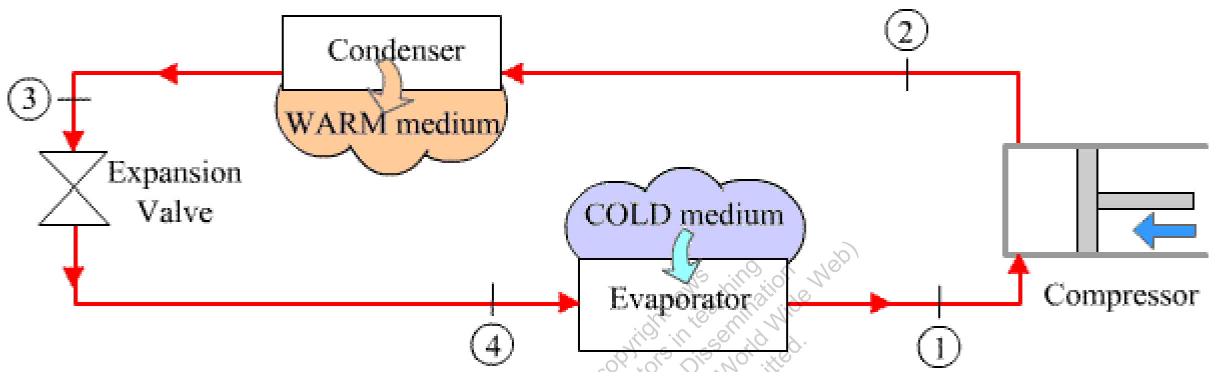
10-4-1 [OQA] A refrigerator uses R-134a as the working fluid and operates on an ideal vapor compression refrigeration cycle between 0.15 MPa and 1 MPa. A temperature difference of 5°C is maintained for effective heat exchange between the refrigerant and its surroundings at the evaporator and condenser. The atmospheric conditions are 100 kPa and 25°C. If the mass flow rate is 0.04 kg/s, (a) perform an exergy inventory on a rate (kW) basis for the entire cycle complete with an exergy flow diagram. Determine the (b) exergetic efficiency and (c) COP of the system. (d) Identify the device with the highest rate of exergy destruction.

SOLUTION:



Dead State: p0 = 100 kPa and T0 = 25 °C (298 K)

Vapor Compression Refrigeration Cycle

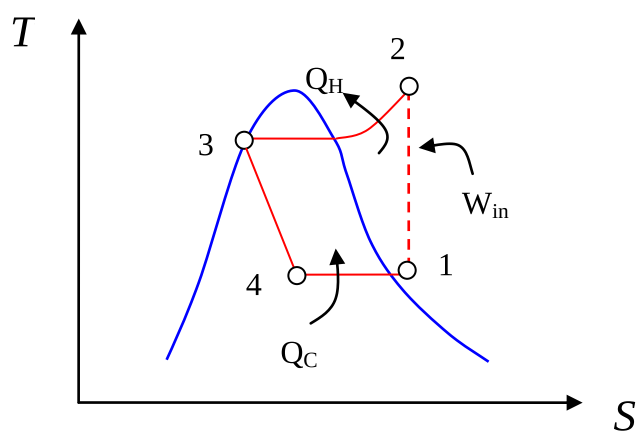


Table 1 Properties at various state points in the refrigeration plant.

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s $\mathrm{kJ/(kg \cdot K)}$	h kJ/kg
State 0	**100**	**298**	0	1.10207	275.31
State 1	**150**	256	0.49330	0.93818	238.78
State 2	**1000**	320	2.07838	**0.93818**	278.41
State 3	**1000**	312	1.75836	0.38878	106.60
State 4	**150**	256	1.36828	0.42149	**106.60**

Note: Blue quantities are given and black quantities are calculated using TEST.

Table 2 Device-specific Analysis

Plant Component	Device	$\lvert \Delta\dot{\Psi} \rvert$ kW	$\lvert \dot{W}_u \rvert$ kW	Exergy Supplied to/from Reservoir kW	$\dot{I}$ kW	Exergetic Efficiency %
Compressor	A	1.58508	1.58508	0	0	100
Condenser	B	0.32002	0	0	0.32002	0
Expansion	C	0.39008	0	0	0.39008	0
Evaporator	D	0.87498	0	0.74951	0.12546	85.66
Total Plant			1.58508	0.74951	0.83557	47.29

$$\dot{Q}_{\text{in}} = \dot{m}\left(h_1 - h_4\right) = 5.28715 \text{ kW}$$

(b) Rate of exergy supplied by the refrigerant to cold medium at 261 K (exergy flows in the opposite direction of heat flow because $T_C < T_0$),

$$-\dot{Q}_{\text{in}}\left(1 - \frac{T_0}{T_C}\right) = -5.28715\left(1 - \frac{298}{261}\right) = 0.749519 \text{ kW}$$

To calculate the exergetic efficiency, η_{II} ,

$$\dot{W}_{net} = 1.58508 \text{ kW}$$

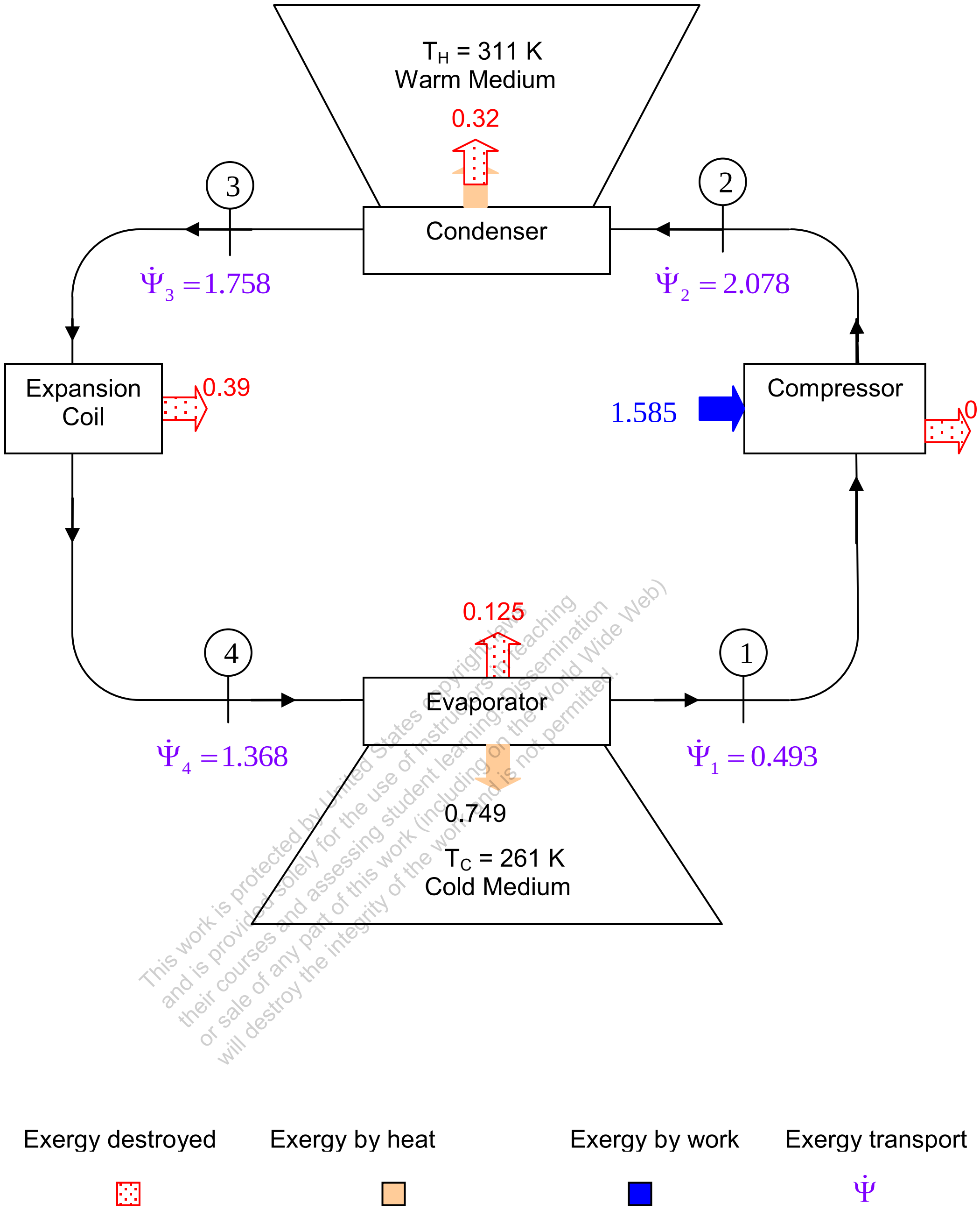
$$\eta_{II} = \frac{-\dot{Q}_{\text{in}}\left(1-\dfrac{T_0}{T_C}\right)}{\dot{W}_{\text{net}}} = \frac{0.7495}{1.5851} = 0.4729 = 47.29\%$$

(c) To calculate COP the Cycle Panel from TEST was used.

$$\dot{W}_{net} = 1.58508 \text{ kW}$$

$$\text{COP} = \frac{\dot{Q}_{\text{in}}}{\dot{W}_{\text{net}}} = \frac{5.28715 \text{ kW}}{1.58508 \text{ kW}} = 3.33$$

(d) Referring to table 2, expansion coil is device with the highest rate of exergy destruction. 24.6 % of exergy is destroyed in expansion device.



Exergy diagram for the vapor compression refrigeration system (on kW basis)

TEST Solution: Use the PC refrigeration cycle TESTcalc to solve this problem. The TEST-code can be found in the Problems module of the professional TEST site at www.thermofluids.net.

10-4-2 [OCP] A vapor-compression refrigeration system circulates R-134a at a rate ($m^{\cdot}$) of 10 kg/min. The refrigerant enters the compressor at -10°C, 1.2 bar and exits at 7 bar. The isentropic compressor efficiency is 68%. There are no significant pressure drops as the refrigerant flows through the condenser and evaporator. The refrigerant leaves the condenser at 7 bar and 24°C. Ignoring the heat transfer between the compressor and its surroundings, determine (a) the coefficient of performance (COP_R), (b) the refrigerating capacity in tons and (c) the irreversibility rates of the compressor and expansion valve each in kW for an ambient temperature of 20°C.

SOLUTION:

Use the manual approach or the PC refrigeration cycle daemon to evaluate the enthalpy for each state as tabulated below.

St.	Given	h (kJ/kg)	St.	Given	h (kJ/kg)
1	$p_1 = 1.2\,\text{bar}$ $T_1 = -10^o C$	245.71	**4**	$p_4 = p_3$ $T_4 = 24^o C$	84.23
2	$p_2 = 7\,\text{bar}$ $s_2 = s_1$	284.45	**5**	$p_5 = p_1$ $h_5 = h_4$	84.23
3	$p_3 = p_2$ $h_3 = h_1 + \dfrac{(h_2 - h_1)}{0.68}$	302.69			

The refrigeration capacity is:

$$\dot{Q}_C = \dot{m}(h_1 - h_5) + = 0.167(345.71 - 84.23) \Rightarrow \dot{Q}_C = 26.91\,\text{kW}$$

$$\Rightarrow \dot{Q}_C = 7.65\text{ tons} \quad (\because 1\text{ kW}=0.284\text{ tons})$$

The work input to the compressor:

$$\dot{W}_{net} = \dot{m}(h_3 - h_1) = 0.167(302.69 - 245.71) = 9.496\,\text{kW}$$

$$\text{COP}_R = \frac{\dot{Q}_C}{\dot{W}_{\text{net}}} = \frac{26.91}{9.496} = 2.83$$

Irreversibility rate in kW during compression:

$$= \dot{S}_{\text{gen}} T_0 = \dot{m}(s_3 - s_1)T_0 = 0.1667(0.0554)293 = 2.704\text{ kW}$$

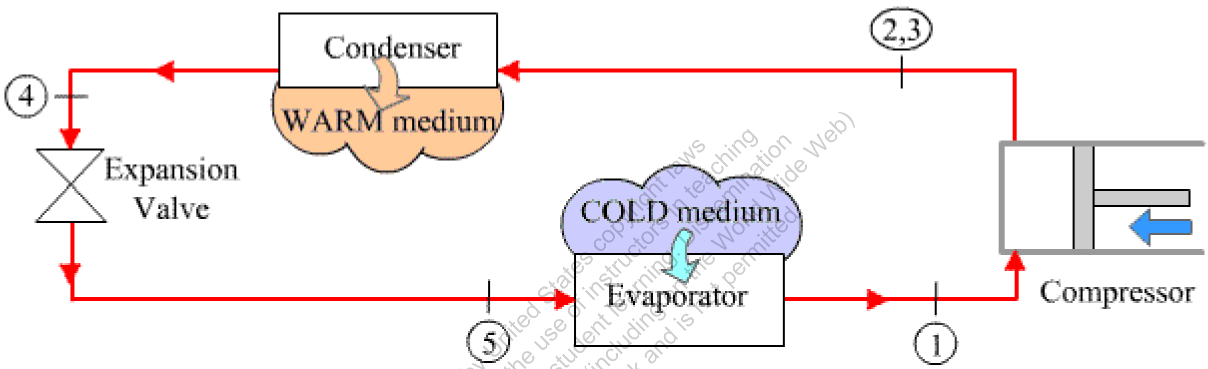
Irreversibility rate in kW during compression:

$$= \dot{S}_{\text{gen}} T_0 = \dot{m}(s_5 - s_4)T_0 = 0.1667(0.0227)293 = 1.108\text{ kW}$$

TEST Solution: Use the PC refrigeration cycle TESTcalc to solve this problem. The TEST-code can be found in the Problems module of the professional TEST site at www.thermofluids.net.

10-4-3 [OQP] A vapor-compression refrigeration system circulates R-134a at a rate ($\dot{m}$) of 10 kg/min. The refrigerant enters the compressor at -10°C, 1.2 bar and exits at 7 bar. The isentropic efficiency of the adiabatic compressor is 68%. There are no significant pressure drops as the refrigerant flows through the condenser and evaporator. The refrigerant leaves the condenser at 7 bar and 24°C. A temperature difference of 5°C is maintained for effective heat exchange between the refrigerant and its surroundings at the evaporator and condenser. The atmospheric conditions are 100 kPa and 25°C. (a) Perform an exergy inventory on a rate (kW) basis for the entire cycle complete with an exergy flow diagram. Determine (b) the exergetic efficiency and (c) COP of the system. (d) Identify the device with the highest rate of exergy destruction.

SOLUTION:



Dead State: p0 = 100 kPa and T0 = 25 °C (298 K)

Vapor Compression Refrigeration Cycle

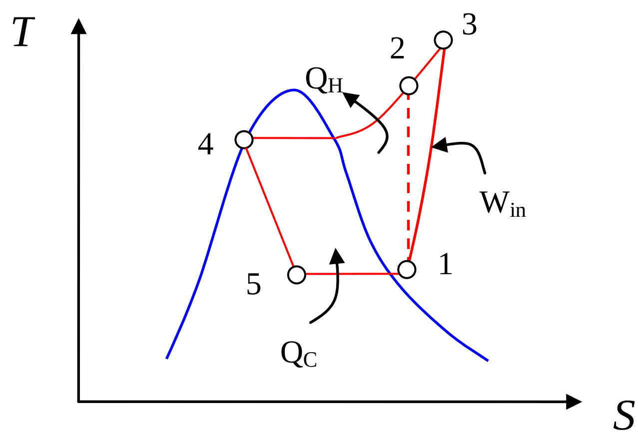


Table 1 Properties at various state points in the refrigeration plant.

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s $\text{kJ}/(\text{kg}\cdot\text{K})$	h kJ/kg
State 0	**100**	**298**	0	1.10207	275.31
State 1	**120**	**263**	1.03502	0.98194	245.70
State 3	**700**	338	7.77819	1.0373	**302.68**
State 4	**700**	**297**	7.20213	1.3025	84.23
State 5	**120**	251	6.07456	0.33893	**84.23**

Note: Blue quantities are given and black quantities are calculated using TEST.

Table 2 Device-specific Analysis

Plant Component	Device	$\lvert\Delta\dot{\Psi}\rvert$ kW	$\lvert\dot{W}_u\rvert$ kW	Exergy Supplied to/from Reservoir kW	$\dot{I}$ kW	Exergetic Efficiency %
Compressor	A	6.74317	9.49627	0	2.7531	71

Condenser	B	0.57597	0	0	0.57597	0
Expansion	C	1.12757	0	0	1.12757	0
Evaporator	D	5.03954	0	5.689	1.32174	73.77
Total Plant			9.49627	5.689	5.77838	39.15

$$\dot{Q}_{\text{in}} = \dot{m}\left(h_1 - h_4\right) = 26.913\text{ kW}$$

(b) Rate of exergy supplied by the refrigerant to cold medium at 256 K (exergy flows in the opposite direction of heat flow because $T_C < T_0$),

$$-\dot{Q}_{\text{in}}\left(1-\frac{T_0}{T_C}\right) = -26.913\left(1\text{-}\frac{298}{256}\right) = 4.415\text{ kW}$$

To calculate the exergetic efficiency, η_{II} ,

$$\dot{W}_{net} = 9.49627\text{ kW}$$

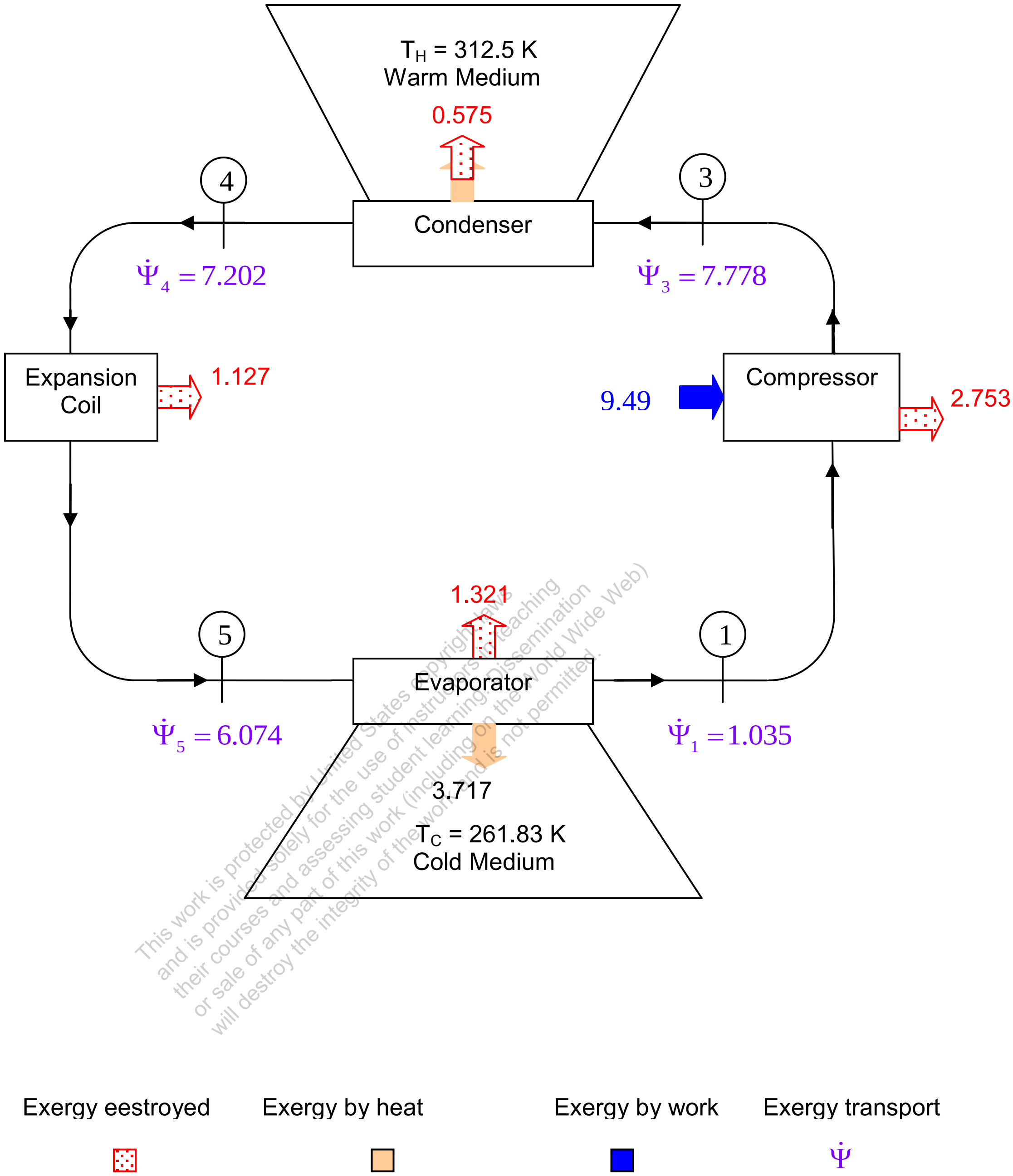
$$\eta_{II} = \frac{-\dot{Q}_{\text{in}}\left(1-\dfrac{T_0}{T_C}\right)}{\dot{W}_{\text{net}}} = \frac{4.415}{9.4962} = 0.465 = 46.5\%$$

(c) To calculate COP the Cycle Panel from TEST was used.

$$\dot{W}_{net} = 9.49627\text{ kW}$$

$$\text{COP}_R = \frac{\dot{Q}_{\text{in}}}{\dot{W}_{\text{net}}} = \frac{26.91269\text{ kW}}{9.49627\text{ kW}} = 2.83$$

(d) Referring to table 2, compressor is device with the highest rate of exergy destruction. 28.99% of exergy is destroyed in compressor.

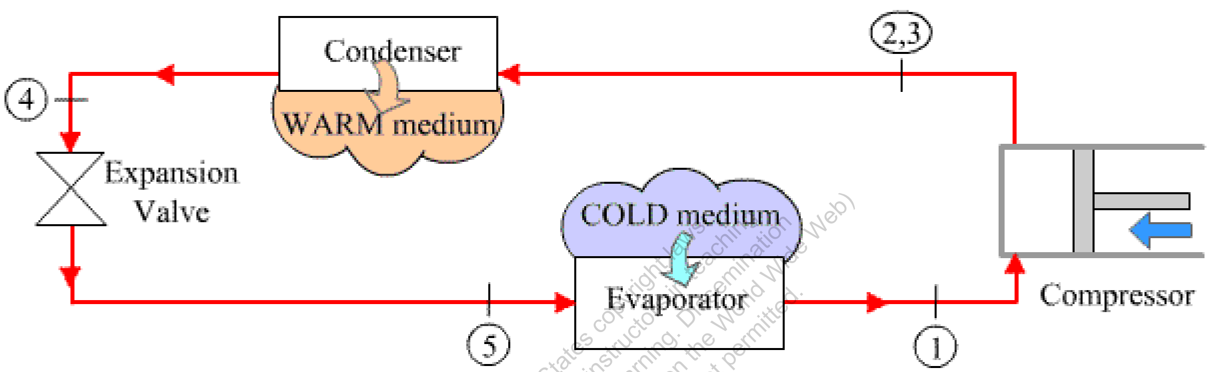


Exergy diagram for the vapor compression refrigeration system (on kW basis)

TEST Solution: Use the PC refrigeration cycle TESTcalc to solve this problem. The TEST-code can be found in the Problems module of the professional TEST site at www.thermofluids.net.

10-4-4 [OQK] A heat pump which operates on the vapor-compression cycle uses R-134a as the working fluid. Refrigerant enters the compressor at 20 lbf/in^2, 10^{o}F and is compressed adiabatically to 200 lbf/in^2, 180^{o}F. Saturated liquid enters the expansion valve at 200 lbf/in^2, 100^{o}F and exits at 20 lbf/in^2. The atmosphere temperature is 20^{o}F. (a) Perform an exergy inventory on a rate (Btu/min) basis for the entire cycle complete with an exergy flow diagram. Determine (b) the exergetic efficiency and (c) COP of the system. (d) Identify the device with the highest rate of exergy destruction.

SOLUTION:



Dead State: p0 = 1 atm (101 kPa) and T0 = 77 °F (298 K)

Vapor Compression Refrigeration Cycle

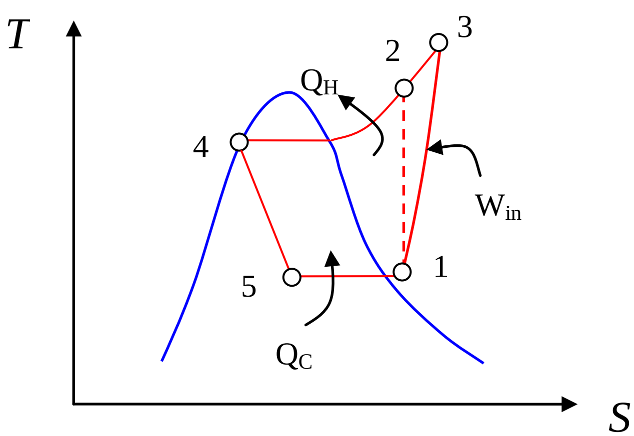


Table 1 Properties at various state points in the refrigeration plant.

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s kJ/(kg·K)	h kJ/kg
State 0	**101**	**298**	0	1.1010	275.29
State 1	**138**	**261**	1.4279	0.9622	243.37
State 3	**1379**	**355**	9.3544	1.0120	310.70
State 4	**1379**	**325**	6.8329	0.4480	125.69
State 5	**138**	254	4.5064	0.4990	**125.69**

Note: Blue quantities are given and black quantities are calculated using TEST.

Table 2 Device-specific Analysis

Plant Component	Device	$\lvert\Delta\dot{\Psi}\rvert$ kW	$\lvert\dot{W}_u\rvert$ kW	Exergy Supplied to/from Reservoir kW	$\dot{I}$ kW	Exergetic Efficiency %
Compressor	A	7.926	10.18	0	2.254	77.8
Condenser	B	2.521	0	0.161	2.36	6.38
Expansion	C	2.327	0	0	2.327	0
Evaporator	D	3.078	0	0	3.078	73.77
Total Plant			10.18	0.161	10.02	1.58

Although heat is transferred from the cold medium to the refrigerant in the evaporator, the exergy flows in the opposite direction if $T_C < T_0$. However, if we assume $T_C = T_0$, there is no exergy transfer.

$$-\dot{Q}_{\text{in}}\left(1-\frac{T_0}{T_C}\right) = -\dot{Q}_{\text{in}}\left(1-\frac{T_0}{T_0}\right) = 0 \text{ kW}$$

The rate of heat transfer from the condenser into the warm medium can be calculated as:

$$\dot{Q}_{\text{out}} = \dot{m}\left(h_3 - h_4\right) = 27.97 \text{ kW}$$

Rate of exergy supplied by the refrigerant to warm medium at 100°F = 311 K,

$$\dot{Q}_{\text{out}}\left(1-\frac{T_0}{T_H}\right)=27.97\left(1\text{-}\frac{261}{311}\right)=0.161\text{ kW}$$

To calculate the exergetic efficiency, η_{II} ,

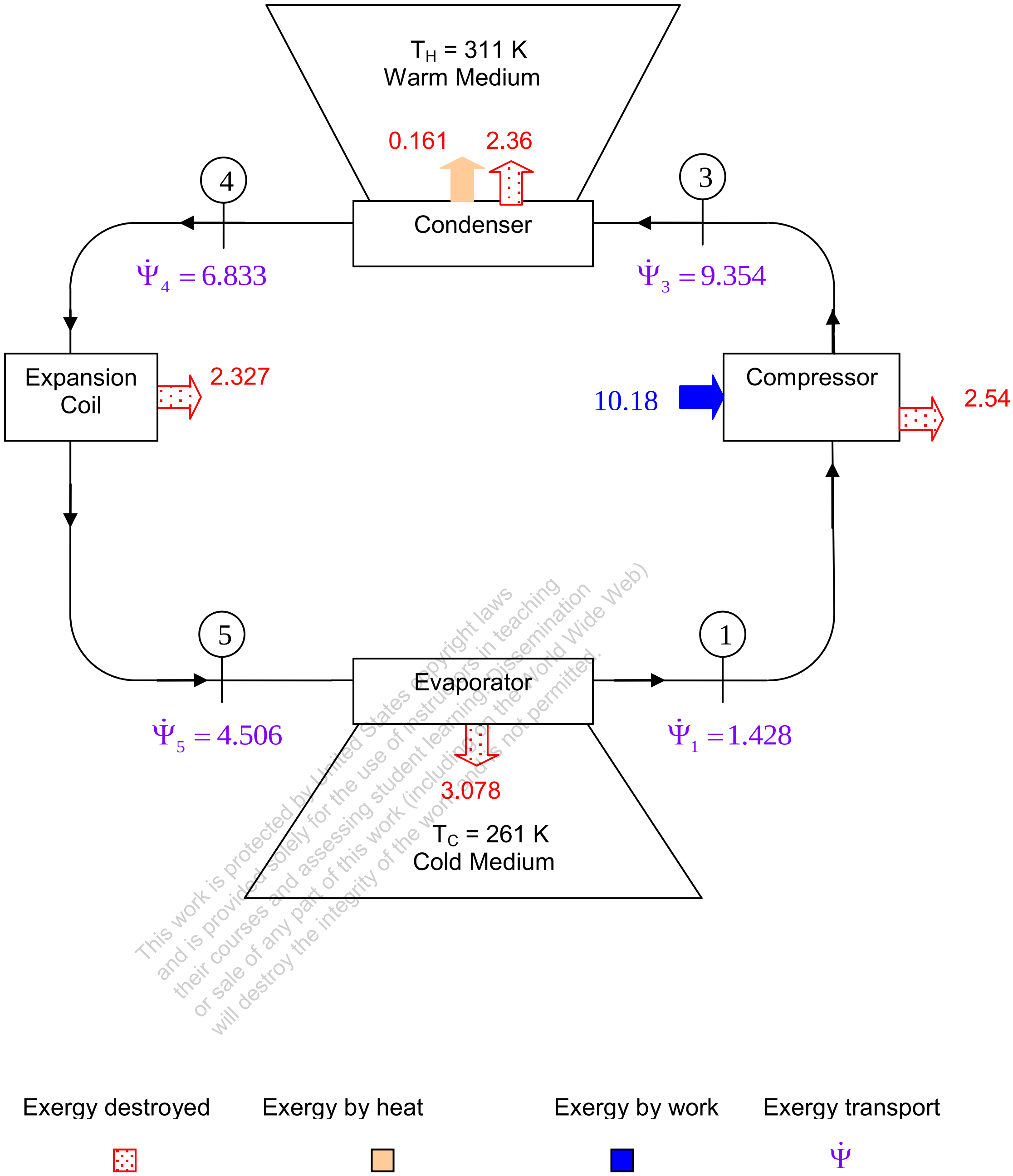
$$\dot{W}_{\text{net}}=\dot{m}\left(h_3-h_1\right)=10.18\text{ kW}$$

$$\eta_{II}=\frac{\dot{Q}_{\text{out}}\left(1-\frac{T_o}{T_H}\right)}{\dot{W}_{net}}=\frac{0.161}{10.18}=0.0158=1.58\%$$

(c) The COP can be calculated as.

$$\text{COP}_{\text{HP}}=\frac{\dot{Q}_{\text{out}}}{\dot{W}_{\text{net}}}=\frac{27.97}{10.18}=2.75$$

(d) Referring to table 2, the condenser is the device with the highest rate of exergy destruction.

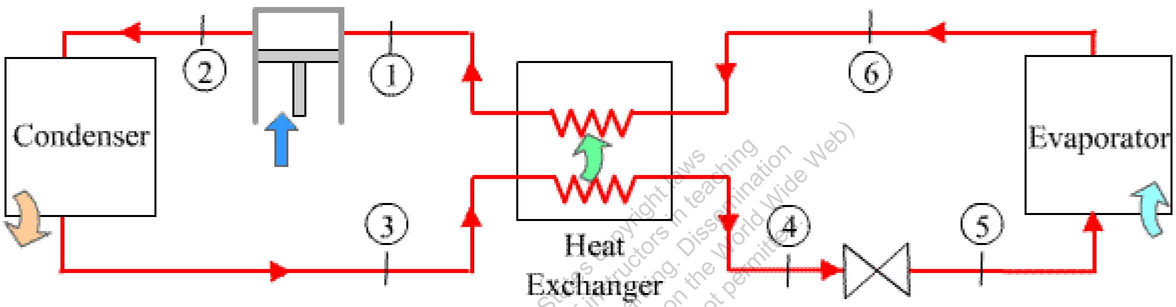


Exergy diagram for the vapor compression refrigeration system (on kW basis)

TEST Solution: Use the PC refrigeration cycle TESTcalc to solve this problem. The TEST-code can be found in the Problems module of the professional TEST site at www.thermofluids.net.

10-4-5 [OQI] An ideal vapor-compression refrigeration cycle uses R-134a as a working fluid and operates between 0.1 MPa and 1.5 MPa. The refrigerant leaves the condenser at 30°C and the heat exchanger at 10°C. The refrigerant is then throttled to the evaporator pressure. Refrigerant leaves the evaporator as a saturated vapor and goes to the heat exchanger. The mass flow rate ($\dot{m}$) is 1 kg/s. A temperature difference of 5°C is maintained for effective heat exchange between the refrigerant and its surroundings at the evaporator and condenser. The atmospheric conditions are 100 kPa and 25°C. (a) Perform an exergy inventory on a rate (kW) basis for the entire cycle complete with an exergy flow diagram. Determine (b) the cooling capacity, (c) exergetic efficiency and (d) COP of the system.

SOLUTION:



Dead State: p0 = 100 kPa and T0 = 25 °C (298 K)

Vapor Compression Refrigeration Cycle

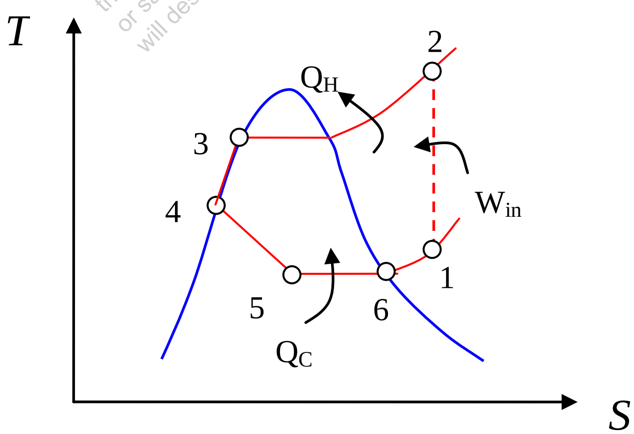


Table 1 Properties at various state points in the refrigeration plant.

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s $\text{kJ/}(\text{kg}\cdot\text{K})$	h kJ/kg
State 0	**100**	**298**	0	1.1020	275.31
State 1	**100**	281	0.42924	1.0524	260.96
State 2	**1500**	372	66.9424	**1.0524**	327.47
State 3	**1500**	**303**	43.9481	0.3446	93.42
State 4	**1500**	**283**	44.3683	0.2494	65.46
State 5	**100**	246	39.081	0.2671	**65.46**
State 6	**100**	246	4.06143	0.9465	232.99

Note: Blue quantities are given and black quantities are calculated using TEST.

Table 2 Device-specific Analysis

Plant Component	Device	$\lvert\Delta\dot{\Psi}\rvert$ kW	$\lvert\dot{W}_u\rvert$ kW	Exergy Supplied to/from Reservoir kW	$\dot{I}$ kW	Exergetic Efficiency %
HX Evaporator side HX Condenser Side	A	3.63219 0.4202	0	0	3.2119	11.57
Compressor	B	66.5131	66.5131	0	0	100
Condenser	C	22.9943	0	0	22.9943	0
Expansion	D	5.2873	0	0	5.2873	0
Evaporator	E	35.0195	0	31.3713	3.648	0
Total Plant			66.5131	31.3713	35.1418	47.17

(b) Cooling Capacity: $\dot{Q}_{\text{in}} = \dot{m}\left(h_6 - h_5\right) = 167\text{ kW}$

(c) Rate of exergy supplied by the refrigerant to cold medium at 261 K (exergy flows in the opposite direction of heat flow because $T_C < T_0$),

$$-\dot{Q}_{\text{in}}\left(1-\frac{T_0}{T_C}\right) = 167.53\times\left(1\text{-}\frac{298}{251}\right) = 31.37\text{ kW}$$

To calculate the exergetic efficiency, η_{II} ,

$$\dot{W}_{\text{net}} = \dot{m}\left(h_2 - h_1\right) = 66.5131 \text{ kW}$$

$$\eta_{II} = \frac{\dot{Q}_{\text{in}}\left(1 - \frac{T_0}{T_C}\right)}{\dot{W}_{net}} = \frac{31.3713 \text{ kW}}{66.5131 \text{ kW}} = 0.4717 = 47.17\%$$

(d) To calculate COP.

$$\text{COP}_R = \frac{\dot{Q}_{\text{in}}}{\dot{W}_{\text{net}}} = \frac{167.536 \text{ kW}}{66.5131 \text{ kW}} = 2.518$$

(e) Referring to table 2, condenser is device with the highest rate of exergy destruction. 34.57 % of exergy is destroyed in condenser.

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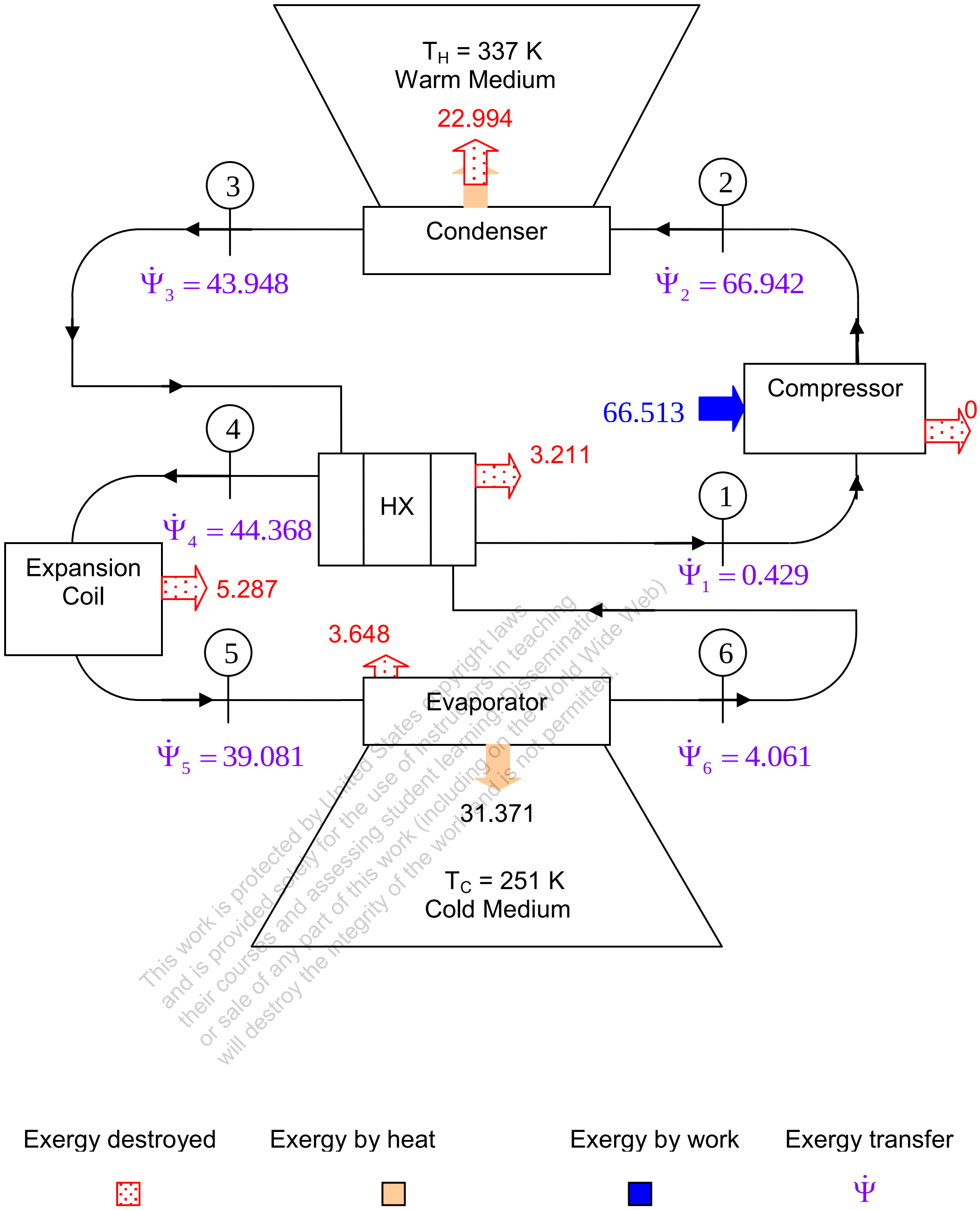


Exergy diagram for the vapor compression refrigeration system (on kW basis)

TEST Solution: Use the PC refrigeration cycle TESTcalc to solve this problem. The TEST-code can be found in the Problems module of the professional TEST site at www.thermofluids.net.

10-4-6 [OQL] Repeat problem 10-4-5 [OQI] with the heat exchanger removed.

SOLUTION:

Dead State: p0 = 100 kPa and T0 = 25 °C (298 K)

Vapor Compression Refrigeration Cycle

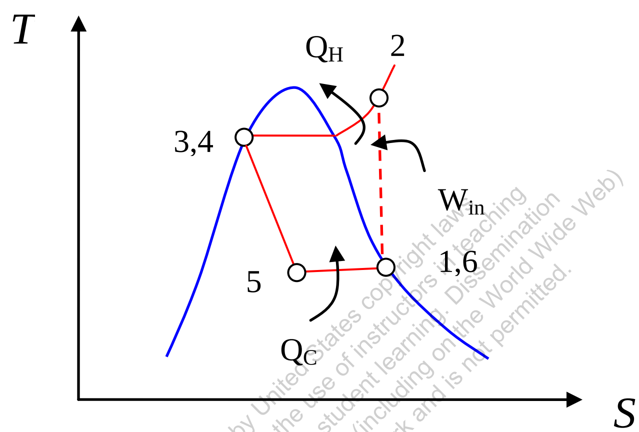


Table 1 Properties at various state points in the refrigeration plant.

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s kJ/(kg·K)	h kJ/kg
State 0	**100**	**298**	0	1.1020	275.31
State 1	**100**	246	4.06143	0.9465	232.99
State 2	**1500**	339	60.95501	**0.9465**	289.89
State 3	**1500**	**303**	43.94814	0.3446	93.42
State 4	**1500**	**303**	43.94814	0.3446	93.42
State 5	**100**	246	33.23584	0.3805	**94.42**
State 6	**100**	246	4.06143	0.9465	232.99

Note: Blue quantities are given and black quantities are calculated using TEST.

Table 2 Device-specific Analysis

Plant Component	Device	$\lvert\Delta\dot{\Psi}\rvert$ kW	$\lvert\dot{W}_u\rvert$ kW	Exergy Supplied to/from Reservoir kW	$\dot{I}$ kW	Exergetic Efficiency %
HX Evaporator side	A	N/A	N/A	N/A	N/A	N/A
HX Condenser side		N/A				
Compressor	B	56.8935	56.8935	0	0	100
Condenser	C	17.0068	0	0	17.0068	0
Expansion	D	10.7123	0	0	10.7123	0
Evaporator	E	29.1744	0	26.1351	3.039	0
Total Plant			56.8935	26.1351	30.7584	45.94

(b) Cooling Capacity: $\dot{Q}_{\text{in}} = \dot{m}\left(h_6 - h_5\right) = 139.6\text{ kW}$

(c) Rate of exergy supplied by the refrigerant to cold medium at 261 K (exergy flows in the opposite direction of heat flow because $T_C < T_0$),

$$-\dot{Q}_{\text{in}}\left(1-\frac{T_0}{T_C}\right)=139.6\times\left(1\text{-}\frac{298}{251}\right) = 26.13 \text{ kW}$$

To calculate the exergetic efficiency, η_{II} ,

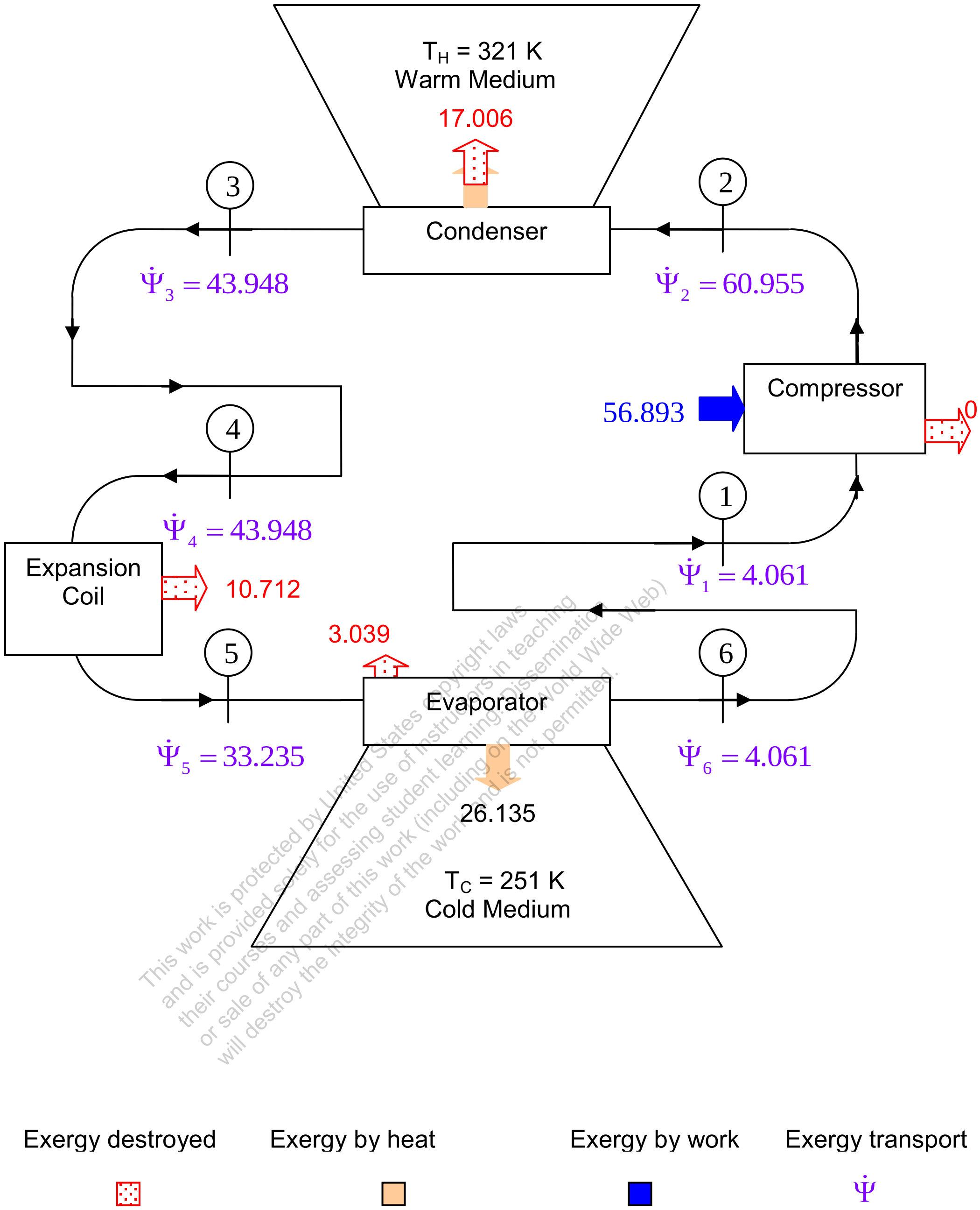
$$\dot{W}_{\text{net}} = \dot{m}\left(h_2 - h_1\right) = 56.89 \text{ kW}$$

$$\eta_{II} = \frac{\dot{Q}_{\text{in}}\left(1-\frac{T_0}{T_C}\right)}{\dot{W}_{net}} = \frac{26.13}{56.89} = 0.4594 = 45.94\%$$

(d) To calculate COP.

$$\text{COP}_R = \frac{\dot{Q}_{\text{in}}}{\dot{W}_{\text{net}}} = \frac{139.6}{56.89} = 2.453$$

(e) Referring to table 2, condenser is device with the highest rate of exergy destruction. 29.89 % of exergy is destroyed in condenser. In addition, exergetic efficiency of system dropped from 47.17% to 45.94% due to removal of heat exchanger.

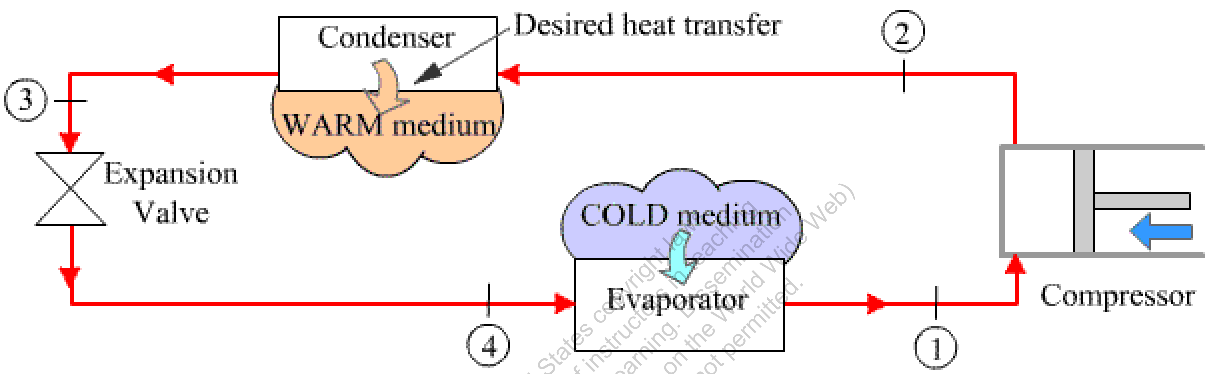


Exergy diagram for the vapor compression refrigeration system (on kW basis)

TEST Solution: Use the PC refrigeration cycle TESTcalc to solve this problem. The TEST-code can be found in the Problems module of the professional TEST site at www.thermofluids.net.

10-4-7 [OQG] A heat pump which operates on the ideal vapor-compression cycle with R-134a is used to transfer heat at a rate of 20 kW to a space maintained at 50°C from outside atmosphere at 0°C. A temperature difference of 5°C is maintained for effective heat exchange between the refrigerant and its surroundings at the evaporator. The atmospheric conditions are 100 kPa and 0°C. (a) Perform an exergy inventory on a rate (kW) basis for the entire cycle complete with an exergy flow diagram. Determine (b) the power consumption rate, (c) the exergetic efficiency and (d) the COP of the system.

SOLUTION:



Dead State: p0 = 100 kPa and T0 = 0 °C (273 K)

Vapor Compression Refrigeration Cycle

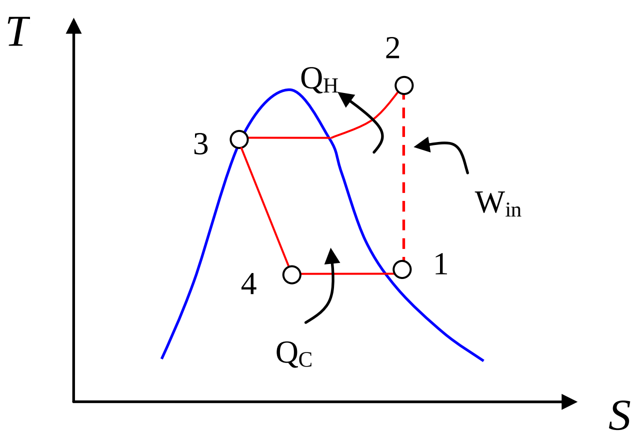


Table 1 Properties at various state points in the refrigeration plant.

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s $\text{kJ}/(\text{kg}\cdot\text{K})$	h kJ/kg
State 0	**100**	**273**	0	1.02897	254.42
State 1	244	**268**	2.48498	0.9297	246.36
State 2	**1492**	334	7.40637	**0.9297**	284.09
State 3	1492	**328**	4.03878	0.4628	130.74
State 4	**244**	268	2.76443	0.33893	**130.74**

Note: Blue quantities are given and black quantities are calculated using TEST.

Table 2 Device-specific Analysis

Plant Component	Device	$\lvert \Delta\dot{\Psi} \rvert$ kW	$\lvert \dot{W}_u \rvert$ kW	Exergy Supplied to/from Reservoir kW	$\dot{I}$ kW	Exergetic Efficiency %
Compressor	A	4.92139	4.92139	0	0	100
Condenser	B	3.36759	0	3.09597	0.27161	91.93
Expansion	C	1.27434	0	0	1.27434	0
Evaporator	D	0.27945	0	0	0.27945	0
Total Plant			4.92139	3.09597	1.82542	62.9

(b)

The mass flow rate can be calculated from:

$$\dot{Q}_{\text{out}} = \dot{m}\left(h_2 - h_3\right) = 20\ \text{kW}$$

$$\Rightarrow \dot{m} = 0.1304\ \frac{\text{kg}}{\text{s}}$$

Power consumption rate: $\dot{W}_{\text{net}} = \dot{m}\left(h_2 - h_1\right) = 4.92\ \text{kW}$

(c)

Although heat is transferred from the cold medium to the refrigerant in the evaporator, the exergy flows in the opposite direction because $T_C < T_0$. However, exergy transferred to the cold medium (which is the ambient atmosphere) is not utilized and is completely destroyed.

Rate of exergy supplied by the refrigerant to warm medium at 323 K,

$$\dot{Q}_{\text{out}}\left(1-\frac{T_0}{T_H}\right) = 20\left(1\text{-}\frac{273}{323}\right) = 3.0967 \text{ kW}$$

$$\eta_{II} = \frac{\dot{Q}_{\text{out}}\left(1-\frac{T_0}{T_H}\right)}{\dot{W}_{net}} = \frac{3.096}{4.92} = 0.6290 = 62.90\%$$

(d) To calculate COP the Cycle Panel from TEST was used.

$$\text{COP}_{\text{HP}} = \frac{\dot{Q}_{\text{out}}}{\dot{W}_{\text{net}}} = \frac{20}{4.92} = 4.06$$

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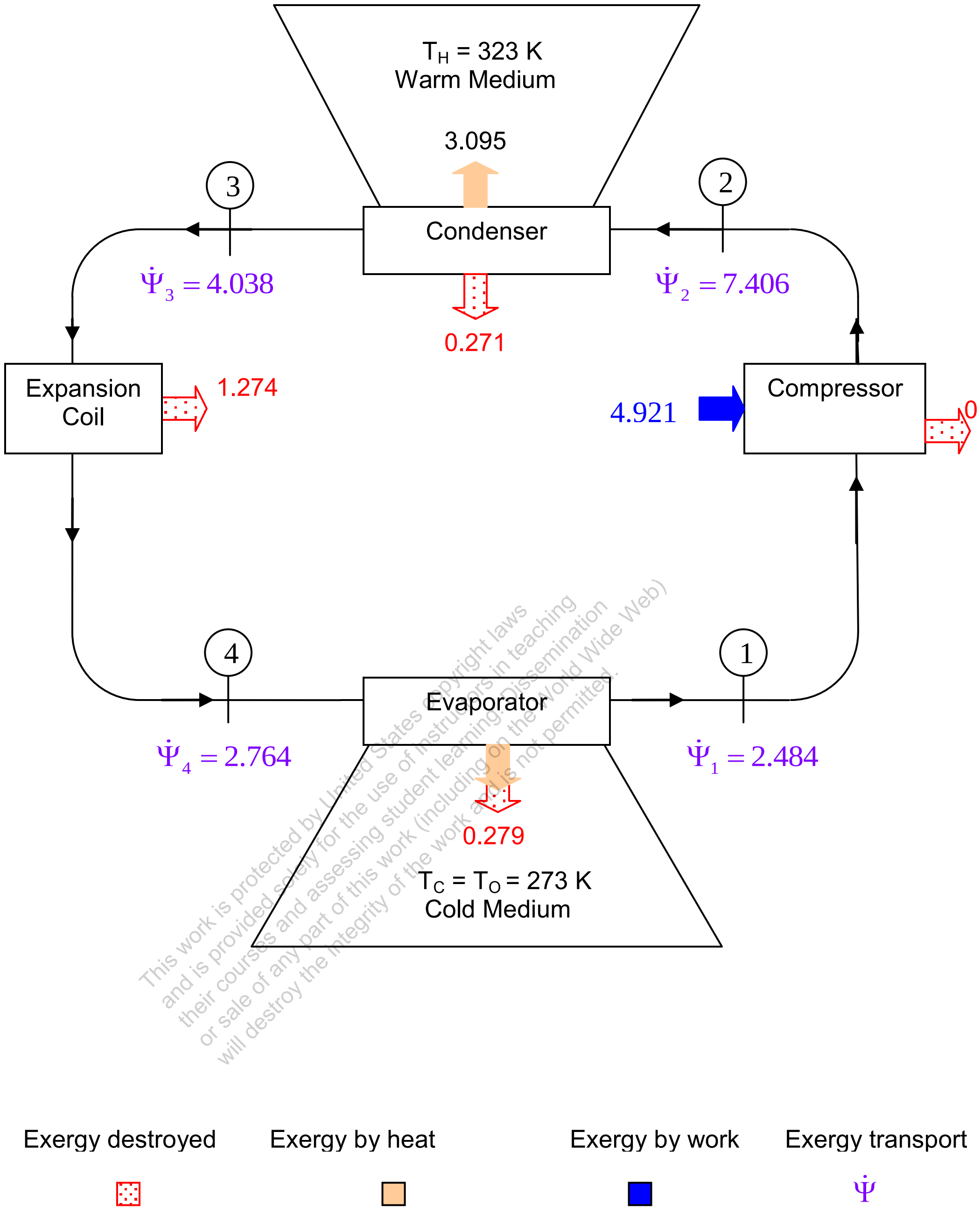
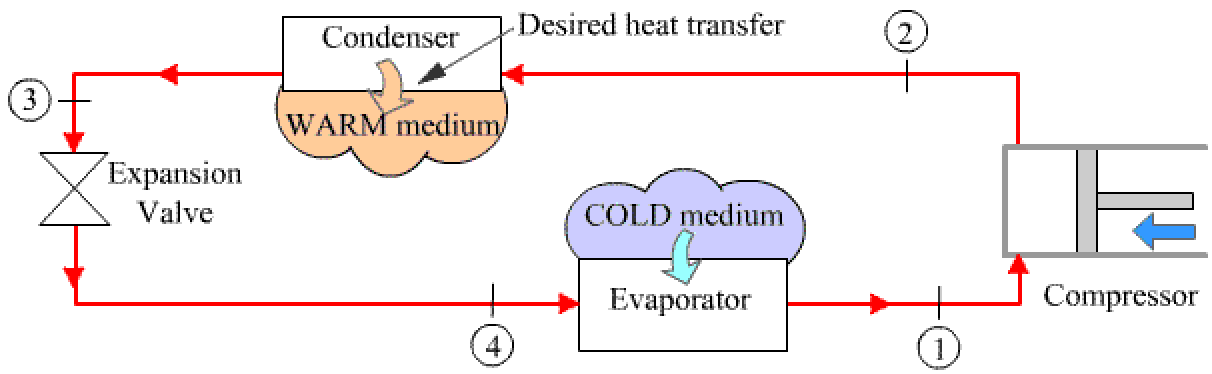


Exergy diagram for the vapor compression refrigeration system (on kW basis)

TEST Solution: Use the PC refrigeration cycle TESTcalc to solve this problem. The TEST-code can be found in the Problems module of the professional TEST site at www.thermofluids.net.

10-4-8 [OQZ] Repeat problem 10-4-8[OQG] with the outside atmosphere at 100 kPa and -5°C.

SOLUTION:



Dead State: p0 = 100 kPa and T0 = -5 °C (268 K)

Vapor Compression Refrigeration Cycle

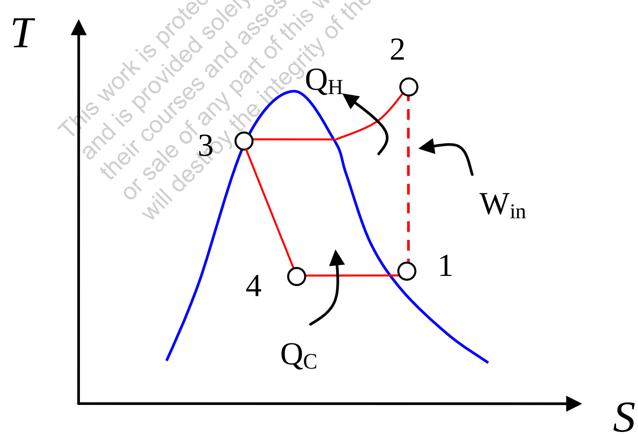


Table 1 Properties at various state points in the refrigeration plant.

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s kJ/(kg·K)	h kJ/kg
State 0	**100**	**268**	0	1.0138	250.35
State 1	201	**263**	1.90070	0.9328	243.3
State 2	**1492**	335	7.32054	**0.9328**	285.14
State 3	1492	**328**	3.64556	0.4628	130.74
State 4	**201**	263	2.17865	0.5050	**130.74**

Note: Blue quantities are given and black quantities are calculated using TEST.

Table 2 Device-specific Analysis

Plant Component	Device	$\lvert\Delta\dot{\Psi}\rvert$ kW	$\lvert\dot{W}_u\rvert$ kW	Exergy Supplied to/from Reservoir kW	$\dot{I}$ kW	Exergetic Efficiency %
Compressor	A	5.41985	5.41985	0	0	100
Condenser	B	3.67498	0	3.405572	0.26940	92.66
Expansion	C	1.46690	0	0	1.46690	0
Evaporator	D	0.27795	0	0	0.27795	0
Total Plant			5.41985	3.405572	2.01427	62.83

The mass flow rate can be calculated from:

$$\dot{Q}_{\text{out}} = \dot{m}\left(h_2 - h_3\right) = 20 \text{ kW}$$

$$\Rightarrow \dot{m} = 0.1295 \ \frac{\text{kg}}{\text{s}}$$

(b) Power consumption rate: $\dot{W}_{\text{net}} = \dot{m}\left(h_2 - h_1\right) = 5.42 \text{ kW}$

(c)

Although heat is transferred from the cold medium to the refrigerant in the evaporator, the exergy flows in the opposite direction because $T_C < T_0$. However, exergy transferred to the cold medium (which is the ambient atmosphere) is not utilized and is completely destroyed.

Rate of exergy supplied by the refrigerant to warm medium at 323 K,

$$\dot{Q}_{\text{out}}\left(1-\frac{T_0}{T_H}\right)=20\left(1\text{-}\frac{268}{323}\right)=3.406\text{ kW}$$

To calculate the exergetic efficiency, η_{II} ,

$$\eta_{II}=\frac{\dot{Q}_{\text{out}}\left(1-\dfrac{T_0}{T_H}\right)}{\dot{W}_{\text{net}}}=\frac{3.406}{5.420}=0.6283=62.83\%$$

(d) To COP can be calculated as:

$$\text{COP}_{\text{HP}}=\frac{\dot{Q}_{\text{out}}}{\dot{W}_{\text{net}}}=\frac{20}{5.42}=3.690$$

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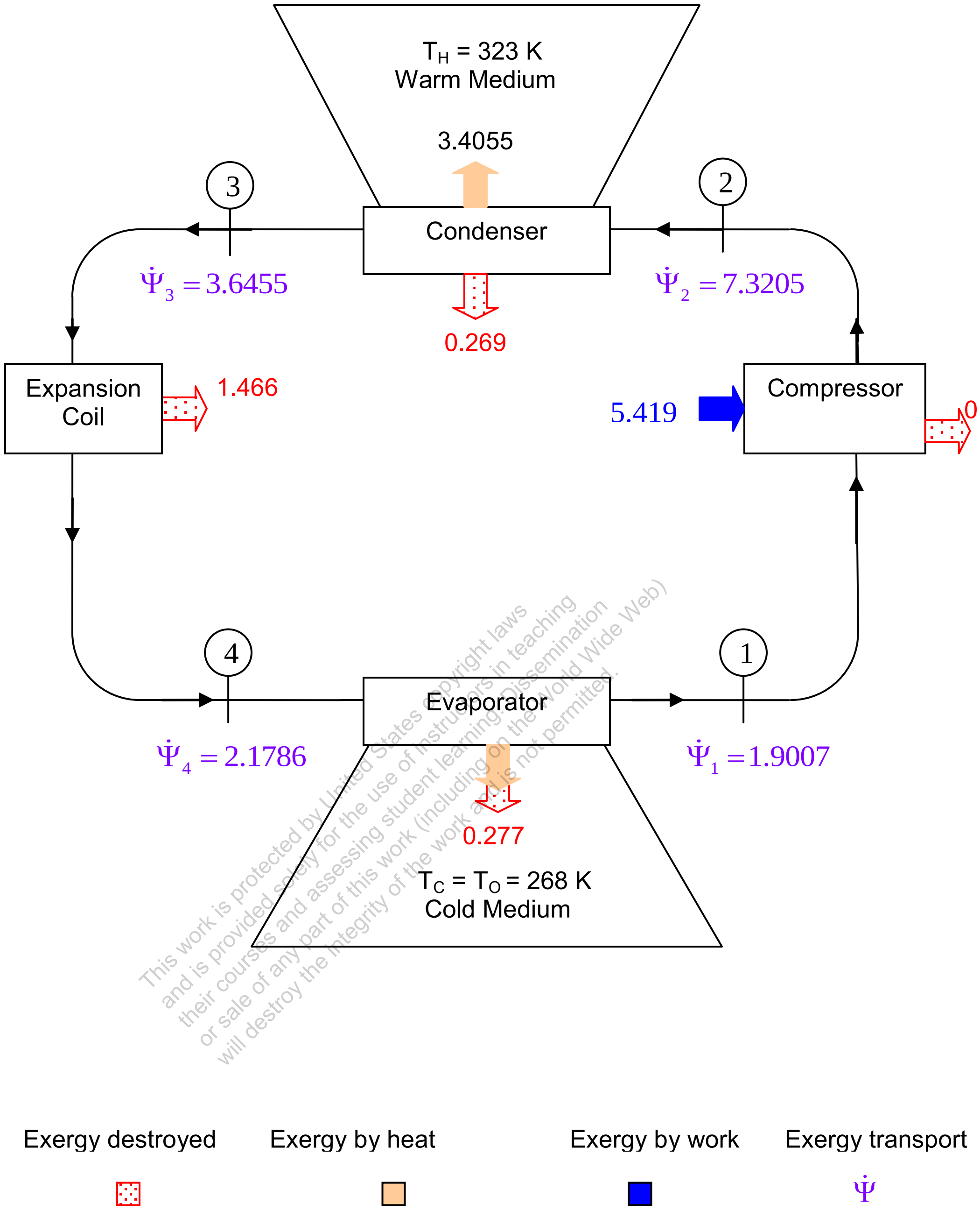

Exergy diagram for the vapor compression refrigeration system (on kW basis)

TEST Solution: Use the PC refrigeration cycle TESTcalc to solve this problem. The TEST-code can be found in the Problems module of the professional TEST site at www.thermofluids.net.