BEE CODE

HVAC-CHILLERS

Prepared for

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CONTENTS

List of figures

List o fables

1 OBJECTIVE & SCOPE

1.1 Objective

1.1.1 The purpose of this BEE Code is to establish rules and guidelines for conducting tests on Chillers at site conditions. This code is simplified to enable calculations and estimations at site conditions with normally available in-line and portable instruments.

1.1.2 The performance of a Chilling Package can be estimated from the *Coefficient of Performance* or *Energy Efficiency Ratio* or *Specific Power Consumption* of the refrigeration system in the *Normal Operating Temperature Range.*

1.2 Scope

1.2.1 This code deals with the Refrigeration Systems of the following types:

- Chilling Packages using Vapour Compression Cycle
- Chilling Packages using Vapour Absorption Cycle

This code does not cover small machines like window air-conditioners and split air-conditioners. It also does not cover ice builders.

1.2.2 The following standards have been reviewed to develop this code:

- IS: 8148 - 1976: Specification for Packaged Air Conditioners
- ARI Standard 550/590 - 1998: Water Chilling Packages using the Vapor Compression Cycle
- ARI Standard 560 - 2000: Method of Testing Absorption Water Chilling and Water Heating Packages
- ANSI/ASHRAE/IESNA Standard 90.1-2001: Energy Standard for Buildings Except Low-Rise Residential Buildings

1.2.3 Testing of a Chiller as defined and described in this code include the following:

- Measurement and estimation of ***Refrigeration Effect*** of the chilling package at the site operating fluid temperature. The fluid may be water, brine, air etc.
- Estimation of ***Shaft Power*** of the compressor or ***Thermal Power Input*** to a Vapour Absorption System at the site operating fluid temperature.
- Estimation of ***Coefficient of Performance*** or ***Energy Efficiency Ratio*** or ***Specific Power Consumption*** of the chilling package at the site operating fluid temperature.

2 DEFINITIONS AND DESCRIPTION OF TERMS

2.1 Basic Units and Symbols

The basic units and symbols used in this code are given in Table-2.1. Subscripts are given in Table - 2.2.

Table 2-1: Basic Units and Symbols

Symbol	**Description**	**Units**
A	Heat Transfer Area	m^2
COP	Coefficient of Performance	pu*
C_p	Specific heat	kJ/kg-K
d	Density	kg/m^3
EER	Energy Efficiency Ratio	Btu/hr-W
GCV	Gross Calorific Value	kcal/kg
h	Enthalpy	kJ/kg
H	Thermal energy input rate	kJ/h
HR	Heat Rejection in Cooling Water	kJ/h
LMTD	Logarithmic Mean Temperature Difference	K
M	Mass flow rate	kg/s
P	Pressure	kPa
Q	Volume rate of flow	m^3/h
R	Net Refrigeration Effect	kJ/h or TR
SPC	Specific Power Consumption	kW/TR
SSC	Specific Steam consumption	kg/h/TR
SFC	Specific fuel consumption	kg/h/TR
T	Temperature, absolute	K
U	Heat Transfer Coefficient	kJ/m^2-s-K
v	Velocity	m/s
W	Shaft Power	kW
η	Efficiency	pu*

* per unit

Table 2-2: Subscripts

Symbol	Description
a	ambient
ab	absorber
air	air
c	compressor shaft
co	condenser
comb	combustion
cond	condensate
db	dry bulb
dis	discharge
ev	evaporator
i	inlet
l	liquid
m	motor
o	outlet
r	rated
sat	saturation
st	steam
t	drive transmission
suc	suction
tur	steam turbine
wb	wet bulb
w	water

2.2 Description of terms

Absorber. The component of the vapour absorption chilling package wherein the refrigerant vapour is absorbed by the liquid absorbent.

Air Handling Unit. An air cooling unit, consisting of a blower or blowers, heat exchanger and filters with refrigerant, chilled water or brine on the tube side to perform one or more of the functions of circulating, cooling, cleaning, humidifying, dehumidifying and mixing of air.

Brine. Solution of anti-freeze substances like Sodium Chloride, Calcium Chloride, Mono-ethylene Glycol, Ethyl Alcohol etc.

Coefficient of Performance. The ratio of *Net Refrigerating Effect* divided by *Compressor Shaft Power* or*Thermal Power Input.* The numerator and denominator should be in the same measuring units.

Compressors. Machines in which compression of refrigerant vapour is effected by the positive action of linear motion of pistons, rotating elements (screws, vanes, scrolls etc.) or conversion of velocity energy to pressure in a centrifugal device.

Compressor, hermetic. Sealed compressor & motor unit, where the electric motor is cooled by the refrigerant and both the compressor and electric motor are not accessible for maintenance.

Compressor, open. Compressor is externally coupled to the prime mover and the refrigerant does not cool the prime mover.

Compressor, semi-hermetic. Compressor motor unit, where the electric motor is cooled by the refrigerant and the compressor is accessible for maintenance.

Condenser. The heat exchanger, which utilizes refrigerant to water/air heat transfer, causing the refrigerant to condense and the water/air to be heated. De-superheating or sub-cooling of the refrigerant may also occur.

Energy Efficiency Ratio. The ratio of *Net Refrigerating Effect (Btu/hr)* divided by *Shaft Power (Watts)* or *Thermal Power Input (Watts)* consumed.

Electric Motor. Electrically operated rotary prime mover.

Enthalpy. The heat content of a substance at a particular temperature.

Engine. Internal combustion engine used as prime mover.

Evaporator. The heat exchanger wherein the refrigerant evaporates and, in the process, cools another fluid I(generally water, brine or air).

Fluid. The substance that is usefully cooled in the chilling package (generally water, brine or air).

Generator. The component of a vapour absorption chilling package wherein the absorbent solution is heated to evaporate the refrigerant and concentrate the absorbent.

Gross Calorific Value. The amount of heat produced per unit of fuel when complete combustion takes place at constant pressure, the products of combustion are cooled to the initial temperature of the fuel and air, and the vapor formed during combustion is condensed.

Net Refrigeration Effect. The useful cooling effect (or heat removal) in the evaporator.

Psychrometric Chart. A chart or plotted curves showing the various parameters of air at different temperatures at atmospheric pressure. The parameters shown include dry bulb temperature, wet bulb temperature, relative humidity, moisture content, enthalpy and sensible heat factor.

Refrigerant. The substance that evaporates in the evaporator to provide cooling effect.

Shaft Power. Power at the shaft of any rotary equipment.

Specific Fuel Consumption. The ratio of *Thermal Power Input (kg/h of liquid fuel or* m^3*/h of gaseous fuel)* consumed to the *Net Refrigerating Effect (Tons of Refrigeration).*

Specific humidity. Mass of water vapour per unit mass of dry air.

Specific Power Consumption. The ratio of *Shaft Power (kW)* to the *Net Refrigerating Effect (Tons of Refrigeration).*

Specific Steam Consumption. The ratio of *Thermal Power Input (kg/h of steam)* to the *Net Refrigerating Effect (Tons of Refrigeration).*

Speed. The number of revolutions per minute of the shaft.

Steam Turbine. Steam driven rotary prime mover.

Temperature, dry bulb. The temperature indicated by any temperature sensing element when held in air.

Temperature, Inlet. Temperature measured at the inlet stream of the heat exchanger.

Temperature, Outlet. Temperature measured at the outlet stream of the heat exchanger.

Temperature, wet bulb: It is the dynamic equilibrium temperature attained by a liquid surface when the rate of heat transfer to the surface by convection equals the rate of mass transfer away from the surface. (It is the equilibrium temperature of a wetted wick in contact with bulb of a thermometer).

Thermal Power Input. The thermal energy input rate to the generator of the absorption chiller.

Ton of Refrigeration. Cooling equivalent to heat extraction rate of 3023 kcal/h or 12000 Btu/h.

Vapour Absorption Chilling Package. A self-contained unit comprising an assembly of evaporator, absorber, condenser, generator(s) and solution heat exchangers, with interconnections and accessories, designed for the purpose of cooling water or brine.

Vapour Compression Chilling Package. A self-contained unit comprising an assembly of evaporator, compressor, condenser and expansion device with interconnections and accessories, designed for the purpose of cooling air, water or brine.

3 GUIDING PRINCIPLES & METHODOLOGY

3.1 Guiding Principles

The *Net Refrigerating Effect* is the useful cooling in the evaporator. Depending on the type of machine, either mechanical power or thermal power input is consumed by the refrigeration machine.

The Specific Power/Fuel/Steam Consumption, COP and EER can be estimated if the Net Refrigeration Effect and the Power/Fuel/Steam Consumption are known.

In some refrigeration machines, direct estimation of refrigeration effect in the evaporator is not possible. In such cases, the refrigeration effect can be estimated indirectly from the condenser cooling load. For *Vapour Compression Chilling Packages,* the *Heat Rejection* in the cooling water or cooling air is the summation of *Net Refrigeration Effect* and the heat equivalent of the *Shaft* Power*.* For *Vapour Absorption Chilling Package,* the *Heat Rejection* in the cooling water or cooling air is the summation of *Net Refrigeration Effect* and *Thermal Power Input minus the Heat Loss in the Stack.* The heat rejected through any other route is assumed to be negligible.

A schematic of a typical chilled water plant, based on vapour compression cycle is given below in fig 3.1.

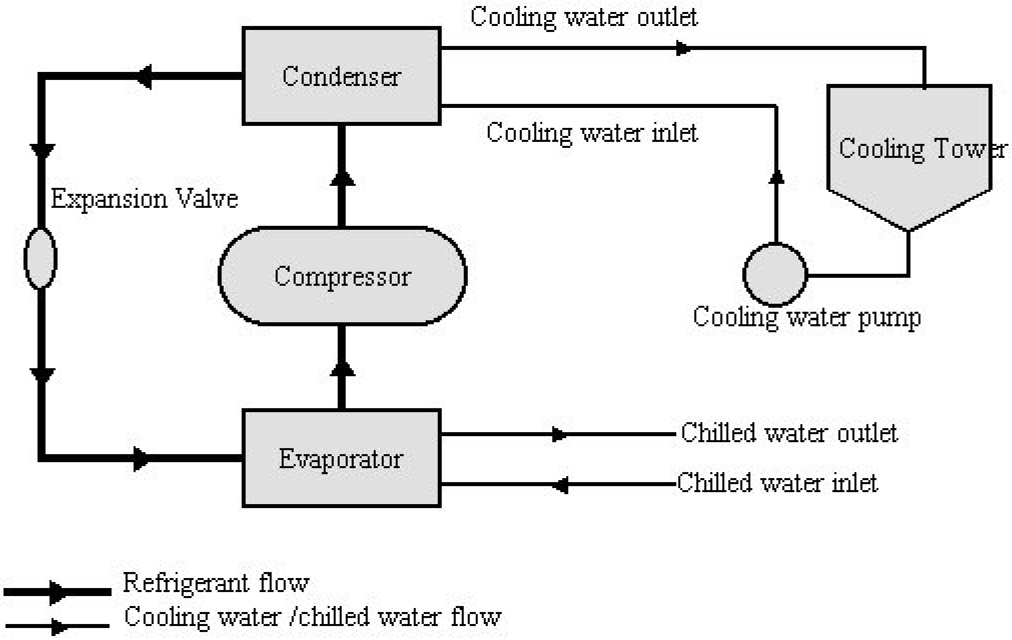


Figure 3-1: Vapour Compression system schematic

The compressor can be driven by an electric motor, an engine or a turbine.

Fig. 3.2 shows schematic of a single effect vapour absorption cycle based refrigeration system having steam as input heat. In place of steam, direct firing and flue gases are also used as input energy stream.

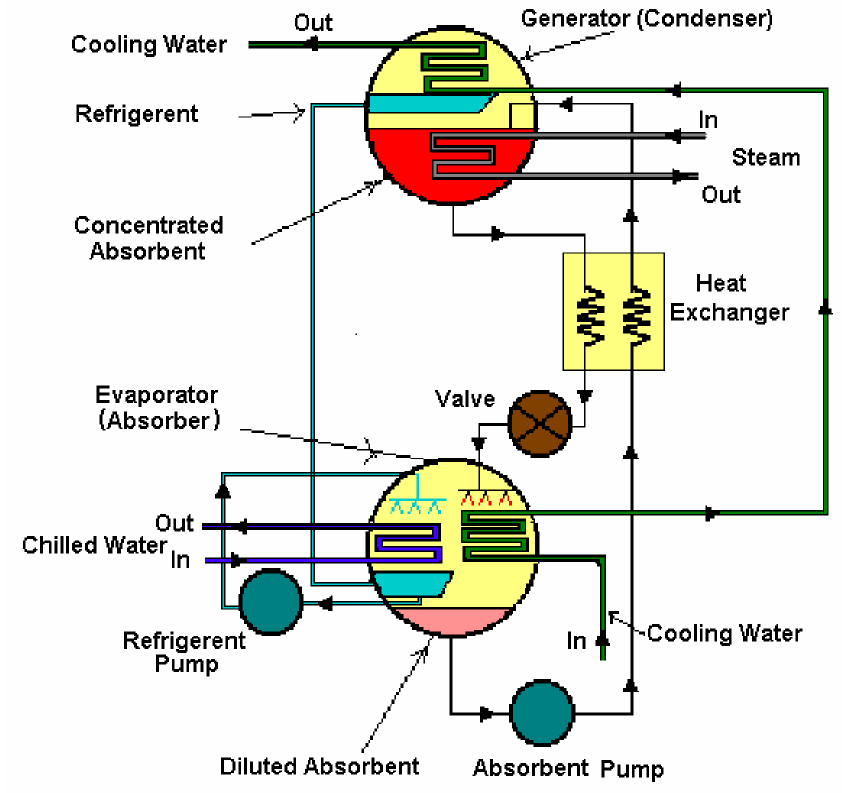


Figure 3-2: Vapour Absorption Cycle-schematic

3.2 Methodology

The proposed methods for estimation of Specific Power/Fuel/Steam Consumption, COP and EER are as follows:

3.2.1 Method 1: Direct Estimation of Net Refrigeration Effect in Evaporator

- This method can be used when the Refrigeration Effect can be estimated from the cooled fluid mass flow rate in the evaporator and the temperatures or enthalpies of the fluid at the inlet and outlet of the evaporator.
- Estimation of Net Refrigeration Effect in the Evaporator.
- Measurement/Estimation of Electrical Power input, Shaft Power input or Thermal Power input to the Refrigeration machine.
- Estimation of Specific Power/Fuel/Steam Consumption, COP and EER.

3.2.2 Method 2: Indirect Estimation of Net Refrigeration Effect in Evaporator by Measurements on Condenser side

- This method can be used when measurement or estimation of cooled fluid flow rate in the evaporator is not possible or inconvenient, but measurement of cooling water or cooling air flow rate in the condenser is possible.
- Estimation of Heat Rejection Rate in the Condenser.
- Measurement/Estimation of Electrical Power input, Shaft Power or Thermal Power input to the Refrigeration machine.
- Estimation of Refrigeration Effect in the Evaporator by the difference of Heat Rejection in the Condenser and the Refrigeration Effect.
- Estimation of Specific Power/Fuel/Steam Consumption, COP and EER.

Based on the above approach and, depending on the site conditions, available instrumentation and type of chilling packages, any of the following methods for measurements and estimations can be selected.

3.3 Comparison of Specific Power Consumption, COP and EER with Design Values for Vapour Compression Packages

For vapour compression packages, manufacturers specify the COP, EER or Specific Power Consumption based on shaft power of open compressors and electrical power input for hermetic and semi-hermetic compressors. Hence it is recommended that, in calculations, Shaft Power be considered for open compressors and Electrical Power input for hermetic or semi-hermetic compressors. This will facilitate comparison of measured values with design values or that expected for efficient chilling packages.

It may be noted for evaluation of the performance of a chilling package, the power consumption of auxiliaries like pumps and blowers are not considered, as the power consumption will vary depending on site specific parameters like static head, piping/ducting lengths etc.

3.4 Estimation of Performance of Water/Brine Chilling Packages from Refrigeration Effect in Evaporator

- Calculation of *Net Refrigeration Effect* as the “multiplication product” of the evaporator liquid (water, brine etc.) mass flow rate, specific heat of the liquid and difference in temperature of liquid entering and leaving the evaporator.

- For electric motor driven compressors of Vapour Compression Chilling Package, calculation of *Compressor Shaft Power* as the “multiplication product” of measured motor input, estimated motor efficiency and drive (usually belt or gear) transmission efficiency.

- For engine driven compressor, measurement of engine fuel consumption and estimation of compressor shaft power.

- For steam turbine driven compressors, calculation of *Turbine Shaft Power* as the “multiplication product” of mass flow of steam and difference of enthalpies of steam and condensate and turbine mechanical efficiency (for more details on the methodology, refer BEE Code on Cogeneration). The *Compressor Shaft Power* can be calculated as the multiplication product of *Turbine Shaft Power* and *Drive* (usually gear) *transmission efficiency.*

- For steam-heated Vapour Absorption Chilling Package, calculation of *Thermal Power Input* to the Vapour Absorption Chilling Package as the “multiplication product” of steam mass flow rate and the difference of enthalpies of steam at inlet and condensate at outlet.

- For direct-fired absorption chilling, calculation of *Thermal Power Input* to Vapour Absorption Chilling Package as the "multiplication product" of fuel mass flow rate and the Gross Calorific Value of the fuel.

- For waste heat based Vapour absorption systems, the thermal power input to generator is estimated from measurement/estimation of flue gas flow, average specific heat of flue gases and temperature drop of flue gas in the generator.

- The calculation of *Coefficient of Performance* as the ratio of the *Net Refrigeration Effect* to the *Compressor Shaft Power* in Vapour Compression Chilling Package or *Thermal Power Input* in Vapour Absorption Chilling Package.

- Calculation of Energy Efficiency Ratio (EER) and Specific Power Consumption (SPC) or Specific Steam Consumption (SSC) or Specific Fuel Consumption (SFCL or SFCG) from the calculated value of COP.

3.5 Estimation of Performance of Water/Brine Chilling Packages & Direct Air Cooling Packages from Heat Rejection in Cooling Water

- Calculation of *Heat Rejection* as the "multiplication product" of cooling water mass flow rate, specific heat of water and the difference in temperature of fluid entering and leaving the system. Please note that in the case of *Vapour compression chilling package*, the cooling water picks up heat from the condenser only, while in the case of *Vapour absorption chilling package*, the cooling water picks up heat from both the absorber and the condenser. In case de-superheater is installed before the condenser for heat recovery, the heat rejected in the de-superheater should also be added separately as the "multiplication product" of de-superheater water mass flow rate, specific heat of water and the difference in temperature of fluid entering and leaving the de-superheater.

- For electric motor driven compressors of Vapour Compression Chilling Package, calculation of *Compressor Shaft Power* as the product of measured motor input, estimated motor efficiency and drive (usually belt or gear) transmission efficiency.

- For engine driven compressor, measurement of engine fuel consumption and estimation of compressor shaft power.

- For steam turbine driven compressors, calculation of *Turbine Shaft Power* as the "multiplication product" of mass flow of steam and difference of enthalpies of steam and condensate and turbine mechanical efficiency (for more details on measurement methodology, refer Code on Cogeneration Systems). The *Compressor Shaft Power* can be calculated as the "multiplication product" of *Turbine Shaft Power* and *Drive (usually gear) transmission efficiency.*

- For steam-heated Vapour Absorption Chilling Package, calculation of *Thermal Power Input* to Vapour Absorption Chilling Package as the "multiplication product" of steam mass flow rate and the difference of enthalpies of steam and condensate.

- For direct-fired absorption chilling package, calculation of *Thermal Power Input* by Vapour Absorption Chilling Package as the "multiplication product" of fuel mass flow rate and the Gross Calorific Value of fuel.

- For waste heat based Vapour absorption systems, the thermal power input to generator is estimated from measurement/estimation of flue gas flow, average specific heat of flue gases and temperature drop of flue gas in the generator.

- Calculation of *Refrigeration Effect* by subtracting the heat equivalent of *Compressor Shaft Power* or *Thermal Power Input* from the *Heat Rejection* value.

- The calculation of *Coefficient of Performance* by dividing the *Net Refrigeration Effect* of the Evaporator by the *Compressor Shaft Power* in vapour compression chilling package or *Thermal Power Input* in vapour absorption chilling package.

- The Calculation of Energy Efficiency Ratio (EER) and Specific Power Consumption (SPC) or Specific Steam Consumption (SSC) or Specific Fuel Consumption (SFCL or SFCG) from the calculated value of COP.

Note:

1. This method is especially recommended for chillers where measurements on evaporator side are practically difficult or sub-cooling of refrigerant is being done by refrigerant from the same system.

2. This method is not applicable to evaporative condensers and atmospheric condensers, where the heat picked by the evaporating water cannot be accounted. As drift water loss may also be significant, make-up water cannot be assumed as the evaporation loss.

3.6 Estimation of Performance of Direct Air Cooling Packages from Refrigeration Effect in Evaporator

- The calculation of *Net Refrigeration Effect* as the “multiplication product” of evaporator air mass flow rate and the difference in enthalpy of air entering and leaving the evaporator.

- For electric motor driven compressors of Vapour Compression Chilling Package, calculation of *Compressor Shaft Power* as the “multiplication product” of measured motor input, estimated motor efficiency and drive (usually belt or gear) transmission efficiency.

- For engine driven compressor, measurement of engine fuel consumption and estimation of compressor shaft power.

- For steam turbine driven compressors, calculation of *Turbine Shaft Power* as the multiplication product of mass flow of steam and difference of enthalpies of steam and condensate and turbine mechanical efficiency (for more details on measurement methodology, refer BEE Code on Cogeneration). The *Compressor Shaft Power* can be calculated as the “multiplication product” of *Turbine Shaft Power* and *Drive transmission (usually gear) efficiency.*

- The calculation of *Coefficient of Performance* by dividing the *Net Refrigeration Effect* of the Evaporator by the *Compressor Shaft Power* in vapour compression chilling package.

- Calculation of Energy Efficiency Ratio (EER) and Specific Power Consumption (SPC) from the calculated value of COP.

Note: This method is not applicable to Vapour Absorption Chilling Packages, which are generally not designed for direct cooling of air.

3.7 Estimation of COP of Water/Brine Chilling Packages & Direct Air Cooling Packages from Heat Rejection in Air Cooled Condensers

- Calculation of *Heat Rejection* as the “multiplication product” of condenser cooling air mass flow rate with the difference in enthalpies of air entering and leaving the system. In case de-superheater is installed for heat recovery, the heat rejected in the de-superheater should also be added separately as the “multiplication product” of de-superheater water mass flow rate, specific heat of water and the difference in temperature of fluid entering and leaving the de-superheater.

- For electric motor driven compressors of Vapour Compression Chilling Package, calculation of *Compressor Shaft Power* as the “multiplication product” of *measured motor input*, *estimated motor efficiency* and *drive (usually belt or gear) transmission efficiency*.

- For engine driven compressor, measurement of engine fuel consumption and estimation of compressor shaft power.

- For steam turbine driven compressors, calculation of *Turbine Shaft Power* as the “multiplication product” of mass flow of steam and difference of enthalpies of steam and condensate and turbine mechanical efficiency (for more details on measurement methodology, refer BEE Code on Cogeneration). The *Compressor Shaft Power* can be calculated as the “multiplication product” of *Turbine Shaft Power* and *Drive (usually gear) transmission efficiency.*

- Calculation of *Refrigeration Effect* by subtracting the heat equivalent of *Compressor Shaft Power* or *Thermal Power Input* from the *Heat Rejection* value.

- The calculation of *Coefficient of Performance* as the ratio the *Net Refrigeration Effect* of the Evaporator by the *Compressor Shaft Power* in vapour compression chilling package.

- Calculation of Energy Efficiency Ratio (EER) and Specific Power Consumption (SPC) from the calculated value of COP.

Note: This method is not applicable to Vapour Absorption Chilling Packages as, in India, these machines are generally not designed with air-cooled absorbers/condensers due to high summer air temperatures.

3.8 Pre-test Requirements

1. Specifications of the machine should be written down from the name plate or technical literature.
2. While conducting the tests at site, a qualified person, who is familiar with the installation, should be present to ensure safe conduct of the trial.
3. Ensure that the thermo-wells (for temperature measurements) are clean and filled with suitable fluid, a few hours before the test.
4. Ensure that the chilling package is in operation for sufficient time to achieve steady state temperature and flow rate conditions, close to normal operating temperatures, before beginning measurements. Care should be taken to ensure that the temperature or enthalpy difference across the chiller is nearly constant during the test. The refrigeration load should be reasonably steady to ensure that unloading of some cylinders or loading of some cylinders of reciprocating machines or operation of sliding valve of screw compressors or operation of inlet guide vanes of centrifugal compressors do not take place during the test. Any variable speed drives in the system for compressors or pumps should be bypassed during the test or should be programmed to operate the compressor and/or pump and/or fan at a constant speed during the test.
5. It may be noted that testing of the chiller at partial refrigeration load is permitted but the load should be steady during the test.
6. Access to the electrical power panel should be ensured to enable simultaneous measurement of electrical parameters along with the temperature differential across the chiller. It is advisable to keep the portable power analyzer connected through the duration of the test.
7. In the case of fuel-fired machines, calibrated in-line flow meters or calibrated fuel day tanks should be available for fuel flow measurement.
8. For steam turbine driven equipment, calibrated in-line steam flow meter should be available for steam flow measurement.
9. For steam heated absorption chilling packages, calibrated in-line steam flow meter or arrangement for collecting steam condensate in a calibrated container should be available for steam flow measurement.
10. For liquid flow measurements, use of in-line calibrated flow meters is recommended. In the absence of in-line meters, transit type ultrasonic flow meters may be used.

11. It is desirable that performance characteristics of associated pumps are available (from test certificates or family performance curves for the particular pump model) for a quick check of estimated water flow rate, especially when the flow rate is estimated from the velocity measurement by ultrasonic flow meters.
12. Psychrometric chart should be available where air is the media.

3.9 Precautions during Test

1. Request the machine operator to ensure that all necessary installed instruments and safety trips are operational.
2. Use appropriate safety precautions while taking measurements on live cables with portable instruments.
3. Make sure the clamp-on jaws of current transformers are completely closed. The jaws do not always close tightly, especially in situations with number of cables in close proximity. Even a small gap in the jaws can create a large error. To ensure the jaws are fully closed, move the probe slightly, making sure it moves freely and without pressure from adjacent cables or other obstructions.
4. Some of the anti-freeze agents used for brine solutions may be corrosive and irritable for the skin, eyes etc. hence due care should be exercised.
5. Maintain a safe distance from live electrical equipment and rotating mechanical equipment during measurements. Ensure that at least two persons are present at the time of measurements.
6. Use safe access routes or safe ladders to access measurement points located at a height. (Unsafe practices like stepping on working or idle motors, compressors, belt guards, valves should be avoided).
7. Be sure of the location of the “emergency stop” switch of the machine before start of any test.
8. Tappings from pipe lines for pressure and flow measurements should be flushed before measurements as these may be choked due to liquid stagnation.

4 INSTRUMENTS AND METHODS OF MEASUREMENTS

4.1 Recommended Measurements for Chilling Packages

Measurement/estimation of the following parameters should be done for the Chilling Package to estimate its performance.

4.1.1 Vapour Compression Chilling Package

a) Measurement of fluid (water, brine, air etc.) flow rate in evaporator.
b) Measurement of cooling air or cooling water flow rate, as applicable, in the condenser.
c) When the fluid being cooled is liquid, measurement of liquid temperature at the inlet and outlet of the evaporator.
d) When the fluid being cooled is air, measurement of dry bulb temperature and wet bulb temperatures of air at the inlet and outlet of the evaporator (normally called air handling unit).
e) For water-cooled condensers, water temperature at the inlet and outlet of the condenser.
f) For air-cooled condensers, dry bulb and wet bulb temperatures of the air at inlet and outlet of the condenser.
g) Estimation of shaft power of compressor from electrical power input to the motor or engine fuel consumption rate or turbine steam flow rate.

4.1.2 Vapour Absorption Chilling Package

a) Measurement of fluid (water, brine, air etc.) flow rate in the evaporator.
b) Measurement of cooling water flow rate, as applicable, in the condenser.
c) Measurement of cooled fluid temperature at the inlet and outlet of the evaporator.
d) For water-cooled condensers, measurement of water temperature at the inlet and outlet of the condenser.
e) Measurement of steam mass flow rate for steam heated package.
f) Measurement of fuel flow rate for direct-fired package.

4.2 Temperature Measurements

Temperature measurements include the following:

1. Liquid temperature measurements at the inlet and outlet of the evaporator.
2. Air dry bulb and wet bulb measurements at the inlet and outlet of the evaporator.
3. Water temperature measurements at the cooling water inlet and outlet and de-super heater water inlet and outlet, where applicable.
4. Air dry bulb and wet bulb measurements at the inlet and outlet of the condenser.

4.2.1 Temperature Measuring Instruments

The inlet and outlet fluid temperatures may be measured with any of the following instruments:

a) Calibrated mercury in glass thermometer (bulb diameter not greater than 6.5 mm).
b) Calibrated thermocouple with calibrated indicator.
c) Calibrated electric resistance thermometer.

The measuring instruments should be duly calibrated. The least count for temperature indicating instruments should be 0.1°C.

Measurement Techniques

1. Use thermo-wells made of thin steel or brass tube welded or brazed to a hole pierced in the piping before and after the heat exchanger. The wells should be partly filled with a suitable fluid of sufficient quantity to cover the thermometer bulb. The thermo-well should extend into the pipe a distance of 100 mm or 1/3rd of the pipe diameter whichever is less.
2. The measuring instruments used to measure temperature should be arranged so that they can be readily interchanged between inlet and outlet positions to improve accuracy. Under steady state conditions, to reduce error, the same temperature sensor and indicator may be used to measure the inlet and outlet temperature. At least three sequential measurements should be taken to ensure that the chiller is in steady state.
3. In the absence of thermo-wells, direct temperature measurement can be attempted by leaking water or brine from the nipples with valves, if available (usually these are available for installation of pressure gauges). Care has to be taken to ensure that the nipple length is small and the leakage flow is large enough to reduce the error, due to temperature pick-up as the leaked fluid flows through the un-insulated nipple, to a negligible value. Measurement of temperature can be done by collecting the liquid in a small container and allowing the liquid to continuously overflow from the container by opening the valve sufficiently. However, the fluid should be leaked only for a few minutes to facilitate temperature measurement and not continuously. The quantity of fluid being leaked out should be negligibly small compared to the flow through the evaporator.

4.3 Liquid Flow Measurement

Liquid flow measurements include the following:

a. Liquid (water or brine) flow in the evaporator.
b. Water flow in water-cooled condenser.

4.3.1 Liquid Flow Rate Measuring Instruments / Methods

Liquid flow may be measured with any of the following instruments/methods:

a) Calibrated in-line liquid flow rate meter. (In the case of differential pressure based flow measuring devices like orifices, venturis, annubars etc., flushing of the impulse lines is recommended to ensure that there is no choking).
b) Volumetric measurements based on liquid levels from a calibrated tank.
c) Velocity measurement using Transit Time Ultrasonic flow meter. Measurement of pipe internal diameter using ultrasonic thickness guage or estimation of the same using standard tables for the particular class of pipe. Estimation of flow area from the pipe internal diameter. Estimation of the flow as the “multiplication product” of the velocity and flow area. In the case of ultrasonic flow meters, care may be taken to ensure that the error is less than 5%. (Use of Ultrasonic Meter requires a dry pipe surface, hence chilled water/brine pipe lines, thermal insulation has to be removed and pipe surface has to smoothened and wiped dry, followed by quick fixing of the sensor probes).
d) Estimation of pump flow from discharge pressure, electrical power measurements, estimation of pump shaft power and co-relation with performance curves from test certificate or performance characteristics for the particular pump model. This method is valid only if one pump or a group of pumps are connected to a single chilling package. The error in flow estimation by this method can be 5 to 10% or even higher, especially when general pump model type performance characteristics are used to estimate the flow. This method is not recommended unless the use of inline or portable flow measuring instruments is ruled out due to site constraints.

4.4 Flow Rate Measuring Instruments / Methods

flow measurements include the following:

1. Air flow in the Air Handling Unit.
2. Air flow in air-cooled condenser.
3. Flue gas flow measurement for waste heat based vapour absorption machine

4.4.1 Gas Velocity Measuring Instruments

Air flow may be measured with any of the following instruments:

a) Vane Anemometer
b) Hot wire anemometer
c) Pitot tube

The measuring instruments should be duly calibrated. The least count for anemometers should be 0.1 m/s.

Air flow rate is calculated as the multiplication product of the average air velocity in the plane of measurement and the flow area. The measurements include the following:

1. Air velocity measurement at the Air Handling Unit or air-cooled condenser at a convenient plane perpendicular to flow.
2. A temporary ducting of suitable length may have to be provided in cases where there is no installed ducting.
3. Measurement of the dimensions of the plane of flow measurements by calibrated measuring tape.

The points for measurement of air flow should be selected as per the Log-Tchebycheff method.

4.4.2 Measurement Points for Rectangular Ducts (Log Tchebycheff Method)

Refer figure 4.1. The intersection points of vertical and horizontal line are the points were air flow measurement is required. For width H and height V, the location of measurement points are indicated in the figure. Air flow is obtained by multiplying average velocity measured at all points with the duct cross sectional area.

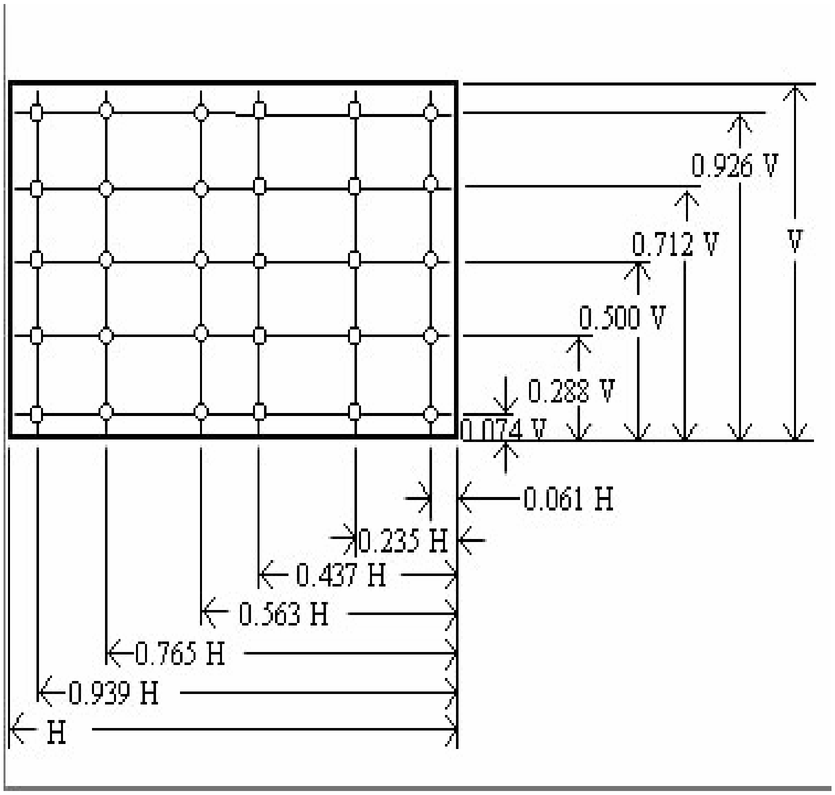


Figure 4-1: Air flow measurement points

Table 4-1: Location of Measurement Points

No. of traverse lines		
5 (for H<30”)	**6 (for 36”>H>30”**	**7 for H>36”**
0.074	0.061	0.053
0.288	0.235	0.203
0.5	0.437	0.366
0.712	0.563	0.5
0.926	0.765	0.634
	0.939	9.797
		0.947

4.4.3 Measurement Points for Circular Ducts (Log Tchebycheff Method)

The duct is divided into concentric circles, applying multiplying factors to the diameter. An equal number of readings is taken from each circular area, thus obtaining the best average. Air flow is obtained by multiplying average velocity measured at all points with the duct cross area.

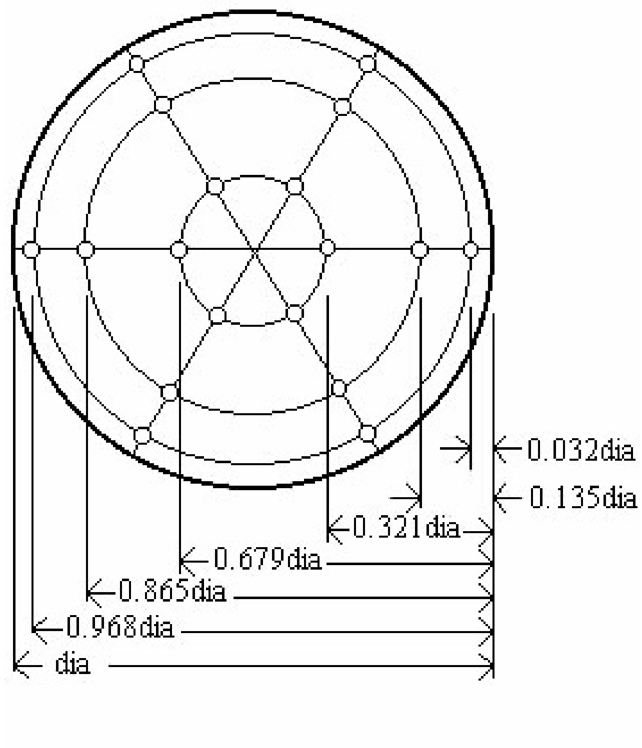


Figure 4-2: *Airflow measurement points*

4.5 **Electrical and Mechanical Power Consumption**

4.5.1 For Electric Motor driven compressors, shaft power of the compressor shall be estimated as the "multiplication product" of motor input power, motor operating efficiency and drive transmission efficiency. Motor efficiency should be estimated by any of the following methods.

a. From the manufacturers' test certificates.

b. From motor performance data from catalogues of manufacturers.

c. From motor efficiency test at actual load, as per the BEE draft code for electric motors.

4.5.2 The following data for Drive Transmission Efficiency can be used, in the absence of other reliable information.

Table 4-2: Drive transmission losses

Power transmission by	Efficiency
Properly lubricated precision gear drive	98% for each step
Synthetic Flat belt drive	97%
V- belt drive	95%

4.5.3 Electrical measurements at the compressor motor input shall be done by any of the following methods

a. Calibrated Power meter or Energy meter. In case of Energy measurement for a defined time period, the time period should be measured with a digital chronometer (stop-watch) with least count of 1/100 second.

b. Calibrated Wattmeter method, following the two Wattmeter method.

d. Multiplication product of v3, Voltage, Current and Power Factor for 3-phase electric motors.

4.5.4 For Engine driven compressors, shaft power of the engine shall be estimated by the co-relation of fuel consumption with the engine shaft load as per available performance test data from engine manufacturer.

4.5.5 For compressors driven by condensing steam turbines.

4.6 Thermal Power Consumption

4.6.1 For steam heated vapour absorption chilling package, the thermal power consumption may be measured with any of the following instruments:

a) Calibrated in-line steam flow meter.
b) Collection of condensate in calibrated volume (container) for a defined time period. The time period should be measured with a digital chronometer (stop-watch) with least count of 1/100 second. The condensate may be cooled to reduce the flash steam losses.

4.6.2 For fuel fired vapour absorption systems, the thermal power may be measured with any of the following instruments:

a) Calibrated In-line fuel flow meter.
a) Fuel level difference for a defined time period in a calibrated day tank. The time period should be measured with a digital chronometer (stop-watch) with least count of 1/100 second.

4.7 Recommended Accuracies for Measuring Instruments

The recommended accuracies for each of the above instruments and measurements is given below. For calibrating various instruments, visit www.nabl-india.org for a detailed list of accredited laboratories. Calibration interval suggested for instruments is 6 months.

Table 4-3: Summary of Instrument Accuracies

Instrument and range	**Accuracy**
Mass, in kg	1 g (0.001 kg)
Mass, in g	1 mg (0.001g)
Fluid Flow, kg/hr or m^3/hr	2%
Steam flow	3%
Temperature	1%. (Precision of 0.1 C)
Humidity	0.5%
Airflow	1.0%

5 COMPUTATION OF RESULTS

5.1 Planning of the Test

1. A chiller may operate under variable load condition in field conditions. For Vapor Compression Chilling Package, ensure that refrigerant is correctly charged and the operation is under steady temperature conditions (in the evaporator and condenser) through out the test period.
2. For a Vapour Absorption Chilling Package, ensure the operation is under steady temperature conditions (in the evaporator, condenser and generator) throughout the duration of the test.
3. COP at any actual operating load can be estimated by the methods described in this code. However, make sure that steady constant load conditions are maintained constant throughout the test period. Cyclic load variations during the test should be avoided.
4. The calibration charts of all measuring instruments should be available.
5. If thermo-wells are provided in the system, make sure that they are properly cleaned and suitable fluid is filled in at least 2 hours before test.

5.2 Estimation of Performance of Water/Brine Chilling Packages from Refrigeration Effect in Evaporator

The Performance Evaluation involves the following steps:

1. Measure liquid (water, brine) flow rate, Q_l, in the evaporator under steady conditions.
2. Measure of fluid temperature at evaporator inlet, T_{ei}, and fluid temperature at evaporator outlet, T_{eo}, under steady load conditions.
3. For motor driven package using vapour compression cycle, simultaneous estimation of compressor shaft power, W_c, under steady conditions, as the "multiplication product" of measured motor input power, $W_{m\text{-}i}$, motor efficiency, η_m, and drive transmission efficiency, η_t. For hermetic and semi-hermetic compressors, the motor input power can be used without accounting for motor and transmission losses.
4. For engine driven vapour compression chilling package, measure engine fuel consumption rate, M_f. Total energy input, W_c is calculated by multiplying engine fuel consumption with calorific value of the fuel when estimating COP on the basis of input energy to engine.
5. While estimating COP on the basis of compressor shaft power, calculation of *Engine Shaft Power* from the engine fuel consumption and co-relation with the engine performance test data, available from the manufacturer is required. The *Compressor Shaft Power* can be calculated as the "multiplication product" of *Engine Shaft Power* and *Drive* (usually belt) *transmission efficiency.*
6. For steam turbine driven chilling package, measure steam consumption rate, M_{st}. The steam turbine shaft power, W_{tur}, is estimated using the method elaborated in the Performance Testing Code for Cogeneration. The compressor shaft power, W_c, is estimated as the "multiplication product" of W_{tur} and transmission efficiency, η_t.
7. For package using vapour absorption cycle, simultaneous measurement of Thermal Energy Input Rate by measurement of steam mass flow rate, M_{st} (for steam fired package), or fuel mass consumption rate, M_f (for fuel fired package).

$$\text{COP} = \frac{Q_l \times d \times C_p \times (t_{ei} - T_{eo})}{3600 \times W_c}$$

For Vapour Compression Chilling Packages with electric motor driven compressors,

$$W_c = W_{mi} \times \eta_m \times \eta_t$$

For Vapour Compression Chilling Packages with engine driven compressors,

$$W_c = W_e \times \eta_t$$

For Vapour Compression Chilling Packages with steam turbine driven compressors,

$$W_c = W_{tur} \times \eta_t$$

For Steam Fired Vapour Absorption Chilling Packages,

$$W_c = \frac{M_{st} \times (h_{st} - h_{cond})}{3600}$$

For Direct Fired Packages using Vapour Absorption Cycle,

$$W_c = \frac{M_f \times GCV}{3600}$$

Where:

Q_l = Fluid flow in evaporator, m^3/h
d_l = Density of cooled liquid, kg/m^3
C_p = Specific heat of fluid, kJ/kg-K
T_{ei} = Fluid temperature at evaporator inlet, K
T_{eo} = Fluid temperature at evaporator outlet, K
W_{m-i} = Motor input Power, kW
W_e = Engine Shaft Power, kW
W_{tur} = Steam Turbine Shaft Power, kW
W_c = Compressor Shaft Power or Thermal Power Input, kW
η_m = Motor efficiency, pu
η_t = Drive transmission efficiency, pu
M_{st} = Steam consumption rate, kg/h
h_{st} = Enthalpy of steam at operating pressure, kJ/kg
h_{cond} = Enthalpy of condensate, kJ/kg
M_f = Fuel consumption rate, kg/h
GCV = Gross Calorific Value of fuel, kJ/kg

The above calculations are summarized in table 5.1 below in MS Excel programmable worksheet. The calculations are given for a motor driven compressor chilling plant.

Table 5-5-1: Measurements are calculations

	A	B	C	D
1	**Parameter**	**Value or Formula in column D**	**Unit**	**Value**
2	Test run number			
3	Date			
4	Duration of run	As measured	minutes	
5	Compressor Speed	As measured	rpm	
6	Compressor suction pressure	As measured	kPa	
7	Compressor discharge pressure	As measured	kPa	
8	Ambient dry bulb temperature	As measured	°C	
9	Ambient wet bulb temperature	As measured	°C	
10	Evaporator Liquid flow, Q_l	As measured	m^3/h	
11	Liquid density, d_l	From literature	kg/ m^3	
12	Specific heat of liquid, C_{p-l}	From literaure	kJ/kg/K	
13	Liquid temperature at evaporator inlet, T_{e-i}	As measured	°C	
14	Liquid temperature at evaporator outlet, T_{e-o}	As measured	°C	
15	Cooling water inlet temperature, T_{c-i}	As measured	°C	
16	Cooling water outlet temperature, T_{c-o}	As measured	°C	
17	Refrigeration Effect, R	D10 * D11 * D12 * (D14 - D13)	kJ/h	
18	Refrigeration Effect, R	D17 / (3600 * 3.51)	TR	

	A	B	C	D
	Parameter	**Value or Formula in column D**	**Unit**	**Value**
19	Power input to motor, W_m	As measured	kW	
20	Likely motor efficiency, η_m	From literature	pu	
21	Likely drive transmission efficiency, η_t	From literature	pu	
22	Estimated Compressor shaft power, W_c	D19 * D20 * D21	kW	
23	**For Open Compressor**			
24	Coefficient of Performance, COP	D17 / (D22 * 3600)	pu	
25	Energy Efficiency Ratio, EER	D24 * 3.418	Btu/h-W	
26	Specific power consumption, SPC	3.51 / D24	kW/TR	
27	**For Hermetic & Semi-hermetic Compressor**			
28	Coefficient of Performance, COP	D17 / (D19 * 3600)	pu	
29	Energy Efficiency Ratio, EER	D28 * 3.418	Btu/h-W	
30	Specific power consumption, SPC	3.51 / D28	kW/TR	

5.3 Estimation of Performance of Direct Air Cooling Packages from Refrigeration Effect in Evaporator

Direct Air Cooling machines packages are generally vapour compression machines; vapour absorption cooling is not used.

The Performance Evaluation involves the following steps:

1. Measurement of air flow rate, Q_{air}, in the evaporator under steady load conditions.
2. Measurement of dry bulb temperature, T_{db}, and wet bulb temperature, T_{wb}, of air at evaporator inlet and outlet, under steady conditions. Estimation of enthalpy of air, h_{air}, at evaporator inlet and outlet, using T_{db} , T_{wb} and psychrometric chart. The density of air is to be taken as average of densities at inlet and outlet. For a given T_{db} & T_{wb}, specific volume of air can be obtained from psychrometric chart. The density is reciprocal of specific volume. The psychrometric chart is shown in Annexure-3.
3. For motor driven package using vapour compression cycle, simultaneous estimation of compressor shaft power, W_c, under steady conditions, as the multiplication product of measured motor input power, W_{m-i}, motor efficiency, η_m, and drive transmission efficiency, η_t. For hermetic and semi-hermetic compressors, the motor input power can be used without accounting for motor and transmission losses.
4. For engine driven vapour compression chilling package, measure engine fuel consumption rate, M_f. Total energy input, W_c is calculated by multiplying engine fuel consumption with calorific value of the fuel when estimating COP on the basis of input energy to engine.

   While estimating COP on the basis of compressor shaft power, calculation of Engine Shaft Power from the engine fuel consumption and co-relation with the engine performance test data, available from the manufacturer is required. The Compressor Shaft Power can be calculated as the "multiplication product" of Engine Shaft Power and Drive (usually belt) transmission efficiency
5. For steam turbine driven chilling package, measure steam consumption rate, M_{st}. The steam turbine shaft power, W_{tur}, is estimated using the method elaborated in the Performance Testing Code for Cogeneration. The compressor shaft power, W_c, is estimated as the multiplication product of W_{tur} and transmission efficiency, η_t.

$$\text{COP} = \frac{Q_{air} \times d_{air} \times (h_{airi} - h_{airo})}{3600 \times W_c}$$

For electric motor driven compressors, $W_c = W_{mi} \times \eta_m \times \eta_t$

For engine driven compressors, $W_c = W_e \times \eta_t$

Where:

Q_{air} = Air flow in evaporator, m^3/h
d_{air} = Density of air, kg/m^3
h_{airi} = Enthalpy of air at evaporator inlet, kJ/kg
h_{airo} = Enthalpy of air at evaporator outlet, kJ/kg
W_{mi} = Motor input Power, kW
W_e = Engine Shaft Power, kW
W_{tur} = Steam Turbine Shaft Power, kW
W_c = Compressor Shaft Power
η_m = Motor efficiency, pu
η_t = Drive transmission efficiency, pu

The above calculations are summarized in table 5.2 below in MS Excel programmable worksheet. The calculations are given for a motor driven compressor chilling plant.

Table 5-2: Measurements are calculations

	A	B	C	D
1	**Parameter**	**Formula**	**Unit**	**Value**
2	Test run number			
3	Date			
4	Duration of run		minutes	
5	Compressor Speed	As measured	rpm	
6	Compressor suction pressure	As measured	kPa	
7	Compressor discharge pressure	As measured	kPa	
8	Ambient dry bulb temperature	As measured	℃	
9	Ambient wet bulb temperature	As measured	℃	
10	Air flow, Q_{air}	As measured	m^3/h	
11	Air density, d_{air}	From psychrometric chart	kg/ m^3	
12	Air dry bulb temperature at evaporator inlet, $T_{air-db-i}$	As measured	℃	
13	Air wet bulb temperature at evaporator inlet, $T_{air-db-o}$	As measured	℃	
14	Enthalpy of air at evaporator inlet, h_{air-I}	From psychrometric chart	kJ/kg	
15	Air dry bulb temperature at evaporator outlet, $T_{air-db-o}$	As measured	℃	
16	Air wet bulb temperature at evaporator inlet, $T_{air-wb-o}$	As measured	℃	
17	Enthalpy of air at evaporator inlet, h_{air-o}	From psychrometric chart	kJ/kg	
18	Cooling water inlet temperature, T_{c-I}	As measured	℃	
19	Cooling water outlet temperature, T_{c-o}	As measured	℃	
20	Refrigeration Effect, R	D10 * D11 * (D17 – D14)	kJ/h	
21	Refrigeration Effect, R	D20 / (3.51 * 3600)	TR	
22	Power input to motor, W_m	As measured	kW	
23	Likely motor efficiency, η_m	From literature	pu	
24	Likely drive transmission efficiency, η_t	From literature	pu	
25	Estimated Compressor shaft power, W_c	D22 * D23 * D24	kW	
26	Coefficient of Performance, COP	D20 / (D25 * 3600)	pu	
27	Energy Efficiency Ratio, EER	D26 * 3.418	Btu/h-W	
28	Specific power consumption, SPC	3.51 / D26	kW/TR	

5.4 Estimation of Performance of Water/Brine Chilling Packages & Direct Air Cooling Packages from Heat Rejection in Water Cooled Condensers

The Performance Evaluation involves the following steps:

1. Measure fluid flow, Q_{co}, in the condenser cooling fluid (water or air) under steady conditions.
2. In the case of Vapour Compression Chilling Package, measurement of condenser cooling fluid temperature at condenser inlet, T_{coi}, and fluid temperature at condenser cooling outlet, T_{coo}, under steady conditions.
3. In the case of Vapour Absorption Chilling Package, measurement of condenser cooling fluid temperature at absorber inlet, T_{abi}, and fluid temperature at condenser cooling outlet, T_{coo}, under steady conditions.

4. For Vapour Compression Chilling Package, measure compressor motor input power, W_{mi}, under steady conditions.

   For motor driven package using vapour compression cycle, simultaneous estimation of compressor shaft power, W_c, under steady conditions, as the multiplication product of measured motor input power, W_{m-i}, motor efficiency, η_m, and drive transmission efficiency, η_t. For hermetic and semi-hermetic compressors, the motor input power can be used without accounting for motor and transmission losses.

5. For engine driven vapour compression chilling package, measure engine fuel consumption rate, M_f. Total energy input, W_c is calculated by multiplying engine fuel consumption with calorific value of the fuel when estimating COP on the basis of input energy to engine.

6. While estimating COP on the basis of compressor shaft power, calculation of *Engine Shaft Power* from the engine fuel consumption and co-relation with the engine performance test data, available from the manufacturer is required. The *Compressor Shaft Power* can be calculated as the "multiplication product" of *Engine Shaft Power* and *Drive* (usually belt) *transmission efficiency.*

7. For steam turbine driven chilling package, measure steam consumption rate, M_{st}. The steam turbine shaft power, W_{tur}, is estimated using the method elaborated in the *BEE Code for Cogeneration*. The compressor shaft power, W_c, is estimated as the multiplication product of W_{tur} and transmission efficiency, η_t.

8. For Vapour Absorption Chilling Package, simultaneous measurement of steam condensate (for steam fired package) or fuel consumption (for fuel fired package).

9. Estimation of combustion efficiency, η_{comb}, for direct fired Vapour Absorption Chilling Package. η_{comb} can be estimated by flue gas analysis and using methodology shown in annexure 2.

$$\text{COP} = \frac{Q_{co} \times d_w \times C_{pw} \times (t_{coo} - T_{coi})}{3600 \times W_c} - 1$$

For Vapour Compression Chilling Packages with electric motor driven compressors,

$$W_c = W_{mi} \times \eta_m \times \eta_t$$

For Vapour Compression Chilling Packages with engine driven compressors,

$$W_c = W_e \times \eta_t$$

For Vapour Compression Chilling Packages with steam turbine driven compressors,

$$W_c = W_{tur} \times \eta_t$$

For Steam Fired Vapour Absorption Chilling Packages,

$$W_c = \frac{M_{st} \times (h_{st} - h_{cond})}{3600}$$

For Fuel Fired Packages using Vapour Absorption Cycle,

$$\text{COP} = \frac{Q_{co} \times d_w \times C_{pw} \times (t_{coo} - T_{abi})}{3600 \times W_c} - \eta_{comb}$$

$$W_c = \frac{M_f \text{ x GCV}}{3600}$$

Where:

Q_{co} = Fluid flow in condenser, m^3/h
d_w = Density of water, kg/m^3
C_{p-w} = Specific heat of water, kJ/kg-K

T_{ab-i} = Fluid temperature at absorber inlet, K for Vapour Absorption Chiller and fluid temperature at condenser inlet for Vapour Compression Chiller
T_{co-o} = Fluid temperature at condenser outlet, K
W_c = Compressor Shaft Power, kW
W_e = Engine Shaft Power, kW
W_{tur} = Steam Turbine Shaft Power, kW
W_c Compressor Shaft Power or Thermal Power Input, kW
η_m = Motor efficiency, pu
η_t = Drive transmission efficiency, pu
η_{comb} = Combustion Efficiency
M_{st} = Steam consumption rate, kg/h
h_{st} = Enthalpy of steam at operating pressure, kJ/kg
h_{cond} = Enthalpy of condensate, kJ/kg
M_f = Fuel consumption rate, kg/h
GCV = Gross Calorific value of fuel, kJ/kg

The above calculations are summarized in table 5.3 below in MS Excel programmable worksheet. The calculations are given for a motor driven compressor chilling plant.

Table 5-3: Measurements and calculations

	A	B	C	D
1	**Parameter**	**Formula**	**Unit**	**Value**
2	Test run number			
3	Date			
4	Duration of run	As measured	minutes	
5	Compressor Speed	As measured	rpm	
6	Compressor suction pressure	As measured	kPa	
7	Compressor discharge pressure	As measured	kPa	
8	Ambient dry bulb temperature	As measured	℃	
9	Ambient wet bulb temperature	As measured	℃	
10	Cooling Water flow, Q_w	As measured	m^3/h	
11	Liquid density, d_w	From literature	kg/ m^3	
12	Specific heat of liquid, C_{p-w}	From literature	kJ/kg/K	
13	Cooling water inlet temperature, T_{c-i}	As measured	℃	
14	Cooling water outlet temperature, T_{c-o}	As measured	℃	
15	Heat Rejection, HR*	D10 * D11 * D12 * (D14 – D13)	kJ/h	
16	Power input to motor, W_m	As measured	kW	
17	Likely motor efficiency, η_m	From literature	pu	
18	Likely drive transmission efficiency, η_t	From literature	pu	
19	Estimated Compressor shaft power, W_c	D16 * D17 * D18	kW	
20	Refrigeration Effect, R	D15 – [D19 * 3600]	kJ/h	
21	Refrigeration Effect, R	D20 / (3.51 * 3600)	TR	
22	Coefficient of Performance, COP	D20 / (D19 * 3600)	pu	
23	Energy Efficiency Ratio, EER	D22 * 3.418	Btu/h-W	
24	Specific power consumption, SPC	3.51 / D22	kW/TR	

* In case desuperheater is installed, the heat recovery in desuperheater should be added to 'D15' (heat rejection in condenser).

5.5 Estimation of Performance of Water/Brine Chilling Packages & Direct Air Cooling Packages from Heat Rejection in Air Cooled Condensers

The Performance Evaluation involves the following steps:

1. Measurement of air flow rate, Q_{air}, in the condenser under steady conditions.
2. Measurement of dry bulb temperature, T_{db}, and wet bulb temperature, T_{wb}, of air at condenser inlet and outlet, under steady conditions. Estimation of enthalpy of air, h_{air}, at evaporator inlet and outlet, using T_{db} , T_{wb} and Psychrometric chart. Density of air is to be taken as average of densities at inlet and outlet. For a given T_{db} & T_{wb}, specific volume of air can be obtained from psychrometric chart. Density is reciprocal of specific volume. A psychrometric chart is given in Annexure-3.

3. For motor driven package using vapour compression cycle, simultaneous estimation of compressor shaft power, W_c, under steady conditions, as the multiplication product of measured motor input power, W_{m-i}, motor efficiency, η_m, and drive transmission efficiency, η_t. For hermetic and semi-hermetic compressors, the motor input power can be used without accounting for motor and transmission losses.
4. For engine driven vapour compression chilling package, measure engine fuel consumption rate, M_f. Total energy input, W_c is calculated by multiplying engine fuel consumption with calorific value of the fuel when estimating COP on the basis of input energy to engine.
5. While estimating COP on the basis of compressor shaft power, calculation of *Engine Shaft Power* from the engine fuel consumption and co-relation with the engine performance test data, available from the manufacturer is required. The *Compressor Shaft Power* can be calculated as the "multiplication product" of *Engine Shaft Power* and *Drive* (usually belt) *transmission efficiency.*
6. For steam turbine driven chilling package, measure steam consumption rate, M_{st}. The steam turbine shaft power, W_{tur}, is estimated using the method elaborated in the Performance Testing Code for Cogeneration. The compressor shaft power, W_c, is estimated as the multiplication product of W_{tur} and transmission efficiency, η_t.

$$\text{COP} = \frac{Q_{air} \times d_{air} \times (h_{airi} - h_{airo})}{3600 \times W_c} - 1$$

For electric motor driven compressors, $W_c = W_{mi} \times \eta_m \times \eta_t$

For engine driven compressors, $W_c = W_e \times \eta_t$

Where:

Q_{air} = Air flow in evaporator, m^3/h
d_{air} = Density of air, kg/m^3
h_{air-i} = Enthalpy of air at evaporator inlet, kJ/kg
h_{air-o} = Enthalpy of air at evaporator outlet, kJ/kg
W_{m-i} = Motor input Power, kW
W_e = Engine Shaft Power, kW
W_{tur} = Steam Turbine Shaft Power, kW
W_c = Compressor Shaft Power
η_m = Motor efficiency, pu
η_t = Drive transmission efficiency, pu

The above calculations are summarized in table 5.4 below in MS Excel programmable worksheet. The calculations are given for a motor driven compressor chilling plant.

Table 5-4: Measurements and calculations

	A	B	C	D
1	**Parameter**	**Formula**	**Unit**	**Value**
2	Test run number			
3	Date			
4	Duration of run	As measured	minutes	
5	Compressor Speed	As measured	rpm	
6	Compressor suction pressure	As measured	kPa	
7	Compressor discharge pressure	As measured	kPa	
8	Ambient dry bulb temperature	As measured	°C	
9	Ambient wet bulb temperature	As measured	°C	
10	Cooling Air flow in condenser, Q_{air}	As measured	m^3/h	
11	Air density, d_{air}	From psychrometric chart	kg/ m^3	
12	Air dry bulb temperature at condenser inlet, $T_{air-db-i}$	As measured	°C	
13	Air wet bulb temperature at condenser inlet, $T_{air-db-o}$	As measured	°C	

14	Enthalpy of air at condenser inlet, h_{air-I}	From psychrometric chart	kJ/kg	
15	Air dry bulb temperature at condenser outlet, $T_{air-db-o}$	As measured	℃	
16	Air wet bulb temperature at condenser inlet, $T_{air-wb-o}$	As measured	℃	
17	Enthalpy of air at condenser outlet, h_{air-o}	From psychrometric chart	kJ/kg	
18	Heat Rejection in Cooling air, H_{air}	D10 * D11 * (D17 – D14)	kJ/h	
19	Fuel consumption rate of engine, H_e	As measured	kg/h	
20	Likely engine shaft power, W_e	From D19 and performance data	kW	
21	Likely drive transmission efficiency, η_t	From literature	pu	
22	Estimated Compressor shaft power, W_c	D20 * D21	kW	
23	Refrigeration Effect, R	D18 – (D22 * 3600)	kJ/h	
24	Refrigeration Effect, R	D23 / (3.51 * 3600)	TR	
25	Coefficient of Performance, COP	D23 / D20	pu	
26	Energy Efficiency Ratio, EER	D25 * 3.418	Btu/h-W	
27	Specific power consumption, SPC	3.51 / D25	kW/TR	

5.6 **Estimation of EER and Specific Energy Consumption (kW/TR for kg/h/TR)**

For Vapour Compression Chilling Package

Energy Efficiency Ratio, EER = COP x 3.418
Specific Energy Consumption, SPC = 3.51 / COP

For Vapour Absorption Chilling Package (Steam heated)

Energy Efficiency Ratio, EER = COP x 3.418
Specific Steam Consumption,
SSC = 3.51 x 3600/ [COP x (h_{st} - h_{cond})]

For Vapour Absorption Chilling Package (Direct fired)

Energy Efficiency Ratio, EER = COP x 3.418
Specific Fuel Consumption, SFC = 3.51 x 3600 / (COP x GCV)

6 REPORT OF TEST RESULTS

6.1 Format of data collection & Test results

The methods for estimation of cooling effect is same for Vapour Compression and Vapour Absorption Chilling Packages. The methods for estimating input energy varies depending upon whether the system is compressor system, absorption system or engine driven.

The following formats are given for a few configurations of chilling plants.

6.1.1 Vapour Compression System- Evaporator Side (Chilled Water/Brine) Method

Name of Industry:

Test date:

Time:

Details of instruments used

Sl.No	Description	Measured parameter	Description of accuracy
1	Electrical Power Analyser	Voltage, current, p.f, power input, frequency	
2	Flow meter	Water/brine flow	
3	Thermometer	Temperature	

Sl. No	Package Specifications	Unit	Value
1	Manufacturer:		
2	Model / Type Number:		
3	Rated Speed	rpm	
4	Rated Capacity at Full Load	TR	
5	Drive Motor Nameplate Rating	kW	
6	Fluid being cooled in the evaporator		
78	Rated Evaporator Fluid Flow Rate, Q_{e-r}	m^3/h	
9	Rated Evaporator inlet temperature, T_{e-i-r}	℃	
10	Rated Evaporator outlet temperature, T_{e-o-r}	℃	
11	Rated Condenser Flow Rate, Q_{c-r}	m^3/h	
12	Rated Condenser inlet temperature, T_{c-i-r}	℃	
13	Rated Condenser outlet temperature, T_{c-o-r}	℃	
14	Rated COP / EER / SEC (if available)		

Sl. No.	Measurements and results	Unit	Quantity
1	Equipment Tag no.		
2	Test run number		
3	Date		
4	Duration of run	minutes	
5	Compressor Speed	rpm	
6	Compressor suction pressure	kPa	
7	Compressor discharge pressure	kPa	
8	Ambient dry bulb temperature	°C	
9	Ambient wet bulb temperature	°C	
10	Evaporator Liquid flow, Q_l	m^3/h	
11	Liquid temperature at evaporator inlet, T_{e-i}	°C	
12	Liquid temperature at evaporator outlet, T_{e-o}	°C	
13	Cooling water inlet temperature, T_{c-i}	°C	
14	Cooling water outlet temperature, T_{c-o}	°C	
15	Refrigeration Effect, R	TR	
16	Power input to motor, W_m	kW	
17	Estimated Compressor shaft power, W_c	kW	
18	Coefficient of Performance, COP	pu	
19	Uncertainty	%	

Test conducted by:
(Energy Auditing Firm)

Test witnessed by:
(Energy Manager)

6.1.2 Vapour Compression System- Evaporator Side (Air-Psychrometric) Method

Name of Industry:

Test date:

Time:

Details of instruments used

Sl.No	Description	Measured parameter	Description of accuracy
1	Electrical Power Analyser	Voltage, current, p.f, power input, frequency	
2	Air Flow meter	Air flow	
3	Psychrometer	Air temperature	

Sl.No	**Package Specifications**	**Unit**	**Value**
1	Manufacturer:		
2	Model / Type Number:		
3	Rated Speed	rpm	
4	Rated Capacity at Full Load	TR	
5	Drive Motor Nameplate Rating	kW	
6	Fluid being cooled in the evaporator		
7	Rated Evaporator Fluid Flow Rate, Q_{e-r}	m^3/h	
8	Rated Evaporator inlet temperature, T_{e-i-r}	℃	
9	Rated Evaporator outlet temperature, T_{e-o-r}	℃	
10	Rated Condenser Flow Rate, Q_{c-r}	m^3/h	
11	Rated Condenser inlet temperature, T_{c-i-r}	℃	
12	Rated Condenser outlet temperature, T_{c-o-r}	℃	
13	Rated COP / EER / SEC (if available)		

	Measurements and results	Unit	Value
1	Test run number		
2	Duration of run	minutes	
3	Compressor Speed	rpm	
4	Compressor suction pressure	kPa	
5	Compressor discharge pressure	kPa	
6	Ambient dry bulb temperature	℃	
7	Ambient wet bulb temperature	℃	
8	Air flow, Q_{air}	m^3/h	
9	Air dry bulb temperature at evaporator inlet, $T_{air-db-i}$	℃	
10	Air wet bulb temperature at evaporator inlet, $T_{air-db-o}$	℃	
11	Air dry bulb temperature at evaporator outlet, $T_{air-db-o}$	℃	
12	Air wet bulb temperature at evaporator inlet, $T_{air-wb-o}$	℃	
13	Refrigeration Effect, R	TR	
14	Power input to motor, W_m	kW	
15	Estimated Compressor shaft power, W_c	kW	
16	Coefficient of Performance, COP	pu	
17	Uncertainty	%	

Test conducted by:
(Energy Auditing Firm)

Test witnessed by:
(Energy Manager)

6.1.3 Vapour Compression System- Condenser Side (Cooling Water) Method

Name of Industry:

Test date:

Time:

Details of instruments used

Sl.No	Description	Measured parameter	Description of accuracy
1	Electrical Power Analyser	Voltage, current, p.f, power input, frequency	
2	Flow meter	Water flow	
3	Thermometer	Temperature	

Sl.No	**Package Specifications**	**Unit**	**Value**
1	Manufacturer:		
2	Model / Type Number:		
3	Rated Speed	rpm	
4	Rated Capacity at Full Load	TR	
5	Drive Motor Nameplate Rating	kW	
6	Fluid being cooled in the evaporator		
7	Rated Evaporator Fluid Flow Rate, Q_{e-r}	m^3/h	
8	Rated Evaporator inlet temperature, T_{e-i-r}	°C	
9	Rated Evaporator outlet temperature, T_{e-o-r}	°C	
10	Rated Condenser Flow Rate, Q_{c-r}	m^3/h	
11	Rated Condenser inlet temperature, T_{c-i-r}	°C	
12	Rated Condenser outlet temperature, T_{c-o-r}	°C	
13	Rated COP / EER / SEC (if available)		

Sl.No	**Measurements and results**	Unit	Value
1	Test run number		
2	Date		
3	Duration of run	minutes	
4	Compressor Speed	rpm	
5	Compressor suction pressure	kPa	
6	Compressor discharge pressure	kPa	
7	Ambient dry bulb temperature	°C	
8	Ambient wet bulb temperature	°C	
9	Cooling Water flow, Q_w	m^3/h	
10	Cooling water inlet temperature, T_{c-i}	°C	
11	Cooling water outlet temperature, T_{c-o}	°C	
12	Heat Rejection, HR	kJ/h	
13	Power input to motor, W_m	kW	
14	Estimated Compressor shaft power, W_c	kW	
15	Refrigeration Effect, R	TR	
16	Coefficient of Performance, COP	pu	
17	Uncertainty	%	

Test conducted by:
(Energy Auditing Firm)

Test witnessed by:
(Energy Manager)

6.1.4 Vapour Absorption System- Condenser Side (Cooling Water) Method

Name of Industry:

Test date:

Time:

Details of instruments used

Sl.No	Description	Measured parameter	Description of accuracy
1	Electrical Power Analyser	Voltage, current, p.f, power input, frequency	
2	Flow meter	Water flow	
3	Thermometer	Temperature	

Sl.No	**Package Specifications**	**Unit**	
1			
2	Manufacturer:		
3	Model / Type Number:		
4	Rated Generator temperature		
5	Rated Capacity at Full Load	TR	
6	Fluid being cooled in the evaporator		
7	Rated Evaporator Fluid Flow Rate, Q_{e-r}	m^3/h	
8	Rated Evaporator inlet temperature, T_{e-i-r}	℃	
9	Rated Evaporator outlet temperature, T_{e-o-r}	℃	
10	Evaporator heat transfer area, A_{ev}	m^3	
11	Rated Condenser Flow Rate, Q_{c-r}	m^3/h	
12	Rated Condenser inlet temperature, T_{c-i-r}	℃	
13	Rated Condenser outlet temperature, T_{c-o-r}	℃	
14	Condenser heat transfer area, A_{co}	m^3	
15	Rated COP / EER / SEC (if available)		

Sl.No	**Measurements and results**	Unit	Value
1	Test run number		
2	Date	Units	Measurements
3	Duration of run	minutes	
4	Ambient dry bulb temperature	°C	
5	Ambient wet bulb temperature	°C	
6	Cooling Water flow, Q_w	m^3/h	
7	Cooling water inlet temperature, T_{c-I}	°C	
8	Cooling water outlet temperature, T_{c-o}	°C	
9	Heat Rejection, HR	kJ/h	
10	Generator temperature	°C	
11	Steam Pressure	kPa	
12	Steam consumption rate, M_{st}	kg/h	
13	Condensate temperature	°C	
14	Estimated Thermal Power Input, W_c	kJ/h	
15	Refrigeration Effect, R	kJ/h	
16	Refrigeration Effect, R	TR	
17	Coefficient of Performance, COP	pu	
18	Uncertainty		

Test conducted by:
(Energy Auditing Firm)

Test witnessed by:
(Energy Manager)

7 UNCERTAINTY ANALYSIS

7.1 Introduction

Uncertainty denotes the range of error i.e. guessing the extent of likely error. The purpose of uncertainty analysis is to use information in order to quantify the amount of confidence in the result. The uncertainty analysis tells us the level of confidence in the results obtained from a test.

Guide to the Expression of Uncertainty in Measurement (or GUM as it is now often called) was published in 1993 (corrected and reprinted in 1995) by ISO. The focus of the ISO *Guide* or GUM is the establishment of "general rules for evaluating and expressing uncertainty in measurement that can be followed at various levels of accuracy ".

The following methodology is a simplified version of estimating combined uncertainty at field conditions based on GUM.

7.2 Methodology

Uncertainty is expressed as X +/- y where X is the calculated result and y is the estimated standard deviation. As instrument accuracies are increase, y decreases thus increasing the confidence in the results.

A calculated result, r, which is a function of measured variables X_1, X_2, X_3,….., X_n can be expressed as follows:

$r = f(X_1, X_2, X_3,\ldots.., X_n)$

The uncertainty for the calculated result, r, is expressed as

$$\partial_r = \left[\left(\frac{\partial r}{\partial X_1}\times\delta x_1\right)^2 + \left(\frac{\partial r}{\partial X_2}\times\delta x_2\right)^2 + \left(\frac{\partial r}{\partial X_3}\times\delta x_3\right)^2 + \ldots\ldots.\right]^{0.5} \quad \text{----(1)}$$

Where:

∂_r = Uncertainty in the result

δxi = Uncertainties in the measured variable X_i

$\frac{\partial r}{\partial X_i}$ = Absolute sensitivity coefficient

In order to simplify the uncertainty analysis and enable calculations on simple spreadsheet applications, each term on RHS of the equation (1) can be approximated by:

$$\frac{\partial r}{\partial X_1} \times \Delta X_1 = r(X_1+\Delta X_1) - r(X_1) \quad \text{----(2)}$$

The basic spreadsheet is set up as follows, assuming that the result r is a function of the four parameters X_1, X_2, X_3 & X_4. Enter the values of X_1, X_2, X_3 & X_4 and the formula for calculating **r** in column A of the spreadsheet. Copy column A across the following columns once for every variable in **r** (see table 7.1). It is convenient to place the values of the uncertainties $\partial(X_1)$, $\partial(X_2)$ and so on in row 1 as shown.

Table 7-1: Uncertainty evaluation sheet-1

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	X_1	X_1	X_1	X_1
4	X_2	X_2	X_2	X_2	X_2
5	X_3	X_3	X_3	X_3	X_3
6	X_4	X_4	X_4	X_4	X_4
7					
8	$y=f(X_1, X_2, X_3, X_4)$	$y=f(X_1, X_2, X_3, X_4)$	$y=f(X_1, X_2, X_3, X_4)$	$y=f(X_1, X_2, X_3, X_4)$	$y=f(X_1, X_2, X_3, X_4)$

Add □X_1 to X_1 in cell B3 and □ X_2 to X_2 in cell C4 *etc.*, as in Table 7.2. On recalculating the spreadsheet, the cell B8 becomes $f(X_1+$ □ $X_1, X_2, X_3, X_4)$.

Table 7-2: Uncertainty evaluation sheet-2

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	$X_1+\partial X_1$	X_1	X_1	X_1
4	X_2	X_2	$X_2+\partial X_2$	X_2	X_2
5	X_3	X_3	X_3	$X_3+\partial X_3$	X_3
6	X_4	X_4	X_4	X_4	$X_4+\partial X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1', X_2, X_3, X_4)$	$r=f(X_1, X_2', X_3, X_4)$	$r=f(X_1, X_2, X_3', X_4)$	$r=f(X_1, X_2, X_3, X_4')$

In row 9 enter row 8 minus A8 (for example, cell B9 becomes B8-A8). This gives the values of ∂ (r, X_1) as shown in table 7.3.

∂ $(r, X_1)=f(X_1+\partial X_1), X_2, X_3\ldots) - f(X_1, X_2, X_3..)$ *etc.*

To obtain the standard uncertainty on *y*, these individual contributions are squared, added together and then the square root taken, by entering ∂ $(r, X_1)^2$ in row 10 (Figure 7.3) and putting the square root of their sum in A10. That is, cell A10 is set to the formula, SQRT(SUM(B10+C10+D10+E10)) which gives the standard uncertainty on r, ∂ (r).

Table 7-3: Uncertainty evaluation sheet-3

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	$X_1+\partial X_1$	X_1	X_1	X_1
4	X_2	X_2	$X_2+\partial X_2$	X_2	X_2
5	X_3	X_3	X_3	$X_3+\partial X_3$	X_3
6	X_4	X_4	X_4	X_4	$X_4+\partial X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1', X_2, X_3, X_4)$	$r=f(X_1, X_2', X_3, X_4)$	$r=f(X_1, X_2, X_3', X_4)$	$r=f(X_1, X_2, X_3, X_4')$
9		$\partial (r,X_1)$	$\partial (r,X_2)$	$\partial (r,X_3)$	$\partial (r,X_4)$
10	$\partial (r)$	$\partial (r,X_1)^2$	$\partial (r,X_2)^2$	$\partial (,X_3)^2$	$\partial (r,X_4)^2$

7.3 Uncertainty Evaluation of Chiller Efficiency Testing

Based on above discussions, the methodology for estimating uncertainty in COP and specific power consumption using equations given in section 5.2. is explained below.

COP and specific steam consumption of absorption chiller is estimated below. The following are the details of measurements.

Inlet water temperature at the evaporator, T1 = 9.2 C
Outlet water temperature of the evaporator, T2 = 7.1 C
(Temperature measured with thermometer having 0.1C accuracy)

Chilled water flow, Q_w = 1790 m^3/hr, measured using in-line flow meter having 1% accuracy.

Steam flow = 6340 kg/hr, measured using in-line steam flow meter, having 1% accuracy.

Table 7-4: Uncertainty estimation

			Measurements				
				δT_1	δT_2	δQ_{ch-w}	δQ_{steam}
			Instrument accuracy, %	1	1	5	2
			Absolute accuracy	0.1	0.1	89.5	126.8
	Symbol	Units	Qty.				
Inlet Temperature	T_1	C	9.2	9.3	9.2	9.2	9.2
Outlet Temperature	T_2	C	7.1	7.1	7.2	7.1	7.1
Chilled water flow rate	Q_{ch-w}	m3/hr	1790.0	1790	1790	1879.5	1790.0
Steam consumption	Q_{steam}	kg/hr	6340.0	6340.0	6340.0	6340.0	6466.8
Density of water	d	kg/m3	1000.0	1000.0	1000.0	1000.0	1000.0
Specific heat capacity of chilled water	Cp	kJ/kg-C	4.2	4.2	4.2	4.2	4.2
Latent heat of steam	H	kJ/kg	2250.0	2250.0	2250.0	2250.0	2250.0
Chiller capacity		TR	1243.1	1302.2	1183.9	1305.2	1243.1
Coefficient of performance			1.10	1.15	1.05	1.16	1.08
delta				-0.05	0.05	-0.06	0.02
delta ^{2}				0.00275	0.0027511	0.0030331	0.0004665
Uncertainty				0.09487			
				8.6%			
Specific steam consumption		kg/hr/TR	5.1	4.9	5.4	4.9	5.2
delta				0.2	-0.3	0.2	-0.1
delta ^{2}				0.05374	0.0650335	0.0589873	0.0104054
Uncertainty				0.43378			
				8.5%			

The specific steam consumption is thus represented as 5.1 ± 0.43 kg/h/TR

8 CHECK LIST FOR IMPROVING ENERGY EFFICIENCY

8.1 Diagnostics

The following check list provides a guide to help diagnose the reasons for poor COP in chiller packages.

For Vapour Compression Machines

1. Compare the COP with that expected for similar end-use temperatures.
2. In case the COP is lower than expected, compare the suction and discharge pressures with that of normally expected values for the particular refrigerant. Lower suction pressures indicate poor heat transfer in the evaporator. Higher discharge pressures indicate poor heat transfer in the condenser.
3. In case poor heat transfer is suspected, the heat transfer coefficient may be calculated. The method of calculating the Logarithmic Mean Temperature Difference,LMTD, and heat transfer coefficient, U, is shown in annexure 4. These values should be compared with good design values.
4. The heat transfer may be poor due to fouling of the heat exchangers (scaling, oil film due to poor oil separation etc.), inadequate fluid flow, inadequate heat transfer area or poor cooling tower performance or poor pump or fan performance or a combination of these factors.
5. The cooling tower performance may be poor due to fouling of the fill, damaged fill, inadequate water flow, excess water flow, poor water distribution, inadequate air flow or under-sizing of cooling tower.
6. In the case of air-conditioning machines, choking of air filters of Air Handling Units, can lead to lower suction pressures.
7. Poor suction conditions for fans can lead to significantly reduced air flow.
8. Fouling of heat exchangers may be due to carry over of lubricating oil into heat exchangers or scaling of heat transfer surfaces due to poor water treatment or other product related fouling. The precise cause will have to be identified by further study.
9. The COP may also drop due drop in efficiency of the compressor. The drop may be in volumetric efficiency or thermodynamic efficiency of the compressor. This requires additional information on actual positive displacement in the compressor and theoretical calculations using Mollier charts. Volumetric efficiency may drop due to wear & tear of pistons & cylinder linings or malfunctioning of suction & discharge valves. The thermodynamic efficiency may drop due to poor compressor cooling, especially intercoolers in multi-stage machines.

For Vapour Absorption Machines

1. Compare the COP with that expected for similar end-use temperatures.
2. Lower generator temperatures indicate operation at reduced capacity.
3. In the case of absorption machines, the COP will generally be close to expected values. However, the ability of the machine to deliver rated capacity will be compromised if there are any system deficiencies. Reduced capacity may lead to increase in number of operating machines and also wasted auxiliary energy consumption in pumps, cooling towers etc.
4. Inadequate cooling in cooling towers leads to reduced capacity of absorption chilling packages.

8.2 Check List for Energy Conservation in HVAC

Avoid Refrigeration & Air-conditioning to the Extent Possible

- Use evaporative cooling for comfort cooling in dry areas

- Use cooling tower water at higher flows for process cooling

Operate at Higher Temperature

- Increase the chilled water temperature set point if possible.
- Improve Air Distribution and Circulation
- Improve air Distribution in Cold Storages
- Measure and control temperature accurately

Reduction in Air-conditioning Volume and Shift Unnecessary Heat Loads

- Keep Unnecessary Heat Loads Out
- Use False Ceilings
- Use Small Power Panel Coolers
- Use Pre-Fabricated, Modular Cold Storage Units

Minimise Heat Ingress

- Check and Maintain Thermal Insulation
- Insulate Pipe Fittings
- Use Landscaping to the Reduce Solar Heat Load
- Reduce Excessive Window Area
- Use Low Emissivity (Sun Control) Films
- For air-conditioned spaces, low emissivity (sun control) films, revolving doors, air-curtains, PVC strip curtains etc
- Use Low Conductivity Window Frames
- Provide Insulation on Sun-Facing Roofs and Walls.
- Provide Evaporative Roof Cooling
- Building Structure Cooling
- Use Doors, Air-Curtains, PVC Strip Curtains
- Use High Speed Doors for Cold Storage

Using Favourable Ambient Conditions

- Use Cooling Tower Water Directly for Cooling in Winter
- Design New Air-conditioning Systems with Facility for 100% Fresh Air during Winter
- Use Ground Source Heat Pumps

Compressors

- Ensure correct charging of refrigerant and check seals regularly for leaks
- Avoid throttling of suction/discharge valves

Use Evaporators and Condensers with Higher Heat Transfer Efficacy

- Use Heat Exchangers with Larger Surface Area
- Install desuperheaters with heat recovery for applications requiring hot water.
- Use Plate Heat Exchangers for Process and Refrigeration Machine Condenser Cooling
- Avoid the Use of Air Cooled Condensers
- Evaporative Pre-coolers for Air-cooled Condensers
- Sub-cooling of liquid refrigerant is desirable by over-sizing of condenser.

Energy Saving Opportunities in Normal Operation

- Use Building Thermal Inertia

- Put HVAC Window Air Conditioners and Split Units on Timer or Occupancy Sensing Control
- Interlock Fan Coil Units in Hotels with Door Lock or Master Switch
- Improve Utilisation Of Outside Air.
- Maintain Correct Anti-freeze Concentration
- Install a Control System to Co-Ordinate Multiple Chillers.
- Permit Lower Condenser Pressures during Favourable Ambient Conditions
- Optimise Water/Brine/Air Flow Rates
- Defrosting
- Match the Refrigeration System Capacity to the Actual Requirement
- Monitor Performance of Refrigeration Machines

Maintenance to Ensure Energy Efficient Operation

- Clean Fouled Heat Exchangers
- Specify Appropriate Fouling Factors for Condensers
- Purging the Condenser of Air
- Do Not Overcharge Oil
- Maintain compressor seals to avoid refrigerant leaks

PumpsFans/Blowers

- Optimise the performance of pumps, fans & blowers as the flow rates can have significant impact on the performance of the chilling package

Inter-fuel Substitution for Energy Cost Reduction

- In locations with process waste heat or waste heat from captive power plants, consider the use of absorption chilling packages.
- In locations with cheap fuel sources, like agro-waste, pit head coal or natural gas, consider the use of absorption chilling packages.
- Gas engine driven vapour compression packages can also be considered, especially when it is part of a cogeneration system.

System Design and Equipment Selection for Energy Efficient Operation

- Provide air conditioning only for small areas when required for manufacturing process. Comfort air conditioning should be minimised to the extent possible.
- Avoid oversizing to the extent possible – try to match the actual load, provide efficient method of modulation.
- Use larger heat transfer areas of evaporators and condensers.
- Sub-cooling of liquid refrigerant can be considered to reduce flashing of refrigerant in evaporator.
- Consider the use of vapour absorption machines when waste heat or other economical heat energy sources are available.
- Larger pipe diameters, especially vapour lines.
- Thicker insulation on pipes and vessels.
- Thicker insulation on the structure, provide building insulation.
- Use smooth, well-rounded air inlet cones for fan air intakes.
- Avoid poor flow distribution at the fan inlet.
- Minimise fan inlet and outlet obstructions.
- Use airfoil shaped fan blades.
- Use low slip or no-slip (timing) belts.
- Use variable speed drives for large pump and fan loads.
- Use energy efficient motors for continuous or near continuous operation.
- Eliminate or reduce reheat whenever possible.
- Purchase only high efficiency machines, even at a premium.

- Consider ground source heat pumps.

Cooling Towers

- Control cooling tower fans based on temperature range and temperature approach. Ensure as low an approach as possible at the rated temperature.
- Control to the optimum temperature as determined from cooling tower and chiller performance data. Lower cooling water temperatures generally help reduce compressor power consumption.
- Use two-speed or variable speed drives for cooling tower fan control if the fans are few. Stage the cooling tower fans with on-off control if there are many.
- Turn off unnecessary cooling tower fans when loads are reduced.
- Cover hot water basins (to minimise algae growth that contributes to fouling.
- Balance flow to cooling tower hot water basins.
- Periodically clean plugged cooling tower distribution nozzles.
- Install new nozzles to obtain a more uniform water pattern.
- Replace splash bars with self-extinguishing PVC cellular film fill.
- On old counterflow cooling towers, replace old spray type nozzles with new square spray ABS practically non-clogging nozzles.
- Replace slat type drift eliminators with low pressure drop, self extinguishing, PVC cellular units.
- Follow manufacturer’s recommmended clearances around cooling towers and relocate or modify structures that interfere with the air intake or exhaust.
- Optimise cooling tower fan blade angle on a seasonal and/or load basis.
- Correct excessive and/or uneven fan blade tip clearance and poor fan balance.
- Use a velocity pressure recovery fan ring.
- Consider on-line water treatment.
- Restrict flows through large loads to design values.
- Shut off loads that are not in service.
- Take blow down water from return water header.
- Optimise blowdown flow rate.
- Send blowdown water to other uses or to the cheapest sewer to reduce effluent treament load.
- Install interlocks to prevent fan operation when there is no water flow.

Thermal Storage

- Consider Thermal Storage (eg. ice banks) for energy cost saving, where electric supply utilities are having *Time of Use* tariff with high peak time rates and low off peak rates.

ANNEXURE-1: SAMPLE CALCULATIONS

A1.1. Method 1:

This is a sample calculation for a Vapour Absorption Chilling Package. Measurements are shown along with equations and estimation of results. Data collection and calculations are presented here in the format as given in Table 6.4.

Table A1.1: Equipment Specification

Sr. No.	Parameter	Unit	Qty.
	Package Specifications		
1	Manufacturer:		
2	Model / Type Number:		
	Rated Generator temperature (in case of vapour absorption chilling package)		165
3	Rated Capacity at Full Load	TR	1180
5	Fluid being cooled in the evaporator		Water
6	Rated Evaporator Fluid Flow Rate, Q_{e-r}	m^3/h	713
7	Rated Evaporator inlet temperature, T_{e-i-r}	°C	12
8	Rated Evaporator outlet temperature, T_{e-o-r}	°C	7
9	Rated Condenser Flow Rate, Q_{c-r}	m^3/h	1427
10	Rated Condenser inlet temperature, T_{c-i-r}	°C	27
11	Rated Condenser outlet temperature, T_{c-o-r}	°C	32
12	Rated COP / EER / SEC (if available)		1.0

Measurements and estimation of parameters is given in Table A1.2 below.

Table A1.2: Estimation of Performance from Refrigeration Effect in Evaporator for Steam Heated Vapour Absorption Chilling Packages for Chilling Water

	A	B	C	**D**
1	**Parameter**	**Value or Formula in column D**	**Unit**	**Value**
2	Test run number			1
3	Date & Time			25-05-03, 1100 hrs
4	Duration of run	Measured	minutes	60
5	Ambient dry bulb temperature	Measured	°C	38
6	Ambient wet bulb temperature	Measured	°C	25
7	Liquid flow, Q_l	Measured or estimated	m^3/h	620
8	Liquid density, d_l	From literature	kg/ m^3	1000
9	Specific heat of liquid, C_{p-l}	From literature	kJ/kg/K	4.18
10	Liquid temperature at evaporator inlet, T_{e-i}	Measured	°C	8.8
11	Liquid temperature at evaporator outlet, T_{e-o}	Measured	°C	6.8
12	Cooling water inlet temperature, T_{c-i}	Measured	°C	26.6
13	Cooling water inlet temperature, T_{c-o}	Measured	°C	29.1
14	Refrigeration Effect, R	D7* D8 * D9 * (D11 – D10)	kJ/h	5183200
15	Refrigeration Effect, R	D14 / (3.51 * 3600)	TR	410
16	Generator temperature	Measured	°C	120
17	Steam Pressure	Measured	kPa	300
18	Enthalpy of steam, h_{st}	From literature	kJ/kg	2734.1
19	Steam consumption rate, M_{st}	Measured by flowmeter	kg/h	2151.1
20	Condensate temperature	Measured	°C	100
21	Enthalpy of condensate, h_{cond}	From literature	kJ/kg	418
22	Estimated Thermal Power Input, W_c	D19 * (D18 – D21)	kJ/h	4982162.7
23	Coefficient of Performance, COP	D14 / D22	pu	1.04
24	Energy Efficiency Ratio, EER	D23 * 3.418	Btu/h-W	3.56
25	Specific Steam consumption, SSC	3.51 * 3600/[D23 * (D18 – D21)]	kg/h/TR	5.25

A1.2. Method 2

For the above Vapour Absorption Chilling package, condenser side measurements were also done simultaneously. COP is estimated by using format given in table 6.10. Measurements and estimation of parameters is given in Table A1.3 below.

Table A1.3: Estimation of Performance from Heat Rejection in Cooling Water for Water Cooled, Steam Heated Vapour Absorption Chilling Packages for Chilling Water

	A	B	C	D
1	**Parameter**	**Formula**	**Unit**	**Value**
2	Test run number			1
3	Date			25-05-2003
4	Duration of run	Measured	minutes	60
5	Ambient dry bulb temperature	Measured	°C	38
6	Ambient wet bulb temperature	Measured	°C	25
7	Cooling Water flow, Q_w	Measured	m^3/h	975
8	Water density, d_w	From literature	kg/ m^3	1000
9	Specific heat of water, C_{p-w}	From literature	kJ/kg/K	4.18
10	Cooling water inlet temperature, T_{c-I}	Measured	°C	26.6
11	Cooling water outlet temperature, T_{c-o}	Measured	°C	29.1
12	Heat Rejection, HR	D7* D8 * D9 * (D11 – D10)	kJ/h	10188750
13	Generator temperature	Measured	°C	120
14	Steam Pressure	Measured	kPa	300
15	Enthalpy of steam, h_{st}	From steam tables	kJ/kg	2734.1
16	Steam consumption rate, M_{st}	Measured by flowmeter	kg/h	2151.1
17	Condensate temperature	Measured	°C	100
18	Enthalpy of condensate, h_{cond}	From steam tables	kJ/kg	418
19	Estimated Thermal Power Input, W_c	D16 * (D15 – D18)	kJ/h	4982162.7
20	Refrigeration Effect, R	D12 – D19	kJ/h	5206587.3
21	Refrigeration Effect, R	D20 / (3.51 * 3600)	TR	412
22	Coefficient of Performance, COP	D20 / D19	pu	1.05
23	Energy Efficiency Ratio, EER	D22 * 3.418	Btu/h-W	3.6
24	Specific Steam consumption, SSC	3.51 * 3600 / [D22 * (D15 – D18)]	Kg/h/TR	5.2

A1.3. Psychrometric method: Evaporator side

This a sample calculation for an office air conditioning system working on Vapour Compression Chilling Package having direct expansion type air handling unit. COP is estimated by using format given in table 6.6.

Table A1.4: Equipment Specification

Sr. No.	**Parameter**	**Unit**	**Qty.**
	Package Specifications		
1	Manufacturer:		
2	Model / Type Number:		
	Rated Speed	rpm	1460
3	Rated Capacity at Full Load	TR	40
4	Drive Motor Nameplate Rating	kW	37
5	Fluid being cooled in the evaporator		Air
6	Rated Evaporator Fluid Flow Rate, Q_{e-r}	m^3/h	38775.5
7	Rated Evaporator inlet temperature, T_{e-i-r}	°C	-
8	Rated Evaporator outlet temperature, T_{e-o-r}	°C	-
9	Rated Condenser Flow Rate, Q_{c-r}	m^3/h	-
10	Rated Condenser inlet temperature, T_{c-i-r}	°C	-
11	Rated Condenser outlet temperature, T_{c-o-r}	°C	-
12	Rated COP / EER / SEC (if available)		-

Measurements and estimation of parameters is given in Table A1.5 below.

Table A1.5: Estimation of Performance from Refrigeration Effect in Evaporator for Motor Driven Vapour Compression Chilling Packages for Direct Air Cooling

	A	B	C	D
1	**Parameter**	**Formula**	**Unit**	**Value**
2	Test run number			1
3	Date			25-08-2003
4	Duration of run	Measured	minutes	60
5	Compressor Speed	Measured	rpm	
6	Compressor suction pressure	Measured	kPa	476
7	Compressor discharge pressure	Measured	kPa	1632.7
8	Ambient dry bulb temperature	Measured	℃	30
9	Ambient wet bulb temperature	Measured	℃	26.7
10	Air flow, Q_{air}	Measured	m^3/h	31063
11	Air density, d_{air}	From literature	kg/ m^3	25.3
12	Air dry bulb temperature at evaporator inlet, $T_{air-db-i}$	Measured	℃	20.6
13	Air wet bulb temperature at evaporator inlet, $T_{air-db-o}$	Measured	℃	1.16
14	Enthalpy of air at evaporator inlet, h_{air-I}	From psychrometric chart	kJ/kg	59.85
15	Air dry bulb temperature at evaporator outlet, $T_{air-db-o}$	Measured	℃	17.9
16	Air wet bulb temperature at evaporator inlet, $T_{air-wb-o}$	Measured	℃	16.2
17	Enthalpy of air at evaporator outlet, h_{air-o}	From psychrometric chart	kJ/kg	45.82
18	Cooling water inlet temperature, T_{c-I}	Measured	℃	
19	Cooling water outlet temperature, T_{c-o}	Measured	℃	
20	Refrigeration Effect, R	D10 * D11 * (D17 – D14)	kJ/h	505544.1
21	Refrigeration Effect, R	D20 / (3.51 * 3600)	TR	40
22	Power input to motor, W_m	Measured	kW	31.4
23	Likely motor efficiency, η_m	From literature	pu	0.91
24	Likely drive transmission efficiency, η_t	From literature	pu	100 (direct driven)
25	Estimated Compressor shaft power, W_c	D22 * D23 * D24	kW	28.6
26	Coefficient of Performance, COP	D20 / (D25 * 3600)	pu	4.9
27	Energy Efficiency Ratio, EER	D26 * 3.418	Btu/h-W	16.8
28	Specific power consumption, SPC	3.51 / D26	kW/TR	0.72

ANNEXURE-2: COMBUSTION EFFICIENCY CALCULATIONS

The method described below can be used for estimating combustion efficiency of a direct fired absorption chilling unit. The methodology is the “Indirect Method” to estimate combustion efficiency, wherein which the losses are estimated from flue gas analysis to estimate efficiency.

Observations

General

a) Avg. ambient air temperature, T_a (℃)
b) Fuel temperature into combustion, T_f (℃)

Flue Gas
a) Average % CO_2 (v/v)
b) Average % O_2 (v/v)
c) Average stack gas temperature, T_{exh} (℃)

Fuel Analysis (Furnace Oil)
a) % Moisture (w/w), M
c) % Carbon (w/w), C
d) % Hydrogen (w/w), H
e) % Nitrogen (w/w), N_2
f) % Sulphur (w/w), S
g) Gross calorific valve, GCV (kJ/Kg)

8.2.1 Calculations

a) Dry gas loss (D.G.L.) = $\dfrac{W \times (T_{exh} - T_a)}{GCV + Sensible\ Heat.in\ Oil}$

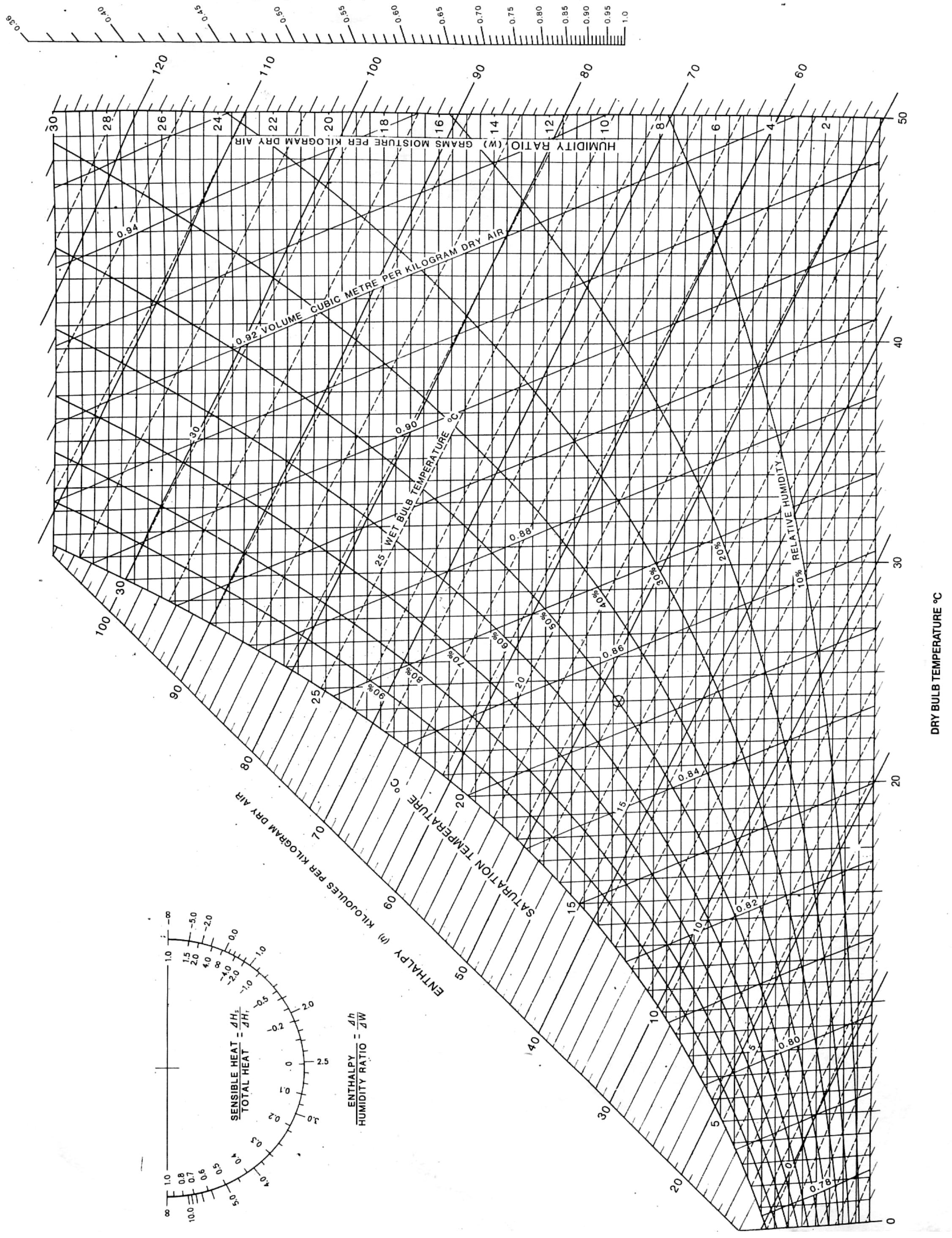
Where, W = $\dfrac{[(11 \times CO_2) + (7 \times N_2) + (8 \times O_2)]}{3 \times CO_2} \times C + \dfrac{S}{1.83}$

b) Wet Gas Loss (W.G.L.) = $\dfrac{(9H + M) \times [(100 - Tf) + 540 + 0.5(Texh - 100)]}{GCV + Sensible\ heat\ in\ oil}$

c) Total stack losses = D.G.L + W.G.L
d) Combustion efficiency (pu) by indirect method = [100 - (Total losses)] / 100

ANNEXURE-3: PSYCHROMETRIC CHART

Psychrometric Chart 4 - NormalTemperature (SI)



ANNEXURE 4: CALCULATION OF LMTD AND HEAT TRANSFER COEFFICIENT

Calculation of these parameters can help understand and provide clues for improving the performance of refrigeration machines.

For Evaporator

Compressor suction pressure, P_{suc}, kPa
Evaporator refrigerant saturation temperature, $T_{e-r-sat}$,K
(from compressor suction pressure & Mollier chart or table for the refrigerant)
Evaporator inlet chilled water/brine/air temperature, T_{e-i}, ,K
Evaporator outlet chilled water/brine/air temperature, T_{e-o},K

Logarithmic Mean Temperature Difference, LMTD, ºC = $\dfrac{(T_{e-i} - T_{e-sat}) - (T_{e-o} - T_{e-sat})}{\ln[(T_{e-i} - T_{e-sat})/(T_{e-o} - T_{e-sat})]}$

Refrigeration effect, R, kJ/s

Evaporator heat transfer area, A_e, m^2

Evaporator heat transfer coefficient, U_e, kJ/s-m^2-ºC = $\dfrac{R}{LMTD_e \times A_e}$

For Condenser

Compressor discharge pressure, P_{dis}, kPa
Condenser refrigerant saturation temperature, T_{e-sat},K (from compressor discharge pressure)

(from compressor suction pressure & Mollier chart or table for the refrigerant)

Specific heat of refrigerant at constant pressure, C_p
Specific heat of refrigerant at constant volume, C_v
Polytropic exponent, $\gamma = C_p/C_v$
Condenser inlet refrigerant temperature, T_{c-r-i},K = $(P_{dis}/P_{suc})^{\gamma} \times T_{e-sat}$

Condenser inlet cooling water/air temperature, T_{c-i}, ,ºC
Condenser outlet cooling water/air temperature, T_{c-o},ºC

Logarithmic Mean Temperature Difference, LMTD, ºC = $\dfrac{(T_{c-r-i} - T_{c-o}) - (T_{c-sat} - T_{c-i})}{\ln[(T_{c-r-i} - T_{c-o})/(T_{c-sat} - T_{c-i})]}$

Refrigeration effect, R, kJ/s

Evaporator heat transfer area, A_e, m^2

Evaporator heat transfer coefficient, U_c, kJ/s-m^2-ºC = $\dfrac{R}{LMTD_e \times A_e}$

ANNEXURE 5: SI UNITS, CONVERSION FACTORS & PREFIXES

QUANTITY	SI UNITS	CONVERSION FACTORS
Length	m	1 ft = 0.3048 m 1 inch= 0.0254 m
Mass	kg	1 ton (metric) = 1000 kg 1lb = 0.454 kg
Time	s	1h = 3600 sec
Electric Current	A	Ampere
Thermodynamic Temperature	K	t^{0C} = (t+ 273.15) k $t^{0}F = [\frac{(t-32)}{1.8} + 273.15]$
Acceleration	m/s^2	1 ft/s^2 = 0.3048 m/s^2
Area	m^2	1 ft^2 = 0.0929 m^2
Density	kg/m^3	1ton / m^3 =10^3 kg/ m^3 1lb / ft^3 =16.02 kg/ m^3
Force (weight)	N (Newton) Kg-m/s^2	1 kgf= 9.81N 1lbf = 4.45N
Specific heat (Of phase change)	J /kg	1 kcal /kg= 4190 J/kg 1 Btu = lb = 2326 J /kg
Surface tension	N/m	1 kgf / m = 9.81 N/m = 9.81 J/m^2
Thermal conductivity	W/m.k	1 kcal/ h-m-k = 1.163 W/m.k 1 Btu/ Ft-h-^{0}F = 1.73 W/m.k
Viscosity, dynamic	Pa.s	1pa = 0.1 pa 1 cp = 10^{-3}pa
Viscosity, kinematics	m^2 /s	1 st= 10^{-4} m^2 /s 1 ft^2 /s = 0.093 m^2 /s
Volume	m^3	1 ft^3 = 0. 02831685 m^2 /s
Work, Energy, Quantity of heat	J (joule) N-m	1 kgf-m = 9.80665 N 1 kWh = 3.6x 10^6 J 1kcal = 4.19 kJ 1 lb-ft = 1.356 J 1 Btu = 1055.1 J

ANNEXURE 5: SI UNITS, CONVERSION FACTORS & PREFIXES (cont'd)

QUANTITY	SI UNITS	CONVERSION FACTORS
Frequency	Hz (Hertz)	1 rps = 1 Hz
Heat (enthalpy) Specific energy	J/kg	1 kcal/kg = 4190 J/kg
Heat transfer coefficient	W/ m^2.k	1 kcal/m^2-h-k = 1.163 W/ m^2-K 1 Btu/ft^2-h-^{0}F = 5.6 W/ m^2-K
Power (radiant flux)	W (watt) J/s	1 kcal/ h = 1.163 W 1 kgf-m/s= 9.81 W 1 lb-ft/s =1.356 W
Pressure	Pa (Pascal) N/m^2	1 bar = 10^5 pa 1 kgf/ cm^2 = 1 atm = 735 mm Hg = 9.81 x 10^4 Pa 1 atm = 760 mmHg = 101325 Pa 1 mmH_2O = 9.81Pa 1mm Hg = 133.3 Pa 1 lbf /in^2(psi) = 6894.76 Pa
Rate of flow, mass	kg/ s	1 lb/s = 0.454 kg/s
Rate of flow, volumetric	m^3/s	1 ft^3/s = 28.3 x 10^{-3} m^3/s

S.I Prefixes

Kilo	K	10^3
Mega	M	10^6
Giga	G	10^9
Tera	T	10^{12}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro		10^{-6}
nano	n	10^{-9}
pico	P	10^{-12}

ANNEXURE-6: REFERENCES

- IS: 8148 - 1976: Specification for Packaged Air Conditioners
- ARI Standard 550/590 - 1998: Water Chilling Packages using the Vapor Compression Cycle
- ARI Standard 560 - 2000: Method of Testing Absorption Water Chilling and Water Heating Packages
- ANSI/ASHRAE/ESNA Standard 90.1-2001: Energy Standard for Buildings Except Low-Rise Residential Buildings
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