Module 4
District cooling

Part of the SHaKE Educational Package on District Heating and Cooling Systems

EXERCISES

Cooling and heat pump simulation, refrigerant comparison and environmental impact assessment with suggested solutions

Developing institution: Universitat Jaume I de Castellón
Erasmus+ KA220-HED Cooperation Partnerships in Higher Education
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https://www.shakeproject-dhc.eu/

EXERCISES

Exercises are presented first, followed by the corresponding solutions at the end of the section. Only problems requiring a quantitative or analytical answer are solved.

All exercises are mandatory

1. Cooling Mode (Chiller Simulation)

Related to: Section 4.2.1 (Compression chillers), Section 4.1 (Cooling role in SHC), and Section 4.4 (Operating temperatures)

Using Bitzer software, solve the following tasks:

1. Choose reciprocating semi-hermetic compressor
2. Select refrigeration mode
3. Select single compressor and choose the last model.
4. Based on the compressor model selected, choose two refrigerants:
   R134a (baseline HFC) (table 4.17)
   R1234ze (low-GWP alternative) (table 4.18)
5. Simulate for evaporating temperatures from –20 °C to +20 °C with steps of 10 °C
6. and condensing temperatures from 15 °C to 55 °C with steps of 10 °C
7. Use 10 K useful superheating and 2 K subcooling
8. Record the EER in the tables of each refrigerant for each temperature combination
9. You can export or reproduce the generated data and generate graphs any software

Analysis:

1. Compare EER across refrigerants and temperature points
2. Identify trends: how does EER evolve with evaporator/condensator Temperatures?
3. What effect does refrigerant type have on efficiency?
4. Is it possible to work in all conditions reflected on the table? Justify your answer.

Tevap/Tcond	15	25	35	45	55
-20					
-10					
0					
10					
20					

Table 4.17. EER results for R134a.

Tevap/Tcond	15	25	35	45	55
-20					
-10					
0					
10					
20					

Table 4.18. EER results for R1234ze.

2. Heating Mode (Heat Pump Simulation)

Related to: Section 4.1 (Heat pump operation), Section 4.4 (Heating integration into DHN), Section 4.3 (Refrigerant performance)

Using Bitzer software, solve the following tasks:

1. Switch the BITZER software to heat pump mode
2. Use same two refrigerants from Part 1 and compressor model
3. Simulate evaporating temperatures from –25 °C to +25 °C, and condensing temperatures from 45 °C to 75 °C with steps of 10 °C
4. Record the COP in the tables of each refrigerant for each temperature combination
5. You can export or reproduce the generated data and generate graphs in any software

Analysis:

1. How does performance change under cold-source conditions?
2. Which refrigerant performs better at low source temperatures?
3. Could either configuration be used in a 4th or 5th generation DHN?
4. Is it possible to work in all conditions reflected on the table? Justify your answer.

Tevap/Tcond	45	55	65	75
-25				
-15				
-5				
5				
15				
25				

Table 19. COP results for R134a.

Tevap/Tcond	45	55	65	75
-25				
-15				
-5				
5				
15				
25				

Table 20. COP results for R1234ze.

3. Climate Adaptation and Application to District Energy

Related to: Section 4.1 (SHC), 4.4 (configuration options), and real-world case studies in the final theory section

Using Bitzer software, solve the following tasks:

Select one of the following climate conditions and propose an adapted heat pump design using your simulation data:

1. Cold climate (e.g. Helsinki): high heating demand, possibility of SHC
2. Hot/arid climate (e.g. Riyadh): dominant cooling demand
3. Tropical (e.g. Singapore): balanced cooling, possibility for SHC

Consider air-to-air heat pump with glid of 15 K between heat source and evaporator, and heat sink and condenser

In each case:

1. Identify required temperature ranges
2. Recommend refrigerant and operating mode
3. Discuss seasonal COP variation and implications for design
4. Evaluate possible simultaneous heating/cooling (SHC) benefits

4. Environmental Impact Evaluation

Related to: Section 4.3 (Refrigerants, GWP, TEWI)

Solve the following tasks:

Task:

For each refrigerant simulated:

1. Research GWP (Global Warming Potential)
2. Estimate TEWI (Total Equivalent Warming Impact) using energy results and refrigerant leakage assumptions (use data provided by Australian institute (AIRAH)) for 15 years life cycle for Spain, France and Hungary

Submission Requirements

Students must submit:

1. A brief report (max. 6 pages) including:
2. Simulation parameters
3. COP/EER tables and graphs
4. Refrigerant comparison
5. Answers to analysis questions
6. Screenshots of BITZER results
7. References (web sources, literature, and declaration of AI tools if used)

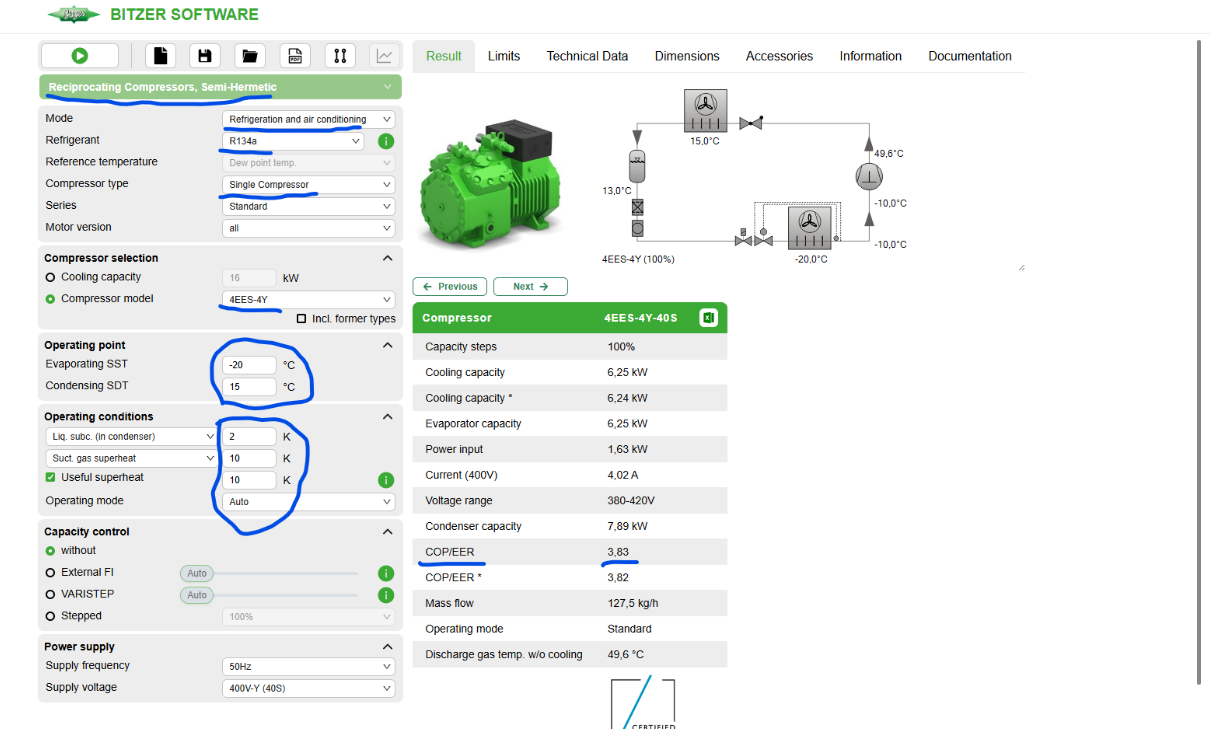
SOLUTIONS

1. Cooling Mode (Chiller Simulation)

Related to: Section 4.2.1 (Compression chillers), Section 4.1 (Cooling role in SHC), and Section 4.4 (Operating temperatures)

Using Bitzer software (https://www.bitzer.de/gb/en/tools-archive/software/software/software-versions.jsp), solve the following tasks:

1. Choose reciprocating semi-hermetic compressor
2. Select refrigeration mode
3. Select single compressor and choose the model 4EES-4Y.
4. Based on the compressor model selected, choose two refrigerants:
    R134a (baseline HFC) (table 4.17)
    R1234ze (low-GWP alternative) (table 4.18)



Reciprocating Compressors, Semi-Hermetic

Mode: Refrigeration and air conditioning
Refrigerant: R134a
Reference temperature: Dew point temp.
Compressor type: Single Compressor
Series: Standard
Motor version: all

Compressor selection
○ Cooling capacity: 16 kW
● Compressor model: 4EES-4Y
☐ Incl. former types

Operating point
Evaporating SST: -20 °C
Condensing SDT: 15 °C

Operating conditions
Liq. subc. (in condenser): 2 K
Suct. gas superheat: 10 K
☑ Useful superheat: 10 K
Operating mode: Auto

Capacity control
● without
○ External FI: Auto
○ VARISTEP: Auto
○ Stepped: 100%

Power supply
Supply frequency: 50Hz
Supply voltage: 400V-Y (40S)

Compressor	4EES-4Y-40S
Capacity steps	100%
Cooling capacity	6,25 kW
Cooling capacity *	6,24 kW
Evaporator capacity	6,25 kW
Power input	1,63 kW
Current (400V)	4,02 A
Voltage range	380-420V
Condenser capacity	7,89 kW
COP/EER	3,83
COP/EER *	3,82
Mass flow	127,5 kg/h
Operating mode	Standard
Discharge gas temp. w/o cooling	49,6 °C

5. Simulate for evaporating temperatures from –20 °C to +20 °C with steps of 10 °C
6. and condensing temperatures from 15 °C to 55 °C with steps of 10 °C
7. Use 10 K useful superheating and 2 K subcooling
8. Record the EER in the tables of each refrigerant for each temperature combination
9. You can export or reproduce the generated data and generate graphs in any software

Analysis:

5. Compare EER across refrigerants and temperature points

The higher the pressure rate (higher difference between Tevap and Tcond) the lower is the EER because the compressor power consumption increases to achieve higher temperature. Regarding refrigerants, the R134a present slightly higher EER at low temperatures and major

temperature operating range, however the R1234ze present higher EER at high temperatures but has a limited temperature range for cooling mode, this phenomenon occur due to two properties: the suction density of R1234ze is lower than R134a, to achieve the same capacity require higher compressor volume, and the saturation properties (temperature-pressure relation)

6. Identify trends: how does EER evolve with evaporator/condensator Temperatures?

Decreases when the temperature difference increases

7. What effect does refrigerant type have on efficiency?

It can increase or decrease the efficiency depending on temperature range and thermodynamic properties reflecting that there is no better or worse refrigerant, each one is suitable for determined temperature range, this in thermodynamic terms.

8. Is it possible to work in all conditions reflected on the table? Justify your answer.

No, two factor limit the possible working conditions: the compressor limit defined by the manufacturer to assure large life cycle, efficiency, and working of it, and the type of refrigerant due to the saturation pressure of each one.

Tevap/Tcond	15	25	35	45	55
-20	3.83	2.93	2.28	1.78	1.36
-10	5.65	4.09	3.10	2.38	1.84
0	-	5.87	4.22	3.15	2.40
10	-	8.81	5.87	4.20	3.12
20	-	-	-	-	-

Table 4.17. EER results for R134a.

Tevap/Tcond	15	25	35	45	55
-20	-	-	-	-	-
-10	-	4.02	3.04	2.34	1.80
0	-	5.89	4.24	3.16	2.40
10	-	-	6.03	4.30	3.19
20	-	-	-	5.97	4.27

Table 4.18. EER results for R1234ze.

2. Heating Mode (Heat Pump Simulation)

Related to: Section 4.1 (Heat pump operation), Section 4.4 (Heating integration into DHN), Section 4.3 (Refrigerant performance)

Using Bitzer software, solve the following tasks:

6. Switch the BITZER software to heat pump mode
7. Use same two refrigerants from Part 1 and compressor model
8. Simulate evaporating temperatures from –25 °C to +25 °C, and condensing temperatures from 45 °C to 75 °C with steps of 10 °C
9. Record the COP in the tables of each refrigerant for each temperature combination
10. You can export or reproduce the generated data and generate graphs in any software

Analysis:

5. How does performance change under cold-source conditions?

The main focus in this section is the heating, therefore the lower heat source temperature (evaporating temperature) the lower is the COP

6. Which refrigerant performs better at low source temperatures?

Is stated before the R134a is more suitable for low temperature, however when the heat source temperature increases, the R1234ze becomes more suitable, in this case starts from -15 °C Tevap.

7. Could either configuration be used in a 4th or 5th generation DHN?

Yes, conditions from 5 to 25 Tevap can fit 5th generation DHN as local heat pump, the rest can work in 4th generation DHN as central heat pump.

8. Is it possible to work in all conditions reflected on the table? Justify your answer.

No, R134a cover the lowest temperature conditions, and R1234ze cover the highest temperature conditions due to the saturation pressure of each refrigerant.

Tevap/Tcond	45	55	65	75
-25	2.51	2.14	1.82	-
-15	3.07	2.59	2.20	-
-5	3.74	3.10	2.60	-
5	4.63	3.74	3.07	-
15	-	-	-	-
25	-	-	-	-

Table 19. COP results for R134a.

Tevap/Tcond	45	55	65	75
-25	-	-	-	-
-15	3	2.54	2.16	1.83
-5	3.74	3.09	2.59	2.18
5	4.68	3.77	3.10	2.57
15	6.05	4.68	3.75	3.05
25	8.09	5.96	4.62	3.68

NOTE: Bitzer not only calculate the COP and EER, but also compressor power consumption, heating capacity, and cooling capacity.