EACREEE
Building a Sustainable Energy Future

Association of Energy Professionals Eastern Africa

Energy Efficiency (EE) e-training - East Africa

Rahul Raju Dusa
Senior Expert

Monday, 22 March 2021 | Copenhagen

UNEP DTU PARTNERSHIP | COPENHAGEN CENTRE ON ENERGY EFFICIENCY
SEforALL EE HUB

Today's Agenda

#	Minutes	Title	Description
1	30 min	Energy Efficiency – HVAC Systems	Rahul Raju Dusa
2	20 min	Energy Efficiency – Lighting Systems	Clara Camarasa
3	20 min	Opportunities for Energy Efficiency in Water Supply Systems	Rahul Raju Dusa
4	20 min	Energy Efficiency in Water Supply Systems	Xianli Zhu
	10 min	Q & A	

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Energy Efficiency - HVAC

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What?

Why?

When?

Energy Efficiency - HVAC

Where?

How?

What ?

What is HVAC system

Heating Ventilation and Air Conditioning System

- Heating and cooling equipment
- Circulating pumps
- Fans and blowers
- Cooling towers
- Air Handling Units
- Pipelines, ducts and insulation
- Others

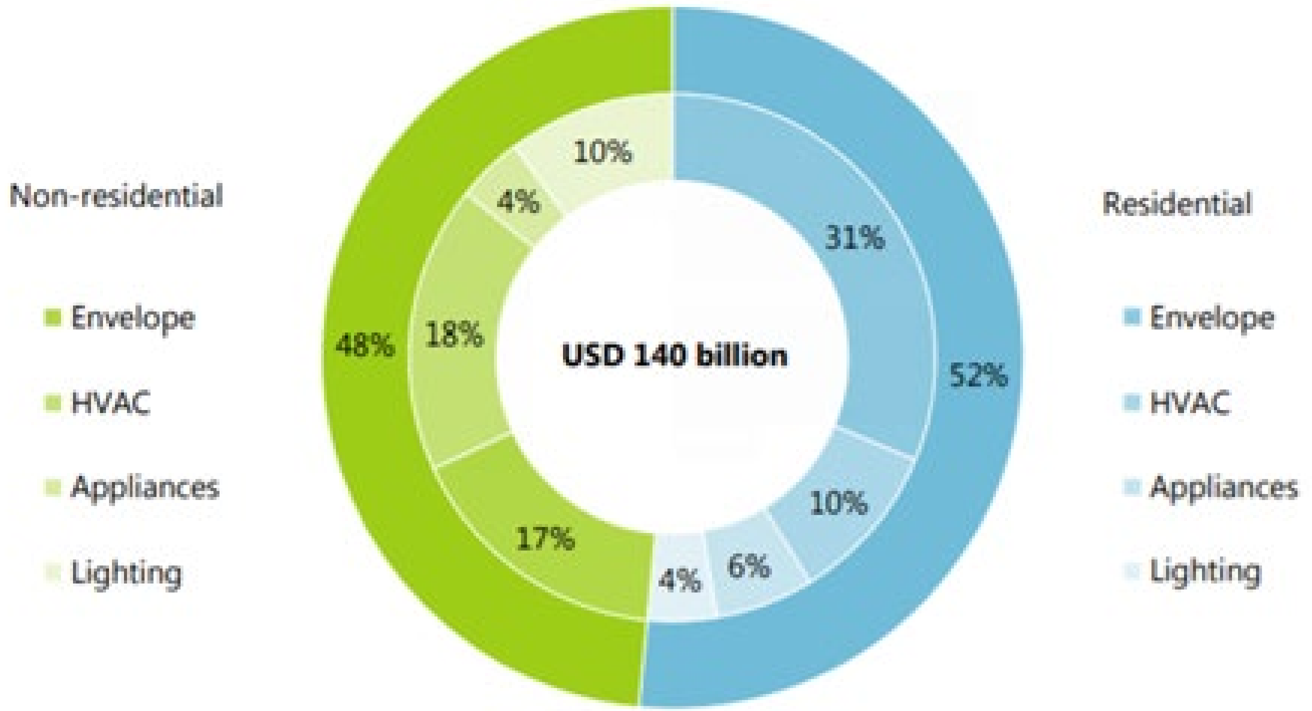
What is HVAC system

Heating Ventilation and Air Conditioning system components				
Mixed-air plenum and outdoor air control	Air filters	Supply fan	Exhaust fan	Outdoor air intake
Ducts	Terminal devices	Return air system	Heating and cooling coils	Self contained heating or cooling unit
Cooling tower	Boiler	Control system	Chiller units	Humidification and dehumidification equipment

Why ?

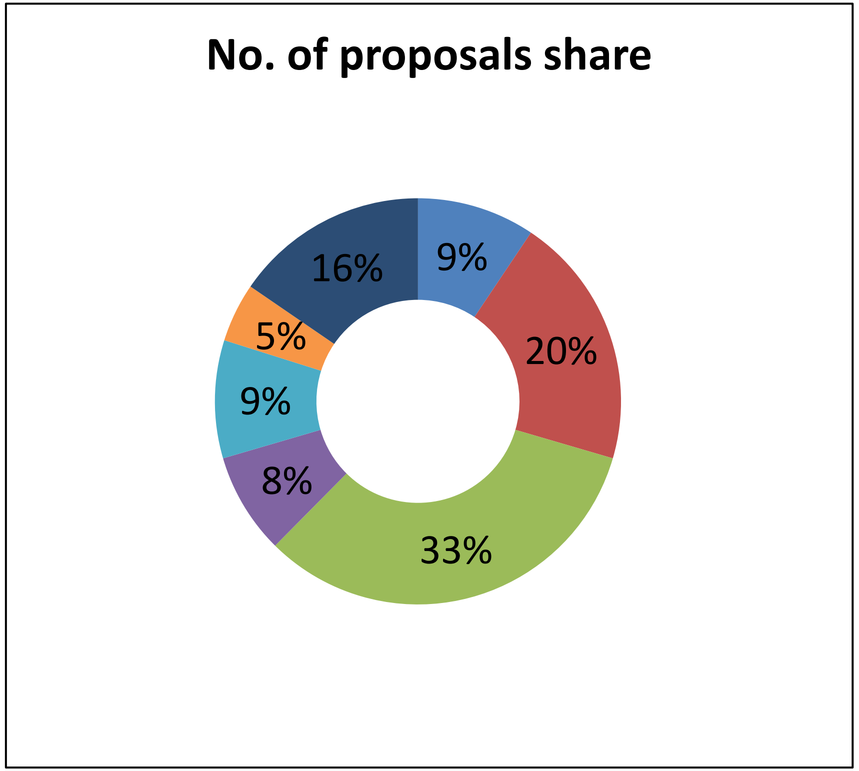
Why HVAC system?

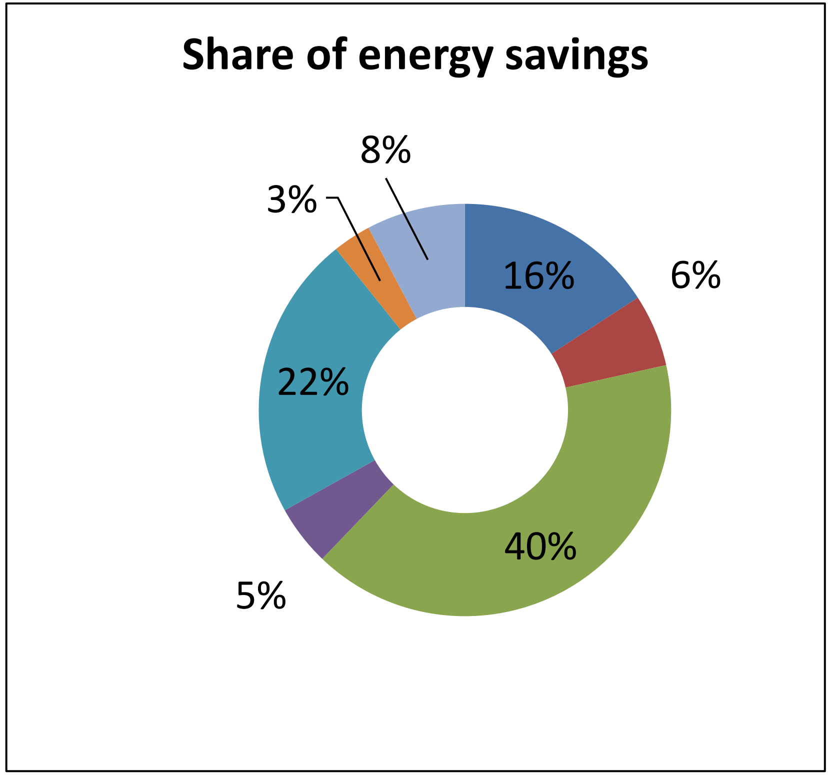
Energy efficiency investment in buildings by subsector and end use, 2017

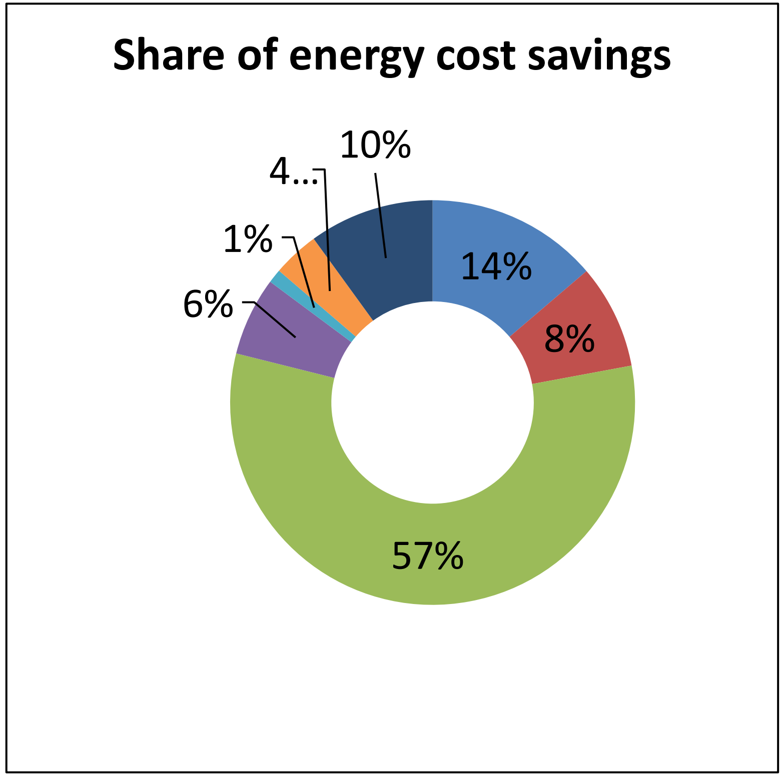


Source: IEA (2018), Energy Efficiency 2018, https://www.iea.org/efficiency2018/;

Why HVAC?







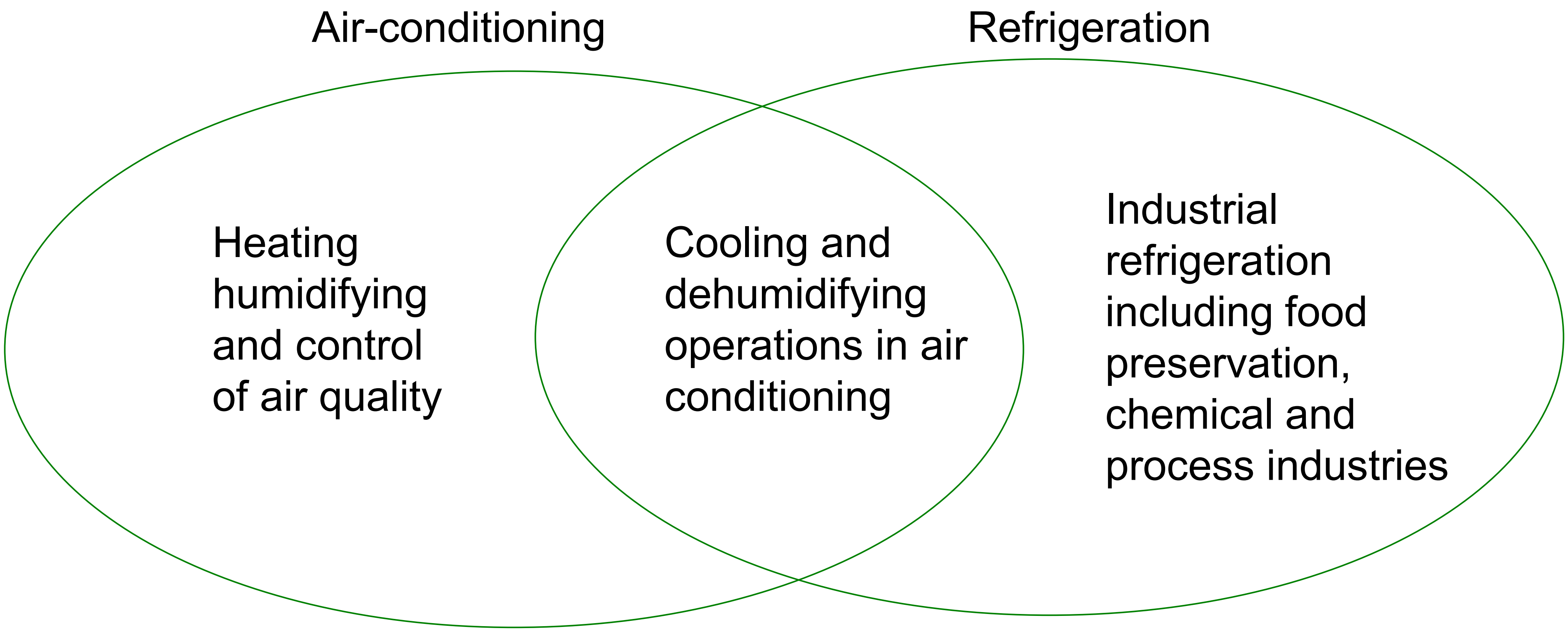
■ Electrical systems ■ Electrical drives ■ HVAC ■ Other Pumping and cooling towers ■ Boiler and steam ■ Compressed air ■ Lighting

*Note: Representing climatic zones – Hot and Dry/Warm and Humid/Composite/Moderate/Tropical

Representing building types Educational, Institutional, Assembly Business, Industrial, Storage, Merchantile

When and Where ?

When and where do we need HVAC systems



Source: BEE India;

When and where do we need HVAC systems

Comfort air conditioning (20^0C-25^0C)

Process cooling – chilled water system (8^0C-10^0C)

Brine systems (sub-zero applications)

Source: BEE India;

How ?

How?

How HVAC system works ?

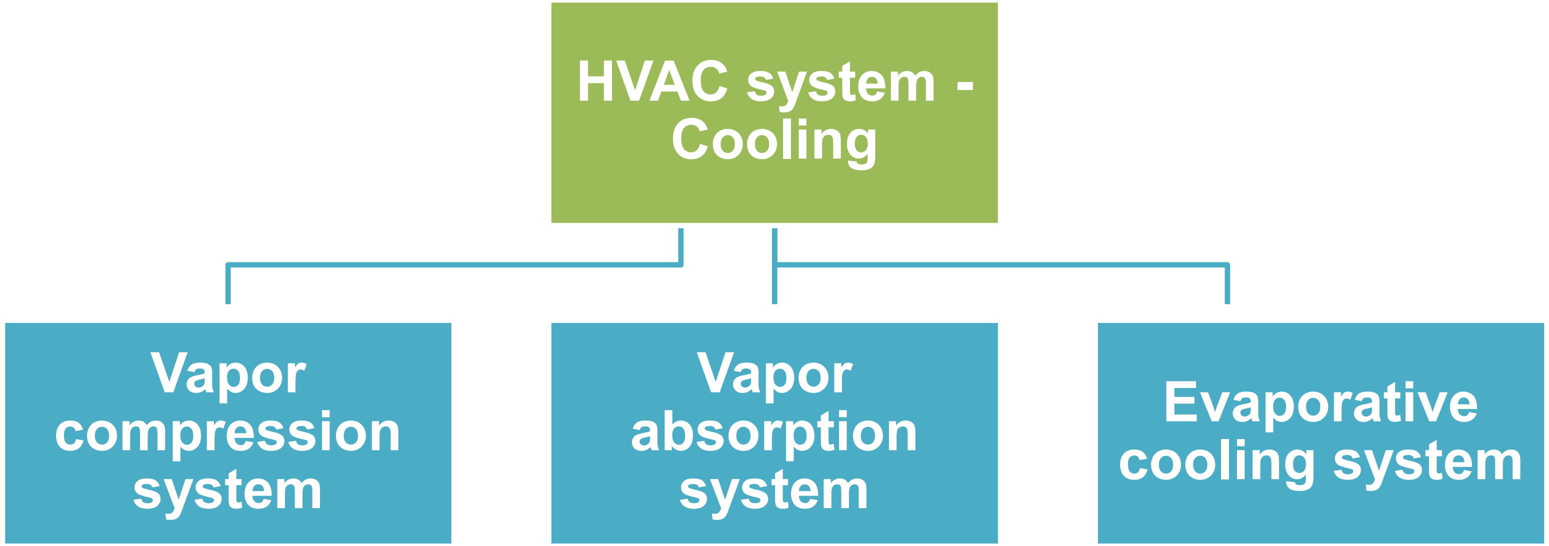
How we assess energy efficiency performance ?

How to save energy ?

Source: BEE India;

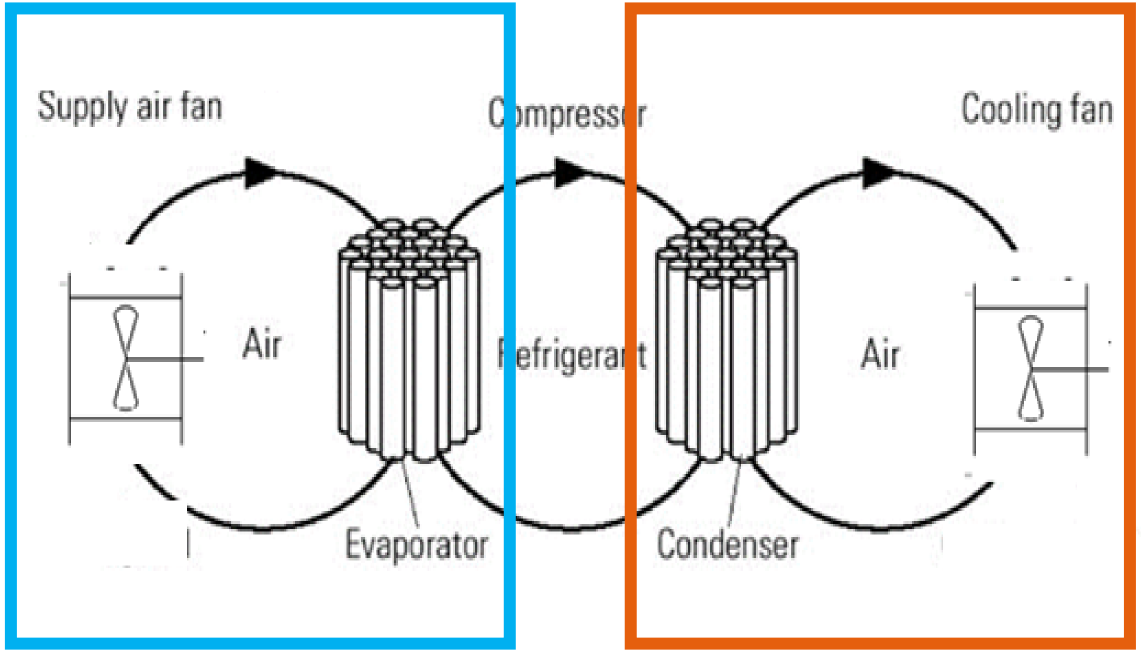
How HVAC system works?

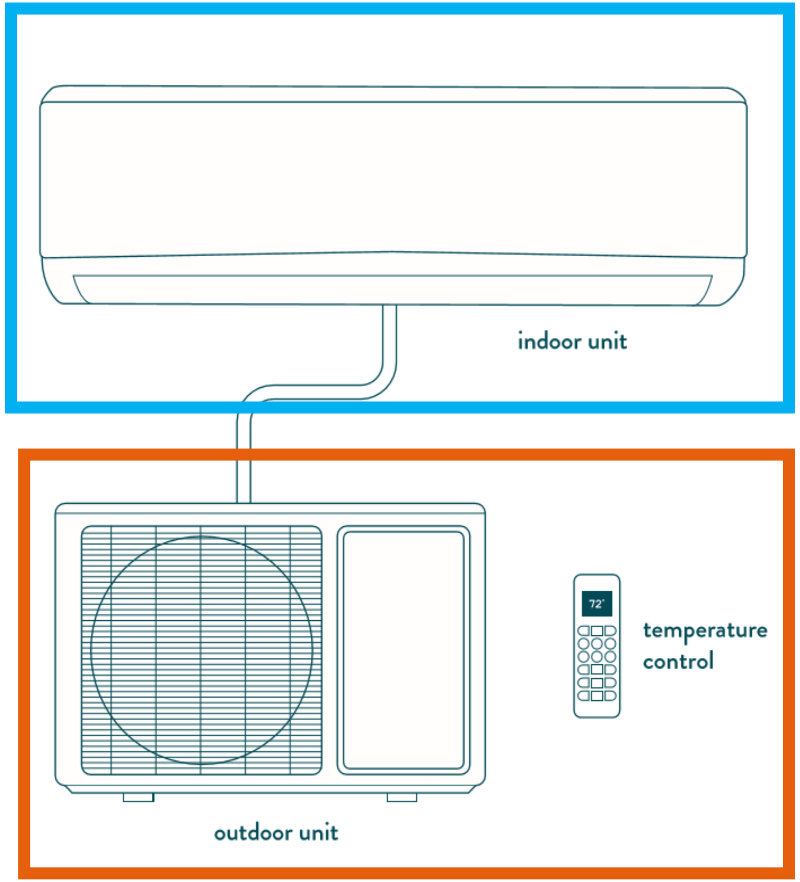
Types – cooling and air conditioning



Vapour compression system – Heat transfer loops

Air cooled system (small capacities, D/X type)

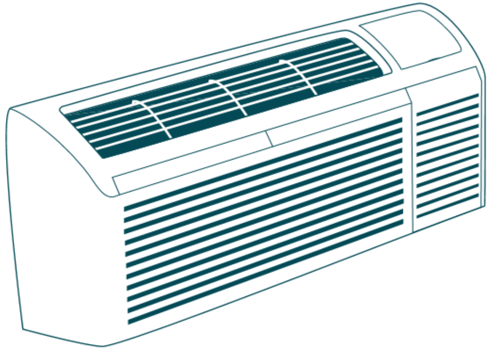




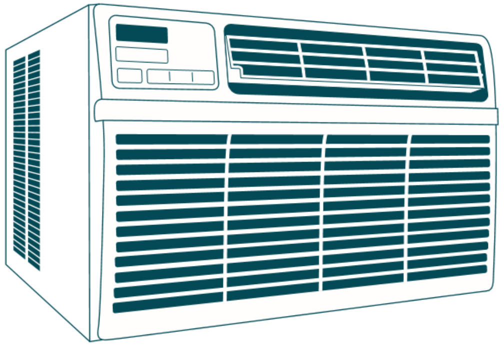
Source: BEE India;

Vapour compression system – Air cooled system (small capacities, D/X type)

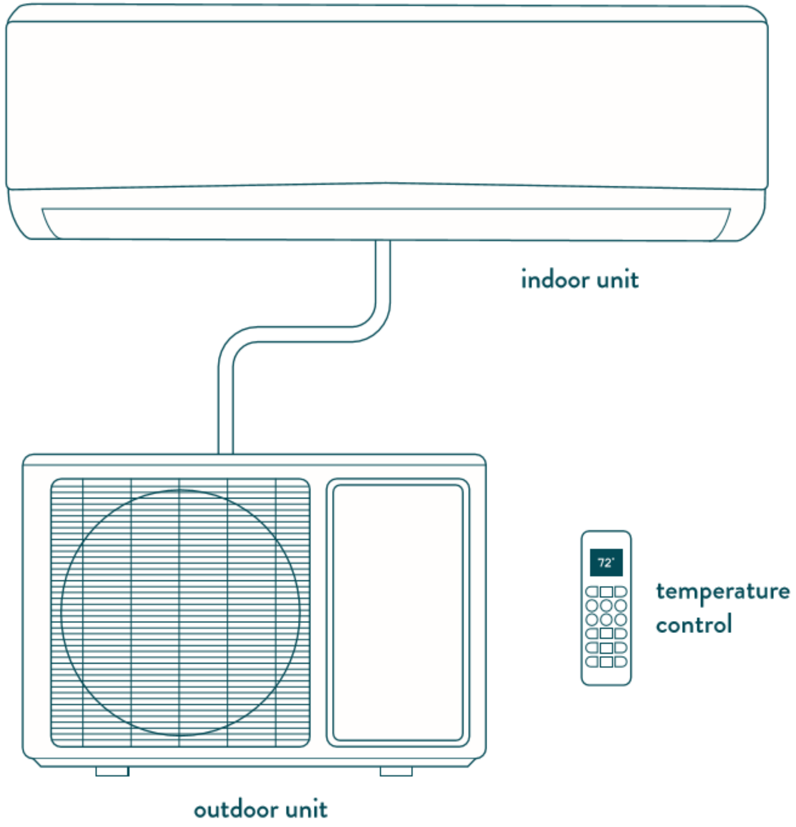
Packaged terminal air-conditioner or heat pump



Window air-conditioner



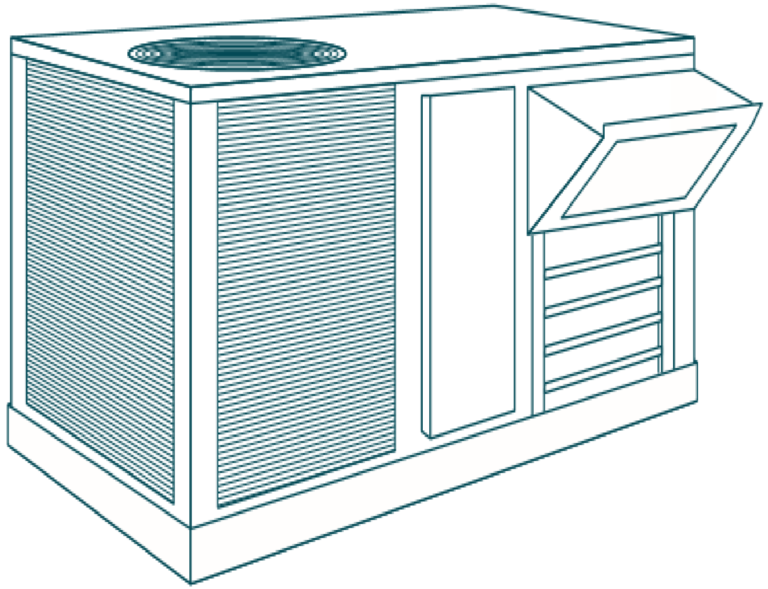
Non-ducted split system AC or heat pump



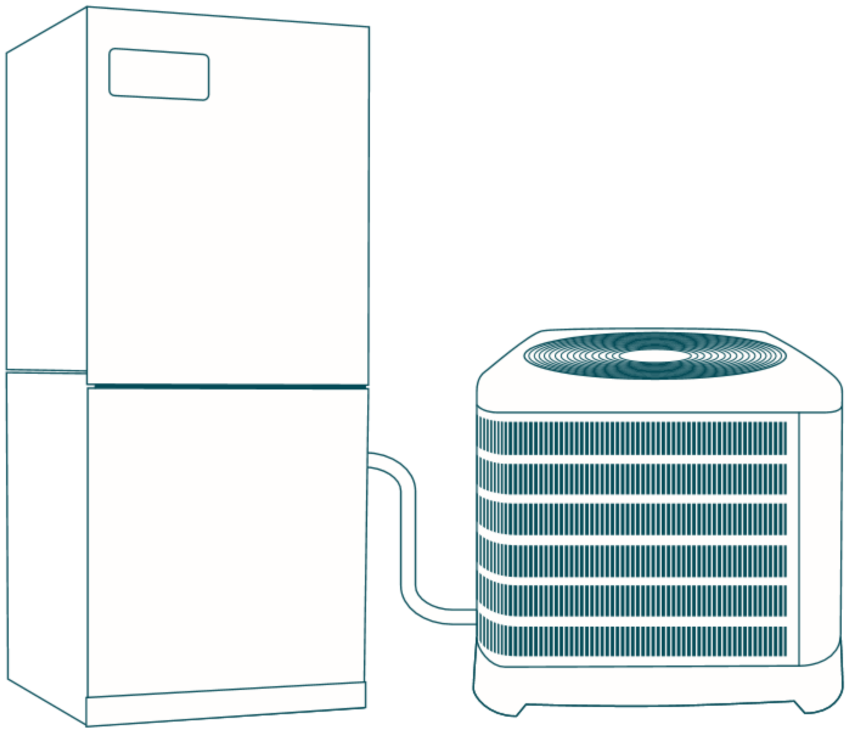
Source: Domestic Air Conditioner Test Standards and Harmonization, IEA 2020

Vapour compression system – Air cooled system (small capacities, D/X type)

Packaged ducted AC or heat pump



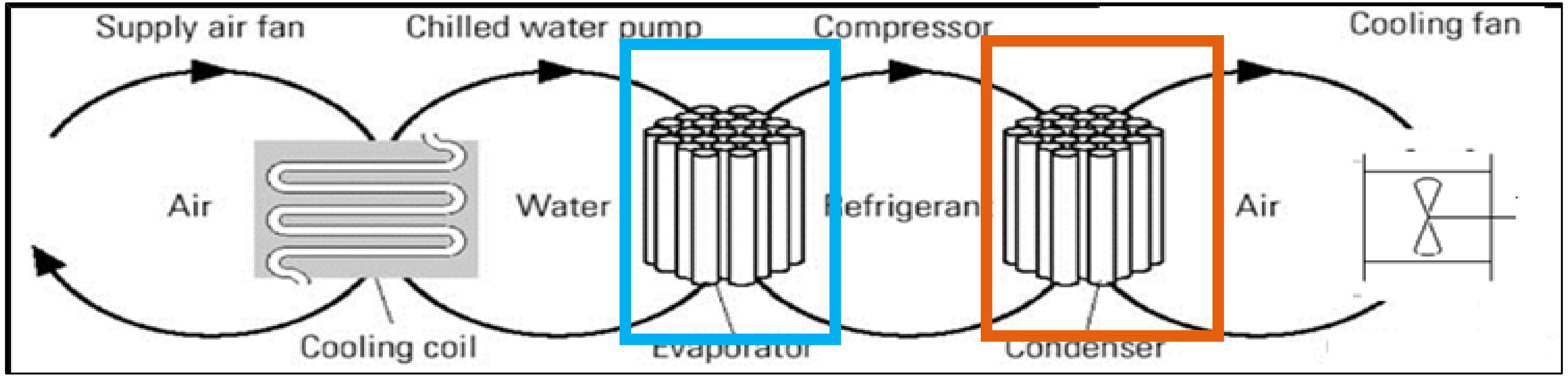
Ducted split system AC or heat pump



Source: Domestic Air Conditioner Test Standards and Harmonization, IEA 2020

Vapour compression system – Heat transfer loops

Air cooled system



Source: [Trane air cooled chiller]

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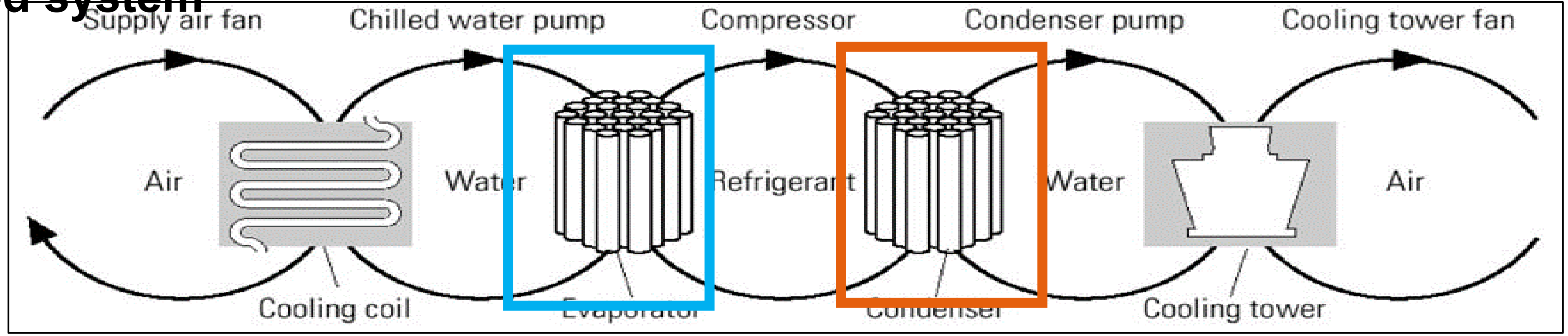
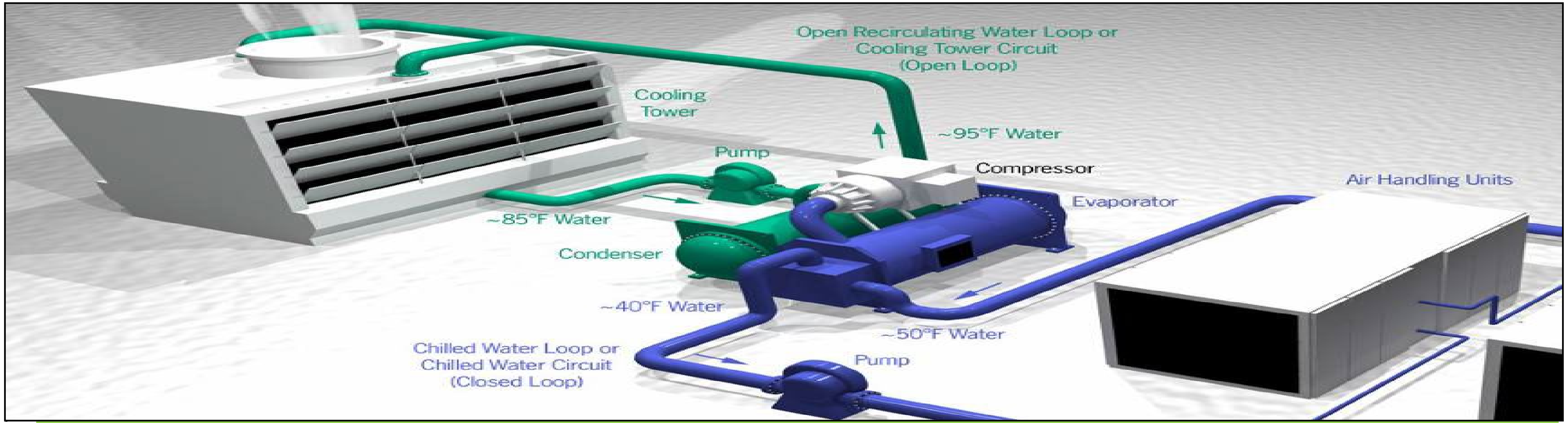
Vapour compression system – Heat transfer loops

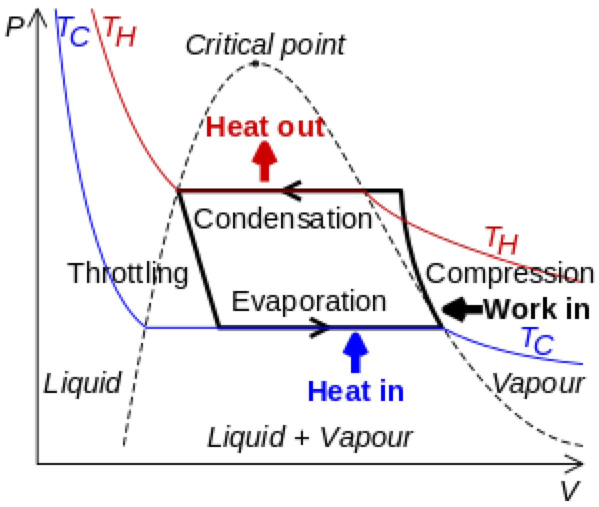
Water cooled system

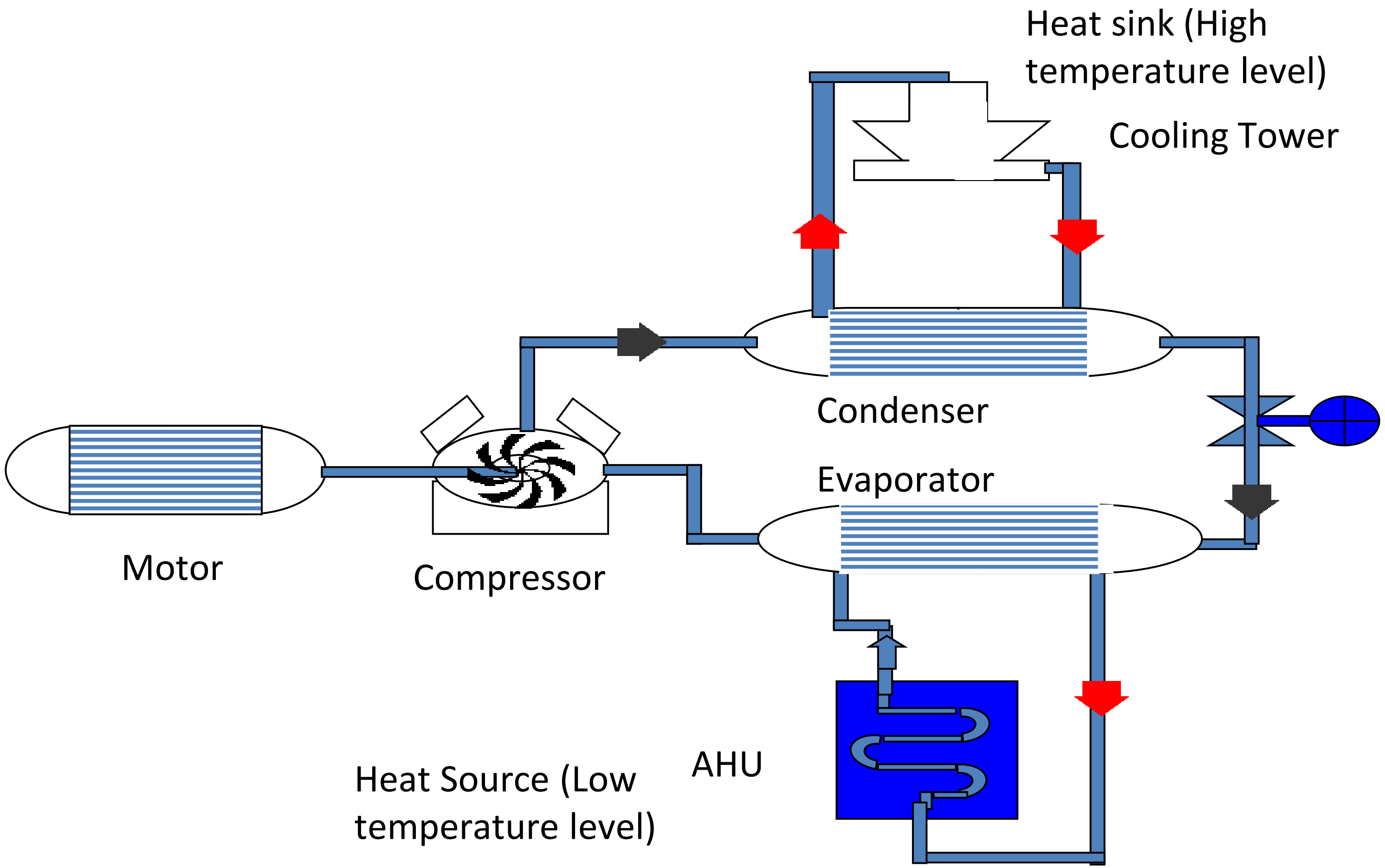




Source: 1. HVAC and Refrigeration system, Bureau of Energy Efficiency, India
2. Hudson Technologies

Vapour compression system



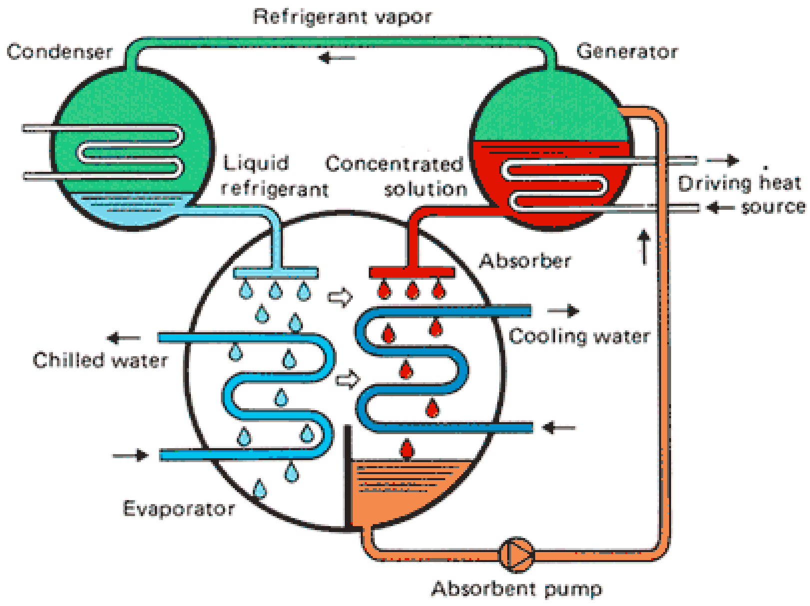


Vapour compression system

Comparison of different types of vapor compression systems

Parameters	Reciprocating	Centrifugal	Screw
1.Refrigeration temp. Range (Brine/water)	+7 to -30°C	+7 to 0°C	+7 to -25°C
2.Sp. Power consumption • Air conditioning • Sub zero temp.	▪ 0.7–0.9 kW/TR ▪ 1.2–2.5 kW/TR	▪ 0.59–0.63 kW/TR	▪ 0.65–0.7 kW/TR ▪ 1.25–2.5 kW/TR
3.Refrigerant *(For complete list)	R_{11}, R_{123}, R_{134A} Ammonia	R_{22}, R_{12}	R_{22}, R_{134A} Ammonia
4.Typical single unit capacity • Air conditioning • Sub zero temp.	▪ Upto 150 TR ▪ 10-50 TR	▪ 250 TR & above	▪ 50-250 TR ▪ 50-200 TR

Vapour Absorption system



Types of VAM

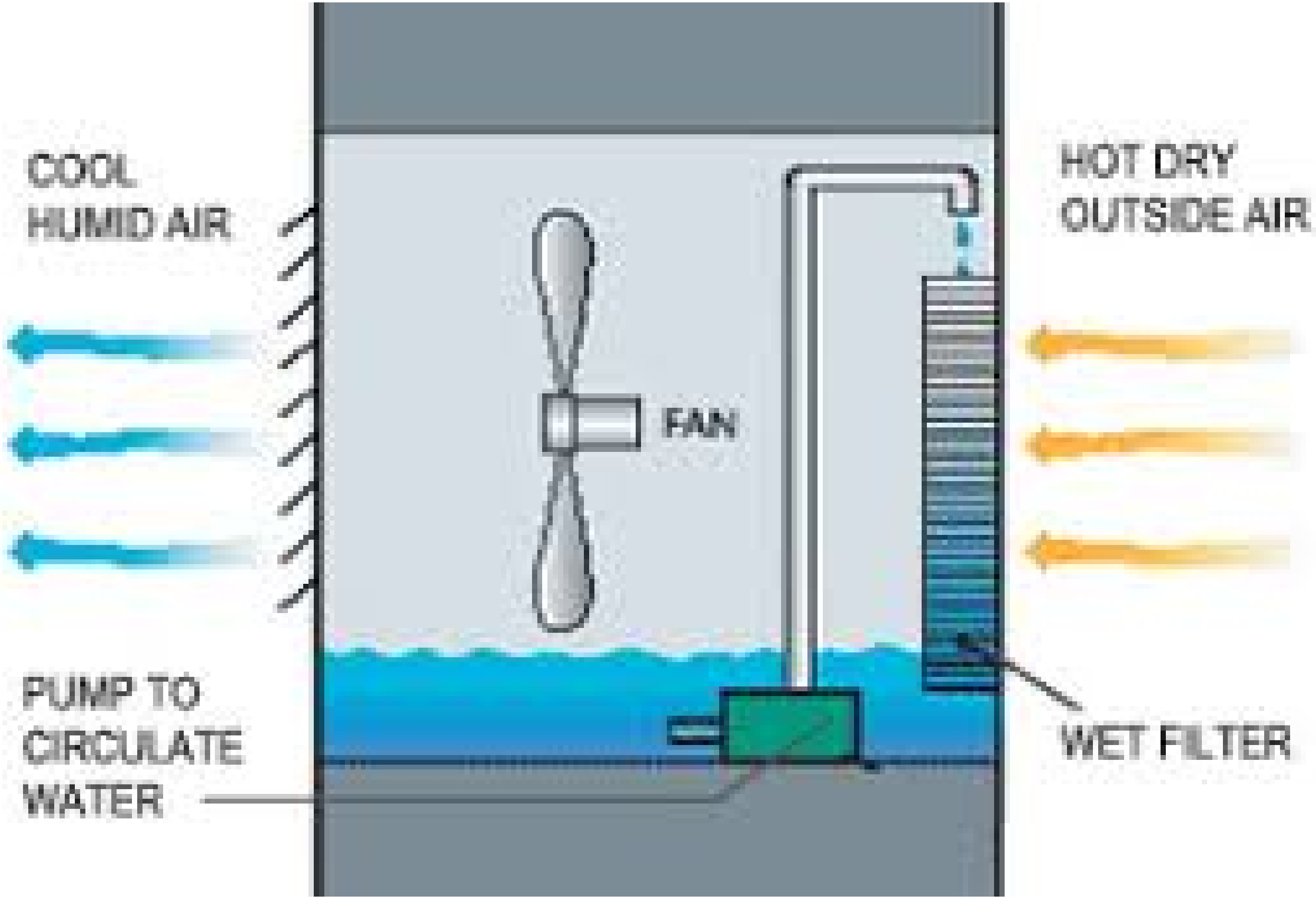
Parameter	Single	Double	Half	Triple	Single (Ammonia)
Refrigeration temp (^{0}C)	Above 6^{0}C				Upto -33^{0}C
Energy input (Heat)	Steam/Hot Water/Hot Oil/Direct fired	Steam/Hot Water/Hot Oil/Direct fired	Hot Water	Steam/Hot Oil/Direct fired	Steam/Hot Water/Hot Oil
Min heat input temp. (^{0}C)	85	130	55	190	85
Energy to TR ratio (kcal/TR)	5000	2575	7500	2000	4615
Refrigerant	Pure water				Pure Ammonia
Absorbent	Water-LiBr solution				Ammonia – LiBr solution
Air conditioning range (TR)	≥30	≥30	≥30	≥50	≥30

VCM vs VAM

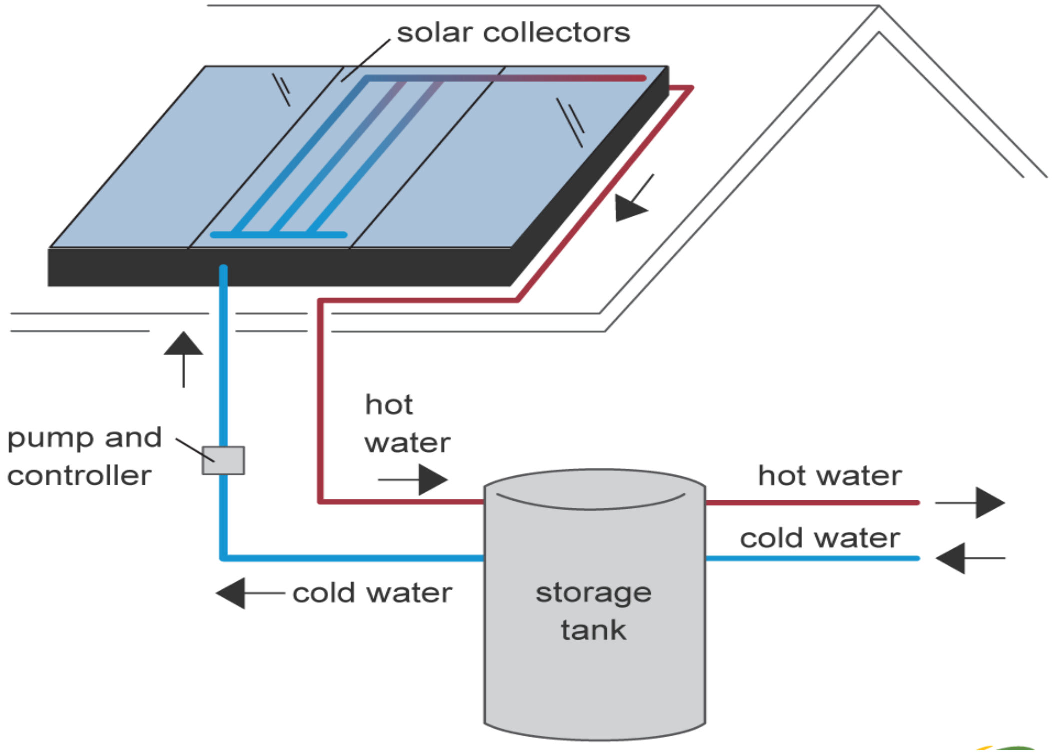
	VCM	VAM
Energy input	Electricity for compressor motor.	Electricity for two small circulating pumps only. Primary input heat energy
COP	4 to 5 for AC applications	Low 1.1 (for 2-stage LiBr machines)
Heat rejection factor	1.2	2.5 (very high – higher CT and pump capacity required)
Life span	Relatively high	Relatively low (LiBr is corrosive in nature)

Use VAM only if you have waste heat or cheaper fuel source

Evaporative cooling



Types - Heating



Simple solar thermal system

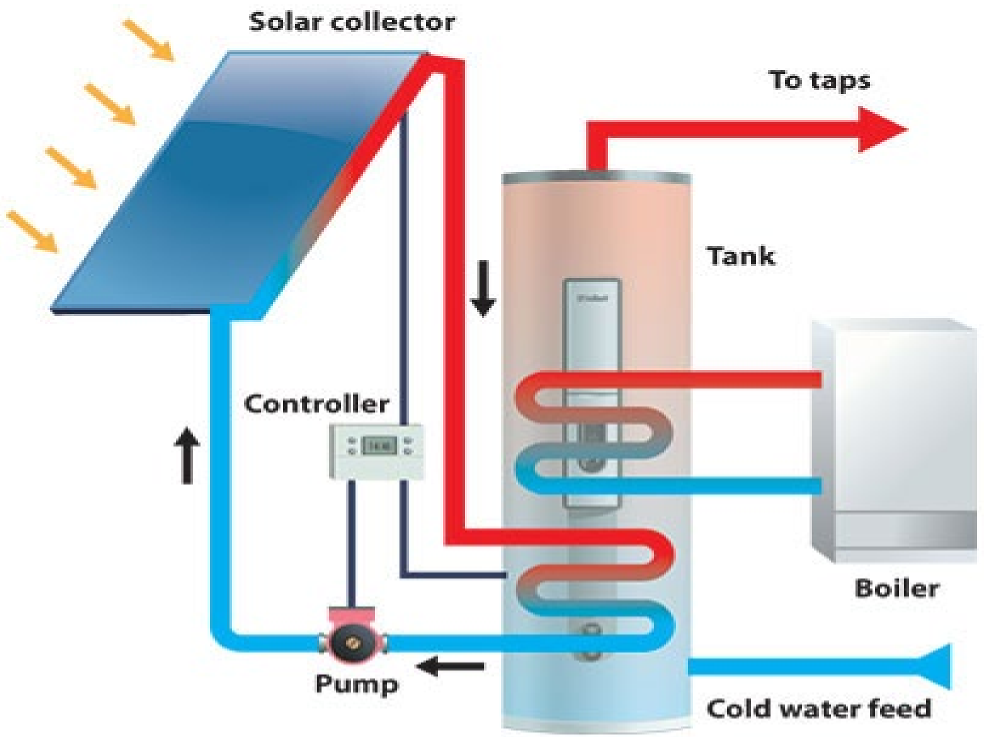
Source: https://images.app.goo.gl/xswD85XiP4UNfFEY6;

Types - Heating

Boilers (gas, electrical, oil/diesel, etc.)

Source: https://images.app.goo.gl/3QjZFGT8zZaF1Wv29;

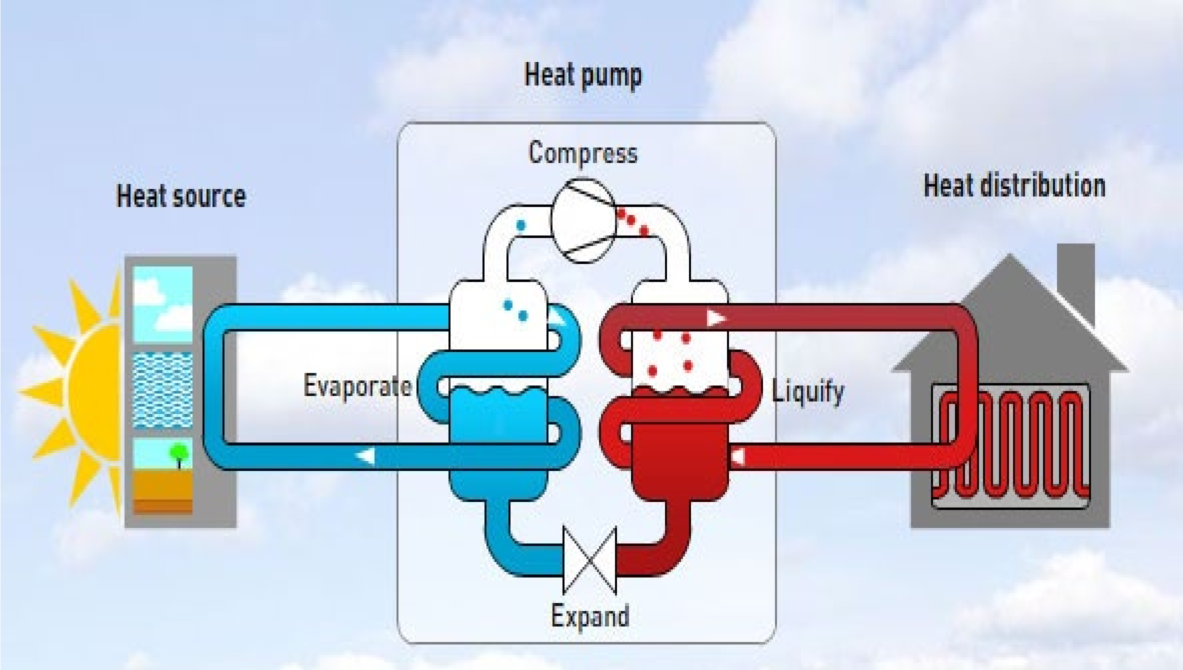
Types - Heating



Solar thermal + boiler integrated system

Source: https://images.app.goo.gl/bqnbZ3KJTxAVb1927;

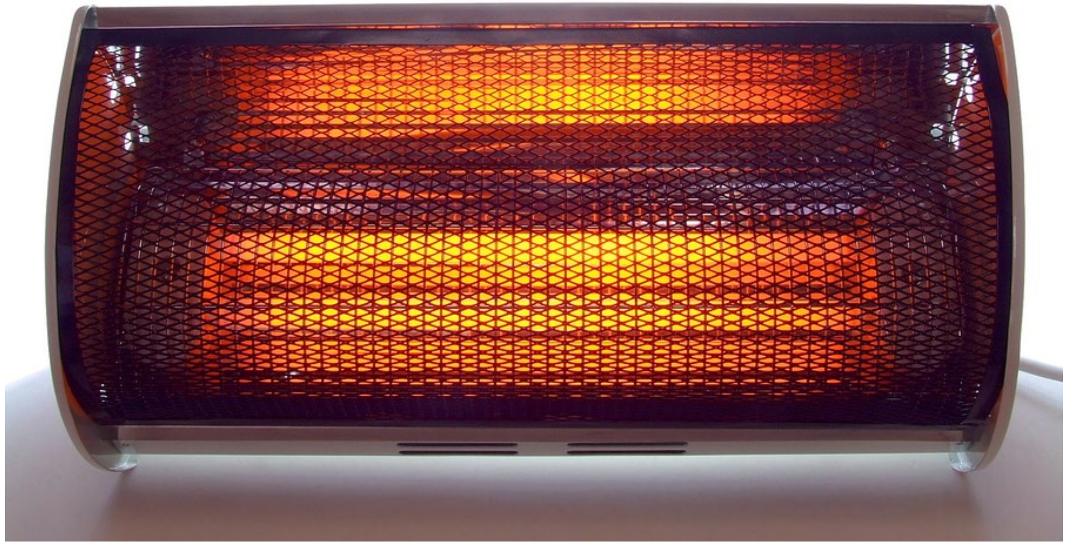
Types - Heating



Heat pumps

Source: https://images.app.goo.gl/vDayAimQhbTCKdcD6; https://images.app.goo.gl/wkreCM6XqTJSeucX8;

Types - Heating

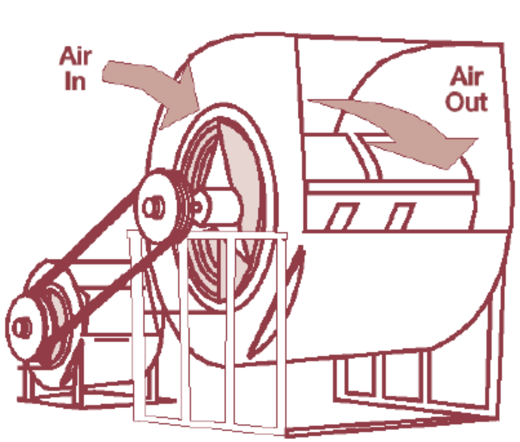


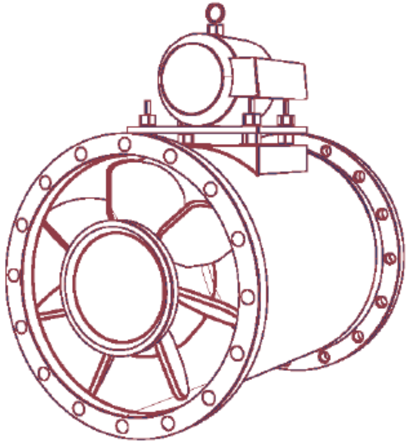
Electrical resistance heaters

Source: https://images.app.goo.gl/RrZHcrqm9A2uktWM7; https://images.app.goo.gl/C3q9LHN1FwBdoxKt6;

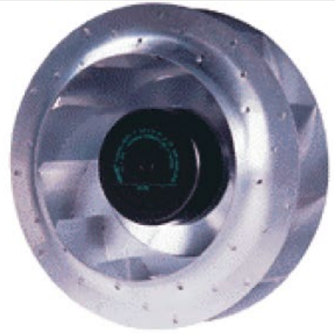
Types - Ventilation

Centrifugal





Axial

Paddle Blade (Radial blade)	Forward Curved (Multi-Vane)	Backward Curved
		

Tube Axial	Vane Axial	Propeller
		

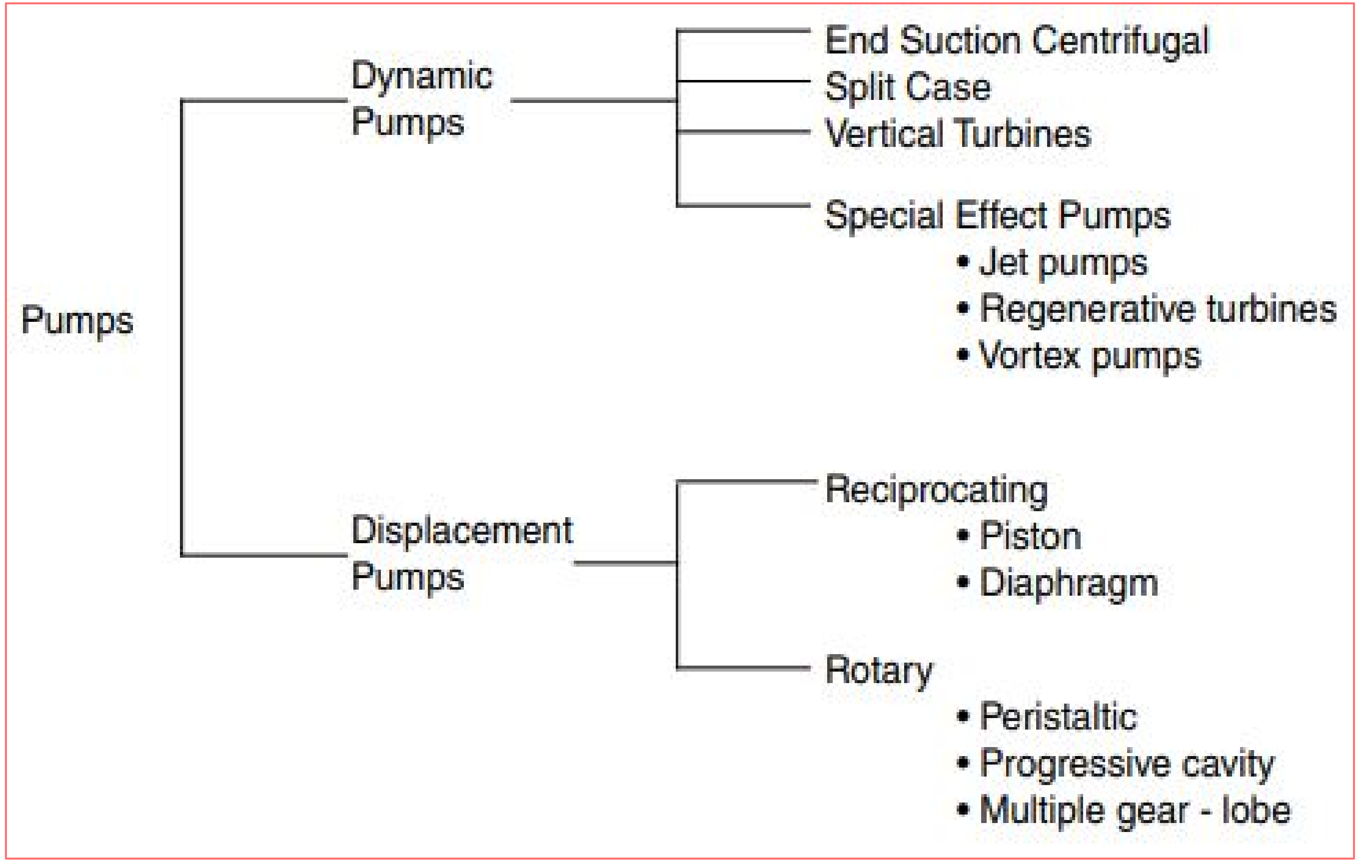
Source: BEE, India

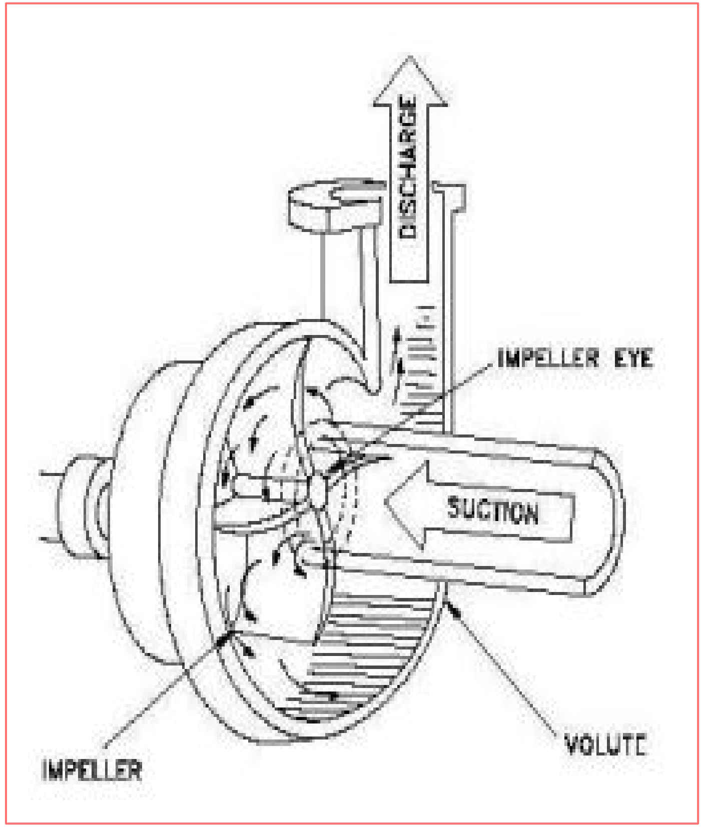
Types - Ventilation

Centrifugal			Axial		
Radial	High pressure / Medium flow	Industrial applications	Propeller	Low pressure, high flow	Air circulation, ventilation, exhaust
Forward curved	Medium pressure, high flow	Low pressure HVAC, packaged units, clean environment	Tube-axial	Medium pressure, high flow	HVAC, exhaust systems, ovens
Backward curved	High pressure, high flow	HVAC, industrial applications	Vane-axial	High pressure, medium flow	High pressure applications, HVAC systems

Source: BEE, India

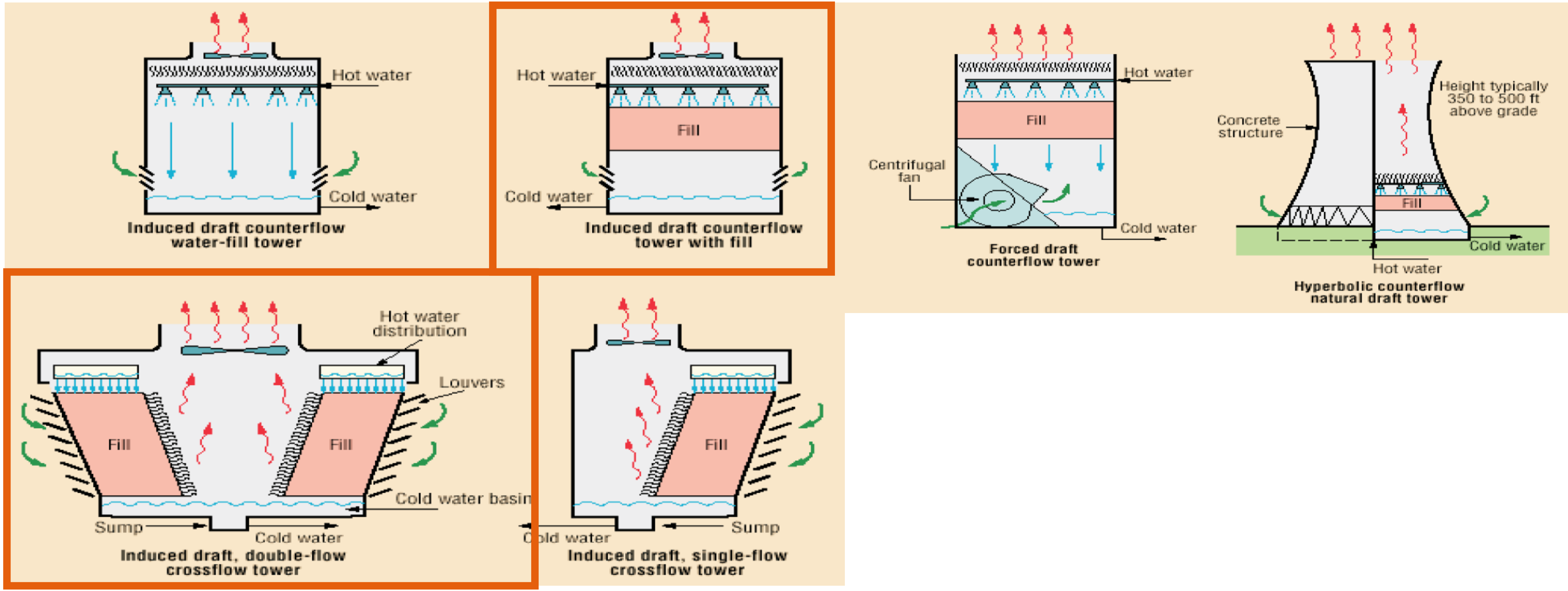
Types - Pumps





Source: BEE, India

Types – Cooling towers



Source: BEE, India

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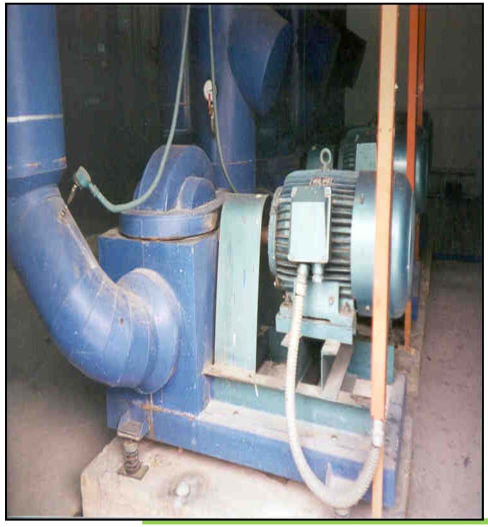
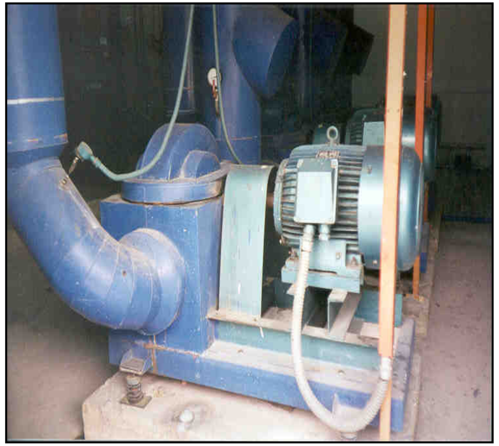
How we assess efficiency performance?

Measurements of HVAC systems





Chiller performance testing

The cooling effect of refrigeration systems is measured in Tonnes of Refrigeration (TR)

A ton of refrigeration is defined as quantity of heat to be removed in order to form 1 ton of ice in 24 hours when the initial temperature of water is 0°C.

1 TR = 3024 kcal/hour = 3.51 kW = 12,000 BTU/hour

Chiller performance testing

Efficiency ratios

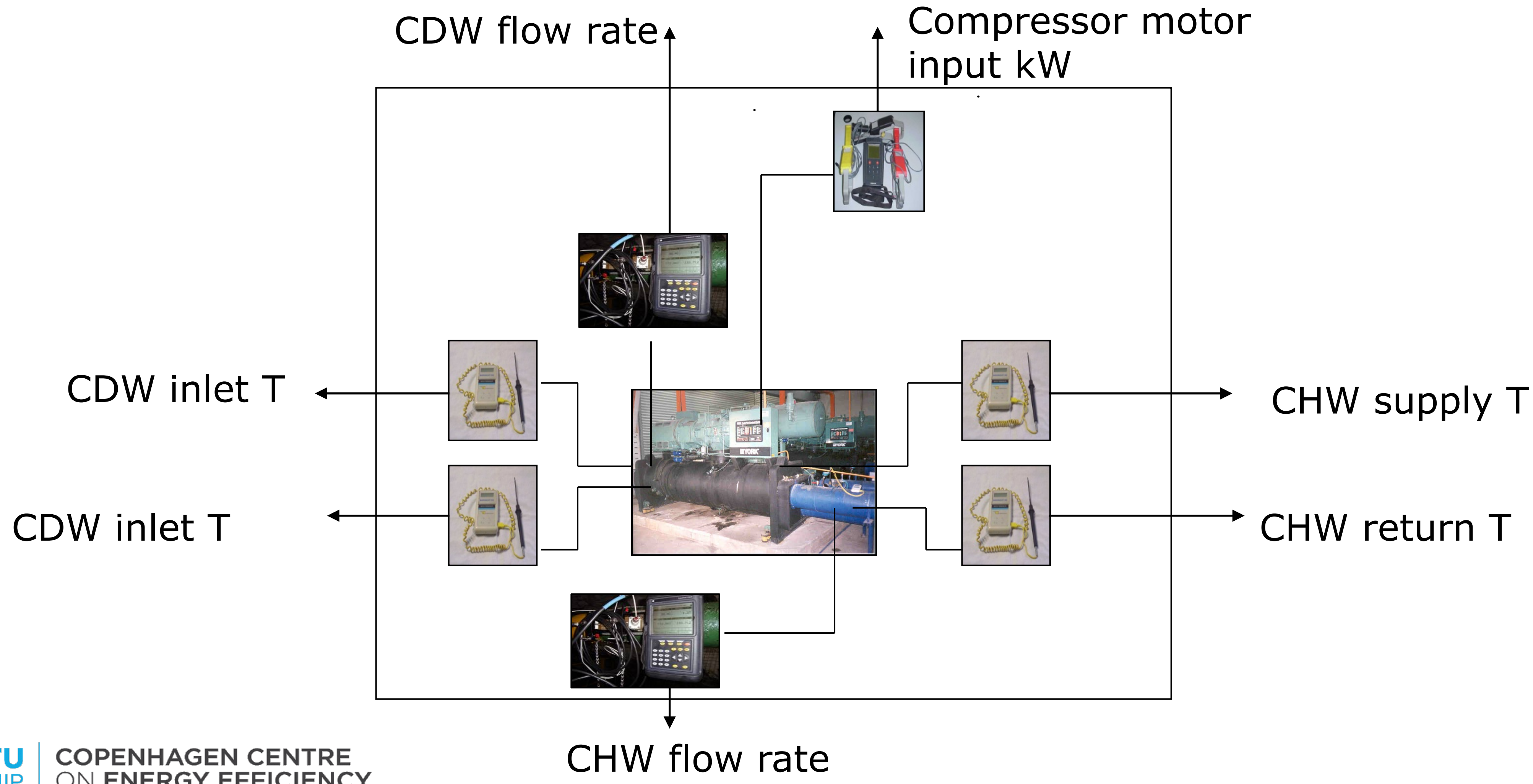
Coefficient of Performance COP = $\frac{Useful\ refrigerating\ effect\ or\ heat\ removed\ (kW)}{Net\ energy\ supply\ from\ external\ sources\ (kW)}$

Energy Efficiency Ratio EER = $\frac{Useful\ refrigerating\ effect\ (\frac{BTU}{hour})}{Work\ done\ (W)}$

Specific Power Consumption SPC = $\frac{Power\ consumption\ (kW)}{Refrigeration\ effect\ (TR)}$

kW/TR = $\frac{12}{Energy\ Efficiency\ Ratio\ (EER)} = \frac{3.516}{Coefficient\ of\ Performance\ (COP)}$

Chiller performance testing



Chiller performance testing

Chiller

$$TR = \frac{FlowRate\left(\frac{kg}{h}\right) \times SpecificHeat\left(\frac{kcal}{kg^{0}C}\right) \times Temp.difference\ (°C)}{3024}$$

Cooling coil

$$TR = \frac{AirFlow\left(\frac{m^3}{h}\right) \times Density\left(\frac{kg}{m^3}\right) \times Enthalpy.difference\ \left(\frac{kcal}{kg}\right)}{3024}$$

Chiller performance testing

- Screw chiller : 250 TR
- Chilled water flow rate : 42 lps
- Inlet water temperature : 12.2°C
- Outlet water temperature : 7.2°C
- Refrigeration capacity : $\frac{42 \times 3600 \times 1 \times (12.2 - 7.2)}{3024} = 250\ TR$

Power consumption : 403.2 kW

Specific power consumption : $\frac{403.2}{250} \frac{kW}{TR} = 0.62 \frac{kW}{TR}$

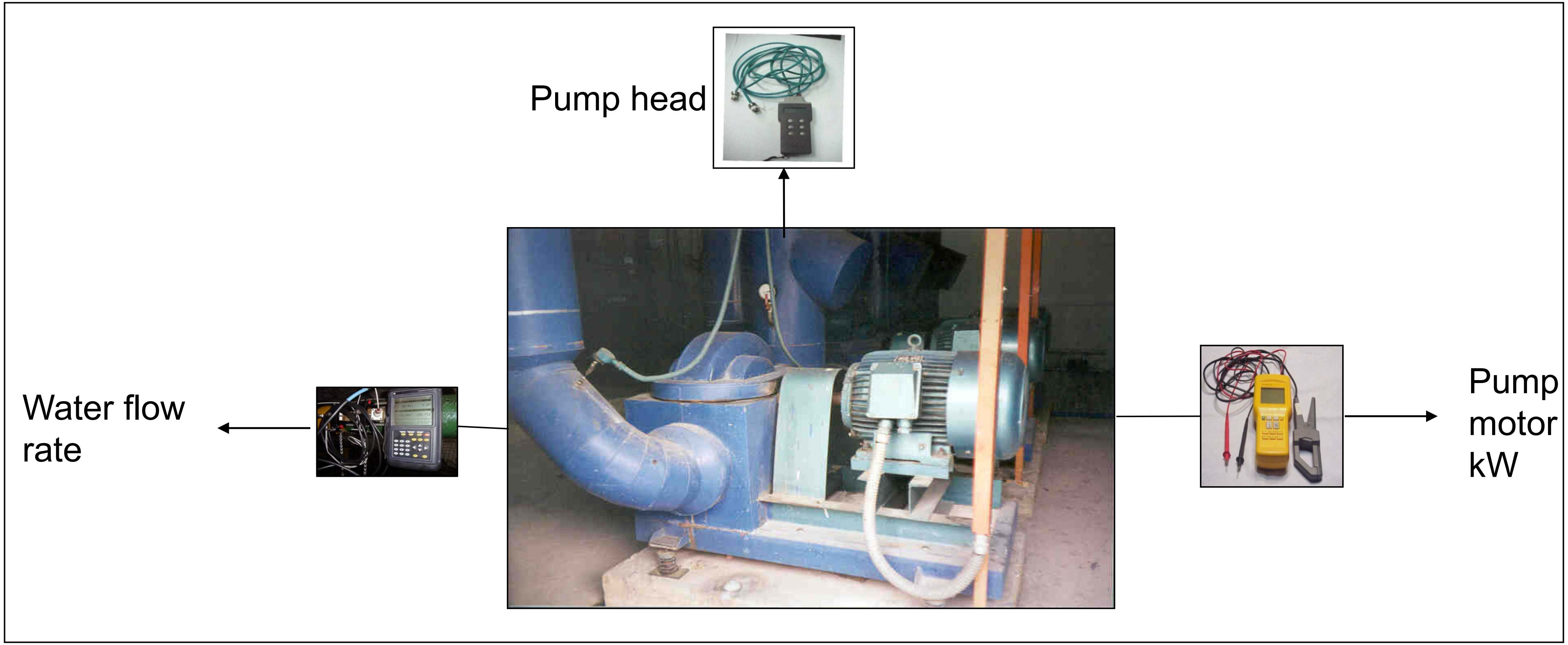
Chiller performance testing

Cooling load estimation

- Small office cabins - 0.1 TR/m²
- Medium size office - 0.06 TR/m²
- Large multi-storeyed office - 0.04 TR/m²

Note: for indicative purpose only. Cannot be taken as a basis for any investment grade activities.

Pump performance testing



Pump performance testing

Pump efficiency

$$\text{Pump Efficiency} = \frac{\textit{Hydraulic Power}, P_h}{\textit{Power Input to the pump shaft}} X100$$

Hydraulic Power, P_h (kW) = Q X (Hd – Hs) X ρ X g/1000

Q = Volume flow rate (m^3/s)

ρ = Density of fluid (kg/m^3)

g = Acceleration due to gravity (m/s^2)

Hd = Discharge pressure (meter)

Hs = Suction pressure (meter)

Power Input to the pump shaft = Drive input power X Motor efficiency,%

Pump performance testing

Pump efficiency

Pump operating parameters

Q = 350 m^3/h, ρ = 1000 kg/m^3, g = 9.81m/s^2

Discharge pressure = 30 meter,

Suction pressure = 3 meter,

Total Head = (30 – 3) = 27 meter,

Input Power = 35kW

Motor efficiency = 92%

$$\text{Pump } \eta = \frac{\dfrac{\left(\frac{350}{3600}\right) X\ 27\ X\ 1000\ X\ 9.81}{1000}}{35\ X\ \left(\frac{92}{100}\right)} X100$$

Pump η = 80%

Pump performance testing

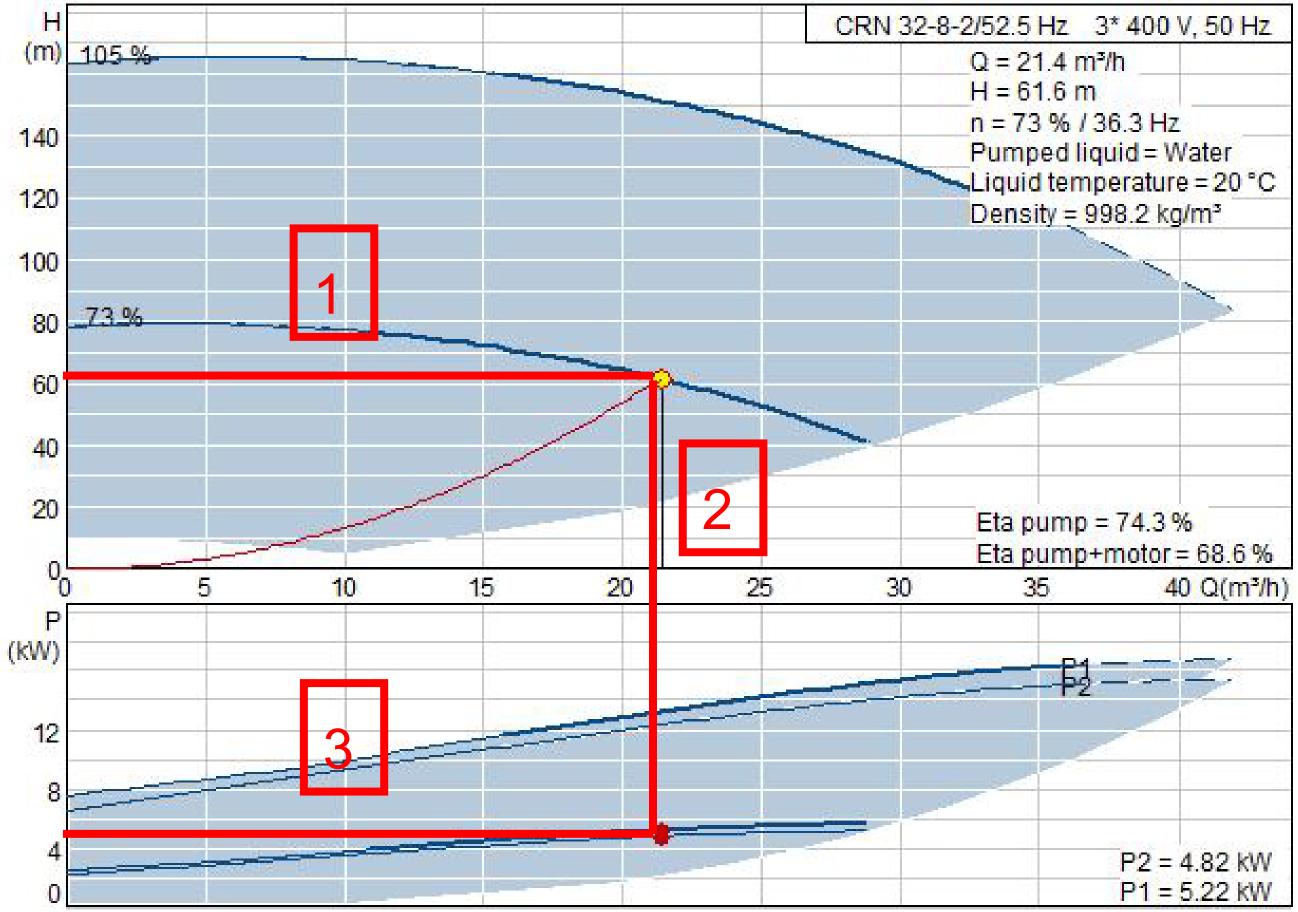
Pump performance curve

Q = 21.4 m^3/h,

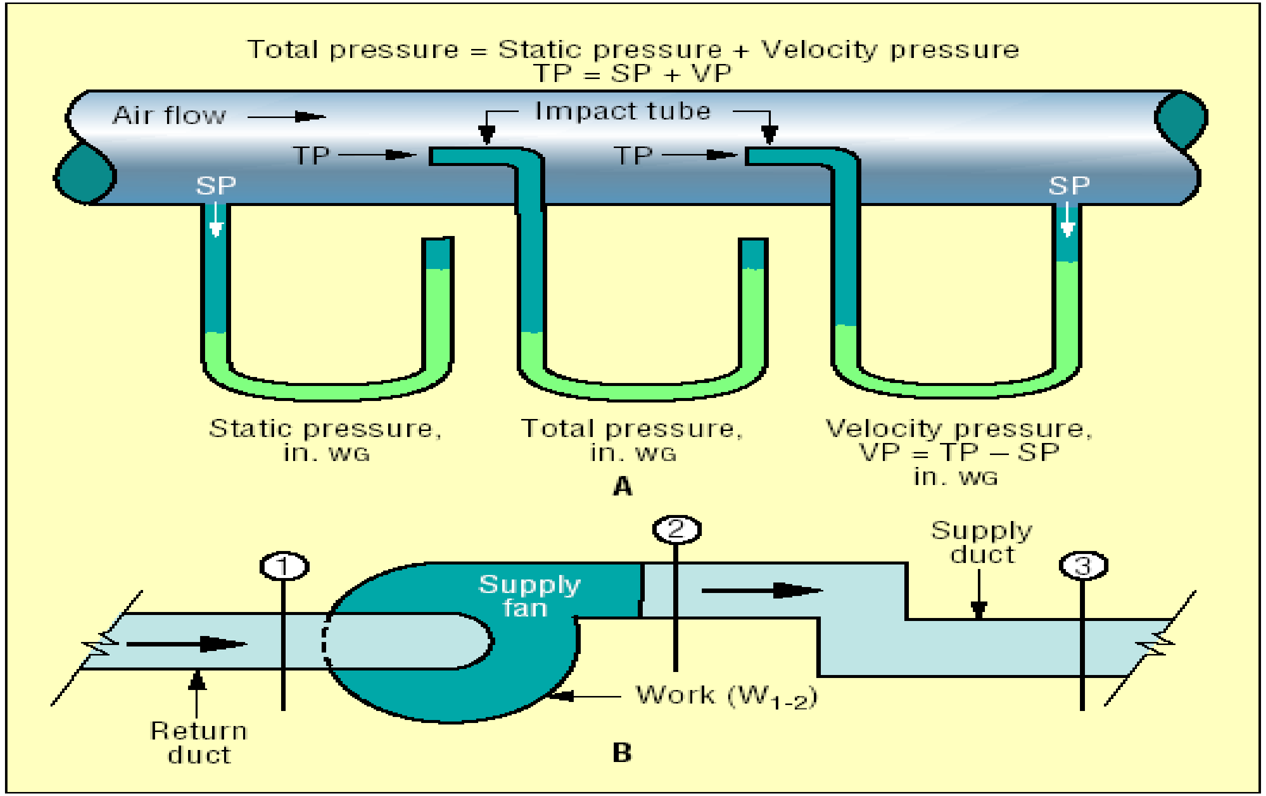
H = 61.6 m

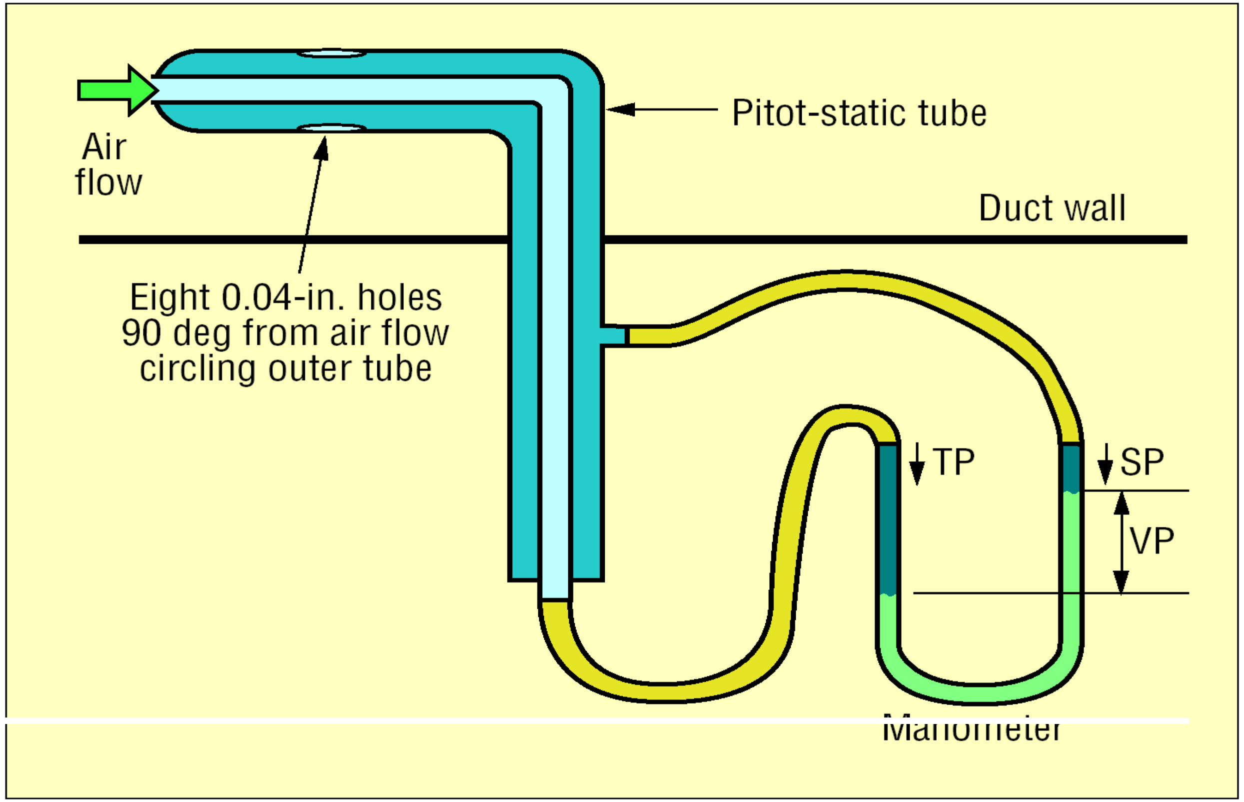
P = 5.2 kW

Pump efficiency = 73%



Fan & Blower performance testing





Source: BEE, India

Fan & Blower performance testing

$\rho_2 = \rho_1 \times \frac{T_1}{T_2} \times \frac{P_1}{P_2}$

ρ: Density, kg/m^3
P: Pressure, mm Wg (kg/m^2)
T: Temperature, Kelvin

Suffix -1 represents parameters at NTP

ρ_1= 1.29 kg/Nm^3
P_1= 1 bar = 10330 mm wg
T_1= 0 °C = 273 K

Suffix – 2 represents measured parameters at sample point

Velocity $V = C \times \frac{\sqrt{2 \times g \times h}}{\rho}$

Where,
C: Pitot factor
g: Acceleration due to gravity, 9.81 m/s^2
h: Dynamic pressure, mm Wg (kg/m^2)
r: Density at sample point, kg/m^3

If the inlet side is not ducted, then the velocity can be obtained directly by using an Anemometer.

Source: BEE, India

Fan & Blower performance testing

Flow, Q m^3/s = A x V

A= cross sectional area (m^2), $\frac{\pi \times Duct\ diameter^2}{4}$

or height x width

V = Velocity (m/s)

Air Horse power, kW $= \frac{Q \times \Delta Pt \times g}{1000}$

Q: Flow in m^3 / sec

H: Head in m

ΔPt: Total pressure rise in mm wg (kg/m^2)

g: Acceleration due to gravity, 9.81m/s^2

Shaft Horse Power (SHP), kW

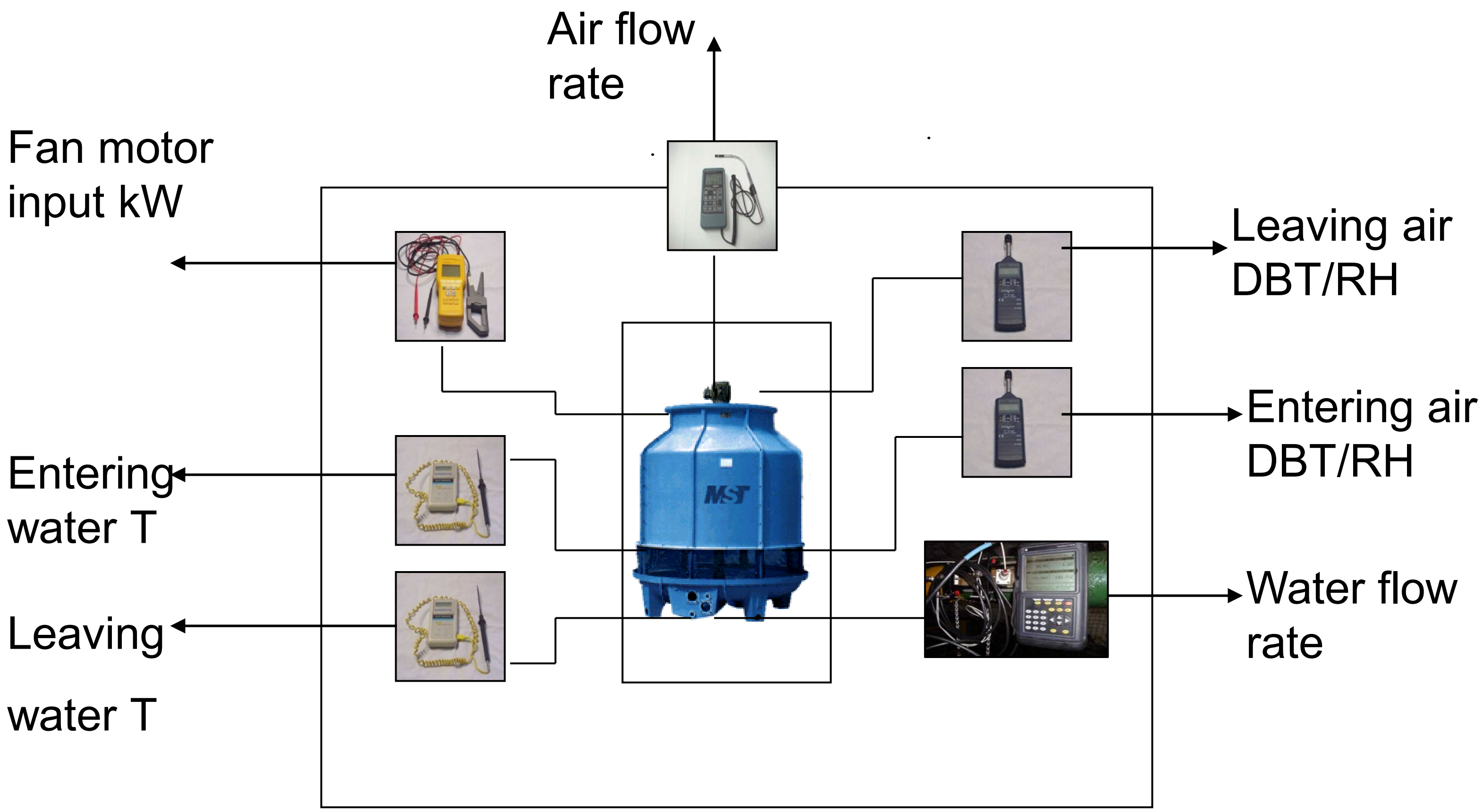
= Motor input power, kW x η motor

(η motor = Efficiency of motor)

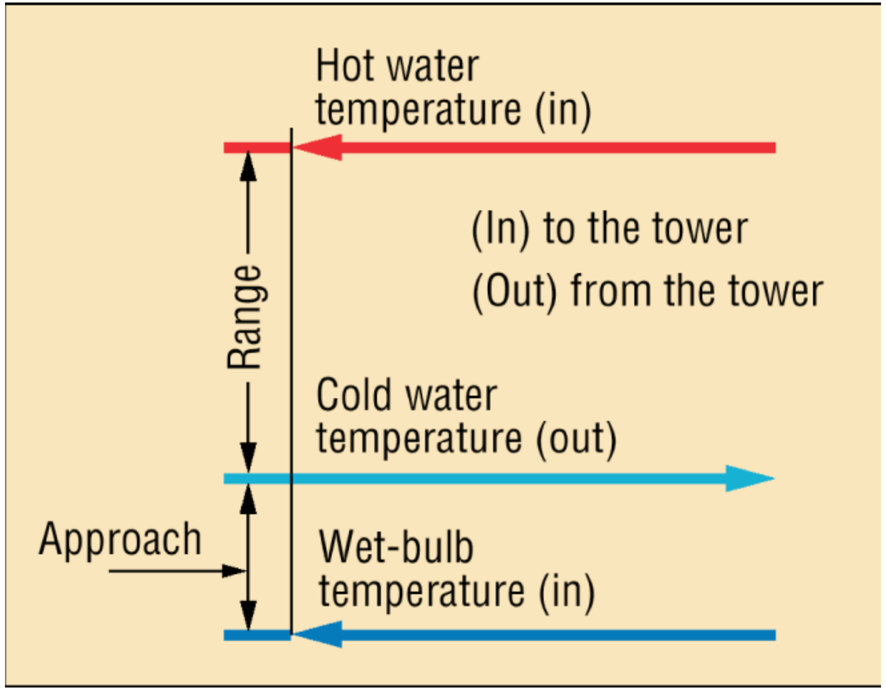
Fan efficiency $\eta = \frac{AHP}{SHP}$

Source: BEE, India

Cooling tower performance testing



Cooling tower performance testing



Source: BEE, India

$$Range = T(hot) - T(cold)$$

$$Approach = T(cold) - T(wet\ bulb)$$

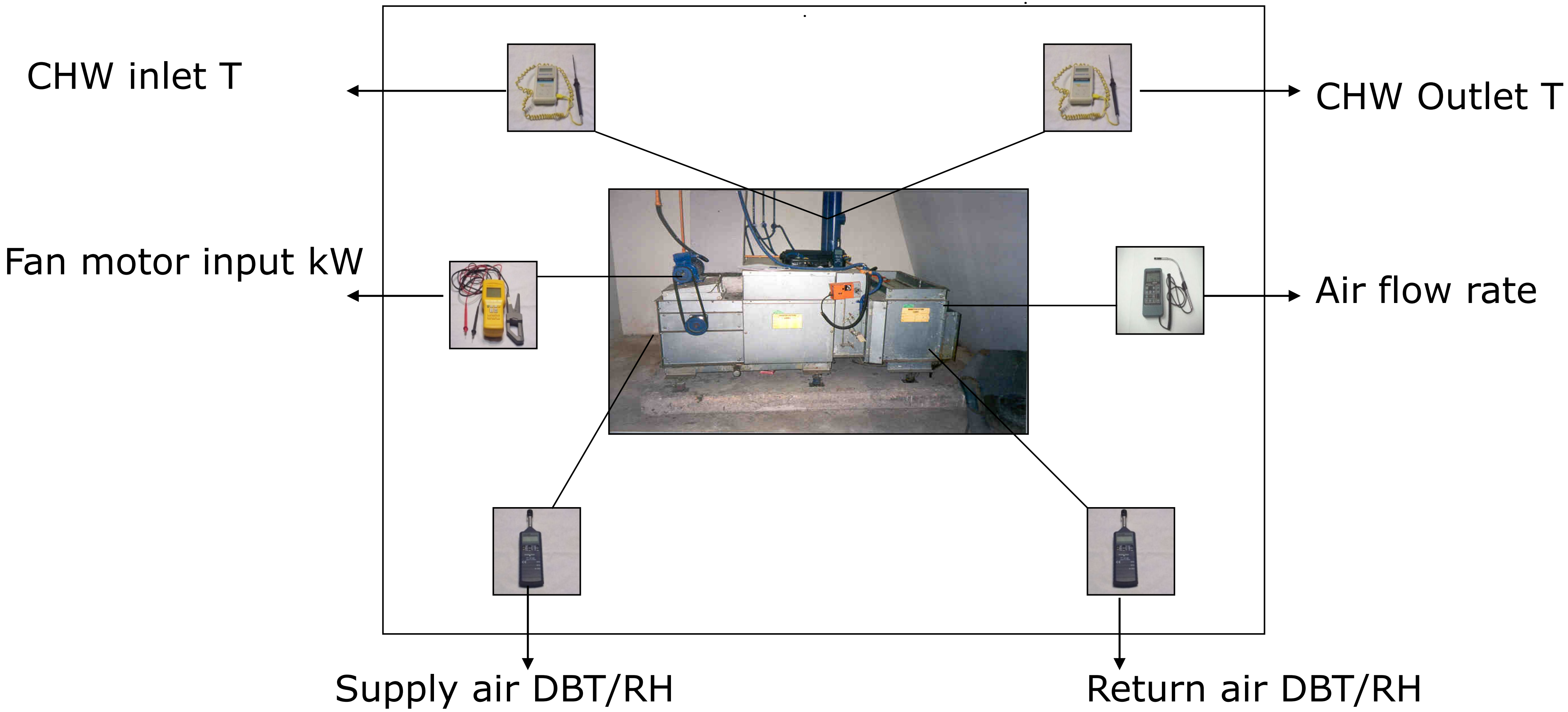
$$Effectiveness = \frac{Range}{Range + Approach}$$

$$Evaporation\ loss \left(\frac{m3}{hr}\right)$$

$$= 0.00085 \times 1.8 \times circulation\ rate\ (\frac{m3}{hr})$$

$$\times (Tin - Tout)$$

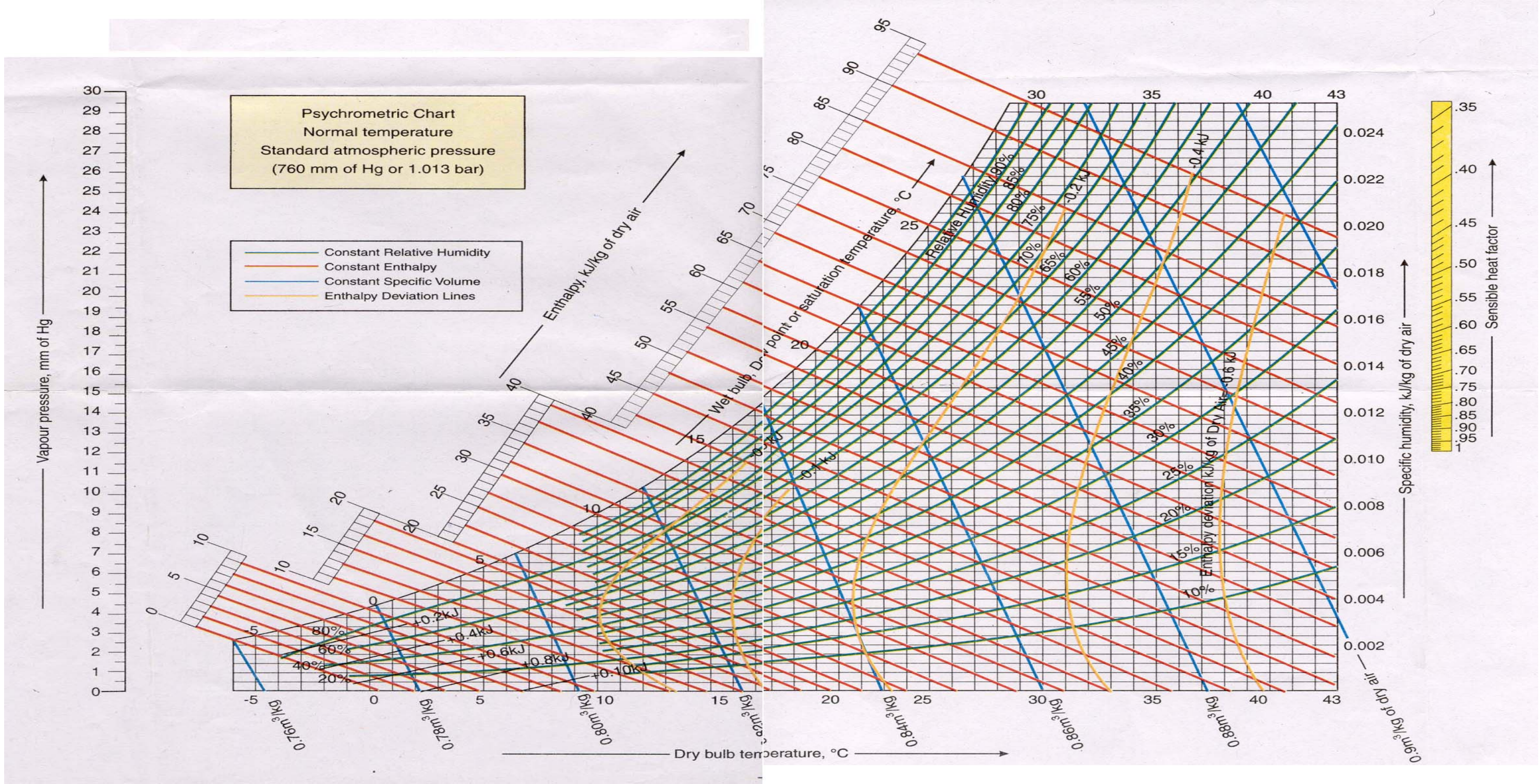
AHU Performance testing



AHU / package / DX unit performance testing

Inlet air flow	: 21665 m^3/h (6.02 m^3/s)
Entering air	: 24.2°DBT, 17.2 °C WBT, 51.5% RH
Entering air enthalpy	: 52 kJ/kg
Leaving air	: 14.0°DBT, 12.5 °C WBT, 85% RH
Leaving air enthalpy	: 38 kJ/kg
Entering air density	: 1.05 kg/m^3
Tons of refrigeration	: $21665 \times 1.05 \times \frac{(52-38)}{(3024 \times 4.18)} = 25.2\ TR$

AHU / package / DX unit performance testing



UNEP DTU PARTNERSHIP | COPENHAGEN CENTRE ON ENERGY EFFICIENCY SEforALL EE HUB

Heat pump performance

$$COP = \frac{Q\ useful\ heat}{Q\ electric}$$

If a heat pump releases 4 kW of heat and consumes 1 kW of electric power then

$$COP = \frac{4kW}{1\ kW} = 4.0$$

Boiler performance testing

$$Boiler\ efficiency(\eta) = \frac{Heat\ output}{Heat\ input} \times 100$$

$$= \frac{Heat\ in\ steam\ output\ (kcals)}{Heat\ in\ fuel\ input\ (kcals)} \times 100$$

$$= \frac{Ms \times (Hs - Hf)}{Qc \times GCV} \times 100$$

Example:

$$\frac{6000\frac{kg}{h} \times (662 - 32)\frac{kcal}{kg}}{1200\frac{kg}{h} \times 4930\frac{kcal}{kg}} \times 100 = 63.9\%$$

Parameters to be monitored:

- Quantity of steam generated per hour (**Ms**) in kg/h
- Quantity of fuel used per hour (**Qc**) in kg/h
- Working pressure (in kg/cm^2(g)) and steam temperature (^{o} C), corresponding enthalpy (**Hs**) in Kcal/kg
- The temperature of feed water (^{o} C) and corresponding enthalpy **(Hf)** in kcal/kg
- Type of fuel and gross calorific value of the fuel (**GCV**) in kcal/kg of fuel .

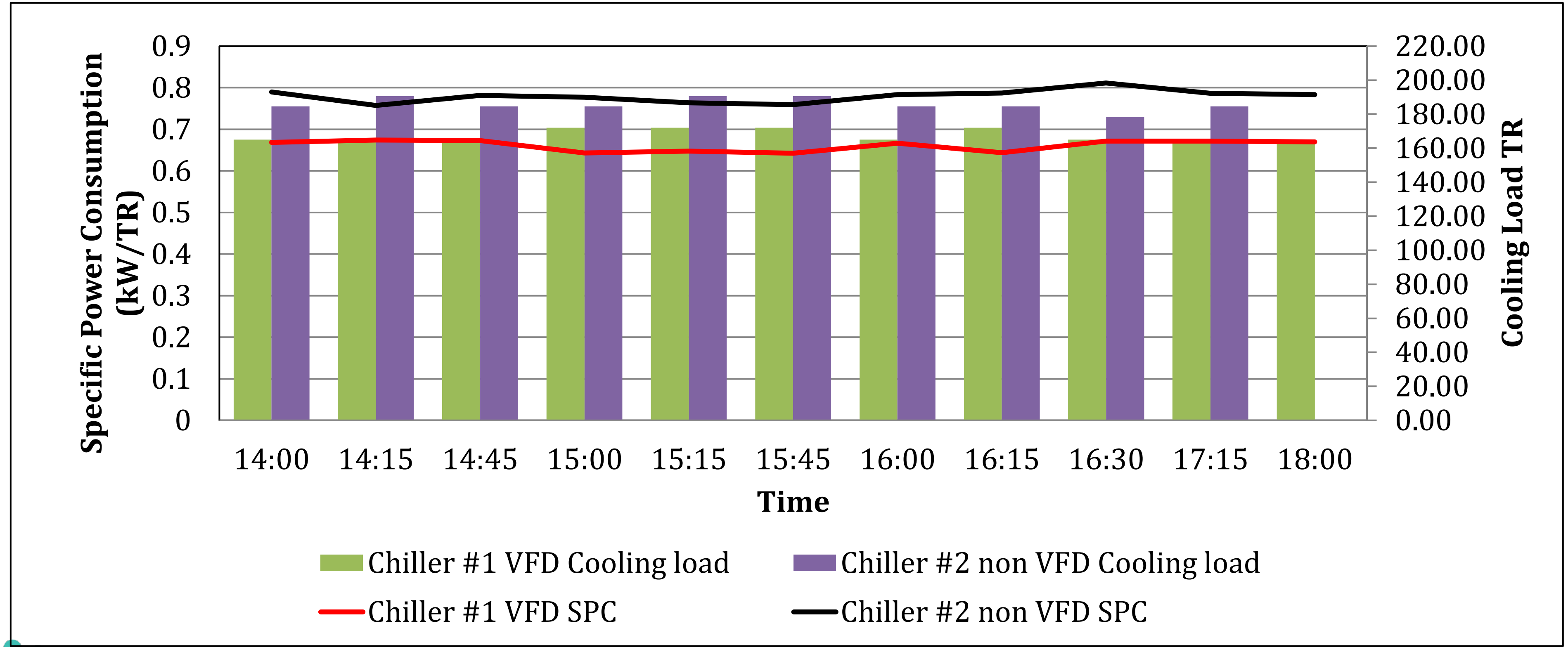
How to save energy?

EE measures – air conditioning and refrigeration

- Follow best energy labelling standards available
- User of inverter integrated products.
- Maintenance of heat exchanger surfaces (evaporator, condenser, cooling coils)
- Matching capacity to system load
- Capacity control
- Chilled water storage

Case: Chiller operations with VFD

Specific Power Consumption (SPC) and Cooling load details comparison of Chiller #1 (VFD) and Chiller #2 (non-VFD)



Annual energy savings with VFD : 2.2 Lakh kWh

EE measures – air conditioning and refrigeration

- Economic insulation thickness - cold insulation
- Adoption of roof coatings/false ceiling/sun control films
- Adoption of variable air volume (VAV’s)/air curtains
- Adoption of pre-cooling fresh air / optimum no. of air changes
- Reducing heat loads in conditioned space
- Heat recovery units and recuperators

EE measures – air conditioning and refrigeration

Capacity control types for vapour compression systems

Parameters	Reciprocating	Centrifugal	Screw
Capacity controls	▪ on/off (small)	▪ Inlet guide vane (IGV)	▪ Slide valve
	▪ Unloading of cylinders	▪ Variable speed drive with IGV	▪ Variable speed drive ▪ Suction throttling
Typical COP at part load upto 50%	Reduces at part load	Reduces at part load	Improves by 15 – 20%

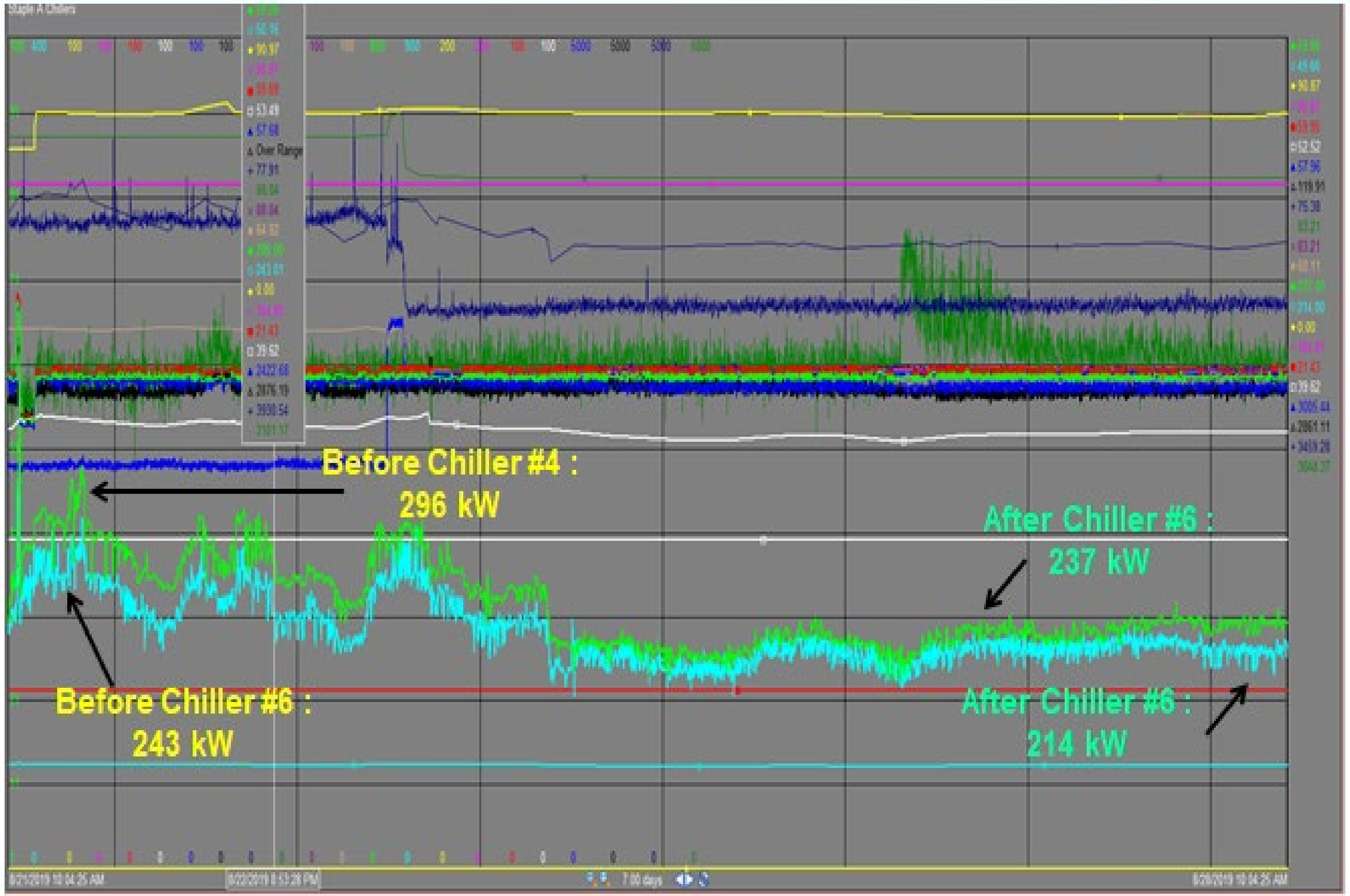
EE measures – air conditioning and refrigeration

- Least count of thermocouples to be used - 0.1°C
- In general,

  chilled water flow - 0.68 m³/h per TR (3 gpm/TR)

  Condenser water flow - 0.91 m³/h per TR (4 gpm/TR)
- A reduction of 0.55°C temperature in water returning from the cooling tower reduces compressor power consumption by 3%.
- A 1°C raise in evaporator temperature can help to save almost 3% on power consumption
- Lowest possible cooling tower water should be passed through chillers
- Leaving water temperature (Evaporator) should be monitored (most of the cases)

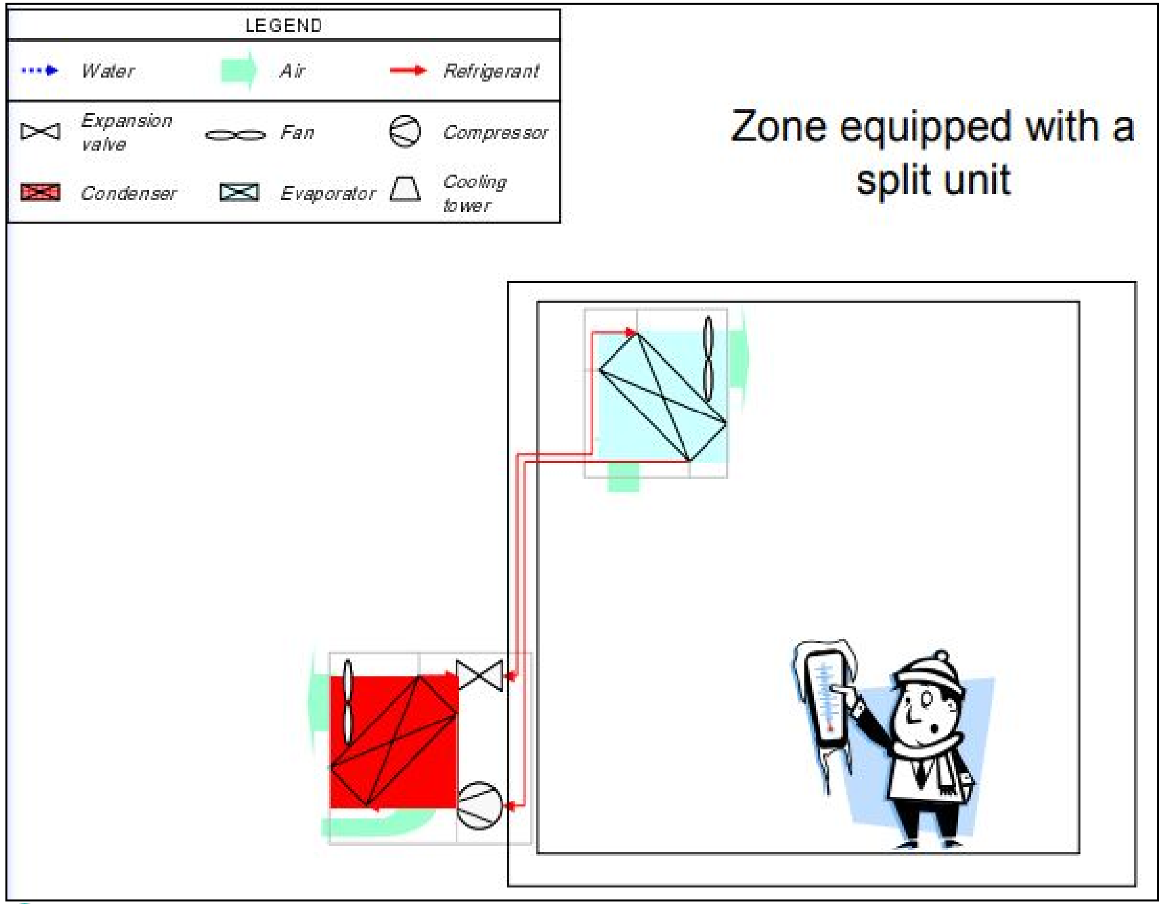
Case: Rectify system flows and pressures

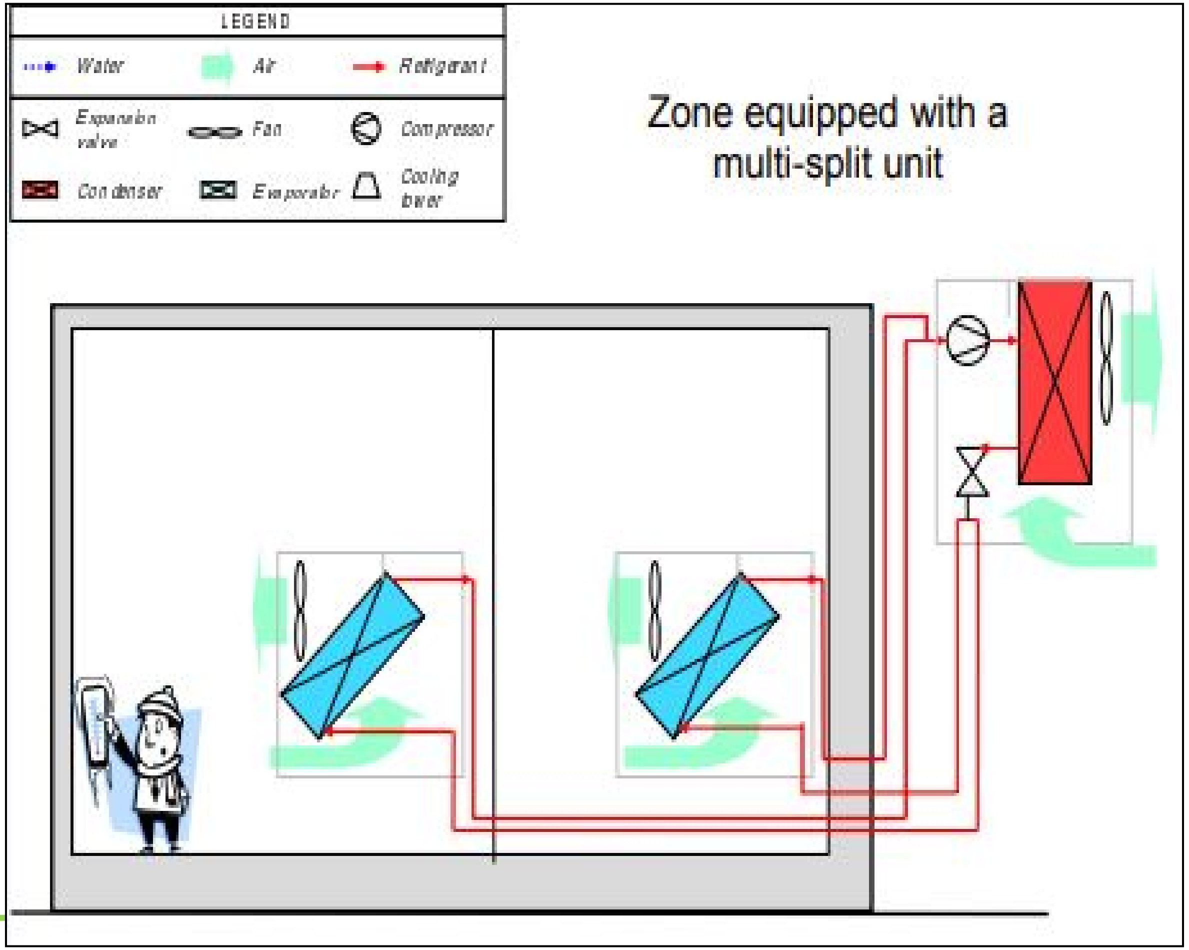


Particulars	Unit	Before	After
Chiller #4			
SPC	kW/TR	0.617	0.444
COP	kW/kW	5.69	7.9
Chiller #6			
SPC	kW/TR	0.533	0.459
COP	kW/kW	6.59	7.65

Annual energy savings achieved : 6.3 Lakh kWh

EE measures – air conditioning and refrigeration



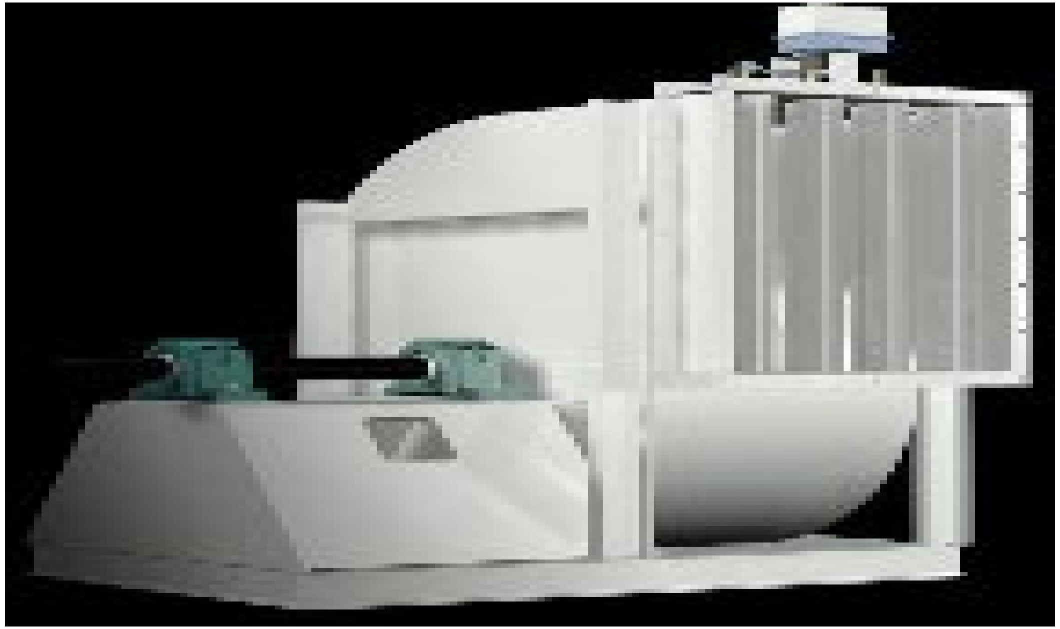


EE measures – Pumps, Fans and blowers

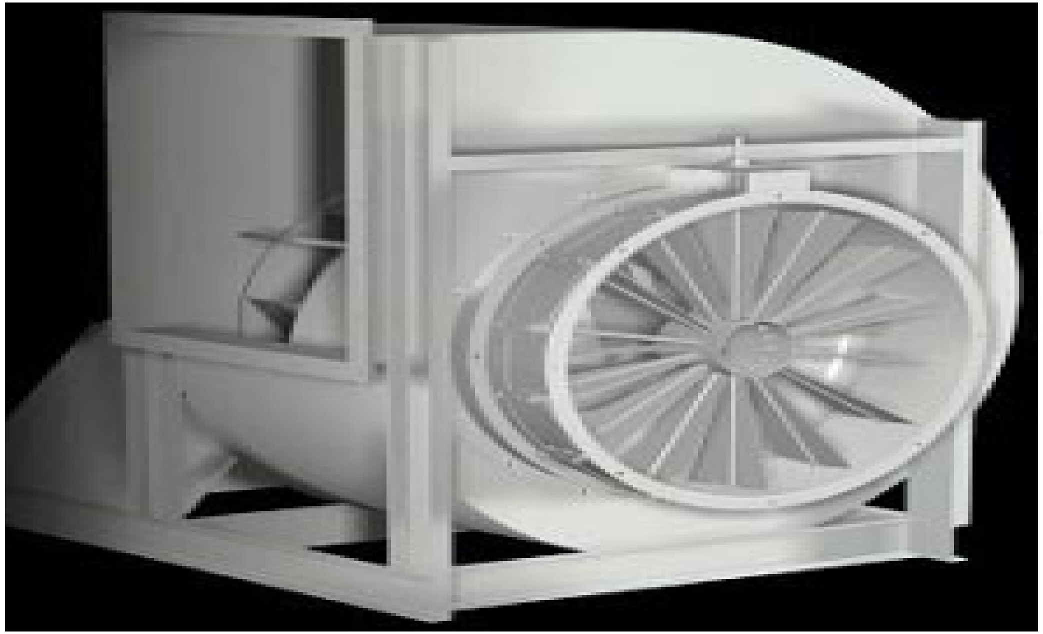
- Avoid oversizing
- Change of impeller by high efficiency impeller
- Replacing with high efficiency equipment
- Impeller de-rating (by a smaller dia impeller)
- Speed reduction by pulley dia change (for fans and blowers)
- Options for energy efficient flat belts in place of V-belts (for fans and blowers)
- Adopting Inlet guide vanes in place of damper control (for fans and blowers)
- Minimizing system resistance and pressure drops
- Variable speed drive / variable speed fluid coupling application

EE measures – Fans and blowers

Damper change



Inlet Guide Vanes



Control mechanisms

EE measures – Fans and blowers

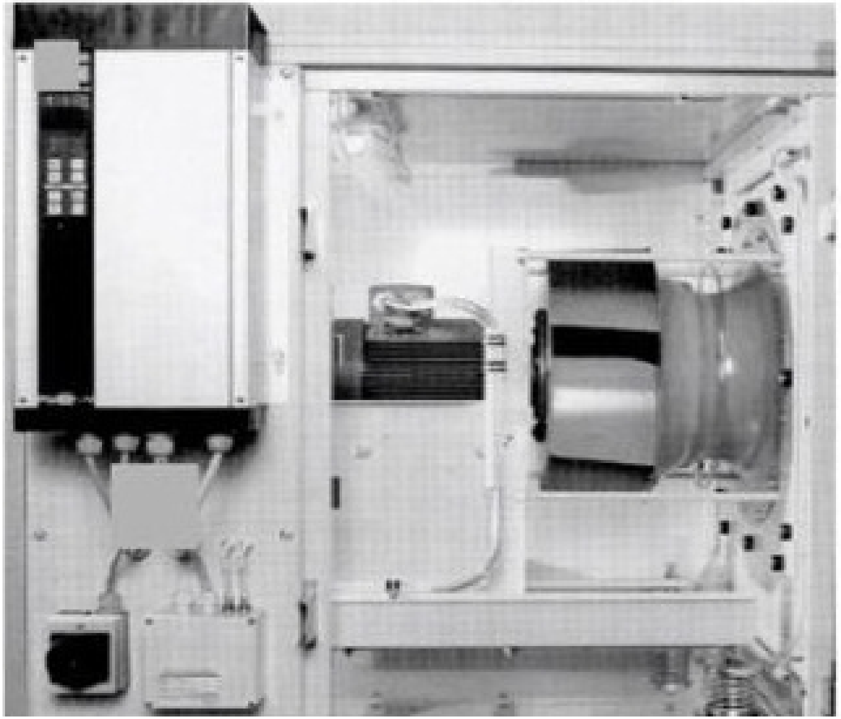
Centrifugal Fans	Peak Efficiency Range
Airfoil, backward curved/inclined	79-83
Modified radial	72-79
Radial	69-75
Pressure blower	58-68
Forward curved	60-65
Axial fan	
Vanaxial	78-85
Tubeaxial	67-72
Propeller	45-50

Case : Air loss through stand-by blowers

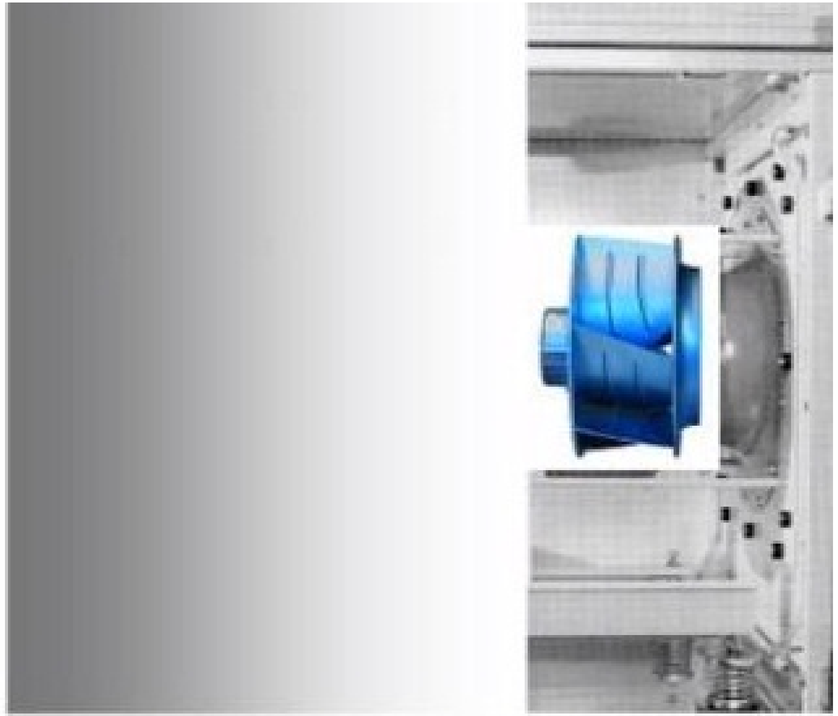
Annual energy Savings:
0.21 lakh kWh

Payback - Immediate

Case 7: Technology upgradation - AHU



Conventional motor-fan with VFD



EC motors

Case 6: Technology upgradation - AHU

S No.	AHU Name			Actual Before		Actual After		Saving
		Rating KW	After Rating KW	KW	CFM	KW	CFM	
1	Ahu-4	15	12	9.38	7791	4.64	7810	51%
2	Ahu-1	15	12	9.22	11456	5.06	11520	45%
3	Ahu-8	7.5	6	5.96	5456	2.36	5490	60%
4	AHU 2	11	15	9.5	23150	5.31	23985	44%
5	AHU 3	7.5	6.8	6.22	18207	4	18613	36%
6	AHU 5	15	15	12.81	27968	8.5	25580	34%
7	AHU 6	15	15	15.01	18681	9.3	18735	38%
8	AHU 7	11	12	5.52	8132	2.75	8875	50%
9	AHU 9	11	10.2	7.06	8213	3.58	8522	49%
10	QA 12	11	10	10.09	9667	4.69	10894	54%
11	Warehouse-G	15	15	12.06	17555	6.34	17980	47%
12	Warehouse-F	15	15	13.1	15993	6.86	16025	48%

EE measures - Heating

- Avoid electric resistance heaters
- If electricity is the only choice, heat pumps are preferable in most climates - they easily cut electricity use by 50% when compared with electric resistance heating
- Insulation of pipes and equipment
- Installation of thermostatic regulators on radiators
- Install balancing valves
- Energy metering and monitoring

Source: https://www.unece.org/fileadmin/DAM/energy/se/pdfs/geee/study/Final_Master_file_-_March_11_final_submission.pdf;

EE measures - Heating

Boilers

- Optimal stack temperatures
- Encourage feed water preheating (economizer, solar thermal or heat pump integration)
- Avoid incomplete combustion
- Excess air control
- Minimize surface radiation and convection losses
- Use of condensing boilers

Source: https://www.unece.org/fileadmin/DAM/energy/se/pdfs/geee/study/Final_Master_file_-_March_11_final_submission.pdf;

EE measures - Heating

Boilers (residential and commercial buildings)

Old low efficiency	Mid-efficiency	High – efficiency
Natural draft	Exhaust fan controls for combustion air and gases	Condensing flue gases in second heat exchanger for extra efficiency
Heavy heat exchanger	Electronic ignition	Sealed combustion
56% - 70% AFUE	Compact and light weight	90% to 98.5% AFUE
	Small dia flue pipe	
	80%-83% AFUE	

Source:https://www.energy.gov/energysaver/home-heating-systems/furnaces-and-boilers

Case: Use of Heat pumps

Background :

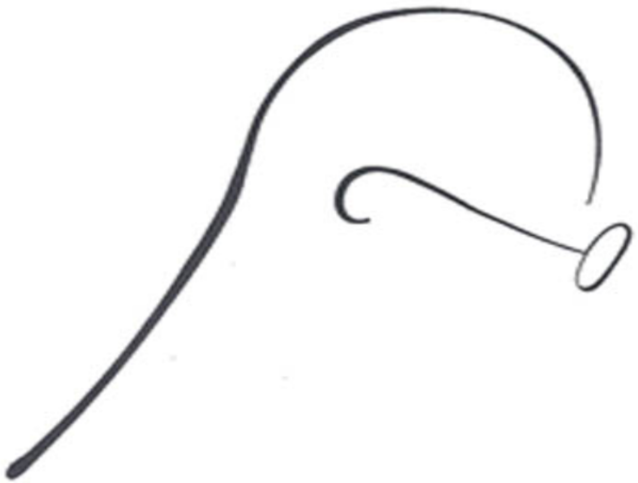
- Diesel fired boilers used for hot water generation in a hotel
- City's location weather highly suitable for heat pump installation.
- The diesel fuel high cost also supported the change.

Recommendation :

- Heat pumps to be installed.
- Existing boiler may be used for back up

Savings:

13.5 kL annual diesel savings



Be the change you want to see in the world

Thank You

Email: rradu@dtu.dk

Thank you for your attention

c2e2.unepdtu.org/
rradu@dtu.dk