MEBS6006 Environmental Services I

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Cooling and Heating

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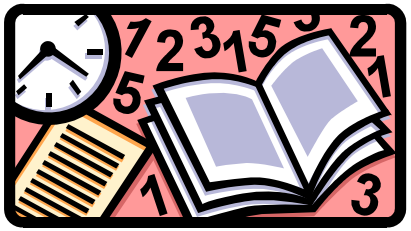
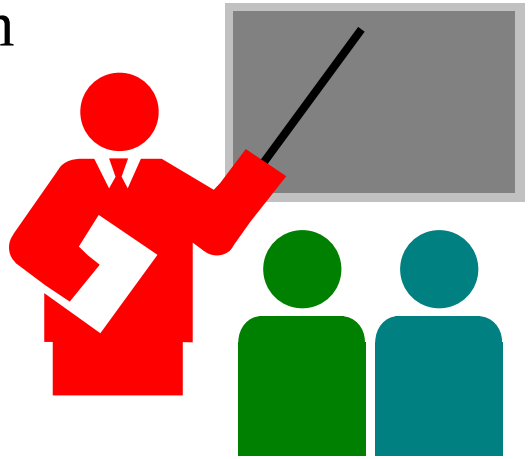
November 2011

Review



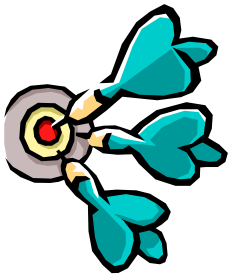
- Covered topics up to this moment
  - Psychrometry, thermal comfort, load estimation
  - All are essentials to define the cooling/heating load of an air conditioning system
- Topics on system to be covered in the remaining lectures
  - Giving an overview of the HVAC system
  - Cooling / Heating system
  - Ventilation system
  - Air side system
  - Water side system
  - Refrigeration and Heat Rejection



Contents

- Some basic stuff on units
- Cooling
  - Methods of cooling
  - Common Air Conditioning Systems
- Heating
  - Heating Load and The Demand for Heating
  - Types of Heating System

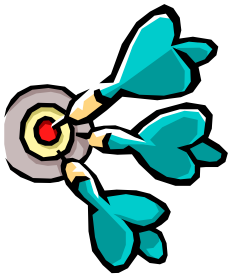
Basics - Unit Conversion



The Units

- 1Btu/hr = 0.2931W (BTU = British Thermal Unit)
- 12,000 Btu/hr = 1 refrigerant ton (TR) = 3.516kW
- 1gallon per minute (gpm) = 0.0631L/s (1L/s = 15.85 gpm)
- 1ft/s (fps) = 0.3048m/s
- 1ft/min (fpm) = 0.00508m/s
- $1ft^3$/min (cfm) = 0.4719L/s (1 L/s = 2.119 cfm)
- 1psi = 0.068948 bar = 6894.8 pascal(Pa) or 6.89kPa
- 1atm = 14.696psi = 29.92mmHg = 1.013 bar = 101.325kPa
- $x^{\circ}C = (1.8x + 32)^{\circ}F$ (deg. Celsius vs deg. Fahrenheit)

Basics - Design Condition



Commonly used Indoor Design Conditions to achieve thermal comfort

Summer

Office and Classroom

Minimum dry bulb temperature	23°C
Minimum relative humidity	50%

Other Applications except Office and Classroom

Minimum dry bulb temperature	22°C
Minimum relative humidity	50%

Winter

Hotel

Maximum dry bulb temperature	24°C
Maximum relative humidity	50%

Other Applications except Hotel

Maximum dry bulb temperature	22°C
Maximum relative humidity	50%

Outdoor Design Conditions

Summer

Maximum dry bulb temperature	33.5°C
Maximum relative humidity	68%

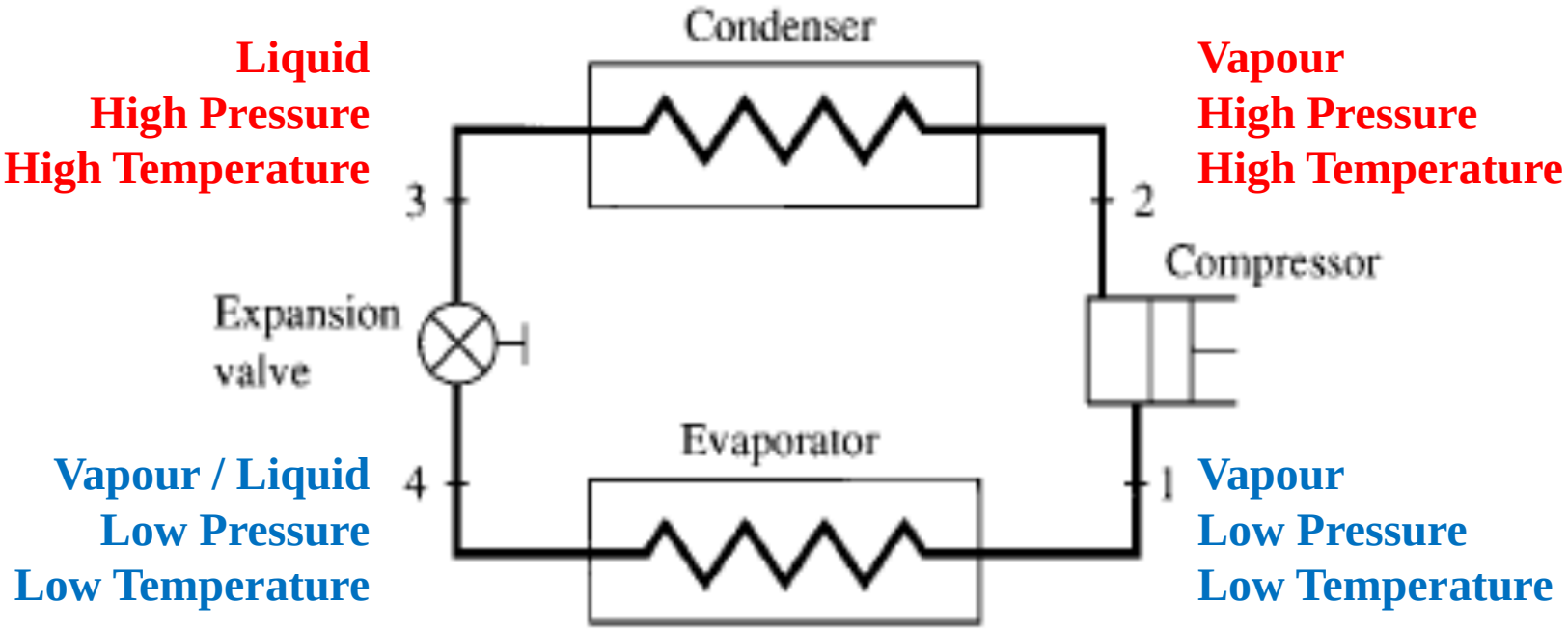
Winter

Minimum dry bulb temperature	7°C
Minimum relative humidity	40%

The outdoor design conditions may adopt the extreme annual conditions.

Methods to Produce Cooling

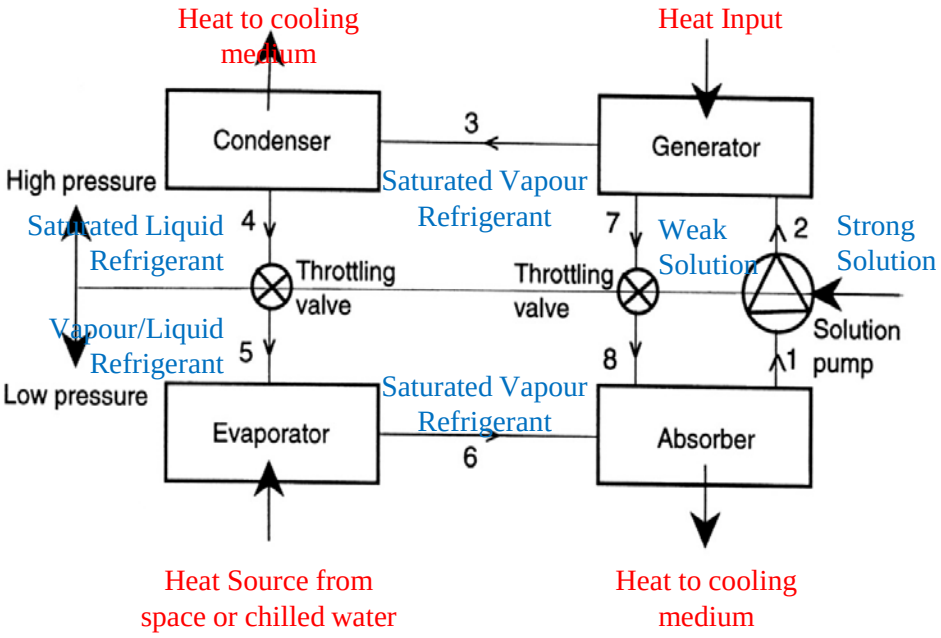
- Methods of producing cooling effect
  - 1) Vapour Compression Refrigeration * (most common)

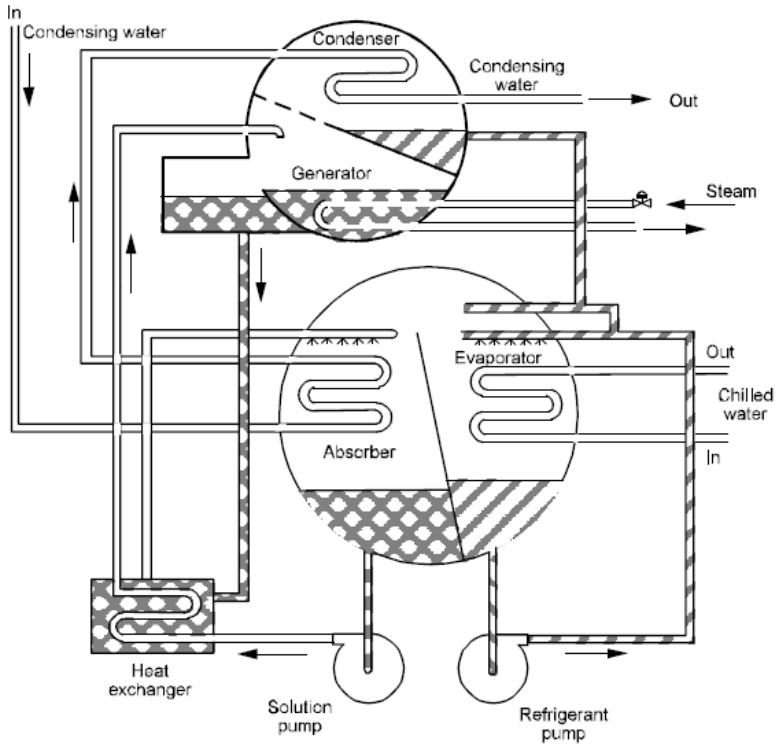


(*Discussion of vapour compression and adsorption cycles in future lectures)

Methods to Produce Cooling

- Methods of producing cooling effect
  - 2) Absorption Refrigeration * (less common in HK, but common in locations where the supply of heat, e.g. steam, is common)

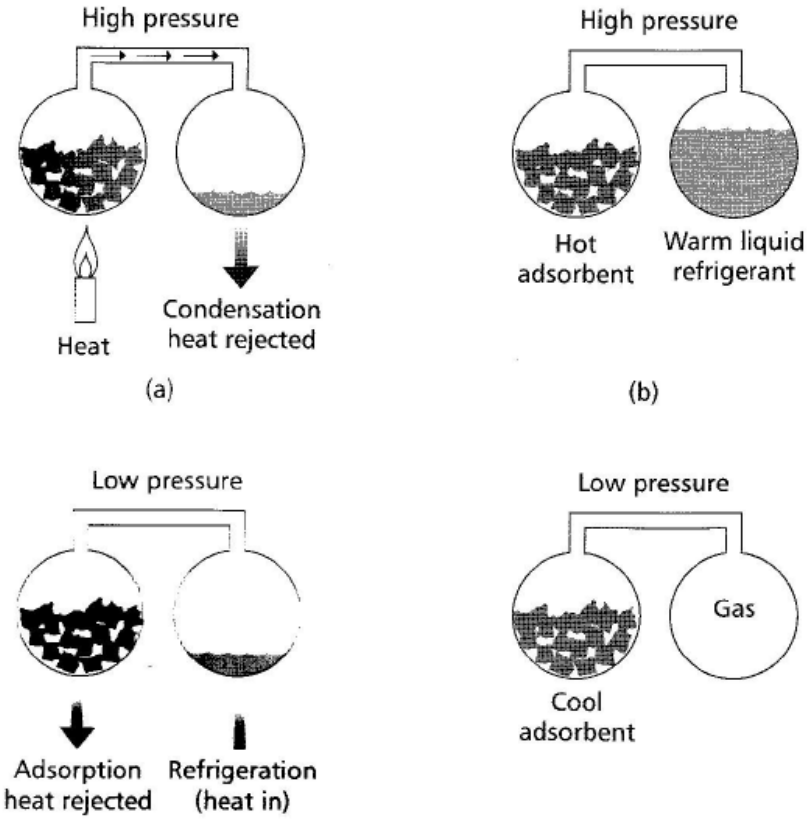




(*Discussion of vapour compression and adsorption cycles in future lectures)

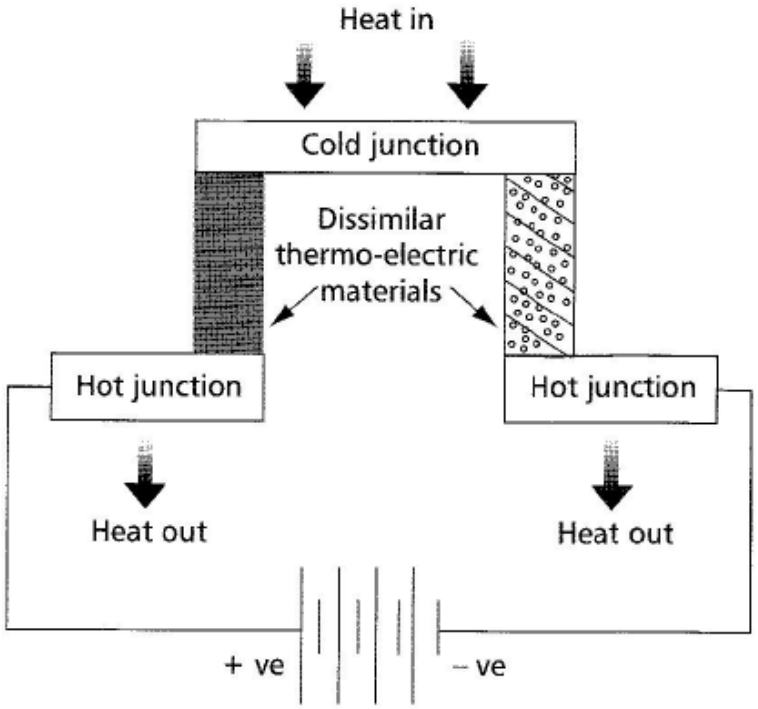
Methods to Produce Cooling

- Methods of producing cooling effect
  - 3) Solid Adsorption System



Methods to Produce Cooling

- Methods of producing cooling effect
  - 4) Thermoelectric Cooling



  - 5) Others

Common Air Conditioning System

Types of Common Air Conditioning System

a) Individual Room Air Conditioning Units
b) Package Air Conditioning Systems
c) Central Hydronic Air Conditioning System

Common Air Conditioning System

a) Individual Room Air Conditioning Units

Window AC Units

- Window air conditioning unit or through-the-wall unit.
- Controlled by thermostat (compressor on/off) and fan speed control
- For single space cooling (e.g. living room, classroom)
- Supply fan, cooling cool, air filter, compressor, condenser…(all-in-one)
- Cooling capacity usually in kW or Btu/hr (or hp)
  - The retail stores frequently use ‘horse power’ to represent different capacities of window units – ¾ hp ~ 7000BTU/hr, 1 hp ~ 9000BTU/hr, …
- Additional features: Timer for the automatic shutting off, better design of air filters
- Some models can provide warm air during heating season (use of reverse cycle)
- Newer models adopt the use of variable frequency drives

Common Air Conditioning System

b) Unitary Package Air Conditioning Systems

Indoor Unit –
Split AC system

Outdoor Unit – Split AC system

Common Air Conditioning System

b) Unitary Package Air Conditioning Systems

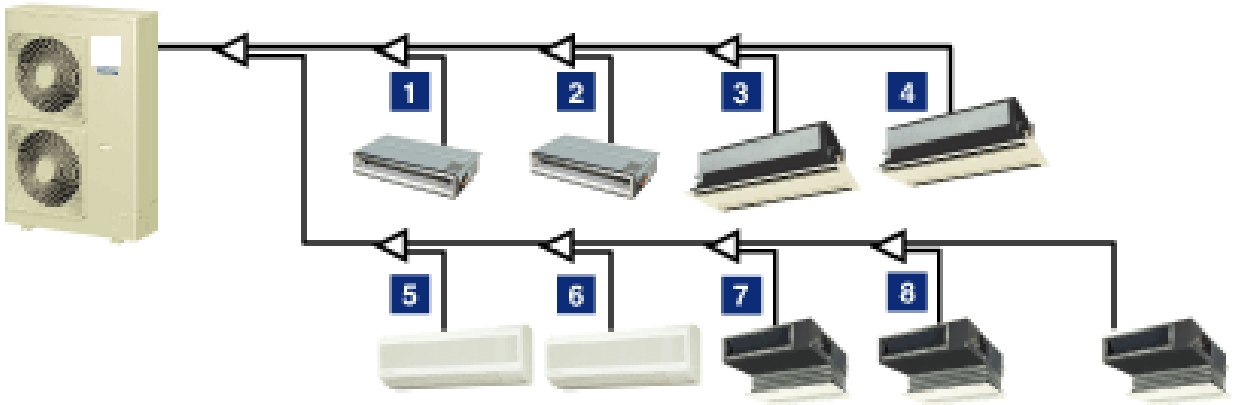
* A Multi-Split System to Fit Even the Most Luxurious of Homes

Model No. / Item			
	Indoor Unit / Outdoor Unit		
Rank			
Capacity	Cooling	kW	
	Heating		
	Cooling	BTU/h	
	Heating		
Moisture Removal		l/h	
Room Air Circulation (High)	Inner	m³/h	
	Outer		
Input Power		V/ø/Hz	
Running Current	Cooling	A	
	Heating		
Power Consumption	Cooling	kW	
	Heating		
Dimensions H x W x D	Inner	mm	
Net Weight		kg(lbs)	
	Outer	mm	
		kg(lbs)	
Connection Method			
Connection Pipe Size (Small/Large)		mm	
Max Pipe Length /Height Difference		m	
Permissible Range of Outdoor Temp.	Cooling	°C	
	Heating		
Refrigerant			

Typical Data on an Split AC unit

Common Air Conditioning System

b) **Unitary Package Air Conditioning Systems**



VRV System

- Slim, compact and sufficient capacity
- High COP
- Low operation sound / Nighttime quiet operation function
- Connectable to up to 9 indoor units / Long piping design possible
- Simple wiring and piping connection / Wide operating temperature range

Common Air Conditioning System

b) **Unitary Package Air Conditioning Systems**

Air-cooled packaged air conditioners

Water-cooled packaged air conditioners

Common Air Conditioning System

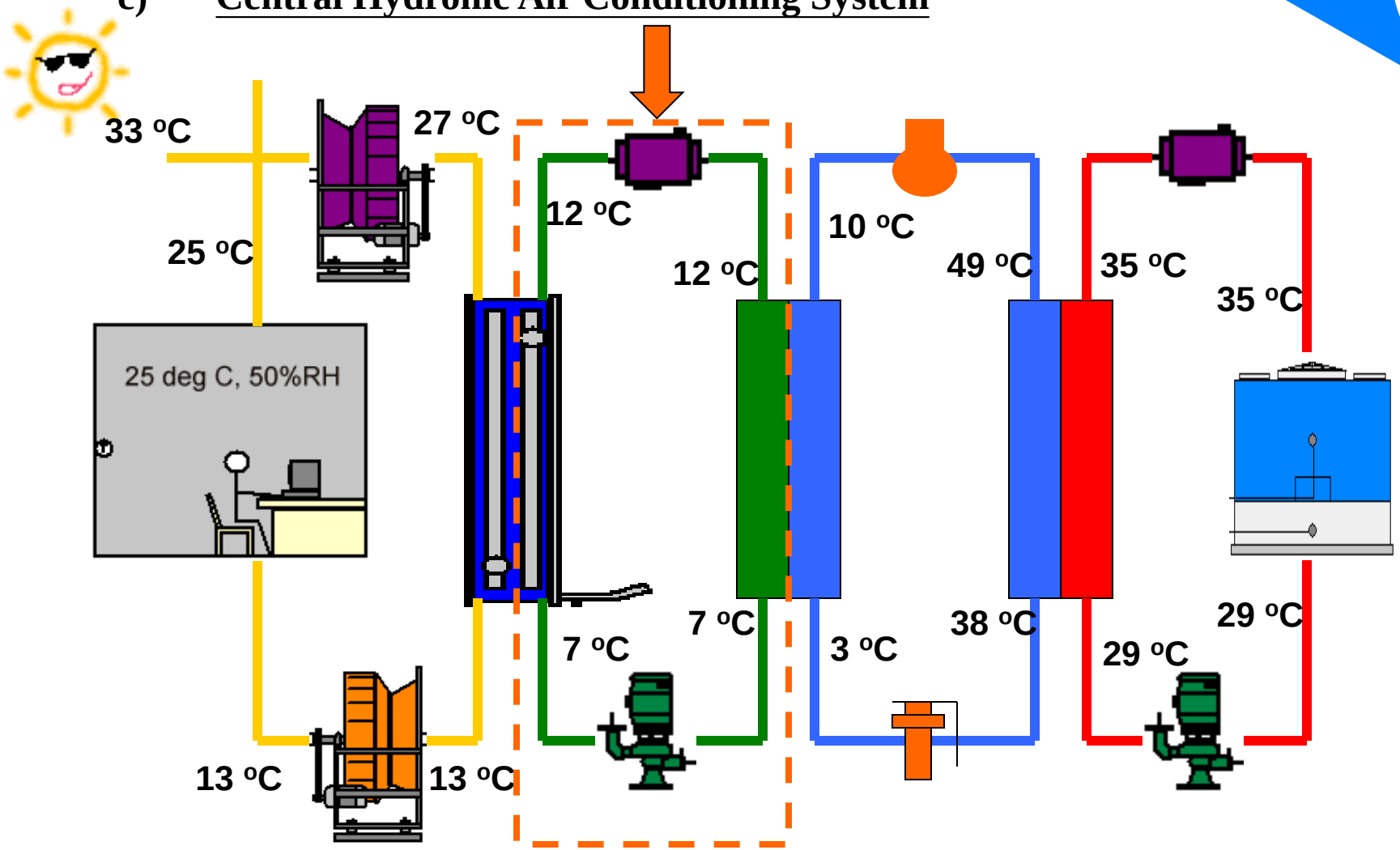
b) **Unitary Package Air Conditioning Systems**

From the previous examples,

- Single, self-contained package units or split systems.
- It may be a split A/C system with indoor unit with fan, filter, and DX-coils and the outdoor condensing unit
- It may be a central system with supply air duct with diffuser and DX-coil for cooling

Common Air Conditioning System

c) Central Hydronic Air Conditioning System

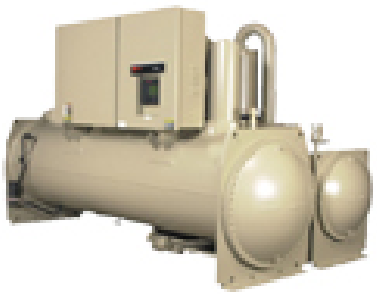


Common Air Conditioning System

c) Central Hydronic Air Conditioning System

Product Name	: Air Cooled Screw Chiller
Model	: ERTAC
Country of Origin	: France
Cooling Capacity	: 400 - 1,500 kW

Product Name	: Water Cooled Screw Chiller
Model	: RTHD
Country of Origin	: USA
Cooling Capacity	: 439.5 - 1,582.2 kW



Common Air Conditioning System

c) Central Hydronic Air Conditioning System

•Chilled water cooling coils in air handling equipment like AHUs / FCUs

•Chilled water, with high specific heat capacity, absorbs the heat and cools the space air

•Involve complicated system arrangement and expensive equipment

•Use of ‘Direct digital control’ (DDC) for overall system control: Electronic sensors send signals to microprocessor operated and control modules which actuates dampers, valves and relays.

Common Air Conditioning System

c) Central Hydronic Air Conditioning System

District Cooling System (DCS)

- It distributes chilled water from a central chiller plant to a number of buildings, whose building owners / operators have subscribed the DCS service.
- After connection with DCS, these service purchasers would no longer require to keep or use their own existing chiller plants.
- The absorbed heat from the user buildings is rejected by either sea water cooling or evaporative cooling towers.
- Any example in Hong Kong?

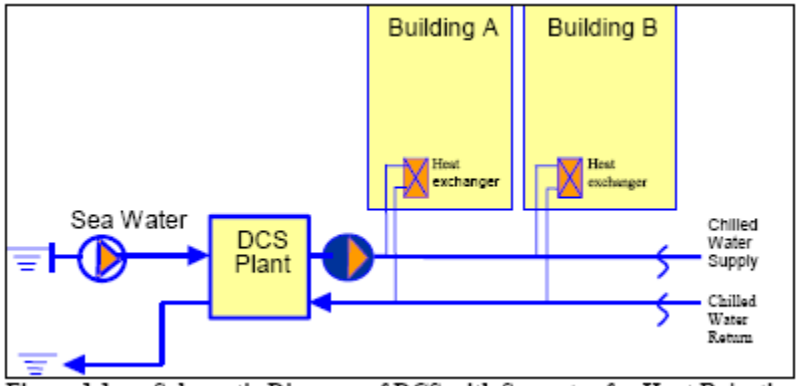


Figure 1.1 Schematic Diagram of DCS with Seawater for Heat Rejection

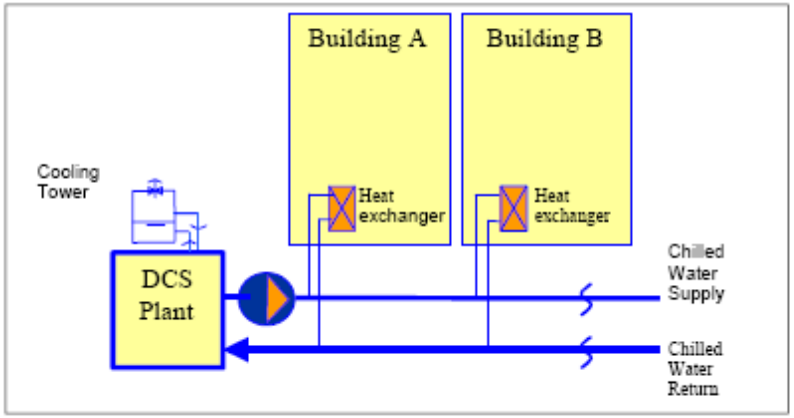


Figure 1.2 Schematic Diagram of DCS with Cooling Tower for Heat Rejection

Common Air Conditioning System

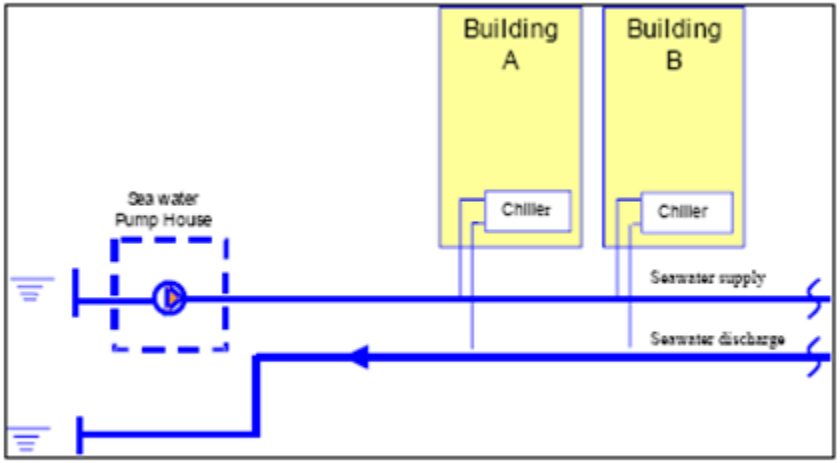
c) Central Hydronic Air Conditioning System

Centralized Piped Supply System for Condenser Cooling (CPSSCC)

•The centralized piped supply system for condenser cooling (CPSSCC) is a large scale central sea water pumping system

•It supplies sea water via the distribution piping network to a number of potential users within the district for heat rejection of their air conditioning systems.

•Any examples in Hong Kong?



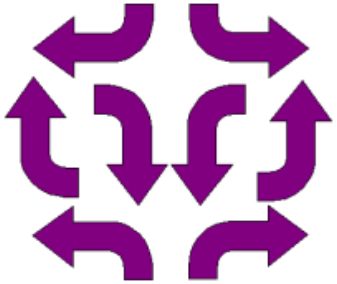
Schematic Diagram for CPSSCC

Common Air Conditioning System

c) Central Hydronic Air Conditioning System

- Subscription of CPSSCC service requires the customer building to be installed with seawater cooled chiller plant.
- Current air-cooled chillers not potential customers for CPSSCC. (space issue?)
- When compared with CPSSCC, DCS is simple, more energy efficient and environmentally friendly.
- As both schemes involve substantial capital investment and public road space for pipes laying, it would not be practical to allow two systems to co-exist in the same district.
- Buildings installed with air-cooled chiller plants likely subscribe for DCS service
- CPSSCC would only be considered under special cases such as re-provision of sea water cooling system for existing seawater cooled buildings when their existing sea water cooling plants become affected by reclamation.

Heating Load



- **Design heating load**
  - **Max. heat energy required to maintain winter indoor design temp.**
    - Usually occurs before sunrise on the coldest days
    - Include transmission losses & infiltration/ventilation
  - **Assumptions:**
    - All heating losses are instantaneous heating loads
    - Credit for solar & internal heat gains is not included
    - Latent heat often not considered (unless w/ humidifier)
    - Thermal storage effect of building structure is ignored

Heating Load

- A simplified approach to evaluate worst-case conditions based on
  - Design interior and exterior conditions
  - Including infiltration and/or ventilation
  - No solar effect (at night or on cloudy winter days)
  - Before the presence of people, light, and appliances has an offsetting effect
- A warm-up/safety allowance of 20-25% is fairly common

Common Space Heating in Hong Kong

- Office for perimeter zone
- Hospital (close temperature control needed)
- Hotel (close temperature control needed)
- Apartment (only some luxury ones)

The Need for Heating

Heating – Hong Kong – Meteorological Data

Green House Effect

Meterological Element	Oct 06	Nov 06	Dec 06
Mean Daily Max Air Temp	29.0°C	25.5°C	20.4°C
Mean Air Temp	26.4°C	23.3°C	18.2°C
Mean Daily Min Air Temp	24.7°C	21.6°C	16.1°C

Meterological Element	Jan 07	Feb 07	Mar 07
Mean Daily Max Air Temp	18.8°C	21.9°C	22.7°C
Mean Air Temp	16.4°C	19.5°C	20.2°C
Mean Daily Min Air Temp	14.3°C	17.8°C	18.4°C

Read from your weather data sheet on extreme annual design temperature

Types of Heating System

Direct systems

- The energy purchased is consumed as required within the space to be heated.
- Fuel directly converted to space heating
- Solid fuel system, Convective heat system (liquid fuel, gaseous fuel, electrical), Radiant heat system (gaseous fuel, electrical)
- Heat Pump (Reverse cycle of refrigeration cycle)

Types of Heating System

Indirect System

- The energy purchased is consumed at some more or less central point outside the space to be heated and then transferred to equipment in that space for liberation.
- A medium carries the heat generated to the space for heating
- Furnace, Boiler plant, Steam plant, Solar plant, Heat Recovery Chiller

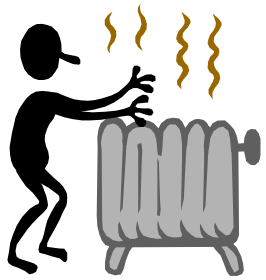
Methods of Heating

- **Convective or Radiant Heating ?**
  - Radiant Systems : minimum 50% of their output is radiant
  - Radiant heating : high air change rates or large volumes (not requiring uniform heating throughout, e.g., factories, and intermittently heated buildings with high ceilings.
  - Radiant heating can require less energy than convective heating (heat transfer at 4^{th} order of Temperature)
  - Radiant heating is used better in situations that ventilation heat losses exceeding fabric heat losses.

Methods of Heating

- **Merits of heating by radiation**
  - Since about 45 % heat lost by the human body is radiation→ the feeling of warmth derived from radiant heating is greater than by convection.
  - Radiant heat gives a greater feeling of warmth with a lower air temperature →15 % saving in fuel costs.
  - The draughts are reduced to a minimum → dust is also kept down to a minimum.
  - Radiant heats solid objects on which it falls →floors and walls derive warmth from radiant heat rays → warm surfaces set up convection currents → heat lost from the human body by convection reduced.

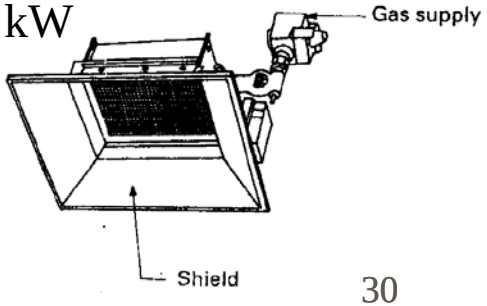
Direct Heating System



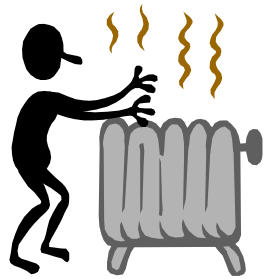
Direct systems - gaseous fuels (primarily radiant)

Infra-red heaters

- Designed primarily for industrial applications in higher buildings
- Pipe connected to supply main or to either butane or propane cylinders.
- For permanent installations : wall mounted or suspended from a ceiling
- Rated up to 30 kW but a range between 3 and 15 kW is more common.
- Flue connections not provided for heaters but minimum rates of outside air ventilation necessary either per unit or per kW rating specified.



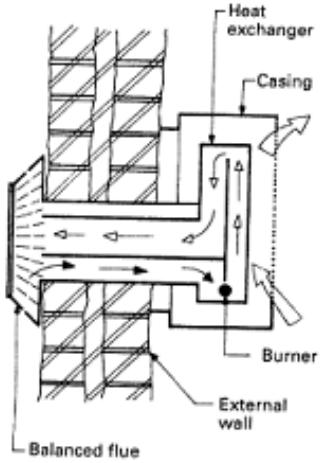
Direct Heating System

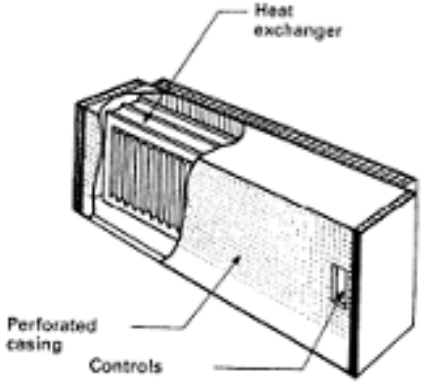


Direct systems - gaseous fuels (primarily convective)

Natural convectors

- Provide means for dispersal of the products of combustion via a conventional outlet or a balanced flue arrangement.
- Heat exchanger so mounted provide a passage for the movement of convected air from a low level inlet to a top or top-front outlet.
- Some heat transfer to the front of the casing and a small radiant output may result.
- For institutional building have ratings of up to 10 kW (3 kW is common).





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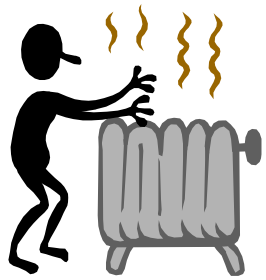
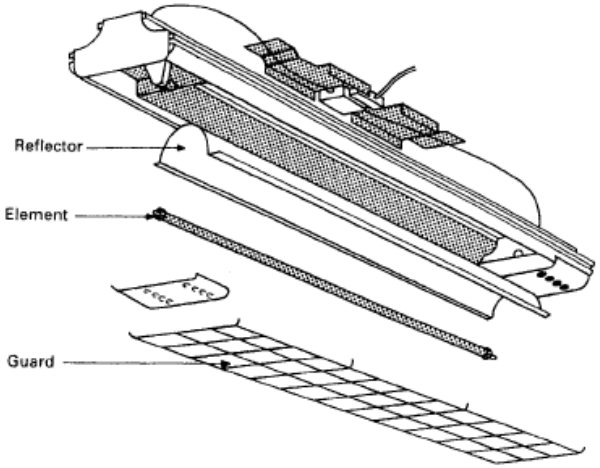


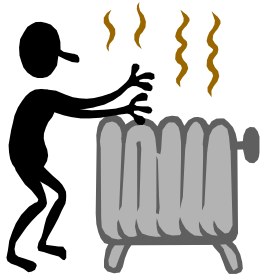
Direct systems - electrical (primarily radiant)

Infra-red heaters

- Wall or ceiling for kitchens and bathrooms (more robust patterns for commercial or industrial).
- The elements operate at about 900 ˚C.
- Not for very high ceilings (e.g. churches) as it may be too high to provide effective radiant cover.
- Ratings are up to 3 kW per unit.

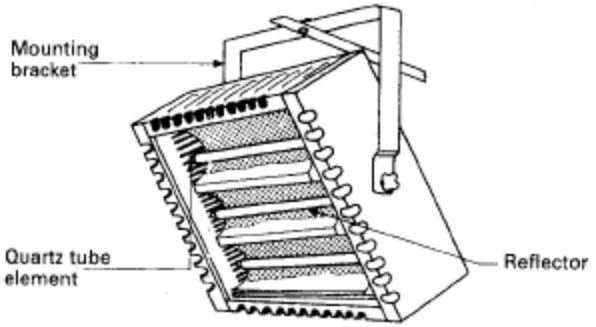


Direct Heating System



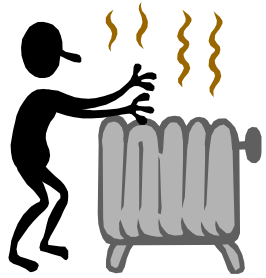
Direct systems - electrical (primarily radiant)

Quartz lamp heaters



- For large spaces requiring intermittent heating or spot heating
- Quartz lamp heaters operate over 2000 ˚C.
- Each element rates at about 1.5 kW.
- A tungsten wire coil sealed within a quartz tube containing gas.
- A number of elements (normally a maximum of six), each mounted in front of a polished parabolic reflector.

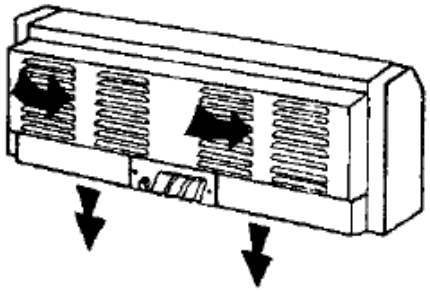
Direct Heating System

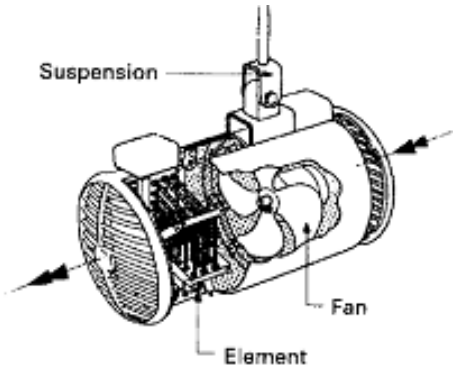


Direct systems - electrical (primarily convective)

Forced convectors

- Compact portable domestic fan heater rated at up to 3 kW.
- Commercial type heaters, fitted with axial-flow fans, having ratings of about 3-6 kW.
- Cased tangential-fan units rated at up to 18 kW for warm air curtains at building exits and entrances.
- Large industrial units rated at 30 kW or more.

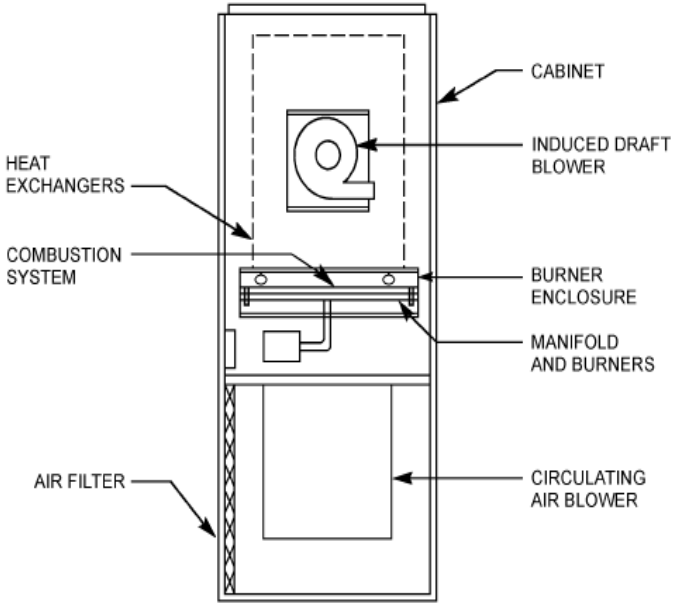




Indirect Heating System

Furnace

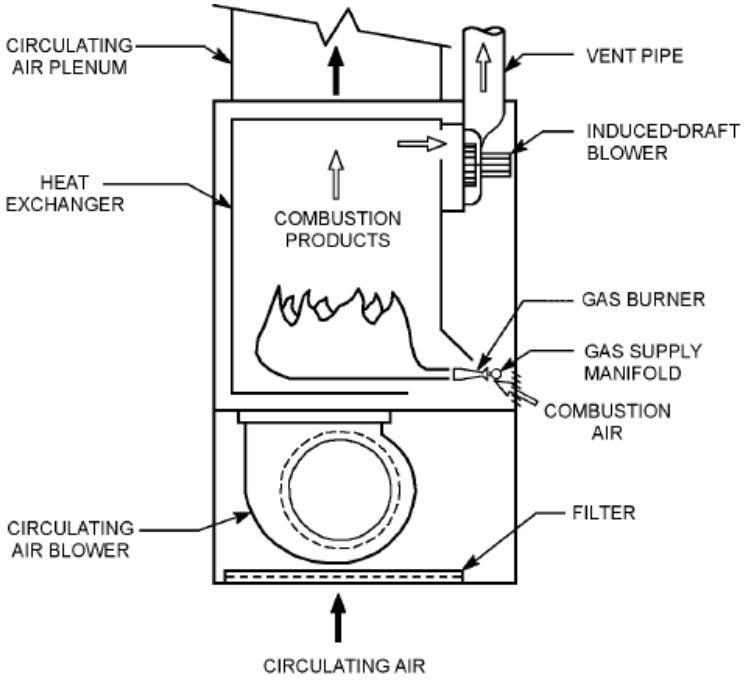
- Provides heated air through ductwork to the space.
- Fuel burning furnaces and electric furnaces.
- Fuel-Burning Furnaces
  - Combustion takes place within a combustion chamber.
  - Circulating air passes over the outside surfaces of a heat exchanger (Gas does not contact the fuel or the products of combustion).
- Electric Furnaces.
  - A resistance-type heating element heats circulating air directly



Indirect Heating System

Upflow or “Highboy” Furnace

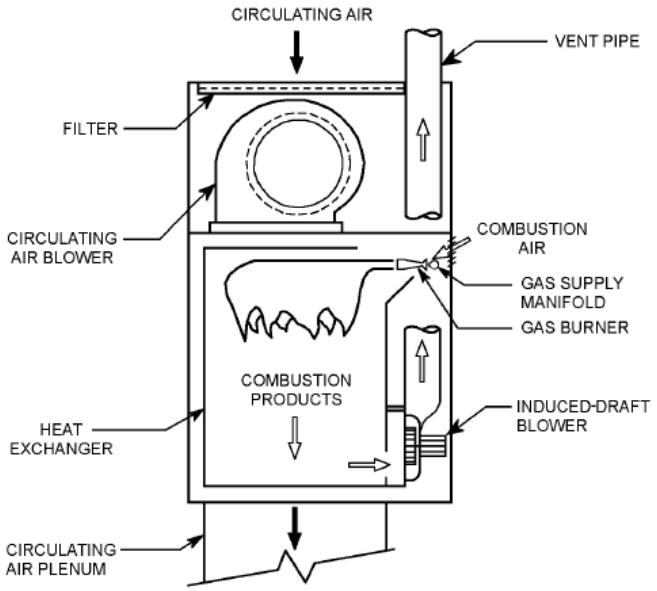
- Blower beneath the heat exchanger and discharges vertically upward.
- Air enters through the bottom or the side of the blower compartment and leaves at the top.
- Used in closets and utility rooms on the first floor or in basements



Indirect Heating System

Downflow Furnace

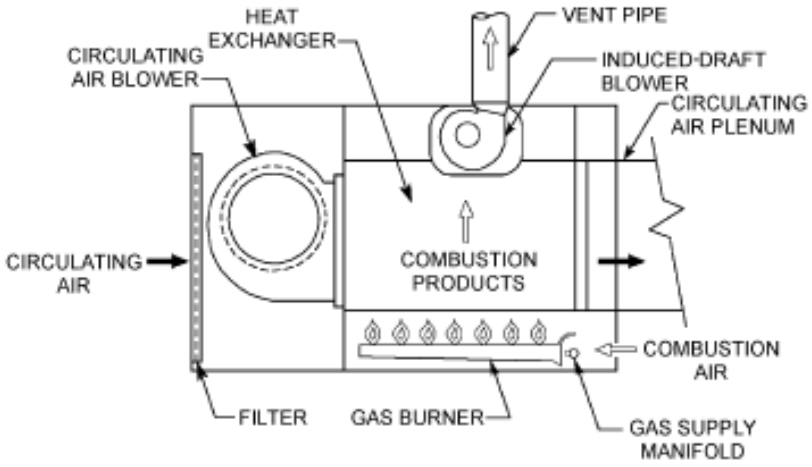
- Blower above the heat exchanger and discharges downward.
- Air enters at the top and is discharged vertically at the bottom.
- Used with a perimeter heating system in a house without a basement.
- Used in upstairs furnace closets and utility rooms supplying conditioned air to both levels of a two-storey house



Indirect Heating System

Horizontal Furnace

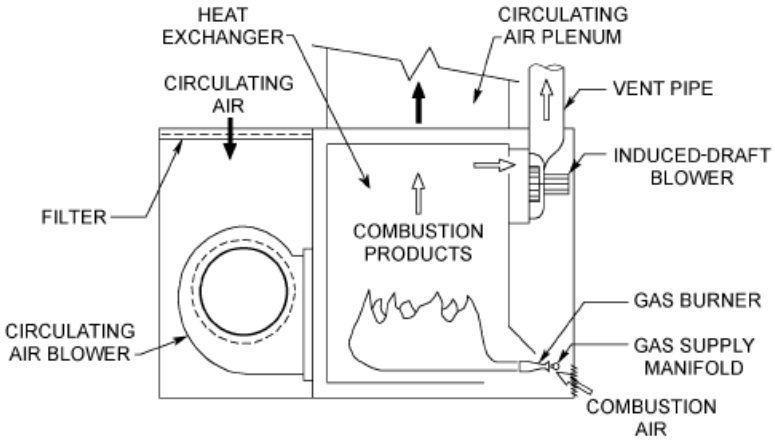
- Blower is located beside the heat exchanger
- Air enters at one end, travels horizontally through the blower and over the heat exchanger
- Use: Limited head room such as attics and crawl spaces
- Use: Suspended under a roof or placed above a suspended ceiling.



Indirect Heating System

Lowboy Furnace

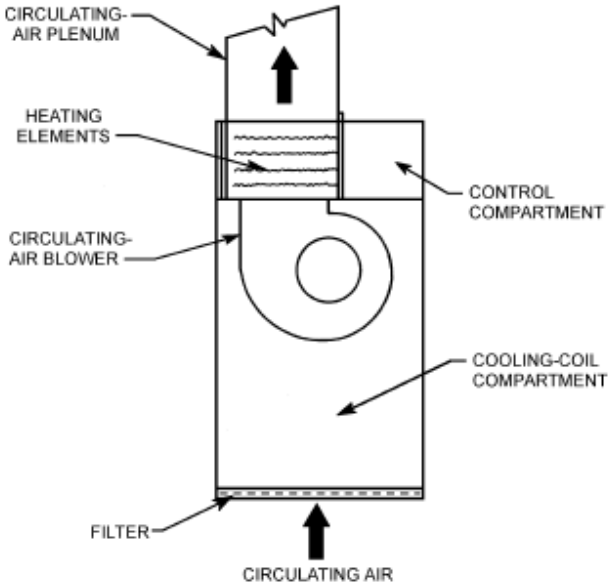
- A variation of the upflow furnace requiring less head room.
- The blower is located beside the heat exchanger at the bottom.
- Air enters the top of the cabinet, is drawn down through the blower, is discharged over the heat exchanger, and leaves vertically at the top.
- Use: Basement



Indirect Heating System

Electric Furnace

- The furnace consists of casing, air filter, and blower.
- The heating elements are made in modular form, with 5 kW capacity being typical for each module.
- Electric furnace controls include electric overload protection, contactor, limit switches and a fan control switch.
- The overload protection may be either fuses or circuit breakers.



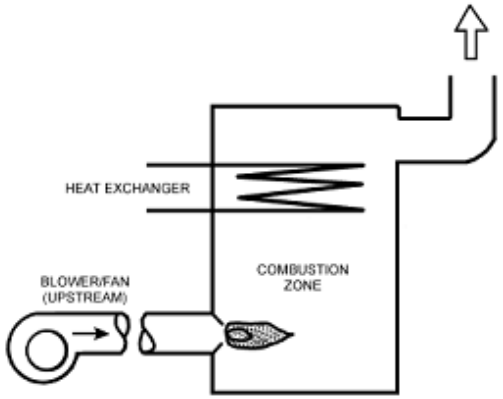
Indirect Heating System

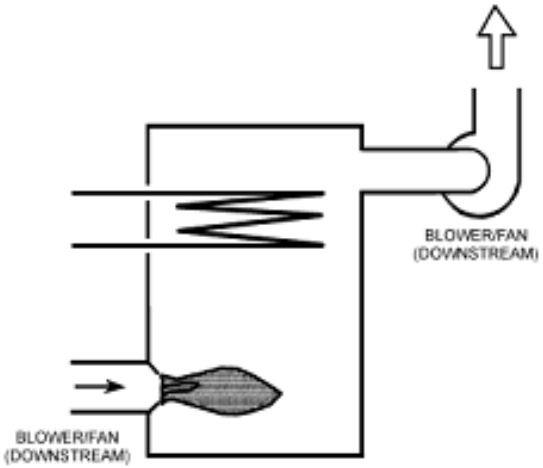
Furnace - Combustion system variations

- Gas-fired furnaces : natural-draft or a fan-assisted combustion system.

- Natural-draft furnace
  - Buoyancy of the hot combustion products carries these products through the heat exchanger, into the draft hood, and up the chimney.

- Fan-assisted combustion furnaces
  - Forced-draft :Combustion blower at upstream, blowing the combustion air into the heat exchangers
  - Induced-draft: blower is downstream.





Indirect Heating System

Points to be noted in the design using furnace

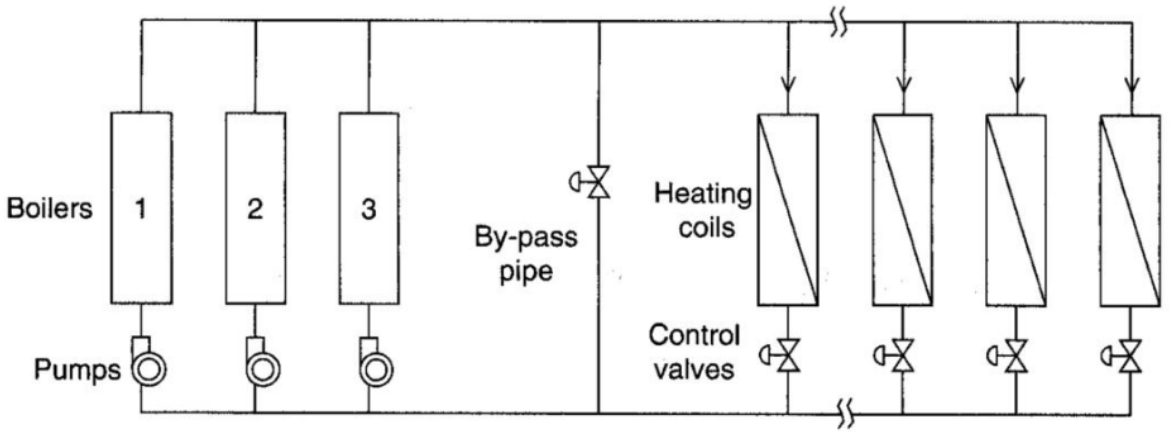
- Net heat available to heat the room/ building;
- Gross furnace output at the outlet of furnace
- Allowance of heat loss in duct and the pickup loss
- Air flow rate and pressure loss at duct

Indirect Heating System

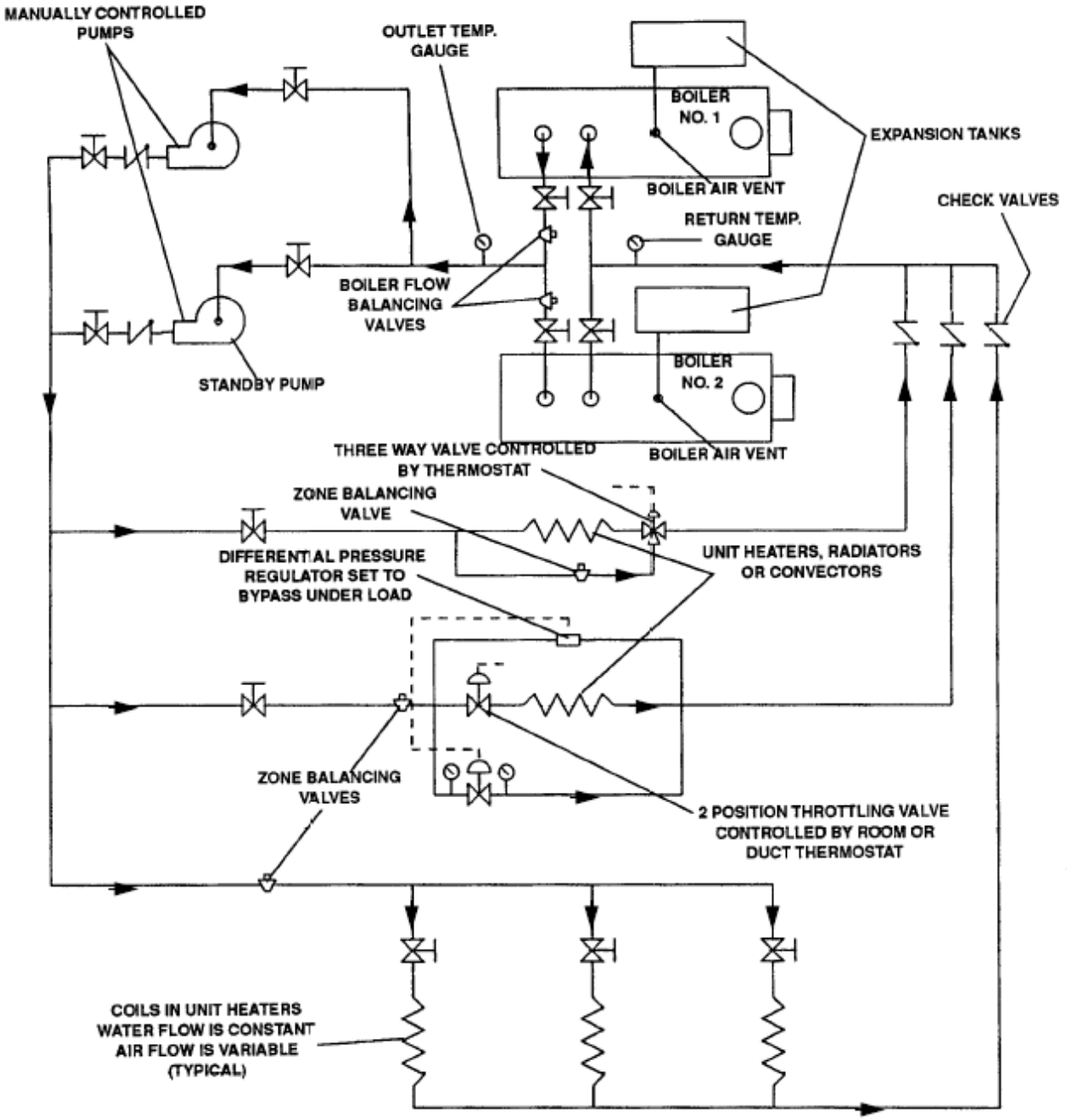
Boiler plant

A centralised hot-water heating system has three basic elements:

- Boiler.
- Heat distribution circuit.
- Heat emitter.



Typical arrangement of boiler plant used for space heating.


MANUALLY CONTROLLED PUMPS
OUTLET TEMP. GAUGE
BOILER NO. 1
EXPANSION TANKS
BOILER AIR VENT
CHECK VALVES
RETURN TEMP. GAUGE
BOILER FLOW BALANCING VALVES
STANDBY PUMP
BOILER NO. 2
BOILER AIR VENT
THREE WAY VALVE CONTROLLED BY THERMOSTAT
ZONE BALANCING VALVE
DIFFERENTIAL PRESSURE REGULATOR SET TO BYPASS UNDER LOAD
UNIT HEATERS, RADIATORS OR CONVECTORS
ZONE BALANCING VALVES
2 POSITION THROTTLING VALVE CONTROLLED BY ROOM OR DUCT THERMOSTAT
COILS IN UNIT HEATERS WATER FLOW IS CONSTANT AIR FLOW IS VARIABLE (TYPICAL)

Indirect Heating System

Low pressure hot water (LPHW)

- Output is limited by system temperatures restricted to a maximum of about 85 ˚C

Medium pressure hot water (MPHW)

- Permits system temperatures up to 120 ˚C
- Allow a greater drop in water temperature and thus smaller pipework.
- Advantage only on a large system.
- Pressurization up to 5 bar absolute.

High pressure hot water (HPHW)

- High pressure systems (up to 10 bar absolute) => greater temperature drops & smaller pipework.
- Cost-effective only for transportation of heat over long distances.

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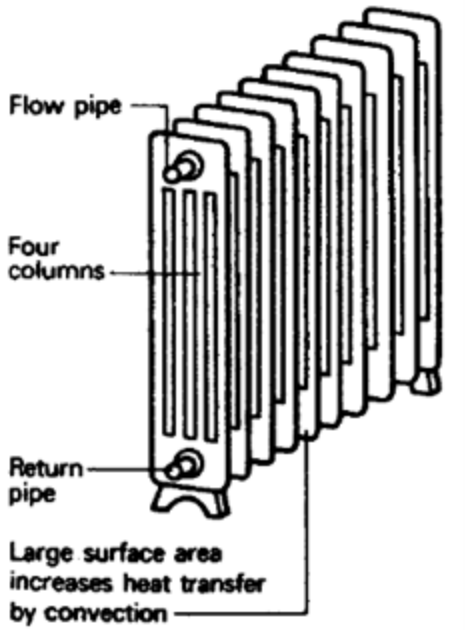
Indirect Heating System

Heat Emitter

Radiators

- Made from either steel or cast iron
- Fitted against a wall, staining of the wall above the radiator will occur due to convection currents picking up dust from the floor.
- To prevent this, a shelf should be fitted about 76 mm above the radiator
- The name 'radiator' is misleading - a greater proportion of heat is transmitted by convection, depending upon the type of radiator used.



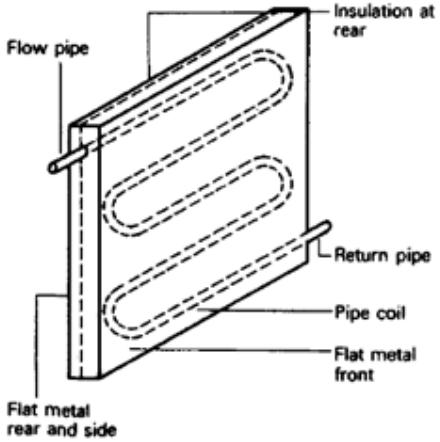
Column type radiator

Indirect Heating System

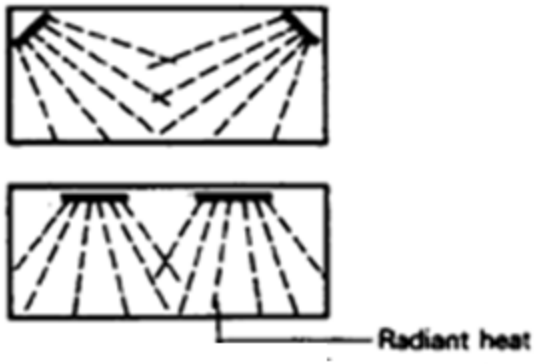
Heat Emitter

Radiant panels

- Similar to panel radiators, transmit a greater proportion of heat by radiation.
- For heating of workshops : suspended at heights from 3 to 4 m above the floor level and heat is radiated downwards.



Radiant panel

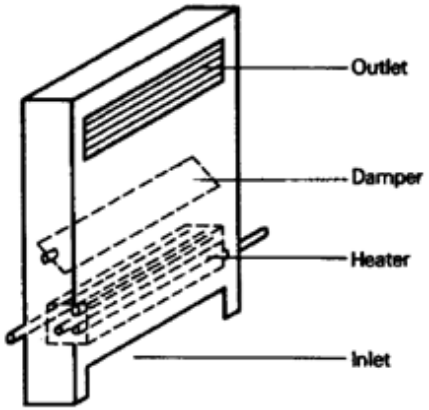


Indirect Heating System

Heat Emitter

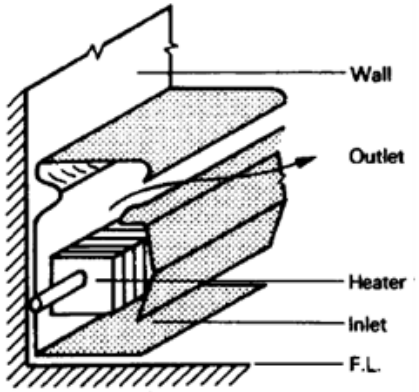
Natural convector

- Cabinet type comprises a finned tubular heating element fitted near to the bottom of the casing, so that a stack effect is created inside the cabinet.



Cabinet type convector

- Skirting types provide a good distribution of heat in a room and are very neat in appearance



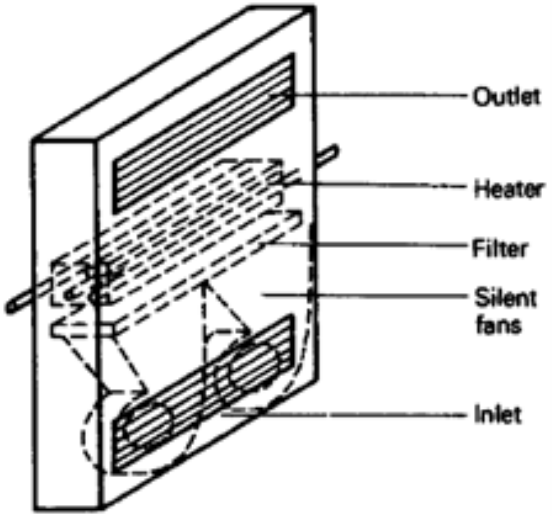
Skirting type convector

Indirect Heating System

Heat Emitter

Fan convectors

- Fans fitted below the element draw air in from the bottom of the casing,
- Air is then forced through the heating element before being discharged through the top of the cabinet.
- Air filter below the heating element
- Quickly heating the air in the room and give a good distribution of heat



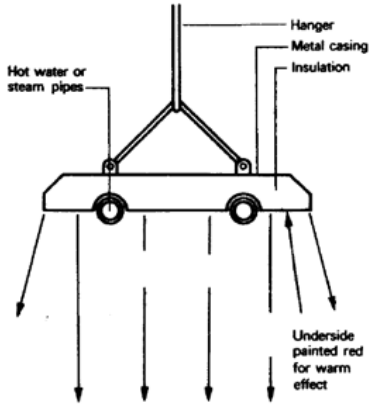
Fan convector

Indirect Heating System

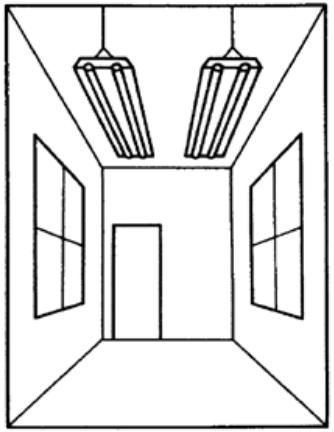
Heat Emitter

Overhead radiant strips

- Heating pipes (up to 30 m long) fixed to an insulated metal plate which also becomes heated by conduction from the pipe
- Minimum mounting height of the strips is governed by the heating system temperature and ranges from about 3 m for low temperature hot water, to about 5 m for high temperature hot water and steam



Overhead radiant strip

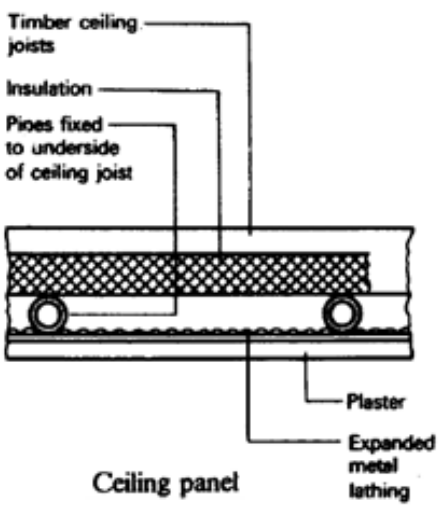

Arrangement of radiant strips

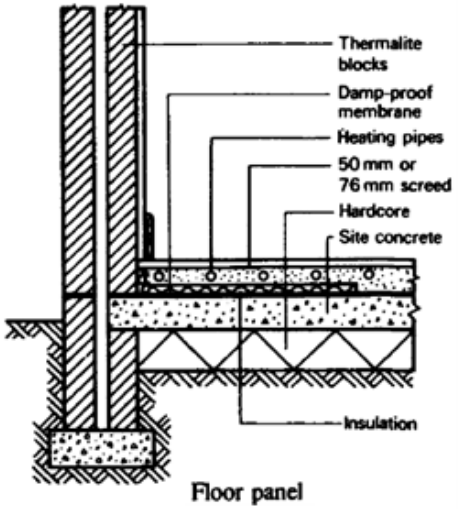
Indirect Heating System

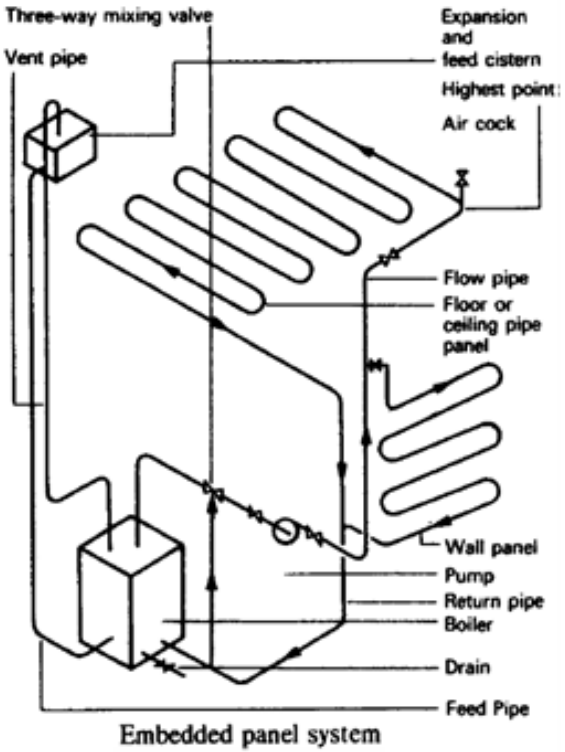
Heat Emitter

Embedded pipe panels

- Continuous coils of copper or steel pipes of 13 or 19mm bore at 225 to 300 mm centres embedded inside the floor or ceiling
- Recommend panel surface temperatures Floors at 26.7 ˚C and Ceilings at 49 ˚C



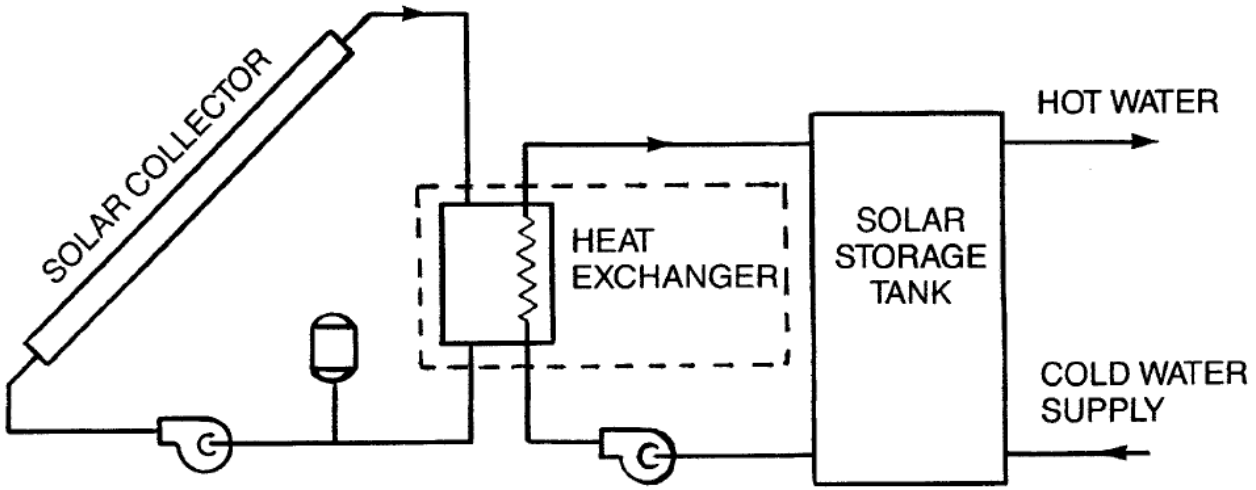




Indirect Heating System

Solar plant

- Collectors

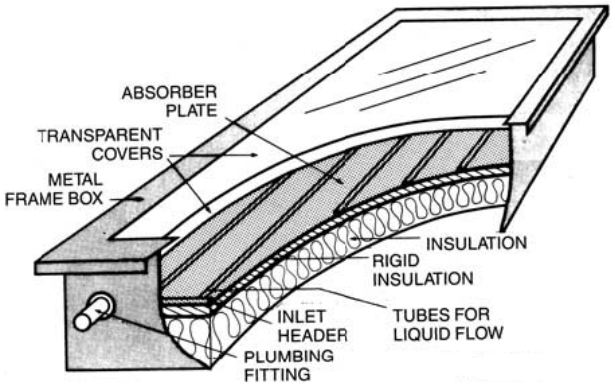


Indirect Heating System

Solar Hot Water System

A flat-plate collector

- Contains an absorber plate covered with a black surface coating and transparent covers.
- Covers are transparent to incoming solar radiation and relatively opaque to outgoing (long-wave) radiation
- Supply hot water at temperatures up to 95˚C
- Also absorb diffuse radiation (important in cloudy climates).



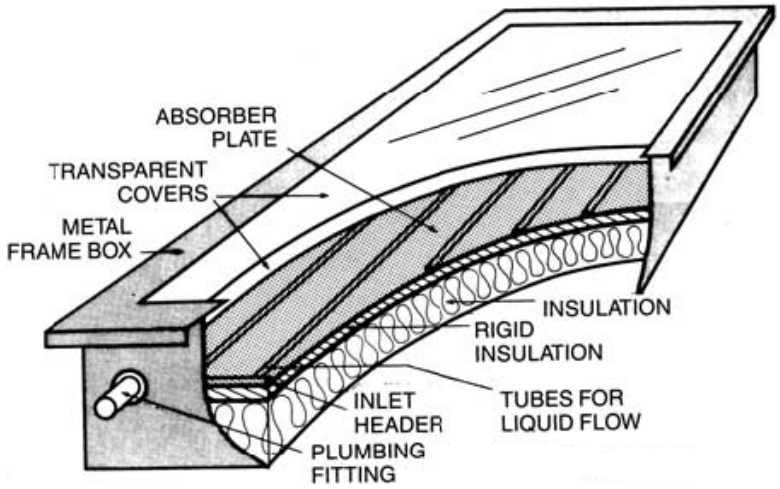
Indirect Heating System

Solar Hot Water System

A flat-plate collector

Collector Performance

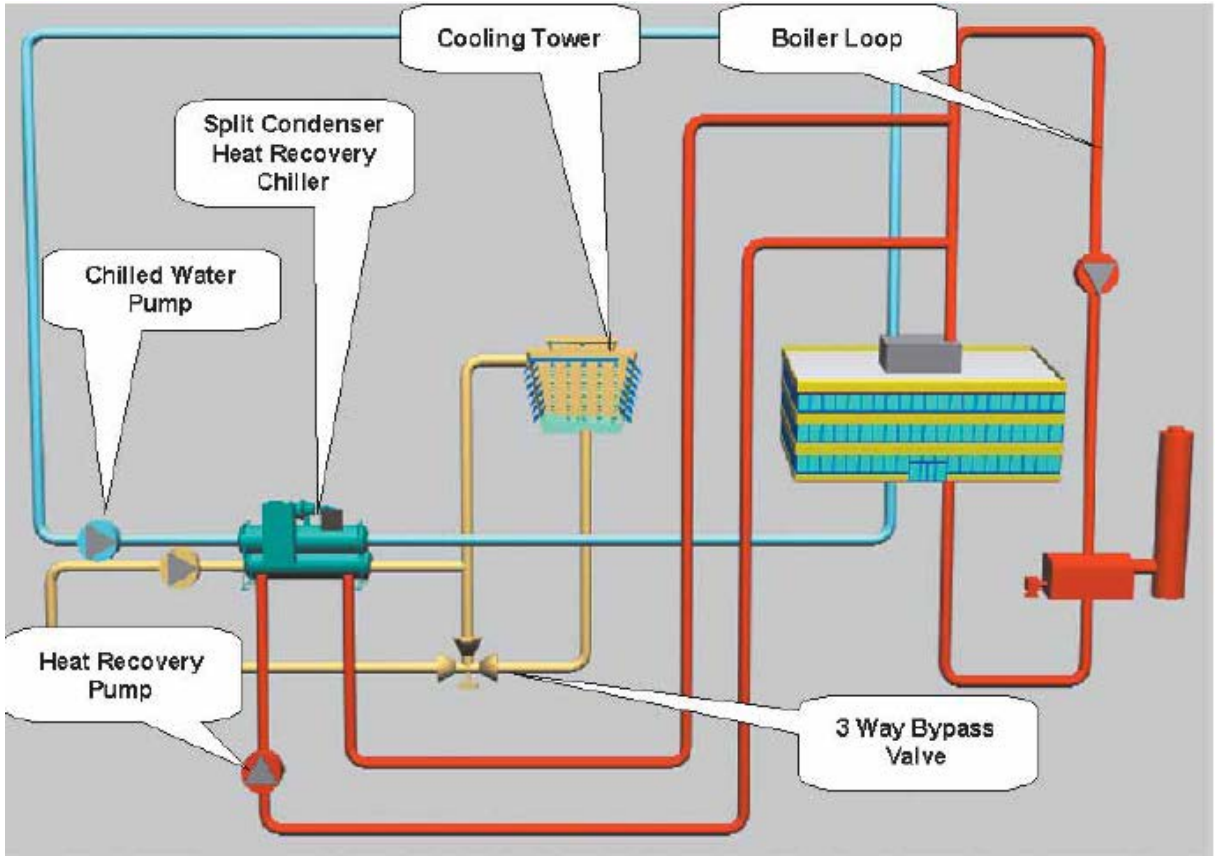
$$q_u = A_c[I_t\tau\alpha - U_L(\bar{t}_p - t_a)]$$



q_u = useful energy delivered by collector, W
A_c = total aperture collector area, m^2
I_t = total (direct plus diffuse) solar energy incident on upper surface of sloping collector structure, W/m^2
τ = fraction of incoming solar radiation that reaches absorbing surface, transmissivity (dimensionless)
α = fraction of solar energy reaching surface that is absorbed, absorptivity (dimensionless)
U_L = overall heat loss coefficient, $W/(m^2 \cdot K)$
$\bar{t}_p$ = average temperature of absorbing surface of absorber plate, °C
t_a = atmospheric temperature, °C

Indirect Heating System

Heat Recovery Chiller



Indirect Heating System

Heat Recovery Chiller

- Heat recovery chillers produce 44 ˚C to 48 ˚C hot water for heating the building.
- Most heating systems are designed to operate at 84 ˚C supply water.
- As the chillers produce hotter condenser water, their performance drops when compared to conventional chilled water production.