## Chapter 4.9: HVAC System

### Short type questions

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| 1. | Define 'tons of refrigeration'?<br>**Ans.** One ton of refrigeration is the amount of cooling obtained by one ton of ice melting in one day. It is equivalent to 3024 kcal/h, 12,000 Btu/h or 3.516 thermal kW. |
| 2. | Where is performance evaluation of air conditioning unit term 'energy efficiency ratio (EER)' is used?<br>**Ans** Energy Efficiency Ratio mainly used in air condition systems. Performance of smaller units and roof top units are frequently measured in EER rather than kW/ton. |
| 3. | To assess the refrigeration capacity, list the basic parameters required?<br>**Ans** For assessment of refrigeration load, basic parameters required are:<br>a) Water flow rate through evaporator<br>b) Temperature difference between entering and leaving water |
| 4. | Write the relation between COP, EER and kW/tonne, which are the different energy efficiency performance indicators of Refrigeration systems?<br>**Ans** The relation between different energy efficiency performances of chillers are:<br>COP - 0.293 EER<br>kW/ton - 12/EER<br>kW/ton - 3.516/CoP |
| 5. | Define the term 'refrigeration'?<br>**Ans** Refrigeration is defined as an art of producing and maintaining the temperature in a space below atmospheric temperature. |
| 6. | Which is the popular low energy cost comfort cooling system in tropical climate (dry regions)?<br>**Ans** Evaporative cooling systems are popular in tropical climate. These systems control humidity up to 50% for human comfort. |
| 7. | Find the dew point temperature (°C) of air for following parameters from psychrometric chart?<br>**Ans** Dry bulb temp (°C) = 25 °C, Wet bulb temperature (°C) = 16 °C<br>Dew point temperature of above air is 10.0 |
| 8. | How cooling tower should be designed for refrigeration systems?<br>**Ans** Cooling water inlet temperature to refrigeration system should be as low as possible. In general, cooling towers will be design with approach WBT + 3 °C for refrigeration systems. |
| 9. | What will be the additional refrigeration (TR) required, if a coffee machine of 3 kWh consumption, added in conditioned space?<br>**Ans** Additional heat inside the space = 3 x 860 = 2580 kcal/h<br>Equivalent refrigeration load (TR) = 2580/3024 = 0.85 TR |
| 10. | Write the coefficient of performance (CoP) for an ideal refrigeration system (Carnot cycle) ?<br>**Ans** COP Carnot = $T_e/T_c$-$T_e$<br>$T_e$=Evaporator temperature; $T_c$- condenser temperature |

**Long type questions**

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| 1. | List the energy saving opportunities in refrigeration air-conditioning plant area?<br>**Ans.** The following are few energy savings opportunities in refrigeration plant area.<br>i. Ensure adequate quantity of chilled water and condenser water flows, avoid by pass flows by closing valves of idle equipment<br>ii. Minimise part load operations by matching loads and plant capacity online; adopt variable speed drives for varying process load<br>iii. Make efforts to continuously optimise condenser and evaporator parameters for minimising specific energy consumption and maximising capacity<br>iv. Ensure regular maintenance of all A/C plant components as per manufacturer guidelines. |
| 2. | Write a short note on maintenance of heat exchanger surfaces effect on power consumption of refrigeration systems?<br>Ans. The key to optimise power consumption is through effective maintenance. Fouled condenser tubes force the compressor to work harder to attain the desired capacity. For example, a 0.8 mm scale build-up on condenser tubes can increase energy consumption by as much as 35%. Similarly fouled evaporators (due to residual lubricating oil or infiltration of air) result in increased power consumption. Equally important is proper selection, sizing, and maintenance of cooling towers. A reduction of 0.55 °C temperature in water returning from the cooling tower reduces compressor power consumption by 3.0%.<br>However, increased velocity results in larger pressure drops in the distribution system and higher power consumption in pumps / fans in refrigeration system auxiliary equipment. |

**Numerical type questions**

1. Calculate the heat load (TR) across air handling unit (AHU). The measured dry bulb and wet bulb temperatures of air across AHU inlet and outlet are:

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| Entering air temperature | : 24.6 °C DBT, 17.0 °C WBT |
| Leaving air temperature | : 13.5 °C DBT, 13.0 °C WBT |
| Measured inlet air flow rate | : 14800 $m^3/h$ |
| AHU heat load (TR) | : $\frac{m \times (h_{in} - h_{out})}{4.18 \times 3024}$ |
| Values obtained from psychrometric chart | |
| Mass flow rate of air | : flow rate ($m^3/h$) x density ($kg/m^3$) |
| Density of air | : 1.16 $kg/m^3$ |
| $H_{in}$ – enthalpy of inlet air at AHU, | : 48 kJ/kg |
| $H_{out}$ – enthalpy of outlet air at AHU, | : 36 kJ/kg |
| Heat load (TR) | : $\frac{14800 \times 1.04 \times (48 - 36)}{4.18 \times 3024}$ |
| | : 16.3 TR |

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| 2. | A multi-storied shopping mall has installed 5 x 110 TR reciprocating compressors of which four compressors are in use for 16 hours per day. Due to higher energy cost shopping mall chief engineer has decided to replace reciprocating compressors with screw compressors. Chief engineer need following input from energy consultant.<br>i. Comparison of power consumption of both reciprocating and screw compressors?<br>ii. Annual cost savings (for 350 days operation). Present unit cost Rs 6.50 per kWh, investment for 220 TR machine Rs 30 lakh.<br>iii. What should be the size of cooling tower required for proposed screw compressors?<br>**Ans.** i. Operating reciprocating compressors capacity : 440 TR<br>Sp. Power consumption of compressor (reciprocating) : 0.8 kW/TR<br>Power consumption per hour : 0.8 x 440 = 352 kW<br>Required screw compressor capacity : 440 TR<br>Sp. Power consumption of compressor (screw) : 0.65 kW/TR<br>Power consumption per hour : 286 kW<br>By replacement of reciprocating compressors with screw compressors reduction in power consumption is 66 kW per hour (or 1056 kWh/day).<br>ii. Annual cost savings:<br>Reduction in power consumption : 66 kW<br>Operating hours : 16 per day<br>Operating days : 350 days per year<br>Annual energy savings : 66 x 16 x 350<br>: 3.69 lakh kWh<br>Annual cost savings : Rs 23.985 lakh<br>(@ Rs 6.50 per kWh)<br>iii. Cooling tower capacity:<br>Operating refrigeration load : 440 TR<br>Vapour compression type refrigeration systems condenser load (TR) will be around 1.2 time of evaporator load (TR)<br>Cooling tower capacity : 1.2 x 440 TR<br>: 528 TR |

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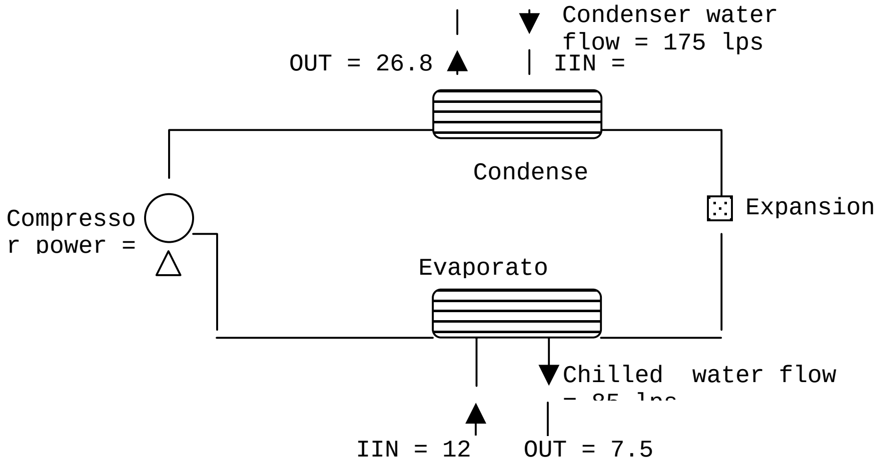
| | 3. Energy measured parameters of centrifugal chiller are given below |




i. Evaluate the performance of centrifugal chiller CoP and EER

ii. Find the ratio of evaporator to condenser

iii. Identify the energy saving potential area

**Ans.** i. Refrigeration load (TR) : $(m \times c_p \times \Delta t)/3024$

: 85 x 3600 x 1 x (12-7.5)/3024

: 455 TR

kW/TR rating : $\frac{282}{455} = 0.62$

Coefficient of performance (CoP) : $\frac{3.516}{kW/TRrating} = 5.67$

Energy efficiency ratio (EER) : $\frac{12}{kW/TRrating}$

: $\frac{12}{0.62} = 19.35$

ii. Evaporator cooling load (TR) : 455 TR

Condenser heat rejection load (TR) : 175 x 3600 x (26.8 – 24.2)/3024

: 542 TR

Ratio : $\frac{Evaporator}{Condenser} = \frac{455}{542} = 0.84$

iii. Cooling water flow rate through condenser is high, whereas Δt across condenser is very less.

The required condenser water flow rate for 542 TR is 137 lps (basis 0.91 $m^3$/h per TR)

By optimising condenser water flow, pump power consumption can be saved.

4. Compare the performance of centrifugal chiller with vapour absorption chiller (VAM).

| Parameter | Centrifugal chiller | VAM |
|---|---|---|
| Chilled water flow ($m^3/h$) | 189 | 180 |
| Condenser water flow ($m^3/h$) | 238 | 340 |
| Chiller inlet temp (°C) | 13.0 | 14.6 |
| Condenser water inlet temp (°C) | 27.1 | 33.5 |
| Chiller water outlet temp (°C) | 7.7 | 9.0 |
| Condenser water outlet temp (°C) | 32.0 | 39.1 |
| Comp. power consumption (kW) | 190 | - |
| Steam consumption (kg/h) | - | 1570 |
| Chilled water pump (kW) | 28 | 28 |
| Condenser water pump (kW) | 22 | 33 |
| Cooling tower fan (kW) | 6.0 | 15 |

i. Evaluate the tons of refrigeration (TR) of both the systems?

ii. Compare both the chillers auxiliary power consumption, give the reason?

**Ans.** Refrigeration load (TR) :

$$\frac{\text{Chilled water flow}\,(m^3/h) \times \text{Sp.heat} \times \text{difference in temp}(°C)}{3024}$$

Density of water : 1000 kg / $m^3$

i. Centrifugal chiller

TR : 189 x 1000 x 1 x (13-7.7) / 3024

: 331

VAM

TR : 180 x 1000 x 1 x (14.6 – 9.0)/3024

: 333

ii. Centrifugal chiller Auxiliary power consumption: Chilled water pump + condenser water pump + cooling tower fan

Centrifugal chiller Auxiliary power (kW) : 28 + 22 + 6.0 = 56 kW

VAM auxiliary power (kW) : 28 + 33 + 15 = 76 kW

Reason: For the same refrigeration load around 330 TR centrifugal chiller auxiliary power consumption is lower compared to VAM. It is mainly due to higher condenser heat load, where condenser pump and cooling tower fan power consumption is high.