Electrical Equipment/
Refrigeration & AC

Refrigeration & Air Conditioning

Presentation from the

“Energy Efficiency Guide for Industry in Asia”

www.energyefficiencyasia.org

Training Agenda: Refrigeration & Air Conditioning

Electrical Equipment/
Refrigeration & AC

- Introduction
- Type of refrigeration
- Assessment of refrigeration and AC
- Energy efficiency opportunities

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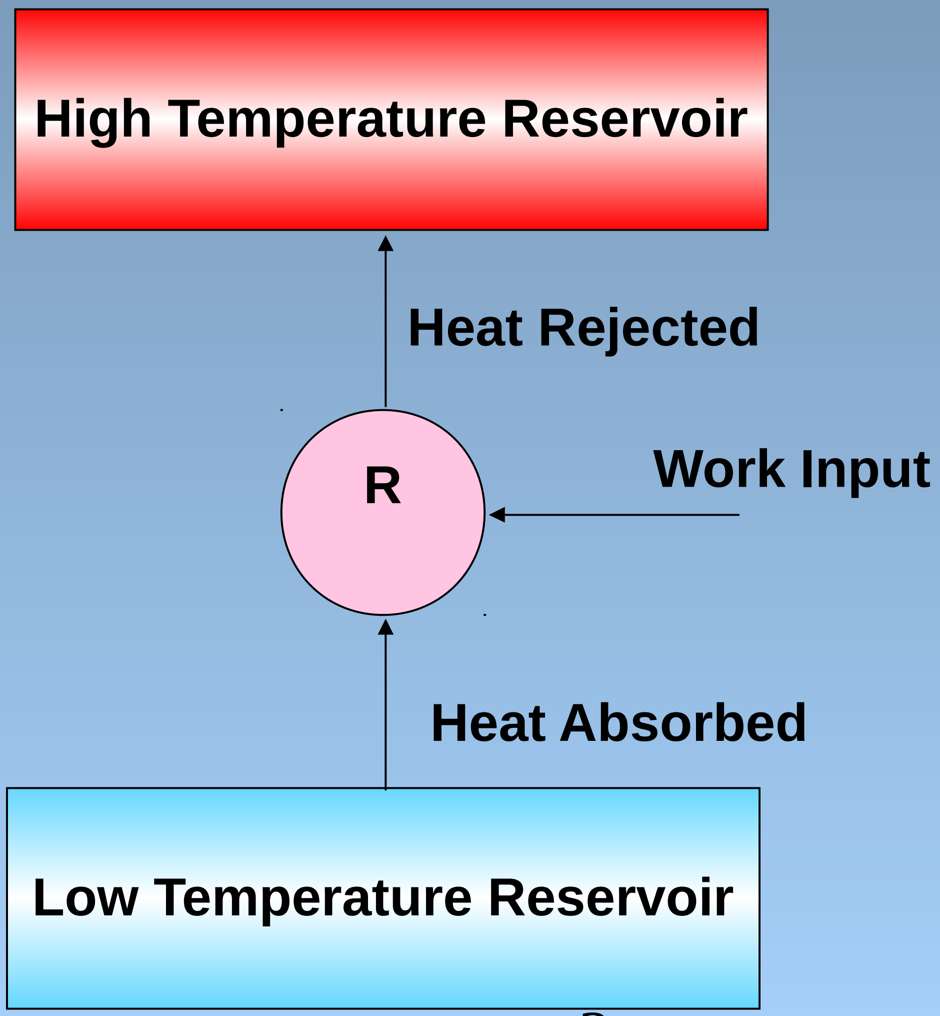
Introduction

Electrical Equipment/
Refrigeration & AC

How does it work?



Electrical Equipment/ Refrigeration & AC

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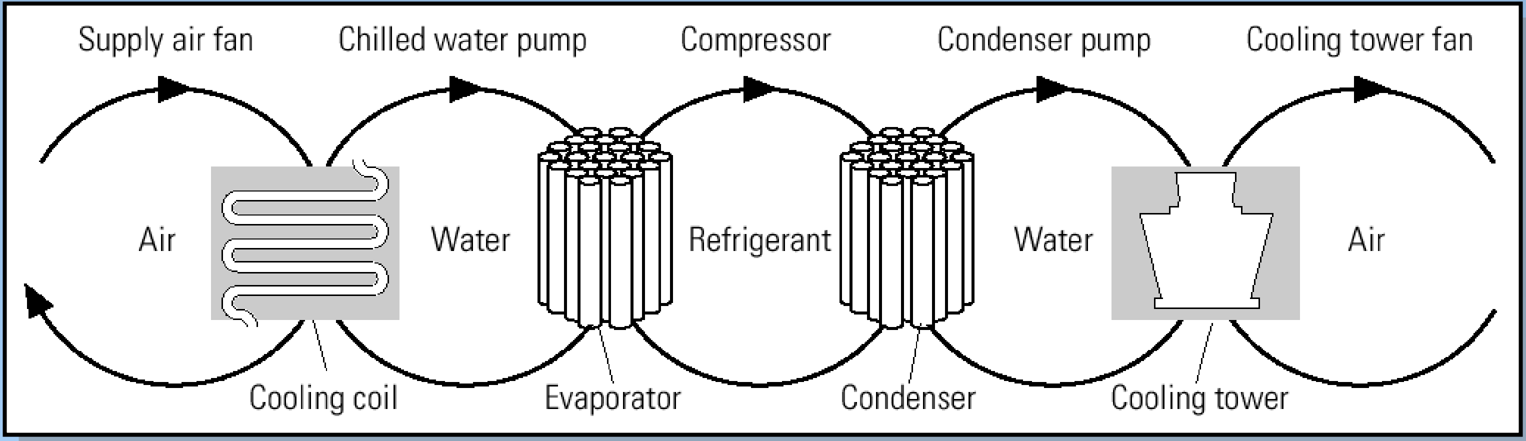
Introduction

How does it work?

Thermal energy moves from left to right through five loops of heat transfer:

1)	2)	3)	4)	5)
Indoor air loop	Chilled water loop	Refrigerant loop	Condenser water loop	Cooling water loop



(Bureau of Energy Efficiency, 2004)

Introduction

AC Systems

AC options / combinations:

- Air Conditioning (for comfort / machine)
- Split air conditioners
- Fan coil units in a larger system
- Air handling units in a larger system

Introduction

Refrigeration systems for industrial processes

- **Small capacity modular units of direct expansion type (50 Tons of Refrigeration)**
- **Centralized chilled water plants with chilled water as a secondary coolant (50 – 250 TR)**
- **Brine plants with brines as lower temperature, secondary coolant (>250 TR)**

Introduction

Electrical Equipment/
Refrigeration & AC

Refrigeration at large companies

- **Bank of units off-site with common**
  - **Chilled water pumps**
  - **Condenser water pumps**
  - **Cooling towers**
- **More levels of refrigeration/AC, e.g.**
  - **Comfort air conditioning (20-25 °C)**
  - **Chilled water system (8 – 10 °C)**
  - **Brine system (< 0 °C)**

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Training Agenda: Refrigeration & Air Conditioning

Electrical Equipment/
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Introduction

Type of refrigeration

Assessment of refrigeration and AC

Energy efficiency opportunities

Types of Refrigeration

Refrigeration systems

- **Vapour Compression Refrigeration (VCR): uses mechanical energy**
- **Vapour Absorption Refrigeration (VAR): uses thermal energy**

Type of Refrigeration

Vapour Compression Refrigeration

- Highly compressed fluids tend to get colder when allowed to expand
- If pressure high enough
  - Compressed air hotter than source of cooling
  - Expanded gas cooler than desired cold temperature

Type of Refrigeration

Vapour Compression Refrigeration

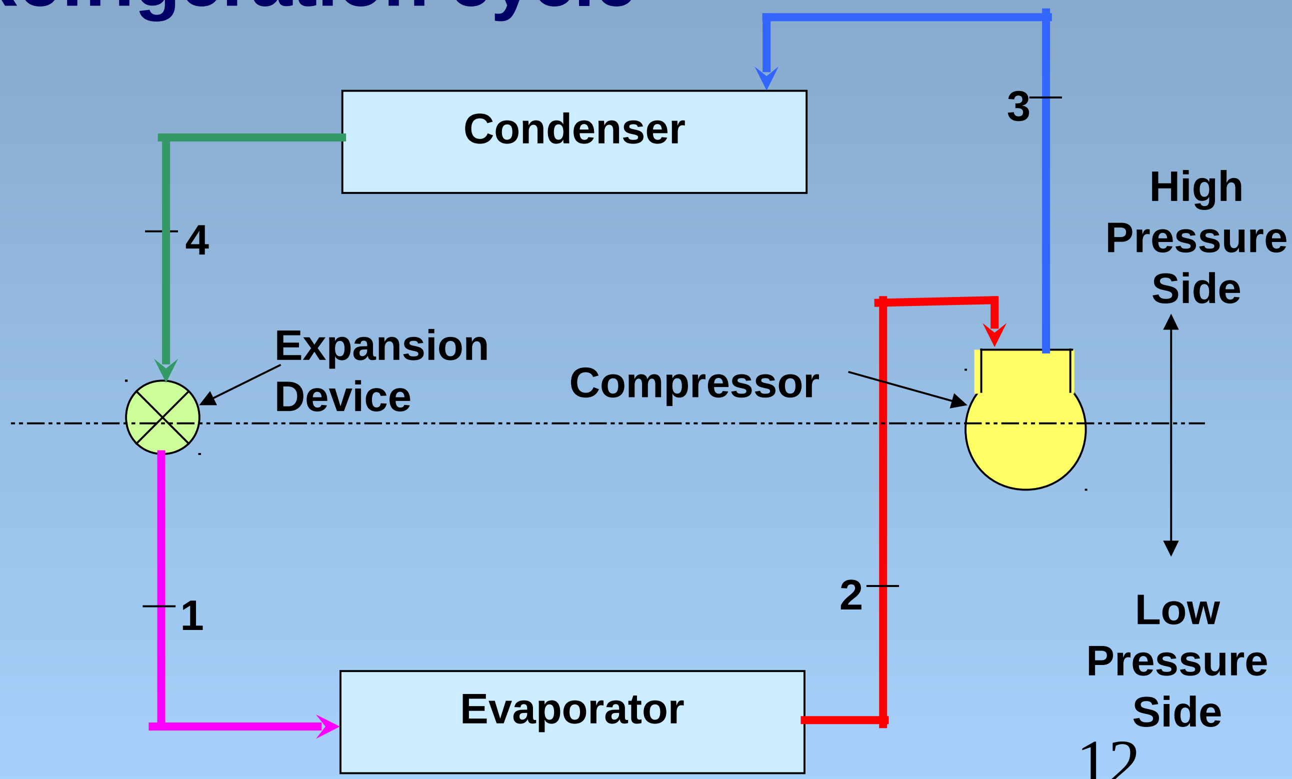
Two advantages

- **Lot of heat can be removed (lot of thermal energy to change liquid to vapour)**
- **Heat transfer rate remains high (temperature of working fluid much lower than what is being cooled)**

Type of Refrigeration

Vapour Compression Refrigeration

Refrigeration cycle



Type of Refrigeration

Low pressure liquid refrigerant in evaporator absorbs heat and changes to a gas

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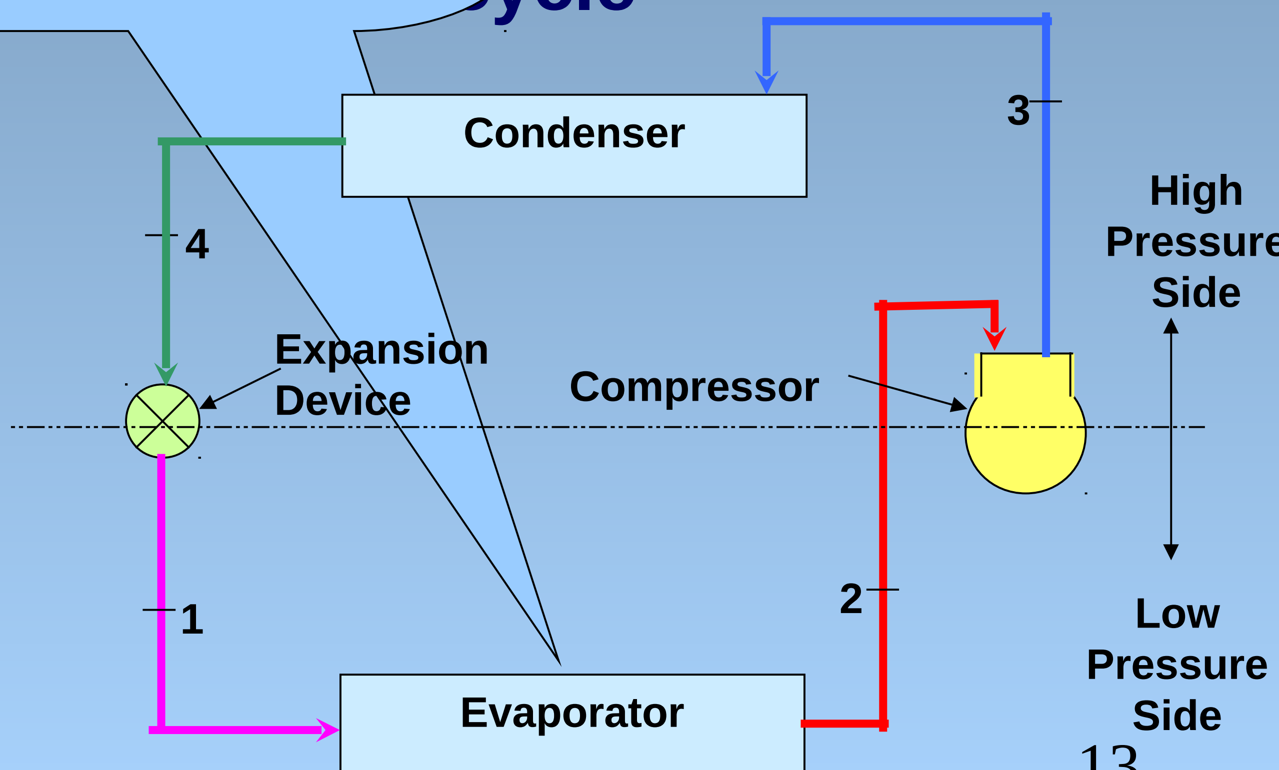
…ycle



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Type of Refrigeration

The superheated vapour enters the compressor where its pressure is raised

…pression Refrigeration

…ycle

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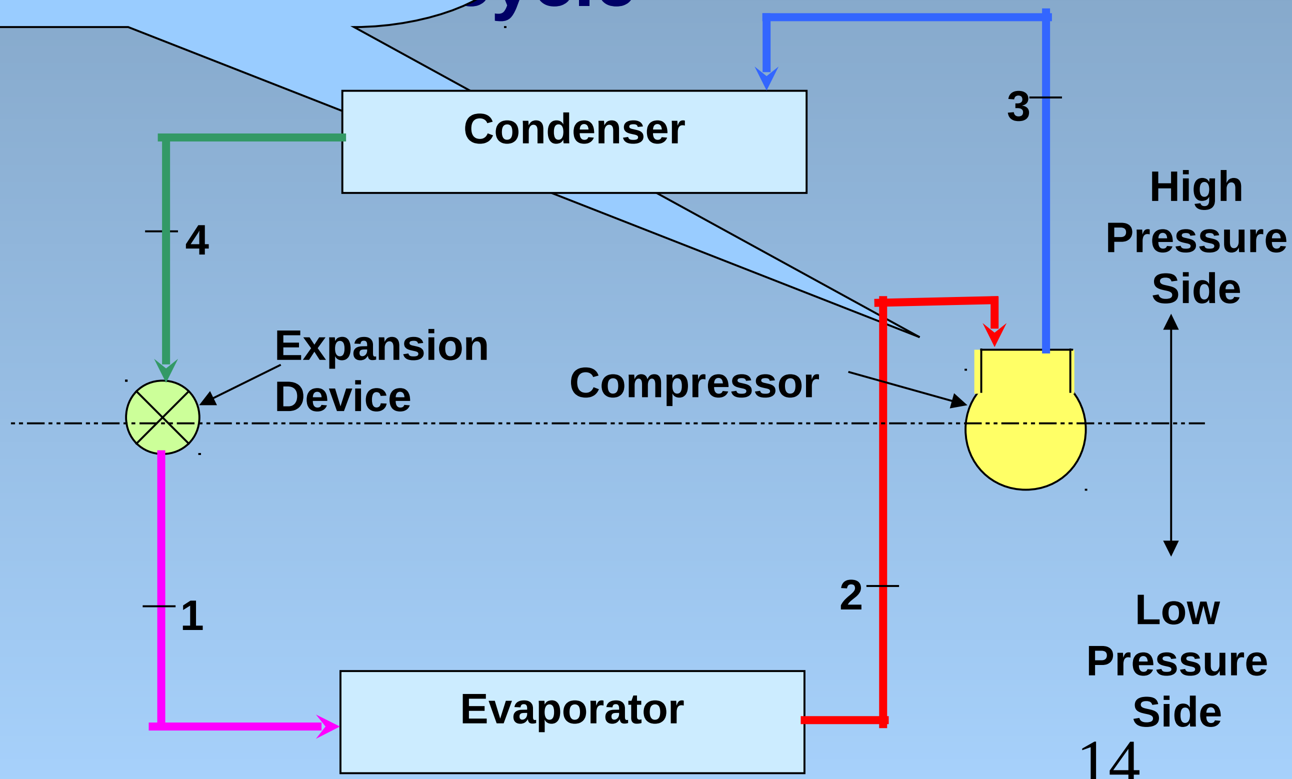

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Type of Refrigeration

The high pressure superheated gas is cooled in several stages in the condenser

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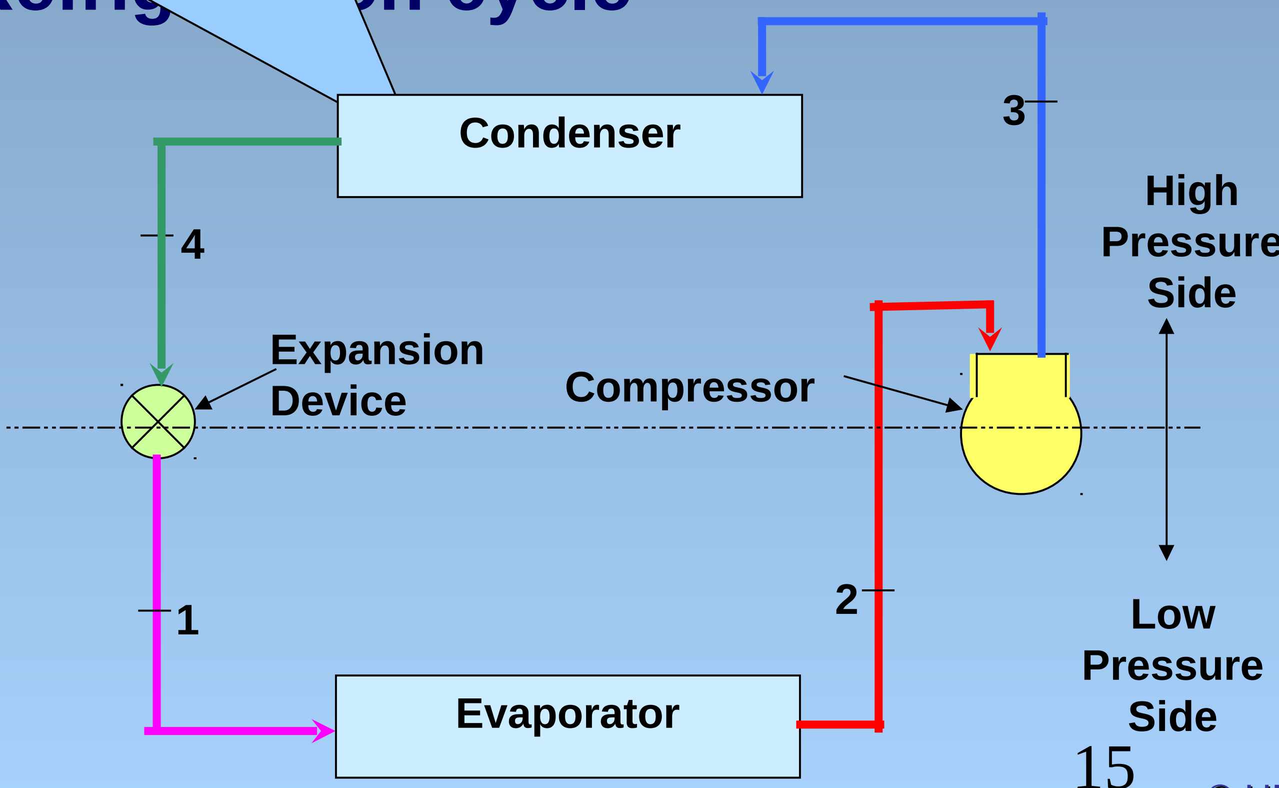
Refrig… …on cycle



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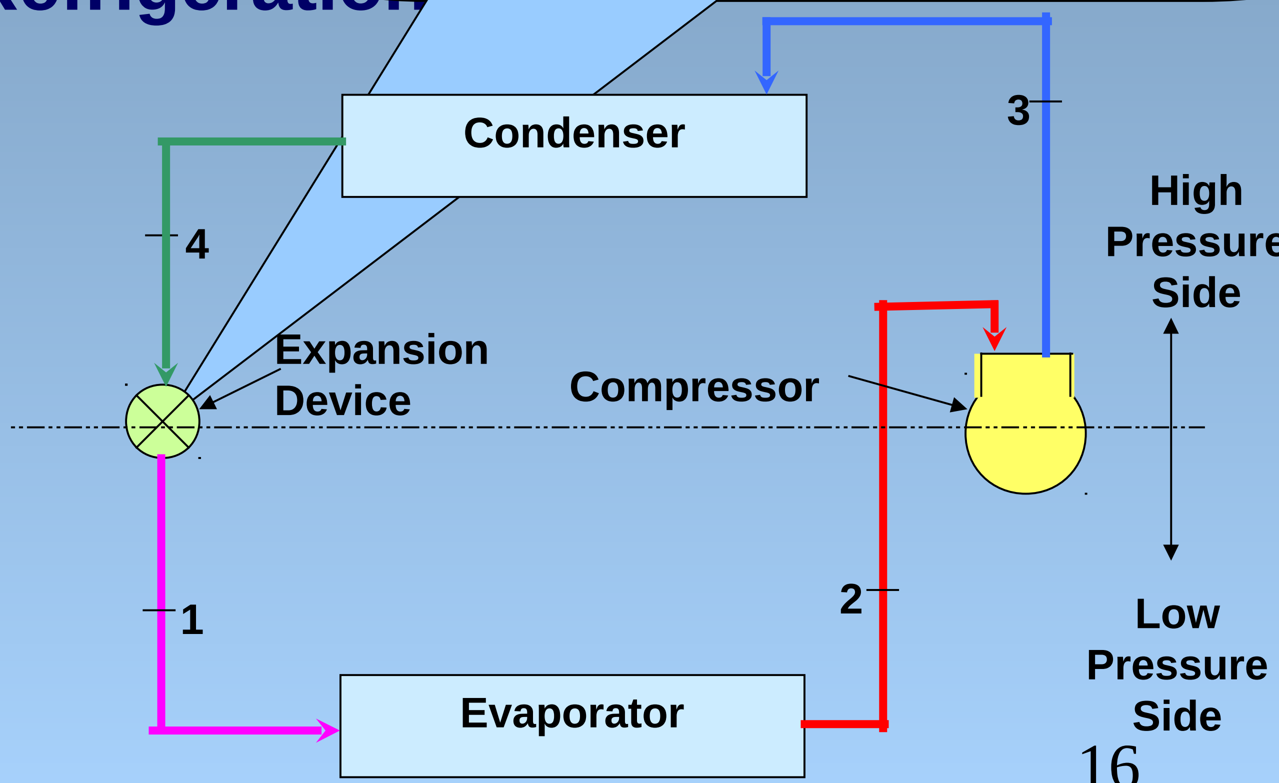
Type of Refrigeration

Vapour

Refrigera

Liquid passes through expansion device, which reduces its pressure and controls the flow into the evaporator



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Type of Refrigeration

Vapour Compression Refrigeration

Type of refrigerant

- Refrigerant determined by the required cooling temperature
- Chlorinated fluorocarbons (CFCs) or freons: R-11, R-12, R-21, R-22 and R-502

Type of Refrigeration

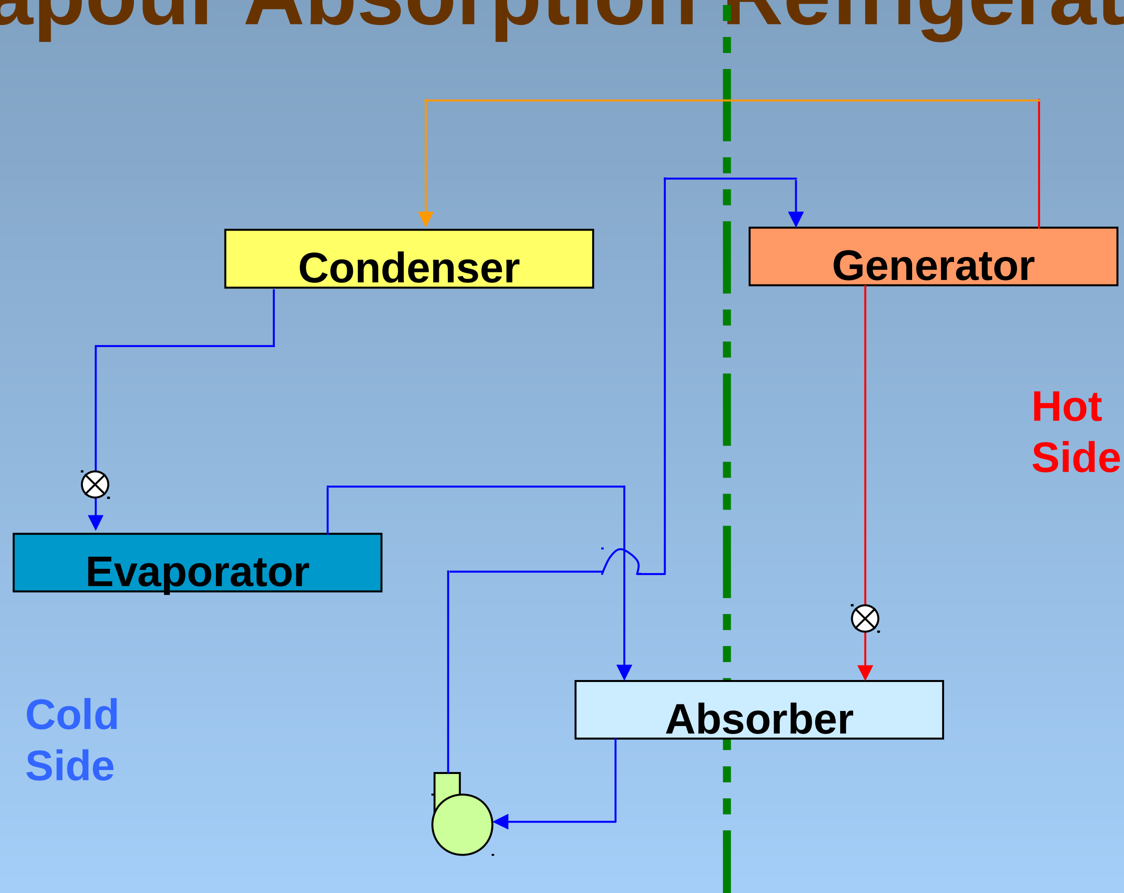
Vapour Compression Refrigeration

Choice of compressor, design of condenser, evaporator determined by

- **Refrigerant**
- **Required cooling**
- **Load**
- **Ease of maintenance**
- **Physical space requirements**
- **Availability of utilities (water, power)**

Type of Refrigeration

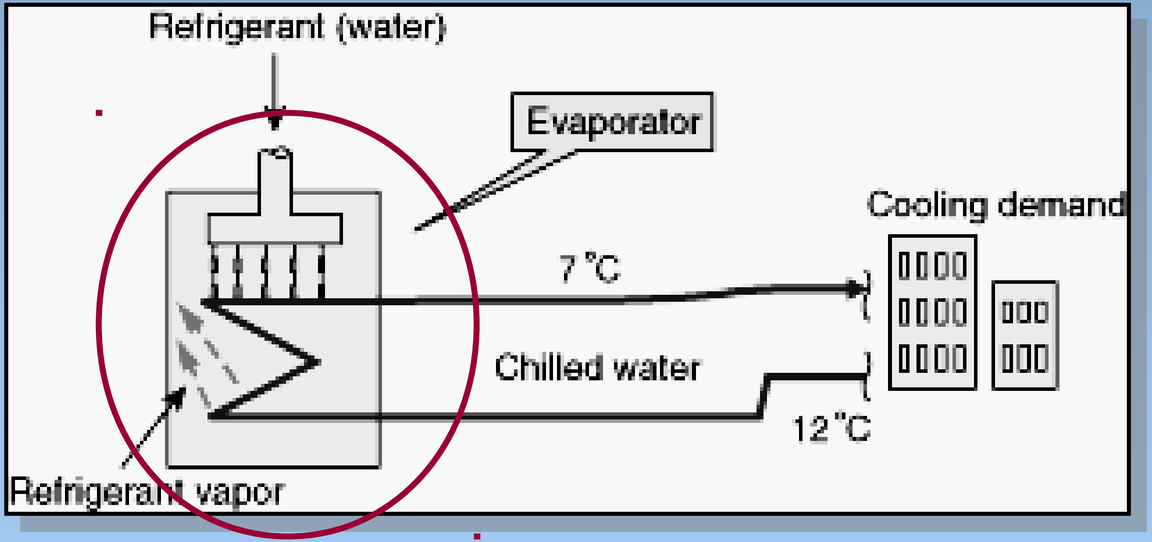
Vapour Absorption Refrigeration



Type of Refrigeration

Vapour Absorption Refrigeration

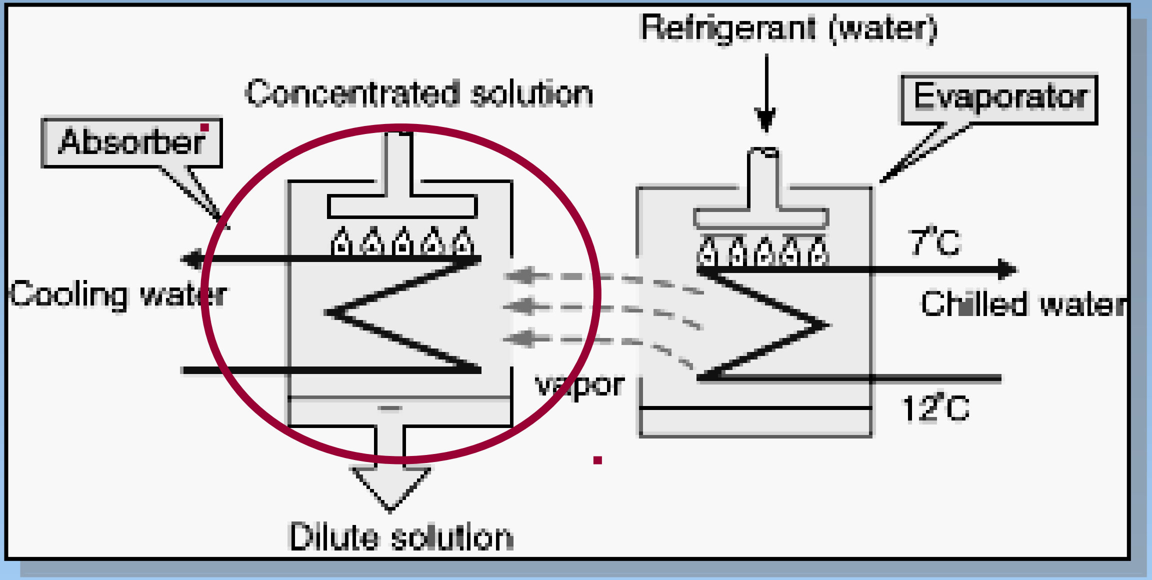
Evaporator



Type of Refrigeration

Vapour Absorption Refrigeration

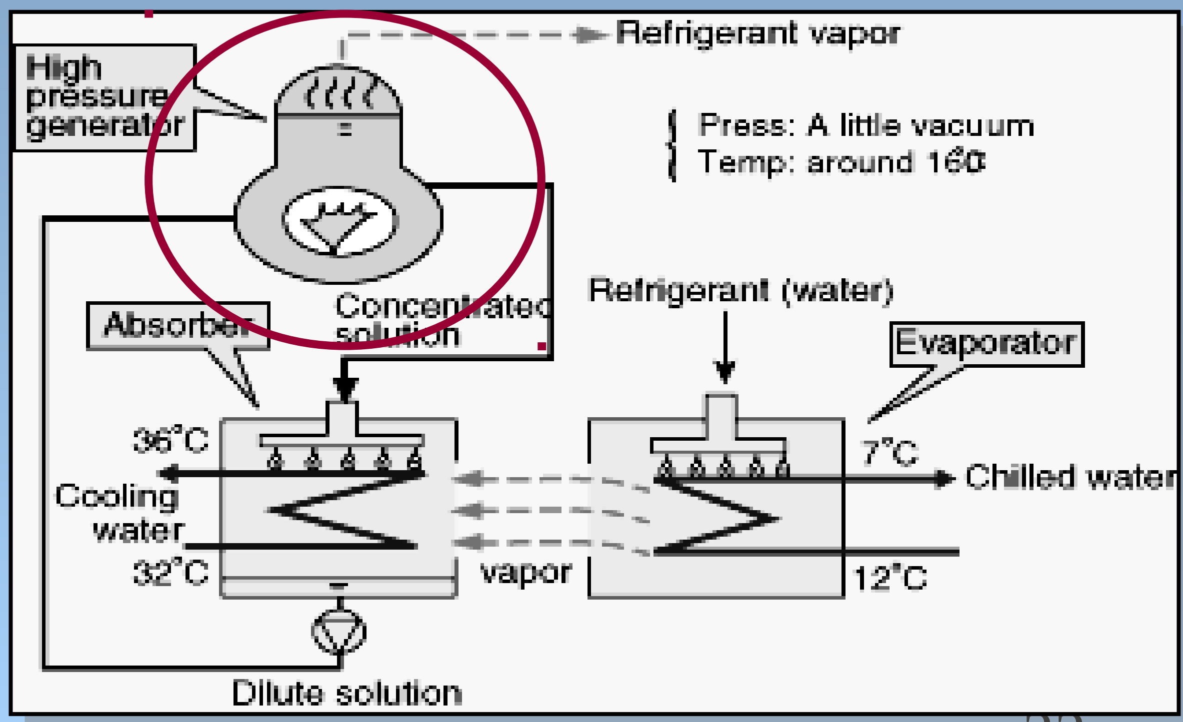
Absorber



Type of Refrigeration

Vapour Absorption Refrigeration

High pressure generator



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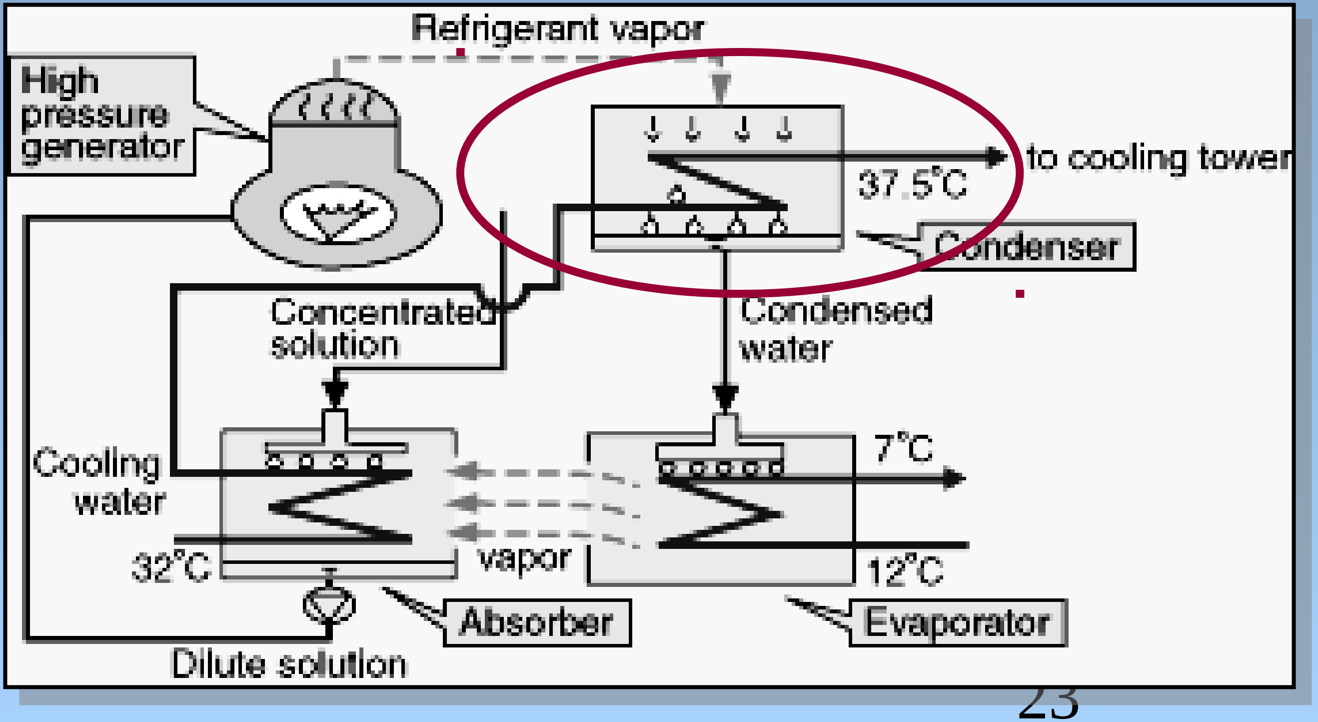
Type of Refrigeration

Electrical Equipment/ Refrigeration & AC

Vapour Absorption Refrigeration

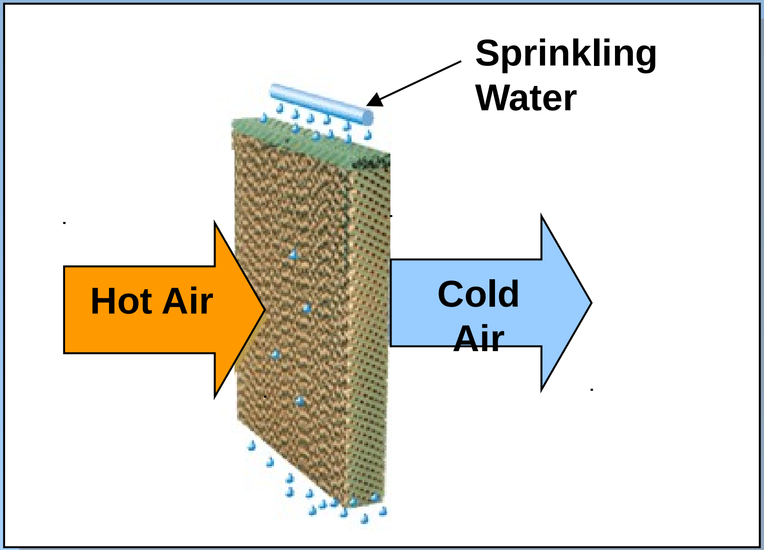
Condenser



Type of Refrigeration

Evaporative Cooling

- Air in contact with water to cool it close to 'wet bulb temperature'
- Advantage: efficient cooling at low cost
- Disadvantage: air is rich in moisture



(Adapted from Munters, 2001)

Training Agenda: Refrigeration & Air Conditioning

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Assessment of Refrigeration

- **Cooling effect: Tons of Refrigeration**

1 TR = 3024 kCal/hr heat rejected

- **TR is assessed as:**

TR = Q x·Cp x· (Ti – To) / 3024

Q = mass flow rate of coolant in kg/hr
Cp = is coolant specific heat in kCal /kg deg C
Ti = inlet, temperature of coolant to evaporator (chiller) in 0C
To = outlet temperature of coolant from evaporator (chiller) in 0C

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Assessment of Refrigeration

Specific Power Consumption (kW/TR)

- Indicator of refrigeration system's performance
- kW/TR of centralized chilled water system is sum of
  - Compressor kW/TR
  - Chilled water pump kW/TR
  - Condenser water pump kW/TR
  - Cooling tower fan kW/TR

Assessment of Refrigeration

Coefficient of Performance (COP_{Carnot})

- **Standard measure of refrigeration efficiency**
- **Depends on evaporator temperature Te and condensing temperature Tc:**

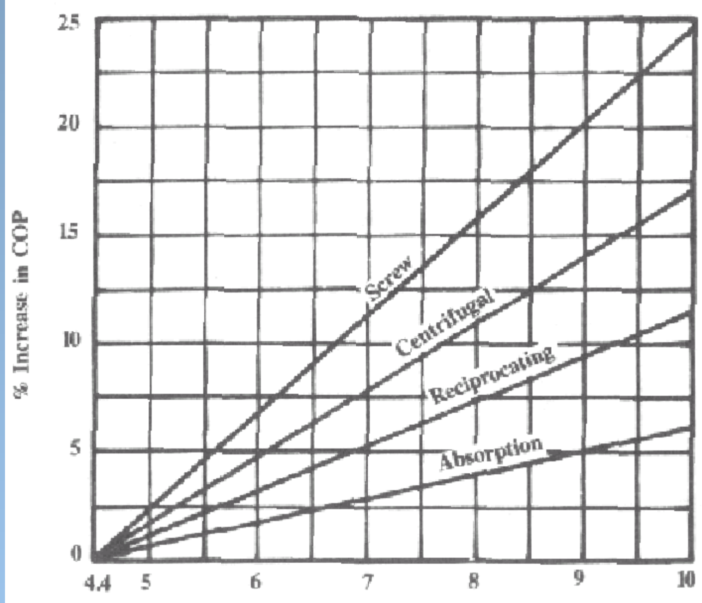
$$COP_{Carnot} = Te / (Tc - Te)$$

- **COP in industry calculated for type of compressor:**

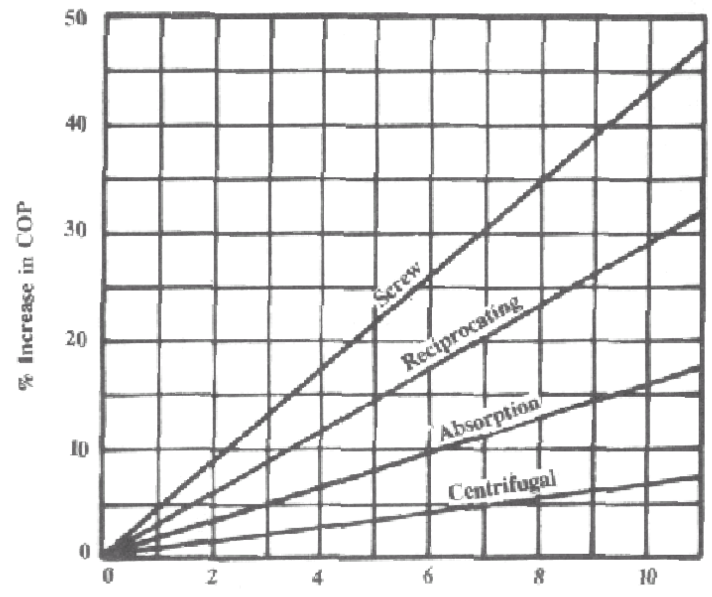
$$COP = \frac{\text{Cooling effect (kW)}}{\text{Power input to compressor (kW)}}$$

Assessment of Refrigeration and AC

Assessment of Refrigeration



COP increases with rising evaporator temperature (Te)



COP increases with decreasing condensing temperature (Tc)

Assessment of Air Conditioning

Measure

- Airflow Q (m3/s) at Fan Coil Units (FCU) or Air Handling Units (AHU): anemometer
- Air density ρ (kg/m3)
- Dry bulb and wet bulb temperature: psychrometer
- Enthalpy (kCal/kg) of inlet air (h_{in}) and outlet air (H_{out}): psychrometric charts

Calculate TR

$$TR = \frac{Q \times \rho \times (h_{in} - h_{out})}{3024}$$

Assessment of Air Conditioning

Indicative TR load profile

- Small office cabins : 0.1 TR/m2
- Medium size office (10 – 30 people occupancy) with central A/C: 0.06 TR/m2
- Large multistoried office complexes with central A/C: 0.04 TR/m2

Considerations for Assessment

- **Accuracy of measurements**
  - **Inlet/outlet temp of chilled and condenser water**
  - **Flow of chilled and condenser water**
- **Integrated Part Load Value (IPLV)**
  - **kW/TR for 100% load but most equipment operate between 50-75% of full load**
  - **IPLV calculates kW/TR with partial loads**
  - **Four points in cycle: 100%, 75%, 50%, 25%**

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Energy Efficiency Opportunities

1. Optimize process heat exchange
2. Maintain heat exchanger surfaces
3. Multi-staging systems
4. Matching capacity to system load
5. Capacity control of compressors
6. Multi-level refrigeration for plant needs
7. Chilled water storage
8. System design features

Electrical Equipment/
Refrigeration & AC

1. Optimize Process Heat Exchange

High compressor safety margins: energy loss

1. **Proper sizing heat transfer areas of heat exchangers and evaporators**
   - **Heat transfer coefficient on refrigerant side: 1400 – 2800 Watt/m2K**
   - **Heat transfer area refrigerant side: >0.5 m2/TR**
2. **Optimum driving force (difference Te and Tc): 1°C raise in Te = 3% power savings**

Energy Efficiency Opportunities

1. Optimize Process Heat Exchange

Evaporator Temperature (^{0}C)	*Refrigeration Capacity*(tons)*	*Specific Power Consumption (kW/TR)*	*Increase kW/TR (%)*
5.0	**67.58**	**0.81**	**-**
0.0	**56.07**	**0.94**	**16.0**
-5.0	**45.98**	**1.08**	**33.0**
-10.0	**37.20**	**1.25**	**54.0**
-20.0	**23.12**	**1.67**	**106.0**

Condenser temperature 40°C

(National Productivity Council)

Condensing Temperature (^{0}C)	*Refrigeration Capacity (tons)*	*Specific Power Consumption (kW /TR)*	*Increase kW/TR (%)*
26.7	**31.5**	**1.17**	**-**
35.0	**21.4**	**1.27**	**8.5**
40.0	**20.0**	**1.41**	**20.5**

****Reciprocating compressor using R-22 refrigerant. Evaporator temperature 10°C***

Energy Efficiency Opportunities

1. Optimize Process Heat Exchange

3. Selection of condensers

- **Options:**
  - **Air cooled condensers**
  - **Air-cooled with water spray condensers**
  - **Shell & tube condensers with water-cooling**
- **Water-cooled shell & tube condenser**
  - **Lower discharge pressure**
  - **Higher TR**
  - **Lower power consumption**

Energy Efficiency Opportunities

2. Maintain Heat Exchanger Surfaces

- **Poor maintenance = increased power consumption**
- **Maintain condensers and evaporators**
  - **Separation of lubricating oil and refrigerant**
  - **Timely defrosting of coils**
  - **Increased velocity of secondary coolant**
- **Maintain cooling towers**
  - **0.55◦C reduction in returning water from cooling tower = 3.0 % reduced power**

Energy Efficiency Opportunities

2. Maintain Heat Exchanger Surfaces

Effect of poor maintenance on compressor power consumption

Condition	*Te (^0C)*	*Tc (^0C)*	*Refrigeration Capacity* (TR)*	*Specific Power Consumption (kW/TR)*	*Increase kW/TR (%)*
Normal	**7.2**	**40.5**	**17.0**	**0.69**	**-**
Dirty condenser	**7.2**	**46.1**	**15.6**	**0.84**	**20.4**
Dirty evaporator	**1.7**	**40.5**	**13.8**	**0.82**	**18.3**
Dirty condenser and evaporator	**1.7**	**46.1**	**12.7**	**0.96**	**38.7**

(National Productivity Council)

3. Multi-Staging Systems

- Suited for
  - Low temp applications with high compression
  - Wide temperature range
- Two types for all compressor types
  - Compound
  - Cascade

Energy Efficiency Opportunities

Electrical Equipment/ Refrigeration & AC

3. Multi-Stage Systems

a. Compound

- Two low compression ratios = 1 high
- First stage compressor meets cooling load
- Second stage compressor meets load evaporator and flash gas
- Single refrigerant

b. Cascade

- Preferred for -46 oC to -101oC
- Two systems with different refrigerants

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Energy Efficiency Opportunities

4. Matching Capacity to Load System

- **Most applications have varying loads**
- **Consequence of part-load operation**
  - **COP increases**
  - **but lower efficiency**
- **Match refrigeration capacity to load requires knowledge of**
  - **Compressor performance**
  - **Variations in ambient conditions**
  - **Cooling load**

5. Capacity Control of Compressors

- Cylinder unloading, vanes, valves
  - Reciprocating compressors: step-by-step through cylinder unloading:
  - Centrifugal compressors: continuous modulation through vane control
  - Screw compressors: sliding valves
- Speed control
  - Reciprocating compressors: ensure lubrication system is not affected
  - Centrifugal compressors: >50% of capacity

5. Capacity Control of Compressors

- **Temperature monitoring**
  - **Reciprocating compressors: return water (if varying loads), water leaving chiller (constant loads)**
  - **Centrifugal compressors: outgoing water temperature**
  - **Screw compressors: outgoing water temperature**
- **Part load applications: screw compressors more efficient**

6. Multi-Level Refrigeration

Bank of compressors at central plant

- Monitor cooling and chiller load: *1 chiller full load more efficient than 2 chillers at part-load*
- Distribution system: individual chillers feed all branch lines; Isolation valves; Valves to isolate sections
- Load individual compressors to full capacity before operating second compressor
- Provide smaller capacity chiller to meet peak demands

6. Multi-Level Refrigeration

Packaged units (instead of central plant)

- Diverse applications with wide temp range and long distance
- Benefits: economical, flexible and reliable
- Disadvantage: central plants use less power

Flow control

- Reduced flow
- Operation at normal flow with shut-off periods

7. Chilled Water Storage

- Chilled water storage facility with insulation
- Suited only if temp variations are acceptable
- Economical because
  - Chillers operate during low peak demand hours: reduced peak demand charges
  - Chillers operate at nighttime: reduced tariffs and improved COP

8. System Design Features

- FRP impellers, film fills, PVC drift eliminators
- Softened water for condensers
- Economic insulation thickness
- Roof coatings and false ceilings
- Energy efficient heat recovery devices
- Variable air volume systems
- Sun film application for heat reflection
- Optimizing lighting loads

Refrigeration & Air Conditioning Systems

THANK YOU

FOR YOUR ATTENTION

Electrical Equipment/ Refrigeration & AC

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