Chillers and Refrigerants

APPA Institute for Facilities Management
February 6, 2020
San Diego, CA

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Today's Presentation

Course Description:

This course explores:

This module will review various types of refrigerants, the pros and cons of each, as well as the general care needed in handling refrigerants. Moreover, it will discuss the latest innovations in chillers and ancillary equipment, attainable efficiencies, and things to look for in evaluating new chillers.

Learning Objectives:

1. Understand how refrigerants work
2. Prepare to deal with requirements for new replacement refrigerants
3. Understand how various cooling mechanisms and machinery provide cooling
4. Understand how the various components of cooling equipment can be integrated into different types of systems
5. Discuss evaluating and specifying chillers

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Agenda

- Refrigerants
  - Background and management issues
  - Safety and handling
- Refrigeration Cycles
- Refrigeration Systems
  - Chillers
  - Towers
  - Pipes & pumping systems
- Future
  - Chilled water systems
  - Chiller specifications

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Words of Wisdom

If at first you don't succeed, try following the instructions.

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Definition:

- Refrigeration
  - The cooling effect of the process of extracting heat from a lower temperature heat source, a substance or cooling medium, and transferring to a higher temperature heat sink, to maintain the temperature of the heat source below that of surroundings
- Refrigeration systems
  - Combination of components, equipment & piping connected to produce the refrigeration effect

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Refrigerants

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Refrigerants

- Terminology
  - Refrigerant:
    - a primary working fluid to transfer heat in a refrigeration system
  - Transport medium:
    - working fluid cooled/heated by refrigerant during evaporation/condensation to transport heat from centralized equipment to remote equipment
  - Liquid absorbent:
    - working fluid to absorb vaporized refrigerant (water or ammonia) after evaporation in an absorption refrigeration system

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Refrigerants

- Required properties of refrigerants
  - Safety (ANSI/ASHRAE Standard 34-1992)
    - Toxicity: Class A and Class B
    - Flammability:
      - Class 1 – no flame propagation
      - Class 2 – lower flammability
      - Class 3 - higher flammability
    - Such as "A1" Group: R-134a & R-22; "B2": ammonia
  - Evaporation and condensation temperatures within operating cycle range
  - Effectiveness of refrigeration cycle (kW/ton)
  - Lubricant oil miscibility
  - Compression ratio

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Refrigerants

- Desired properties:
  - Evaporation pressure > atmospheric
    - Non-condensable gas will not enter the system
  - Lower condensing pressure (lighter construction)
  - High heat of vaporization (better heat transfer)
  - Inert (avoid corrosion, erosion)
  - Leakage can be detected

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Refrigerants

Refrigerant Numbering

- Briefly, the A.S.H.R.A.E. method of designating a refrigerant by number is as follows. (Note that the numbering system begins on the right.)

  First digit on the right= Number of fluorine atoms
  Second digit from the right = Number of hydrogen atoms plus one
  Third digit from the right = Number of carbon atoms minus one (not used when equal to zero)
  Fourth digit from the right = Number of unsaturated carbon-carbon bonds in the compound (not used when equal to zero)

  When bromine is present in place of all or part of the chlorine, the same rules apply except that the capital letter "B" after the designation for the parent compound shows the presence of th bromine (Br). The number following the letter "B" shows the number of Bromine atoms present.

  The lower-case letter that follows the refrigeration designation refers to the form of the molecule when different forms (isomers) are possible, with the most symmetrical form indicated by ths number alone. As the form becomes increasingly unsymmetrical, the letters a, b, and c (lows case) are appended (For example, HFC-134a).

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Refrigerants

- Classification of refrigerants also based on:
  - Ozone depletion potential (ODP)

    - Ratio of ozone depletion rate compared with R-11 (evil refrigerant of yesteryear)
  - Global warming potential (GWP)
    - Global warming effect compared with R-11
- Inorganic compounds
  - ASHRAE assigns numbers 700 to 799
  - Ammonia R-717, water R-718 and air R-729
  - Do not deplete ozone layer

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Refrigerants

- Chlorinated fluorocarbons (CFCs)
  - Contain chlorine, fluorine, and carbon
  - Long lifetime (centuries) in atmosphere
  - Cause ozone depletion and high GWP
  - E.g., R-11, R-12, R-113, R-114, R-115
- Hydrochlorofluorocarbons (HCFCs)
  - Contain hydrogen, chlorine, fluorine, and carbon, reduced ozone depletion, but are greenhouse gases, i.e. have GWP
  - Shorter lifetime in atmosphere
  - E.g., R-22, R-123, R-124, R-401a,b,c
  - Transitional or interim refrigerants, scheduled for restricted production starting in 2004 and phase-out by 2030
- Hydrofluorocarbons (HFCs)
  - Contain only hydrogen, fluorine, and carbon atoms and cause no ozone depletion, but have GWP
  - E.g., R-134a, R-32, R-125 and R-245ca

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Refrigerants

Blends

Azeotropic

- An azeotrope is a mixture of two substances which cannot be separated into its components by distillation.
- It evaporates and condenses as a single substance and its properties are completely different from its constituents.
- For example, azeotrope R-500 is a mixture composed of 73.8 per cent R-12 and 26.2 per cent R-152.

Non-Azeotropic

- Forane® 410A, a non-azeotropical blend consisting of HFCs R-32 and R-125, is a zero ozone depletion potential (ODP) refrigerant usable as a replacement for HCFC-22 in a variety of new equipment applications.

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Refrigerants

- **Alternative refrigerants**
  - **R-22 (HCFC**
  - **R-123 (HCFC, ODP = 0.02), replaces R-11**
    - **R-245a (ODP = 0), replace R-11 (longer term?)**
  - **R-134a (HFC, ODP = 0), replaces R-12**
    - **Not miscible with mineral oil, synthetic lubricant is used**
  - **R404A (R-125/R-134a/143a) and R-407C**
    - **HFCs near azeotropic, ODP = 0; possible long-term alternatives to R-22**
  - **R-507 (R-125/R-134a)**
    - **HFCs azeotropic, ODP = 0; long-term alternative to R-502**
    - **Synthetic lubricant oil is used**
  - **R-402A (R-22/R-125/R-290) as short-term drop-in replacement, also HFC Dupont MO99**

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Refrigerants

Properties of Some Refrigerants

		CFC			HCFC	HFC
Properties	**Ammonia**	**R11**	**R12**	**R22**	**R123**	**R134a**
Coefficient of performance	4.75	5.00	4.69	4.65	4.93	4.61
Ozone depleting potential	0	1.0	1.0	0.05	0.02	0
Global warming potential	0	1500	4500	510	29	420
Occupational exposure limit (ppm)	25	1000	1000	1000	10	1000

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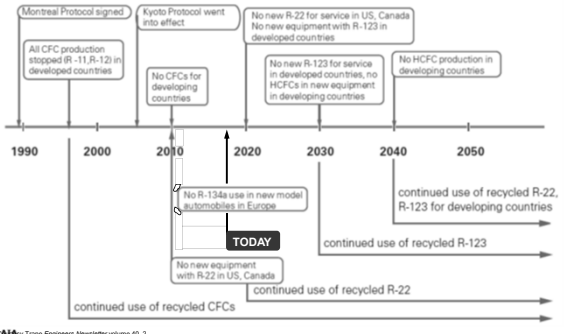
Refrigerant Phase-out



Source: Trane Engineers Newsletter volume 40–2

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Refrigerant Costs and Phase-Out

	COST/ LB	USER COST	FOR NEW EQUIPMENT	SERIES STOCK
CFC - 11	$20.00	$30.00	DEC. 31, 1995	1995
CFC - 12	$32.00	$48.00	DEC. 31, 1995	1995
Ammonia	$2.50	$3.75	not yet scheduled	
HCFC - 22	$20.00	$30.00	2010	2020
HCFC - 123	$1.33	$2.00	2020	2030
HCF - 134A	$5.33	$8.00	not yet scheduled	

As of Dec. 2019 (various unreliable sources)

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Agenda

- **Refrigerants**
  - **Background and management issues**
  - **Safety and handling**
- **Refrigeration Cycles**
- **Refrigerant Systems**
  - **Chillers**
  - **Towers**
  - **Pipes & pumping systems**
- **Future**
  - **Chilled water systems**
  - **Chiller specifications**

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Refrigeration Cycles

- **Refrigeration process**
  - **Change thermodynamic state of refrigerant with energy & work transfer**
  - **1 ton of refrigeration (T_R) = 12,000 Btu/hr (3.516 kW)**
- **Refrigeration Cycle**
  - **Vapor compression**
    - **Mechanical refrigeration using compressors, condensers and evaporators**
  - **Absorption**
    - **Produce refrigeration effect by thermal energy input**
    - **Liquid refrigerant produces refrigeration during evaporation; the vapor is absorbed by an aqueous absorbent**
  - **Gas expansion**
    - **Air or gas is compressed to a high pressure**
    - **It is then cooled by surface water or air and expanded to low pressure to produce refrigeration effect**

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Compression Refrigeration Cycle

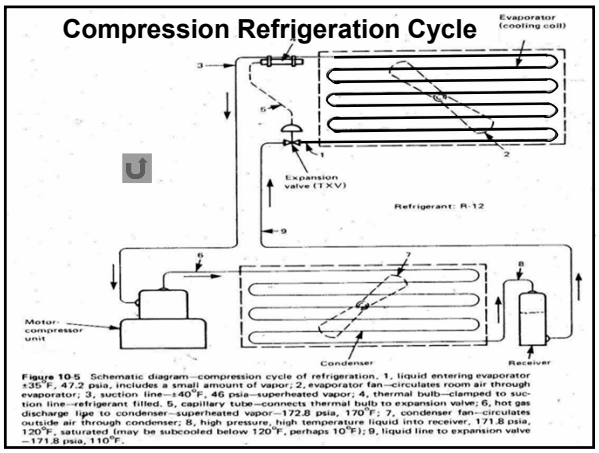
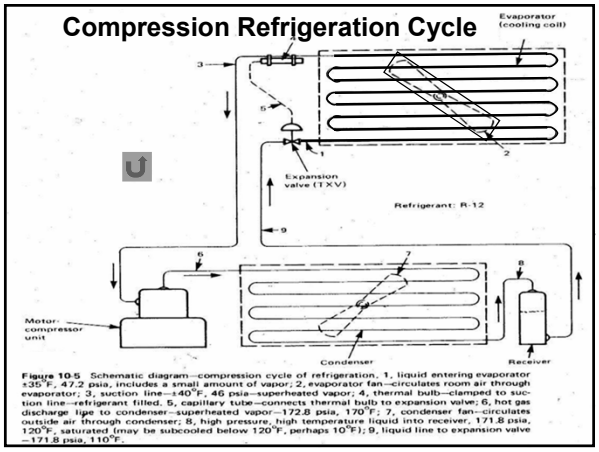


Figure 10-5 Schematic diagram—compression cycle of refrigeration. 1, liquid entering evaporator ±35°F, 47.2 psia, includes a small amount of vapor; 2, evaporator fan—circulates room air through evaporator; 3, suction line—±40°F, 46 psia—superheated vapor; 4, thermal bulb—clamped to suction line—refrigerant filled, 5, capillary tube—connects thermal bulb to expansion valve; 6, hot gas discharge lige to condenser—superheated vapor—172.8 psia, 170°F; 7, condenser fan—circulates outside air through condenser; 8, high pressure, high temperature liquid into receiver, 171.8 psia, 120°F, saturated (may be subcooled below 120°F, perhaps 10°F); 9, liquid line to expansion valve —171.8 psia, 110°F.

Compression Refrigeration Cycle



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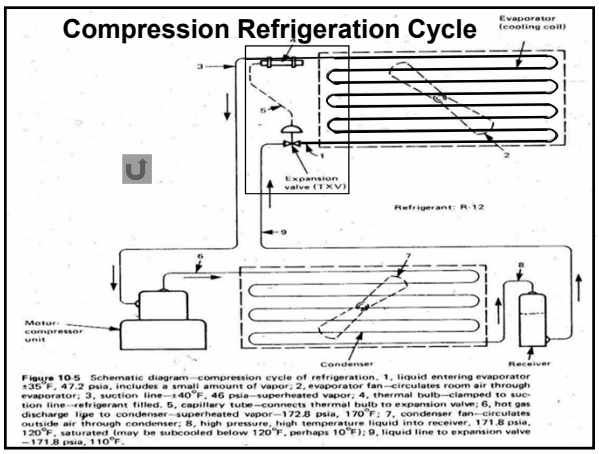

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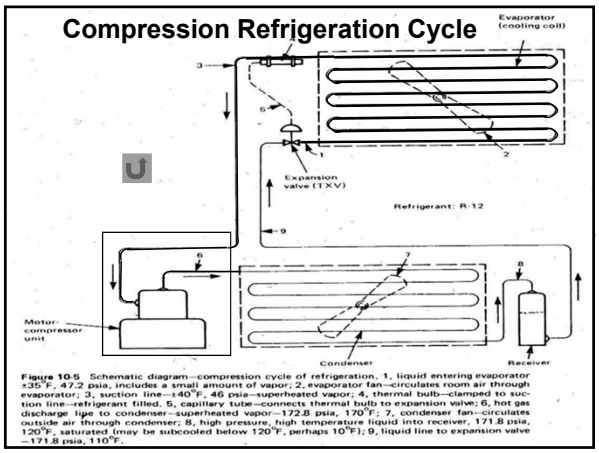

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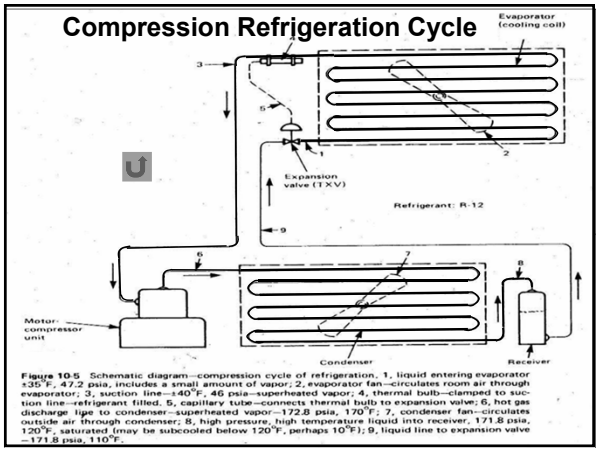

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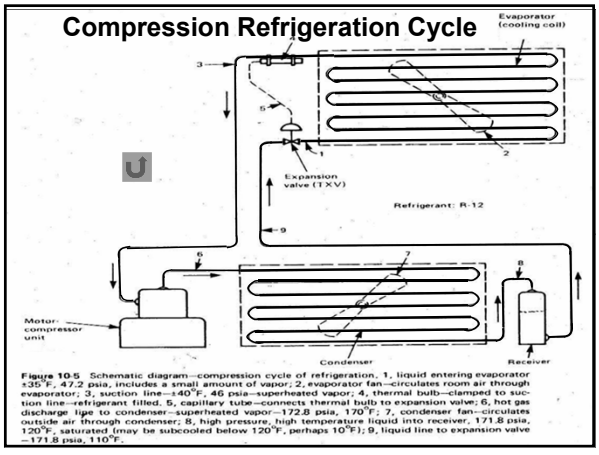

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Refrigeration Cycles

- Coefficient of performance (COP)
  - COP = q_{rf} / W_{in} (same energy units, dimensionless)
    - q_{rf} = refrigeration capacity, i.e. work out, BTU
    - W_{in} = work input to compressor, BTU
- Energy Efficiency Ratio (EER)
  - EER = q_{rf} / W_{in} (different energy units)
    - q_{rf} = refrigeration capacity, i.e. work out, BTU
    - W_{in} = work input to compressor, KW
- "Air Conditioner": produces cooling effect
- Heat pump: produces heating or cooling effect

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- Future
  - Chilled water systems
  - Chiller specifications

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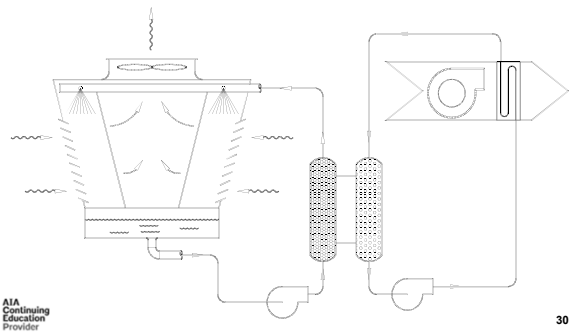
Refrigeration System Components



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Refrigeration Systems

- Classification of refrigeration systems
  - Compression cycle
  - Absorption cycle
  - Other process
- Either single-stage or multistage

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Compression Systems

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Refrigeration Systems

- Direct expansion (DX) systems
  - Generally, part of a packaged A/C system
  - R-22 and R-134a widely used
  - Range 3-100 T_R
  - Components & accessories
    - Compressor(s): reciprocating and scroll
    - Condensers
    - Refrigeration feed
    - Oil lubrication
    - Refrigerant piping

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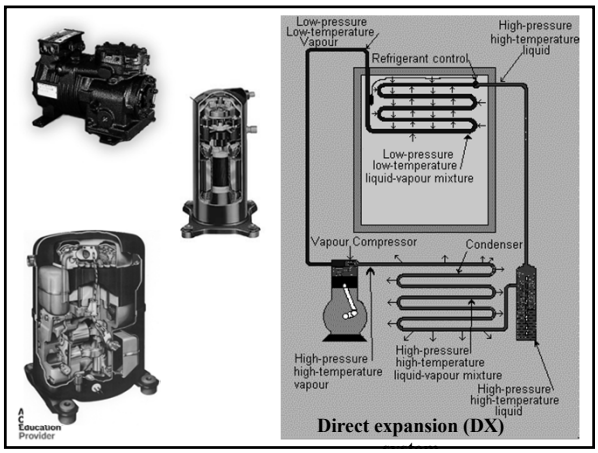
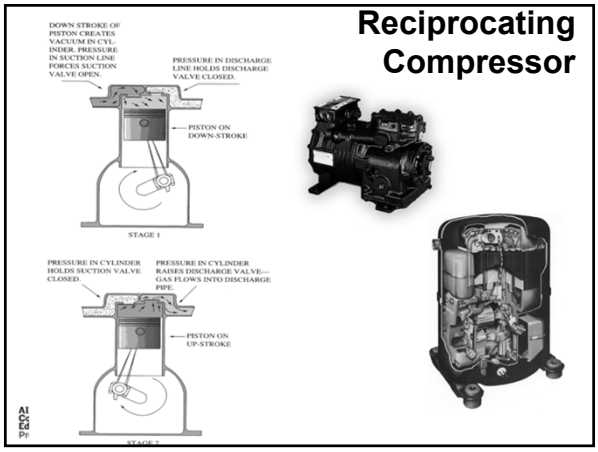


Reciprocating Compressor



Scroll Compressor

Refrigeration Systems

- **Centrifugal chillers**
  - **Chiller = a refrigeration machine using a liquid cooler as an evaporator to provide a chilled heat transport medium (water, typically)**
  - **R-11, R-12, R-22 were used**
    - **R-11 replaced by R-123**
    - **R-12 replaced by R-134a**
  - **System components**
    - **Centrifugal compressor, evaporator, condenser, flash cooler, orifice plates & float valves, purge unit (optional)**

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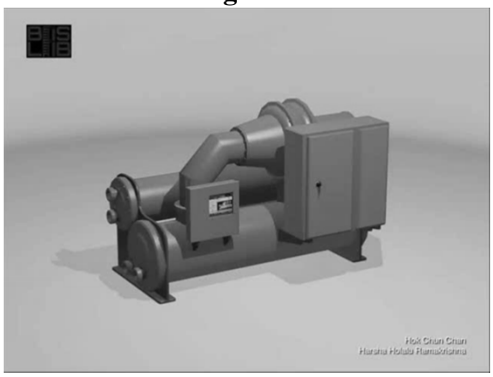
Centrifugal chillers



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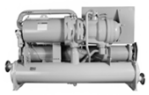
Refrigeration Systems

- **Screw chillers**
  - **Use helical screw compressor**
    - **Twin-screw compressors are widely used**
    - **Capacity 100 to 1000 T_R**
    - **Comparatively vibration-free**



Twin-screw compressor

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Refrigeration Systems

- Heat pumps
  - Three types:
    - Air-source (air-to-air)
      - R-22 often used, range 1.5 to 40 T_R
    - Water-source
    - Ground-coupled (often called "geothermal")
  - Cooling and heating mode operation
    - Winter may require defrosting
  - SEER (seasonal energy efficiency ratio)

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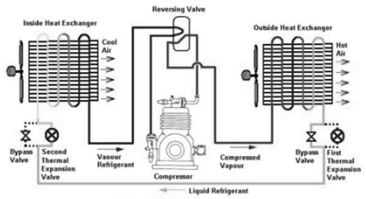

Fig. 1 - Heat Pump in Cooling Mode

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Absorption Systems

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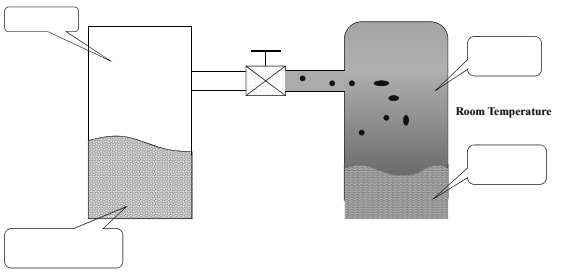
Absorption Refrigeration



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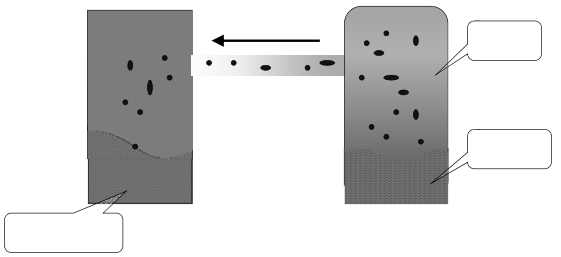
Absorption Refrigeration



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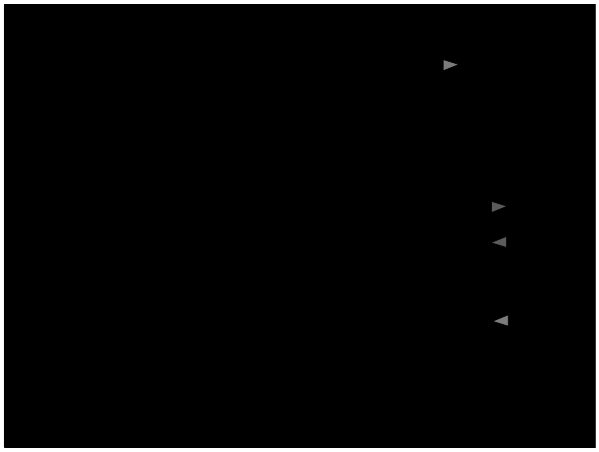

Towers

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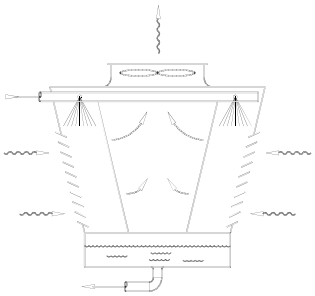
Refrigerant System Components

- Cooling Towers
  - Forced Draft
  - Induced Draft
- Condensers
  - Water Cooled
  - Air Cooled



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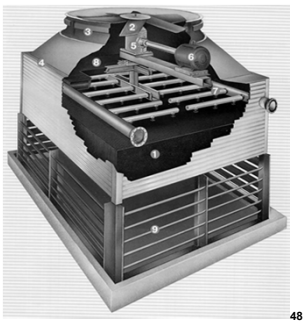
Tower Components

- Cooling Towers
  - Forced Draft
  - Induced Draft



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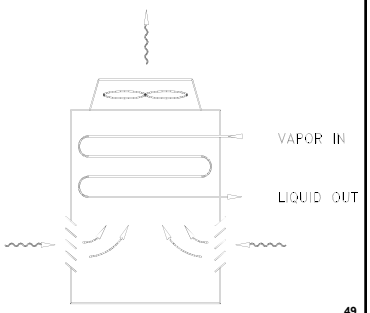
Refrigeration System Components--Condensers

- **Air Cooled Condensers**



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Pumps and Piping

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Refrigeration System Components

- **Pumps/ Piping**
  - **Primary/Secondary Variants**
  - **Direct Primary**

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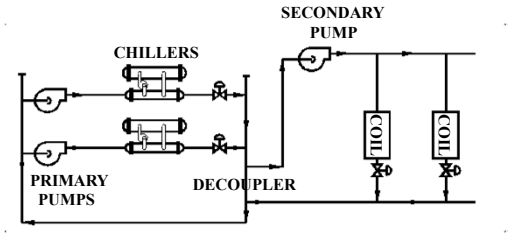
System Configurations Primary/Secondary
(central plant secondary pumping)



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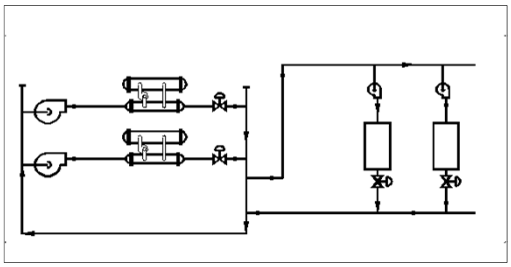
System Configurations Primary/Secondary
(distributed secondary pumping)



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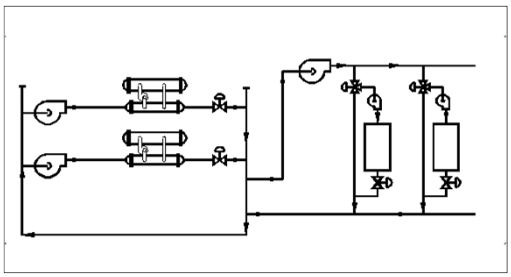
System Configurations Primary/Secondary/Tertiary



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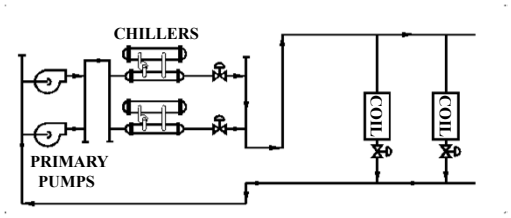
System Configurations
Direct Primary



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Agenda

- Refrigerants
  - Background and management issues
  - Safety and handling
- Refrigeration Cycles
- Refrigerant Systems
  - Chillers
  - Towers
  - Pipes & pumping systems
- Planning
  - Chilled water evaluation
  - Chiller specifications

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Chiller Specifications
How to Evaluate 6000 tons

- 2 @ 3000 tons (York) (R-134a)
- 3 @ 2000 tons (Trane) (R-123)
- 4 @ 1500 tons (Carrier) (R-134a)
- 5 @ 1200 tons (Trane) (R-123)

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Chiller Evaluation Form

Plant Tons	Annual Plant Hours	Cond. Water Temp. (F)	Plant Chilled Water (gpm)	No. of Chillers Operating	Efficiency (kW/ton)	Plant CWS (gpm)	CWR (deg F)	Evap. Delta P (ftw)	Cond. Delta P (ftw)
6000	50	85	8000						
5500	75	85	7300						
5000	130	85	6600						
4500	250	85	6000						
4000	450	82	5300						
3500	550	79	4600						
3000	520	76	4000						
2500	360	73	3300						
2000	165	70	2600						
Chilled Water Supply Temp = 40 deg F Chilled Water Return Temp = 58 deg F									

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Life Cycle Data Worksheet

Specified Performance
Without Condenser Water Reset

Load	Condition	100%	80%	60%	50%
Evaporator	EWT/LWT	58/40	58/40	58/40	58/40
	CHW Flow				
	Evap dP				
Condenser	EWT/LWT	85/___	85/___	85/___	85/___
	CW Flow				
	Cond dP				
Motor	kW				
	kW/Ton				
Sound	dBA				

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Life Cycle Data Worksheet

Specified Performance
With Condenser Water Reset

Load	Condition	100%	80%	60%	50%
Evaporator	EWT/LWT	58/40	58/40	58/40	58/40
	CHW Flow				
	Evap dP				
Condenser	EWT/LWT	85/___	78.75/___	72.5/___	66.25/___
	CW Flow				
	Cond dP				
Motor	kW				
	kW/Ton				
Sound	dBA				

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Key Specification Items

- Life cycle cost analysis -- site specific
- Witnessed factory performance test at specified conditions and beyond ARI -- boundary test
- Refrigerant R-134a or R-123, open or hermetic
- Limit impeller rpm to less than 10,000
- Compatible with variable flow systems, 100% to 50% load/flow change in 300 sec

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Key Specification Items (cont.)

- Smooth bore condenser tubes and at least 0.352 thickness
- Full tube wall thickness at tube sheet supports
- Factory start-up and full on-site commissioning
- Chiller control system capable of seamlessly integrating all data, including kW, into EMCS
- Purge or pump-out system

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Key Specification Items (cont.)

- Annual refrigerant loss less than .5% of total charge
- Form wound motor (4160V) with RTD imbedded in windings
- Extended service contract (5 years) to include complete compressor inspection
- Training--operators and maintenance personnel

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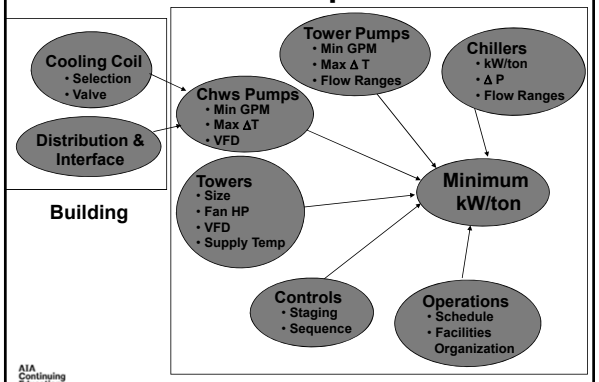
Central Plant Optimization



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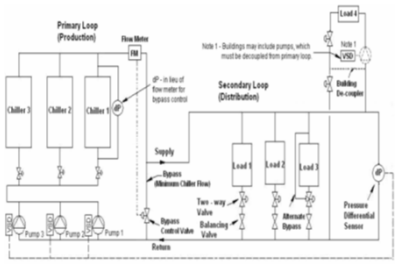
Questions & Potentially, Answers

Thank You!



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This concludes The American Institute of Architects Continuing Education Systems Course

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