ME-415

RWFRIGERATION & BUILDING MECHANICAL SYSTEM

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Contents

1 Lecture 01: Concept of refrigeration and its applications

Date: 05/06/2023

Booklist

1. Ahmadul Ameen (2006), Refrigeration & Air-conditioning, Prentice Hall.
2. Hundy, Trott & Welch, 4th Edition, Refrigeration & Air conditioning, Butterworth-Heinemann.
3. McQuiston, Parker & Spitler (2005), Heating, Ventilating & Air conditioning: Analysis & Design, J. Wiley & Sons, Inc.
4. Stoecker & Jones (1983), Refrigeration & Air-conditioning, McGraw-Hill, Inc.
5. Dossat (1996), Principles of Refrigeration, Prentice Hall.
6. McDowall (2007), Fundamentals of HVAC Systems, Elsevier.
7. Grondzik, Kwok, Stein & Reynolds (2010), Mechanical & Electrical Equipment for Buildings, J. Wiley & Sons, Inc.

1.1 Refrigeration System and Components

Refrigeration

Refrigeration is a process of reducing and maintaining low temperature of a space or material below the temperature of the surroundings.
Alternatively, Refrigeration is the process of removing heat from an enclosed space, or from a substance, and rejecting it elsewhere for the purpose of lowering the temperature of the enclosed space or substance and then maintaining that lower temperature.
It is usually done with the aid of a mechanical device (e.g. pump/compressor) using a substance (called a refrigerant) which absorbs heat from low temperature (objects/space) and releases heat to elsewhere at high temperature. A refrigerant usually works in two-phase conditions, i.e., liquid and gas, e.g., vapor compression refrigeration system.

Refrigeration System: A refrigeration system is a mechanical system designed to remove heat from a space or substance to lower its temperature. It operates on the principle of the refrigeration cycle, which involves the compression, condensation, expansion, and evaporation of a refrigerant to transfer heat from a low-temperature region to a high-temperature region. The main components of a typical refrigeration system include a compressor, condenser, expansion valve, and evaporator.

Types of refrigeration system:

Vapor Compression Refrigeration System : This widely used system compresses a refrigerant gas, causing it to become hot and high-pressure. It then passes through a condenser where it releases heat and condenses into a liquid. The liquid refrigerant expands through an expansion valve, reducing its pressure and temperature, and evaporates in the evaporator, absorbing heat from the surroundings.

Vapor Absorption Refrigeration System : This system uses a mixture of refrigerant and absorbent instead of a compressor to achieve cooling. The mixture circulates through an absorber, generator, condenser, and evaporator. Heat is applied to the generator to separate the refrigerant from the absorbent. The refrigerant vapor then flows to the condenser where it liquefies, and the absorbent is regenerated in the absorber for reuse.

Vapor Ejection Refrigeration System : In this system, a primary refrigerant is compressed, condensed, and expanded similar to a vapor compression system. However, a secondary refrigerant is used to cool the primary refrigerant vapor through a heat exchanger. The cooled primary refrigerant is then expanded further to achieve the desired cooling effect.

Air Cycle Refrigeration : This refrigeration system uses air as the refrigerant. Compressed air is cooled through an expansion process, causing its temperature to decrease. The cooled air is then used to absorb heat from the desired space or substance, creating a cooling effect.

Vortex Tube Refrigeration : A vortex tube refrigeration system utilizes a high-pressure gas stream that enters a tangential nozzle, creating a vortex motion. This vortex separates the gas into hot and cold streams, with the cold stream used for refrigeration purposes.

Thermoacoustic Refrigeration System : Thermoacoustic refrigeration systems utilize sound waves and thermal gradients to achieve cooling. The sound waves cause compression and expansion of the gas, creating temperature differences that enable cooling.

Thermoelectric Refrigeration System : These systems use the Peltier effect, where an electric current is applied to a junction of two different conductive materials, resulting in a temperature difference. This temperature difference allows for cooling when applied in a refrigeration system.

Cascade Refrigeration System : Cascade systems consist of two or more refrigeration cycles working in series. Different refrigerants with varying temperature ranges are used in each cycle, allowing for extremely low temperatures in specific applications.

Cryogenic Refrigeration : Cryogenic refrigeration involves the use of extremely low temperatures, typically below -150 degrees Celsius (-238 degrees Fahrenheit), to achieve cooling. These systems are used in applications such as liquefied natural gas (LNG) processing, scientific research, and medical processes.

Magnetic Refrigeration : Magnetic refrigeration systems use the magnetocaloric effect, where a magnetic material heats up or cools down when subjected to a magnetic field. By cycling the magnetic field, heat can be absorbed or released, providing cooling without the use of traditional refrigerants.

1.2 Different Components of Vapor Compression Refrigeration System

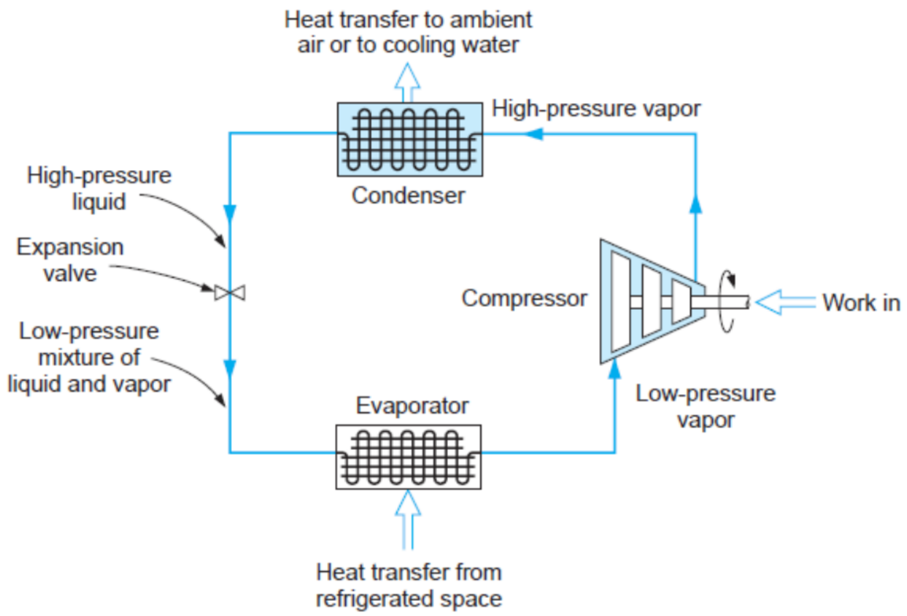


Figure 1: Schematic Diagram of Different Components of Vapor Compression Refrigeration System.

- **Condenser**: The condenser is responsible for removing heat from the refrigerant and converting it from a high-pressure vapor to a high-pressure liquid. It is typically located on the outside of the refrigeration system and uses air or water as a cooling medium. The heat extracted from the refrigerant in the condenser is released into the surroundings.
- **Compressor**: The compressor is the heart of the refrigeration system. Its main function is to increase the pressure and temperature of the refrigerant vapor. The compressor draws low-pressure refrigerant vapor from the evaporator and compresses it to a higher pressure, which raises its temperature as well. This process is crucial for the refrigerant to release heat in the condenser.
- **Evaporator**: The evaporator is where the refrigerant absorbs heat from the surroundings, typically within the refrigerated space or the object being cooled. As the low-pressure, low-temperature refrigerant

enters the evaporator, it absorbs heat from the area and evaporates into a low-pressure vapor. This heat absorption causes the surroundings to cool down. The vapor is then drawn back into the compressor, and the cycle continues.

- **Expansion Valve**: The expansion valve is a throttling device located between the condenser and the evaporator. It serves the purpose of reducing the pressure and temperature of the refrigerant as it passes through. The expansion valve creates a pressure drop, allowing the refrigerant to expand rapidly. This expansion results in a decrease in temperature and prepares the refrigerant for the evaporator.

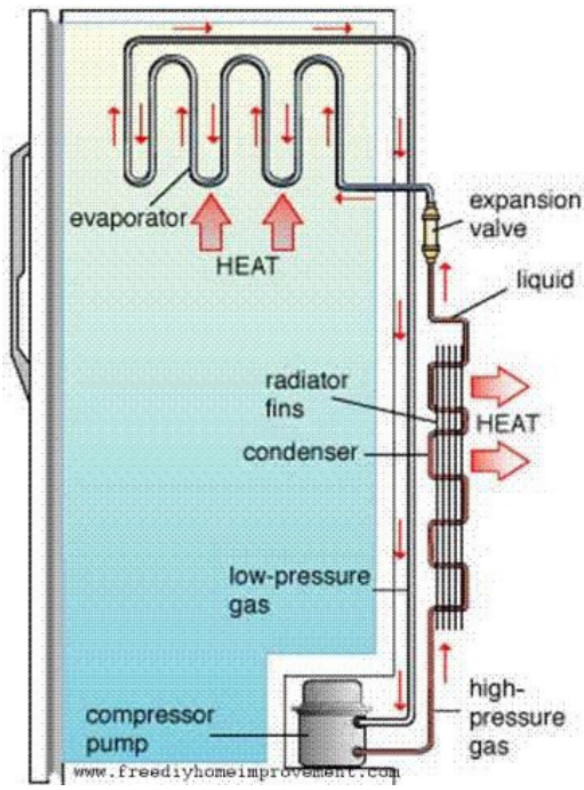


Figure 2: Different Components of a Refrigeration System.

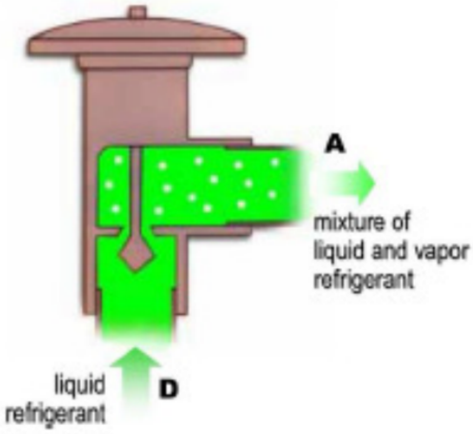
Uses of refrigeration system

- Food and Beverage Industry: Storing and preserving perishable items in supermarkets, warehouses, and transport.
- HVAC: Cooling and dehumidification in residential, commercial, and industrial buildings.
- Industrial Processes: Temperature control in manufacturing, equipment cooling, and raw material storage.
- Cold Chain Logistics: Transporting temperature-sensitive goods, like food, pharmaceuticals, and vaccines.
- Medical and Healthcare: Storing vaccines, medications, and laboratory samples.
- Ice Production: Ice manufacturing for commercial use and recreational activities.
- Research and Scientific Applications: Temperature control in experiments and sample preservation.

(a) condenser

(b) compressor

(c) evaporator



(d) expansion valve

Figure 3: Components of vapour compression refrigeration system

Types of Freezing

- **Slow freezing:** Slow freezing refers to a method of gradually lowering the temperature of a product over an extended period of time to facilitate freezing. Unlike quick freezing methods that aim for rapid freezing, slow freezing allows for a slower and more controlled freezing process. This method is commonly used in certain food preservation techniques, laboratory research, and some industrial processes. Slow freezing can help maintain the quality, texture, and cellular structure of the product, making it suitable for certain applications where slower freezing is desired or required.
- **Quick Freezing** There are three types of quick freezing systems:
  - **Air Blast Freezing:** Uses high-velocity cold air to rapidly freeze products.
  - **Immersion Freezing:** Involves immersing the product in a cold liquid for quick freezing.
  - **Indirect Contact Freezing:** Utilizes cold surfaces in direct contact with the product to achieve rapid freezing.

Industrial Functions of air conditioning

- Temperature control for employee comfort and equipment performance.
- Humidity regulation to prevent condensation and protect materials.
- Ventilation to remove contaminants and ensure a healthy environment.
- Air filtration to maintain air quality and reduce pollutants.
- Process and product cooling to optimize manufacturing and storage conditions.
- Energy efficiency to minimize costs and maximize cooling effectiveness.

2 Lecture 2: Central Air conditioning system

Date: 19/06/2023

Assignment Notice

- Have to calculate required Ton for air conditioner and a CAD model of room (by autocad or solidworks)
- including all the data about room dimension, door specification, dimension, window specification and dimension, slab and wall thickness, heat generating equipment, persons and others

Central Air Conditioning System

A central air conditioning system, also known as a chiller type air conditioning system, is a cooling system that is used to cool large buildings or spaces. It typically consists of a central cooling unit, often referred to as a chiller, that cools water or a refrigerant. The chilled water or refrigerant is then circulated through a network of pipes to various air handling units (AHUs) or fan coil units (FCUs) located throughout the building.

In a chiller type air conditioning system, the chiller unit uses a refrigeration cycle to remove heat from the water or refrigerant, thereby lowering its temperature. The chilled water or refrigerant is then pumped to the AHUs or FCUs, where it passes through heat exchangers. The heat exchangers transfer the coolness from the chilled water or refrigerant to the air, effectively cooling it. The cooled air is then distributed throughout the building via ductwork or individual units, providing a comfortable indoor environment.

Central air conditioning systems offer several advantages, including the ability to cool large spaces efficiently, centralized control and monitoring, and the potential for energy savings through the use of advanced controls and zoning. They are commonly used in commercial buildings, offices, shopping malls, hotels, and other large-scale facilities where cooling requirements are significant.

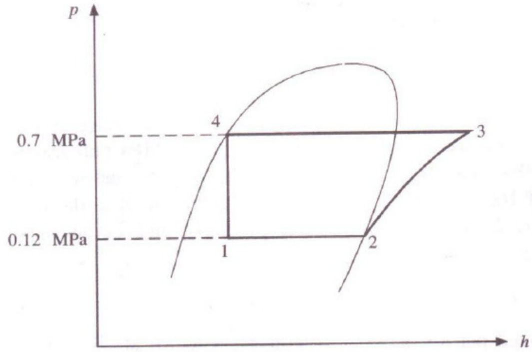
- **Air Handling Unit (AHU)**: An Air Handling Unit, often referred to as an AHU, is a device used in HVAC systems to condition and distribute air. It typically consists of a fan, heating or cooling elements, filters, and dampers. The AHU pulls in air from the surroundings, treats it by heating or cooling, filters out impurities, and then distributes it to different areas through ductwork.
- **Supply Duct**: A supply duct is a part of the HVAC system responsible for delivering conditioned air from the AHU to different spaces within a building. The supply ducts are connected to the outlets of the AHU and carry the treated air to the desired locations. They are designed to distribute the conditioned air evenly and efficiently throughout the building.
- **Return Duct**: A return duct, also known as an exhaust duct or return air duct, is a component of the HVAC system that collects and transports air back to the AHU. It pulls in air from different areas of the building, which may have been circulated through the space or mixed with the indoor air, and directs it back to the AHU for reconditioning.
- **Air Cutter**: An air diffuser or grille designed to direct the flow of conditioned air in a specific pattern or direction. It is typically installed at the outlet of a supply duct or directly on the AHU itself. The air cutter helps to distribute the conditioned air evenly and efficiently throughout the space by controlling the direction, velocity, and spread of the air stream.

3 Lecture 3: Refrigeration Cycle

Date: 10/07/2023

Problem-01

A Simple vapor compression refrigeration cycle using R134a as refrigerant operates on an ideal vapor compression refrigeration cycle between 0.12 and 0.7 MPa. The mass flow rate of the refrigerant is 0.06 kg/s. Determine:
1. The rate of heat removal of the refrigerated space and the power input to the compressor
2. The rate of heat rejection to the environment
3. The Coefficient of performance, COP



(a) p-h diagram

Refrigerant 134a (1,1,1,2-Tetrafluoroethane) 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
−103.30a	0.00039	1591.1	35.496	71.46	334.94	0.4126	1.9639	1.184	0.585	1.164	1120.	126.8	2175.	6.46	145.2	3.08	28.07	−103.30
−100.00	0.00056	1582.4	25.193	75.36	336.85	0.4354	1.9456	1.184	0.593	1.162	1103.	127.9	1893.	6.60	143.2	3.34	27.50	−100.00
−90.00	0.00152	1555.8	9.7698	87.23	342.76	0.5020	1.8972	1.189	0.617	1.156	1052.	131.0	1339.	7.03	137.3	4.15	25.79	−90.00
−80.00	0.00367	1529.0	4.2682	99.16	348.83	0.5654	1.8580	1.198	0.642	1.151	1002.	134.0	1018.	7.46	131.5	4.95	24.10	−80.00
−70.00	0.00798	1501.9	2.0590	111.20	355.02	0.6262	1.8264	1.210	0.667	1.148	952.	136.8	809.2	7.89	126.0	5.75	22.44	−70.00
−60.00	0.01591	1474.3	1.0790	123.36	361.31	0.6846	1.8010	1.223	0.692	1.146	903.	139.4	663.1	8.30	120.7	6.56	20.80	−60.00
−50.00	0.02945	1446.3	0.60620	135.67	367.65	0.7410	1.7806	1.238	0.720	1.146	855.	141.7	555.1	8.72	115.6	7.36	19.18	−50.00
−40.00	0.05121	1417.7	0.36108	148.14	374.00	0.7956	1.7643	1.255	0.749	1.148	807.	143.6	472.2	9.12	110.6	8.17	17.60	−40.00
−30.00	0.08438	1388.4	0.22594	160.79	380.32	0.8486	1.7515	1.273	0.781	1.152	760.	145.2	406.4	9.52	105.8	8.99	16.04	−30.00
−28.00	0.09270	1382.4	0.20680	163.34	381.57	0.8591	1.7492	1.277	0.788	1.153	751.	145.4	394.9	9.60	104.8	9.15	15.73	−28.00
−26.07b	0.10133	1376.7	0.19018	165.81	382.78	0.8690	1.7472	1.281	0.794	1.154	742.	145.7	384.2	9.68	103.9	9.31	15.44	−26.07
−26.00	0.10167	1376.5	0.18958	165.90	382.82	0.8694	1.7471	1.281	0.794	1.154	742.	145.7	383.8	9.68	103.9	9.32	15.43	−26.00
−24.00	0.11130	1370.4	0.17407	168.47	384.07	0.8798	1.7451	1.285	0.801	1.155	732.	145.9	373.1	9.77	102.9	9.48	15.12	−24.00
−22.00	0.12165	1364.4	0.16006	171.05	385.32	0.8900	1.7432	1.289	0.809	1.156	723.	146.1	362.9	9.85	102.0	9.65	14.82	−22.00
−20.00	0.13273	1358.3	0.14739	173.64	386.55	0.9002	1.7413	1.293	0.816	1.158	714.	146.3	353.0	9.92	101.1	9.82	14.51	−20.00
−18.00	0.14460	1352.1	0.13592	176.23	387.79	0.9104	1.7396	1.297	0.823	1.159	705.	146.4	343.5	10.01	100.1	9.98	14.21	−18.00
−16.00	0.15728	1345.9	0.12551	178.83	389.02	0.9205	1.7379	1.302	0.831	1.161	695.	146.6	334.3	10.09	99.2	10.15	13.91	−16.00
−14.00	0.17082	1339.7	0.11605	181.44	390.24	0.9306	1.7363	1.306	0.838	1.163	686.	146.7	325.4	10.17	98.3	10.32	13.61	−14.00
−12.00	0.18524	1333.4	0.10744	184.07	391.46	0.9407	1.7348	1.311	0.846	1.165	677.	146.8	316.9	10.25	97.4	10.49	13.32	−12.00
−10.00	0.20060	1327.1	0.09959	186.70	392.66	0.9506	1.7334	1.316	0.854	1.167	668.	146.9	308.6	10.33	96.5	10.66	13.02	−10.00
−8.00	0.21693	1320.8	0.09242	189.34	393.87	0.9606	1.7320	1.320	0.863	1.169	658.	146.9	300.6	10.41	95.6	10.83	12.72	−8.00
−6.00	0.23428	1314.3	0.08587	191.99	395.06	0.9705	1.7307	1.325	0.871	1.171	649.	147.0	292.9	10.49	94.7	11.00	12.43	−6.00
−4.00	0.25268	1307.9	0.07987	194.65	396.25	0.9804	1.7294	1.330	0.880	1.174	640.	147.0	285.4	10.57	93.8	11.17	12.14	−4.00
−2.00	0.27217	1301.4	0.07436	197.32	397.43	0.9902	1.7282	1.336	0.888	1.176	631.	147.0	278.1	10.65	92.9	11.34	11.85	−2.00
0.00	0.29280	1294.8	0.06931	200.00	398.60	1.0000	1.7271	1.341	0.897	1.179	622.	146.9	271.1	10.73	92.0	11.51	11.56	0.00

(b) Saturated vapor at 0.12 MPa

4.00	0.33766	1281.4	0.06039	205.40	400.92	1.0195	1.7250	1.352	0.916	1.185
6.00	0.36198	1274.7	0.05644	208.11	402.06	1.0292	1.7240	1.358	0.925	1.189
8.00	0.38761	1267.9	0.05280	210.84	403.20	1.0388	1.7230	1.364	0.935	1.192
10.00	0.41461	1261.0	0.04944	213.58	404.32	1.0485	1.7221	1.370	0.945	1.196
12.00	0.44301	1254.0	0.04633	216.33	405.43	1.0581	1.7212	1.377	0.956	1.200
14.00	0.47288	1246.9	0.04345	219.09	406.53	1.0677	1.7204	1.383	0.967	1.204
16.00	0.50425	1239.8	0.04078	221.87	407.61	1.0772	1.7196	1.390	0.978	1.209
18.00	0.53718	1232.6	0.03830	224.66	408.69	1.0867	1.7188	1.397	0.989	1.214
20.00	0.57171	1225.3	0.03600	227.47	409.75	1.0962	1.7180	1.405	1.001	1.219
22.00	0.60789	1218.0	0.03385	230.29	410.79	1.1057	1.7173	1.413	1.013	1.224
24.00	0.64578	1210.5	0.03186	233.12	411.82	1.1152	1.7166	1.421	1.025	1.230
26.00	0.68543	1202.9	0.03000	235.97	412.84	1.1246	1.7159	1.429	1.038	1.236
28.00	0.72688	1195.2	0.02826	238.84	413.84	1.1341	1.7152	1.437	1.052	1.243
30.00	0.77020	1187.5	0.02664	241.72	414.82	1.1435	1.7145	1.446	1.065	1.249
32.00	0.81543	1179.6	0.02513	244.62	415.78	1.1529	1.7138	1.456	1.080	1.257
34.00	0.86263	1171.6	0.02371	247.54	416.72	1.1623	1.7131	1.466	1.095	1.265

(c) Saturated Liquid at 0.7 MPa

Figure 4: Problem-01 Solution

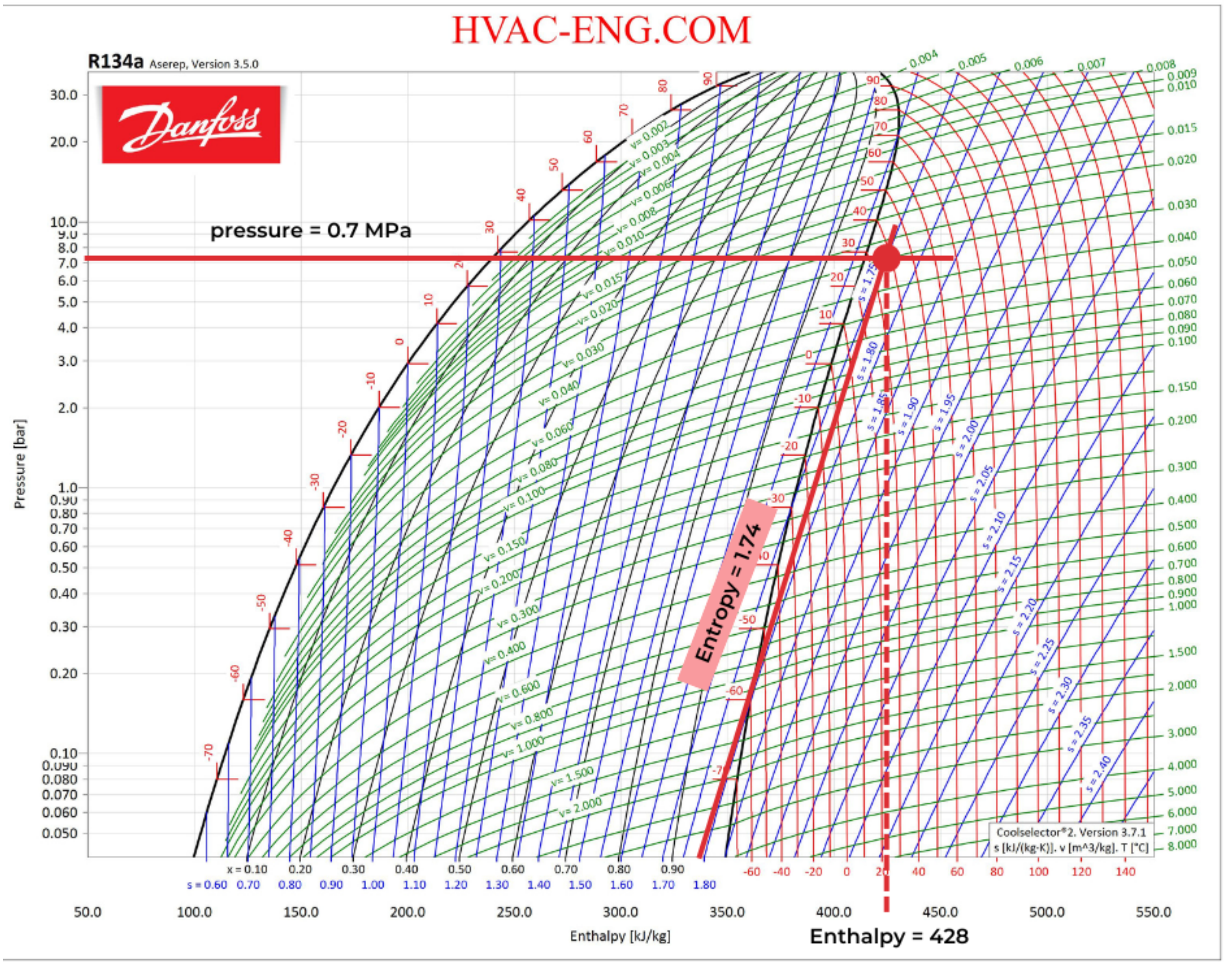


Figure 5: Enthaply at s=1.74 and p = 0.7 MPa

Solution

Here, $P_{cond} = 0.70$ MPa
$P_{eva} = 0.12$ MPa
$\dot{m} = 0.06$ kg/s
For R123a refrigerant, $h_2 = 385.43kJ/kg, h_3 = 428kJ/kg, h_1 = h_4 = 236kJ/kg$

(a)

$$\text{Refrigering capacity, } Q_2 = \dot{m}(h_2 - h_1) = 8.96KW$$
$$\text{Compressor work, } \dot{W} = \dot{m}(h_3 - h_2) = 2.55KW$$

(b)

$$\text{Rate of heat rejection } = Q_2 + \dot{W} = 11.51KW$$

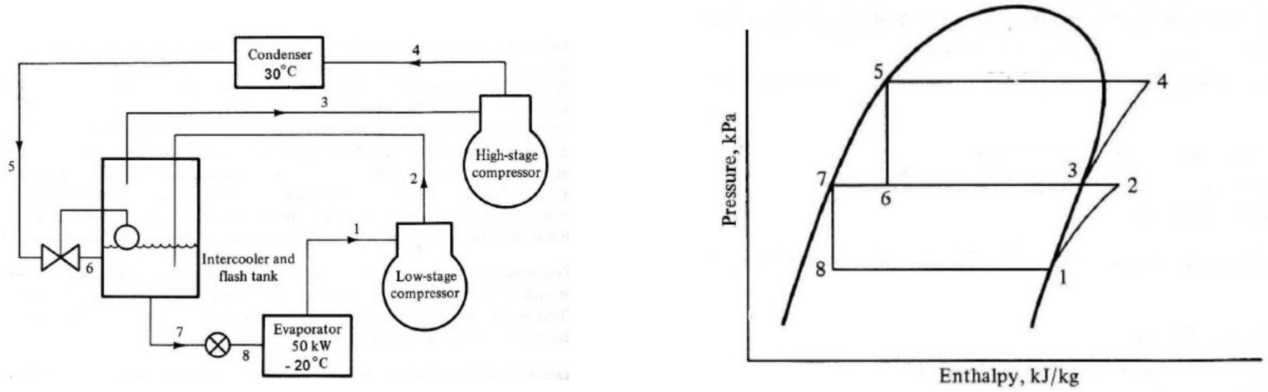
(c)

$$\text{COP } = \frac{R.E.}{\dot{W}} = \frac{8.96}{2.55} = 3.51$$

Problem-02

Determine the COP of 2-stage refrigeration system with flash gas removal. The system uses R134a as a refrigerant to produce 50 kW refrigeration effect. Given that, T_{cond} = 30°C and T_{evap} = -20°C and inter-cooler temperature is 0°C.

Solution



(a) refrigeration cycle (b) p-h diagram

Figure 6: Problem-02 Solution

Given,
T_{cond} = 30°C
T_{evap} = -20°C
$T_{inter-cooler}$ = 0°C
R.E. = 50 kW
C.O.P. = ?
Data:
h_1 = 386.55 kj/kg , s_1 = 1.7413 [From table]
h_2 = 400 kj/kg [From p-h chart]
h_3 = 398.60 kj/kg , s_3 = 1.7271 [From table]
h_4 = 415 kj/kg [From p-h diagram]
$h_5 = h_6$ = 241.72 kj/kg [From table]
$h_7 = h_8$ = 200 kj/kg [from table]

$$\text{Now, } h_6 = h_7 + x(h_3 - h_7)$$
$$\Rightarrow 241.72 = 200 + x(398.60 - 200)$$
$$\Rightarrow x = 0.21$$

$$\text{Again, } R.E. = \dot{m}(1-x)(h_1 - h_8)$$
$$\Rightarrow 50 = \dot{m} \times 0.79 \times (386.55 - 200)$$
$$\Rightarrow \dot{m} = 0.339$$

$$W_{1-2} = \dot{m}(1-x)(h_2 - h_1) = 4.29KW$$

$$W_{3-4} = \dot{m}(h_4 - h_3) = 6.80KW$$

$$C.O.P. = \frac{R.E.}{W_{1-2} + W_{3-4}} = 4.50KW$$

Problem-03

Do the same problem for the single stage refrigeration system

Solution

Given,
T_{cond} = 30°C
T_{evap} = -20°C
R.E. = 50 kW
C.O.P. = ?
Data:
h_1 = 386.55 kj/kg , s_1 = 1.7413 [From table]
h_2 = 420 kj/kg [From p-h chart]
$h_3 = h_4$ = 241.72 kj/kg [From table]

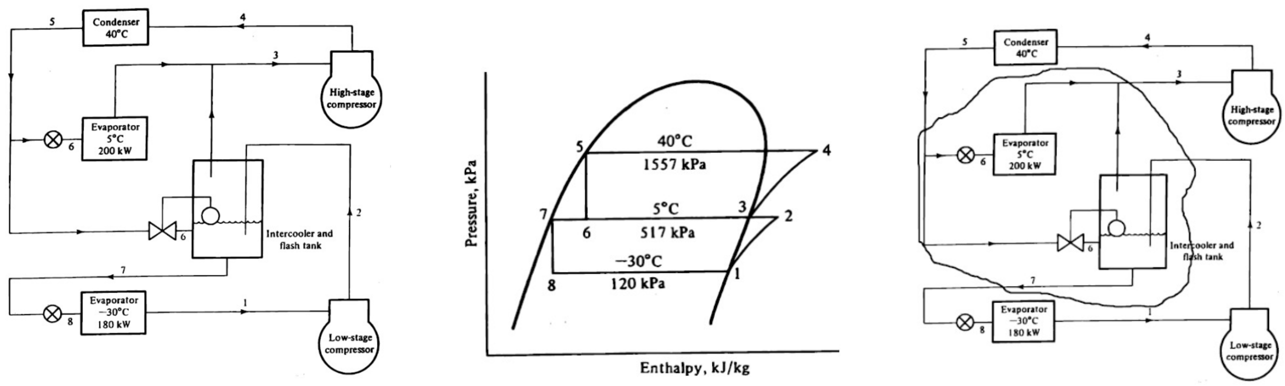
$$\text{Again, } R.E. = \dot{m}(h_1 - h_4)$$
$$\Rightarrow 50 = \dot{m} \times (386.55 - 241.72)$$
$$\Rightarrow \dot{m} = 0.345$$

$$W_{1-2} = \dot{m}(h_2 - h_1) = 11.54\,KW$$

$$C.O.P. = \frac{R.E.}{W_{1-2}} = 4.33\,KW$$

4 Lecture 4: 2 compressor & 2 evaporator

Date: 17/07/2023



(a) 2 compressor and 2 evaporator (b) Phase diagram (c) Control volume approach

Figure 7: Two compressor and two evaporator problem

Solution:

Here,
$m_1 = m_2 = m_7 = m_8$
$m_3 = m_4 = m_5$

Reading the properties:

$$\begin{aligned}
h_1 &= 380.32\,\text{kj/kg}, s_1 = 1.7515 \\
h_2 &= 405\,\text{kj/kg}, s_2 = 1.7515 \\
h_3 &= 401\,\text{kj/kg}, s_3 = 1.7250 \\
h_4 &= 404\,\text{kj/kg} \\
h_5 &= 256\,\text{kj/kg} \\
h_7 &= h_8 = 206\,\text{kj/kg}
\end{aligned}$$

Now, Refrigetation effect, R.E.:

$$\begin{aligned}
m_1(h_1 - h_8) &= 180\,kW \\
m_1 &= 1.03\,kg/s
\end{aligned}$$

Here, In intercooler, m_2 & m_5 enters and m_3 & m_7 exits. We are trying to avoid m_6 for simplicity.

So, we found:

$$m_2h_2 + m_5h_5 + 200 = m_3h_3 + m_7h_7$$

As, $m_1 = m_2 = m_7$ and $m_3 = m_5$,by solving,

$$m_3 = 2.793\,kg/s$$

$$W_{1-2} = m_1(h_2 - h_1) = 25.4204\,kW$$

$$W_{3-4} = m_3(h_4 - h_3) = 8.375\,kW$$

$$C.O.P. = \frac{R.E.}{W_{1-2} + W_{3-4}} = 5.326$$

Some others important parameters:

- $$EER = \frac{\text{R.E. in BTU/hr}}{\text{Power Required in W}}$$
- $$kW/ton = \frac{3.516}{C.O.P.}$$
- $$EER \times kW/ton = 12$$

5 Lecture 5: Cooling Load Estimation Using CLTD/CLF Method

Date: 24/07/2023

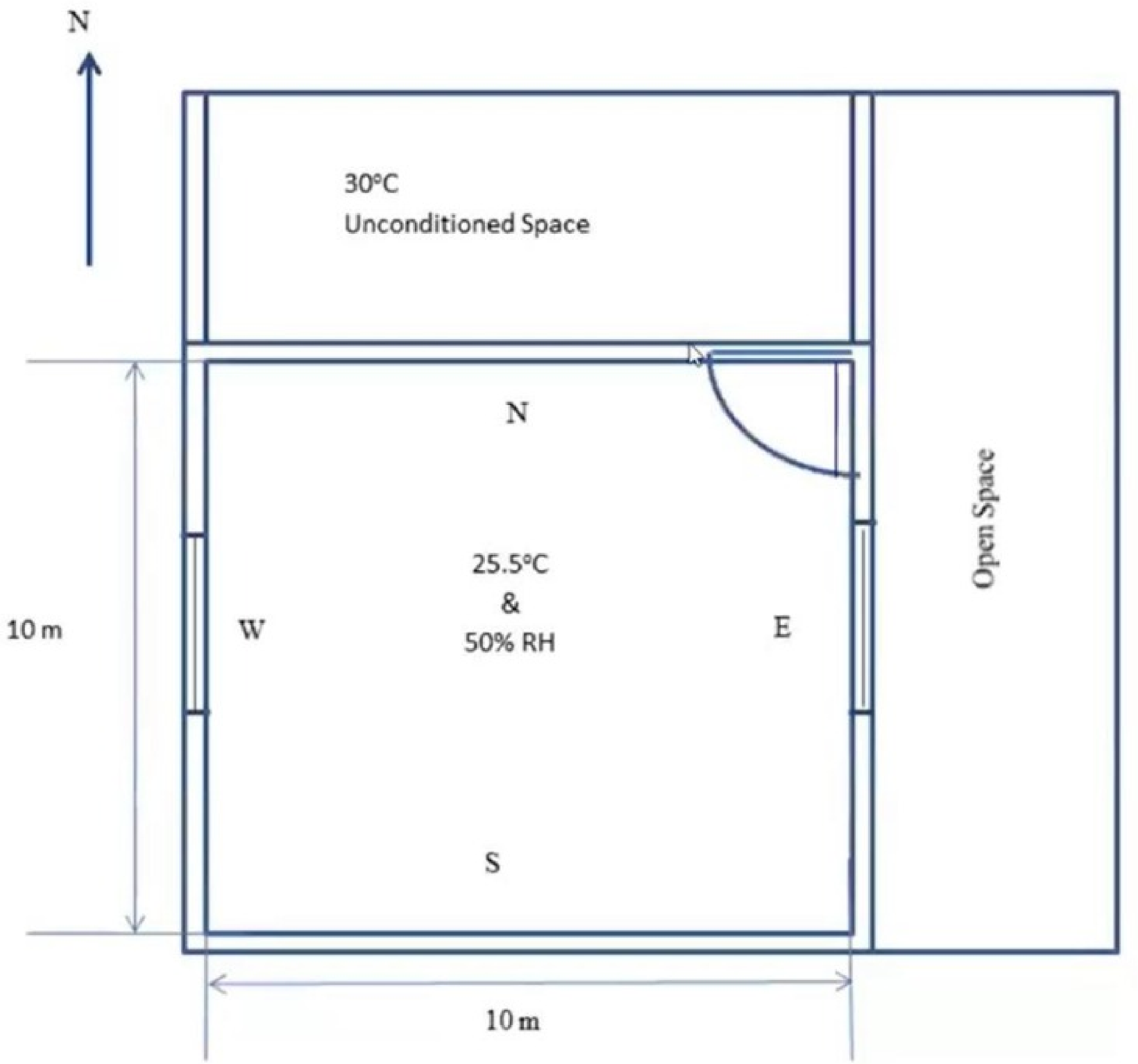


Figure 8: CAD model of room for cooling load estimation

1. Normally at 5-6 pm, temperatures are high. Also in April/May, temperatures are high. So, we have to design for the worst case scenario.
2. Room height: 3.0 m
3. West & South Walls: Metal curtain wall, construction type G with 75 mm insulation, sunlit, dark color.
4. Partition walls (North & East): 127 mm brick with 25 mm plaster on both sides.
5. Roof: Type 4, 50 mm insulation without suspended ceiling
6. Window: 6 m^2 on west & east side.
   U = 2.86 $W/m^2 - k$
   - 13 mm thickness
   - Light construction
7. No heat transfer through floor
8. Air exchange rate: 1.0 / h
   - ($10 \times 10 \times 3 = 300\, m^3/h$)
9. Light & Occupants from 8 am to 6 pm.
10. Average light density: 25 W/m^2, flouroscent light
    - 25 $\times$ Area of Base = 2500
11. 5 Occupants seated, using 1 computer.
12. Door in North wall: Door size: $2m \times 1m$, 25 mm thick, hard wood.

Heat Conduction through Surface

1. Conduction Through Shaded Partition/Surface:

$$Q = U.A.TD$$

2. Conduction Through Sunlit Surface:

$$Q = U.A.CLTD$$

- $U \rightarrow$ Overall heat conductance $(W/m^2 - k)$
- $TD \rightarrow$ Temperature difference accross the surface $(°C)$
- $CLTD \rightarrow$ Cooling load temperature difference $(°C)$
- $U = 1/R_{th}$
- $R_{th} = R_o + R + R_i$

Roof

- Type: Type 4, 50 mm insulation without suspended ceiling
- Read data from **Table 12(a)**
- Layers for type-4 : $A0 - E2 - E3 - B5 - C12 - E0$
- Here, 50 mm insulation not available on type 4. That's why we have to switch from $B5$ to $B6$.
- So, we have to calculate for: $A0 - E2 - E3 - B6 - C12 - E0$
- Read the resistance of the layers from **Table-16**

12(a) Roof Construction Code

Roof No.	Description	Code Numbers of Layers (see Table 8)
1	Steel Sheet with 25-mm insulation	A0, E2, E3, B5, A3, E0
2	25-mm wood with 25-mm insulation	A0, E2, E3, B5, B7, E0
3	100-mm l. w. concrete	A0, E2, E3, C14, E0
✓	50-mm h. w. concrete with 25-mm insulation	A0, E2, E3, B5, C12, E0
5	25-mm wood with 50-mm insulation	A0, E2, E3, B6, B7, E0
		A0, E2, E3, B5, C12, E0
5	25-mm wood with 50-mm insulation	A0, E2, E3, B6, B7, E0
6	150-mm l. w. concrete	A0, E2, E3, C15, E0
7	63-mm wood with 25-mm insulation	A0, E2, E3, B5, B8, E0
8	200-mm l. w. concrete	A0, E2, E3, C16, E0
9	100-mm h. w. concrete with 25-mm insulation	A0, E2, E3, B5, C5, E0
10	63-mm wood with 50-mm insulation	A0, E2, E3, B6, B8, E0
11	Roof terrace system	A0, C12, B1, B6, E2, E3, C5, E0
12	150-mm h. w. concrete with 25-mm insulation	A0, E2, E3, B5, C13, E0
13	100-mm wood with 25-mm insulation	A0, E2, E3, B5, B9, E0

Figure 9: Table 12(a) : Type 4

Calculation for Roof:

Layer	A0	E2	E3	B6	C12	E0	Total
R_{th}	0.059	0.099	0.050	1.173	0.029	0.121	1.581

Table 1: Resistance of all layers for roof.

Now, $R_{th} = 1.581$,
so, $U = 1/R_{th} = 0.653$

South & West Wall

- Type: Metal curtain wall, construction type G with 75 mm insulation, sunlit, dark color.
- Read data from **Table-14**
- Layers: $A0 - A3 - B12 - A3 - E0$
- Read resistance value from **Table-16**

142	0.914-1.493	F	101.6-mm Block + Air Space/Insulation	A0, A1, C2, B1/B2, E1, E0
142-181	0.596-0.647	E	50.8-mm Insulation + 101.6-mm Block	A0, A1, B3, C2/C3, E1, E0
229-249	1.669-2.282	E	203.2-mm Block	A0, A1, C7/C8, E1, E0
200-278	0.846-0982	D	203.2-mm Block + Air Space/Insulation	A0, A1, C7/C8, B1/B2, E1, E0
			Clay Tile + (*Finish*)	
190	2.379	F	101.6-mm Tile	A0, A1, C1, E1, E0
190	1.720	F	101.6-mm Tile + Air Space	A0, A1, C1, B1, E1, E0
190	0.993	E	101.6-mm Tile + 25.4-mm Insulation	A0, A1, C1, B2, E1, E0
195	0.625	D	50.8-mm Insulation + 101.6-mm Tile	A0, A1, B3, C1, E1, E0
308	1.681	D	203.2-mm Tile	A0, A1, C6, B1/B2, E1, E0
308	0.857-1.312	C	203.2-mm Tile + Air Space/25.4-mm Insulation	A0, A1, C6, B1/B2, E1, E0
308	0.562	B	50.8-mm Insulation + 203.2-mm Tile	A0, A1, B3, C6, E1, E0
			Metal Curtain Wall	
24-29	0.516-1.306	G	With/without air Space + 25.4-mm/50.8-mm 76.2-mm Insulation	A0, A3, B5/B6/B12, A3, E0
			Frame Wall	
78	0.459-1.010	G	25.4-mm to 76.2-mm Insulation	A0, A1, B1, B2/B3/B4, E1, E0

Figure 10: Table 14 : Type G

Calculation for South & West Walls:

Layer	A0	A3	B12	A3	E0	Total
R_{th}	0.059	0	1.76	0	0.121	1.94

Table 2: West and South walls.

Now, $R_{th} = 1.94$,
so, $U = 1/R_{th} = 0.52$

North & East Wall (Partition Wall)

- 127 mm brick with 25 mm plaster on both sides.
- Read resistance from **Table-16**

- Here, 127 mm brick not available. So, we will take $C4$: 100 mm brick to calculate $k = 0.727$, then calculate the resistance for 127 mm brick with the same K values.
- Also 25 mm plaster not availble. We will take $E1 : 20mm$, then by the value of $k = 0.7277$, will calculate resistance for 25 mm plaster.

C3	100 mm heavy weight concrete block	100	0.813	977	0.84	0.125	99.06
C4	100 mm common brick	100	0.727	1922	0.84	0.140	195.20
C5	100 mm heavy weight concrete	100	1.731	2243	0.84	0.059	227.90
C6	200 mm clay tile	200	0.571	1121	0.84	0.352	227.90
C7	200 mm lightweight concrete block	200	0.571	609	0.84	0.352	123.46
C8	200 mm heavy weight concrete block	200	1.038	977	0.84	0.196	198.62
C9	200 mm common brick	200	0.727	1922	0.84	0.279	390.40
C10	200 mm heavy weight concrete	200	1.731	2243	0.84	0.117	455.79
C11	300 mm heavy weight concrete	300	1.731	2243	0.84	0.176	683.20
C12	50 mm heavy weight concrete	50	1.731	2243	0.84	0.029	113.70
C13	150 mm heavy weight concrete	150	1.731	2243	0.84	0.088	341.60
C14	100 mm lightweight concrete	100	0.173	641	0.84	0.587	64.90
C15	150 mm lightweight concrete	150	0.173	641	0.84	0.880	97.60
C16	200 mm lightweight concrete	200	0.173	641	0.84	1.173	130.30
C17	200 mm lightweight conc blk. (filled)	200	0.138	288	0.84	1.467	58.56
C18	200 mm heavy weight conc. blk. (filled)	200	0.588	849	0.84	0.345	172.75
C19	300 mm lightweight conc. blk. (filled)	300	0.138	304	0.84	2.200	92.72
C20	300 mm heavy weight conc. blk. (filled)	300	0.675	897	0.84	0.451	273.28
E0	Inside surface resistance	0	0.000	0	0.00	0.121	0.00
E1	20 mm plaster or gypsum	20	0.7277	1602	0.84	0.026	30.74
E2	12 mm slag or stone	12	1.436	881	1.67	0.099	11.22
E3	10 mm felt and membrane	10	0.190	1121	1.67	0.050	10.74
E4	Ceiling air space	0	0.000	0	0.00	0.176	0.00

Figure 11: Table 16 : For partition walls

Calculation for North & East Wall:

- $R_{th} = R_o + R_1 + R_2 + R_3 + R_i$
- Outside (R_0) : A0 = 0.059
- 25 mm Plaster (R_1, R_3) : For E1 20 mm plaster, k = 0.7277, now $R_1 = R_3 = L/k = 0.025/0.7277 = 0.0343$
- 127 mm Brick (R_2) : For C4 100 mm brick, k = 0.727, now $R_2 = L/k = 0.127/0.727 = 0.175$
- Inside (R_i) : E0 = 0.121
- Total $(R_{th}) = 0.059 + 0.0343 + 0.175 + 0.0343 + 0.121 = 0.4236$
- $U = 1/R_{th} = 2.36$

Door

- Door size: $2m \times 1m$, 25 mm thick, hard wood
- Read data from **Table-17.6**
- Hard wood, Oak, k= 0.16. $R_d = L/k = 0.025/0.16 = 0.156$
- $R_{th} = R_o + R_d + R_i = 0.059 + 0.156 + 0.121 = 0.336$
- $U = 2.98$

TABLE Typical thermal properties of common building and insulating materials—design values (Contd.)

Description	Density kg/m^3	Conductivity (k) $W/(m \cdot K)$	Conductance (C) $W(m^2 \cdot K)$	Resistance (R) ($1/k$) $m \cdot K/W$	Resistance (R) For thickness listed ($1/\Omega$) $(m^2 \cdot K)/W$	Specific heat, $kJ/(kg \cdot K)$
WOODS (12% moisture content)						
Hardwoods						1.63
Oak	659–749	0.16–0.18	–	6.2–5.5	–	
Birch	682–726	0.167–0.176	–	6.0–5.7	–	
Maple	637–704	0.157–0.171	–	6.4–5.8	–	
Ash	614–670	0.153–0.164	–	6.5–6.1	–	
Softwoods						1.63
Southern Pine	570–659	0.144–0.161	–	6.9–6.2	–	
Douglas Fir-larch	536–581	0.137–0.145	–	7.3–6.9	–	
Southern Cypress	502–514	0.130–0.132	–	7.7–7.6	–	
Hem-Fir, Spruce-Pine-Fir	392–502	0.107–0.130	–	9.3–7.7	–	

Figure 12: Table 17.6 : For door (hardwood, i.e.: Oak)

Heat Conduction through Partition walls/glasses

Sl. No.	Item	Description	A	U	TD	Q (Watt)
1.	Partition Wall	North	28	2.36	4.5	297.4
2.	Door	North	2	2.98	4.5	26.8
3.	Partition Wall	East	24	2.36	7.5	424.8
4.	Partition Glass	East	6	2.86	7.5	128.7
	Total					877.7

Figure 13: Heat Conduction through Partition walls/glasses

- For 1 & 2: $TD = T_o - T_i = 30 - 25.5 = 4.5$
- For 3 & 4: $TD = T_{o,max} - T_i = 33 - 25.5 = 7.5$ [From table-9: $T_{o,max} = 33$ for BD]
- For 1: A = Northern wall - Door = $(10 \times 3) - (2 \times 1) = 28$
- For 3: A = Eastern wall - Window = $30 - 6 = 24$

Sydney	33	52S	151	12E	42	3	4	6	32	29	27	7	23	23	22	N	4	NE
AUSTRIA																		
Vienna	48	15N	16	22E	196	−19	−14	−12	31	30	28	9	22	21	19	W	7	SSE
AZORES																		
Lajes (Terceira)	38	45N	27	05W	52	6	8	9	27	26	25	6	23	22	22	W	5	NW
BAHAMAS																		
Nassau	25	05N	77	21W	3	13	16	17	32	32	31	7	27	27	26			
BANGLADESH																		
Chittagong	22	21N	91	50E	27	9	11	12	34	33	32	11	28	27	27			
BELGIUM																		
Brussels	50	48N	4	21E	100	−11	−9	−7	28	26	25	11	21	20	19	NE	4	ENE
BERMUDA																		
Kindley AFB	33	22N	64	41W	9	8	12	13	31	30	29	7	26	26	26	NW	8	S
BOLIVIA																		
La Paz	16	20S	68	09W	2659	−2	−1	1	22	21	20	13	14	14	13			
BRAZIL																		
Belem	1	27S	48	29W	13	19	21	22	32	32	31	11	27	26	26	SE	3	E
Belo Horizonte	19	56S	43	57W	915	6	8	10	30	29	28	10	24	24	24			

Figure 14: $T_{o,max}$ from table-9 (design dry bulb - 2.5%)