9. ENERGY PERFORMANCE ASSESSMENT OF HVAC SYSTEMS

9.1 Introduction

Air conditioning and refrigeration consume significant amount of energy in buildings and in process industries. The energy consumed in air conditioning and refrigeration systems is sensitive to load changes, seasonal variations, operation and maintenance, ambient conditions etc. Hence the performance evaluation will have to take into account to the extent possible all these factors.

9.2 Purpose of the Performance Test

The purpose of performance assessment is to verify the performance of a refrigeration system by using field measurements. The test will measure net cooling capacity (tons of refrigeration) and energy requirements, at the actual operating conditions. The objective of the test is to estimate the energy consumption at actual load vis-à-vis design conditions.

9.3 Performance Terms and Definitions

Tons of refrigeration (TR): One ton of refrigeration is the amount of cooling obtained by one ton of ice melting in one day: 3024 kCal/h, 12,000 Btu/h or 3.516 thermal kW.

Net Refrigerating Capacity. A quantity defined as the mass flow rate of the evaporator water multiplied by the difference in enthalpy of water entering and leaving the cooler, expressed in kCal/h, tons of Refrigeration.

kW/ton rating: Commonly referred to as efficiency, but actually power input to compressor motor divided by tons of cooling produced, or kilowatts per ton (kW/ton). Lower kW/ton indicates higher efficiency.

Coefficient of Performance (COP): Chiller efficiency measured in Btu output (cooling) divided by Btu input (electric power).

Energy Efficiency Ratio (EER): Performance of smaller chillers and rooftop units is frequently measured in EER rather than kW/ton. EER is calculated by dividing a chiller's cooling capacity (in Btu/h) by its power input (in watts) at full-load conditions. The higher the EER, the more efficient the unit.

9.4 Preparatory for Measurements

After establishing that steady-state conditions, three sets of data shall be taken, at a minimum of five-minute intervals. To minimize the effects of transient conditions, test readings should be taken as nearly simultaneously.

9.5 Procedure

9.5.1 To determine the net refrigeration capacity

The test shall include a measurement of the net heat removed from the water as it passes through the evaporator by determination of the following:

a. Water flow rate
b. Temperature difference between entering and leaving water

The heat removed from the chilled water is equal to the product of the chilled water flow rate, the water temperature difference, and the specific heat of the water is defined as follows

The net refrigeration capacity in tons shall be obtained by the following equation:

$$\text{Net refrigeration Capacity (TR)} = \frac{m \times c_p \times (t_{in} - t_{out})}{3024}$$

Where
- m – mass flow rate of chilled water, kg/hr
- c_p - Specific heat, kcal/kg °C
- t_{in} – Chilled water temperature at evaporator inlet °C
- t_{out} - Chilled water temperature at evaporator outlet °C

The accurate temperature measurement is very vital in refrigeration and air conditioning and least count should be at least one decimal.

Methods of measuring the flow

In the absence of an on-line flow meter the chilled water flow can be measured by the following methods

- In case where hot well and cold well are available, the flow can be measured from the tank level dip or rise by switching off the secondary pump.
- Non invasive method would require a well calibrated ultrasonic flow meter using which the flow can be measured without disturbing the system
- If the waterside pressure drops are close to the design values, it can be assumed that the water flow of pump is same as the design rated flow.

9.5.2 Measurement of compressor power

The compressor power can be measured by a portable power analyser which would give reading directly in kW.

If not, the ampere has to be measured by the available on-line ammeter or by using a tong tester. The power can then be calculated by assuming a power factor of 0.9

$$\text{Power (kW)} = \sqrt{3} \times V \times I \times \cos\phi$$

9.5.3 Performance calculations

The energy efficiency of a chiller is commonly expressed in one of the three following ratios:

1.Coefficient of performance

$$\textbf{COP} = \frac{\text{kW refrigeration effect}}{\text{kW input}}$$

2. Energy efficiency ratio

$$\textbf{EER} = \frac{\text{Btu/h refrigeration effect}}{\text{Watt input}}$$

3. Power per Ton

$$\textbf{kW/Ton} = \frac{\text{kW input}}{\text{Tons refrigeration effect}}$$

First calculate the kW/ton rating from the measured parameters.

a) $\text{kW/ton rating} = \dfrac{\text{Measured compressor power, kW}}{\text{Net refrigeration Capacity (TR)}}$

Use this data to calculate other energy efficiency parameters with the following relations

COP = 0.293 EER	EER = 3.413 COP
kW/Ton = 12 / EER	EER = 12 / (kW/Ton)
kW/Ton = 3.516 / COP	COP = 3.516 / (kW/Ton)

* Source : American Refrigeration Institute

b) $\text{Coefficient of performance (COP)} = \dfrac{3.516}{\text{kW/ton rating}}$

c) $\text{Energy Efficiency Ratio (EER)} = \dfrac{12}{\text{kW/ton rating}}$

9.5.4 Performance evaluation of air conditioning systems

For centralized air conditioning systems the air flow at the air handling unit (AHU) can be measured with an anemometer. The dry bulb and wet bulb temperatures can be measured at the AHU inlet and outlet. The data can be used along with a psychrometric chart (Figure 9.1) to determine the enthalpy (heat content of air at the AHU inelt and outlet)

$$\textbf{Heat load (TR)} = \frac{m \times (h_{in} - h_{out})}{4.18 \times 3024}$$

m – mass flow rate of air, kg/hr
h_{in} – enthalpy of inlet air at AHU, kJ/kg
h_{out} – enthalpy of outlet air at AHU, kJ/kg

Heat load can also be calculated theoretically by estimating the various heat loads, both sensible and latent, in the air-conditioned room (refer standard air conditioning handbooks). The difference between these two indicates the losses by way of leakages, unwanted loads, heat ingress etc.

9.6 Measurements to be Recorded During the Test

All instruments, including gauges and thermometers shall be calibrated over the range of test readings for the measurement of following parameters.

Evaporator

a. Temperature of water entering evaporator
b. Temperature of water leaving evaporator
c. Chilled water flow rates
d. Evaporator water pressure drop (inlet to outlet)

Compressor

e. Power input to compressor electrical power, kW

9.7 Example

In a brewery chilling system, ethylene glycol is used a secondary refrigerant. The designed capacity is 40 TR. A test was conducted to find out the operating capacity and energy performance ratios. The flow was measured by switching off the secondary pump and measuring the tank level difference in hot well.

Measurements data:

Temperature of ethylene glycol entering evaporator	= (-) 1°C
Temperature of ethylene glycol leaving evaporator	= (-) 4°C
Ethylene glycol flow rates	= 13200 kg/hr
Evaporator ethylene glycol pressure drop (inlet to outlet)	= 0.7 kg/cm^2
Power input to compressor electrical power, kW	= 39.5 kW
Specific heat capacity of ethylene glycol	= 2.34 kCal/kg°C

Calculations

Net refrigeration Capacity (TR) $= \dfrac{m \times c_p \times (t_{in} - t_{out})}{3024}$

$$= \frac{13200 \times 2.34 \times (-1 - (-4))}{3024}$$

= 30.65 TR

kW/ton rating $= \dfrac{\text{Measured compressor power, kW}}{\text{Net refrigeration Capacity (TR)}}$

$$= \frac{39.5 \text{ kW}}{30.65 \text{ TR}}$$

= 1.29 kW/TR

Coefficient of performance (COP) $= \dfrac{3.516}{\text{kW/ton rating}}$

$$= \frac{3.516}{1.29}$$

= **2.73**

Energy Efficiency Ratio (EER) $= \dfrac{12}{\text{kW/ton rating}}$

$$= \frac{12}{1.29}$$

= **9.3**

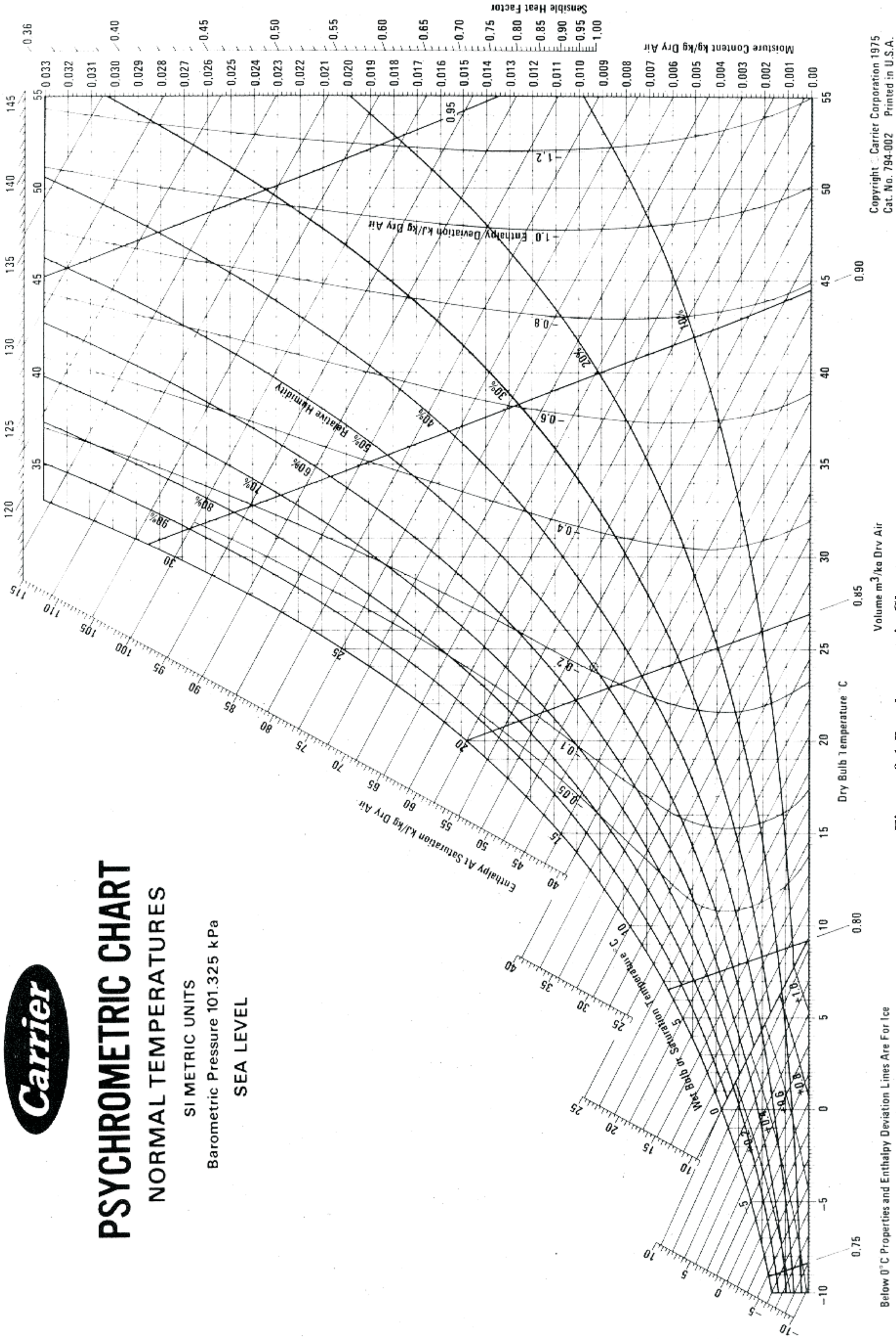

Figure 9.1 Psychrometric Chart

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QUESTIONS

1)	What is meant by a ton of refrigeration?
2)	Define the terms net refrigeration capacity, COP, energy efficiency ratio.
3)	What is the relation between COP and kW/ton of refrigeration?
4)	How would you calculate the heat load for a room to be air-conditioned?
5)	If the power consumed by a refrigerating unit / ton of refrigeration is 2 kW then find energy efficiency ratio?

REFERENCES

1. Refrigeration and Air Conditioning by Richard C.Jordan & Gayle B.Priester - Prentice Hall of India pvt.ltd.
2. Modern Air Conditioning Practice by Norman C.Harris - McGraw-Hill International Edition.