TRANE

Beyond Tomorrow

Training Class

HV Chillers – Combating Climate Change Solution

Ir Dr F.C. Chan

1 Dec 2017

Ingersoll Rand

HV Chillers – Combating Climate Change Solution

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- Climate Change
- Refrigeration Cycle
- Starting Methods Consideration
- Choice of Refrigerant and Global Warming Potential
- Energy Efficiency of Chillers
- District Cooling System
- Conclusion

Climate Change

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Extreme Weather

Climate Change Indicators

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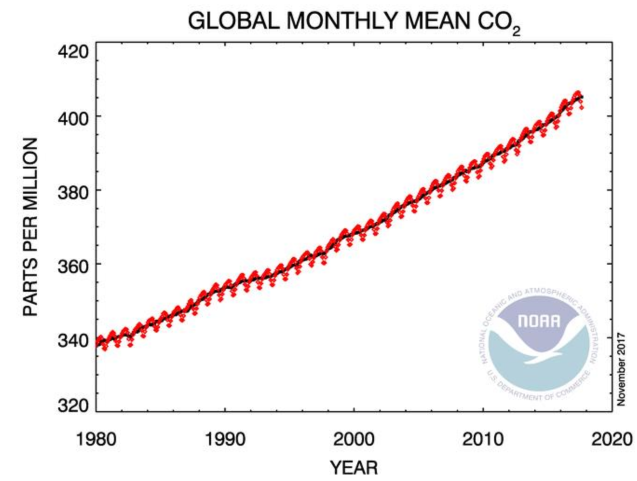
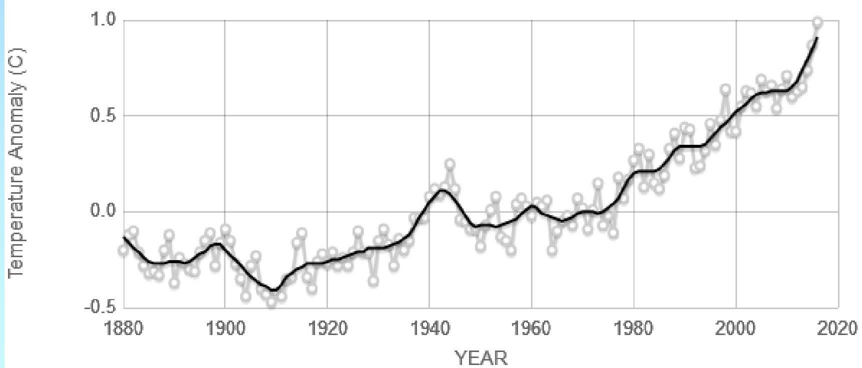
- CO_2 concentration
- Global temperature
- Sea level

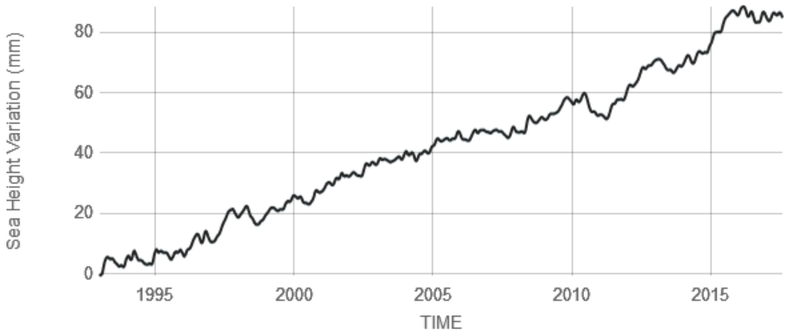


CO_2 concentration



Source: climate.nasa.gov

Global temperature



Source: climate.nasa.gov

Sea level

Climate Change

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Ice sheets melting

Climate Change in Hong Kong

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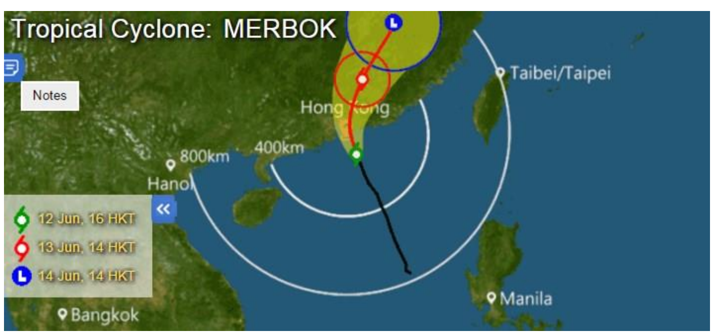

5 No.8 & above Typhoon in 2017

Merbok	12 June 2017	T8
Roke	22 July 2017	T8
Hato	23 August 2017	T10
Pakhar	27 August 2017	T8
Khanun	15 October 2017	T8

Combating Climate Change

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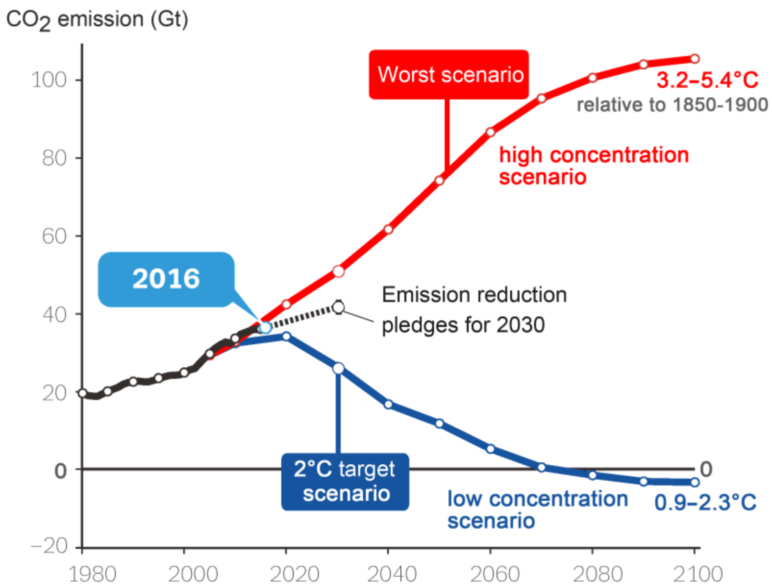
HK Climate Action Plan 2030+



Energy Saving

to minimize the use of energy and to use energy efficiently

Less CO_2 emission

Refrigeration Cycle

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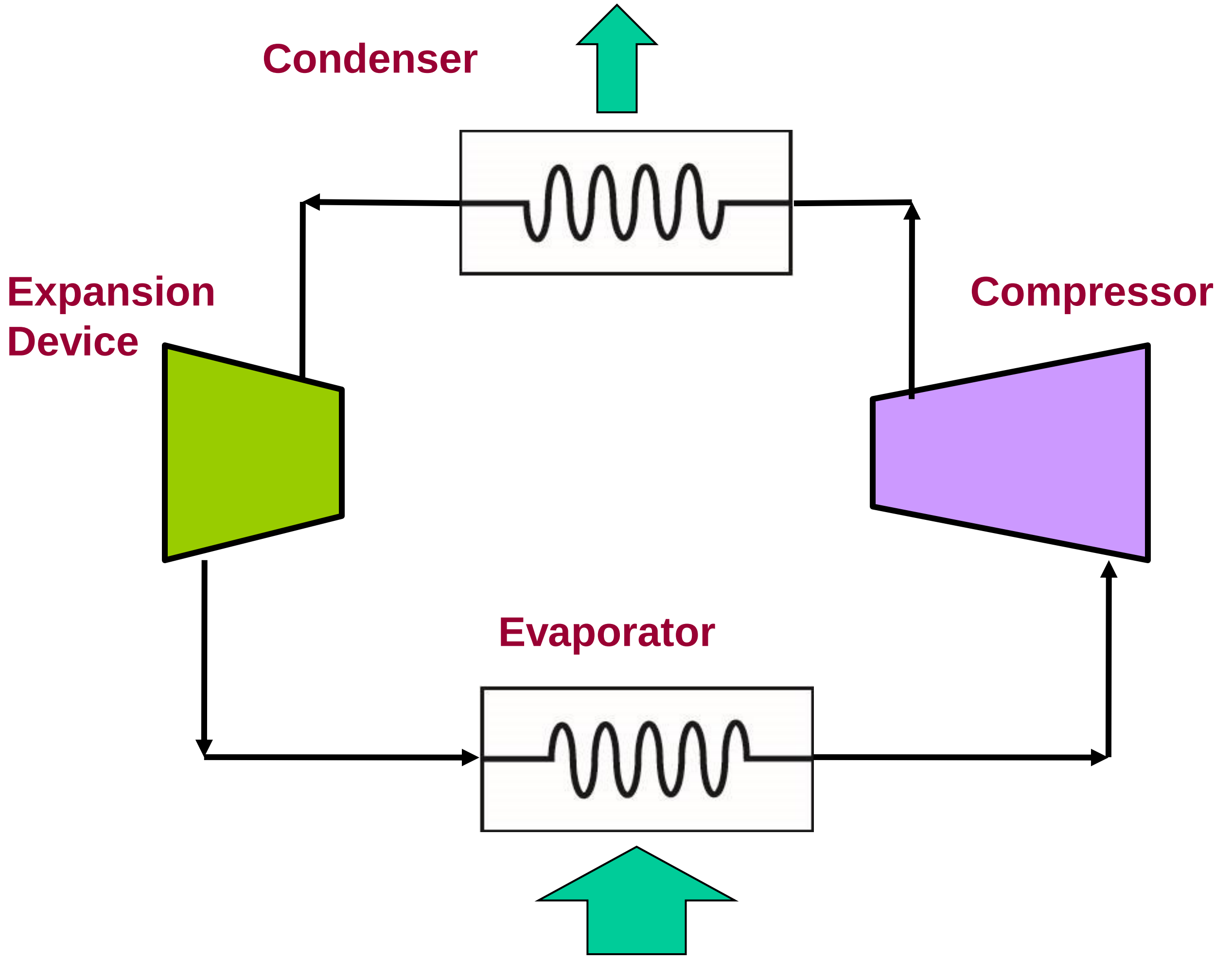
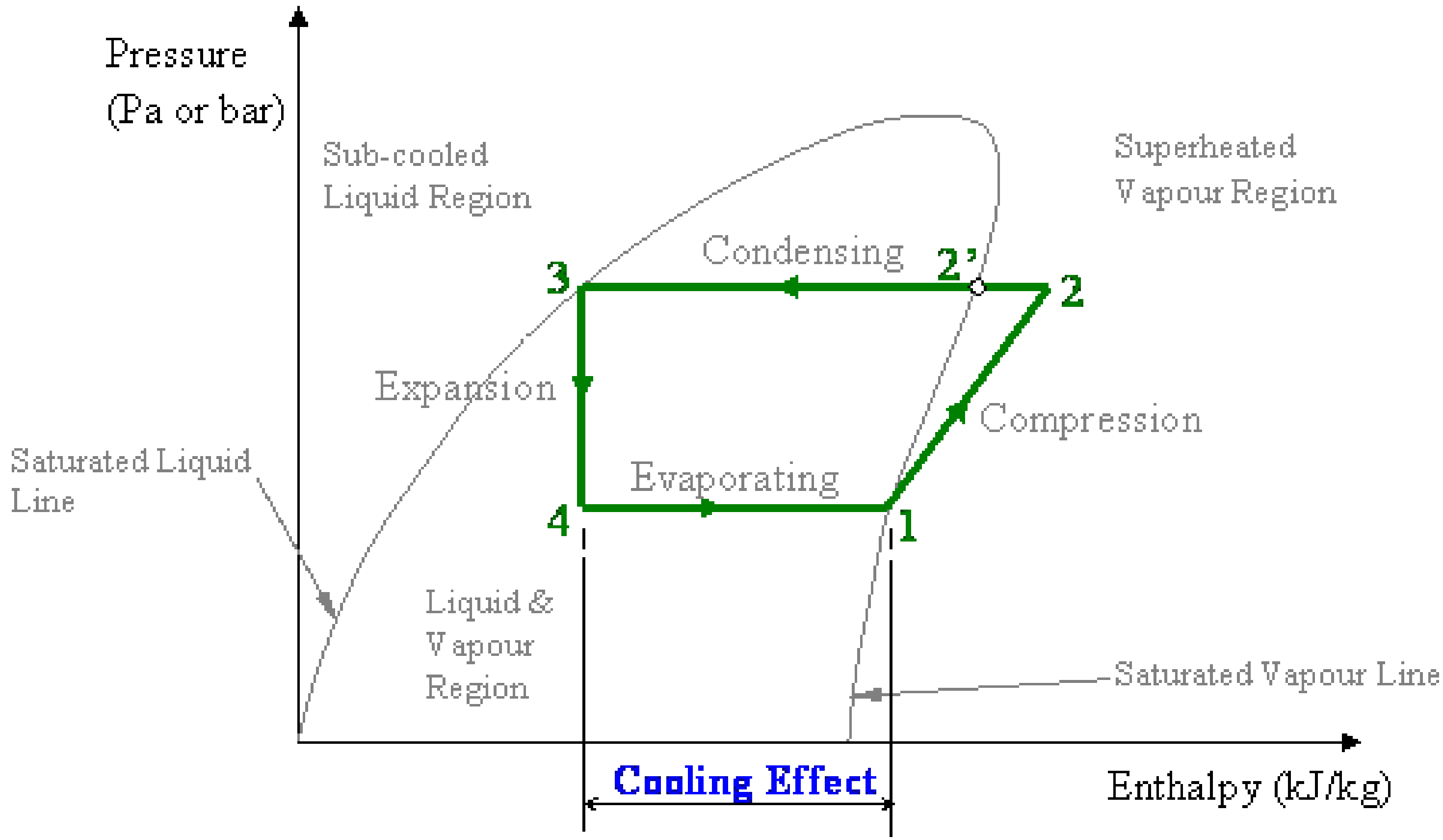


Refrigeration Cycle

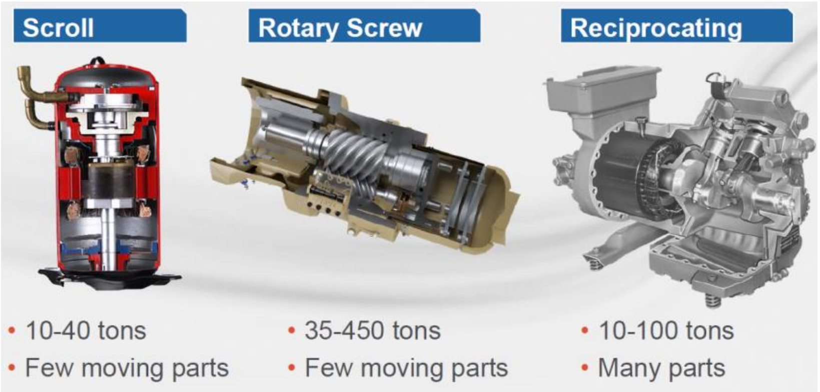


p-H Diagram of Refrigeration Cycle

Compressor Types

Positive Displacement

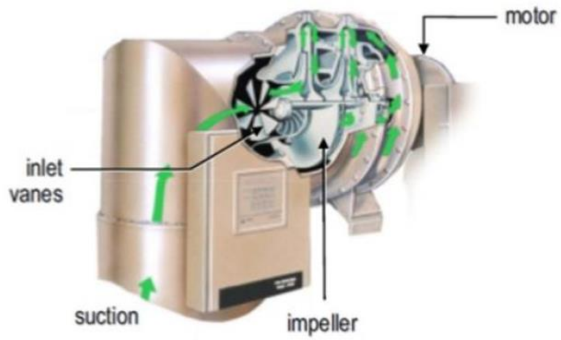
- Scroll
- Screw
- Reciprocating



reduce volume and increase pressure

Dynamic

- Centrifugal



changing kinetic energy to pressure energy by centrifugal force

Reciprocating Compressor

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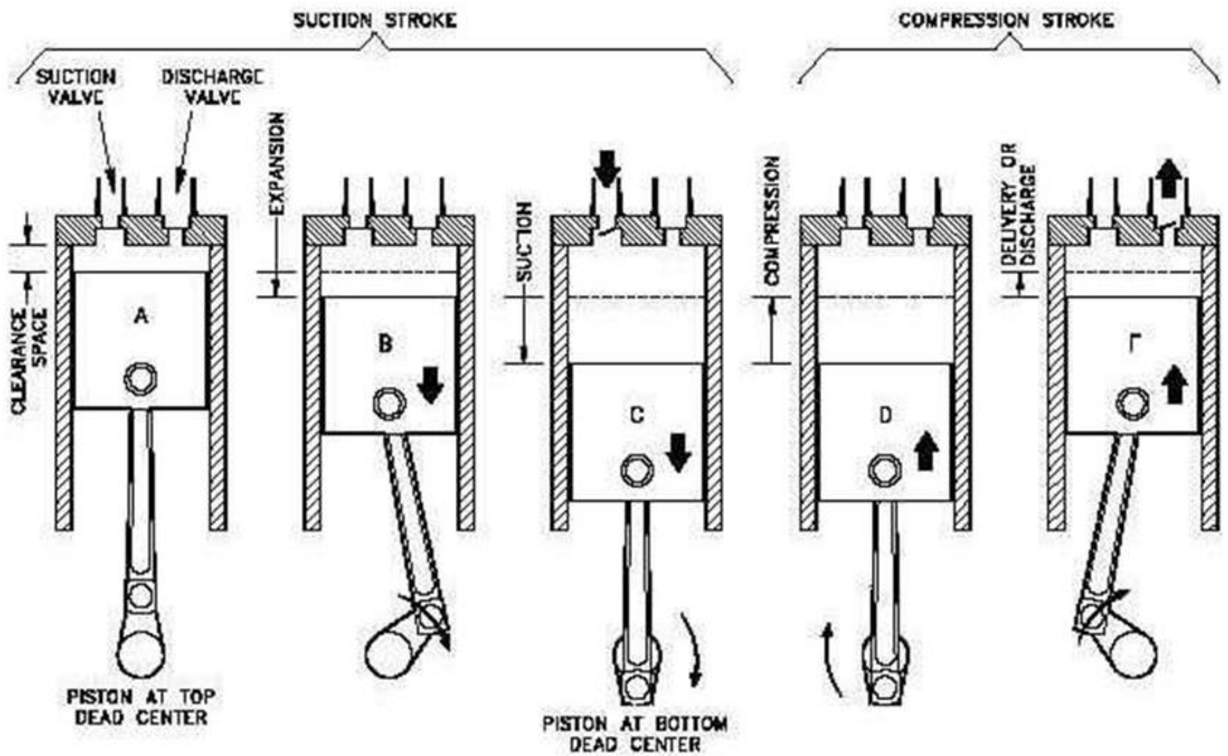
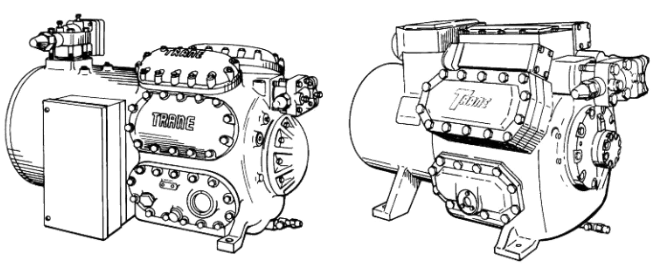
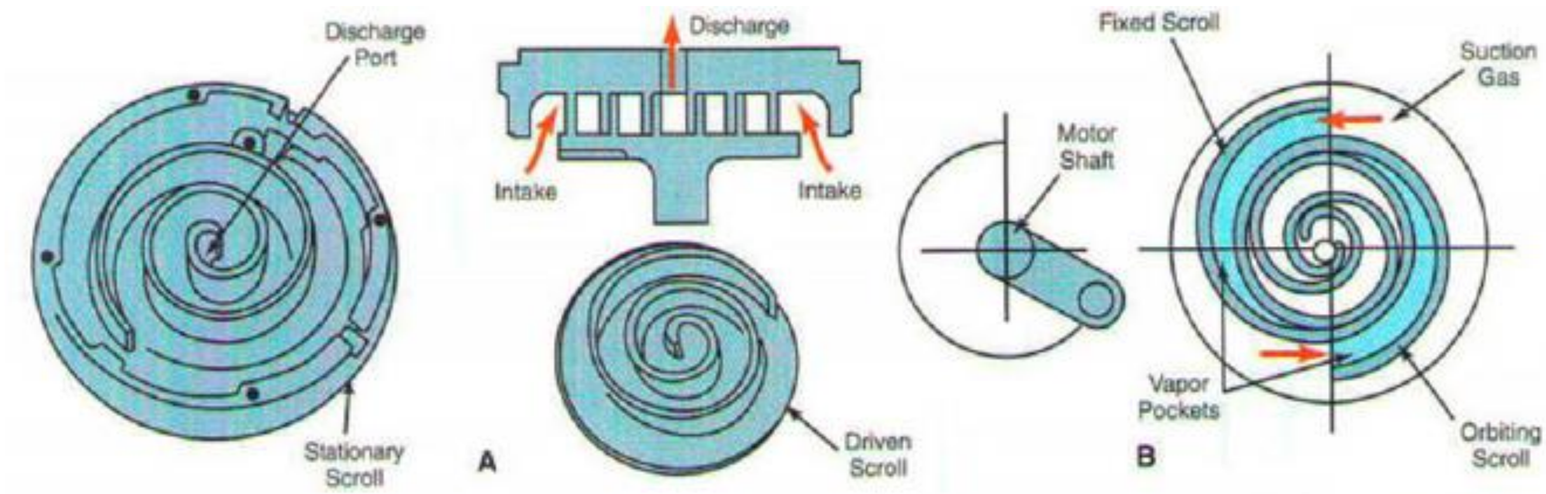


Becoming obsolete



Scroll Compressor



Cooling capacity from 20 RTon up to 70 Rton by multi-compressor configuration

Screw Compressor

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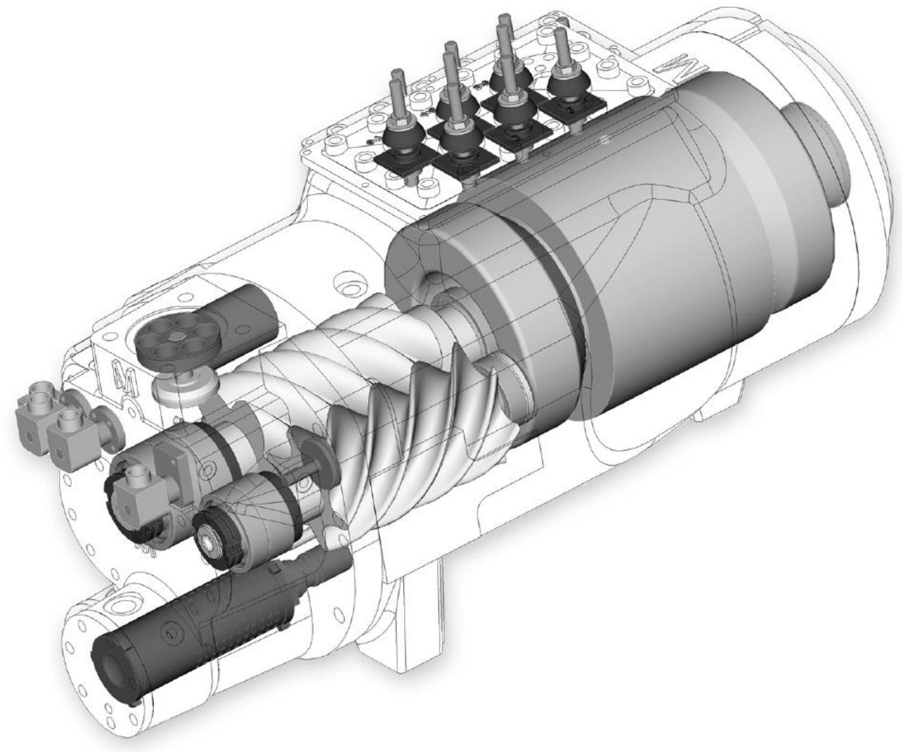

Cooling capacity from 75 RTon up to 450 RTon

Centrifugal Compressor

Cooling capacity from 400 RTon up to 4,000 RTon

Centrifugal Chiller

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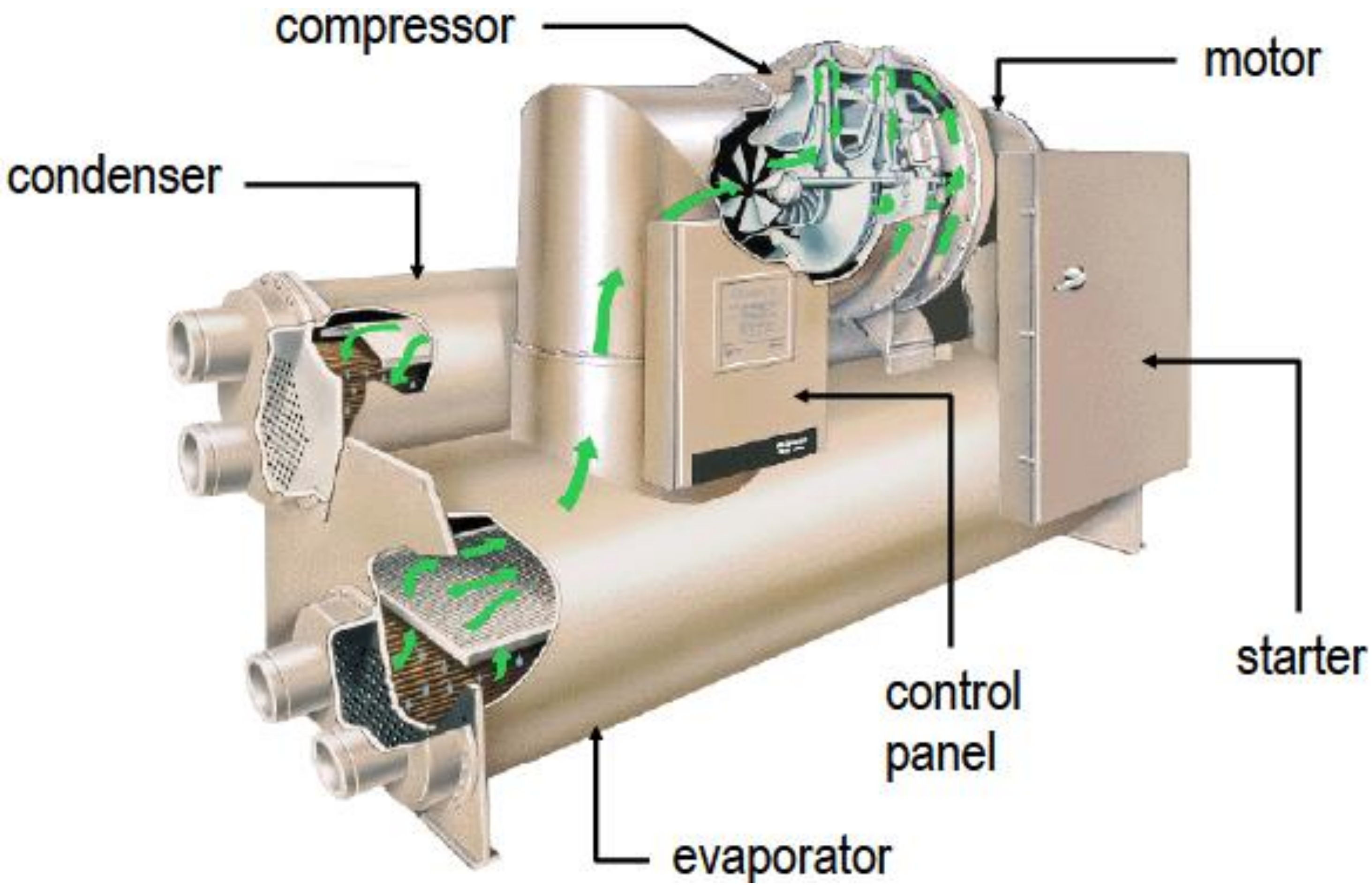

Induction Motor Starting

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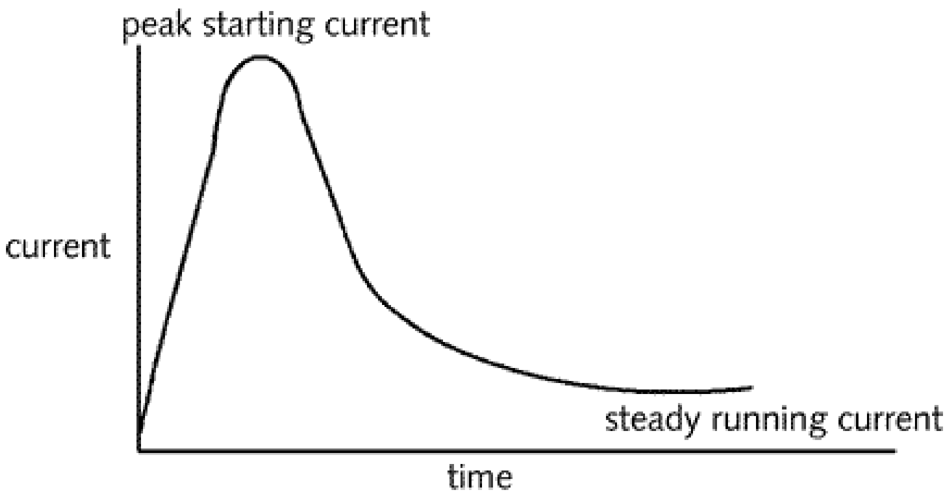
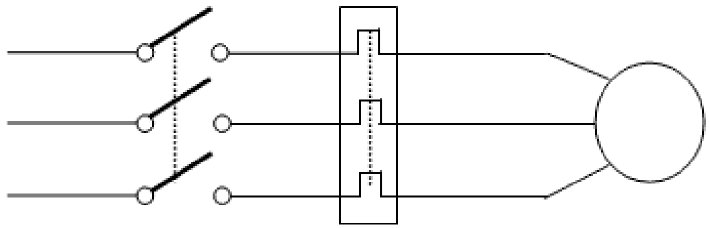
- Motor starting current must overcome friction, load torque and inertia motor-load system within a specified time.
- Starting current (5-7 times of rated current) must not cause overheat and dig in source voltage beyond permissible value.



Induction Motor Starting

- Direct On-Line
- Star-Delta Transformation
- Liquid Resistor
- Variable Speed Drive
- Auto-transformer
- Soft Starter

Direct On-Line Starter

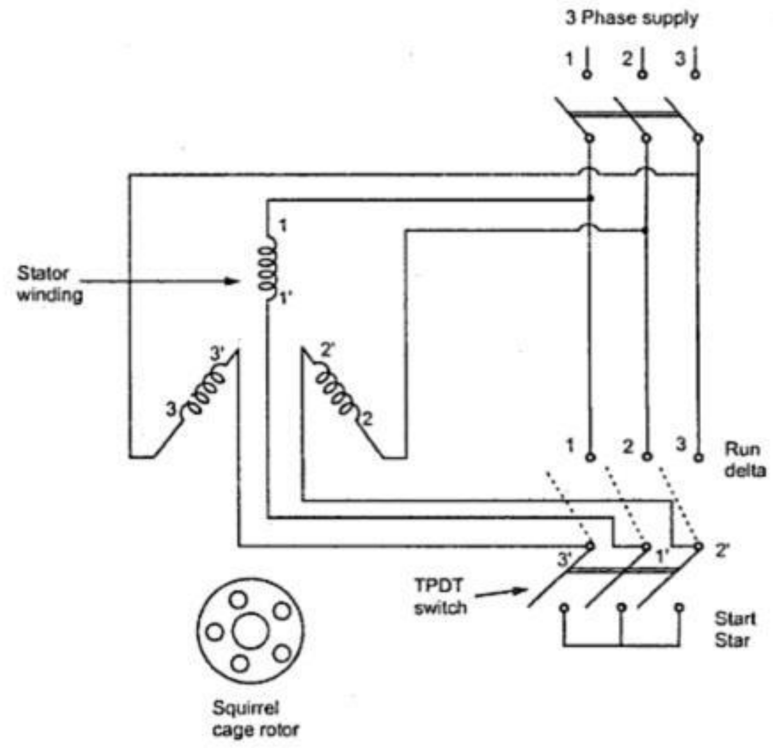


- Simple and Effective
- No complex design is required
- Cost saving (less losses and installation)
- Space saving

High Starting Current exceeding voltage dig limits

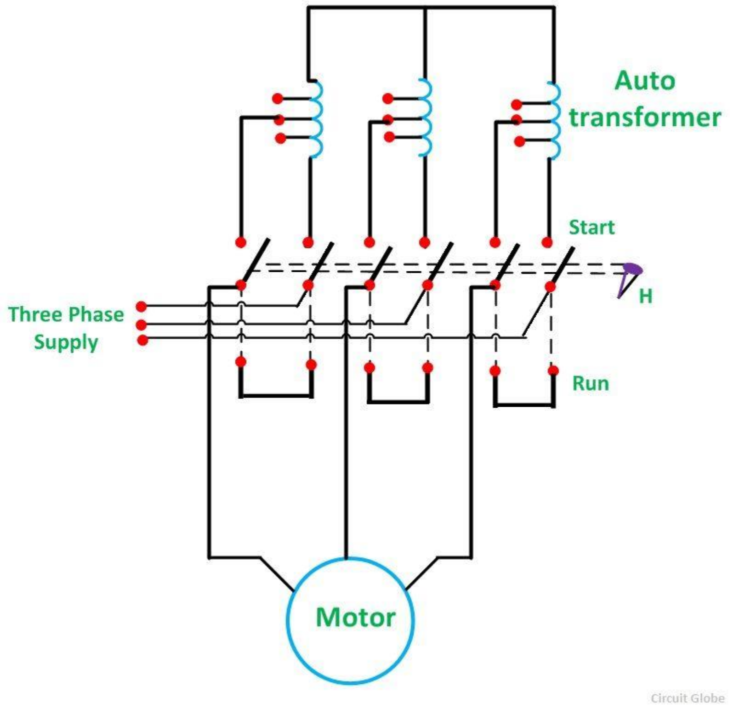
Star-Delta Starter

Training Class



- Practical for small size and LV motor

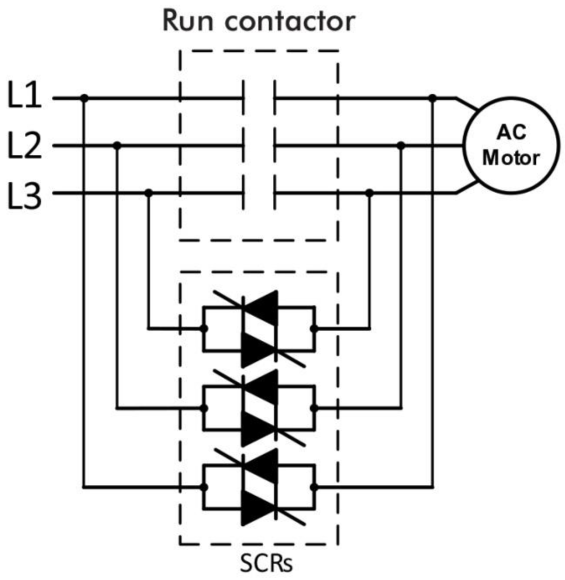
Liquid Resistor / Auto-transformer Starter



- Limit the starting currents

Variable Speed Starter

- Variable speed / frequency to control the loading to be supplied
- Good for part-load



Complex in control and Need filter to limit the harmonics

Deal with surge at low speed and high pressure

Direct On-Line voltage dig calculation

Training Class

Direct On-Line voltage dig calculation

(i) Basic Formula

$$Voltage\ Drop = I(R\cos\theta + X\sin\theta) \text{ volts}$$

$$Voltage\ Depression(\%) = \frac{Voltage\ Drop}{Phase\ Voltage} \times 100\%$$

$$= \frac{Starting\ MVA}{Fault\ Level\ MVA}\left(\frac{R}{Z}\cos\theta + \frac{X}{Z}\sin\theta\right) \times 100\%$$

I = Motor Starting Current
Z = Source Impedance
R = Source Resistance
X = Source Reactance
$\cos\theta$ = Power Factor on Starting

(ii) Quick Method

This quick method could be applied for larger motors: -

$$Voltage\ Depression(\%) \approx \frac{Motor\ Starting\ MVA}{Fault\ Level\ MVA} \times 100\%$$

Direct On-Line voltage dig calculation

Training Class

220 Requirements of Customer's Equipment

1. The Company will specify requirements that the Customer must comply with in order to limit the magnitudes of objectionable effects. These objectionable effects and requirements are set out below for reference :-

Type of Distortion	Type of Abnormal Load	Operational Limit
Voltage Fluctuation	Electric arc furnace	• for 132kV and below 2 %
	Motor starting	• Infrequent (intervals exceeding 2 hours) 3 % • Frequent (intervals not exceeding 2 hours) 1 %
	Rolling mill and traction	• Step-type change :

2. Motors exceeding the sizes listed above shall not during starting cause voltage dip exceeding the figures given below:

	Interval between Startings	Maximum Voltage Dip
Infrequent Starting	Exceeding 2 hours	3%
Frequent Starting	Not exceeding 2 hours	1%

Direct On-Line voltage dig calculation

Training Class

Taking into the 1% voltage dig limit for the source voltage and the minimum 11kV fault level as 70 MVA as the worst case scenario, the maximum motor starting MVA can be calculated as 700kVA. The phase current for motor starting is 37A.

For a normal induction motor with a starting current 5 times of rated current, the motor rated current is 140kVA. The equivalent refrigeration ton load is around 245T.

Direct On-Line voltage dig calculation

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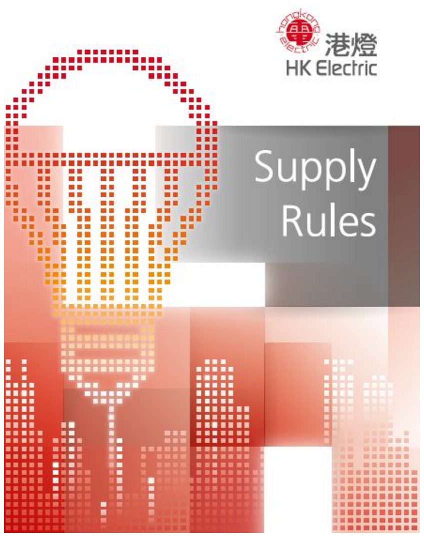
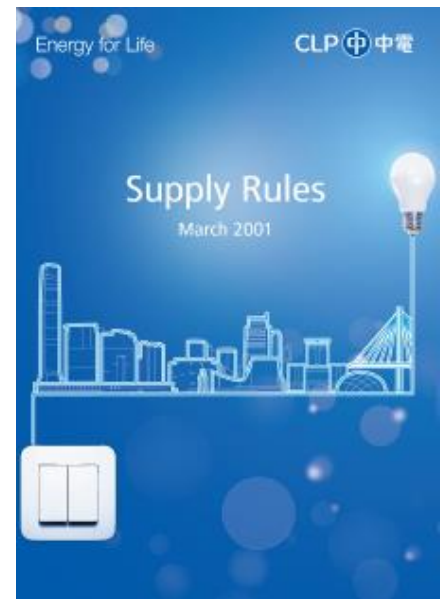
305 LOW VOLTAGE INDUCTION MOTOR

Synchronous motors or high voltage motors shall only be installed by special arrangement with the Company.



Contacting CLP / HEC is required for HV Chillers installation



303 Electric Motor Installation

2. Synchronous Motors and High Voltage Motors
   Synchronous motors and high voltage motors shall only be installed by special arrangement with the Company.

Refrigerant Consideration

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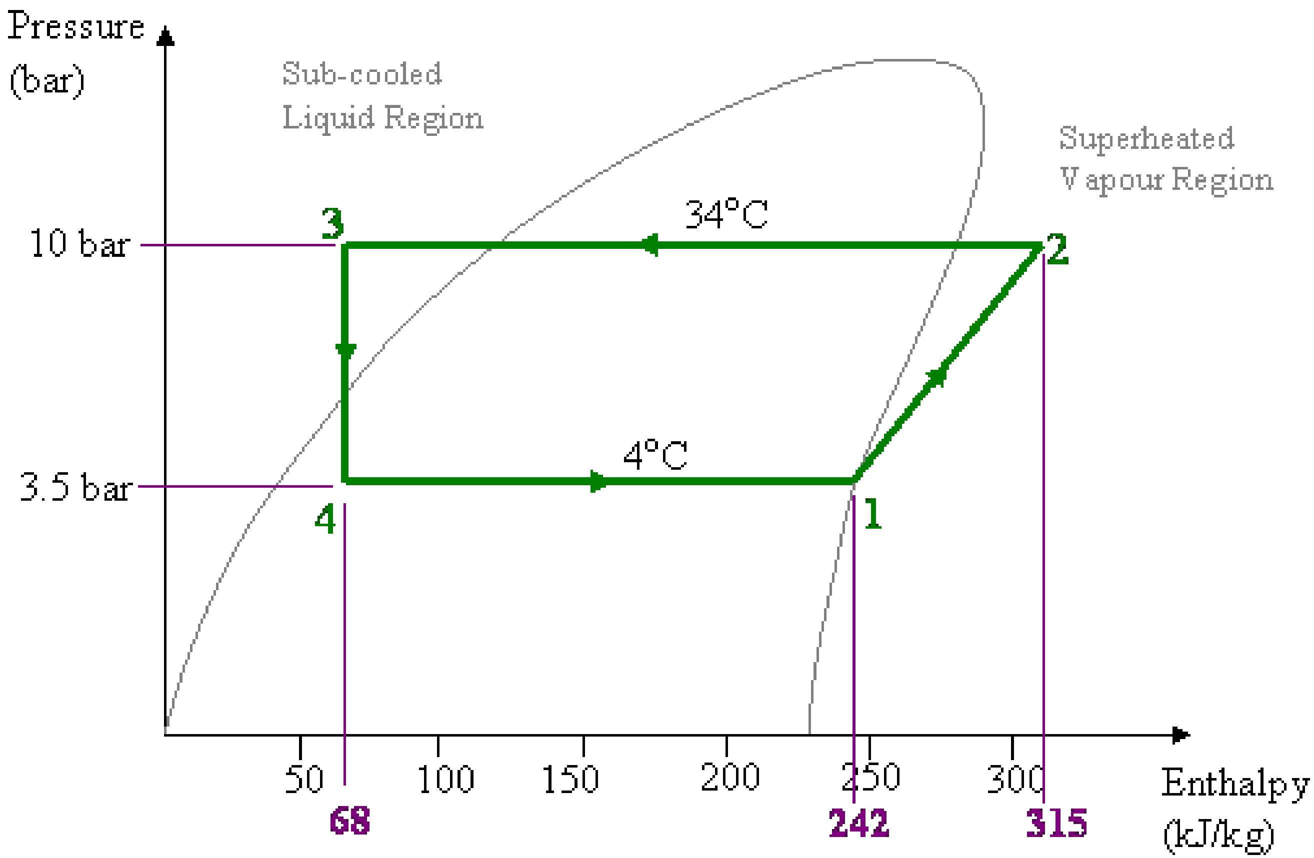

p-H Diagram of Refrigeration Cycle for 134a

Refrigerant Consideration

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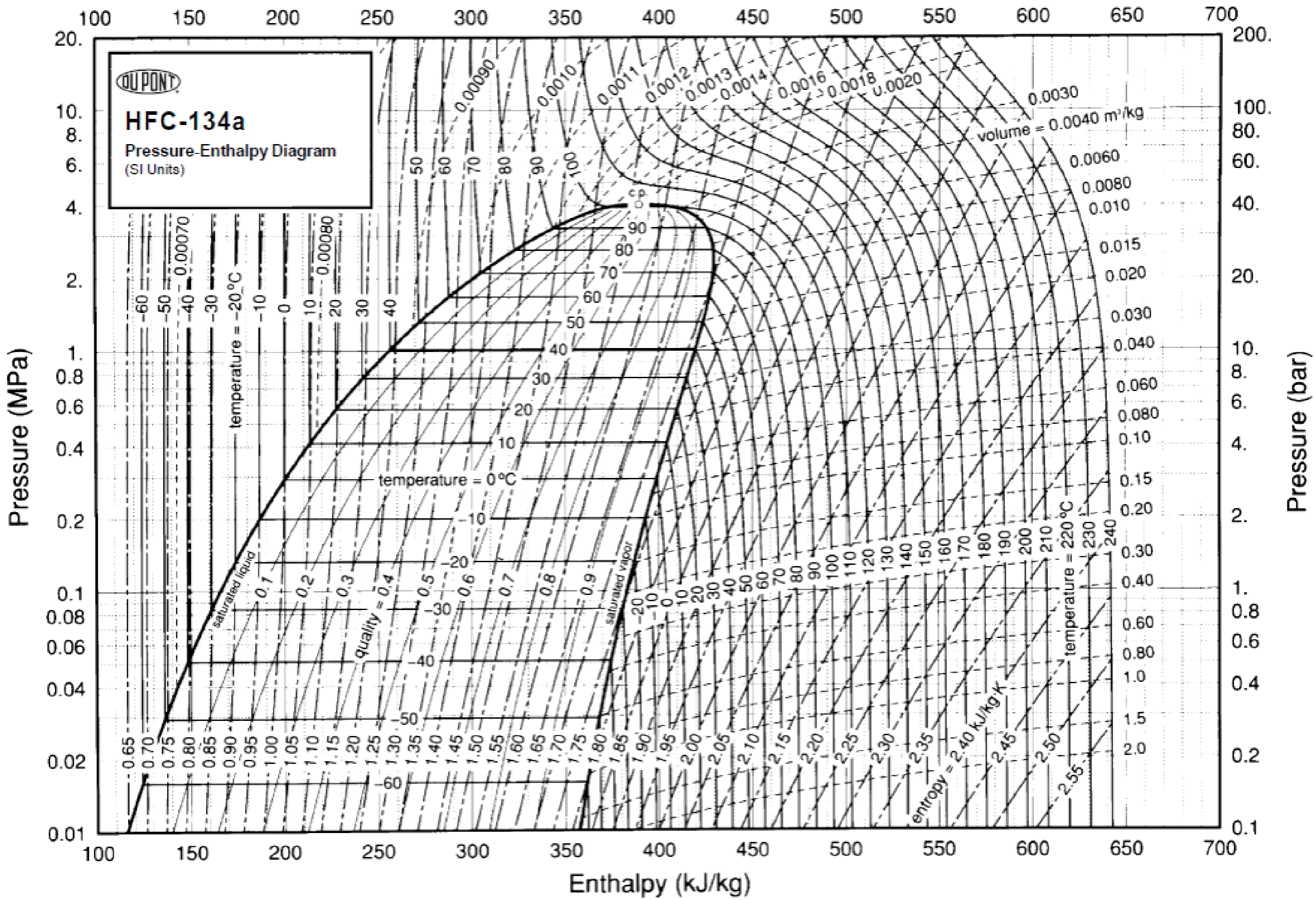
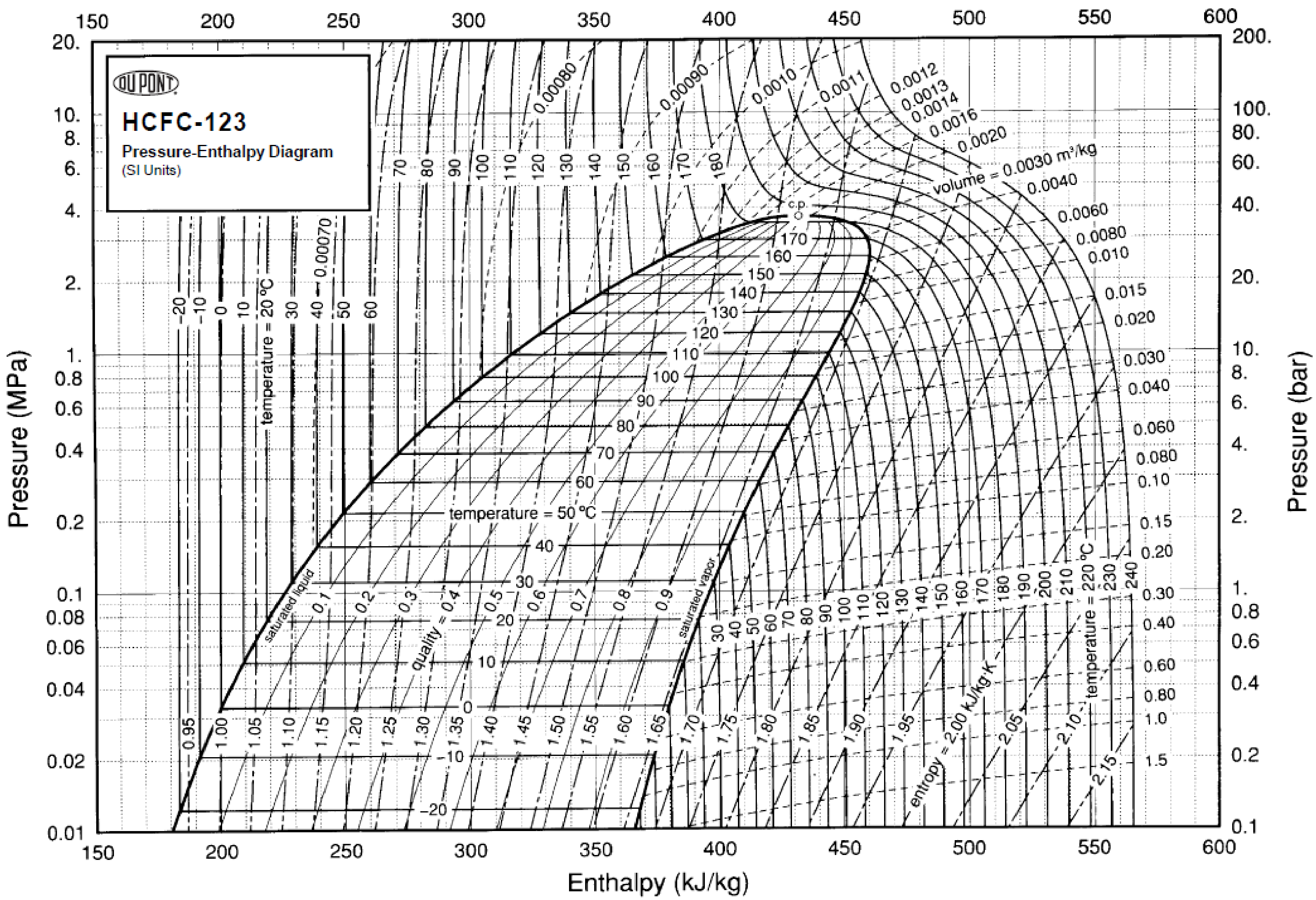
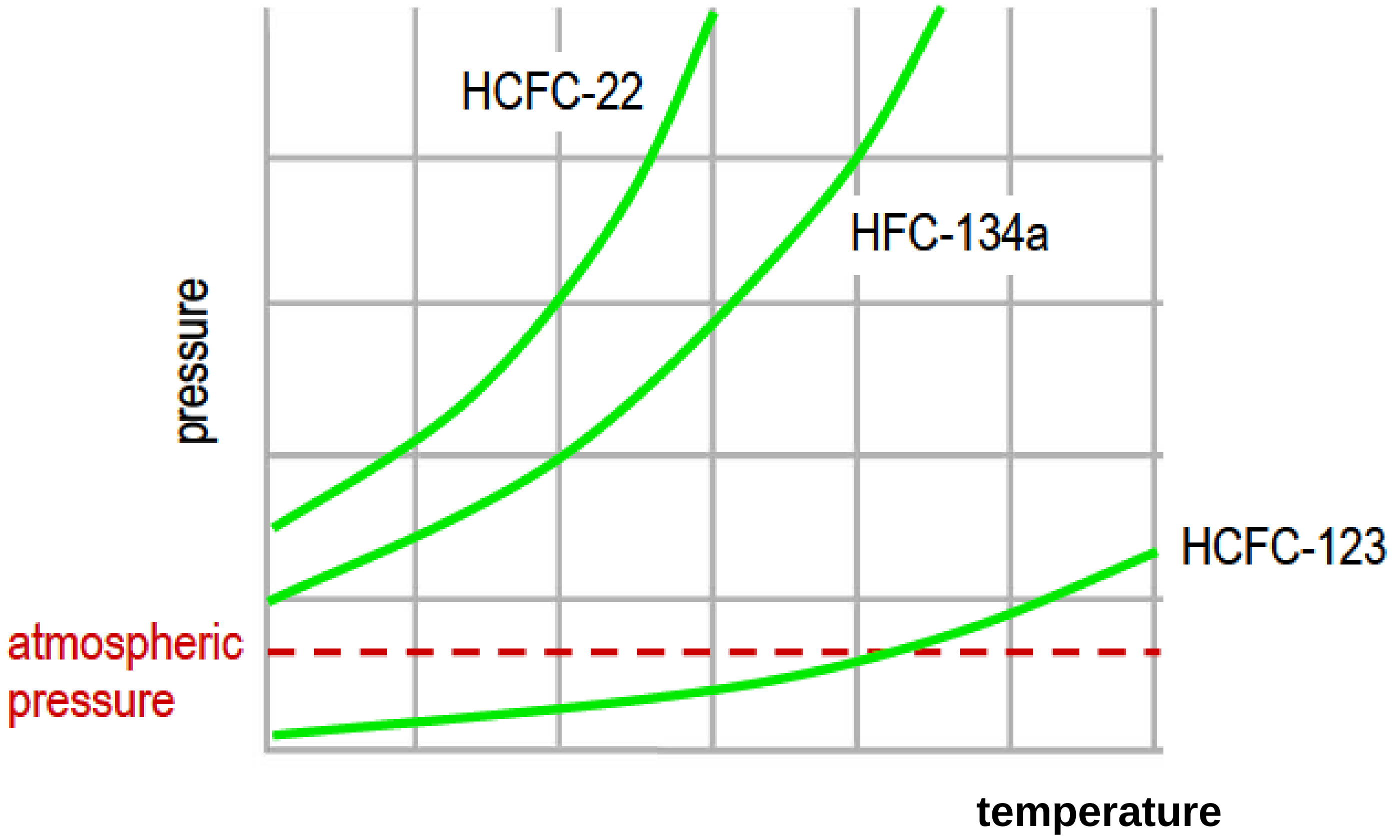


Refrigerant Consideration

Training Class



Refrigerant Consideration



Refrigerant Requirements

- It should have low boiling point and low freezing point. It must have low specific heat and high latent heat.
- It should give high COP in the working temperature range.
- Low Ozone Depletion Potential (ODP) and Global Warming Potential (GWP).

Refrigerant Consideration

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Table 2: Comparison on thermophysical properties between R134a, R1234ze(E) and R1234ze(Z)

Refrigerant name		R134a	R1234ze(E)	R1234ze(Z)
ODP / GWP_{100}		0 / 1430*b	0 / 6*c	0 / <10*d
Safety group (ANSI/ASHRAE 34-2007)		A1	A2L	A2L(expected)*d
Normal boiling temperature		-26.4	-19.3	9.4
Critical temperature		101.1	109.4	150.1
at 65 °C	Pressure [MPa]	1.89	1.44	0.59*e
	Density [kg m^{-3}] *a	100/1026	80.1/1010	28.6/1107*e
	Viscosity [μPa s] *a	14.0/115	14.4/122	12.6/191*e
	Thermal conductivity [mW m^{-1} K^{-1}] *a	19.3/63.9	18.0/61.3	16.0/76.4*e
	Latent heat of vaporization [kJ kg^{-1}]	132.1	129.9	177.8*e
at 30 °C	Pressure [MPa]	0.77	0.58	0.210*e
	Density [kg m^{-3}] *a	38/1187	30.5/1146	10.4/120*e
	Viscosity [μPa s] *a	11.9/183	12.5/188	11.3/277*e
	Thermal conductivity [mW m^{-1} K^{-1}] *a	14.3/79	14/72.5	12.9/87.6*e
	Latent heat of vaporization [kJ kg^{-1}]	173.1	163.1	202.9*e

*a These data at the equilibrium state are listed in the manner of "vapor / liquid". *b IPCC 4th report (Solomon, *et al.*, 2007). *c Honeywell MSDS (2011). *d Koyama *et al.* (2012, 2013). *e Akasaka *et al.* (2013).

Refrigerant Consideration

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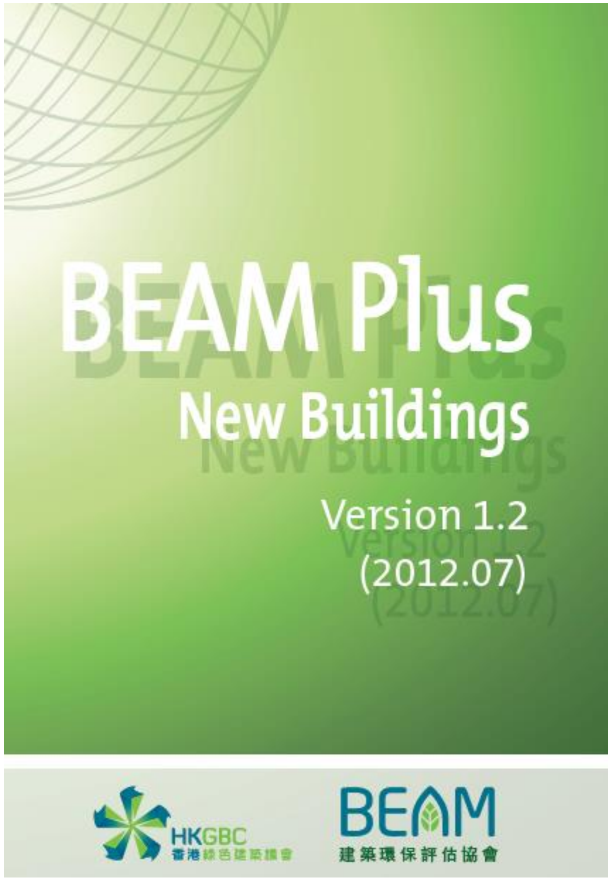
Low Ozone Depletion Potential (ODP) and Global Warming Potential (GWP).

Refrigerant	ODP[1]	GWP[1]
Hydrofluorocarbons		
HFC-23	~0	12240
HFC-32	~0	650
HFC-134a	~0	1320
HFC-152a	~0	140
HFC-402A	~0	1680
HFC-404A	~0	3900
HFC-407C	~0	1700
HFC-410A	~0	1890
HFC-413A	~0	1774
HFC-507A	~0	3900
Hydrochlorofluorocarbons		
HCFC-22	0.04	1780
HCFC-123	0.02	76



Chiller Efficiency

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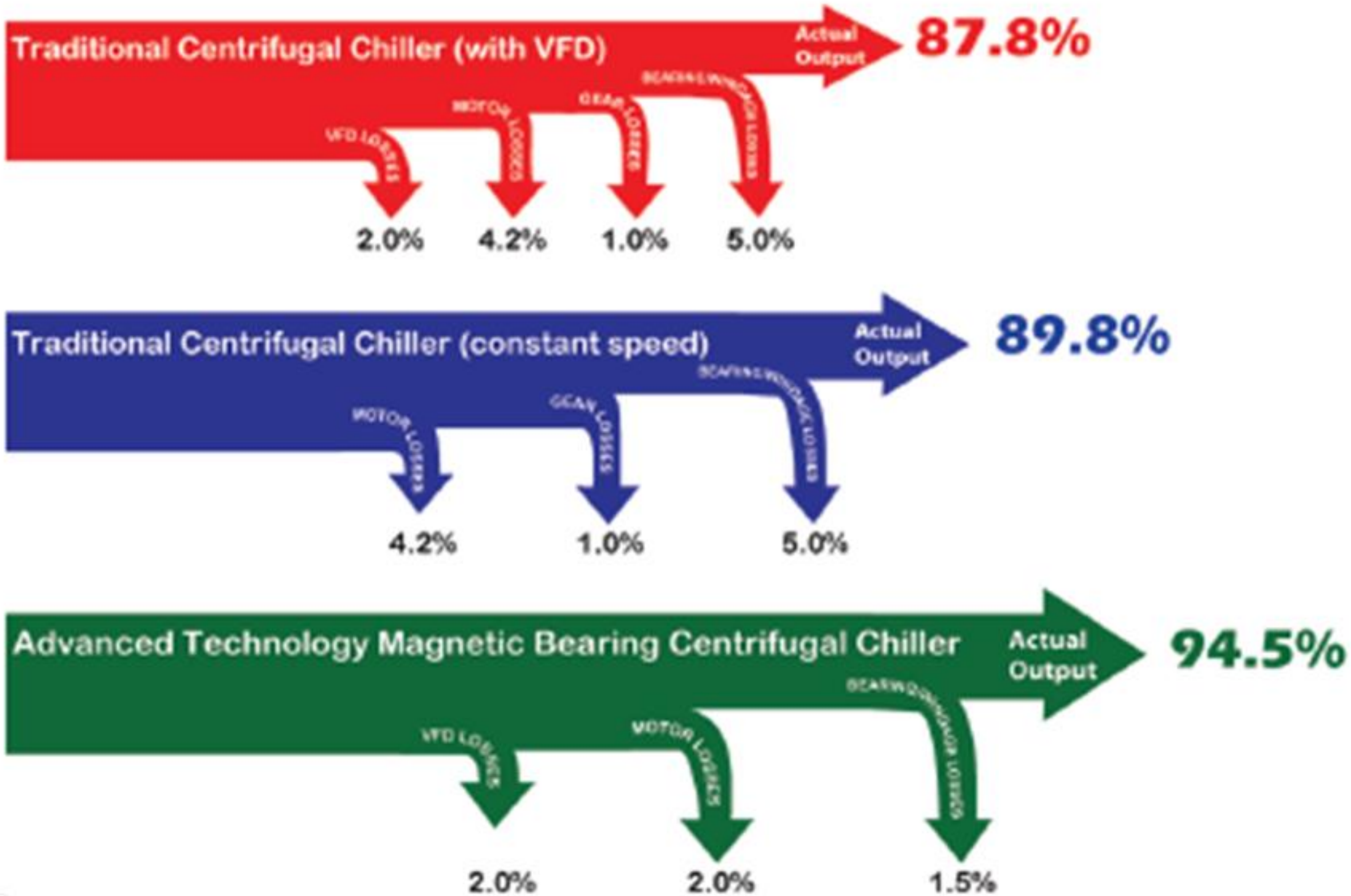
- ## Chiller Efficiency



Chiller Overall Considerations

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- High COP

$$COP = \frac{\text{Refrigeration Effect}}{\text{Work Input}}$$

- Arrangement for higher chiller efficiency
- Life Cycle Cost minimization
- Use less materials hence less CO_2 footprint
- Use product closer to user place to minimize transportation and hence less CO_2 footprint
- Use Refrigerant of zero or low ODP & GWP
- Use Building Information Model as a tool

Chiller Efficiency

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Table 6.12b : Minimum Coefficient of Performance for Chiller@2 at Full Load												
Air-cooled												
Type of compressor	Reciprocating		Scroll			Screw			Centrifugal			
Capacity Range (kW)	Below 400 kW	400 kW & above	All Ratings			All Ratings			All Ratings			
Minimum COP at cooling (free air flow@1)	2.6	2.8	2.7			2.9			2.8			
Water-cooled												
Type of compressor	Reciprocating			Scroll			Screw			Centrifugal		
Capacity Range (kW)	Below 500 kW	500 to 1000 kW	Above 1000 kW	Below 500 kW	500 to 1000 kW	Above 1000 kW	Below 500 kW	500 to 1000 kW	Above 1000 kW	Below 500 kW	500 to 1000 kW	Above 1000 kW
Minimum COP (Cooling)	4.1	4.6	5.2	4.1	4.6	5.2	4.6	4.7	5.5	5.1	5.6	5.7

Note – The above table is extracted from Table 6.12b of the Building Energy Code (BEC)

Refrigeration Cycle and Efficiency

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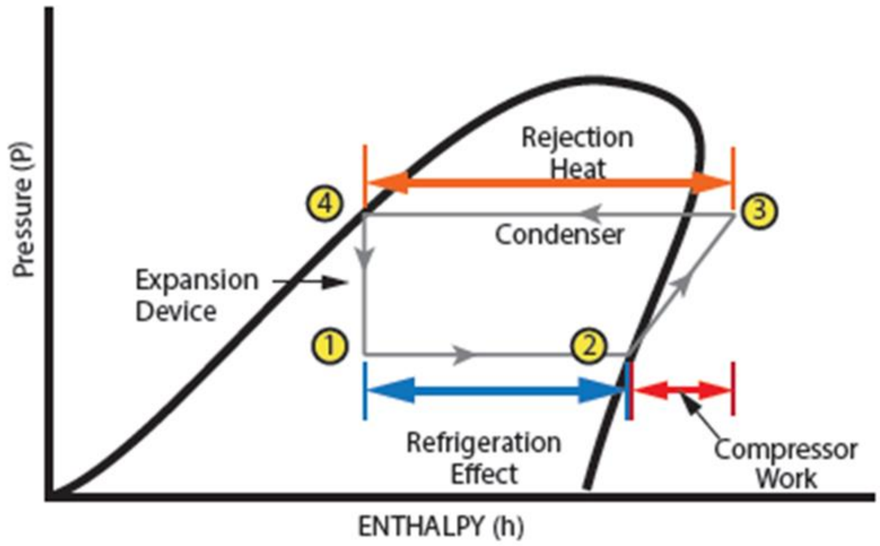
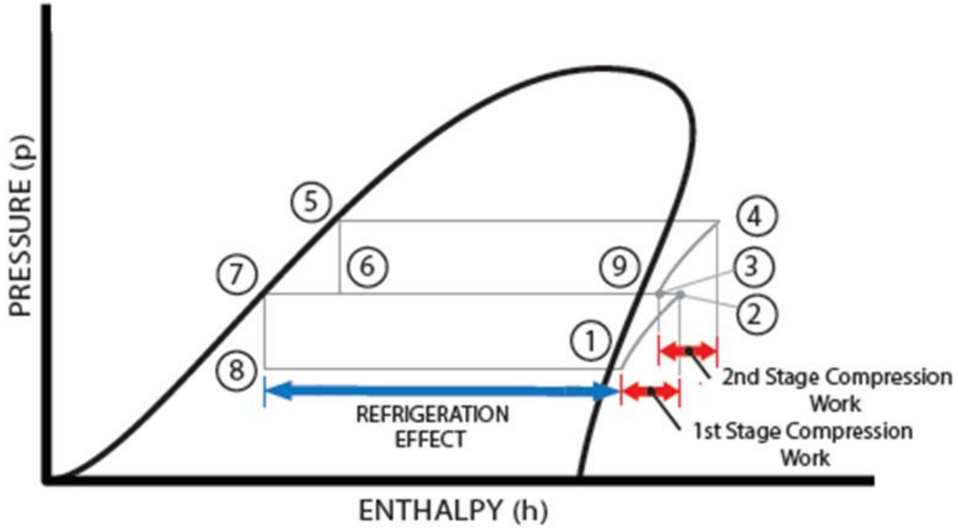


2 stages compression to increase efficiency



Refrigeration Cycle and Efficiency

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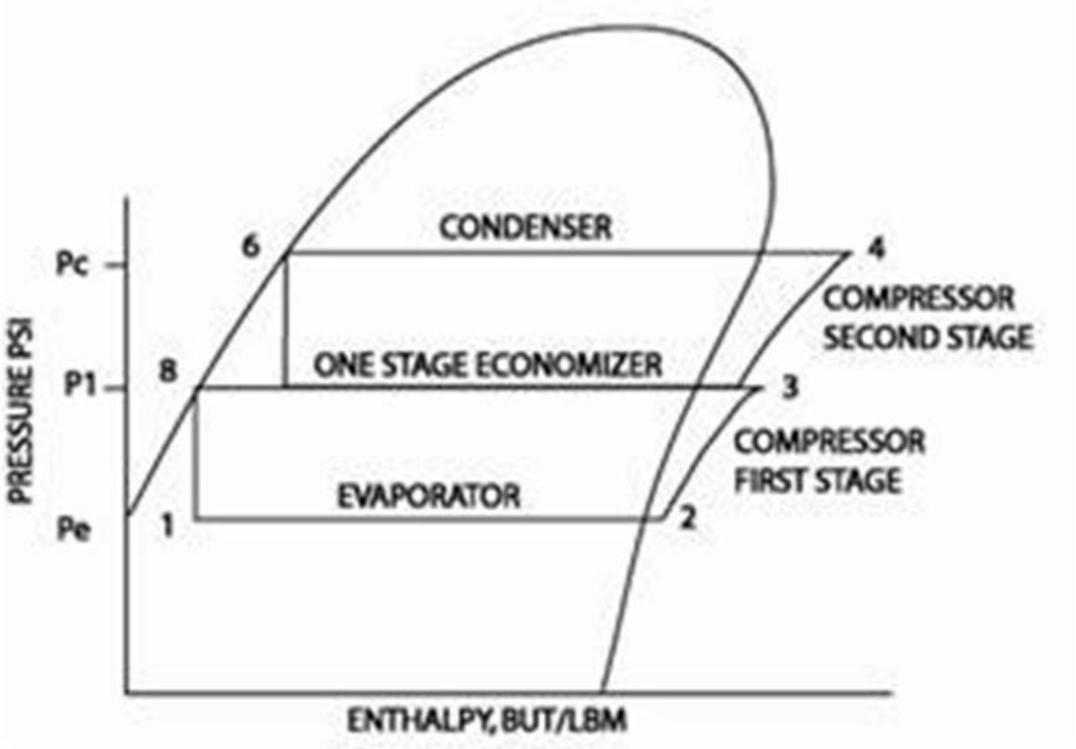
2 stages compression to increase efficiency



Refrigeration Cycle and Efficiency

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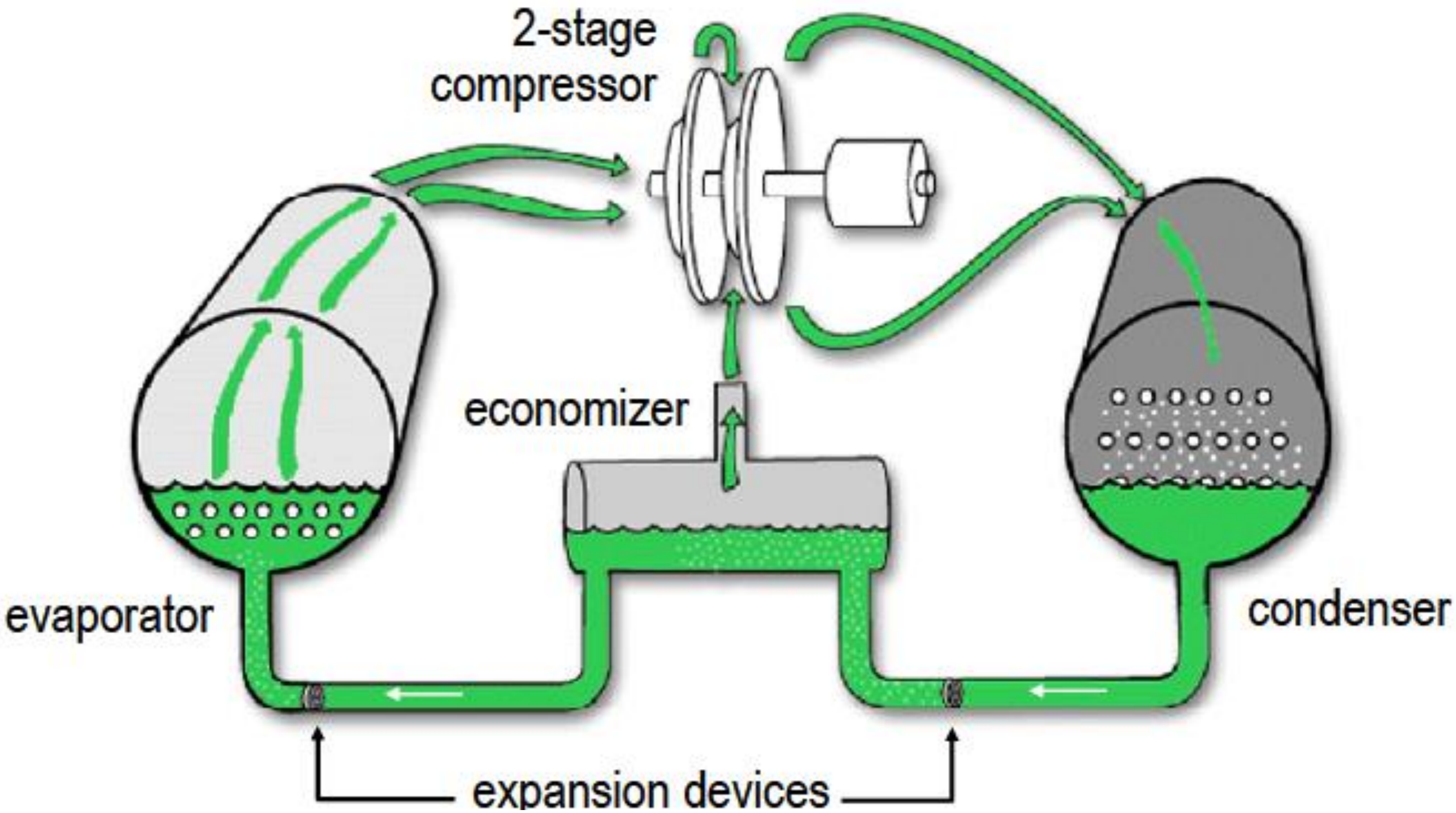
2 stages compression to increase efficiency



District Cooling System

- **District Cooling System can result in an energy saving of 20% and 35% respectively when compared with standalone water-cooled systems and air-cooled system. Some basic requirements:**
  - **the area will have high cooling demand and load density**
  - **the greenfield site presents fewer constraints to the construction of the relevant infrastructure**
  - **buildings in the area can be designed to adopt DCS**
  - **land is available for plant rooms**
  - **the development programme for the DCS fits in with the area's development programme**

Kai Tak District Cooling System

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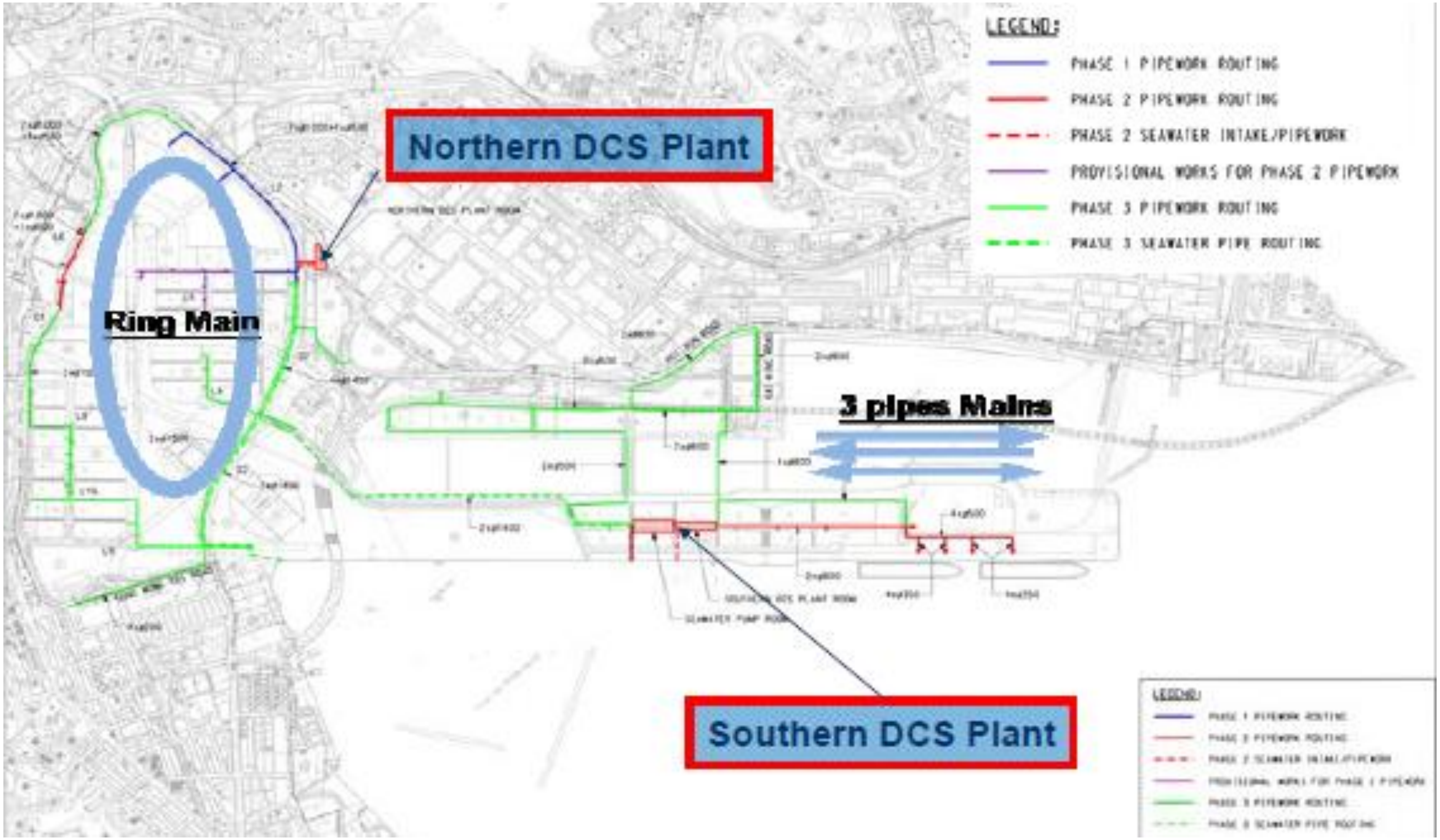

Kai Tak District Cooling System

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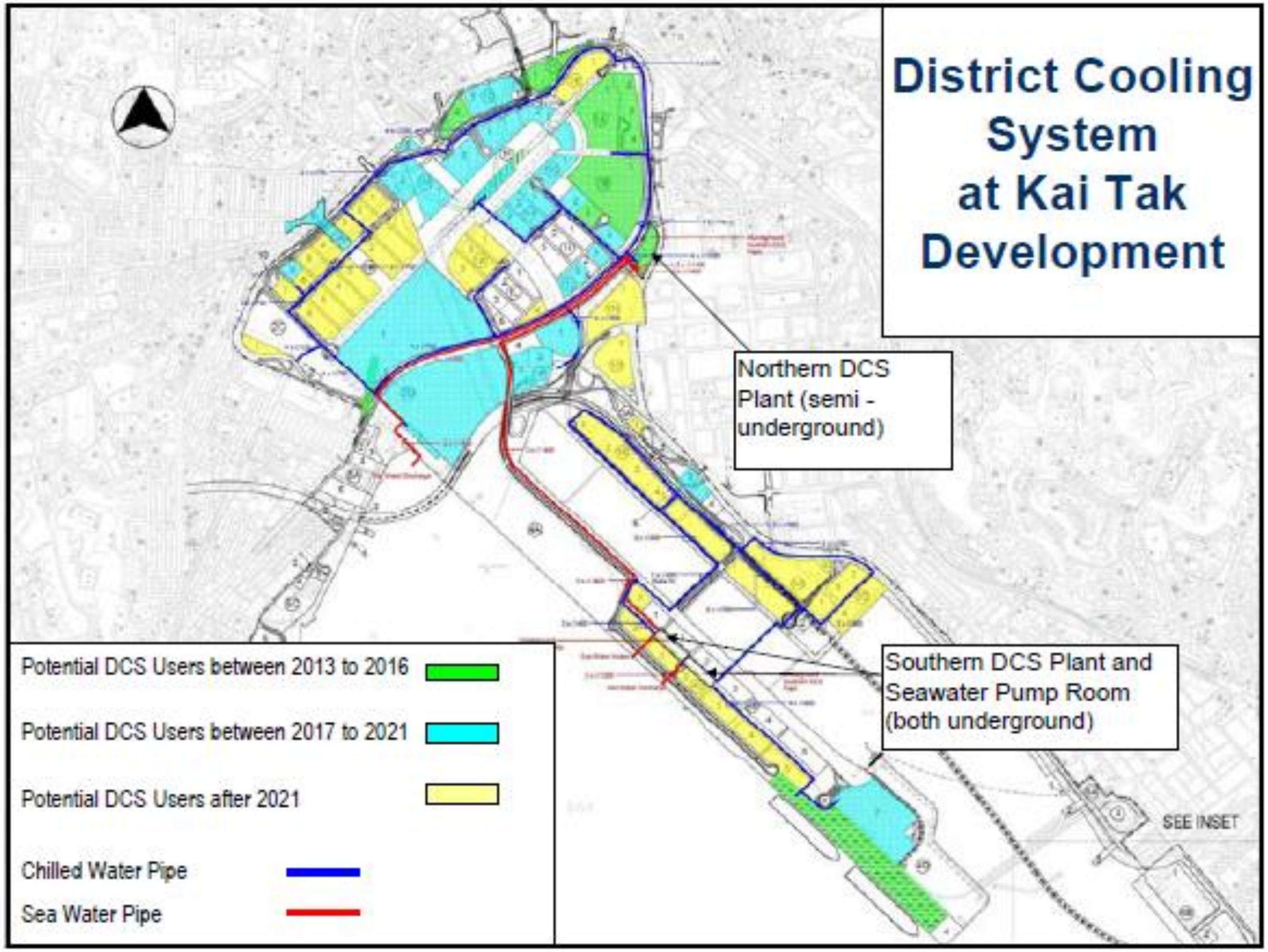

Kai Tak District Cooling System

South Plant (34,950 RT):

- 3 sets 1250 RT (Phase 1)
- 2 sets 600 RT (Phase 1)
- 2 sets 5000 RT (Phase 2)
- 3 sets 5000 RT (Phase 3 – Target on 2021)
- 2 sets 2500 RT (Phase 3 – Target on 2021)

North Plant (48,300 RT)

- 2 sets 1250 RT (Phase1)
- 2 sets 400 RT (Phase 1)
- 2 sets 2500 RT (Phase 2)
- 8 sets 5000 RT (Phase 3 – Target on 2021)

District Cooling System

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The West Kowloon Cultural District in Hong Kong is one of the largest cultural developments in the world, the district cooling system will have over 20,000TR cooling capacity

Conclusion

- We need to respond to Climate Change beyond tomorrow – energy saving and reduce CO_2 emission
- Economy of Scale: efficient, scalable, sustainable
- HV Compressor starting methods
- Choice of Refrigerants
- Energy Efficiency of Chillers
- District Cooling System

HV Chillers –
Combating Climate Change Solution

Ir Dr F.C. Chan

1 Dec 2017

Thank you