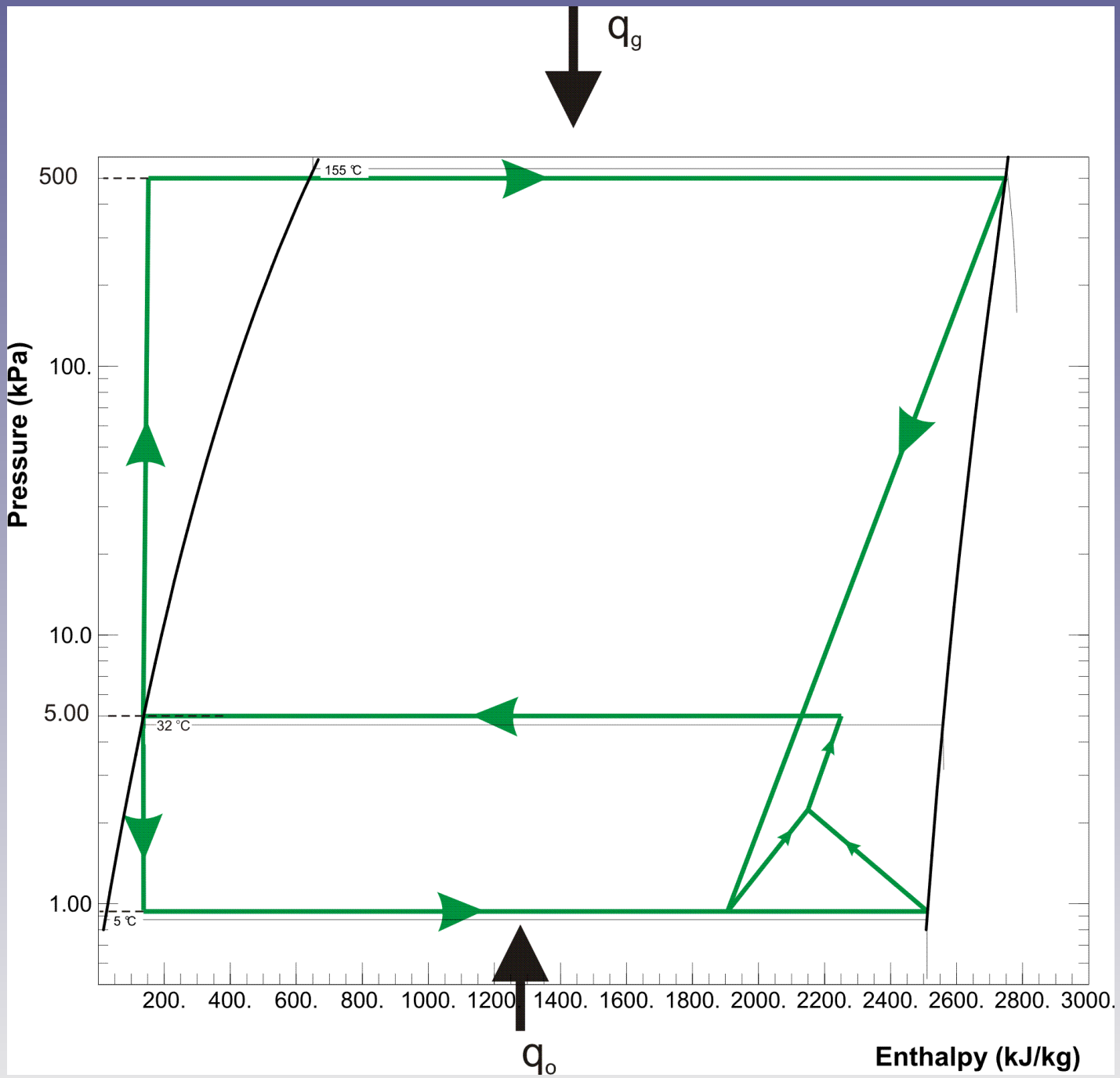


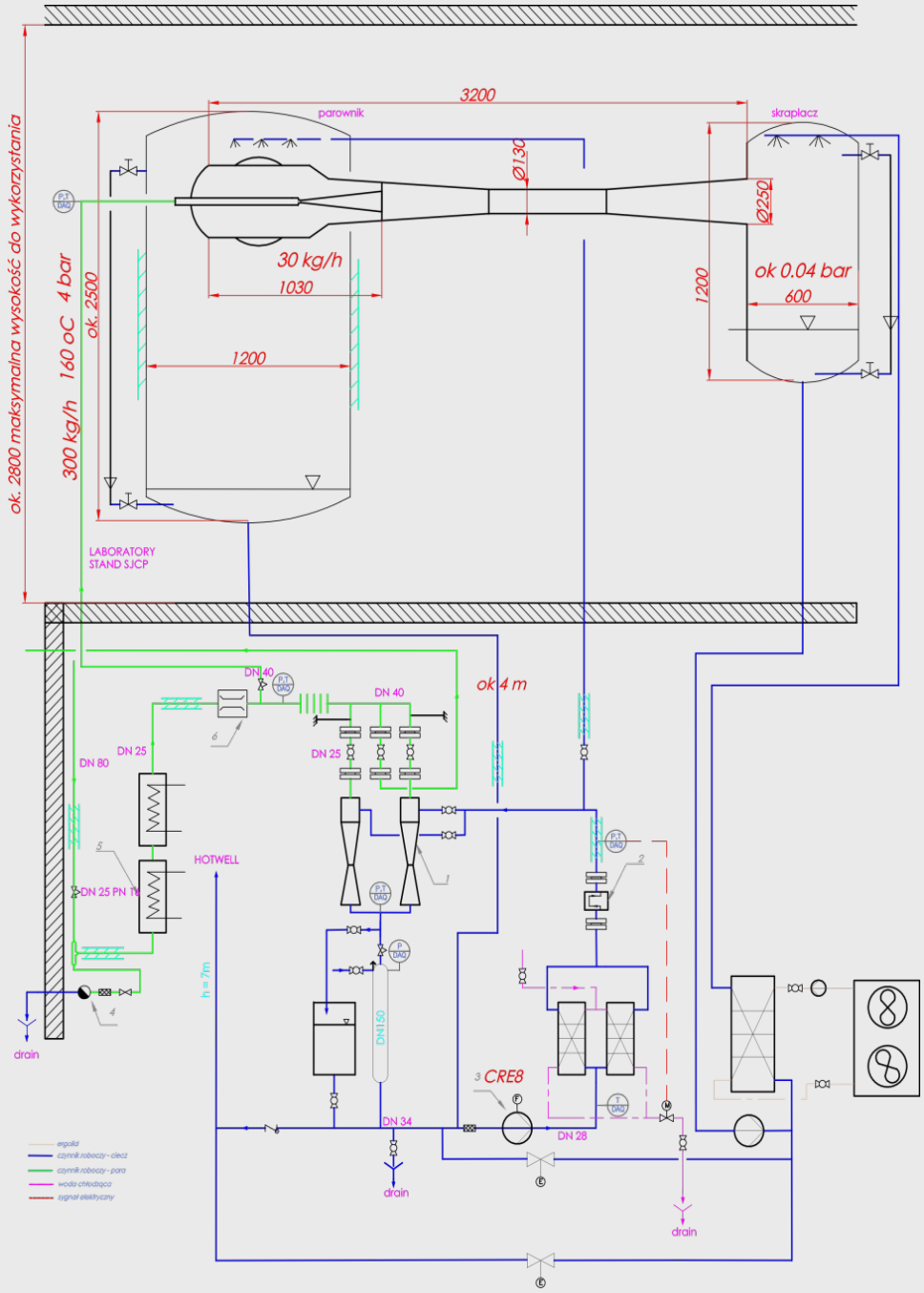
Classic approach: absorption systems

- high investment costs;
- necessity to increase the condensation pressure independently on the required capacity (decrease of the efficiency of the generation of electricity);
- additional losses due to temperature difference between condensation and boling temperatures;
- large dimentions;
- low potential of innovation.


sprężarkowy
układ chłodniczy
chłodnia
kominowa
para
grzewcza
5bar
strumienica
parowa
skraplacz zraszany
wodą
50 mbar (abs)
12 °C
sieć wody
chłodzącej
6 °C
1500 m3/h
zbiornik zimnej
wody
parownik
9 mbar (abs)
płytowy wymiennik
ciepła
dopływ wody
uzupełniającej
290 m3/h
25 °C
upust wody
zbiornik
wody
schłodzonej

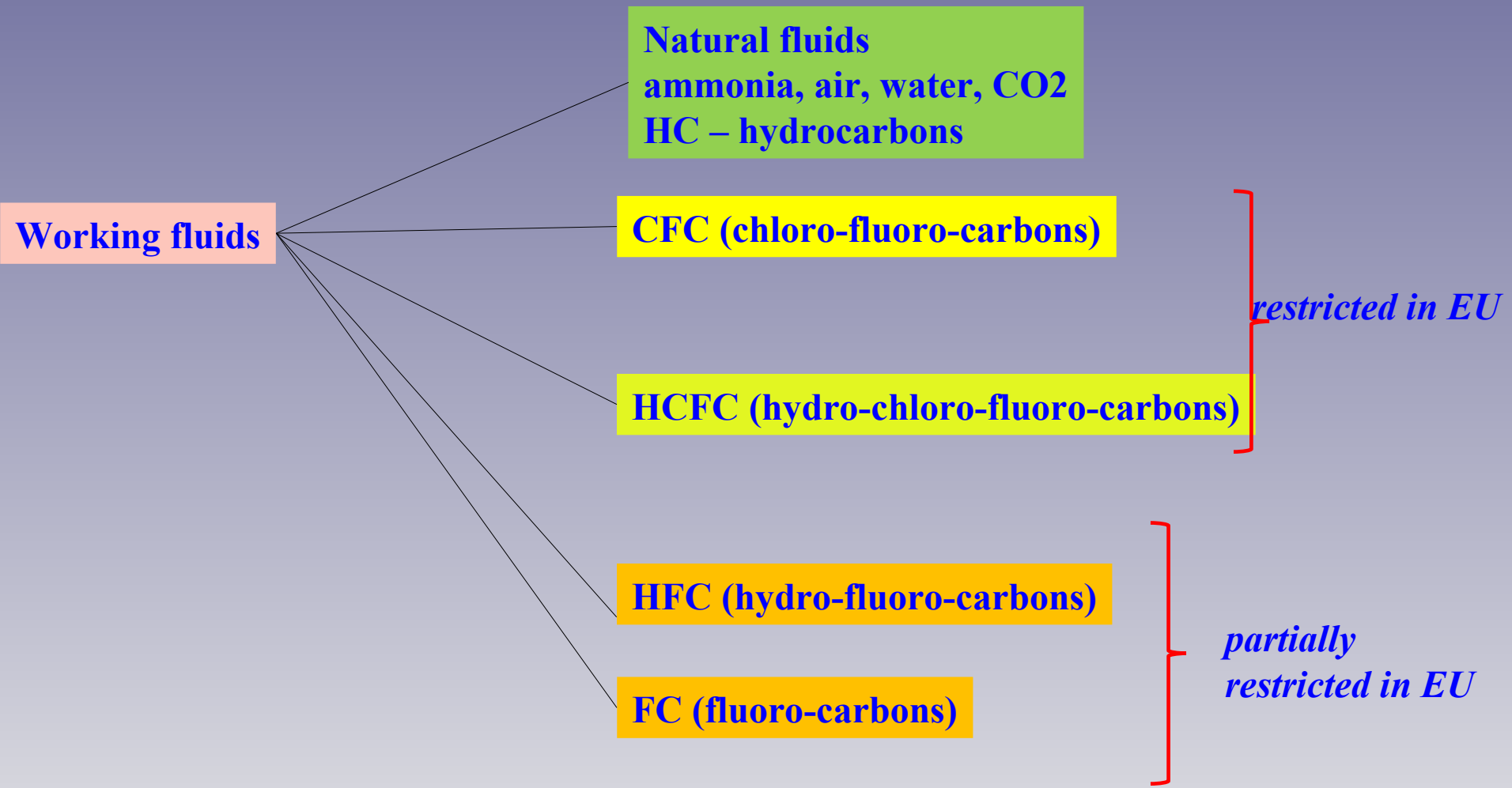

25 °C, 1000 t/h
28 °C
steam ejector
motive steam
DN40
Dt9
150°C, 5 bar, 220
condenser
Qk = 120
DN219
6 °C, 32 kg/h
20 m/s
evaporator
34 °C,54 mbar
18 t/h
31 °C
12 °C, 3 m³/h
Qo = 22 kW
34 °C, 32 kg/h
6 °C, 3 m³/h
ice water


q_g
500
100.
10.0
5.00
1.00
155 °C
32 °C
5 °C
Pressure (kPa)
200. 400. 600. 800. 1000. 1200. 1400. 1600. 1800. 2000. 2200. 2400. 2600. 2800. 3000.
Enthalpy (kJ/kg)
q_o


ok. 2800 maksymalna wysokość do wykorzystania
3200
parownik
skraplacz
Ø130
Ø250
30 kg/h
1030
1200
ok 0.04 bar
600
1200
300 kg/h 160 oC 4 bar
ok. 2500
LABORATORY
STAND SJCP
ok 4 m
DN 40
DN 40
DN 25
DN 25
DN 80
DN 25 PN 10
HOTWELL
h = 7m
DN150
drain
CRE8
DN 34
DN 28
drain
drain

INTECH
Clayton
STEAM GENERATOR
WYŁĄCZNIK GŁÓWNY

5. Working fluids for thermal systems



The potential of ozone depletion was the first important environment criterion for the possible use of the substance. The Ozone Depletion Potential (ODP) is defined as relative measure of ozone destruction in comparison with fluid $CFCl_3$ (with standard notification as R-11) and may be calculated from the semi-empirical relation:

$$\mathrm{ODP} = \Phi\, \alpha\, \frac{\tau_x}{\tau_{\mathrm{R-11}}} \frac{M_{\mathrm{R-11}}}{M_x} \frac{n_x}{3}$$

where: Φ — coefficient of emission of the substance to the atmosphere on the basis of the observations for the substance R-11, τ -lifetime of the substance (x or R-11), M – molar mass, n – number of halogen atoms in the molecule of the substance, α -relative efficiency of halogen atoms of the substance x in relation with chloride (for bromide $\alpha = 45$).

Comparison of some ecological properties of selected fluids

group	substance	molecular mass [kg/kmol]	normal boiling temperature [° C]	ODP	$GWP_{ITH=100\ lat}$	lifetime in the atmosphere [a]
CFC	R-11	137.37	+23.7	1.000	4 600	45
CFC	R-12	120.91	-29.8	0.820	10 600	100
HCFC	R-22	86.47	-40.8	0.034	1 700	11.9
HCFC	R-123	152.93	+27.8	0.012	120	1.4
HFC	R-134a	102.03	-26.1	0.000	1 300	13.8
HFC	R-152a	66.05	-24.0	0.000	120	1.4
HC	R-290	44.10	-42.2	0.000	6.3	0.04
HC	R-600a	58.12	-11.7	0.000	7.0	0.02
FC	R-218	188.02	-36.2	0.000	8 830	42
NH_3	R-717	17.03	-33.3	0.000	< 1.0	-
CO_2	R-744	44.01	-78.4	0.000	1.00	-

The Montreal protocol in 1987 and its amendments have regulated the use of fluids having an impact on the Ozone Layer. CFC (Chloro-Fluoro-Carbons) are first concerned and their use is now prohibited for all possible applications im EU.

The HCFCs (Hydro-Chloro-Fluoro-Carbons) will be progressively concerned and their use will be definitely prohibited since 2015. Now usage of HCFC substances in new applications is banned in EU according to Directive 2037/2000, also for all energy conversion systems.

Therefore, if ODP >0, then fluid is banned!

Warming potential of substance used in energy conversion technologies is the second important criterion. For example, one tone of R-22 can absorb the same quantity of solar heat as almost 1700 tonnes of CO_2!

The Global Warming Potential (GWP) is defined as relative radiative forcing ΔF for the Integral Time Horizon (ITH) for the given substance x related to 1 kg of CO_2:

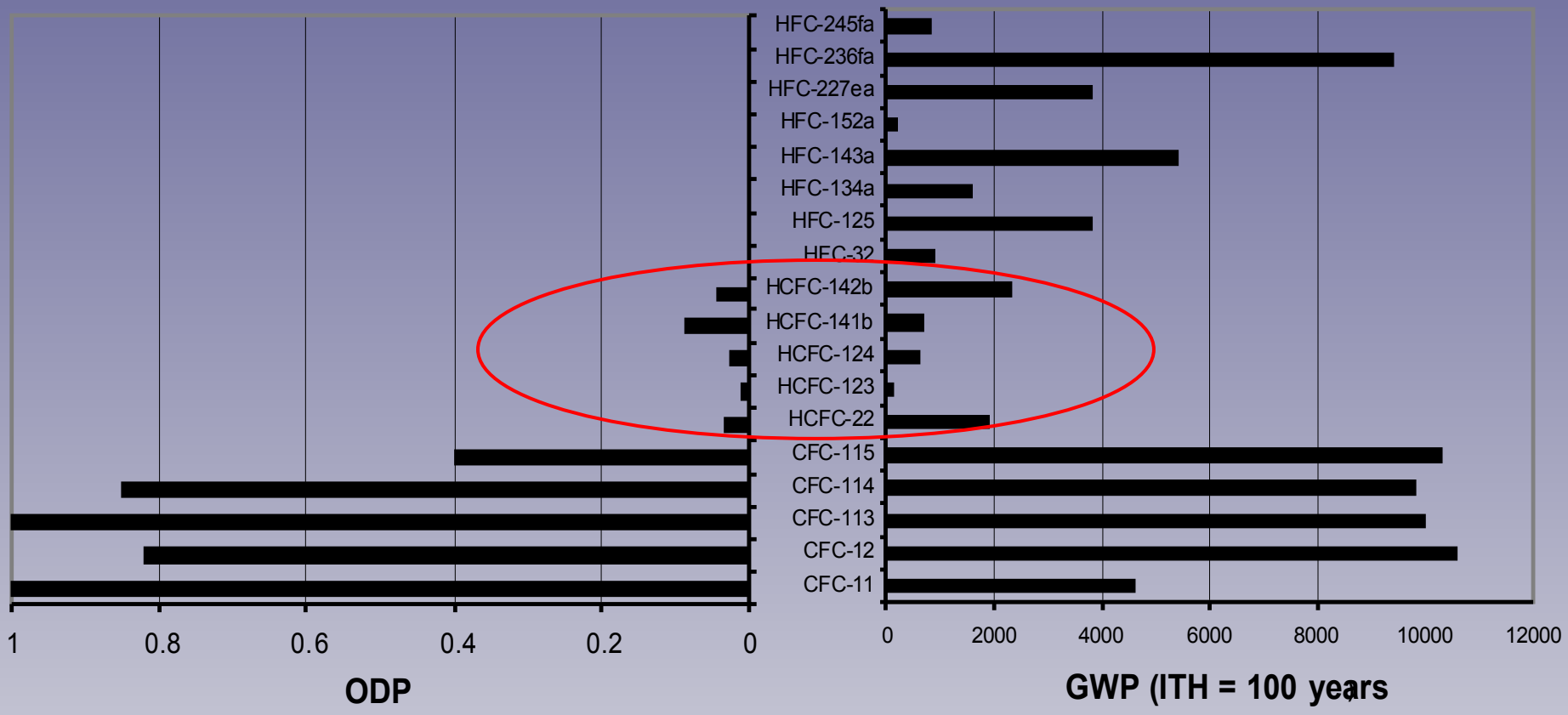
$$GWP_x(ITH) = \int_0^{ITH} \Delta F_x d\tau \Big/ \int_0^{ITH} \Delta F_{CO2} d\tau$$

- **The HFC fluids (Hydro-Fluoro-Carbons) are concerned by the Kyoto Protocol as gases contributing to the global warming. Therefore substances belonging to HFC group are also concerned by the EU regulation on fluorinated gases.**

- **The Directive 842/2006 creates opportunities to limit of some so called F-Gases emissions to the atmosphere by means of very strict technical control of use of listed substances of high GWP values in selected technologies: refrigeration, air-conditioning sector, the heat pumps have been included.**

- **The assessment concerning reduce of application of substances of high GWP is foreseen in 2011. It may be expected that all possible applications of high-GWP fluids will be restricted in near future making necessary to change present technical solutions suitable for wide range of synthetic fluids.**

- **Within this context, natural substances are sustainable options as they combine good environmental criteria in terms of ODP as well as GWP, and in some cases even good thermodynamic performances. As good candidates for environmental friendly fluids may considered natural substances (water, ammonia, carbon dioxide, saturated and non-saturated hydrocarbons) and synthetic fluids of small value of GWP (preferably GWP < 150).**



Comparison of ODP and GWP for selected synthetic fluids

Exemplary case of R-123 (HCFC fluid):

- very good thermodynamic properties ensuring extremely high COP in all OCR and reverse cycles applications;
- very low GWP;
- low operational pressures (NBL +27 ‘C);
- commercialised as an ecological substitute of CFC fluids;
- may be used also as a cleaning fluid;
- can operate with mineral oils;

but also:

- very toxic (cancerogenous);
- deteriorate sealing and many materials used in the systems (e.g. insulations);
- ODP>0.

Exemplary case of CO2 (natural fluid):

- GWP = 1.0 (extremely low value) and ODP = 0;
- non-toxic ands chemically stable;
- predicted as an ecological substitute of HFC fluids;

but also:

- very bad thermodynamic properties causing extremely low COP in all OCR and reverse cycles applications (require new technologies for improving of COP);
- very high operational pressures (CP +31 ‘C);
- requires special synthetic lubricants.

Environmental impact measures

$$TEWI = \sum OR_i \times GWP_i + \sum DR_i \times GWP_i + E$$

OR **– emission of gas during operation of the system;**
DR **– total emission of substance during chase-out of the system;**
E **– indirect CO_2 equivalent emission during motive energy (or fuel) production.**

$$OR_i + DR_i = MN_i + ME_i$$

MN**- mass of the substance at the initial start of the system;**
ME **- additional mass of the substance used during operation.**

$$E = QE + IE$$

QE **– total motive power consumption [kWh];**
IE **– total CO_2 equivalent emission during motive power production [kg CO_2/kWh].**

The more complete assessment of the environment impact of the technology should include some additional CO_2-equivalent emissions during production of the system and embodied energy. These is included in the Life Cycle Climate Performance (LCCP).

$$LCCP = TEWI + \sum OR_i \times \left(EE_i + EF_i\right) + \sum DR_i \times \left(EE_i + EF_i\right)$$

EE **– the CO_2 equivalent emission during production of unit mass of the working fluid (embodied energy);**

FE **- the CO_2 equivalent emission of the other substances emitted during production of the working fluid.**

On the basis of LCCP analysis results made for present air-conditioning and heat pump technologies the energy contribution is much more significant than the refrigerant contribution. Depending on the assumed scenario (refrigerant leak rate, operating hours, servicing practices, equipment efficiency), the energy contribution constituted between 93% and 99.5%.

However, there is a clear need for assessment of the specific data required for LCCP analysis of the present technologies in order make comparison between the systems, This depend not only well defined thermodynamic quantities but also some estimated practical values, e.g. concerning leakage rates, indirect emissions, etc. which should be treated as an additional task in order to develop useful tool for the environment assessment of the energy conversion systems.

- Generally the indirect emission may be assessed as the dominant. However, because of the requirements of legislation measures the list of possible substances for new energy conversion applications have been strictly limited and natural fluids are mostly considered as future ecological substitutes of a wide range of the synthetic substances.

- In some cases application of natural substances leads to low energy efficiency of the system, e.g. in most of technologies using carbon dioxide (heat pumps, solar and waste heat air-conditioning systems, ORC cycles) efficiency is significantly lower than in systems used synthetic fluids. Moreover this requires systems ready for significantly higher pressures. Some of the natural fluids are explosive and flammable (hydrocarbons), and some are also toxic (ammonia).

- The separate issue is concerned in suitable materials and lubricants for operation with natural fluids. Moreover, there is a lack of the system components designed for operation under required high-pressure conditions, providing required level of safety because of toxicity and flammability, or chemical stability of constructional materials.

6. Conclusions

- One of the most promising technology for cooling in application to most of the polygeneration systems if the ejection technology. The current works are focused on improvement of the efficiency of the ejection systems (optimisation of ejector geometry and system configuration) as well as application of fluids of low GWP.
- The ejection systems may be treated as a more profitable solution of polygeneration systems in comparison with the other options like absorption or adsorption systems due to their simplicity and low-cost.
- Natural fluids are mostly considered as future ecological substitutes of a wide range of the synthetic substances.
- Because of limitation of existing data on emission from new systems it is difficult to assess the environmental impact of energy conversion systems basing on LCCP methodology. Generally the indirect emission may be assessed as the dominant, however. Therefore decision based on ODP and GWP figures only may be thought as unappropriate.
- New techniques of increasing of COP and system safety are required for application of natural and low-GWP fluids in energy conversion systems.