ORDRE DES INGÉNIEURS DU QUÉBEC

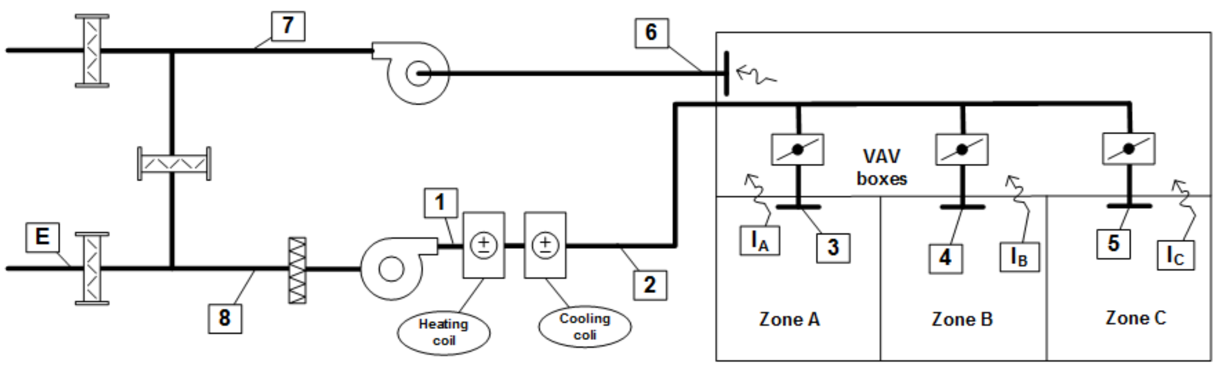
MAI 2020 SESSION

Open-book examination
Calculators : only authorized models
Duration : 3 hours

16-MC-B1
Environmental control in buildings

Problem # 1 (30%)

The figure 1 shows a VAV (Variable Air Volume) air conditioning system.



For the design conditions (the peak of a building load), the specifications are as follows:

- Zones temperature — $t_{Z,A} = t_{Z,B} = t_{Z,C} = 25°C$
- Zones relative humidity — ϕ= 40 à 60%
- Supply air temperature — t_2 =14°C
- Exterior air conditions — t_{db} = 35°C t_{wb}= 26°C
- Exterior air flow rate (state E) — 20% of fan air flow rate
- Temperature rise across the supply fan — Δt_{VA} = 2°C
- Temperature rise across the return fan — Δt_{VR} = 1°C
- Heat gains across the plenum — 12 kW
- Zones air flow rate and zones latent heat gains are as follows :
  - $Q_{Z,A}$ = 1.5 m^3/s — $q_{latent, Z,A}$ = 5.85 kW
  - $Q_{Z,B}$ = 1.0 m^3/s — $q_{latent, Z,B}$ = 7.5 kW
  - $Q_{Z,C}$ = 2.5 m^3/s — $q_{latent, Z,C}$ = 10.5 kW

Locate the **key air states on the psychrometric chart** (points 1 to 8, Z_A, Z_B, and Z_C) *(10%)* and present **the table** *(6%)* with the temperature and humidity ratio of each point. Determine:

a) Humidity ratio of supply air (state 2) *(2%)*;
b) Cooling coil capacity *(4%)*;
c) Bypass cooling coil factor *(3%)*.

If the rotary sensible wheel is used as the heat recovery exchanger, determine and locate on the psychrometric chart the new air states $E_{recovery}$, $8_{recovery}$ and $1_{recovery}$ and find:

d) New cooling coil capacity *(5%)*.

Use the conditions of the standard air : $\rho = 1.2$ kg/m^3 $c_p = 1.005$ kJ/kg ^oC and latent heat of vaporization i_{fg} = 2500 kJ/kg

Problem # 2 (15%)

For a building located in Montreal the specifications are as follows:

Number of floors	10
Floor height	3.5 m
Floor area	85 m * 50 m
Windows area	50% of exterior walls area
Wall thermal resistance	R15 (RSI=2.64 m^{2o}C/W)
Heating and domestic hot water	gas boiler
Annual boiler efficiency	70%
Degree day (balance point temperature of 18^{o}C)	4575
Outdoor design temperature for heating	-29^{o}C
Indoor air temperature	22^{o}C
Gas heating value	37.2 MJ/m^3

Monthly consumption of gas for heating and domestic hot water

Month	Gas Consumption (m^3)
January	36 000
February	38 000
March	23 000
April	11 000
May	6 500
June	3 300
July	3 300
August	3 300
September	3 300
October	7 600
November	25 000
December	34 130
Total	194 430

Determine:

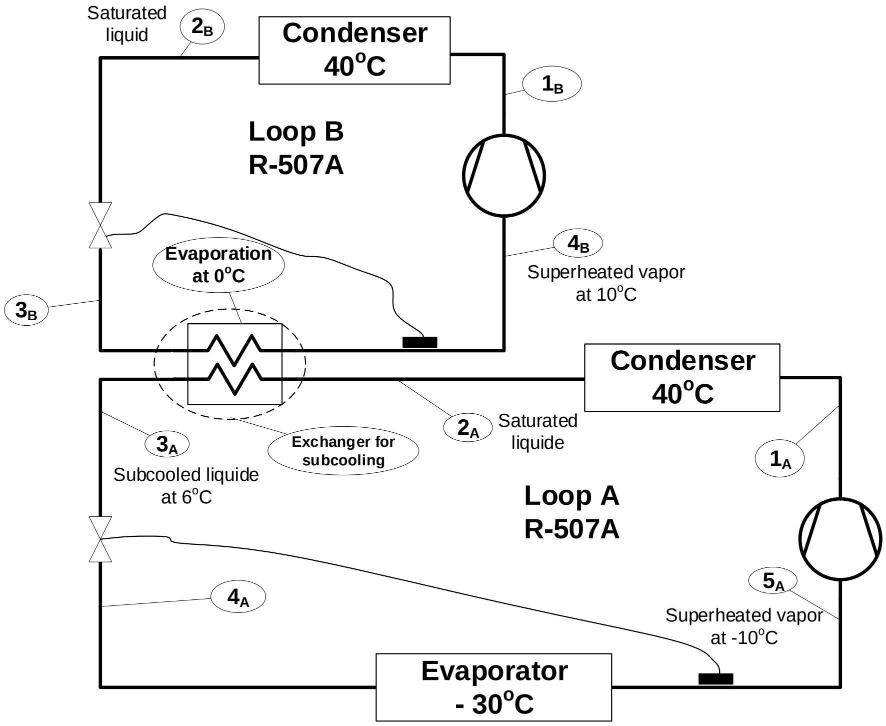
a) annual gas consumption for heating (*2%*).

Use the degree-days method and determine:

b) total building heat loss based on design conditions (in kW) (*3%*);
c) annual gas consumption due to heat loss through the exterior walls (*5%*);
d) impact of increasing of exterior wall thermal resistance from R15 (RSI = 2.64) to R25 (RSI = 4.4) on the annual gas consumption (*5%*).

Problem # 3 (25%)

The evaporator capacity of loop B is of 200 kW. Show the refrigeration cycle on the attached p/h R-507A diagram ***(4 %)*** and determine:



a) The refrigerant mass flow rate in loops A and B *(4 %);*
b) The evaporator capacity in loop A *(4 %);*
c) Heat rejected by the condensers in loops A and B *(4 %);*
d) COP (coefficient of performance) of a proposed system (including the loops A and B) *(4 %).*

Assume that the loop B and the exchanger for sub-cooling are canceled. In this case the refrigerant (saturated liquid) in state 2_A enters the expansion valve of this modified loop A. ***The evaporator capacity of this modified loop is the same as before the modification***. Determine:

e) COP of this modified loop *(5 %).*

Problem # 4 (16%)

Consider a building with five (5) zones (four external zones E, N, O, S and one internal zone I) having the following cooling loads:

Zones cooling peak

	Zone E	Zone N	Zone O	Zone S	Zone I
$q_{sensible}$ kW	20	12	45	50	18
q_{latent} kW	1.5	1.5	5	3	3
	16 June	9 July	6 September	23 June	14 July

Building cooling peak (21 June)

	Zone E	Zone N	Zone O	Zone S	Zone I
$q_{sensible}$ kW	15	10	45	40	18
q_{latent} kW	1.5	1.5	5	3	3

Answer the questions considering two following cases:

1 A **VAV system** with the perimeter heating system in each zone (E, N, O and S) serves the entire building. The temperature of each zone is *24 ^oC* and the supply air temperature is *12 ^oC.* Determine:

a) The maximum supply air flow rate for each zone using to design zone duct dimensions *(4%)*;

b) The maximum fan air flow rate *(4%)*.

2 A **multizone constant air volume system with zonal reheat coils** serves the entire building. The temperature of each zone is *24 ^oC* and the supply air temperature for design conditions is *12 ^oC.* Determine:

c) The supply air flow rate for each zone *(4%)*;

d) The fan air flow rate *(4%)*.

Problem # 5 (14 %)

A variable primary piping system like the one shown in the figure below, has a capacity of 1200 tons (4220 kW) and is designed to operate with water supplied at 42 ^oF (6^oC) and returned at 65 ^oF (18 ^oC). The chillers have equal capacity and there are two 3500 rpm variable speed primary pumps of equal size. Under partial load conditions the chiller flow rates may be reduced a maximum of 30 percent of full flow.

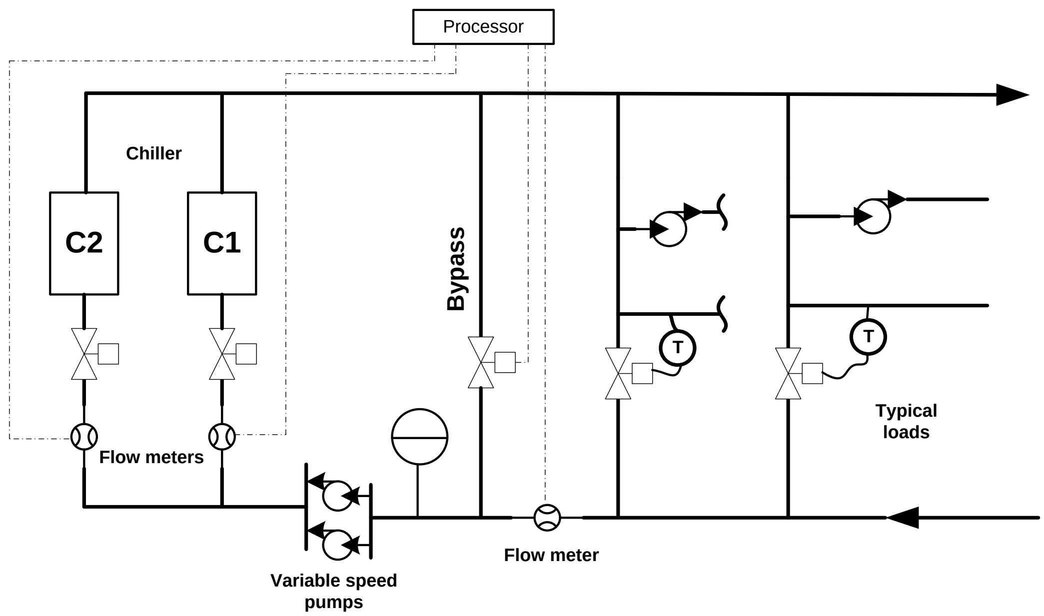
a) Compute the full load chilled water flow rate and describe the operating conditions of the system (flow rates, bypass flow, pumps speed, etc.) *(2 %);*

b) Suppose the system is operating under a load of 900 tons (3165 kW) and describe some acceptable operating conditions *(4 %);*

c) At another time the system is operating at 60 percent of full capacity. Determine satisfactory operating conditions and describe them *(4 %);*

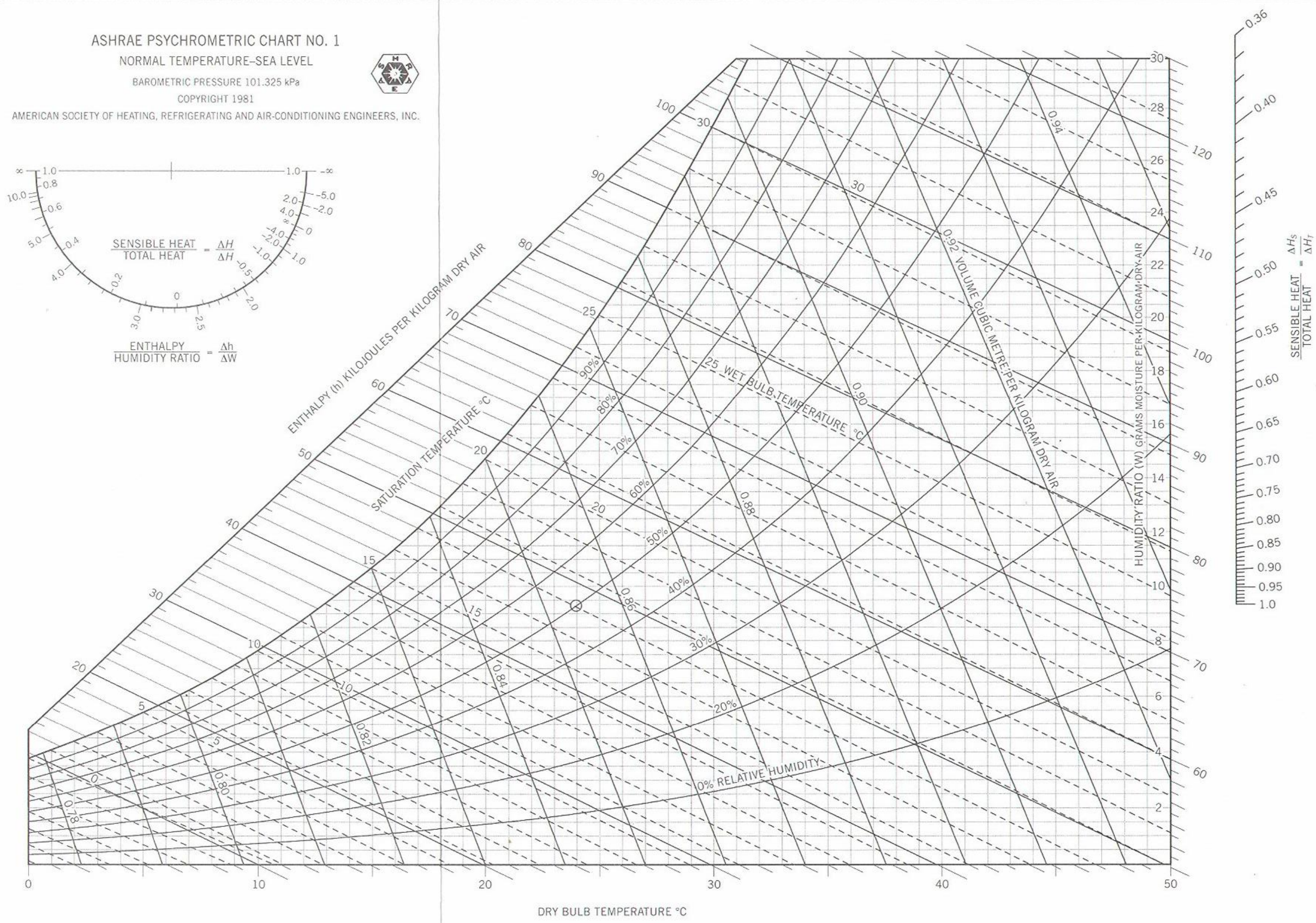
d) At still another time the load drops to 25 percent of full capacity. Determine satisfactory operating conditions and describe them *(4 %).*

Assuming no change in the temperatures.



Processor
Chiller
C2
C1
Bypass
Flow meters
Typical
loads
Flow meter
Variable speed
pumps
T
T

Chart 1*b* ASHRAE Psychrometric Chart No. 1 (SI) (Reprinted by permission of ASHRAE.)



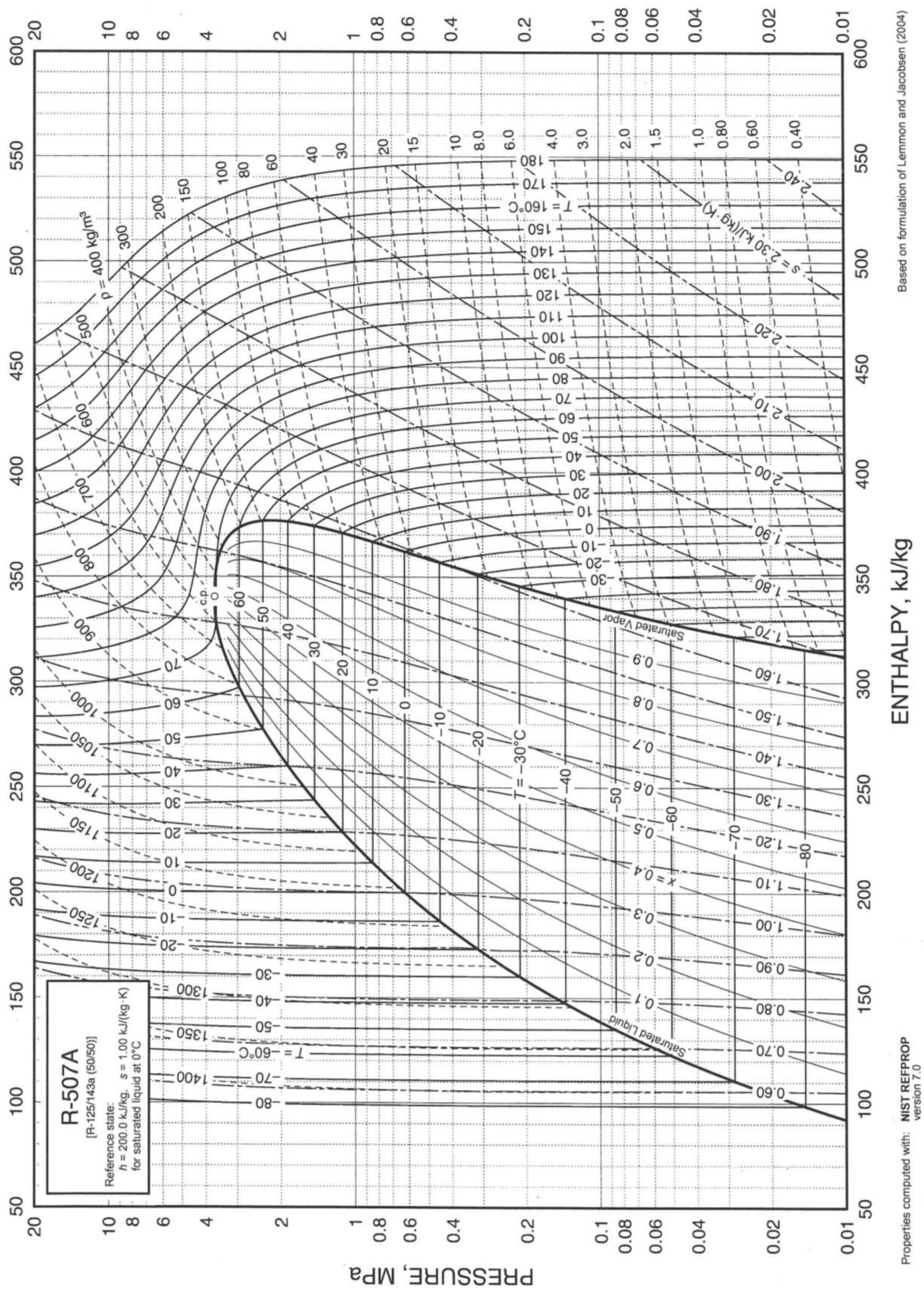


Fig. 15 Pressure-Enthalpy Diagram for Refrigerant 507A

Refrigerant 507A [R-125/143[a] (50/50)] Properties of Saturated Liquid and Saturated Vapor

Temp.,* °C	Pressure,** MPa	Density, kg/m³ Liquid	Volume, m³/kg Vapor	Enthalpy, kJ/kg Liquid	Enthalpy, kJ/kg Vapor	Entropy, kJ/(kg·K) Liquid	Entropy, kJ/(kg·K) Vapor	Specific Heat c_p, kJ/(kg·K) Liquid	Specific Heat c_p, kJ/(kg·K) Vapor	c_p/c_v Vapor	Velocity of Sound, m/s Liquid	Velocity of Sound, m/s Vapor	Viscosity, μPa·s Liquid	Viscosity, μPa·s Vapor	Thermal Cond., mW/(m·K) Liquid	Thermal Cond., mW/(m·K) Vapor	Surface Tension, mN/m	Temp.,* °C
−100	0.00295	1476.9	4.92920	74.41	303.90	0.4323	1.7579	1.219	0.618	1.164	1046	129.6	—	—	124.6	5.77	18.35	−100
−95	0.00458	1461.7	3.25360	80.48	306.85	0.4669	1.7377	1.210	0.631	1.162	1000	131.2	784.2	7.29	121.7	6.06	17.88	−95
−90	0.00693	1446.8	2.20850	86.51	309.83	0.5003	1.7197	1.205	0.644	1.161	960	132.6	701.5	7.49	118.8	6.36	17.41	−90
−85	0.01019	1431.9	1.53750	92.53	312.83	0.5327	1.7036	1.203	0.658	1.159	925	134.0	631.9	7.68	116.1	6.67	16.92	−85
−80	0.01464	1417.1	1.09510	98.54	315.85	0.5642	1.6893	1.203	0.672	1.159	892	135.4	572.7	7.88	113.4	6.99	16.43	−80
−75	0.02058	1402.3	0.79638	104.57	318.88	0.5950	1.6766	1.205	0.686	1.158	862	136.6	521.7	8.07	110.8	7.31	15.92	−75
−70	0.02836	1387.4	0.59012	110.60	321.92	0.6250	1.6652	1.208	0.701	1.158	833	137.8	477.4	8.27	108.2	7.63	15.40	−70
−65	0.03837	1372.5	0.44482	116.66	324.96	0.6545	1.6552	1.213	0.716	1.159	806	138.9	438.5	8.46	105.7	7.96	14.88	−65
−60	0.05105	1357.4	0.34056	122.74	328.00	0.6833	1.6463	1.220	0.732	1.160	779	139.8	404.3	8.65	103.2	8.30	14.34	−60
−55	0.06688	1342.3	0.26444	128.87	331.03	0.7116	1.6384	1.227	0.749	1.161	754	140.7	373.8	8.84	100.8	8.65	13.80	−55
−50	0.08638	1326.9	0.20801	135.03	334.05	0.7395	1.6314	1.235	0.766	1.164	729	141.4	346.5	9.02	98.4	9.00	13.24	−50
−48	0.09533	1320.7	0.18960	137.51	335.25	0.7505	1.6288	1.239	0.773	1.165	719	141.6	336.4	9.10	97.4	9.14	13.02	−48
−46.74[b]	0.10132	1316.8	0.17902	139.07	336.01	0.7574	1.6273	1.241	0.777	1.166	713	141.8	330.2	9.15	96.8	9.23	12.88	−46.74
−46	0.10499	1314.5	0.17313	139.99	336.45	0.7615	1.6264	1.243	0.780	1.166	709	141.9	326.7	9.17	96.5	9.28	12.80	−46
−44	0.11541	1308.2	0.15836	142.48	337.65	0.7724	1.6241	1.247	0.787	1.167	699	142.1	317.4	9.25	95.5	9.42	12.57	−44
−42	0.12662	1301.9	0.14510	144.99	338.84	0.7832	1.6219	1.251	0.795	1.169	690	142.3	308.4	9.32	94.6	9.57	12.34	−42
−40	0.13867	1295.6	0.13317	147.49	340.03	0.7940	1.6198	1.255	0.803	1.170	680	142.5	299.8	9.40	93.7	9.71	12.12	−40
−38	0.15159	1289.2	0.12240	150.01	341.21	0.8047	1.6178	1.259	0.810	1.172	670	142.6	291.4	9.47	92.7	9.86	11.89	−38
−36	0.16542	1282.8	0.11268	152.54	342.38	0.8153	1.6159	1.264	0.818	1.174	661	142.7	283.4	9.55	91.8	10.01	11.66	−36
−34	0.18022	1276.3	0.10388	155.08	343.55	0.8260	1.6141	1.269	0.826	1.176	651	142.8	275.7	9.62	90.9	10.16	11.42	−34
−32	0.19602	1269.7	0.09590	157.63	344.72	0.8365	1.6123	1.274	0.835	1.178	642	142.9	268.3	9.70	90.0	10.31	11.19	−32
−30	0.21287	1263.2	0.08865	160.18	345.88	0.8470	1.6107	1.279	0.843	1.180	632	142.9	261.1	9.77	89.1	10.46	10.96	−30
−28	0.23081	1256.5	0.08205	162.75	347.03	0.8575	1.6092	1.284	0.852	1.183	622	143.0	254.1	9.85	88.2	10.61	10.72	−28
−26	0.24989	1249.8	0.07604	165.33	348.17	0.8679	1.6077	1.289	0.861	1.186	613	143.0	247.4	9.93	87.3	10.77	10.49	−26
−24	0.27016	1243.1	0.07055	167.92	349.30	0.8783	1.6063	1.295	0.870	1.188	603	142.9	240.9	10.00	86.5	10.93	10.25	−24
−22	0.29167	1236.3	0.06553	170.52	350.43	0.8886	1.6049	1.301	0.879	1.191	594	142.9	234.5	10.08	85.6	11.08	10.02	−22
−20	0.31446	1229.4	0.06094	173.13	351.54	0.8989	1.6037	1.307	0.888	1.195	584	142.8	228.4	10.15	84.7	11.24	9.78	−20
−18	0.33858	1222.5	0.05673	175.76	352.65	0.9091	1.6024	1.313	0.898	1.198	575	142.7	222.5	10.23	83.8	11.40	9.54	−18
−16	0.36408	1215.4	0.05286	178.39	353.75	0.9193	1.6013	1.319	0.908	1.202	566	142.5	216.8	10.31	83.0	11.56	9.30	−16
−14	0.39102	1208.4	0.04931	181.04	354.83	0.9295	1.6001	1.326	0.918	1.206	556	142.3	211.2	10.39	82.1	11.73	9.06	−14
−12	0.41945	1201.2	0.04603	183.71	355.91	0.9397	1.5991	1.333	0.929	1.210	547	142.1	205.7	10.47	81.2	11.89	8.82	−12
−10	0.44941	1193.9	0.04301	186.39	356.97	0.9498	1.5980	1.340	0.940	1.214	537	141.9	200.5	10.55	80.4	12.06	8.58	−10
−8	0.48096	1186.6	0.04023	189.08	358.02	0.9599	1.5971	1.348	0.951	1.219	528	141.6	195.3	10.63	79.5	12.23	8.34	−8
−6	0.51416	1179.2	0.03765	191.78	359.06	0.9699	1.5961	1.355	0.962	1.224	518	141.3	190.3	10.71	78.7	12.41	8.10	−6
−4	0.54906	1171.7	0.03527	194.51	360.08	0.9800	1.5952	1.363	0.974	1.230	508	141.0	185.5	10.79	77.8	12.58	7.86	−4
−2	0.58571	1164.0	0.03306	197.25	361.08	0.9900	1.5943	1.372	0.987	1.236	499	140.6	180.7	10.88	77.0	12.76	7.62	−2
0	0.62417	1156.3	0.03101	200.00	362.07	1.0000	1.5934	1.381	0.999	1.242	489	140.2	176.1	10.97	76.2	12.96	7.37	0
2	0.66450	1148.5	0.02910	202.77	363.05	1.0100	1.5925	1.390	1.012	1.249	480	139.8	171.6	11.05	75.3	13.16	7.13	2
4	0.70676	1140.5	0.02733	205.56	364.00	1.0199	1.5917	1.399	1.026	1.256	470	139.3	167.2	11.14	74.5	13.36	6.89	4
6	0.75099	1132.4	0.02568	208.37	364.94	1.0299	1.5908	1.410	1.040	1.264	460	138.8	162.9	11.23	73.7	13.57	6.65	6
8	0.79728	1124.2	0.02415	211.20	365.85	1.0398	1.5900	1.420	1.055	1.272	451	138.2	158.7	11.33	72.8	13.79	6.41	8
10	0.84566	1115.9	0.02271	214.04	366.75	1.0498	1.5891	1.431	1.071	1.282	441	137.6	154.5	11.43	72.0	14.01	6.17	10
12	0.89622	1107.4	0.02138	216.91	367.61	1.0597	1.5883	1.443	1.088	1.291	431	137.0	150.5	11.52	71.2	14.24	5.93	12
14	0.94900	1098.7	0.02012	219.80	368.46	1.0696	1.5874	1.455	1.105	1.302	422	136.3	146.6	11.63	70.4	14.49	5.69	14
16	1.00410	1089.9	0.01895	222.71	369.28	1.0796	1.5865	1.468	1.124	1.314	412	135.6	142.7	11.73	69.6	14.75	5.45	16
18	1.06150	1080.9	0.01785	225.65	370.07	1.0895	1.5856	1.482	1.144	1.327	402	134.9	138.9	11.86	68.8	15.01	5.21	18
20	1.12140	1071.7	0.01683	228.61	370.83	1.0995	1.5846	1.497	1.165	1.341	392	134.1	135.1	11.97	67.9	15.29	4.97	20
22	1.18370	1062.4	0.01586	231.60	371.55	1.1094	1.5836	1.513	1.188	1.356	382	133.2	131.5	12.09	67.1	15.58	4.74	22
24	1.24860	1052.8	0.01495	234.61	372.25	1.1194	1.5826	1.530	1.212	1.372	372	132.3	127.9	12.22	66.3	15.89	4.50	24
26	1.31610	1043.0	0.01410	237.66	372.91	1.1294	1.5815	1.548	1.239	1.391	362	131.4	124.3	12.35	65.5	16.21	4.27	26
28	1.38640	1032.9	0.01329	240.73	373.52	1.1394	1.5804	1.568	1.268	1.411	352	130.4	120.8	12.48	64.7	16.54	4.04	28
30	1.45940	1022.6	0.01253	243.84	374.10	1.1495	1.5792	1.589	1.299	1.433	341	129.3	117.4	12.62	63.9	16.90	3.81	30
32	1.53520	1011.9	0.01182	246.98	374.63	1.1595	1.5779	1.612	1.333	1.458	331	128.2	114.0	12.77	63.1	17.28	3.58	32
34	1.61400	1001.0	0.01114	250.16	375.11	1.1697	1.5765	1.637	1.371	1.485	321	127.1	110.6	12.93	62.2	17.68	3.35	34
36	1.69580	989.7	0.01050	253.39	375.54	1.1799	1.5750	1.664	1.413	1.516	310	125.9	107.3	13.10	61.4	18.12	3.12	36
38	1.78070	978.1	0.00989	256.65	375.91	1.1901	1.5734	1.695	1.459	1.551	300	124.6	104.0	13.28	60.6	18.58	2.90	38
40	1.86880	966.0	0.00932	259.96	376.22	1.2004	1.5717	1.729	1.511	1.591	289	123.2	100.7	13.47	59.8	19.09	2.68	40
42	1.96020	953.5	0.00877	263.33	376.46	1.2108	1.5698	1.767	1.570	1.636	278	121.8	97.5	13.68	59.0	19.63	2.47	42
44	2.05490	940.5	0.00825	266.74	376.61	1.2213	1.5678	1.811	1.638	1.689	267	120.4	94.3	13.90	58.1	20.23	2.25	44
46	2.15310	926.9	0.00776	270.23	376.68	1.2320	1.5655	1.860	1.716	1.750	256	118.8	91.0	14.14	57.3	20.89	2.04	46
48	2.25480	912.7	0.00728	273.78	376.66	1.2427	1.5631	1.918	1.807	1.823	245	117.2	87.8	14.41	56.5	21.62	1.83	48
50	2.36030	897.7	0.00683	277.41	376.52	1.2536	1.5603	1.985	1.915	1.910	233	115.5	84.6	14.70	55.7	22.43	1.63	50
55	2.64090	856.2	0.00578	286.91	375.54	1.2818	1.5519	2.225	2.304	2.228	203	110.8	76.4	15.59	53.6	24.98	1.15	55
60	2.94760	806.1	0.00480	297.28	373.26	1.3120	1.5401	2.677	3.060	2.855	171	105.5	67.7	16.86	51.7	28.77	0.70	60
65	3.28380	739.1	0.00384	309.30	368.44	1.3465	1.5215	3.940	5.190	4.625	135	99.3	57.9	18.93	50.7	35.54	0.31	65
70	3.65570	599.6	0.00260	328.32	353.47	1.4007	1.4740	31.960	44.630	36.780	92	90.7	42.0	25.07	63.2	67.27	0.02	70
70.62[c]	3.70500	490.8	0.00204	340.45	340.45	1.4358	1.4358	∞	∞	∞	0	0.0	—	—	—	—	0.00	70.62

*Temperatures on ITS-90 scale

**Small deviations from azeotropic behavior occur at some conditions; tabulated pressures are average of bubble and dew-point pressures

[b]Normal boiling point

[c]Critical point