

A Review on Heat Pump Technology

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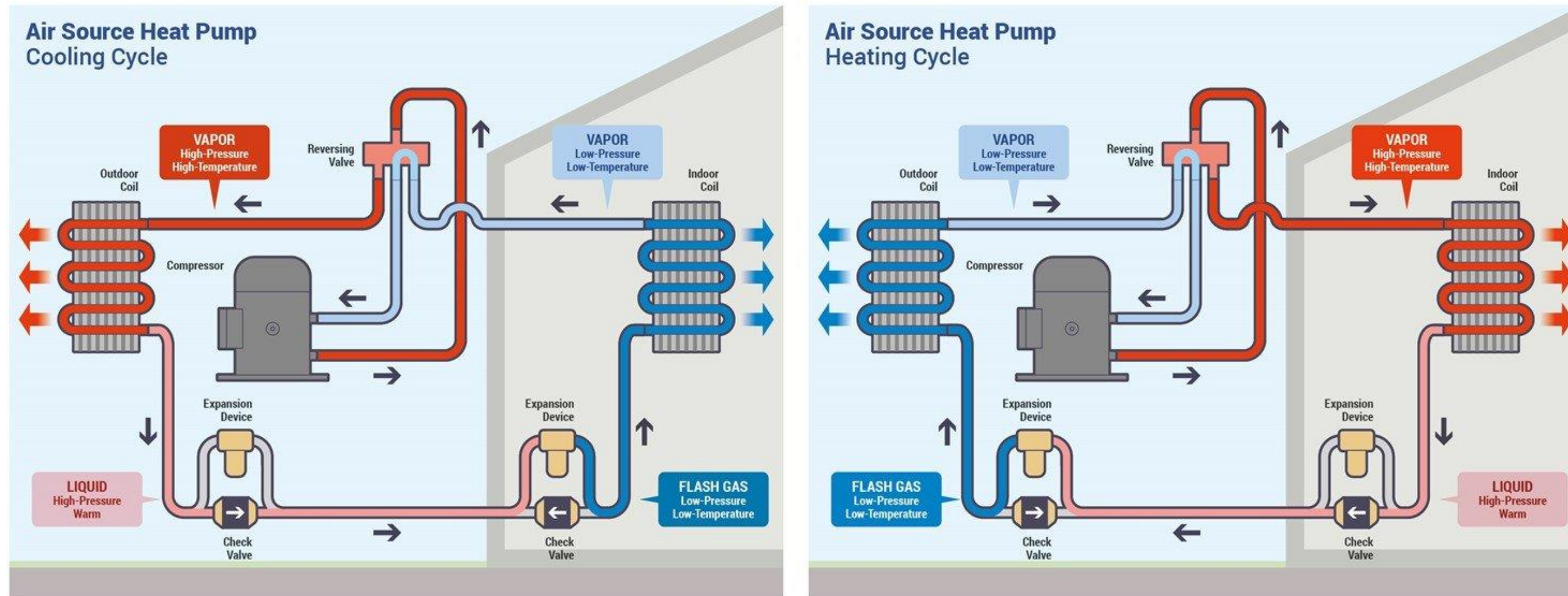


/ What is a Heat Pump?

4 / What is a heat pump?

“ It has become common practice now to call a heat pump any device that extracts heat from a source at low temperature and gives off this heat at a higher temperature, which can be useful” [1]

[1] I. Dincer, M. Kanoglu, (2010), “Refrigeration systems and applications and applications”, Wiley and Sons, Chapter 6.



5 / Heat pump classifications

- **Based on Backup System:**

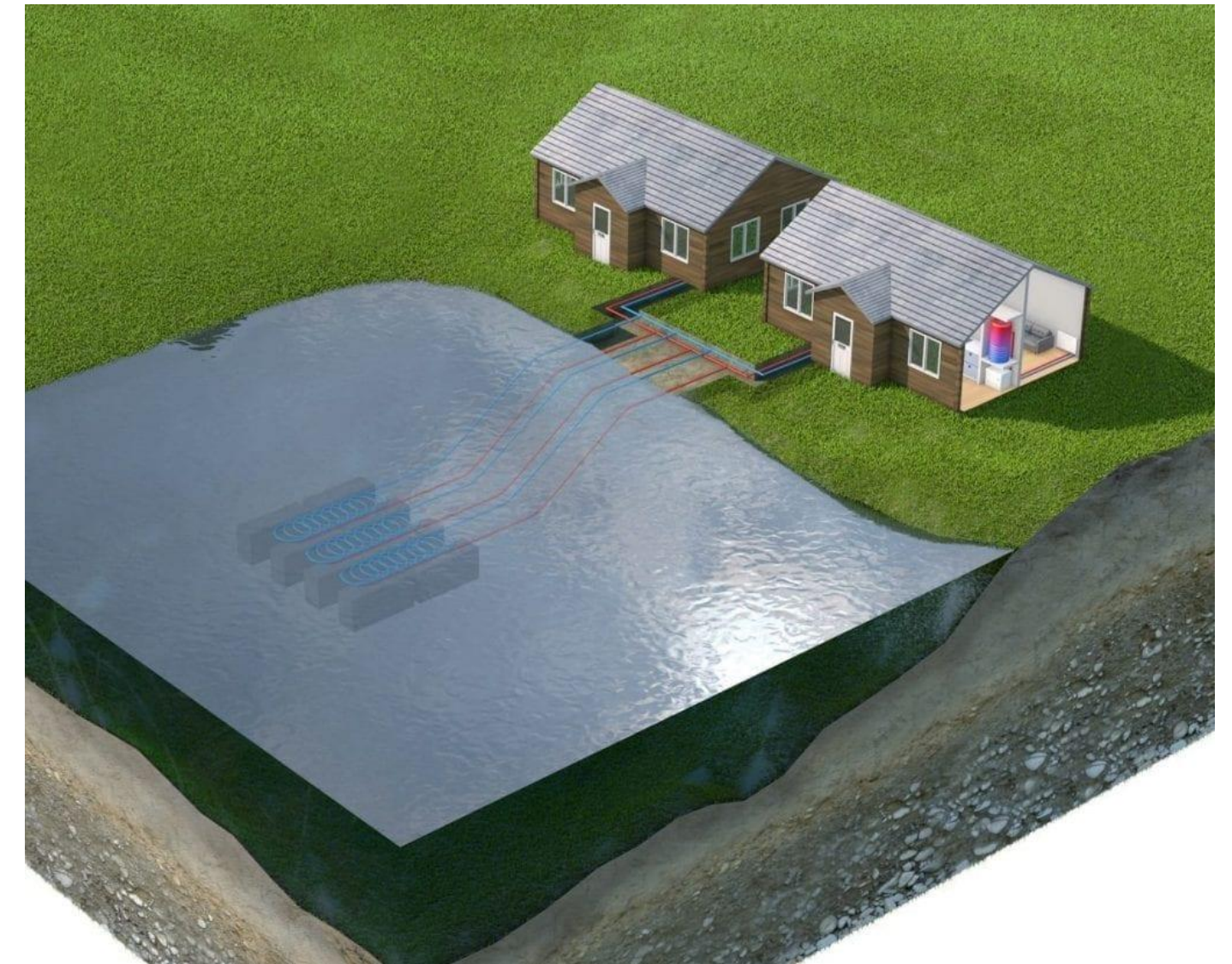
Bivalent: Heat pumps operating with supplementary heat are often said to be operating in a bivalent mode.

Monovalent: A heat pump operating without electric resistance heating or without other backup is said to be operating in a monovalent mode.

- **Based on Heat Source:**

The technical and economical performance of a heat pump is closely related to the characteristics of the heat source. (IEA-HPC 2001)

Heat source	Temperature Range
Ambient air	-10-15
Exhaust air	15-25
Groundwater	4-10
Lake water	0-10
River water	0-10
Sea water	3-8
Rock	0-5
Ground	0-10
Waste water and effluent	>10

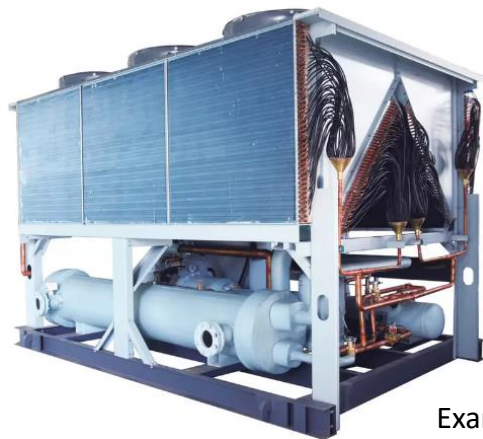


6 / Heat pump classifications

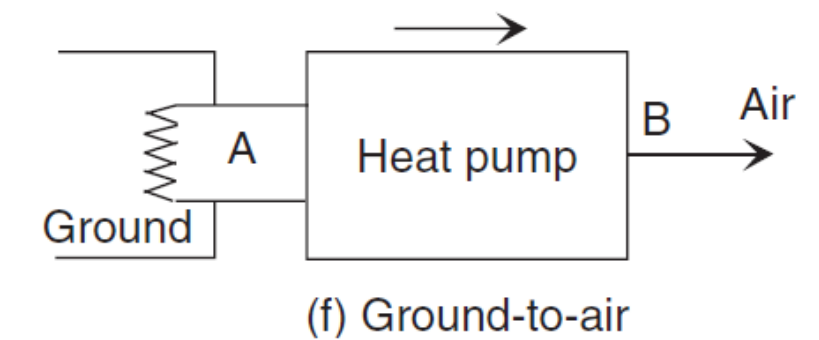
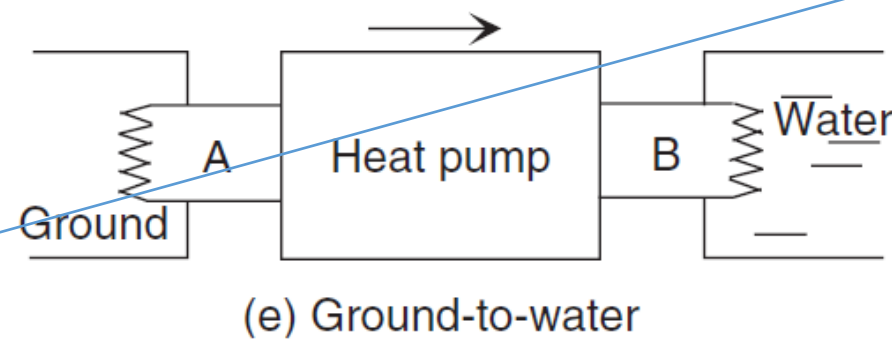
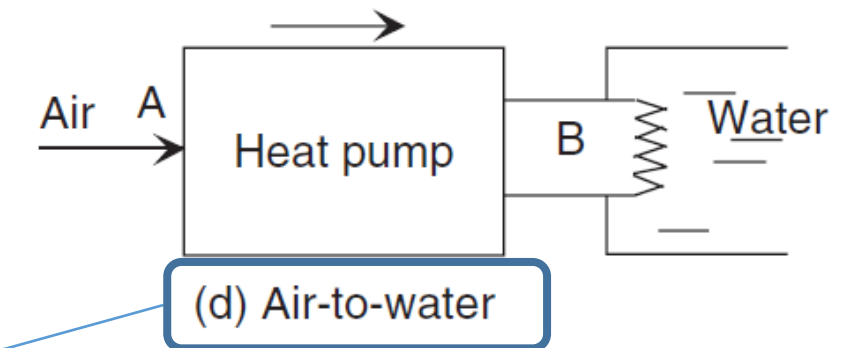
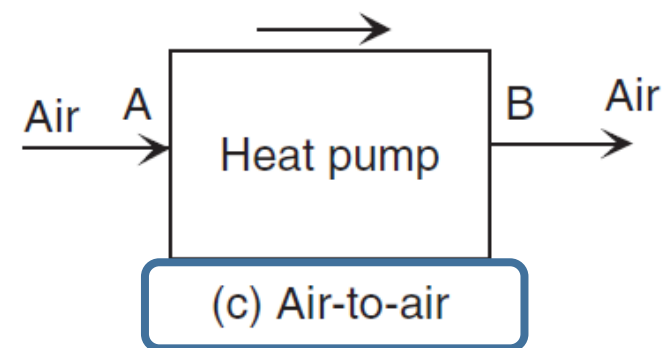
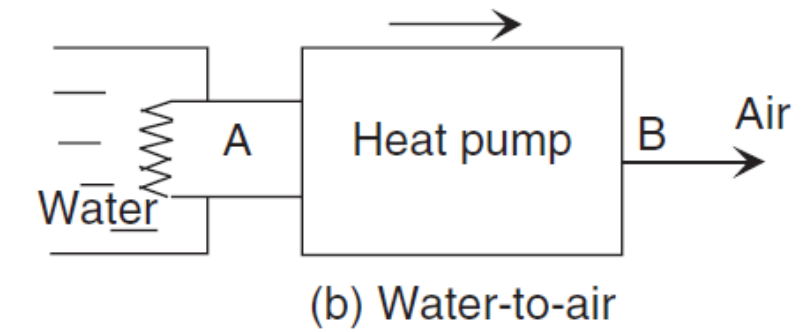
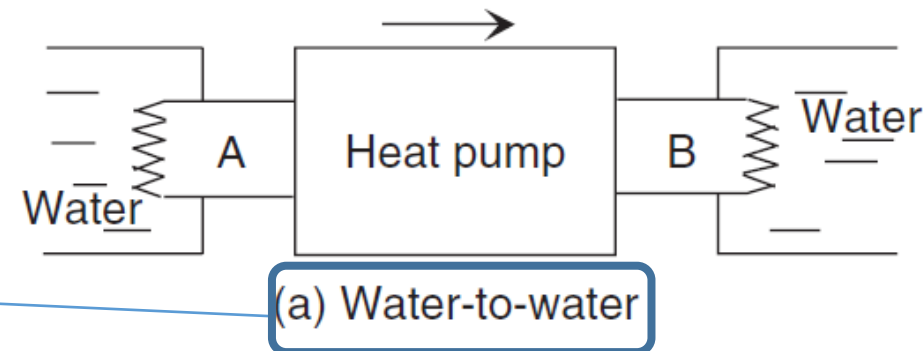
- Based on Source and Sink:



Example
 R134a, R513A (Optional)
 Screw compressor
 Cooling: 470.1kW- 2331 kW
 Heating: 523kW- 2568 kW

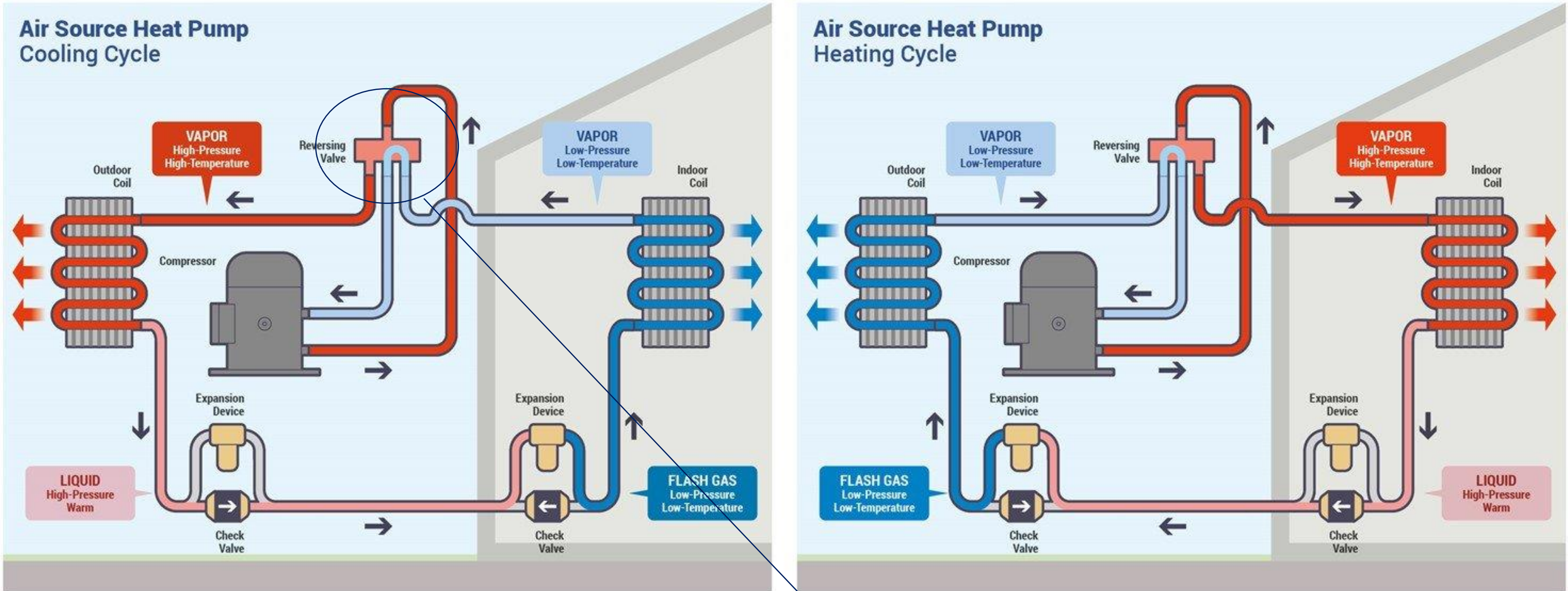


Example
 R134a, R407C
 Screw compressor
 Cooling: 200kW- 1510 kW
 Heating: 220kW- 1684 kW



/ Heat Pump Cycle

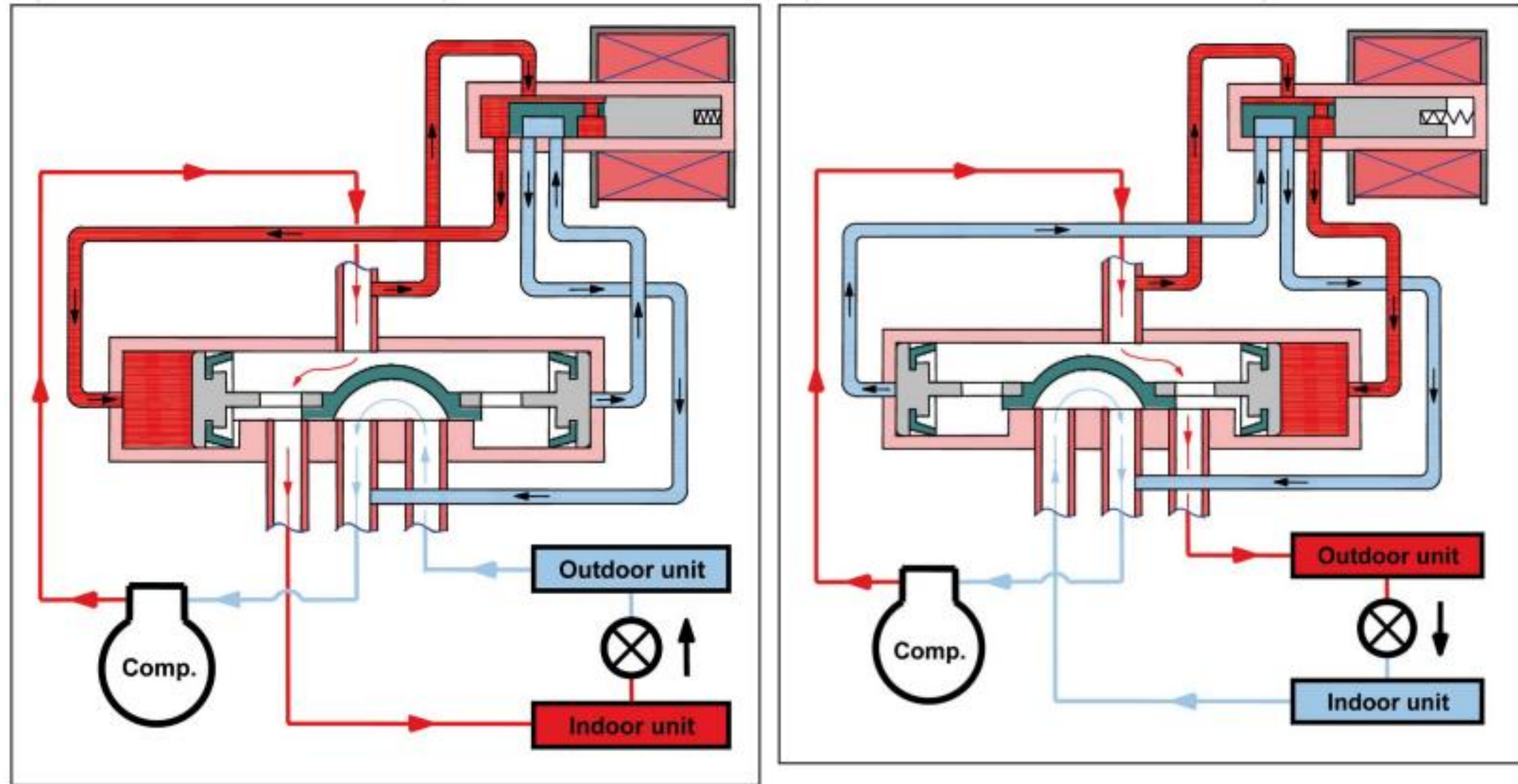
Heat pump cycle



!!!! Don't forget the suction line accumulator

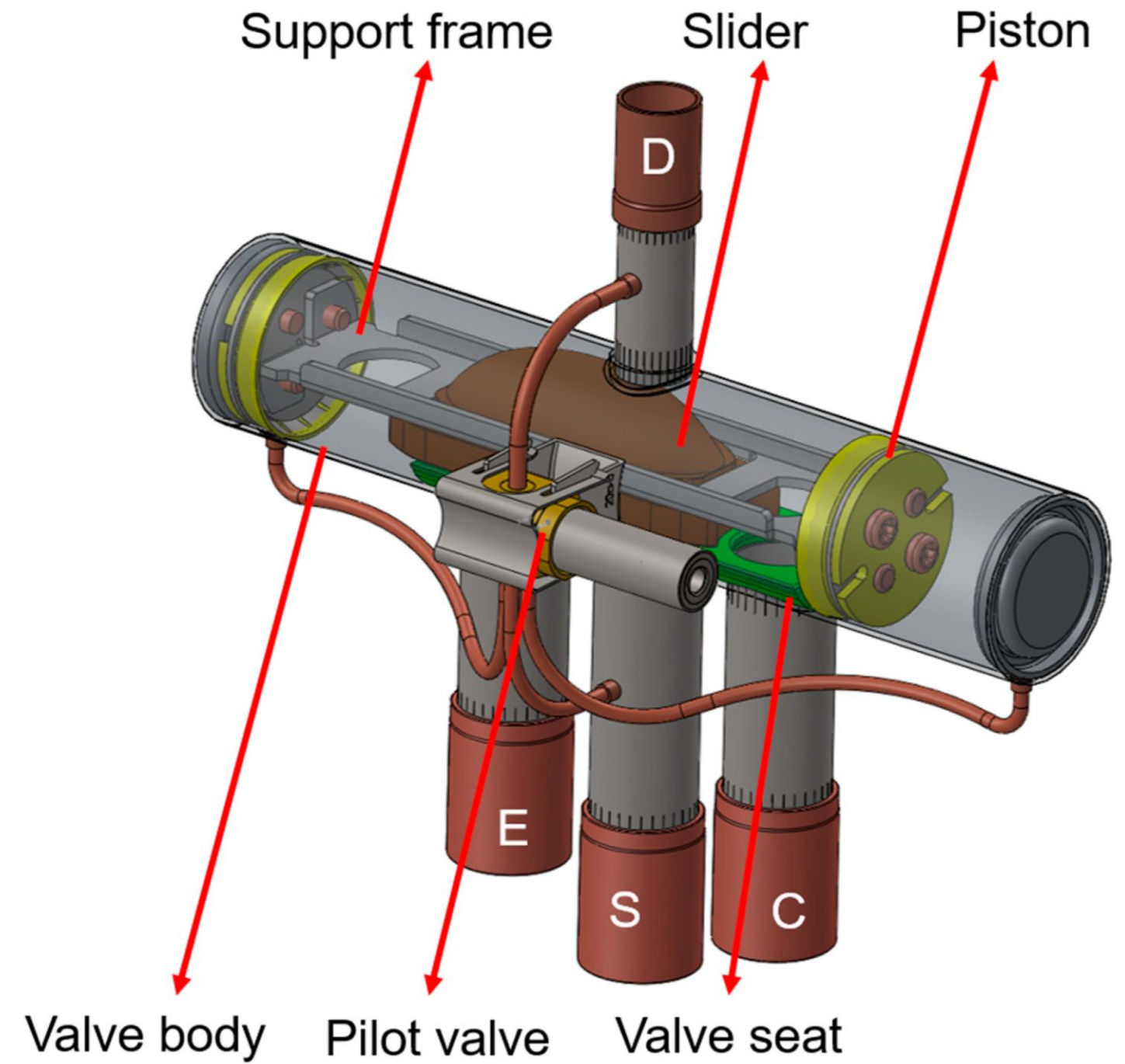


9 / Four way reversing valve



Heating Mode

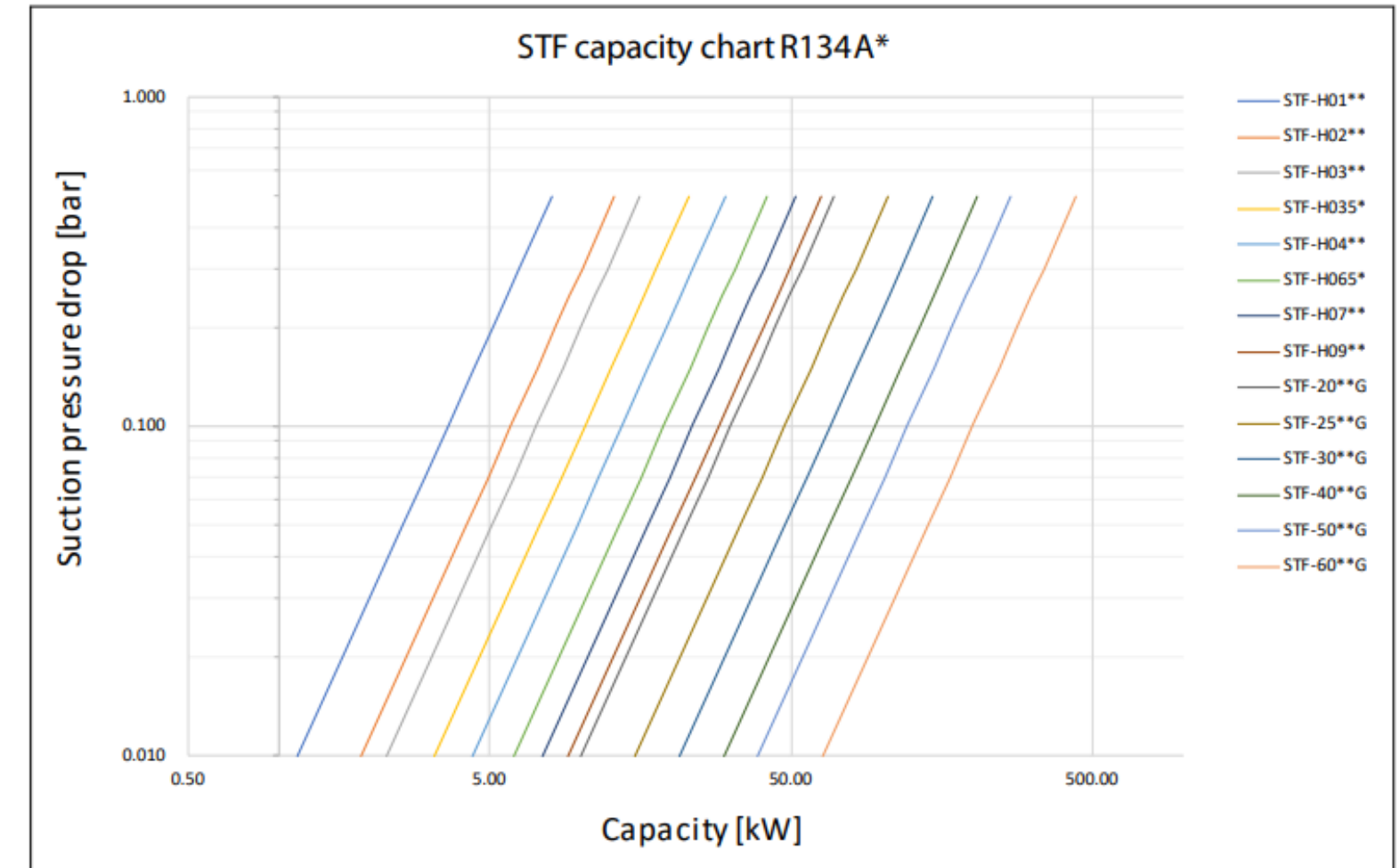
Cooling Mode



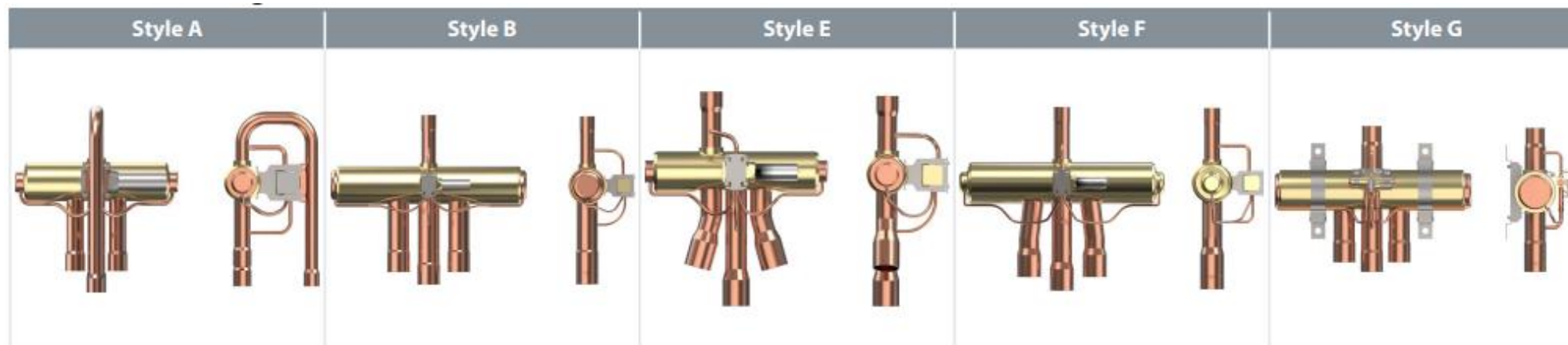
10 / Four way reversing valve

Model	Packing format	Danfoss code	Capacity [kW]	Style	Discharge	Suction	Media temperature	MWP	Approval
			(1)		[in]	[in]	[°C]	[bar]	
STF-H0167	45	061L1348	4.8	A	5/16	3/8	130	45	CE
STF-H0267	32	061L1349	9.5	A	3/8	1/2	130	45	CE
STF-H0321	32	061L1350	9.5	E	1/2	5/8	130	45	CE
STF-H0351	32	061L1351	13.7	B	1/2	5/8	130	45	CE
STF-H0429	24	061L1352	18.2	F	1/2	3/4	130	45	CE
STF-H0651	24	061L1353	25.1	B	1/2	3/4	130	45	CE
STF-H0731	6	061L1354	31.2	F	3/4	7/8	130	45	CE
STF-H0951	6	061L1355	38.12	B	3/4	7/8	160	49	CE
STF-H0954	6	061L1356	38.12	F	7/8	11/8	160	49	CE
STF-2028G	1	061L1357	41.8	F	11/8	13/8	160	49	CE
STF-2525G	1	061L1358	63.2	G	11/8	13/8	160	49	CE
STF-3015G	1	061L1345	89.4	G	11/8	15/8	160	49	CE
STF-4016G	1	061L1346	125.5	G	15/8	15/8	160	49	CE
STF-5017G	1	061L1360	161.3	G	15/8	2 1/2	160	49	CE
STF-6009G	1	061L1361	265.8	G	15/8	2 3/8	160	49	CE
STF-25U25G	1	061L1365	63.2	G	11/8	13/8	160	49	UL
STF-30U15G	1	061L1366	89.4	G	11/8	15/8	160	49	UL
STF-40U16G	1	061L1367	125.5	G	15/8	15/8	160	49	UL
STF-50U16G	1	061L1368	161.3	G	15/8	2 1/2	160	49	UL
STF-60U9G	1	061L1369	265.8	G	15/8	2 3/8	160	49	UL

(1) Capacity is indicated for 0.1bar suction pressure drop and condition 54.5 CCT, 7.2 CET and 5K SH



* Capacity calculated for CT 54.4 °C, ET 7.2 °C, SH 5K



/ Balance Point

12 / Balance Point

Cooling Load=7 kW , Heating Load= 9 kW

The screenshot displays the BITZER Software interface. On the left, the 'Compressor selection' panel shows the following settings: Mode: Refrigeration and Air con; Refrigerant: R134a; Reference temperature: Dew point temp.; Compressor type: Single Compressor; Series: Standard; Motor version: all. Under 'Compressor selection', 'Cooling capacity' is selected with a value of 7 kW. Under 'Operating point', Evaporating SST is 7 °C and Condensing SDT is 50 °C. Under 'Operating conditions', Suct. gas superheat is 8 K. Under 'Capacity control', 'without' is selected. The main area shows a schematic of a refrigeration cycle with a compressor, condenser, evaporator, and expansion valve. The condenser temperature is 74.0 °C, the evaporator temperature is 7.0 °C, and the suction gas temperature is 50.0 °C. The compressor model is 2EES-2Y. Below the schematic is a table of technical data for the compressor.

Compressor	2EES-2Y-40S	2DES-2Y-40S
Capacity steps	100%	100%
Cooling capacity	6.53 kW	7.80 kW
Cooling capacity *	6.59 kW	7.87 kW
Evaporator capacity	6.53 kW	7.80 kW
Power input	2.01 kW	2.44 kW
Current (400V)	3.79 A	4.49 A
Voltage range	380-420V	380-420V
Condenser capacity	8.54 kW	10.24 kW
COP/EER	3.25	3.20
COP/EER *	3.28	3.23
Mass flow	170.8 kg/h	204 kg/h
Operating mode	Standard	Standard
Discharge gas temp. w/o cooling	74.0 °C	74.6 °C

Refrigerants

Cooling Load

Evaporating and Condensing Temperatures

Super heat

13 / Balance Point

Cooling Mode

- Selected Evaporator: 3 Fans (30cm Diameter)
- Selected Condenser: 1 Fan (50 cm Diameter)

$$\dot{Q}_H = C \times Eff \times (T_c - T_{out})$$

Results:

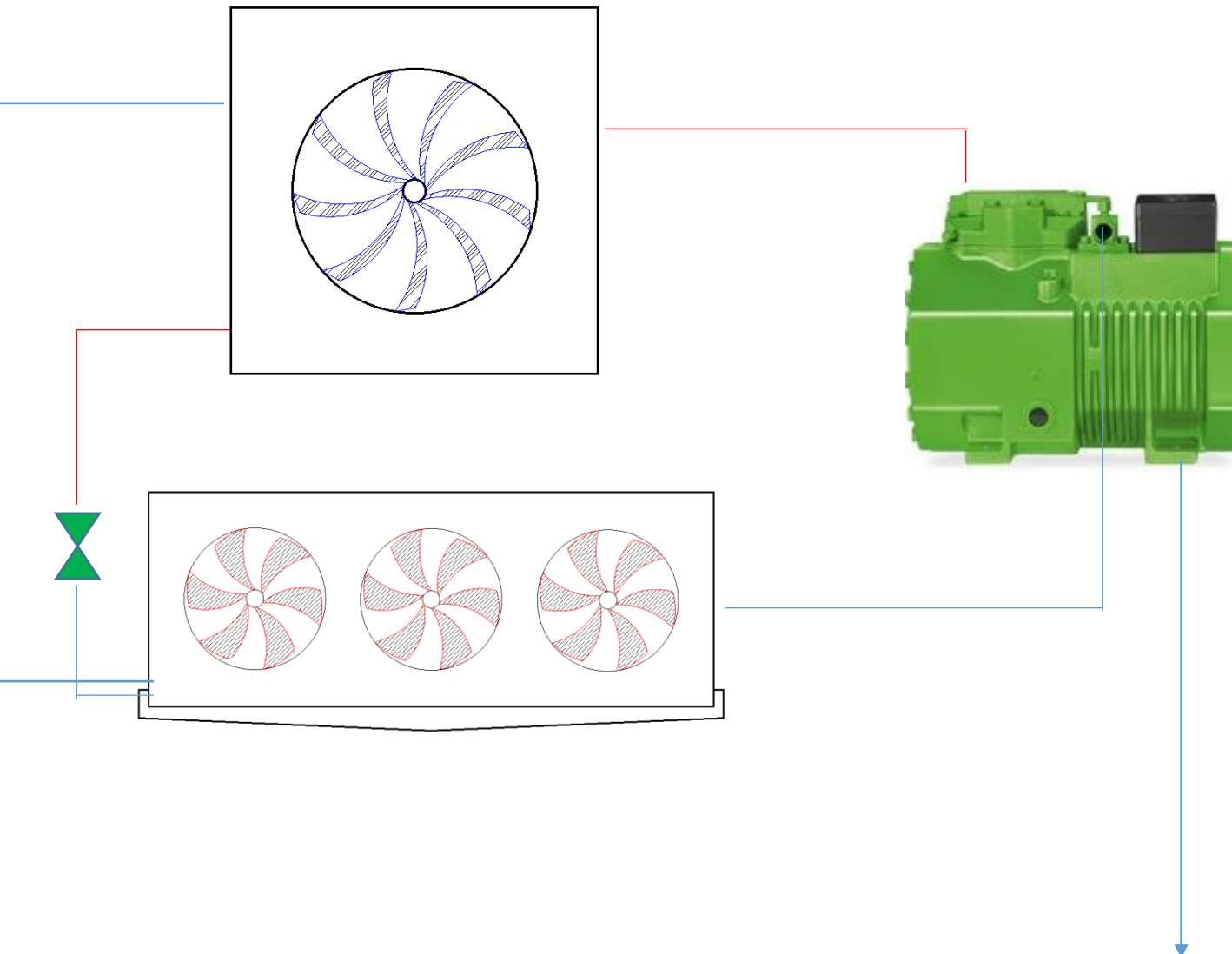
If $T_r=18^\circ\text{C}$ and $T_{out}=40^\circ\text{C}$

Balance Point:

$T_e=8.3^\circ\text{C}$ and $T_c=49.2^\circ\text{C}$

$Q_c=8.35\text{ kW}$, $W=2.45\text{ kW}$, $Q_h=10.8\text{ kW}$

$$\dot{Q}_C = C \times Eff \times (T_r - T_e)$$



$$\dot{Q}_C = c_1 + c_2 T_e + c_3 T_c + c_4 T_e^2 + c_5 T_e T_c + c_6 T_c^2 + c_7 T_e^3 + c_8 T_c T_e^2 + c_9 T_e T_c^2 + c_{10} T_c^3$$

14 / Balance Point

Heating Mode

- Selected Condenser: 3 Fans (30cm Diameter)
- Selected Evaporator: 1 Fan (50 cm Diameter)

$$\dot{Q}_C = C \times Eff \times (T_r - T_e)$$

Results:

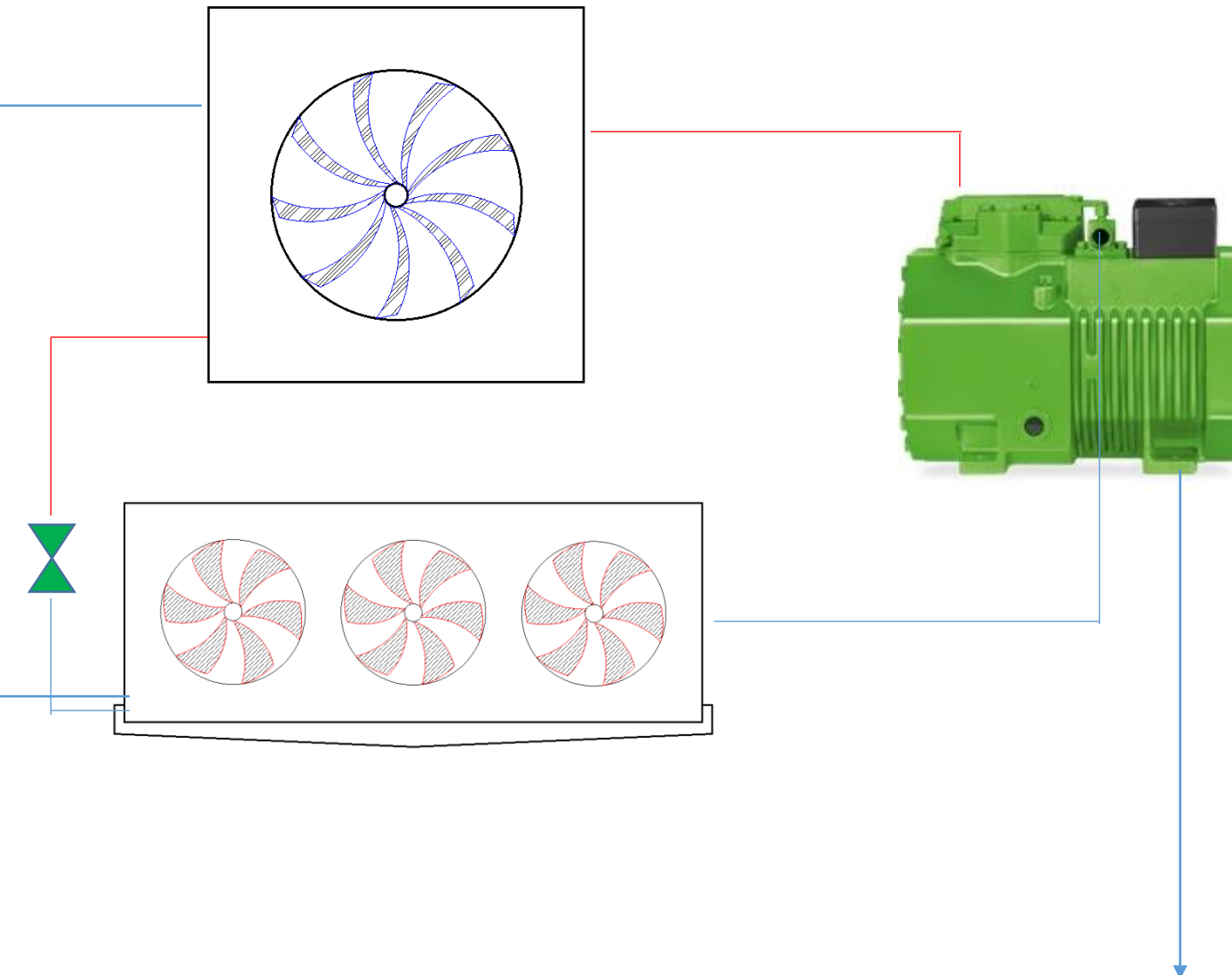
If $T_r=25^\circ\text{C}$ and $T_{out}=5.3^\circ\text{C}$

Balance Point:

$T_e=0.1^\circ\text{C}$ and $T_c=35.4^\circ\text{C}$

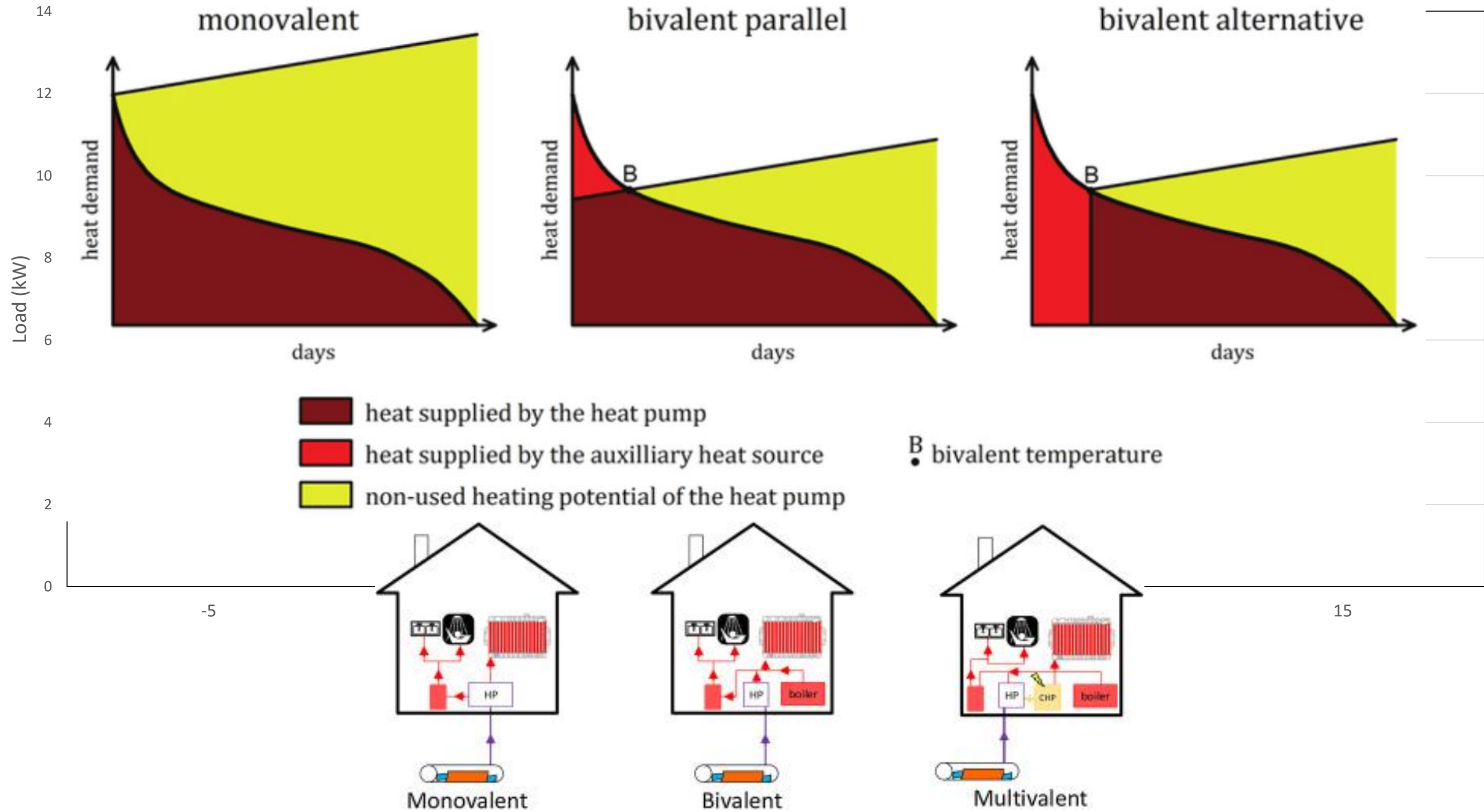
$Q_c=7.2\text{ kW}$, $W=1.8\text{ kW}$, $Q_h=9\text{ kW}$

$$\dot{Q}_H = C \times Eff \times (T_C - T_{out})$$



$$\dot{Q}_C = c_1 + c_2 T_e + c_3 T_c + c_4 T_e^2 + c_5 T_e T_c + c_6 T_c^2 + c_7 T_e^3 + c_8 T_c T_e^2 + c_9 T_e T_c^2 + c_{10} T_c^3$$

15 / Balance Point



/ Suitable Refrigerants

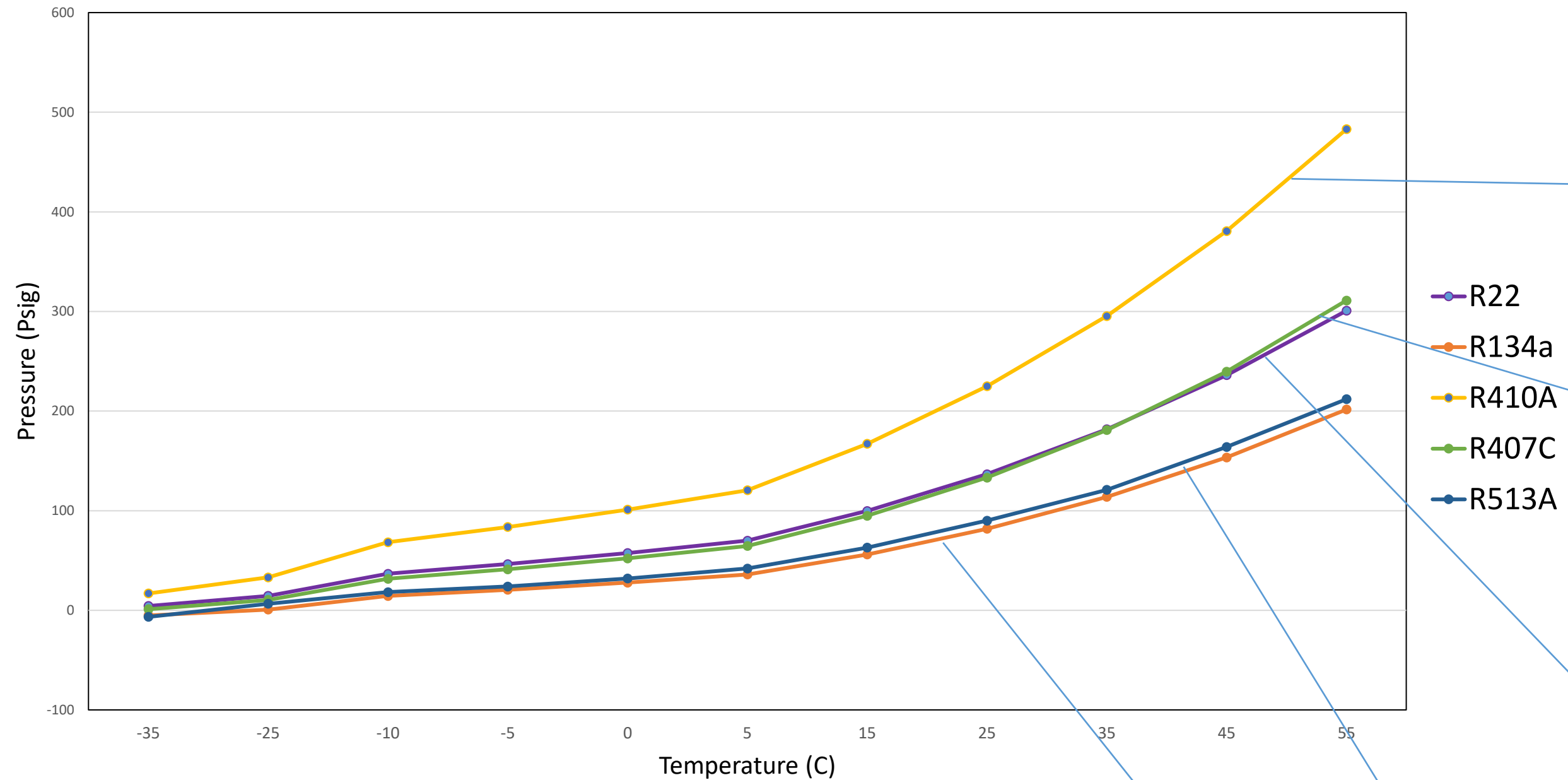
17 / What are the most suitable refrigerants?



- “..HCFC-22, HFC 134-a and HFC-407C are the most widely used refrigerants in new heat pumps...”
S.K. Wang, (2001), “Hand book of Air Conditioning and Refrigeration”, McGraw-Hill, Chapter 12.
- “...R 134a, R407c, R410a, R717 respectively for medium and large sized, small sized and industrial scale heat pumps...”
Aspirationenergy.com, “Refrigerants used in Heat Pumps and How to choose it wisely”
- **R134a, R513A, R407c, R410A, R32, R1234yf, R1234ze** → **Most mentioned**

18 / What are the most suitable refrigerants?

- **Pressure and Compressor Envelope** → **Needs More Attention**

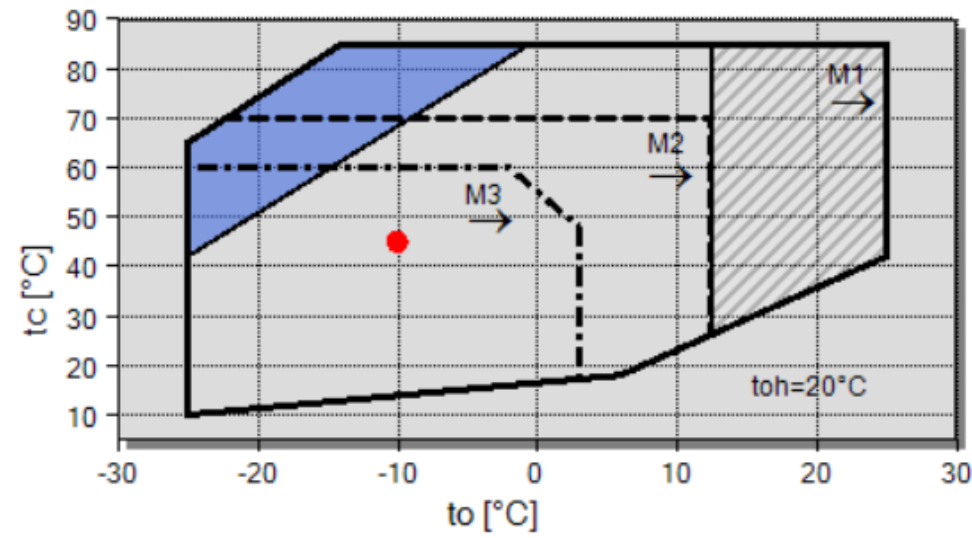


19 / What are the most suitable refrigerants?

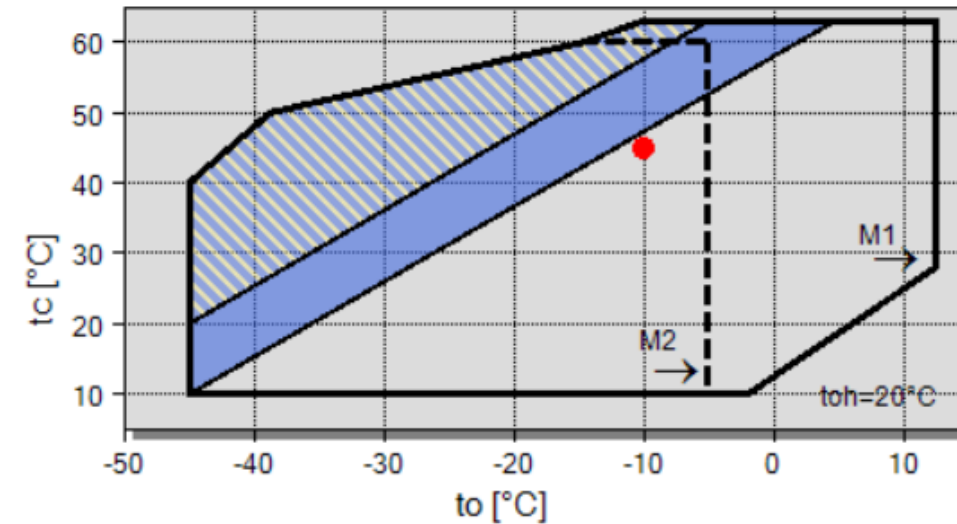
- Pressure and Compressor Envelope \longrightarrow Needs More Attention



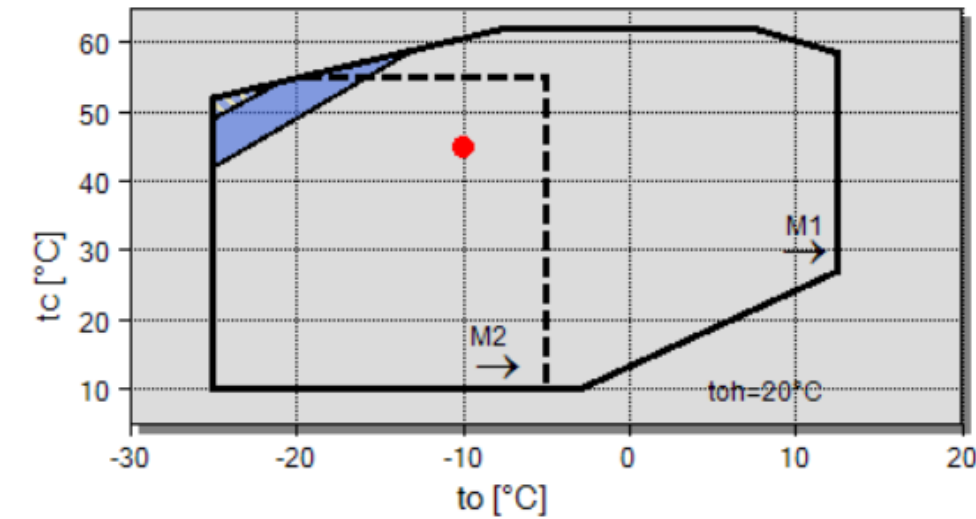
2DES-3Y



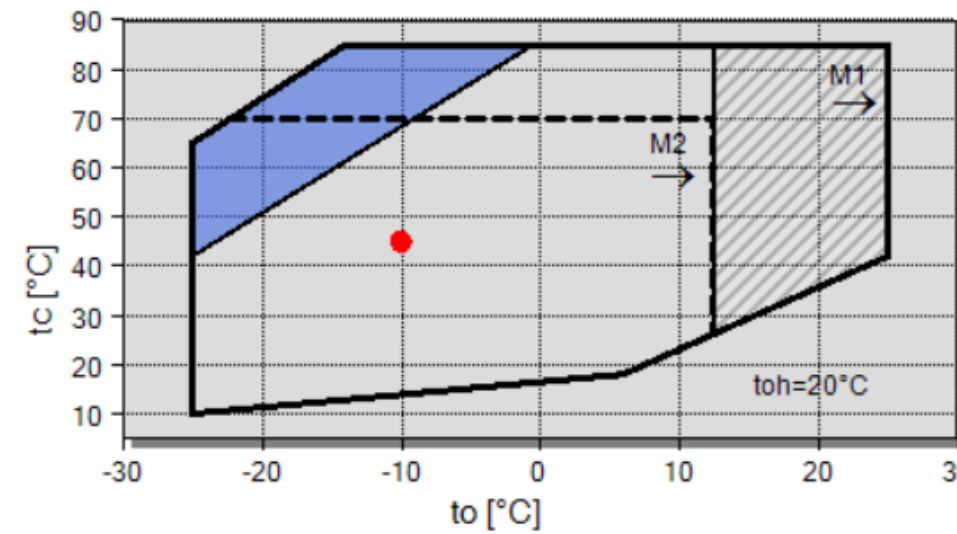
R134a



R22



R407C



R513A

20 / What are the most suitable refrigerants?

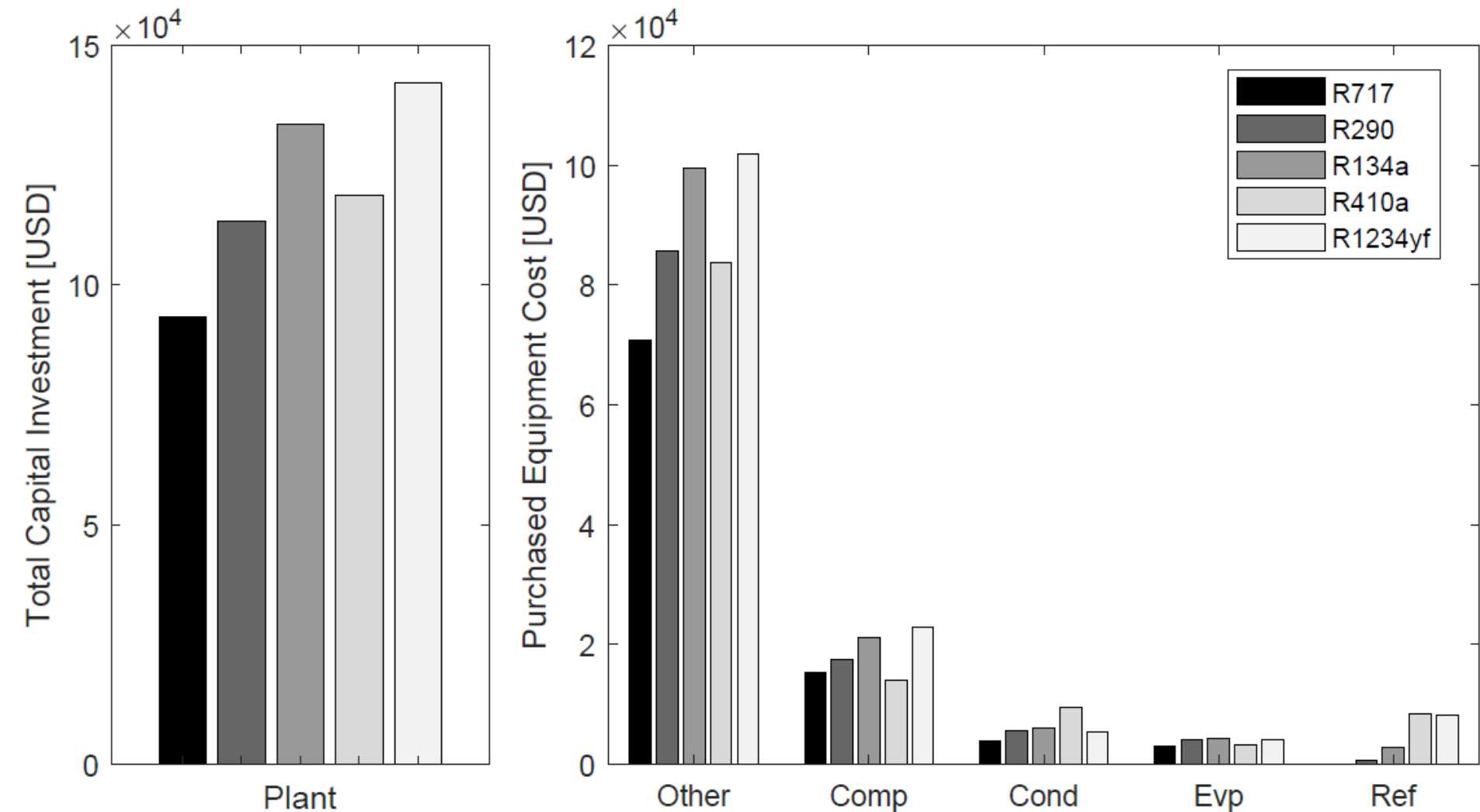


- Pressure and Compressor Envelope → Needs More Attention

- N. Stefan, C.S. Wuust, S. Thorsen, E. Brian, (2018), “Comparison of Heat Pump Design and Performance for Modern Refrigerants” , In Proceedings of 13th IIR- Gustav Lorentzen Conference on Natural Refrigerants.

Refrigerant	Group	GWP 100 [years]	ASHRAE Safety Group	ASHRAE Flammability	ASHRAE Toxicity
R717 (Ammonia)	Natural	0	B2L	Yes (Low)	Yes
R290 (Propane)	Natural	3	A3	Yes (Highly flammable)	No
R1234yf	HFO	4	A2L	Yes (Low)	No
R134a	HFC	1430	A1	No	No
R410A	HFC	2088	A1	No	No

Parameter	Unit	R717	R290	R134a	R410A	R1234yf
Exergy destruction	[kW _{ex}]	22.3	27.6	26.9	25.2	31.7
Exergy efficiency	[-]	0.67	0.64	0.64	0.65	0.62
COP	[-]	3.1	2.6	2.6	2.8	2.3
Total Charge	[kg]	3.5	7.1	15.9	27.1	20.3
Specific Heat Charge	[g · kW ⁻¹]	23	47	106	181	135
Cost of heat	[USD · MWh ⁻¹]	44	51	55	50	60

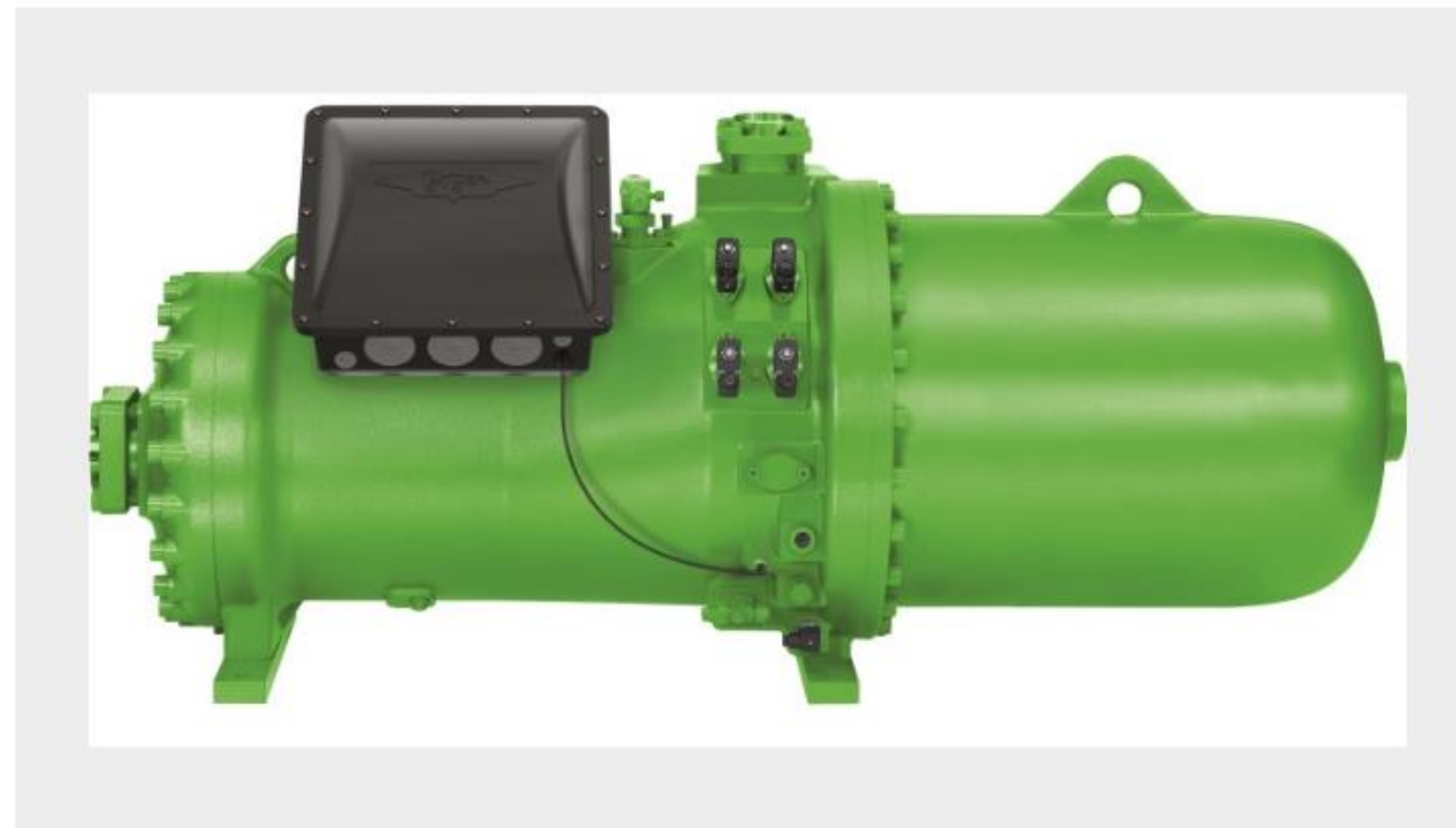


/ Bitzer Screw Compressors For Heat Pump

22 / Bitzer Screw Compressor For Heat Pump

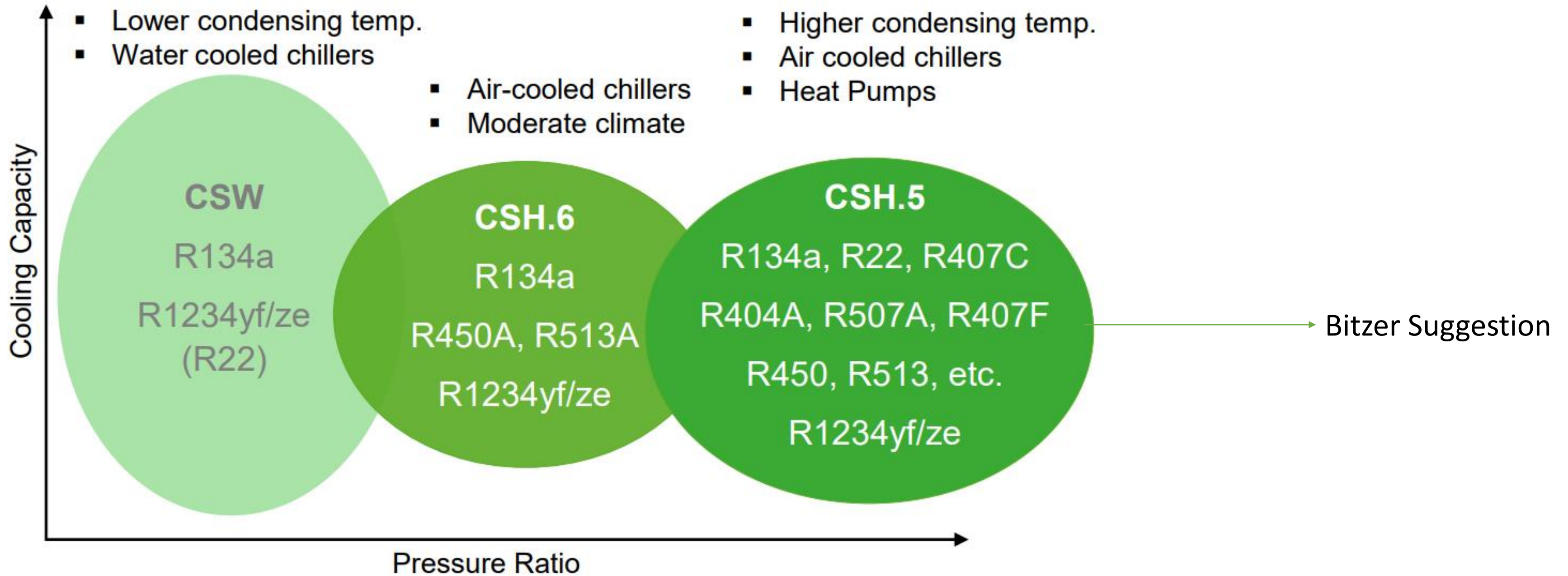
BITZER APPROVES CSH SCREW COMPRESSORS FOR USE IN LARGE HEAT PUMPS

16.03.2021



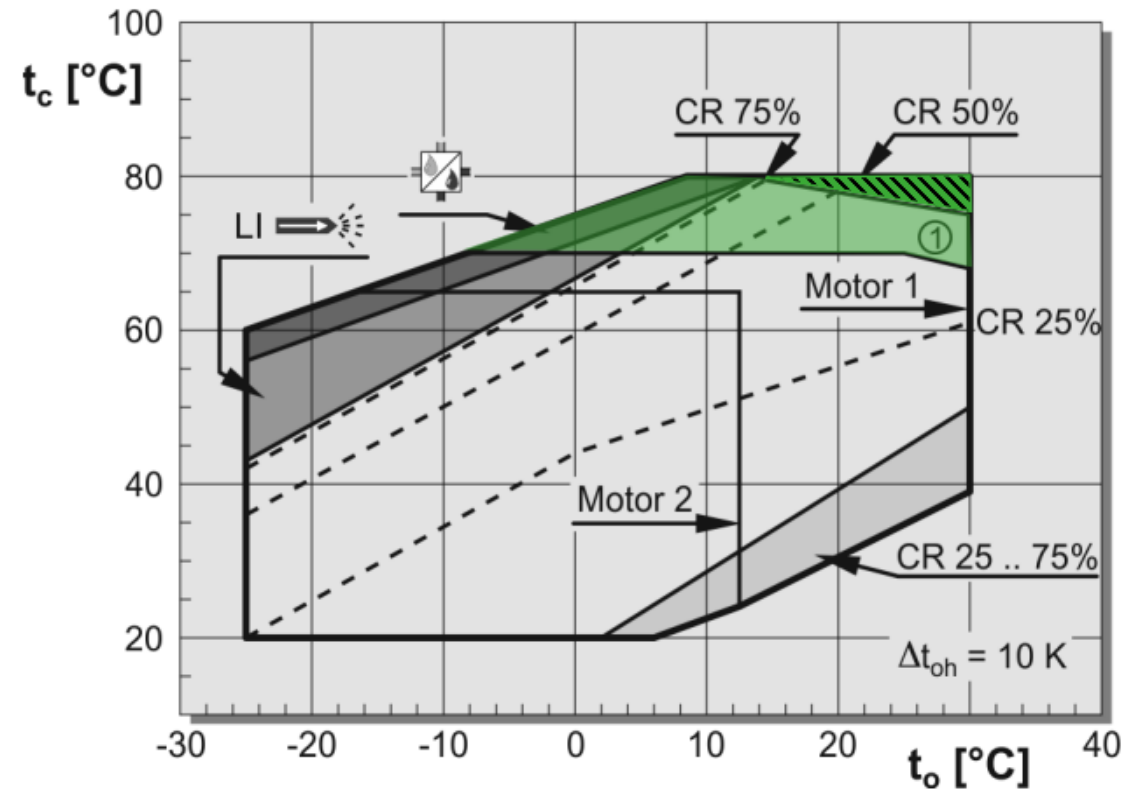
BITZER has approved selected CSH screw compressors for use in large heat pumps

23 / Bitzer Screw Compressor For Heat Pump



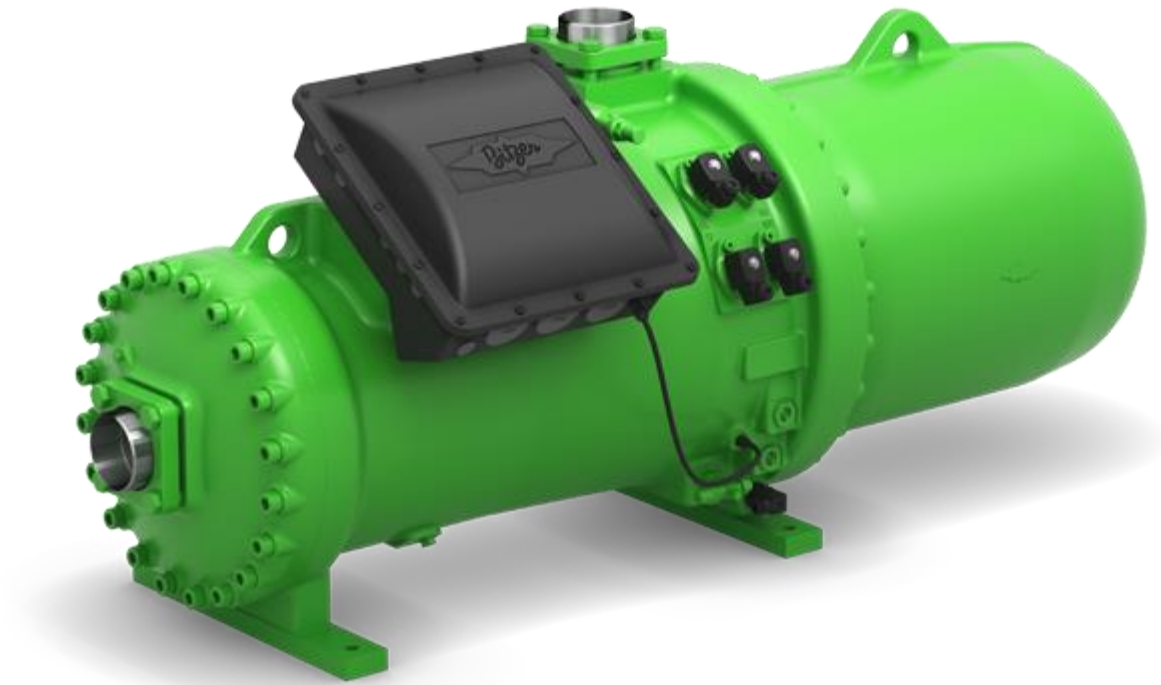
24 / Bitzer Screw Compressor For Heat Pump

For R134a, R1234yf, R450A and R513A



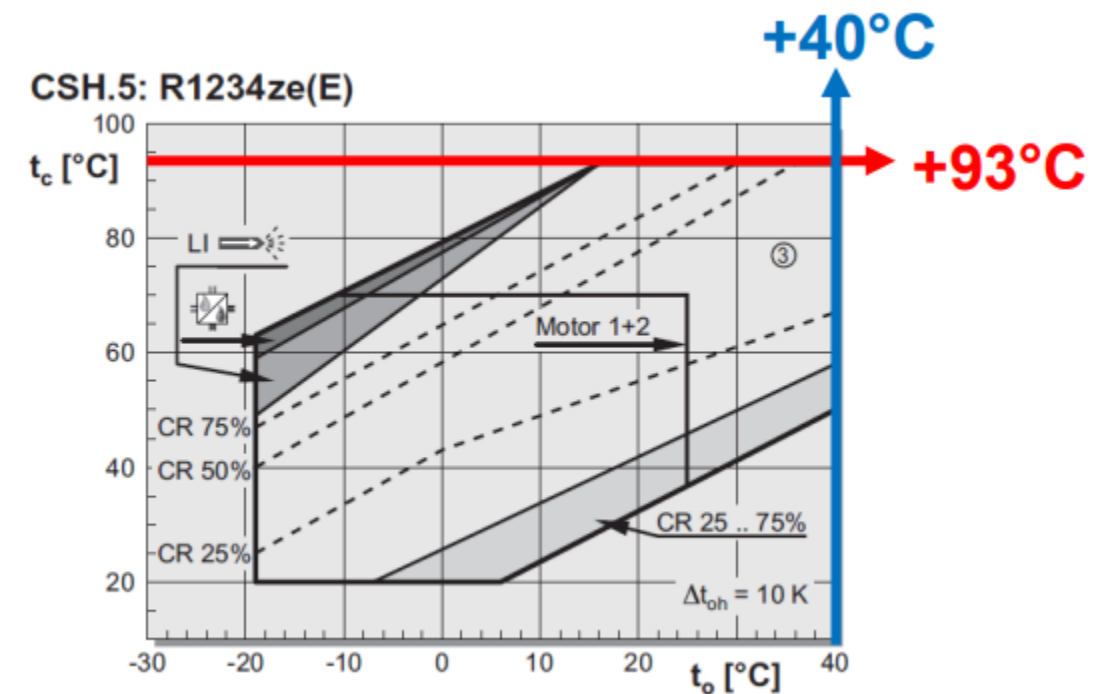
- Only for listed compressors
- Only for listed compressors and R450A

- CSH6553-50(Y)
- CSH6563-60(Y)
- CSH7553-70(Y)
- CSH7563-80(Y)
- CSH7573-90(Y)
- CSH7583-100(Y)
- CSH8553-110(Y)
- CSH8563-125(Y)
- CSH8573-140(Y)
- CSH8593-180(Y)
- CSH9553-180(Y)
- CSH9563-210(Y)
- CSH9573-240(Y)
- CSH9583-280(Y)



Heat-Pump for high-temperature applications

- **CSH.5** with R1234ze(E) and R515B
 - New maxi SDT = **+93°C** (hot sanitary water +90°C)
 - New maxi SST = **+40°C**
- Safe and stable thanks on-board monitoring with SE-i1
- Available in BITZER Software **6.15.2** (05.10.2020)



25 / Bitzer Screw Compressor For Heat Pump

The screenshot displays the Bitzer software interface for heat pump calculations. On the left, the 'Compressor selection' panel shows two circuits, each with one CSH8573-140Y compressor. The operating point is set to -10°C evaporating SST and 70°C condensing SDT. The 'Operating conditions' panel shows a cooling capacity of 300 kW and a condensing subcooling of 0 K.

The central diagram shows a refrigerant cycle with a condenser at 70.0°C and an evaporator at -10.0°C. A compressor is shown with a discharge temperature of n/a. The refrigerant is R515B.

The 'Result' tab shows the following technical data:

A				
Parameter	Value	Unit		
Evaporating SST	-10.00	°C		
Condensing SDT	70.0	°C		
Qe	106.6	kW	Pe	147.9
			EER	Ratio
			W/W	%
Total				
Circuit 1	53.3		73.9	--
CSH8573-140Y-40P	53.3		73.9	0.72 100.0
Circuit 2	53.3		73.9	--
CSH8573-140Y-40P	53.3		73.9	0.72 100.0

Refrigerant

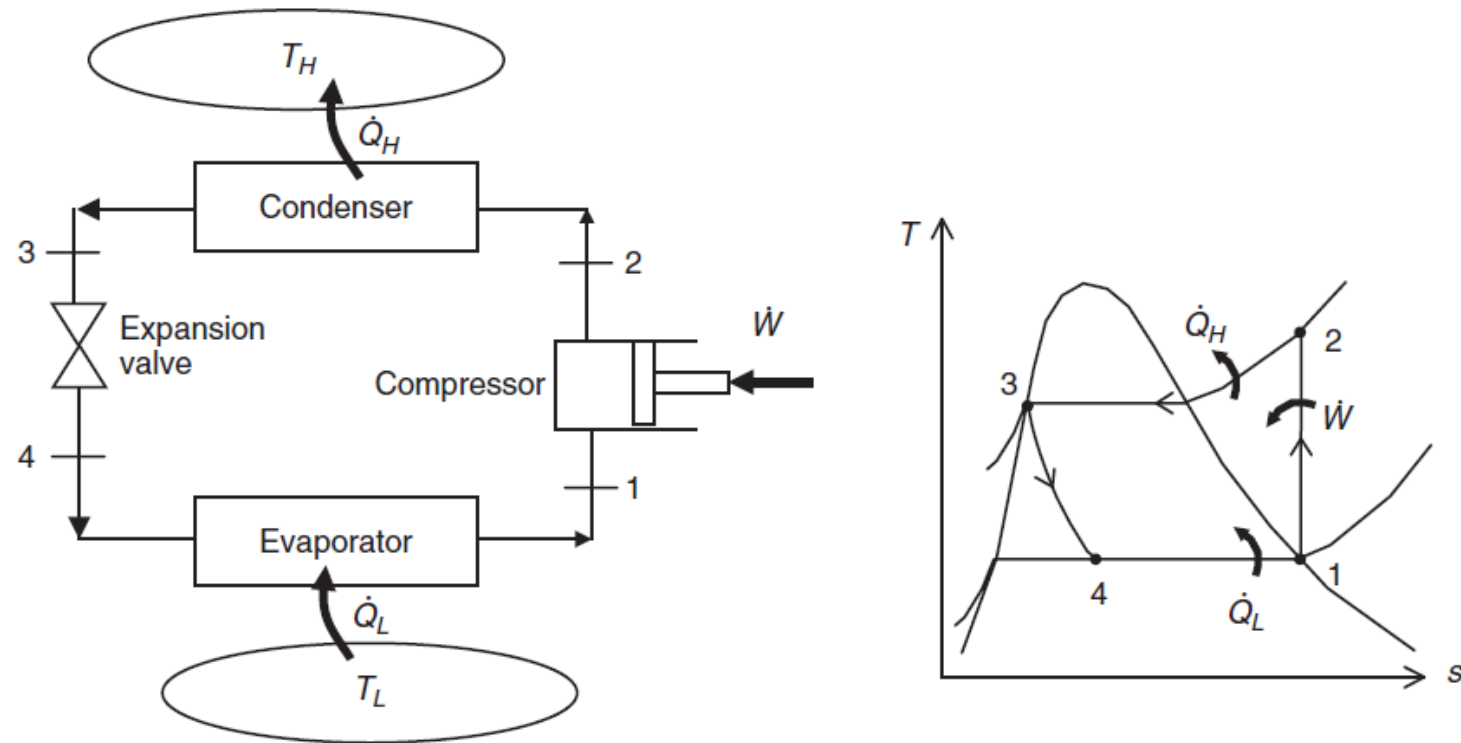
Selected Compressors

Evaporator and Condenser Temperatures

Rejection=254.5 kW

/ Heat Pump Performance

27 / Heat Pump performance evaluation



Compressor: $\dot{W} = \dot{m} \times (h_2 - h_1)$
 Condenser: $\dot{Q}_H = \dot{m} \times (h_2 - h_3)$
 Evaporator: $\dot{Q}_L = \dot{m} \times (h_1 - h_4)$
 Expansion Valve: $h_3 = h_4$



$$COP = \frac{\dot{Q}_H}{\dot{W}}$$

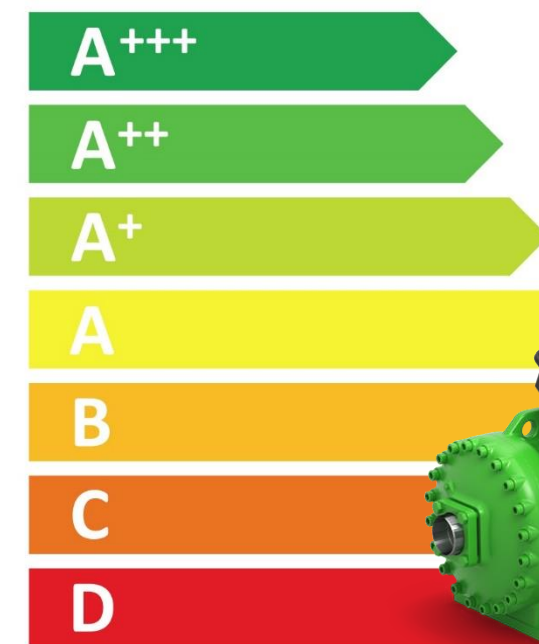
The most common measurement used to rate heat pump efficiency

Air source heat pumps: COPs= 2 to 4

Water source heat pumps: COPs= 3 to 5

$COP @ 8.3^\circ C (47^\circ F)$

$COP @ -9.4^\circ C (17^\circ F)$



✘ While COPs is helpful, it does not provide the whole picture

28 / Heat Pump performance evaluation



- Primary Energy Ratio (PER)

$$PER = \eta \times COP$$

- Energy Efficiency Ratio (EER)

$$EER = \text{cooling capacity} \left(\frac{Btu}{h} \right) / \text{electrical energy input (W)}$$

In practice, EER ratings higher than 10 are the most desirable.

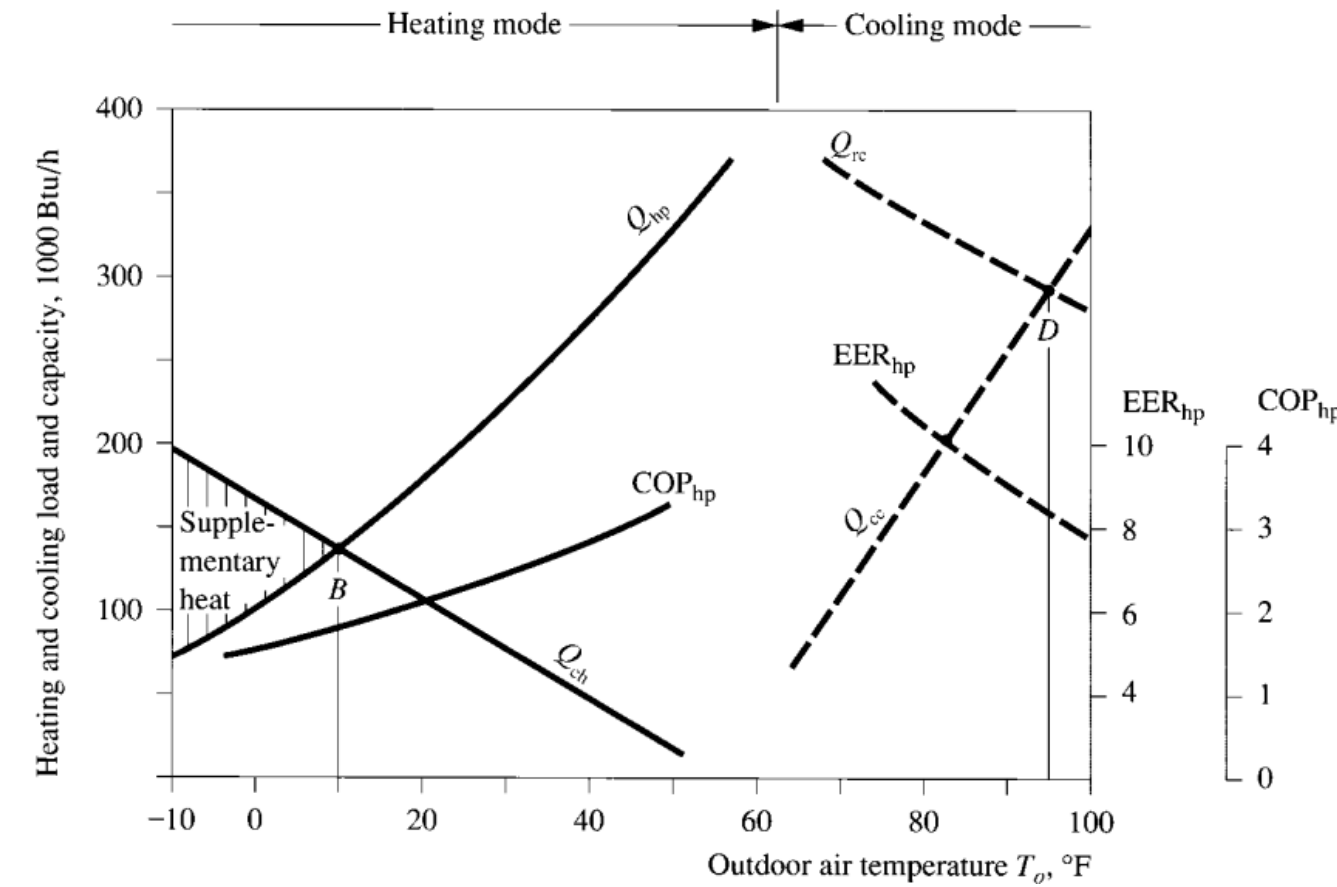
- Heating Season Performance Factor (HSPF)

$$HSPF = \text{total seasonal heating output (Btu)} / \text{total electrical energy input (Wh)}$$

An HSPF of 6.8 corresponds to an average COP of 2. HSPFs of 5-7 are considered good.

- Seasonal Energy Efficiency Ratio (SEER)

$$SEER = \text{total seasonal cooling output (Btu)} / \text{total electrical energy input (Wh)}$$



29 / Heat Pump performance evaluation

- Minimum Performance Based on ASHREA 90.1-1999

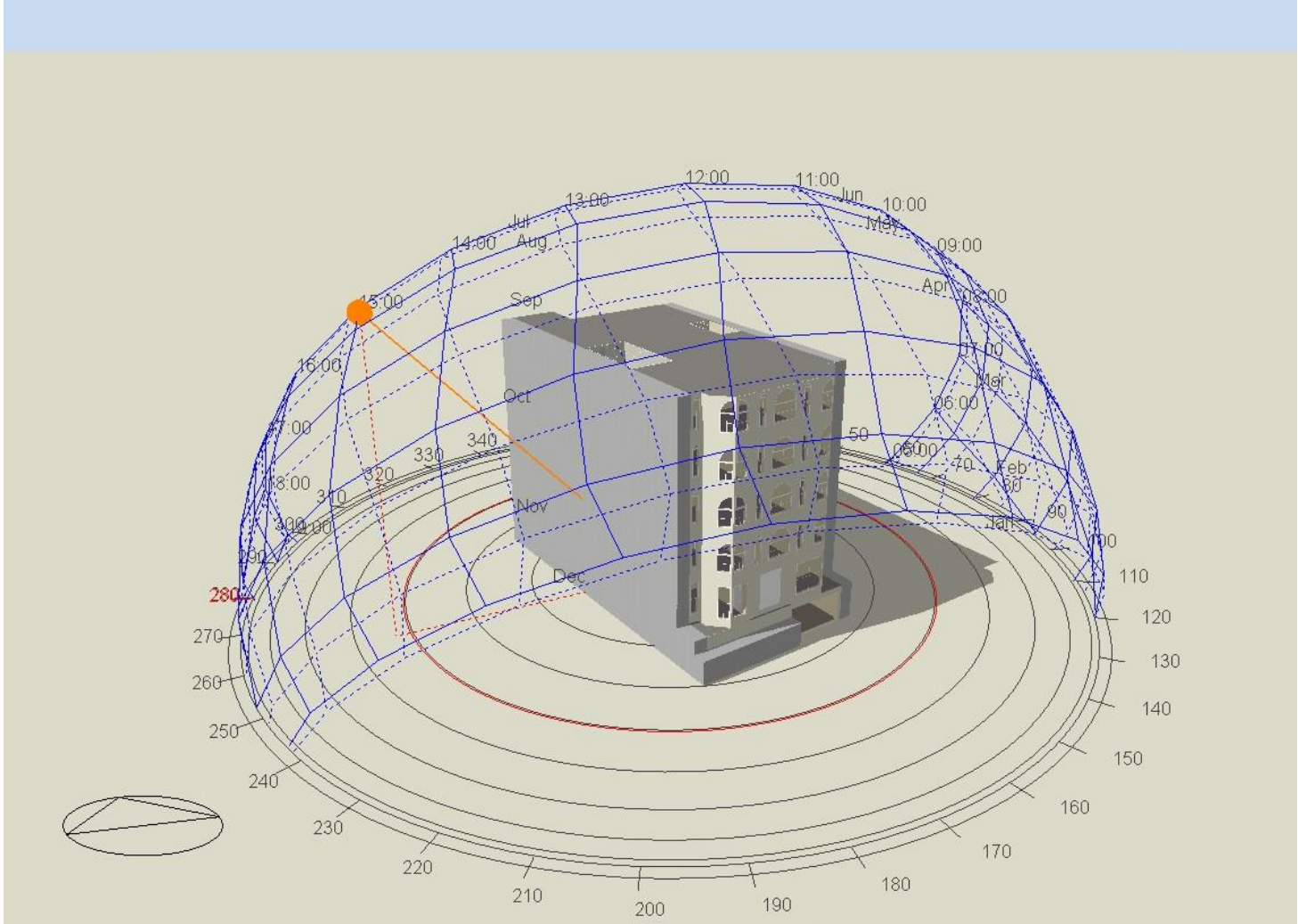
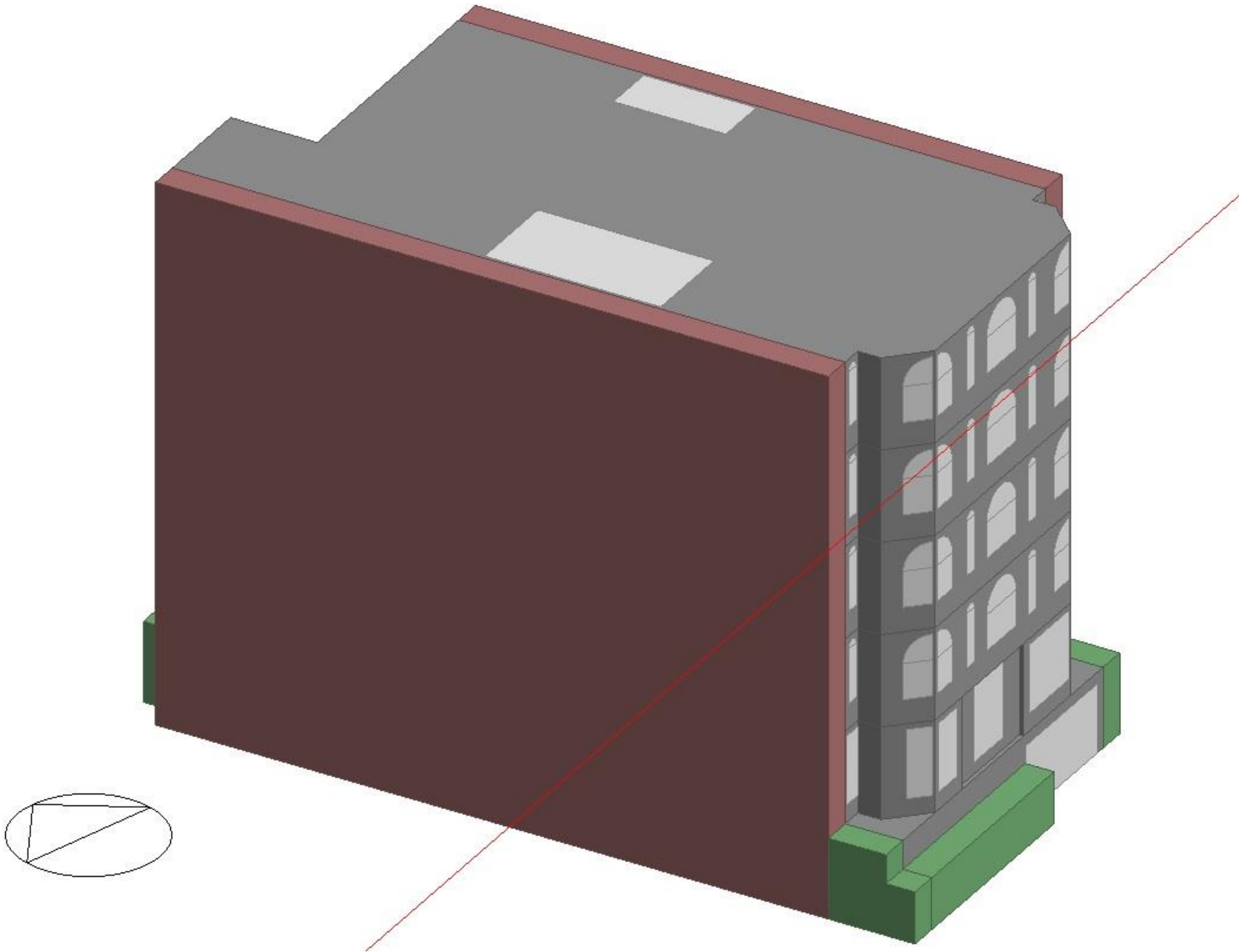
Size	Cooling description	Minimum efficiency	Efficiency as of 10/29/2001	Heating rating condition	Minimum efficiency	10/29/2001
< 65,000 Btu/h	Split system	10.0 SEER	10.0 SEER	Split system	6.8 HSPF	6.8 HSPF
	Single package	9.7 SEER	9.7 SEER	Single package	6.6 HSPF	6.6 HSPF
≥ 65,000 Btu/h and < 135,000 Btu/h	Split system and single package	8.9 EER	10.1 EER	47°Fdb/43°Fwb outdoor air	3.0 COP	3.2 COP
≥ 135,000 Btu/h and < 240,000 Btu/h	Split system and single package	8.5 EER	9.3 EER	47°Fdb/43°Fwb outdoor air (≥ 135,000 Btu/h)	2.9 COP	3.1 COP
≥ 240,000 Btu/h	Split system and single package	8.5 EER 7.52 IPLV	9.0 EER 9.22 IPLV			

Test Standards:

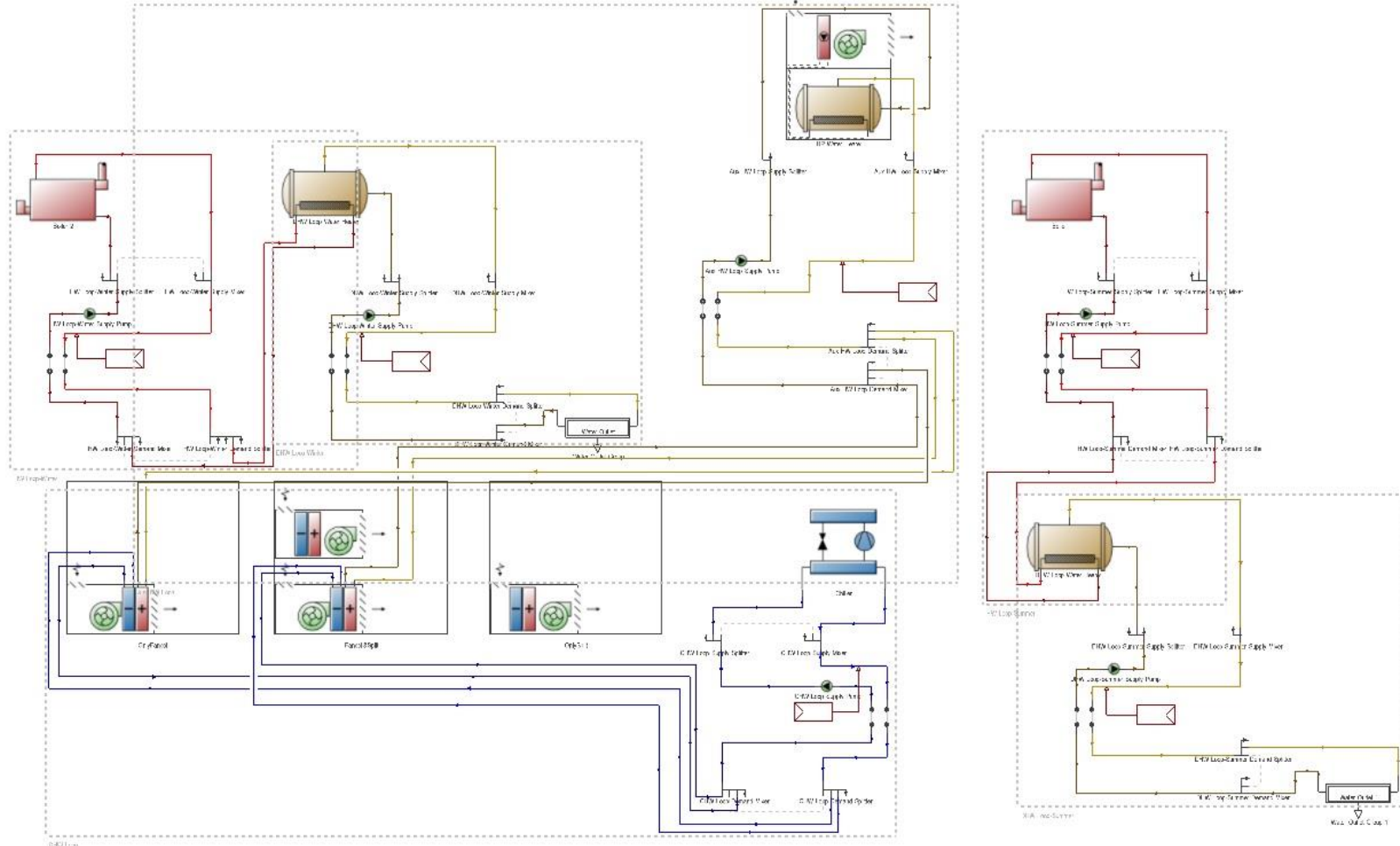
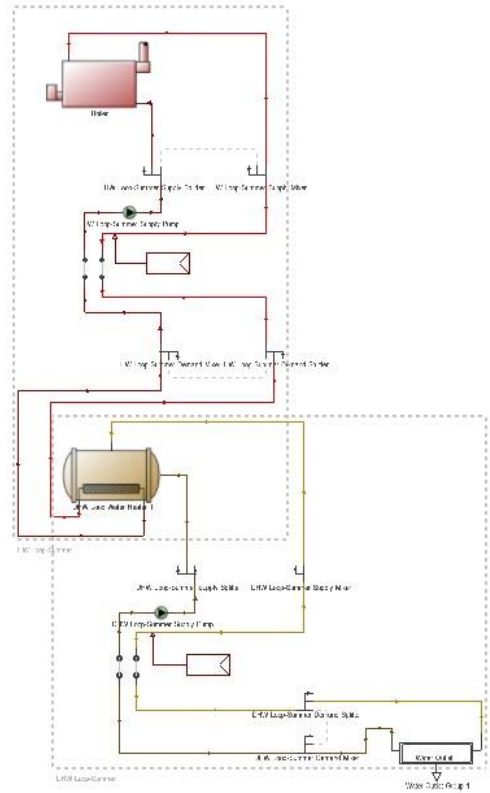
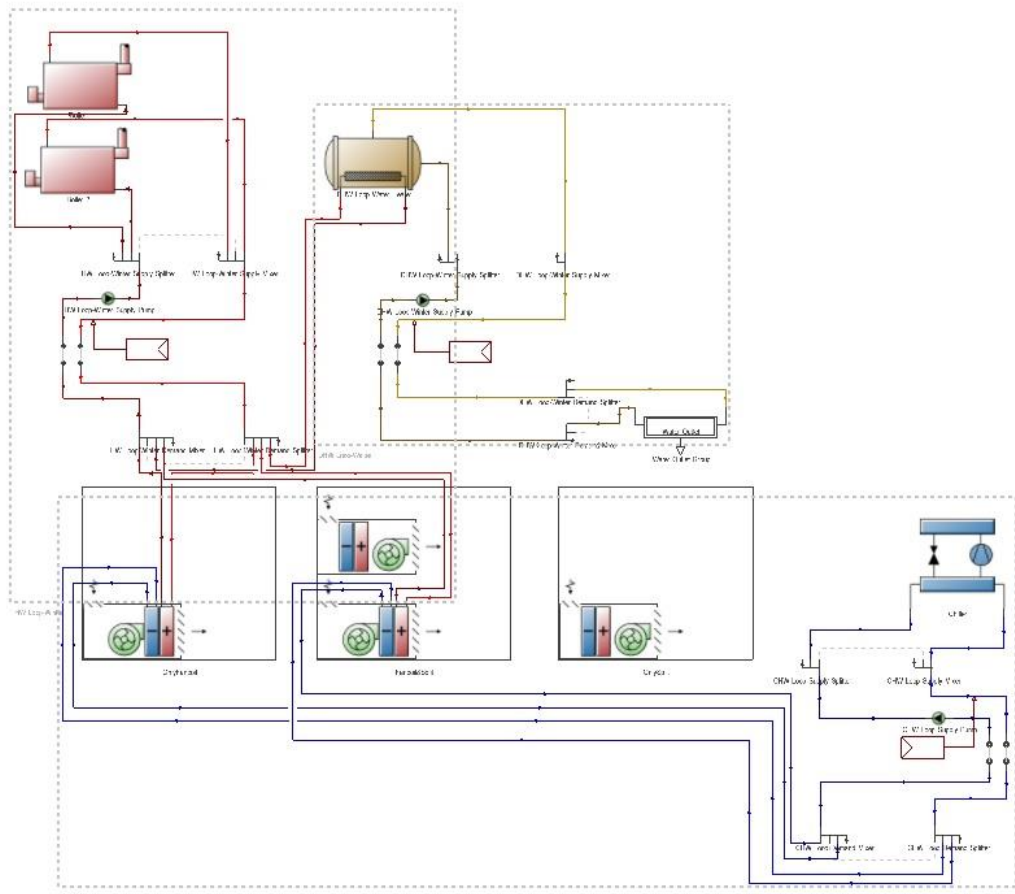
- AHRI Standard 210/240, "Performance Rating of Unitary Air-Conditioning and Air-source Heat Pump Equipment"
- ISO 13256-1:2021, "Water-source heat pumps-Testing and rating for performance-Part1:Water-to-air and brine-to-air heat pumps"
- ISO 13256-2:2021, "Water-source heat pumps-Testing and rating for performance-Part2:Water-to-water and brine-to-water heat pumps"

/ Heat Pump vs Boiler

31 / Heat Pump vs Boiler (Case study)



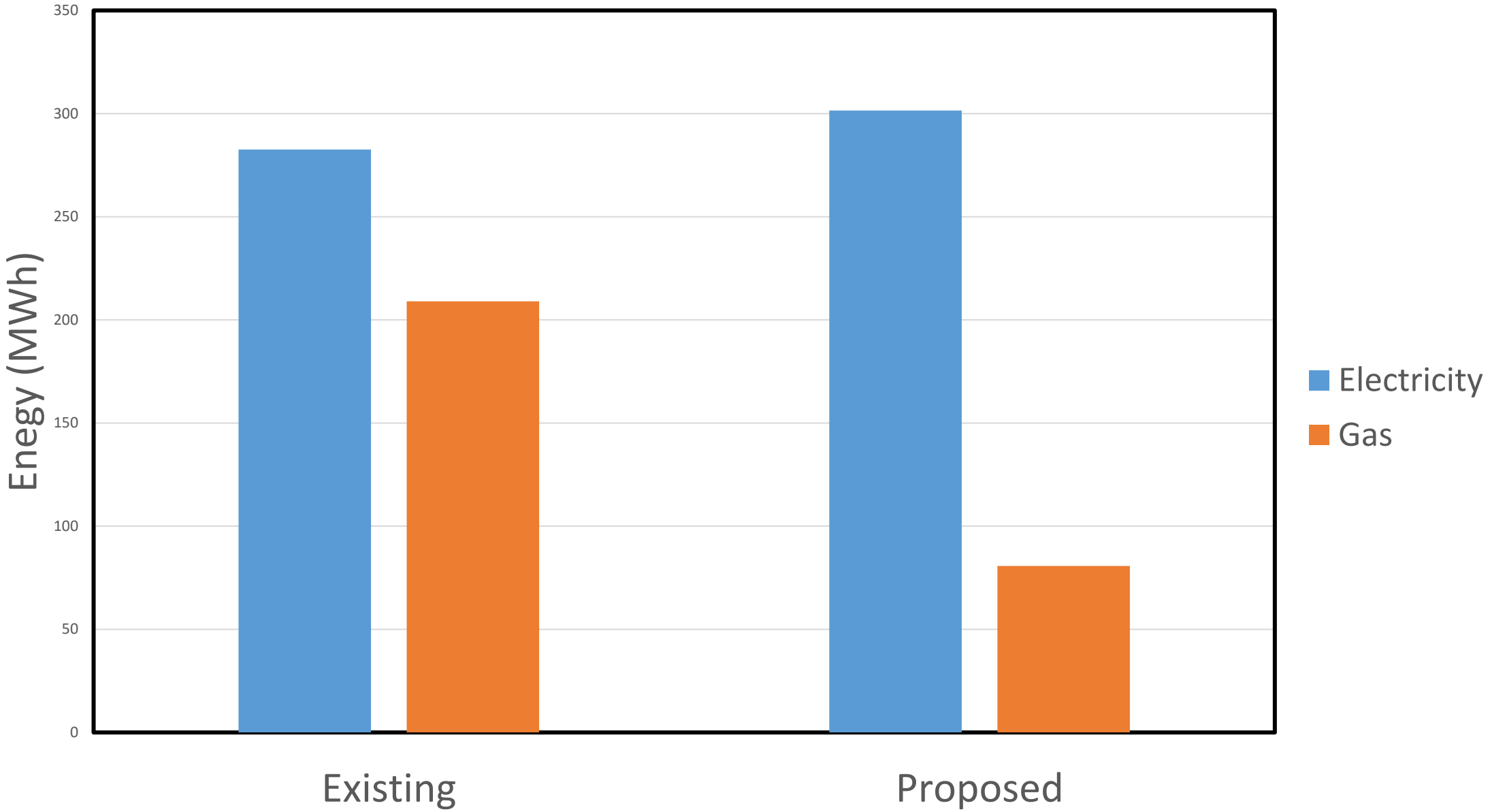
32 / Heat Pump vs Boiler (Case study)



Existing System

Proposed System

33 / Heat Pump vs Boiler (Case study)



Existing System

$$PE = 3 \times 282.59 + 209.3 = 1057.03 \text{ MWh}$$

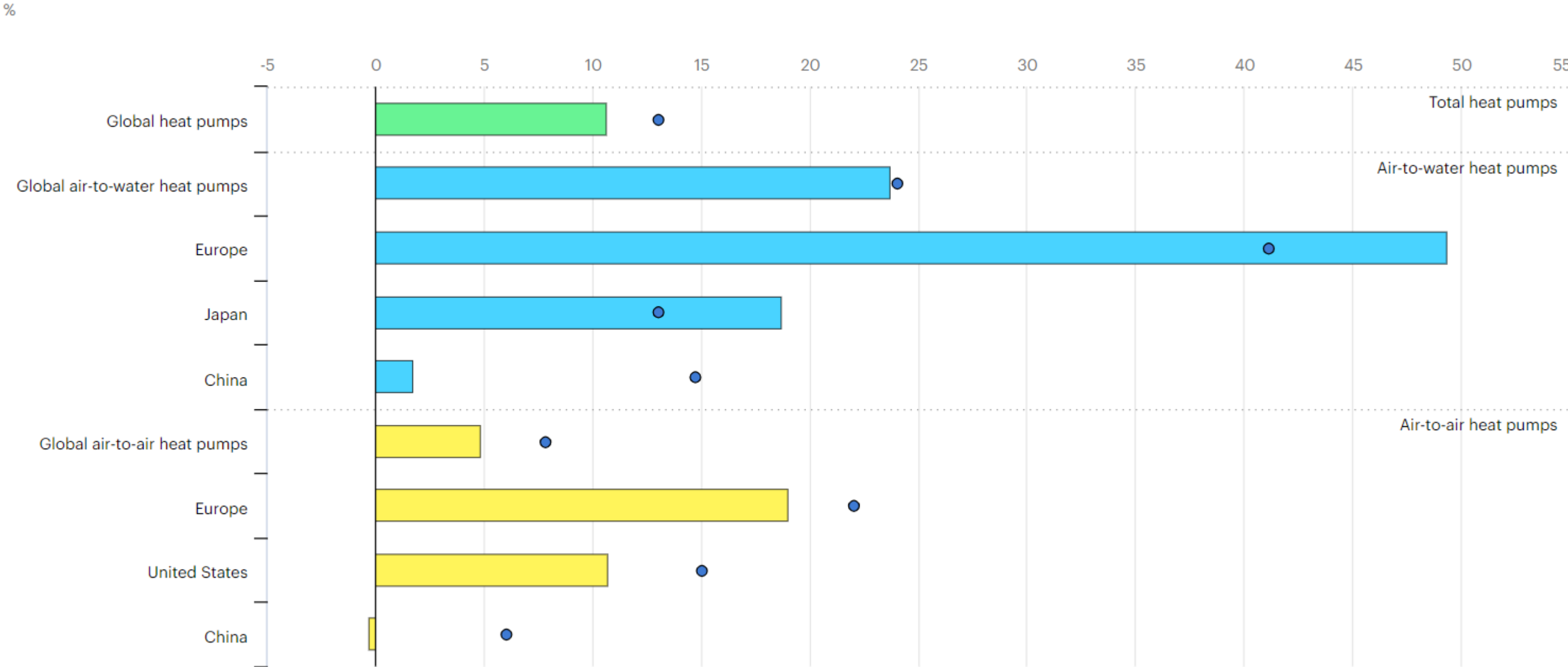
Proposed System

$$PE = 3 \times 301.57 + 80.67 = 985.38 \text{ MWh}$$

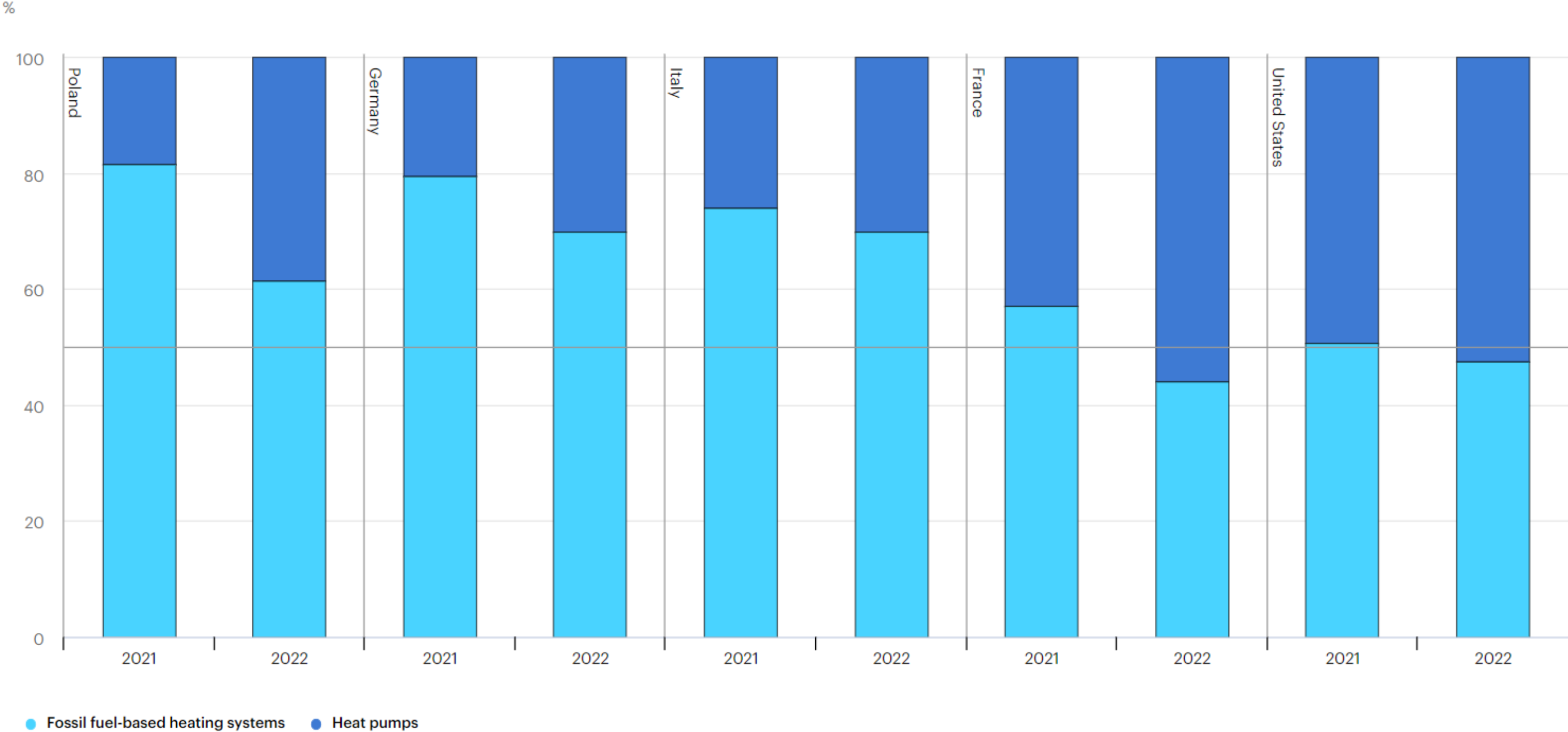
/ Conclusion

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- Global sales of heat pumps grew by **11%** in **2022**, according to the latest IEA analysis.



36 / Conclusion



Thank You!

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