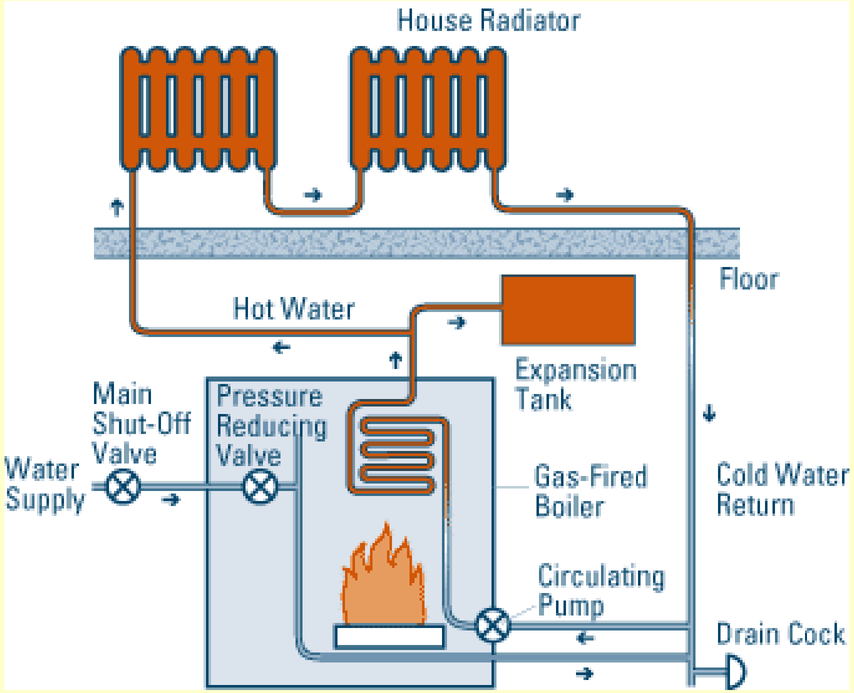


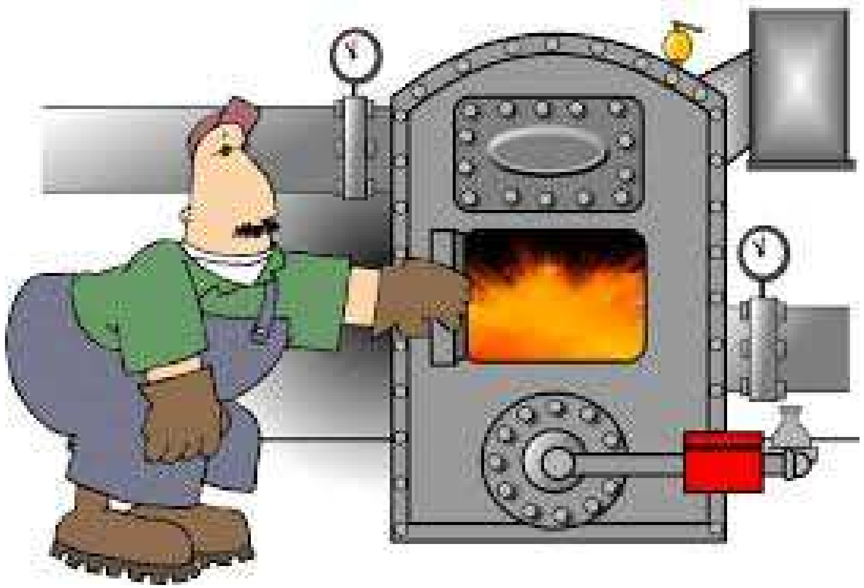
Heating systems

Ir. Dr. Sam C. M. Hui
Faculty of Science and Technology
E-mail: cmhui@vtc.edu.hk

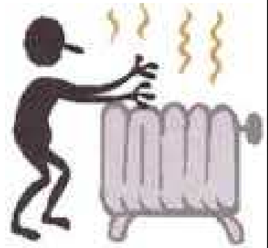
Sep 2017

Contents

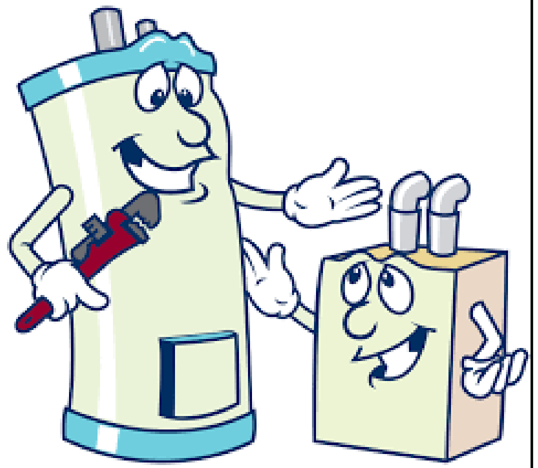
- System types and components
- Design of heating systems
- Boilers
- Warm air furnaces
- Solar heating



System types and components



- In cold climates **heating** is an essential part of creating comfortable internal environments
- Applications of heating systems:
  - Space heating and hot water supply



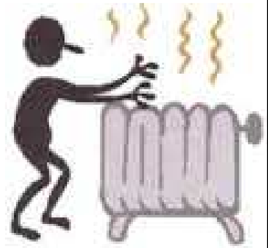
- Components of **heating systems**:
  - Heat source (to generate heat)
  - Distribution medium and network (to distribute the heat around the building)
  - Heat emitters (deliver the heat to the space)

Components of heating systems

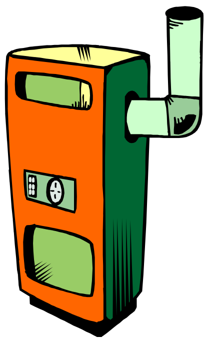
Heat source	Natural gas Liquefied petroleum gas Oil (petroleum) Coal Electricity	Solar thermal Biomass, biofuels Combined heat and power (CHP) Heat pump (air, water or ground-source) Waste heat
Distribution medium	Water (low, medium or high temperature) Air Steam Electricity	
Heat emitters	Radiators Fan convectors Natural convectors Panel heaters Ceiling panels	Underfloor heating coils Unit heaters Storage heaters High temperature radiant panels

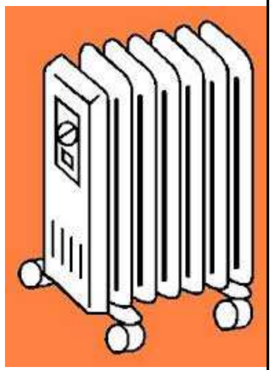
Category of water heating systems	Temperature	Minimum operating pressure
Low temperature hot water (LTHW)	< 90 °C	1 bar
Medium temperature hot water (MTHW)	90 to 120 °C	3 bar
High temperature hot water (HTHW)	> 120 °C	5 bar

System types and components



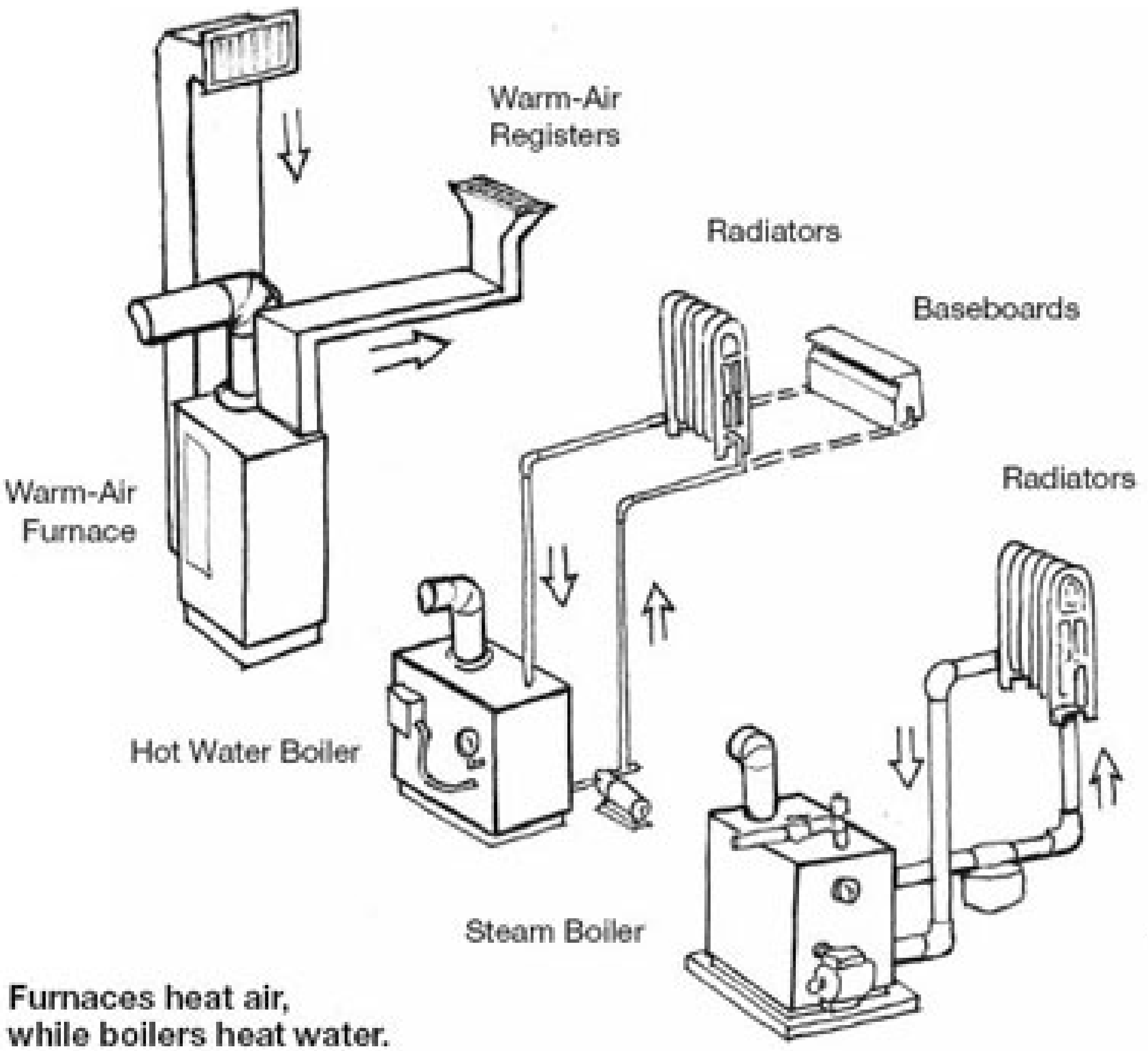
- Common types of heating systems:
  - 1. Heating systems using boilers (water is heated)
  - 2. Warm air furnaces and packaged heating units (air is heated)
  - 3. Heat pumps (reverse cycle of refrigeration cycle) (air, water or ground-source)
  - 4. Individual space heaters (e.g. electric, gas, radiant heaters)
- Centralised versus non-centralised systems

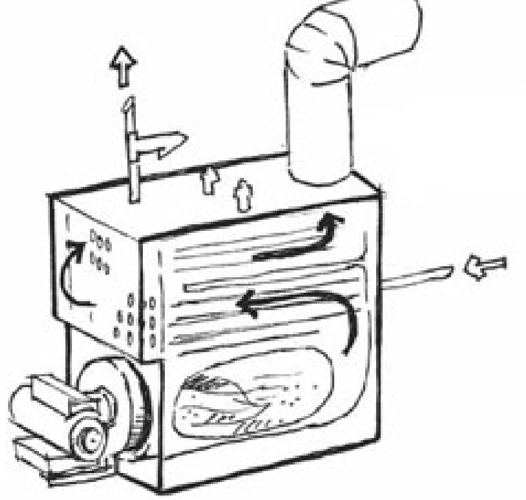




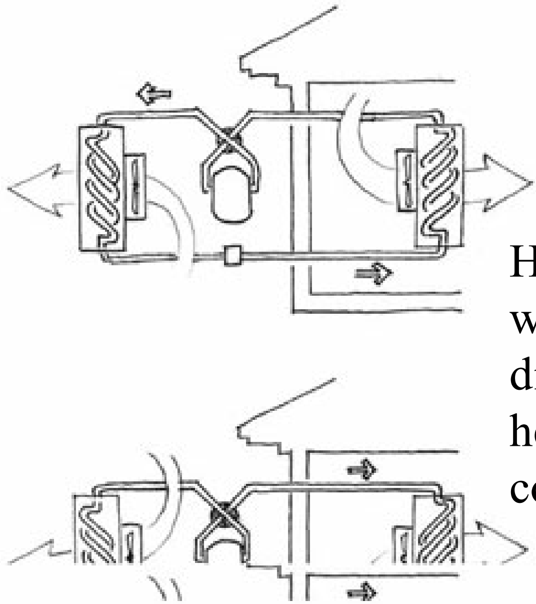
(Video: Types of Heating Systems (2:10) http://youtu.be/j47hxnIgOlA)

Types of heating systems





Boilers work like furnaces, except that they heat water instead of air



Heat pumps can work in two different modes: heating and cooling

(Source: Types of Heating Systems http://smarterhouse.org/heating-systems/types-heating-systems)

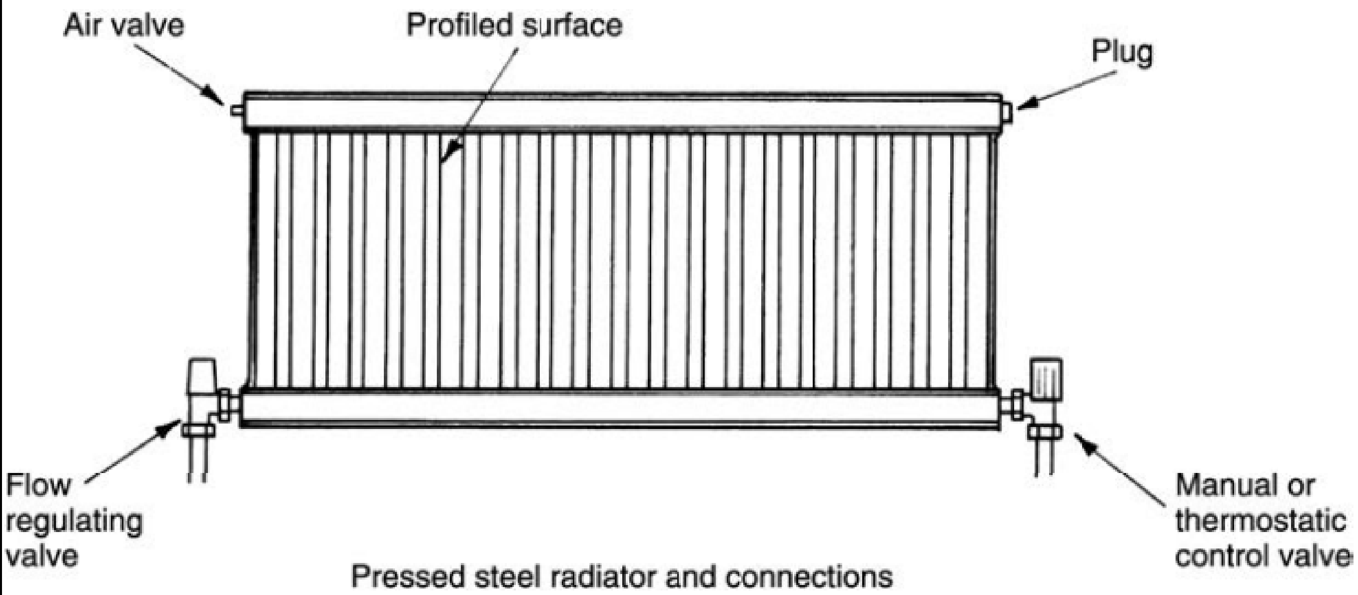
Centralised versus non-centralised systems

	Centralised	**Non-centralised (or Decentralised)**
Capital cost	Capital cost per unit output falls with increased capacity of central plant. Capital cost of distribution systems is high	Low overall capital cost, savings made on minimising the use of air and water distribution systems
Space requirements	Space requirements of central plant and distribution systems are significant, particularly ductwork. Large, high flues needed	Smaller or balanced flues can often be used. Flueing arrangements can be more difficult in some locations
System efficiency	Central plant tends to be better engineered, operating at higher system efficiencies (where load factors are high) and more durable. As the load factor falls, the total efficiency falls as distribution losses become more significant	Energy performance in buildings with diverse patterns of use is usually better
System operation	Convenient for some institutions to have centralised plant. Distribution losses can be significant	May require more control systems. Zoning of the systems can be matched more easily to occupancy patterns
System maintenance and operational life	Central plant tends to be better engineered, more durable. Less resilience if no standby plant provided	Can be readily altered and extended. Equipment tends to be less robust with shorter operational life. Plant failure only affects the area served. Maintenance less specialised
Fuel choice	Flexibility in the choice of fuel, boilers can be dual fuel. Better utilisation of CHP, etc. Some systems will naturally require central plant, e.g. heavy oil and coal burning plant	Fuel needs to be supplied throughout the site. Boilers are single fuel

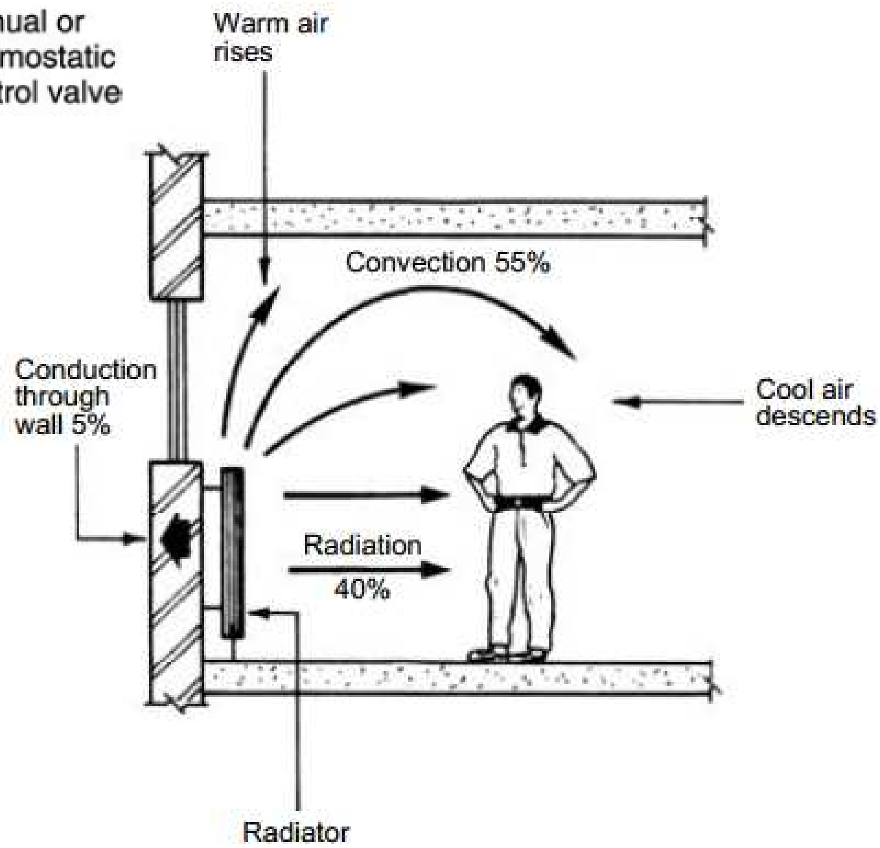
Common emitter/system types

	Design points	Advantages	Disadvantages
Radiators	Output up to 70% convective. Check for limit on surface temperature in some applications, e.g. hospitals	Good temperature control. Balance of radiant and convective output gives good thermal comfort. Low maintenance. Cheap to install	Fairly slow response to control. Slow thermal response
Natural convectors		Quicker response to control. Skirting or floor trench convectors can be unobtrusive	Can occupy more floor space. Can get higher temperature stratification in space
Underfloor heating	Check required output can be achieved with acceptable floor surface temperatures	Unobtrusive. Good space temperature distribution with little stratification	Heat output limited. Slow response to control
Fan convectors	Can also be used to deliver ventilation air	Quick thermal response	Can be noisy. Higher maintenance. Occupies more floor space
Warm air heaters	Can be direct fired units	Quick thermal response	Can be noisy. Can get temp. stratification in space
Low temperature radiant panels	Ceiling panels need relatively low temperatures to avoid discomfort	Unobtrusive. Low maintenance	Slow response to control
High temperature radiant heaters	Can be direct gas or oil fired units. Check that irradiance levels are acceptable for comfort	Quicker thermal response. Can be used in spaces with high air change rates and high ceilings	Need to be mounted at high level to avoid local high intensity radiation and discomfort

Heat transfer of radiator in heating system



Heat energy transfer:
- Radiation
- Convection
- Conduction

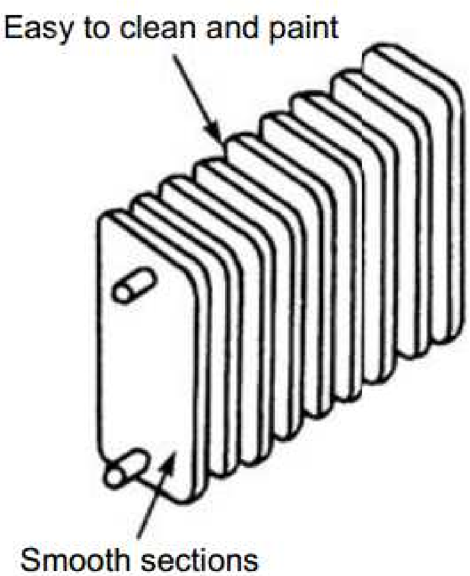


Despite the name, radiator, no more than 40% of the heat transferred is by radiation. The remainder is convected, with a small amount conducted through the radiator brackets into the wall.

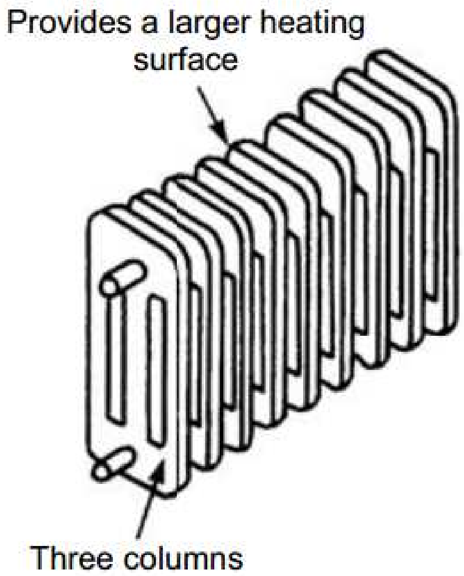
(See also: Heat Emitters http://www.arca53.dsl.pipex.com/index_files/emitters1.htm)

(Source: Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.)

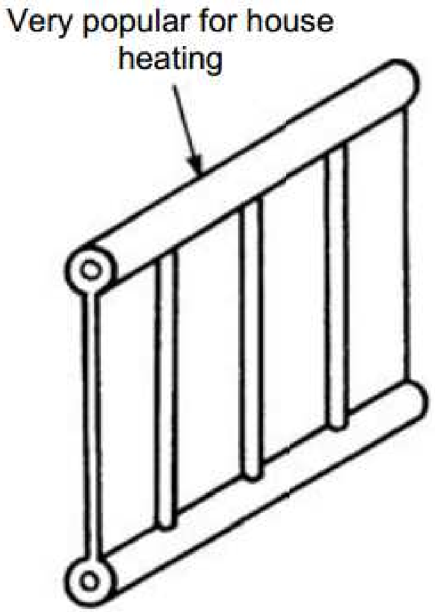
Different types of radiators



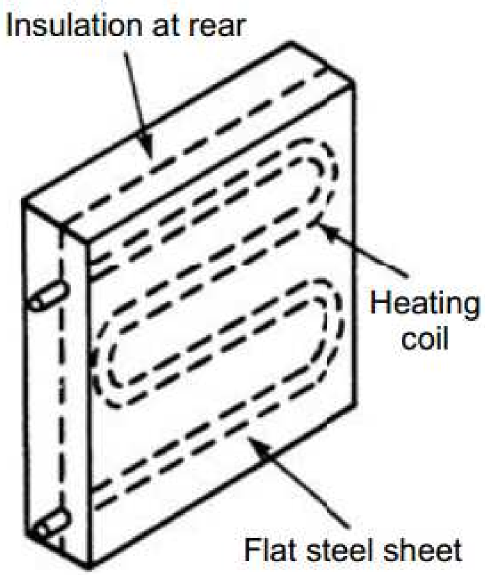
Hospital-type radiator



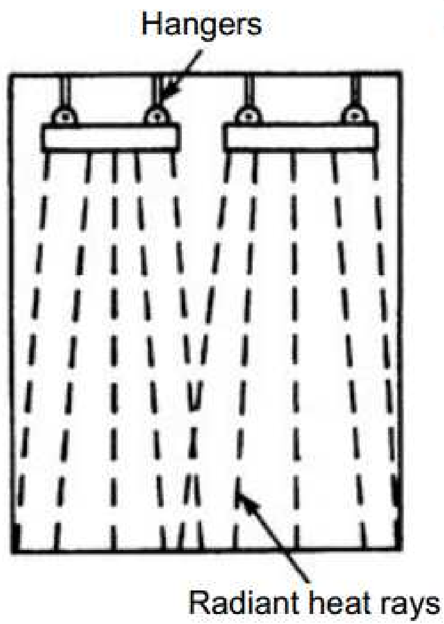
Column-type radiator



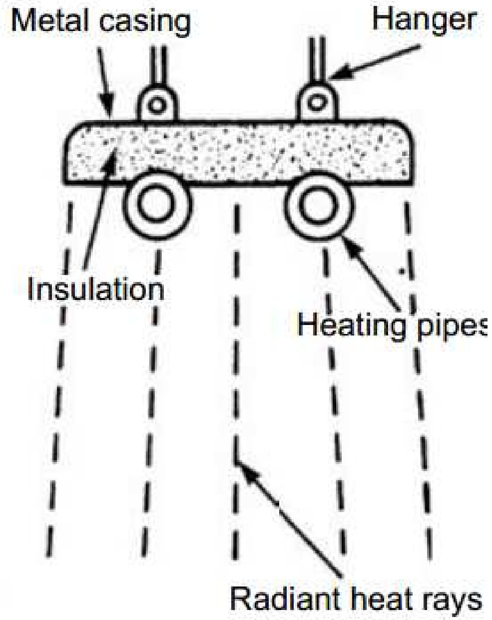
Panel-type radiator



Radiant panel



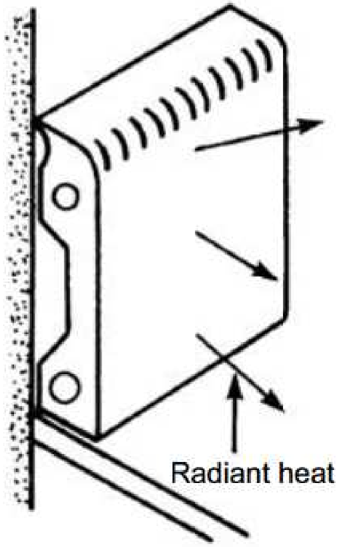
Radiant panels fixed overhead



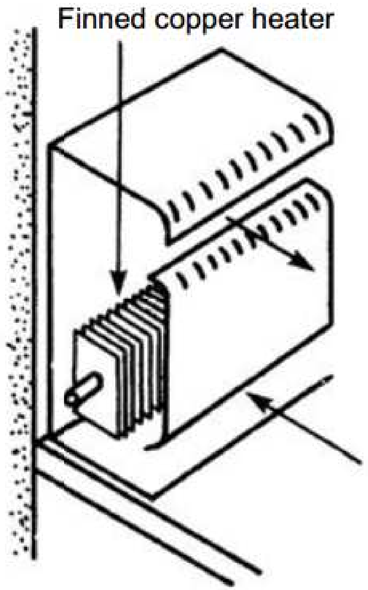
Radiant strip

(Source: Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.)

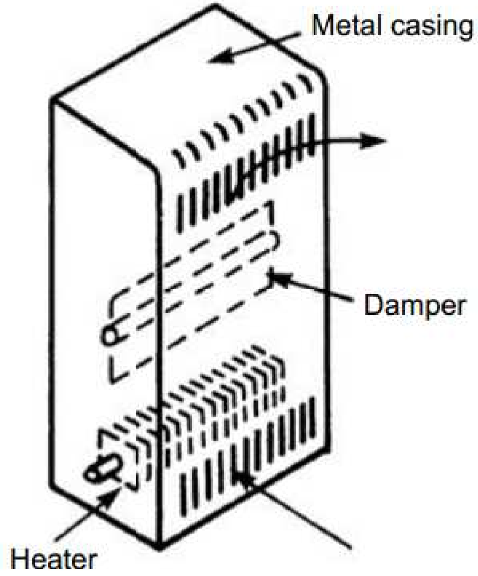
Examples of radiant and convector skirting heaters



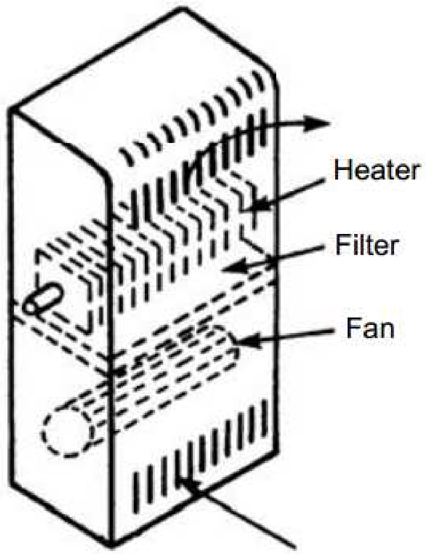
Radiant skirting heater



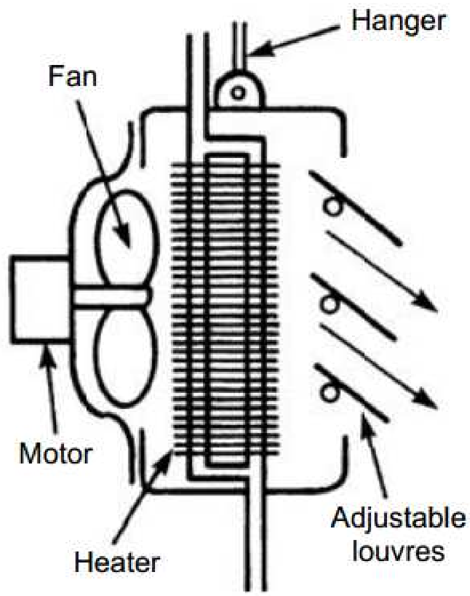
Convector skirting heater



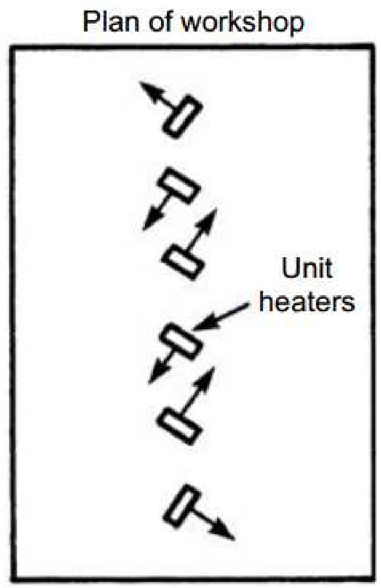
Natural convector



Fan convector



Overhead unit heater



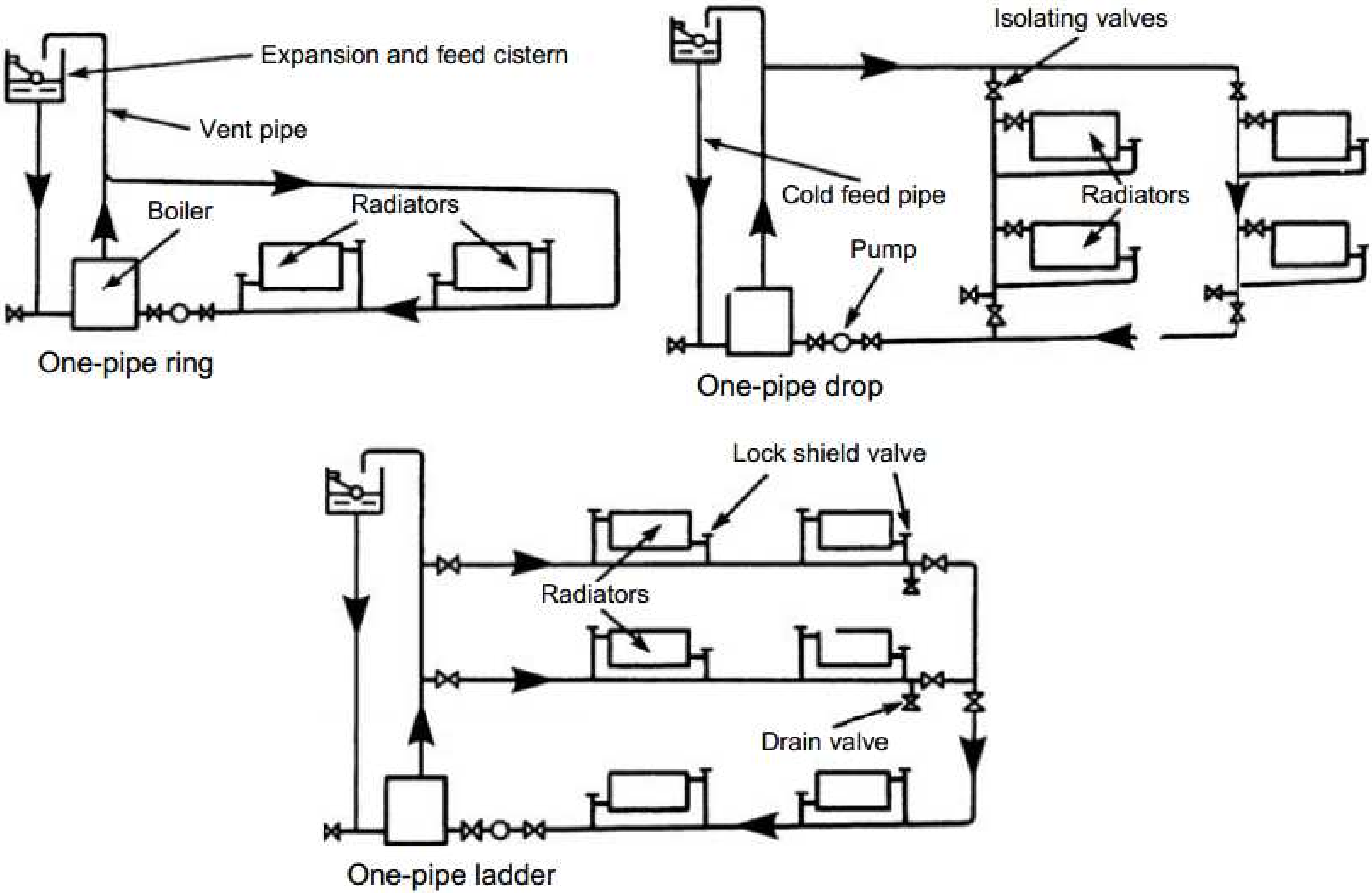
Method of siting overhead unit heaters

(Source: Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.)

Characteristics of heat distribution media

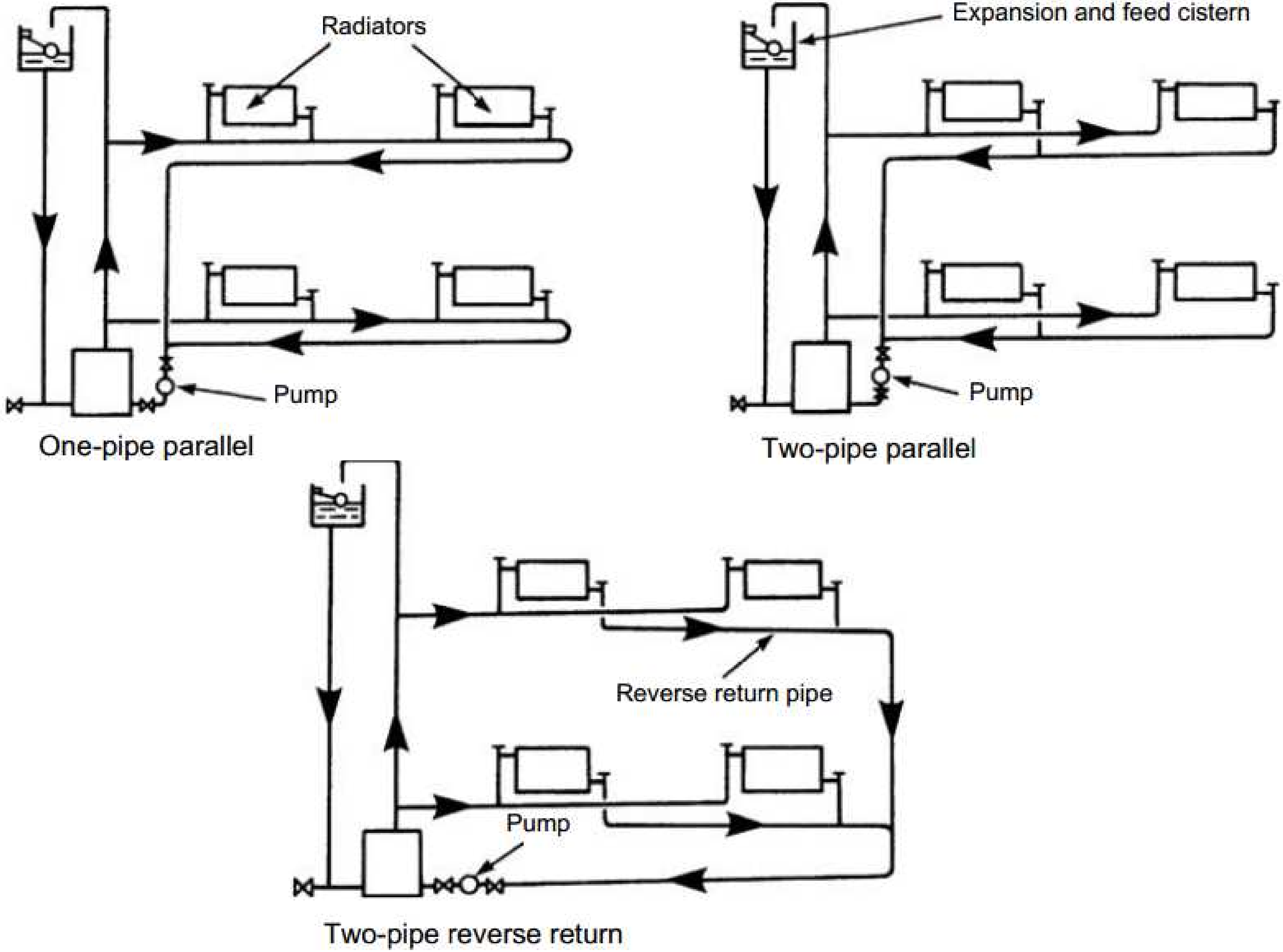
Medium	**Principal characteristics**
Air	Advantages: no intermediate medium or heat exchanger is needed; there is no risk of water leak. Disadvantages: the large volume of air required and size of ductwork; high energy consumption by fans. However, warm air heating can be combined with mechanical ventilation or air conditioning.
Low temperature hot water (LTHW)	Generally recognised as simple to install and safe in operation. Output limited by system temperatures but this may not be a problem in modern, well insulated buildings.
Medium temperature hot water (MTHW)	Permits a greater difference between flow and return temperature than LTHW so smaller pipework required for same heat output. Requires more complex system pressurisation schemes. Unlikely to be cost effective except in very large buildings.
High temperature hot water (HTHW)	Permits even greater flow/return temperature differences than MTHW and so even smaller pipework. However, inherent dangers require that all pipework is welded similar to steam systems. Unlikely to be appropriate except where heat must be transferred over large distances.
Steam	Utilises latent rather than sensible heat so extremely high heat transfer carrying capacity. Can be designed to operate at a wide range of pressures and temperatures. Usually used for large sites or when some site process requires steam.
Hot thermal fluids (oils)	Used for radiant heating in some industrial buildings as a alternative to steam where the thermal fluid also heats process plant . Operates at atmospheric pressure and does not require water treatment.

Pipe layout options of low-temperature hot water heating systems



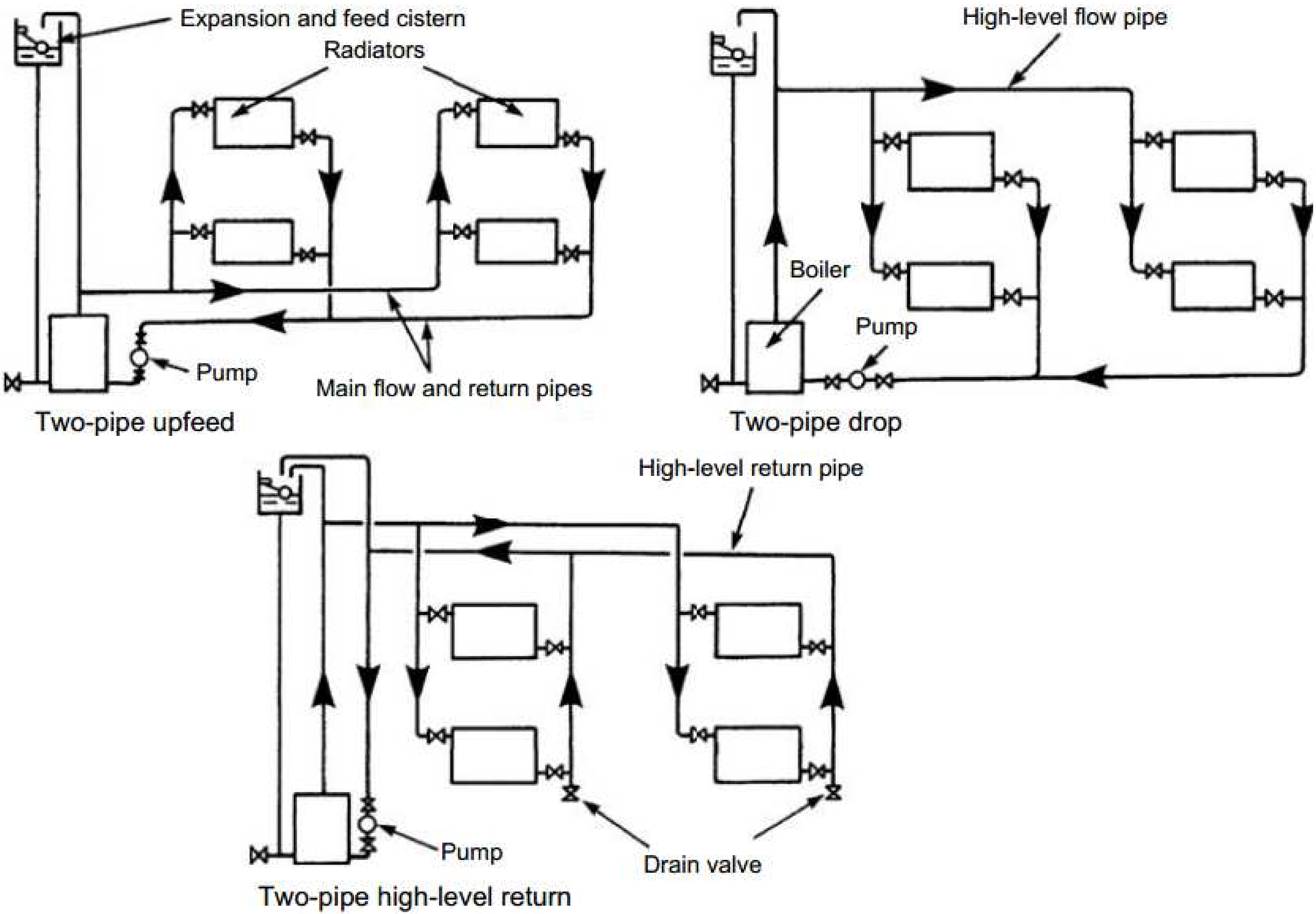
(Source: Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.)

One- and two-pipe parallel systems



(Source: Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.)

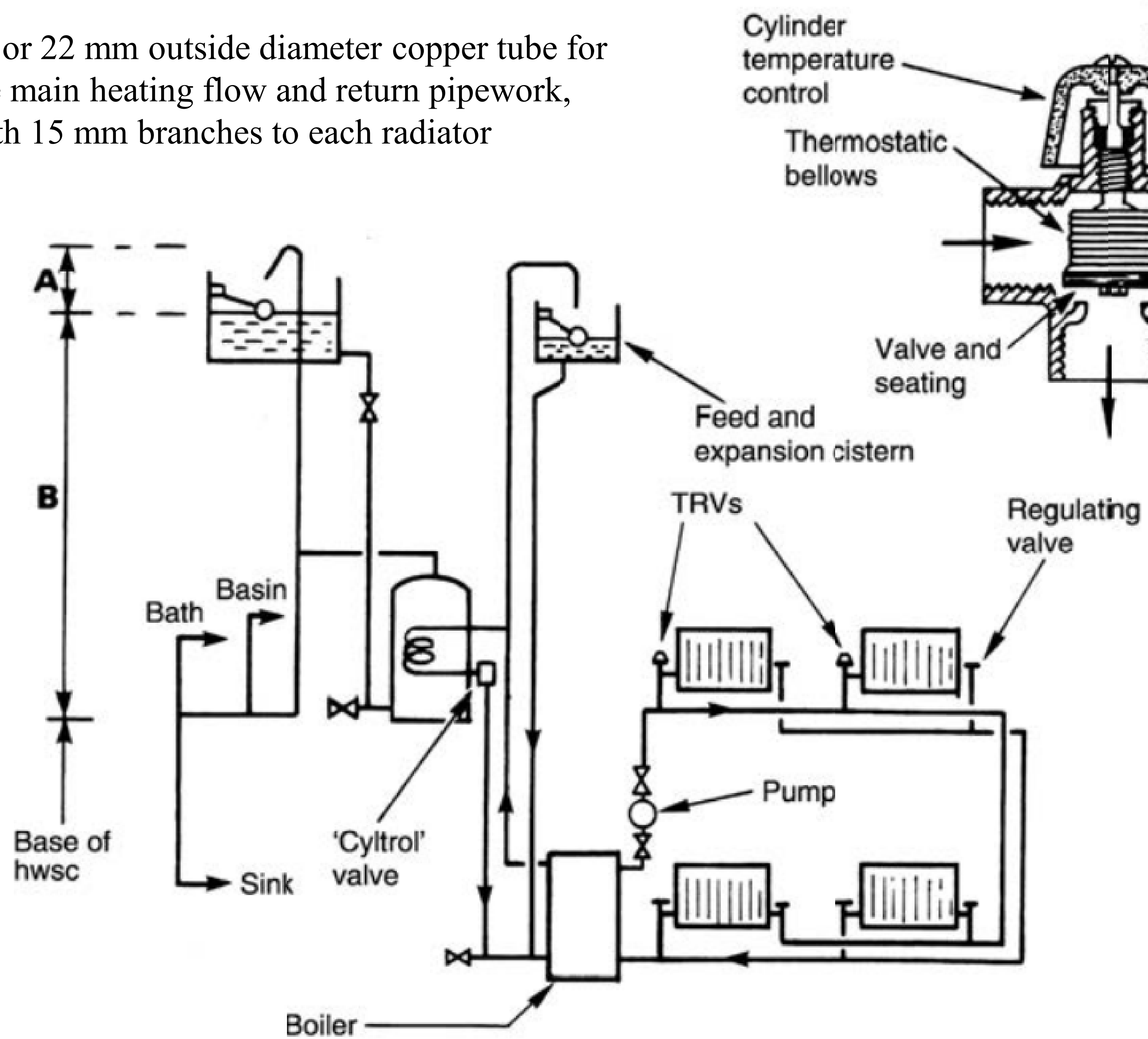
Two-pipe upfeed, drop and high-level return systems



(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

Small bore hot water heating system

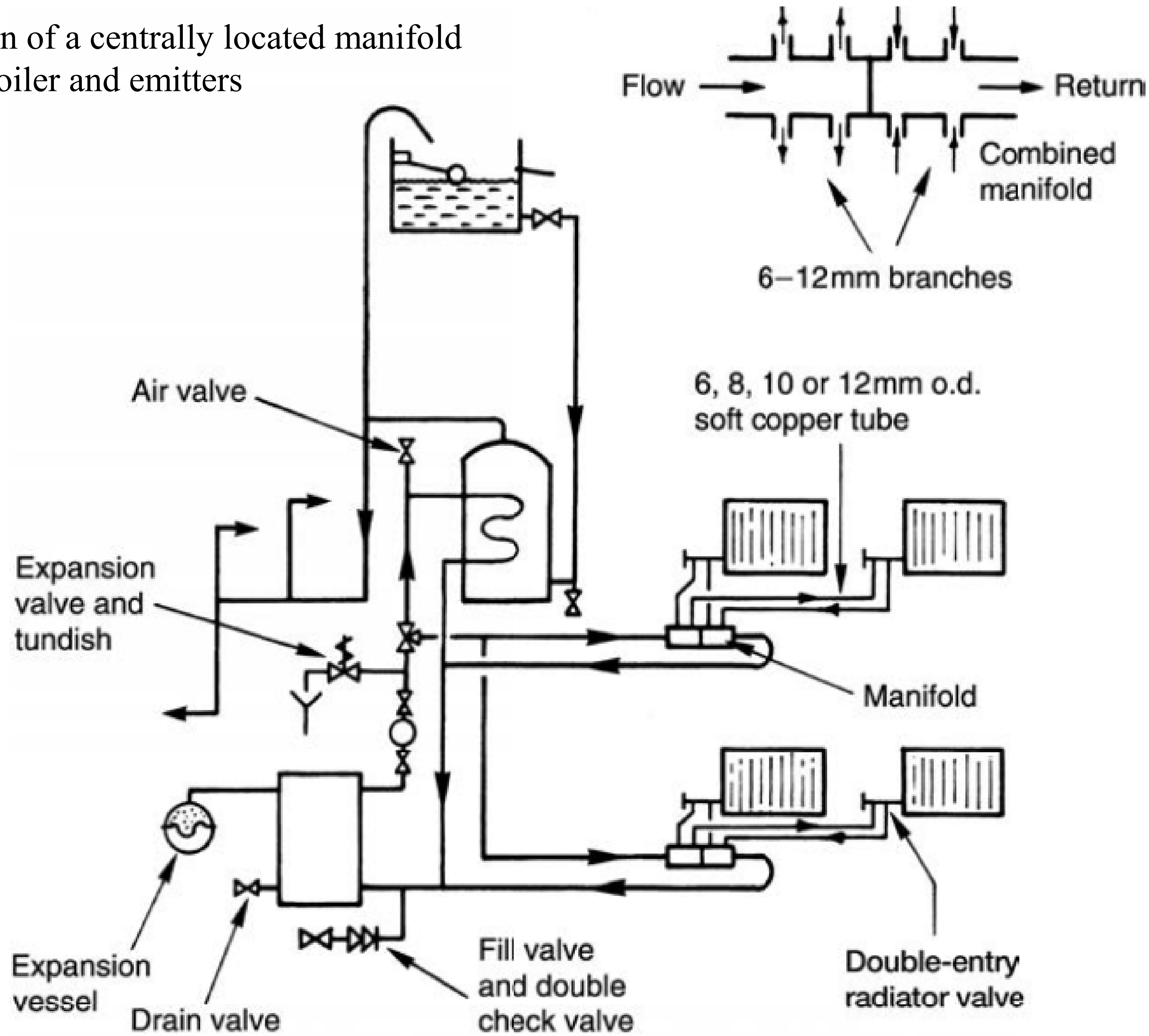
28 or 22 mm outside diameter copper tube for the main heating flow and return pipework, with 15 mm branches to each radiator



(Source: Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.)

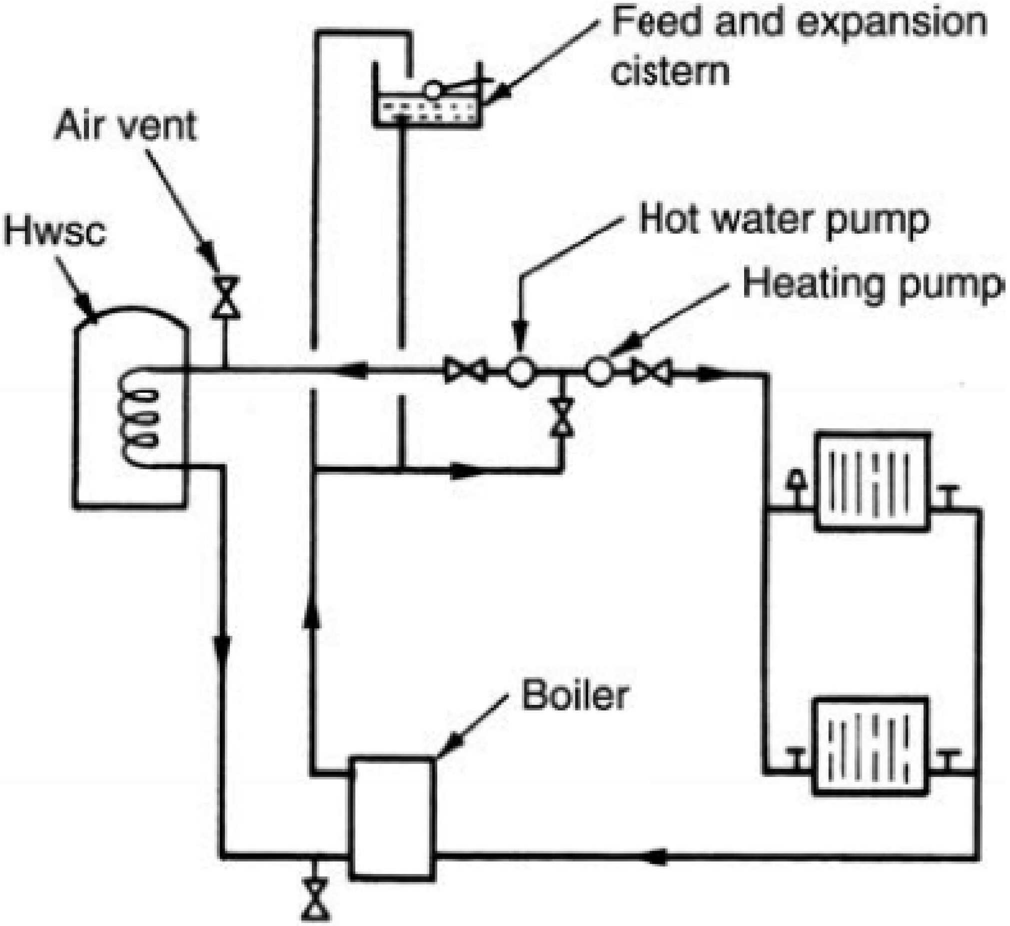
Microbore hot water heating system

Application of a centrally located manifold between boiler and emitters

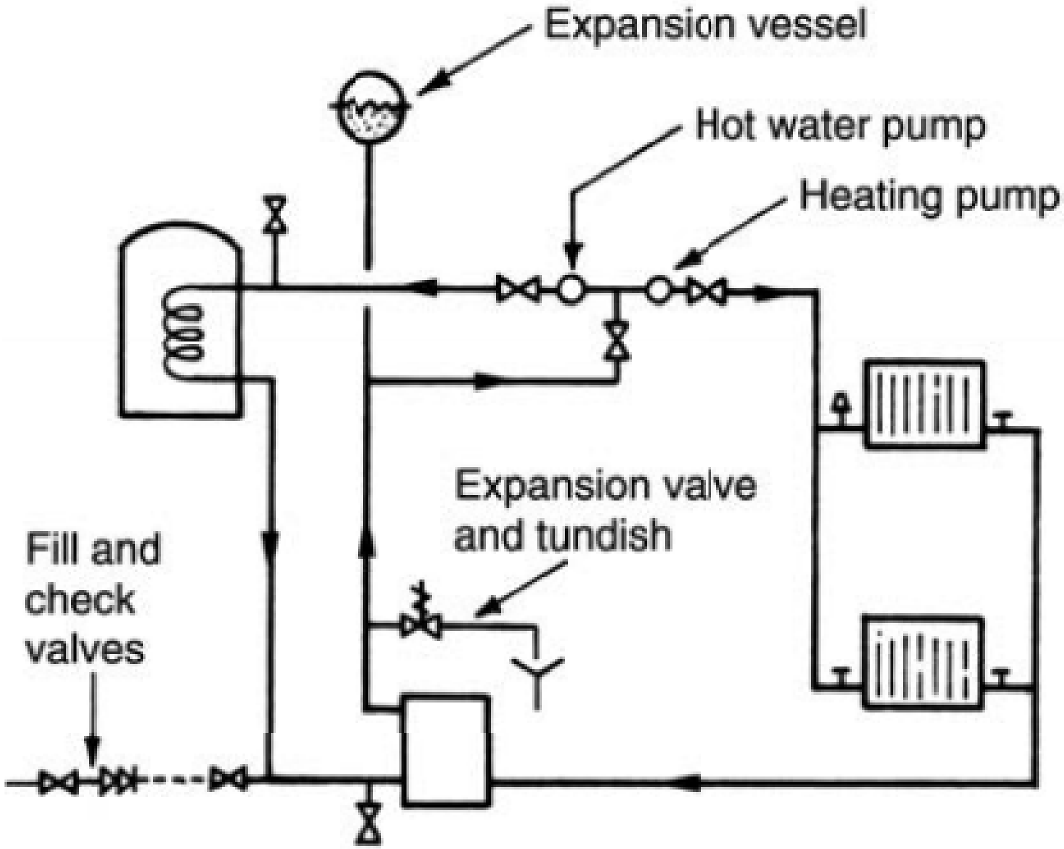


(Source: Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.)

Open-vent and sealed systems



Conventional open-vent system



Typical sealed system

(Source: Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.)

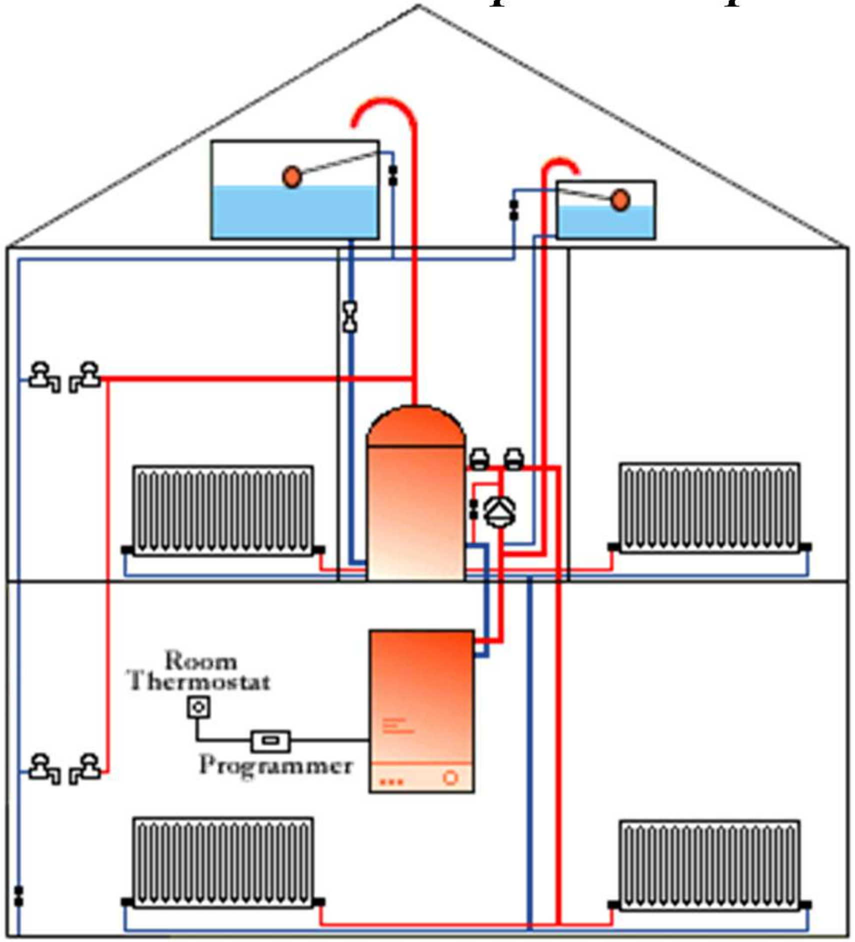
Design of heating systems

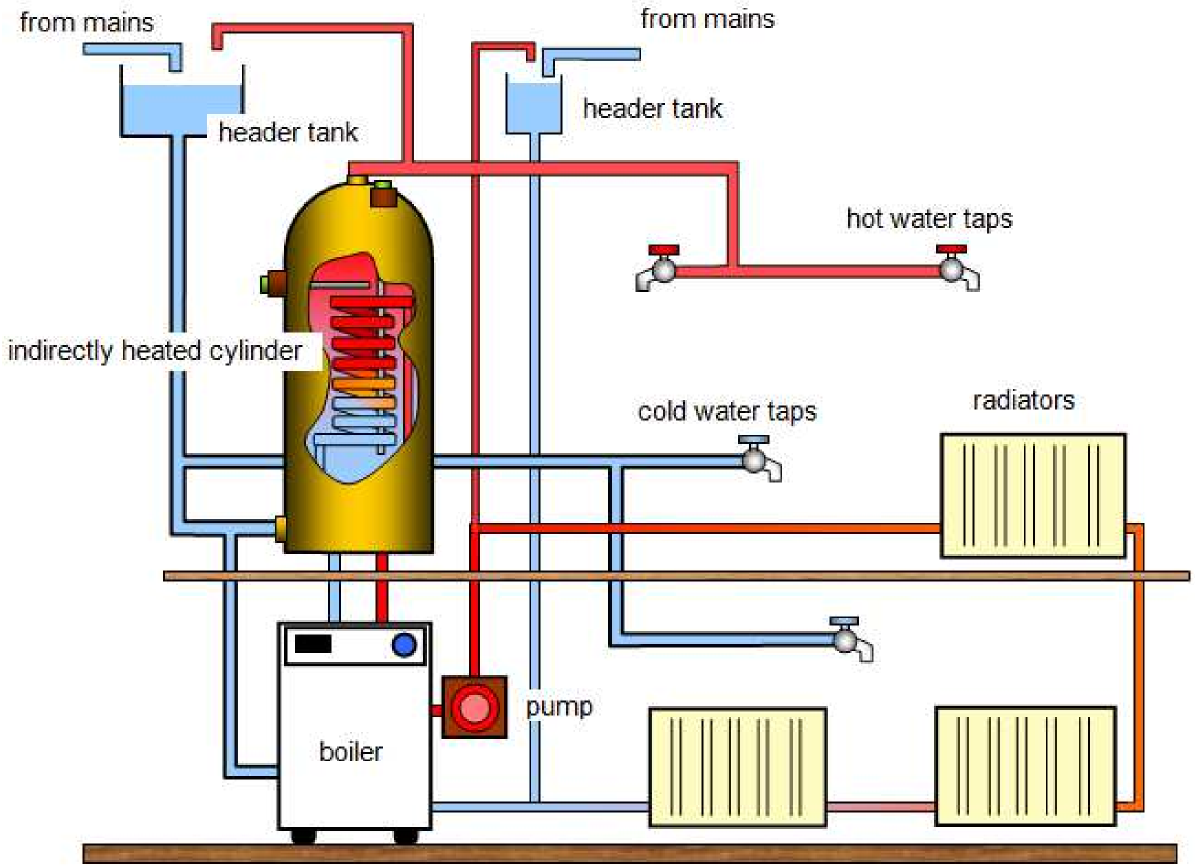
- Factors that influence the choice of heating system*

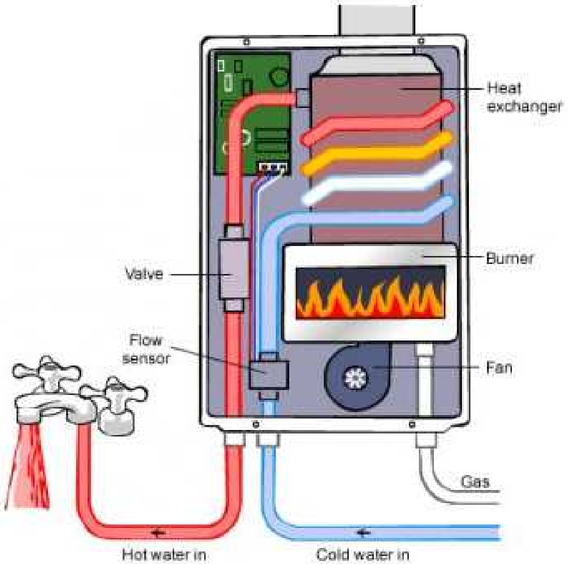
Cost	Security of supply of heat source
Fuel or heat source	Let buildings
Safety	Environmental issues
Type of building	District heating
Comfort	Outside conditions
Power supply	Fluctuating heat demand
Space	Appearances
Vandalism	Industrial waste heat

(*See also: http://www.arca53.dsl.pipex.com/index_files/heat5.htm)

Examples of space heating and hot water systems







Design of heating systems

- Choice of domestic hot water system:
  - Hot water storage calorifiers (centralised or decentralised)
  - Plate heat exchangers with minimal storage (centralised)
  - Point of use hot water heaters (with or without minimal storage capacity)
  - Centralised hot water generators (with minimal storage capacity)

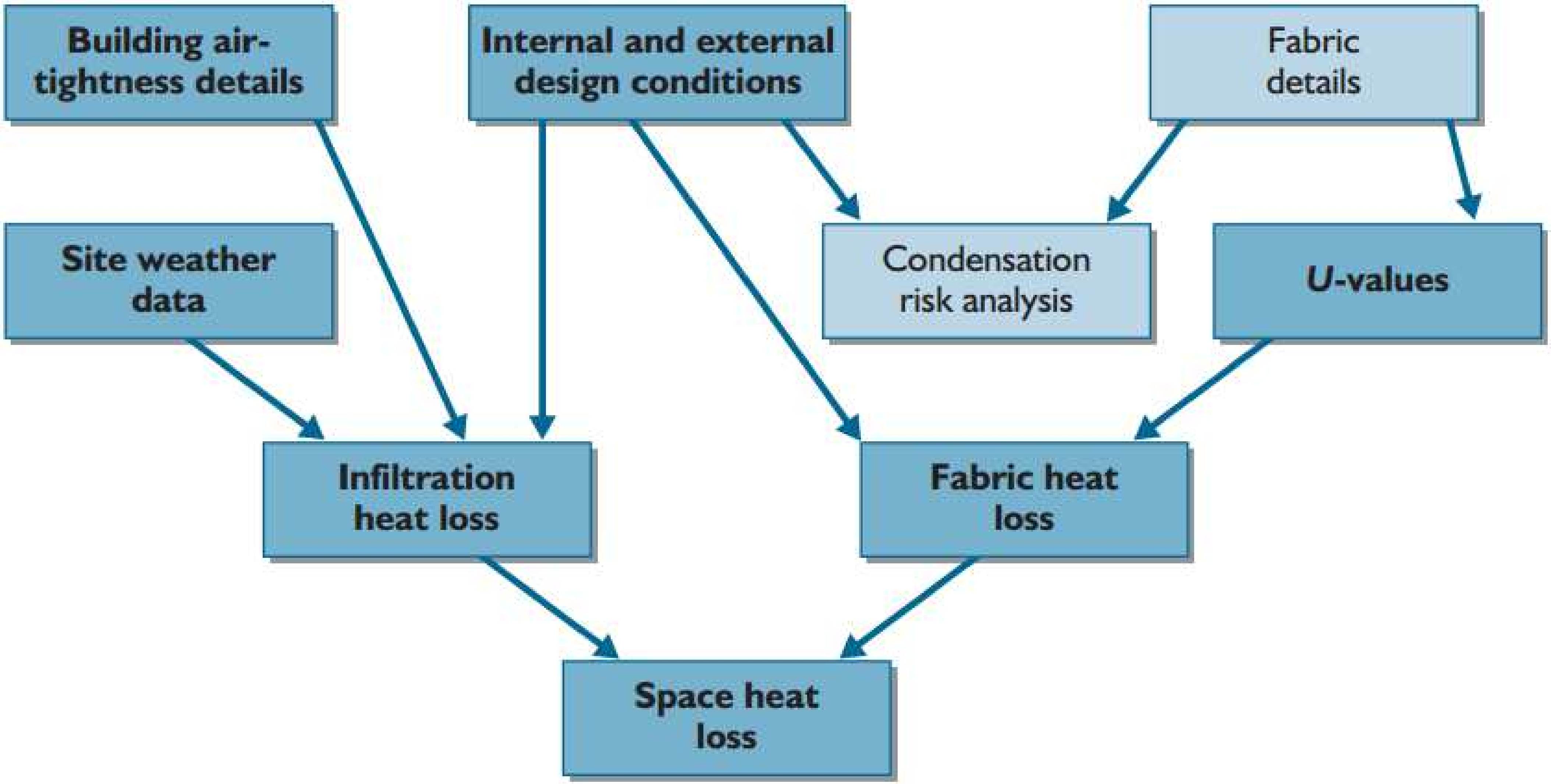
(* More information on hot water systems in the module on piped or plumbing services.)

Heating system design process**

Step 1: pre-design and design brief
Step 2: gather design information
Step 3: design data
Step 4: building thermal performance analysis
Step 5: heating system option analysis and selection
Step 6: space heat losses and heat load
Step 7: equipment sizing and selection
Step 8: heating load analysis
Step 9: plant sizing and selection
Step 10: system analysis and control performance
Step 11: Final value engineering and energy targets assessment
Step 12: design review

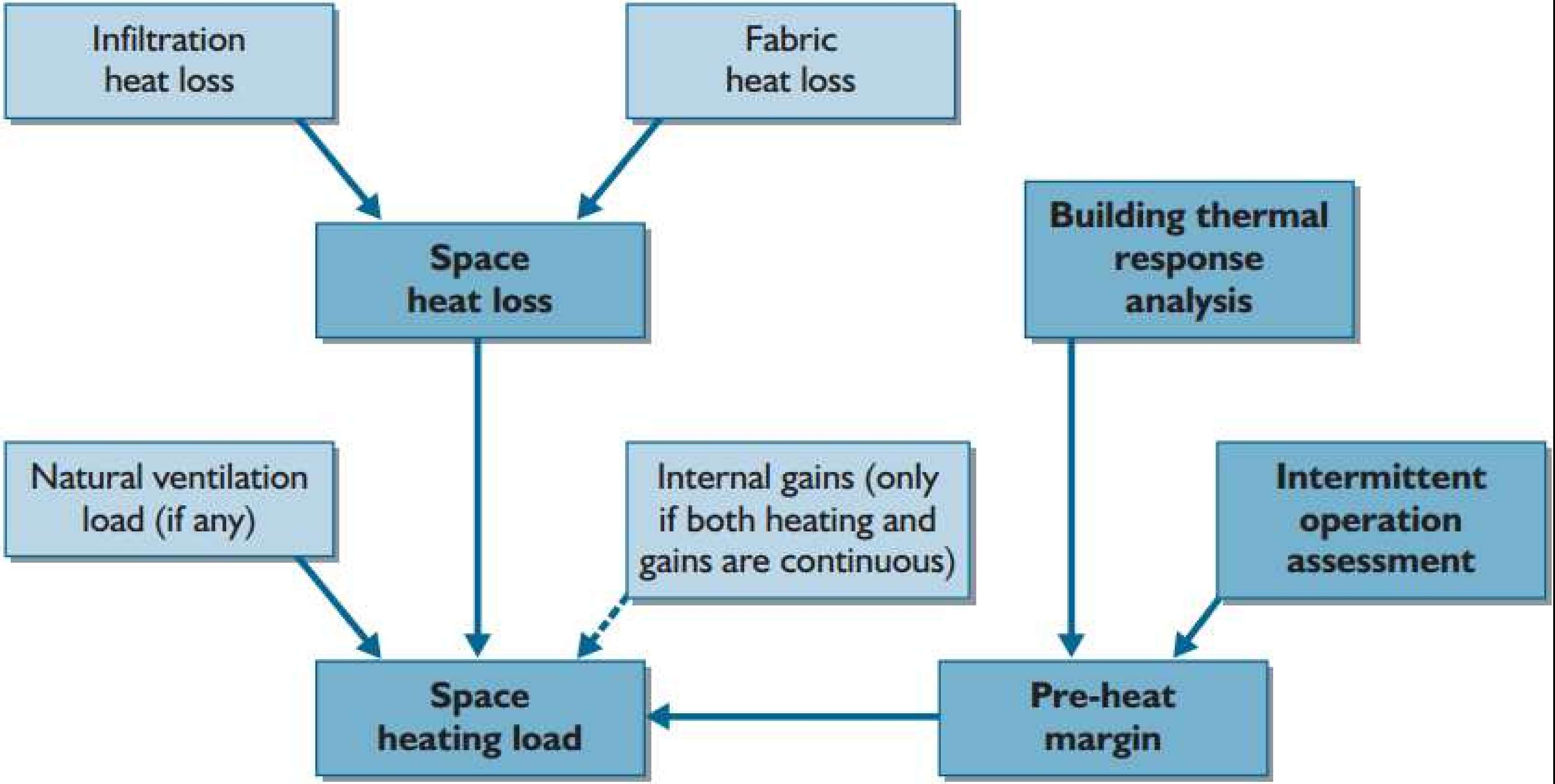
** Recommended design guide: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.

Key steps to establish individual space heat losses



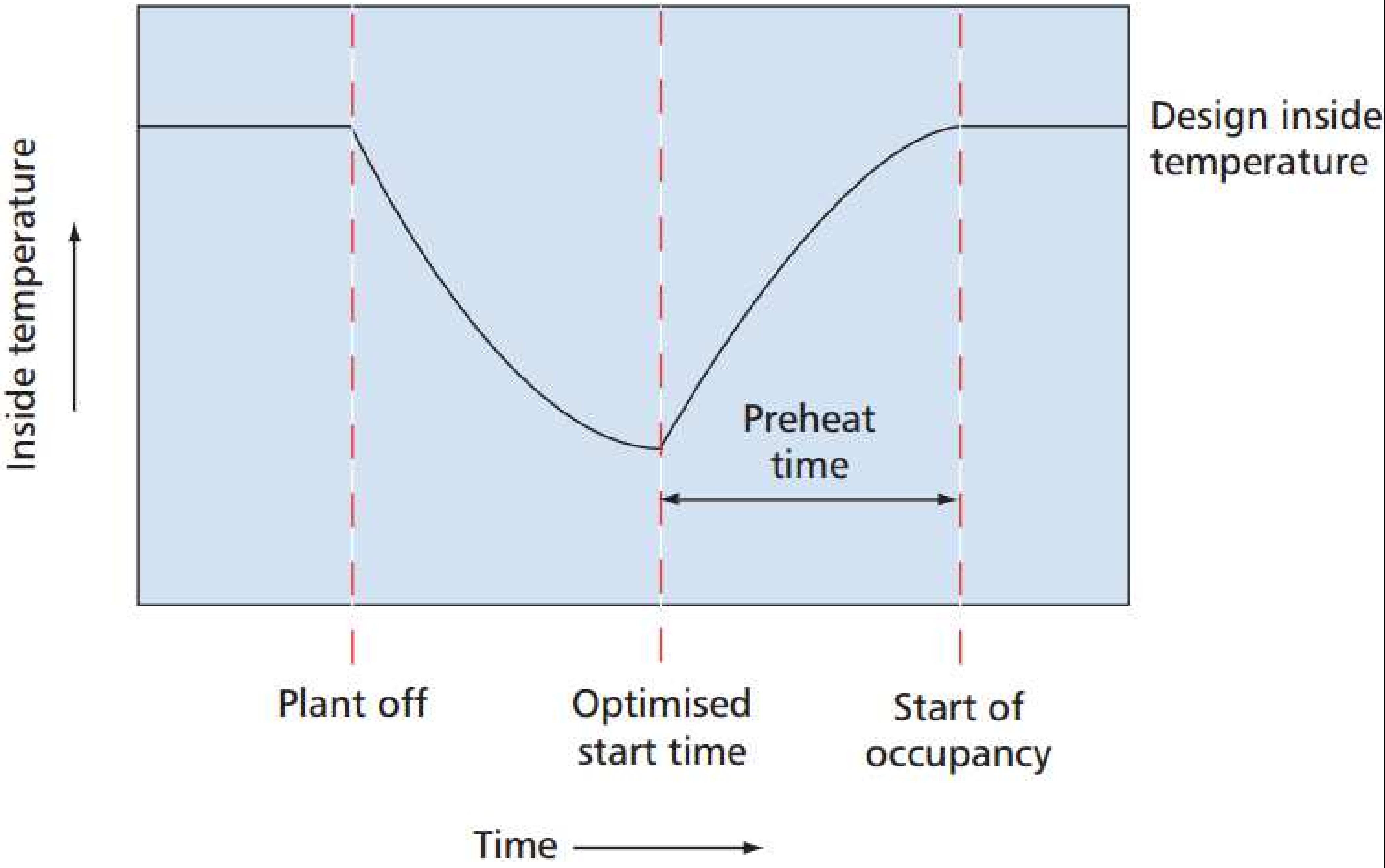
(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

Key steps to establish space heating loads



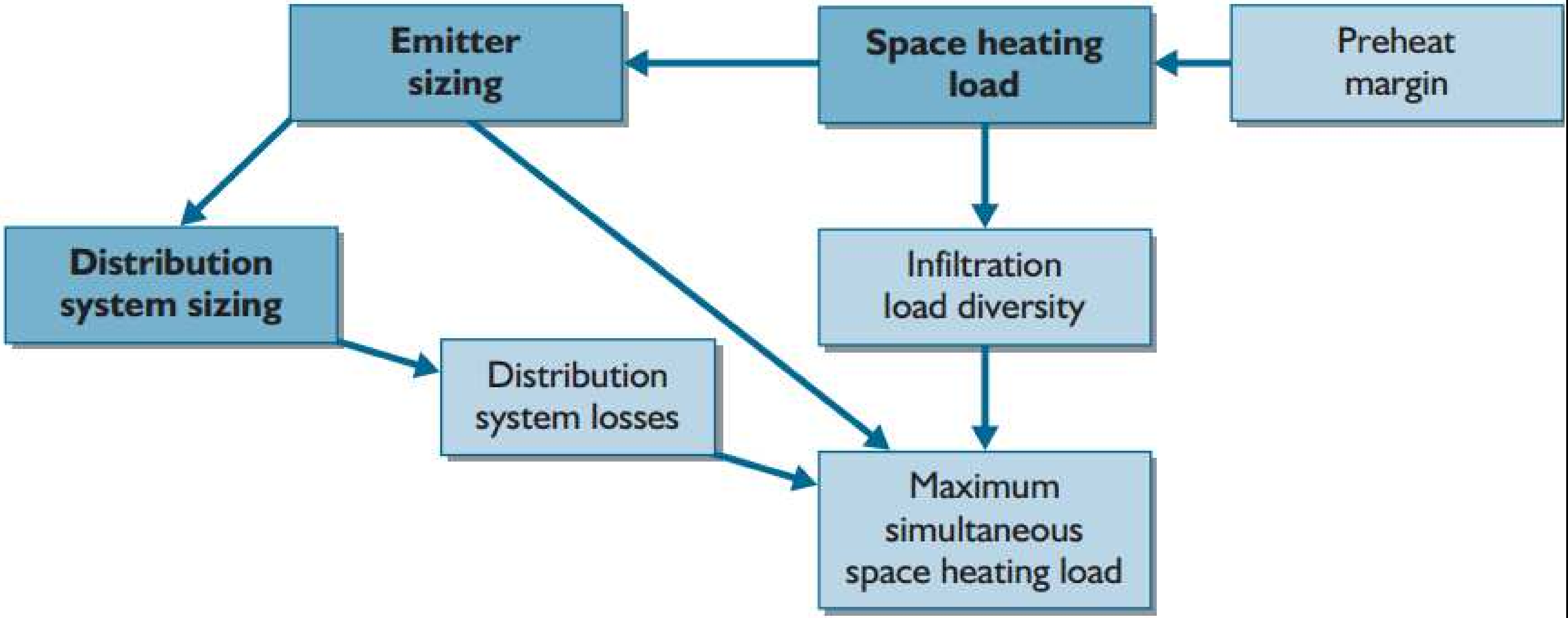
(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

Preheat time before the start of the occupied period



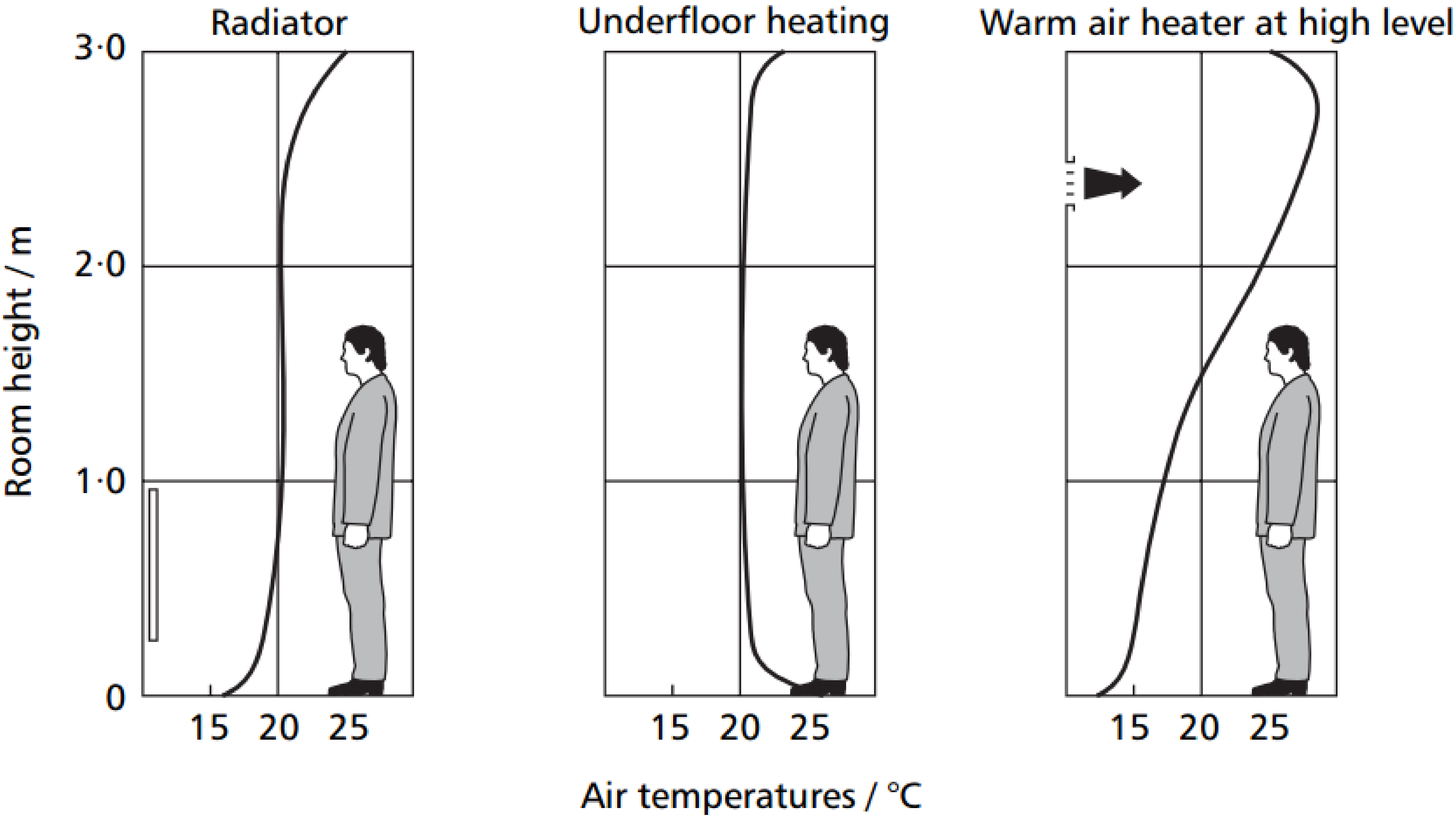
(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

Key steps for emitter and distribution system sizing



(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

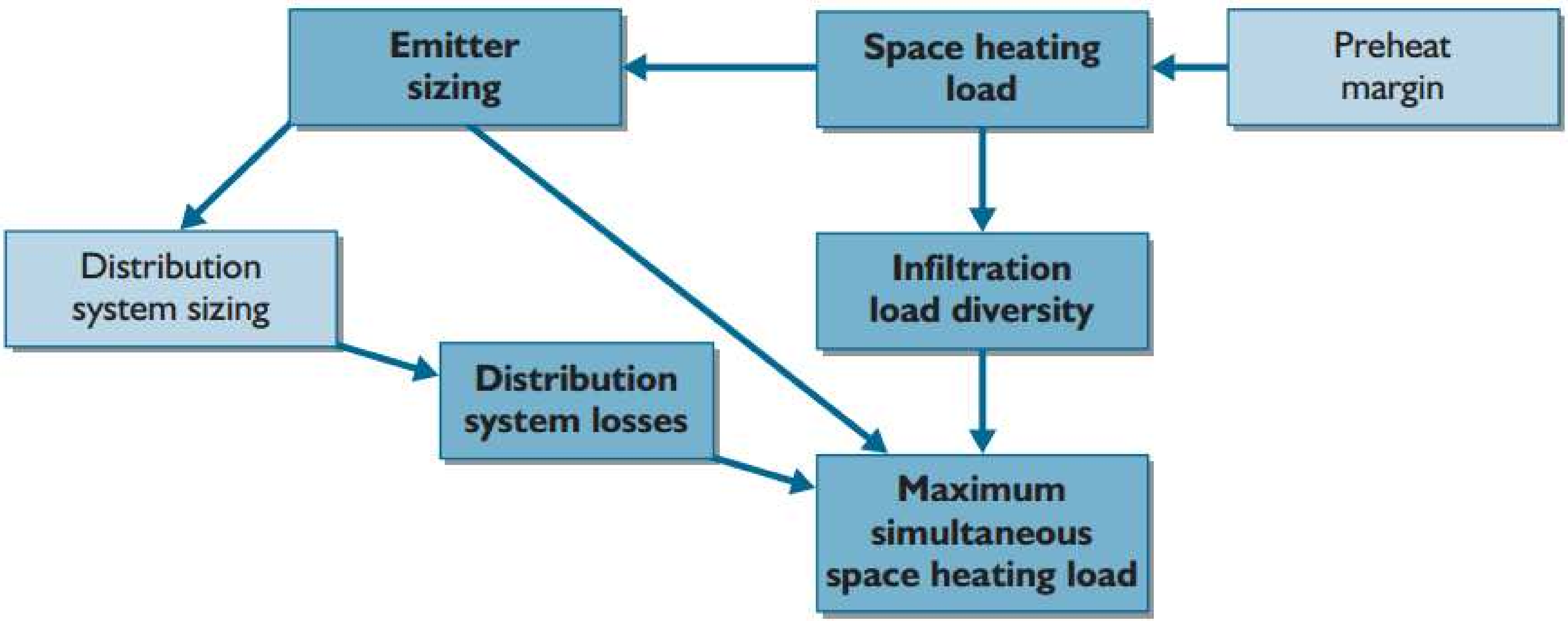
Vertical air temperature gradients for different heating types



Which one do you think is more comfortable?

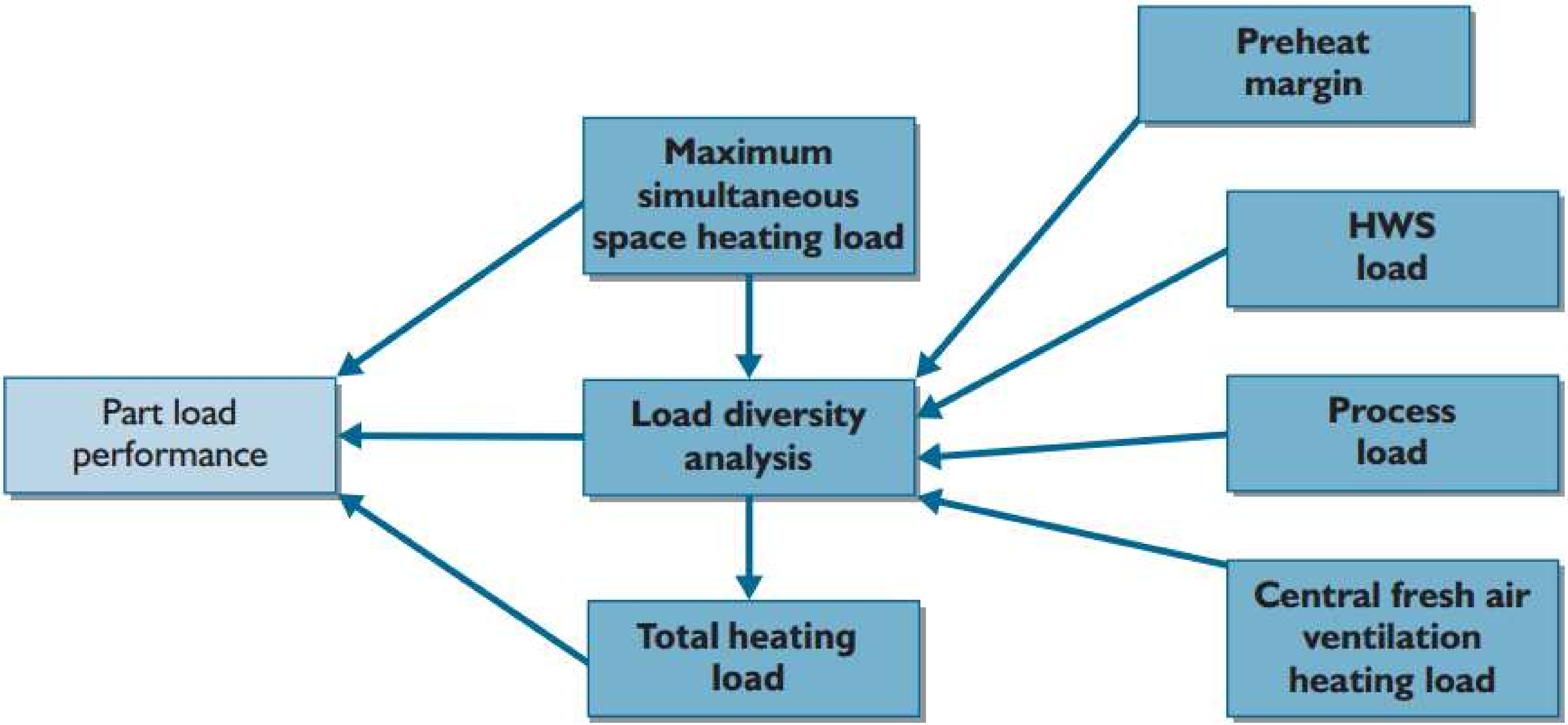
(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

Key steps to establish the maximum simultaneous space heating load



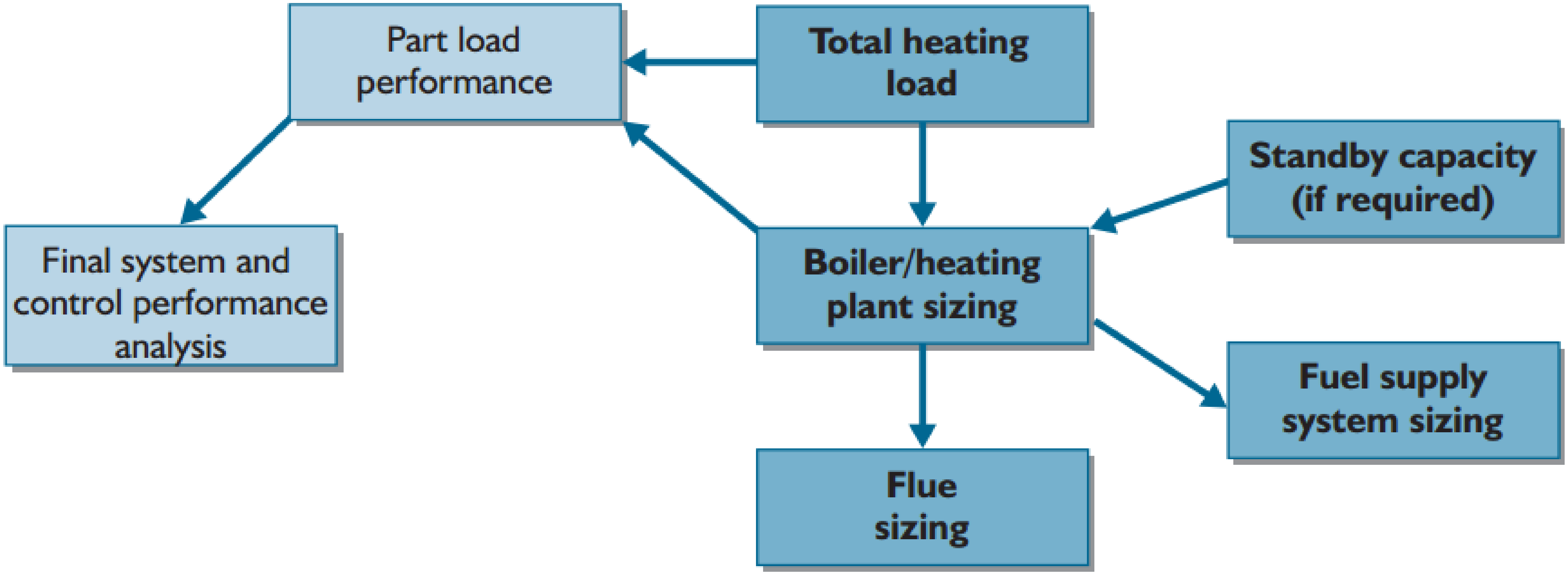
(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

Key steps to establish the total heating load



(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

Key steps for boiler/heating plant sizing and selection



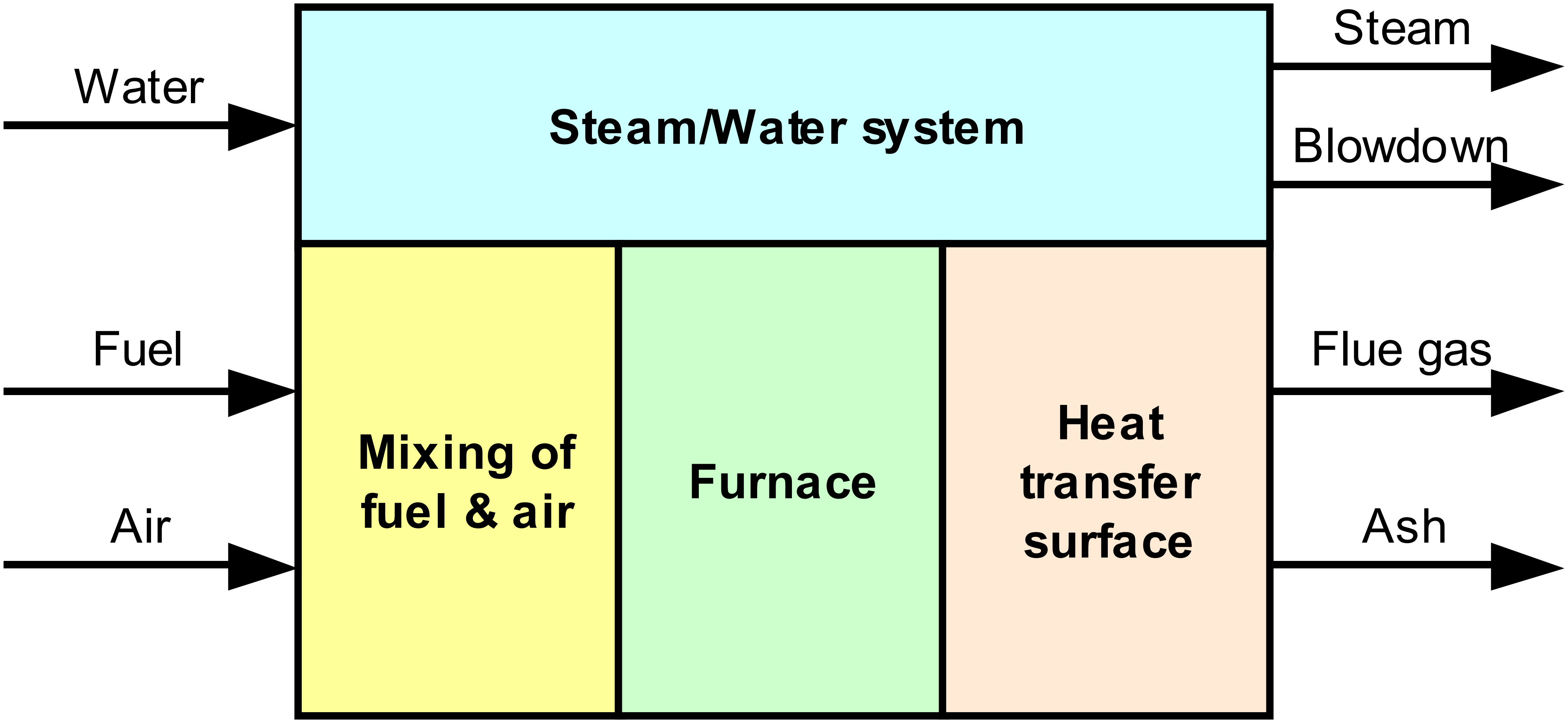
(Source: CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.)

Boilers

- Boilers – classified according to:
  - Type of working fluid or heat carrier used
    - Such as steam and hot water
  - Physical arrangement of the working fluid
    - Fire tube: flue gas products flow through boiler tubes
    - Water tube: water circulates within boiler tubes
  - Combustion gases/fuels
    - Natural gas, town gas, diesel, etc.
    - Gas & oil replace coal for fuel of boiler/furnace
      - Easier to handle & less pollution product

(See also: Types of Boilers http://www.arca53.dsl.pipex.com/index_files/boil1.htm)

Basic diagram of a boiler



Example of boiler efficiency:

Heat content of fuel	100%
Heat loss in flue gases	11.4%
Loss due to unburnt carbon monoxide	1.9%
Heat losses (from boiler casing)	4.2%
Overall thermal efficiency	82.5%

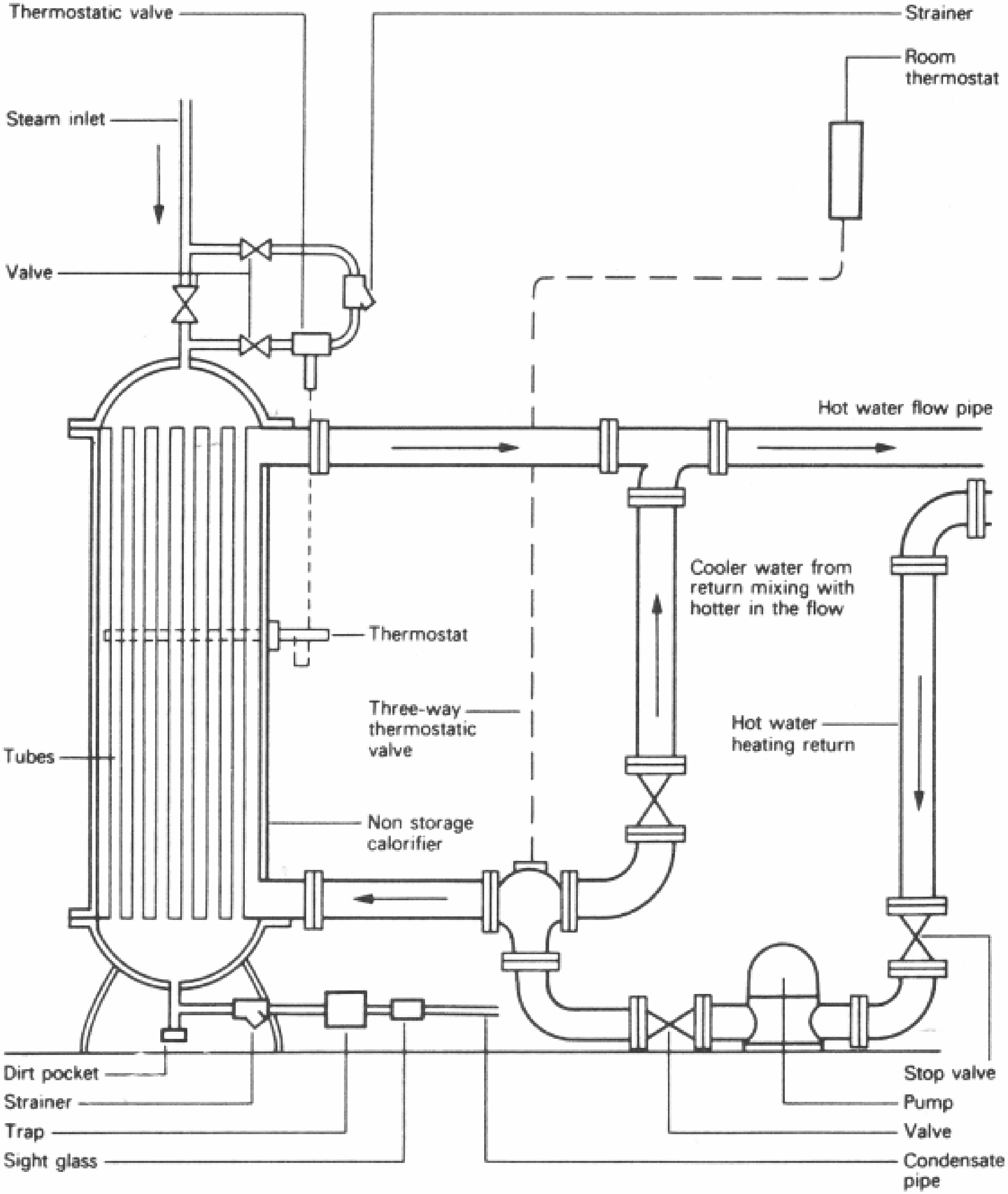
Boilers

- Steam boilers (high and low pressure)
  - High-pressure >100 kPa
    - Reduce size of boiler & steam piping (due to density)
    - But decrease boiler efficiency
    - Good for heat load at long distance
  - Low-pressure <=100 kPa
    - Simpler in both design & operation
    - No pressure-reducing valves are required
    - Water chemical treatment less costly & complex

(*See also: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house.aspx)

Boilers

- Hot water boilers (high and low temperature)
  - High-temperature hot water (HTHW) boiler
    - Water at temp. > 121 ^{o}C or pressure > 1,100 kPa
    - Carry greater heat; reduce pumping & piping costs
  - Low-temperature hot water (LTHW) boiler
    - Water at temp. < 96 ^{o}C or pressure <= 1,100 kPa
- Calorifiers
  - Provide storage & allow heat exchange
  - Non-storage calorifiers can also be used for providing hot water for space heating



Non-storage type calorifier

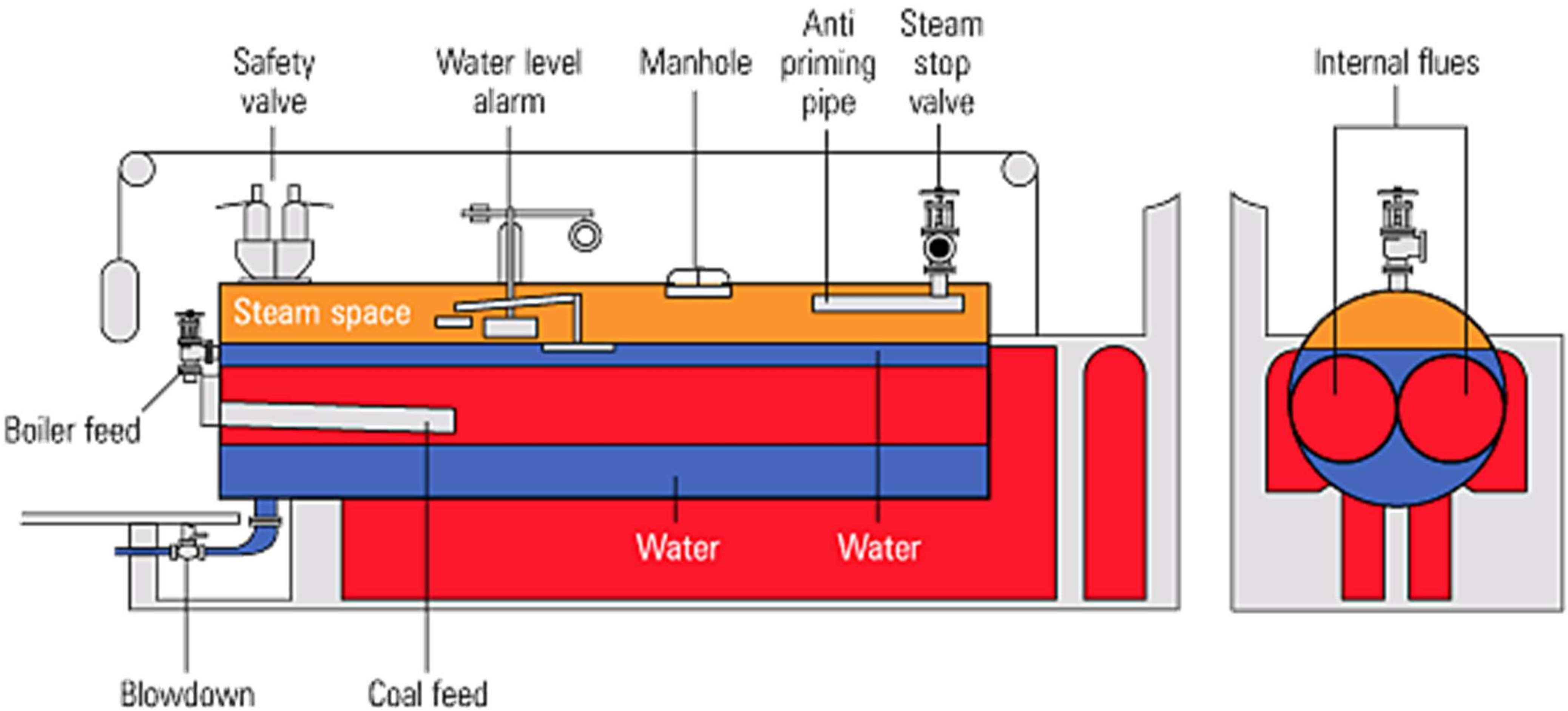
(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Boilers

- Shell boilers
  - The heat transfer surfaces are all contained within a steel shell
  - Also known as 'fire tube' or 'smoke tube' boilers
    - Products of combustion pass through the boiler tubes, which in turn transfer heat to the boiler water
  - Typical types of shell boilers:
    - Lancashire boiler
    - Economic boiler (two-pass or three-pass)
    - Packaged boiler

(See also: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/shell-boilers.aspx)

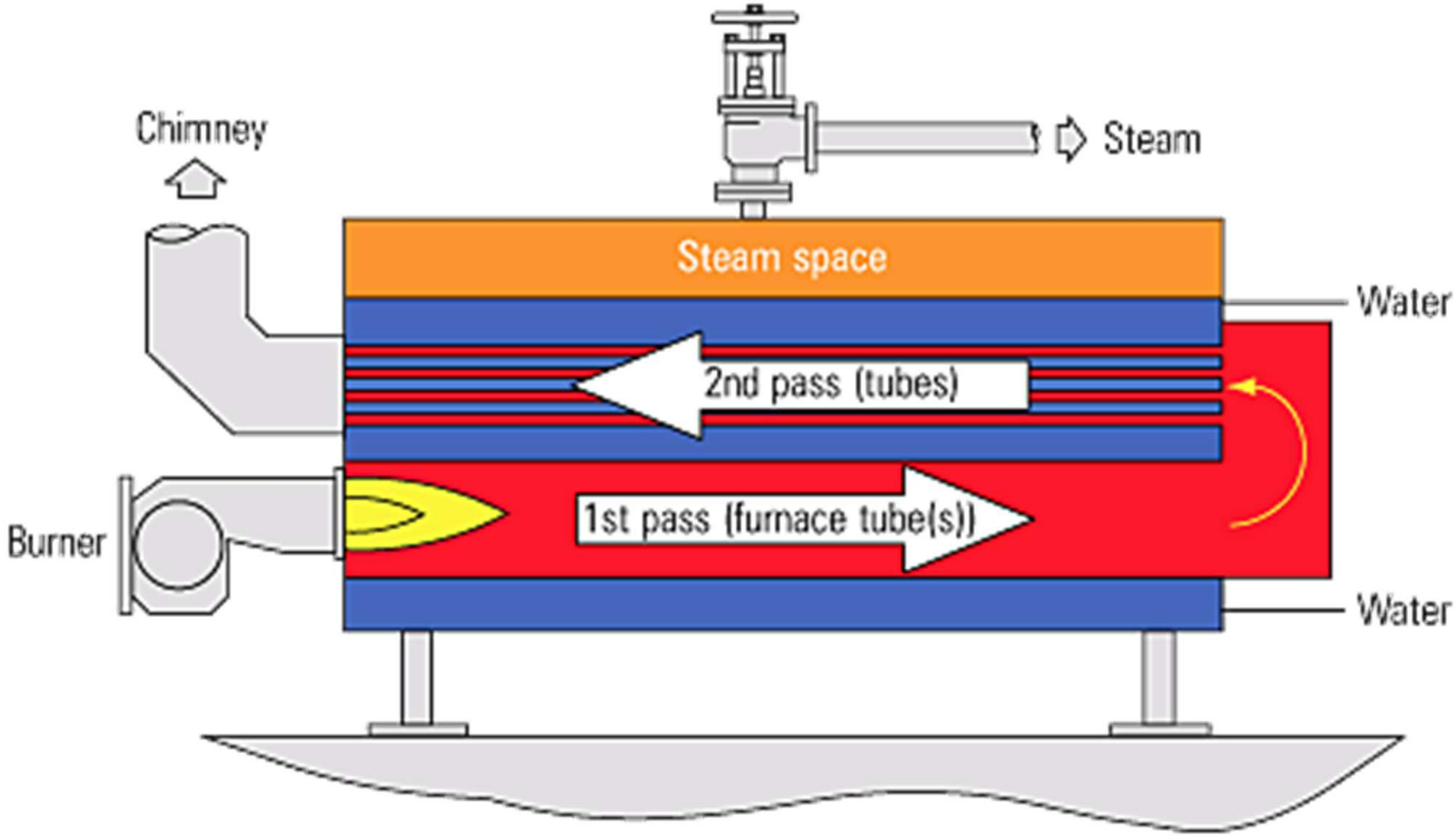
Lancashire boiler (first developed in 1844)



Capacity	Small	Large
Dimensions	5.5 m long x 2 m diameter	9 m long x 3 m diameter
Output	1 500 kg/h	6 500 kg/h
Pressure	Up to 12 bar g	up to 12 bar g

(Source: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/shell-boilers.aspx)

Economic boiler (two-pass, dry back)

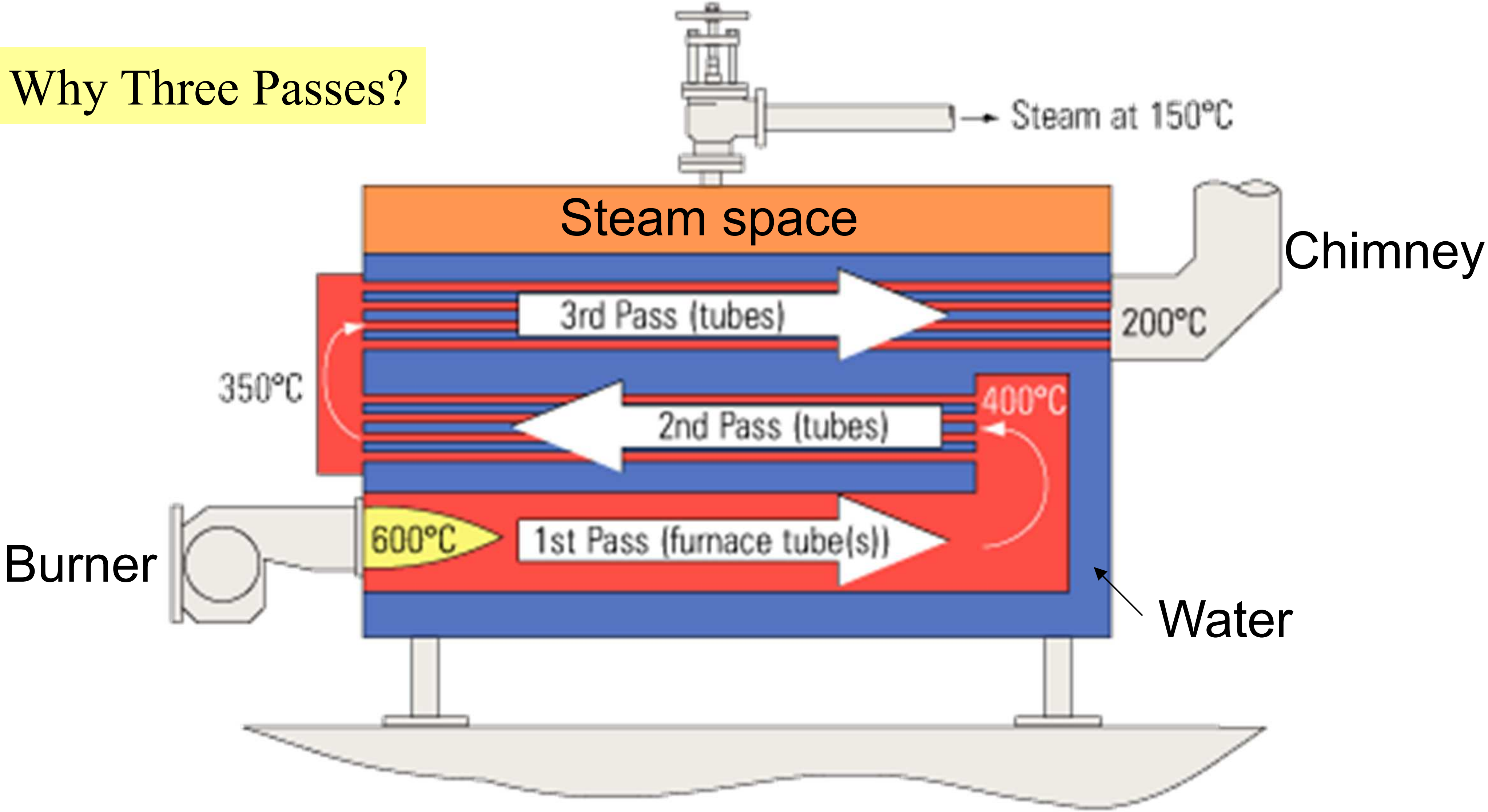


Capacity	Small	Large
Dimensions	3 m long x 1.7 m diameter	7 m long x 4 m diameter
Output	1 000 kg / h	15 000 kg / h
Pressure	Up to 17 bar g	up to 17 bar g

(Source: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/shell-boilers.aspx)

Economic boiler (three-pass, wet back)

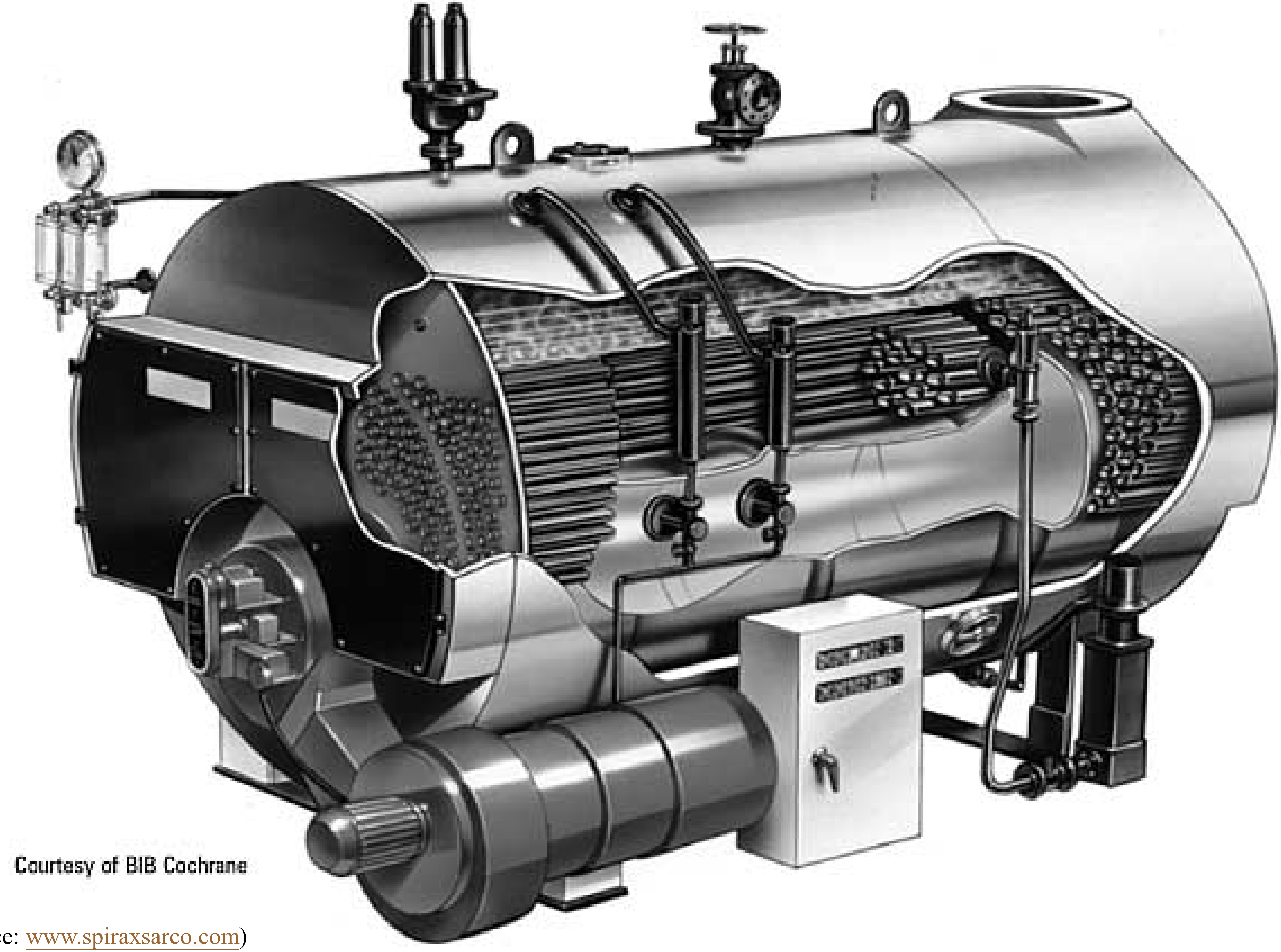
Why Three Passes?



	Area of tubes	Temperature	Proportion of total heat transfer
1st pass	11 m²	1 600°C	65%
2nd pass	43 m²	400°C	25%
3rd pass	46 m²	350°C	10%

(Source: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/shell-boilers.aspx)

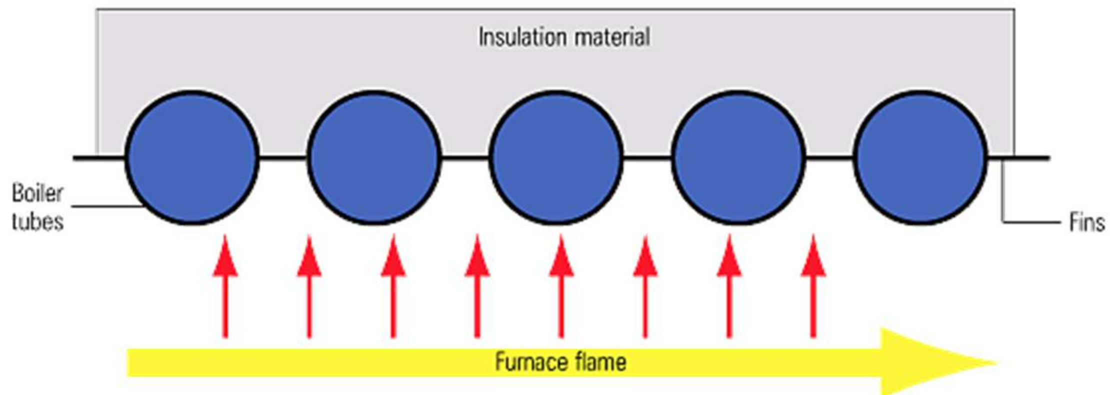
Modern packaged boiler (comes as a complete package with burner, level controls, feedpump and all necessary boiler fittings and mountings)



(Source: www.spiraxsarco.com)

Boilers

- Water-tube boilers
  - The water is circulated inside the tubes, with the heat source surrounding them
  - Used in power station applications that require high pressure and high steam output
  - They are also manufactured in sizes to compete with shell boilers



(See also: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/water-tube-boilers.aspx)

Boilers

- Three types of commonly used boiler ratings:
  - ‘From and at’ rating
    - Widely used as a datum by shell boiler manufacturers
    - Shows the amount of steam in kg/h which the boiler can create ‘from and at 100°C’, at atmospheric pressure
  - kW rating

    $$\text{Steam output (kg/h)} = \text{Boiler rating (kW)} \times \frac{3\,600 \text{ s/h}}{\text{Energy to be added (kJ/kg)}}$$

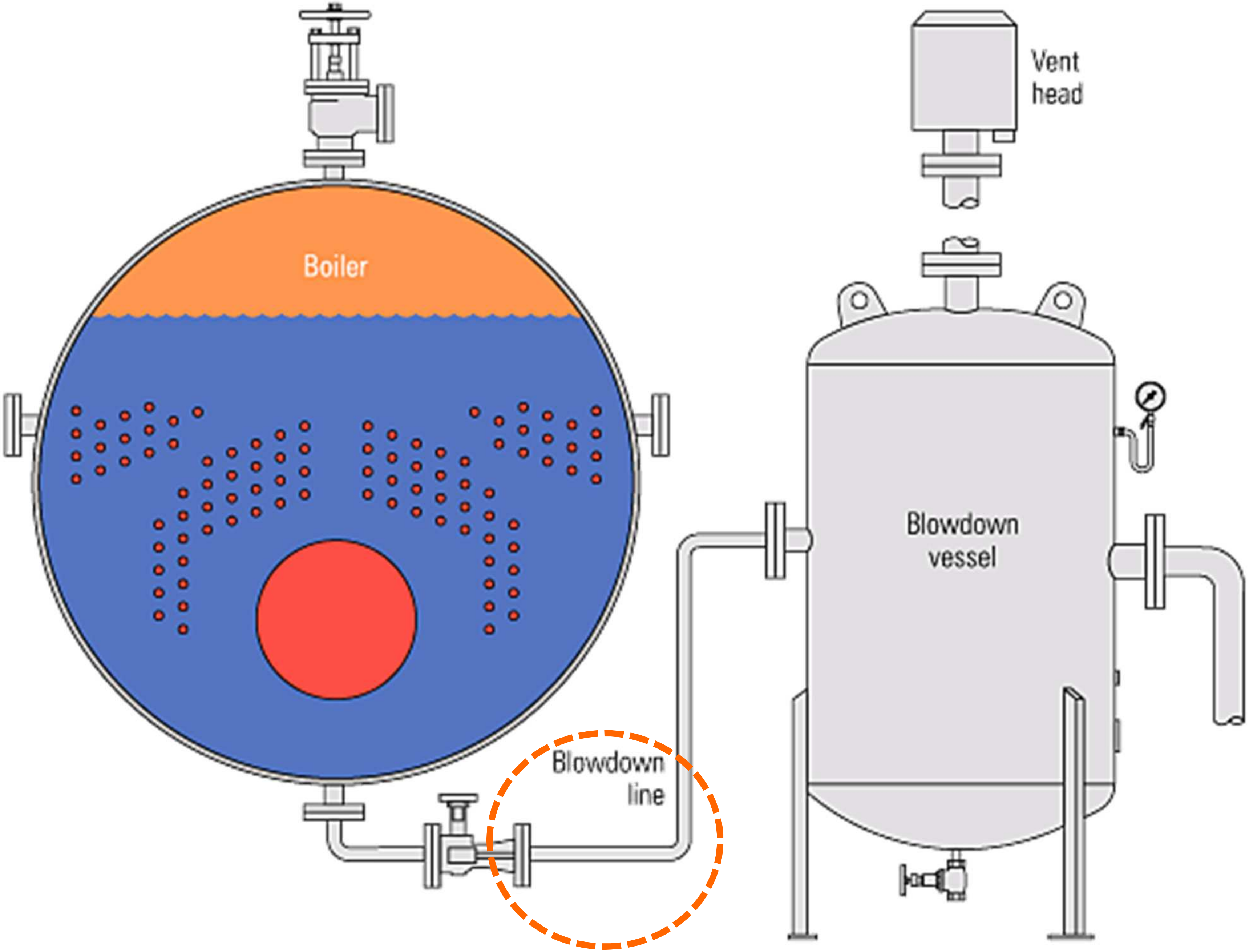
    - To establish the actual evaporation by mass, need to know the feedwater temperature and steam pressure
  - Boiler horsepower (BoHP)
    - Used only in the USA, Australia, and New Zealand

(See also: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/boiler-ratings.aspx)

An example of a boiler name-plate and a boiler safety valve

(Source: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/boiler-fittings-and-mountings.aspx)

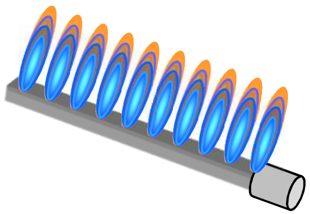
Boiler blowdown (to remove suspended solids)

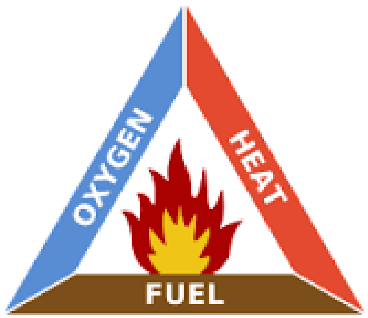


(Source: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/bottom-blowdown.aspx)

Warm air furnaces

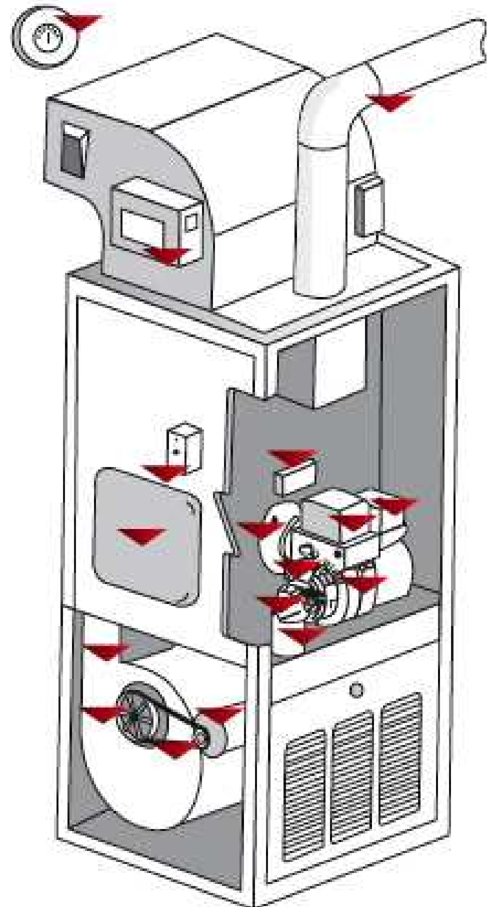
- Warm air furnace
  - A combustion and heating device
    - Gas or oil is directly fired to heat the air through a heat exchange, or air is directly heated by electric resistance elements in order to supply warm air to the space
  - Fuel types
    - Natural gas, manufactured gas, liquefied petroleum gas (LPG), propane, butane, oil, electric energy
  - Gas combustion (=> fire triangle)
    - Combustion requires fuel, oxygen and heat



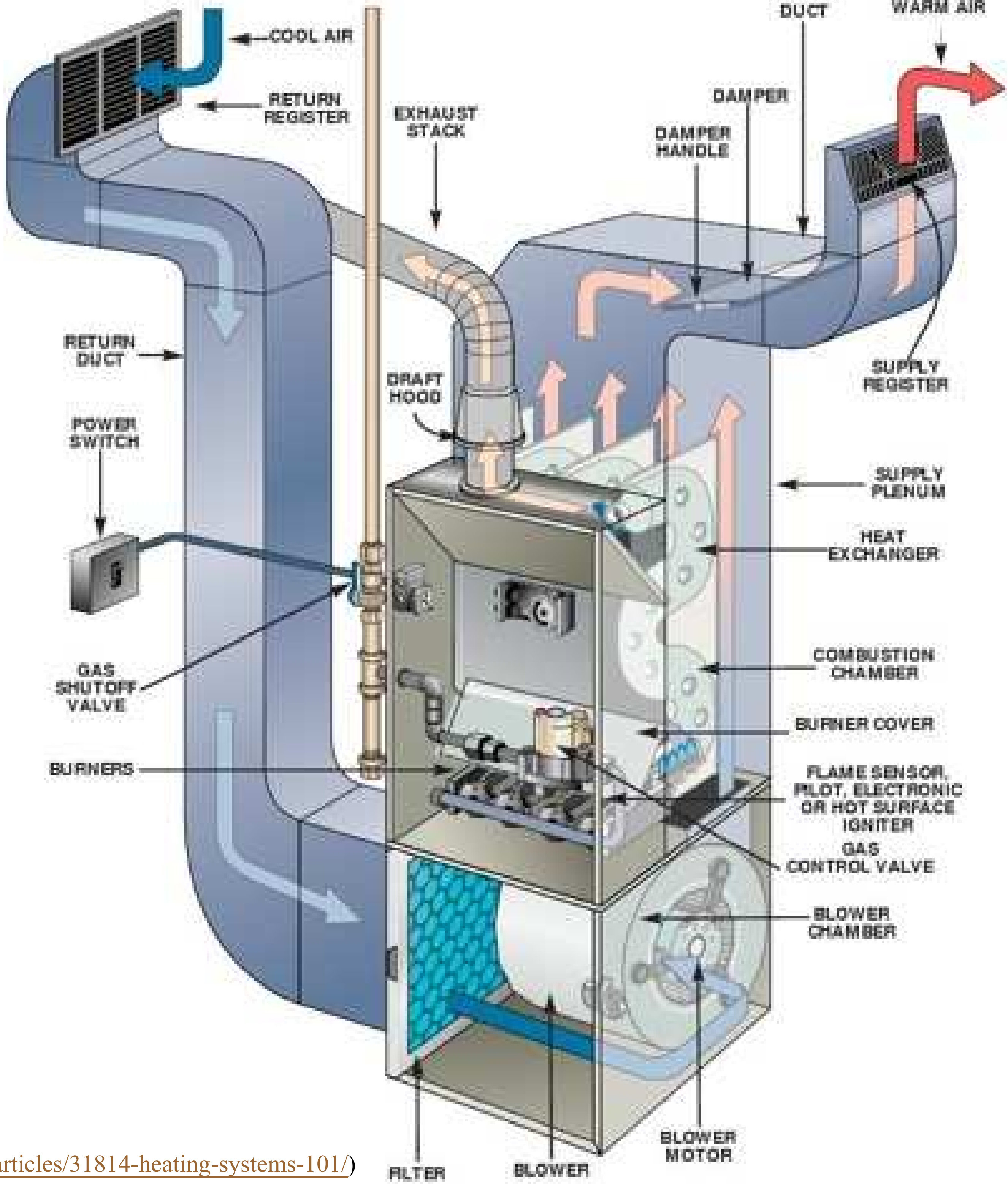


Warm air furnaces

- Heat producing system
  - Manifold, burners, ignition, controls, heat exchanger and venting system
  - Venting system removes flue gases
- Heated air distribution system
  - Blower/fan and controls
  - Ductwork and air distribution system
  - Filter (to remove dust)



Forced warm air furnace

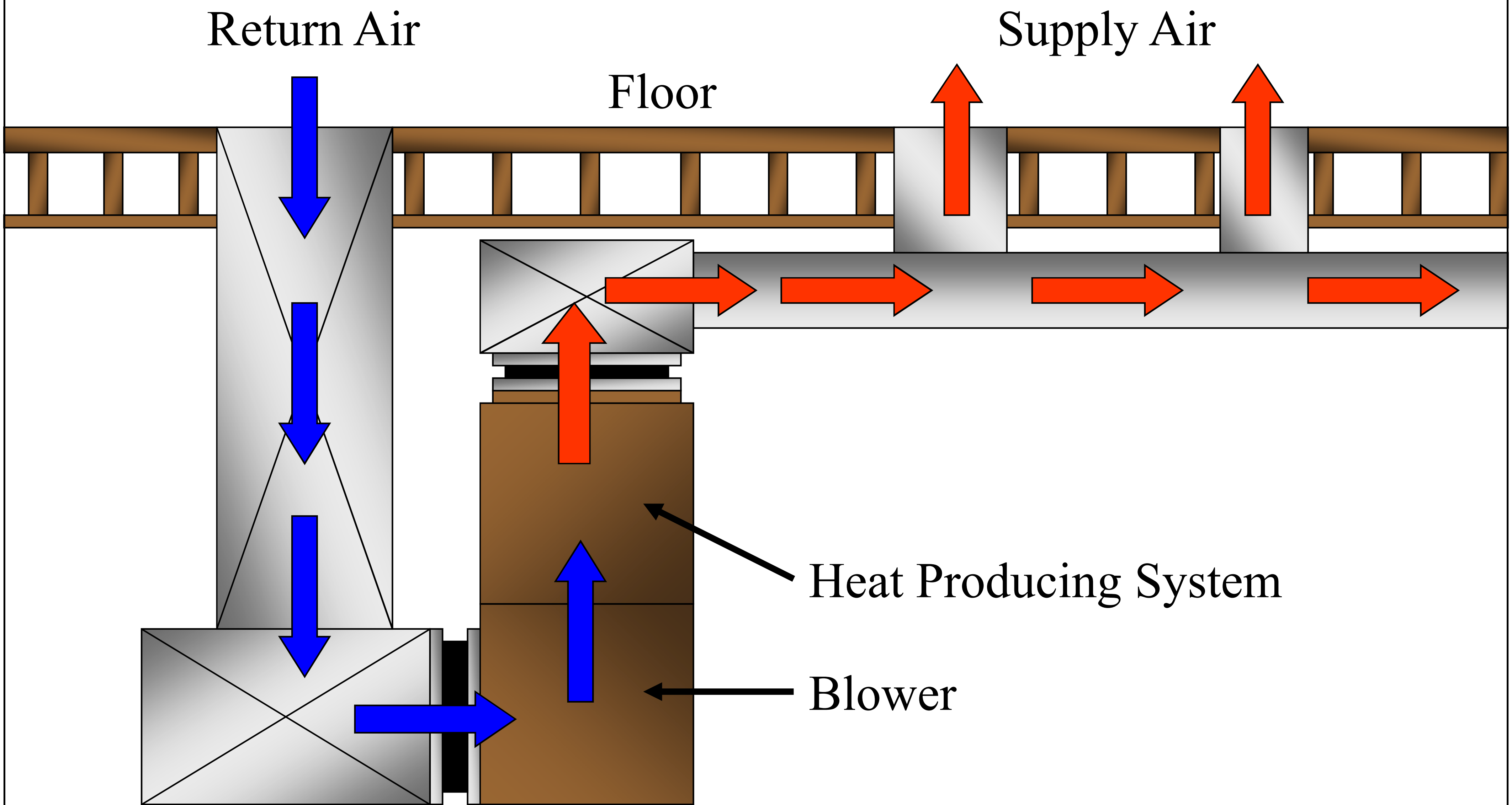


(Source: https://www.bobvila.com/articles/31814-heating-systems-101/)

Warm air furnaces

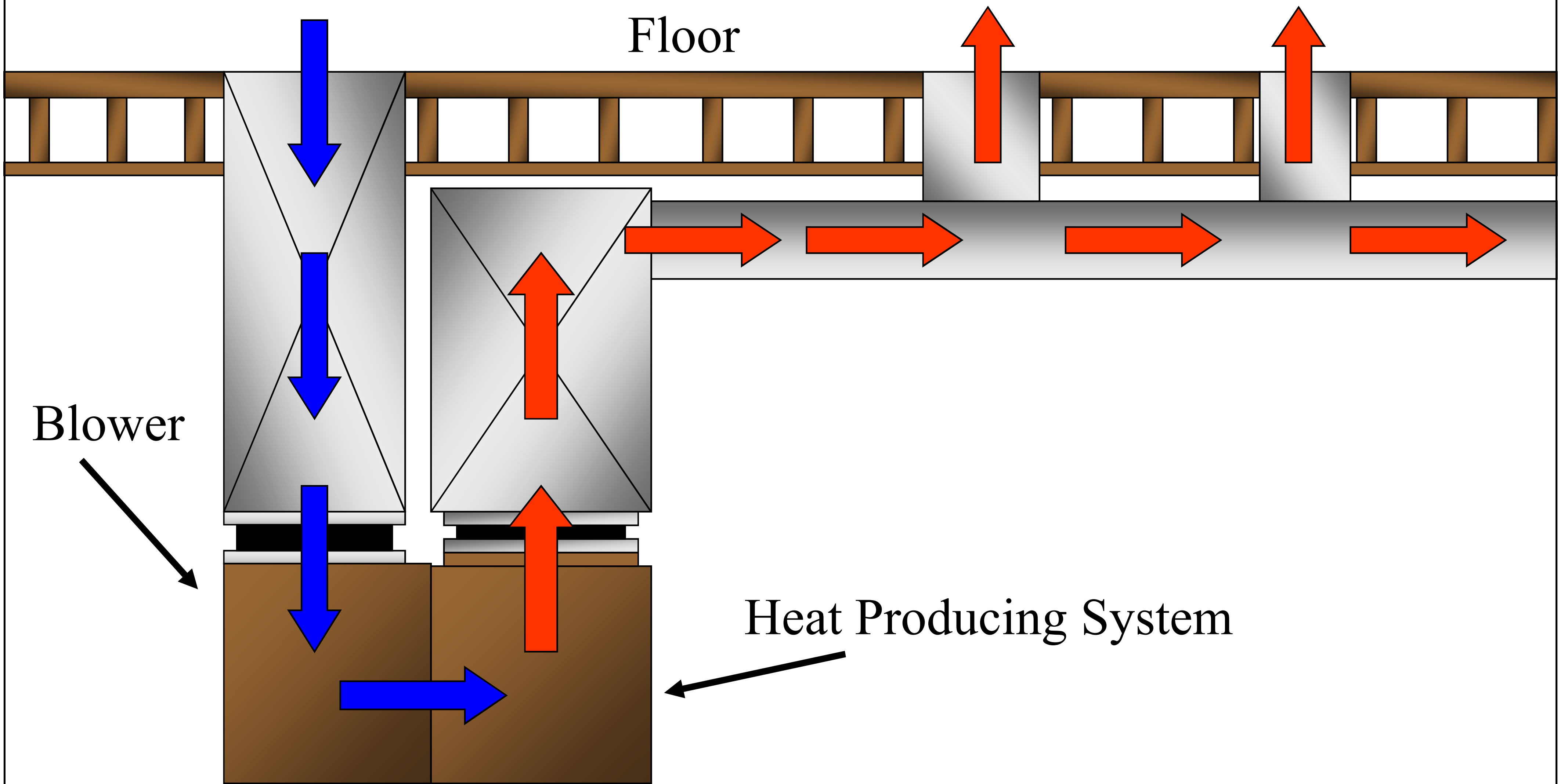
- Types of furnaces
  - Upflow – Stands vertically, top air discharge
  - Low Boy – Used where there is little headroom
    - Both supply and return are at the top
    - Blower located behind the furnace
  - Downflow – Stands vertically, bottom air discharge
  - Horizontal – Left or right discharge
  - Multipoise or Multipositional – Multi-positional

Upflow furnace



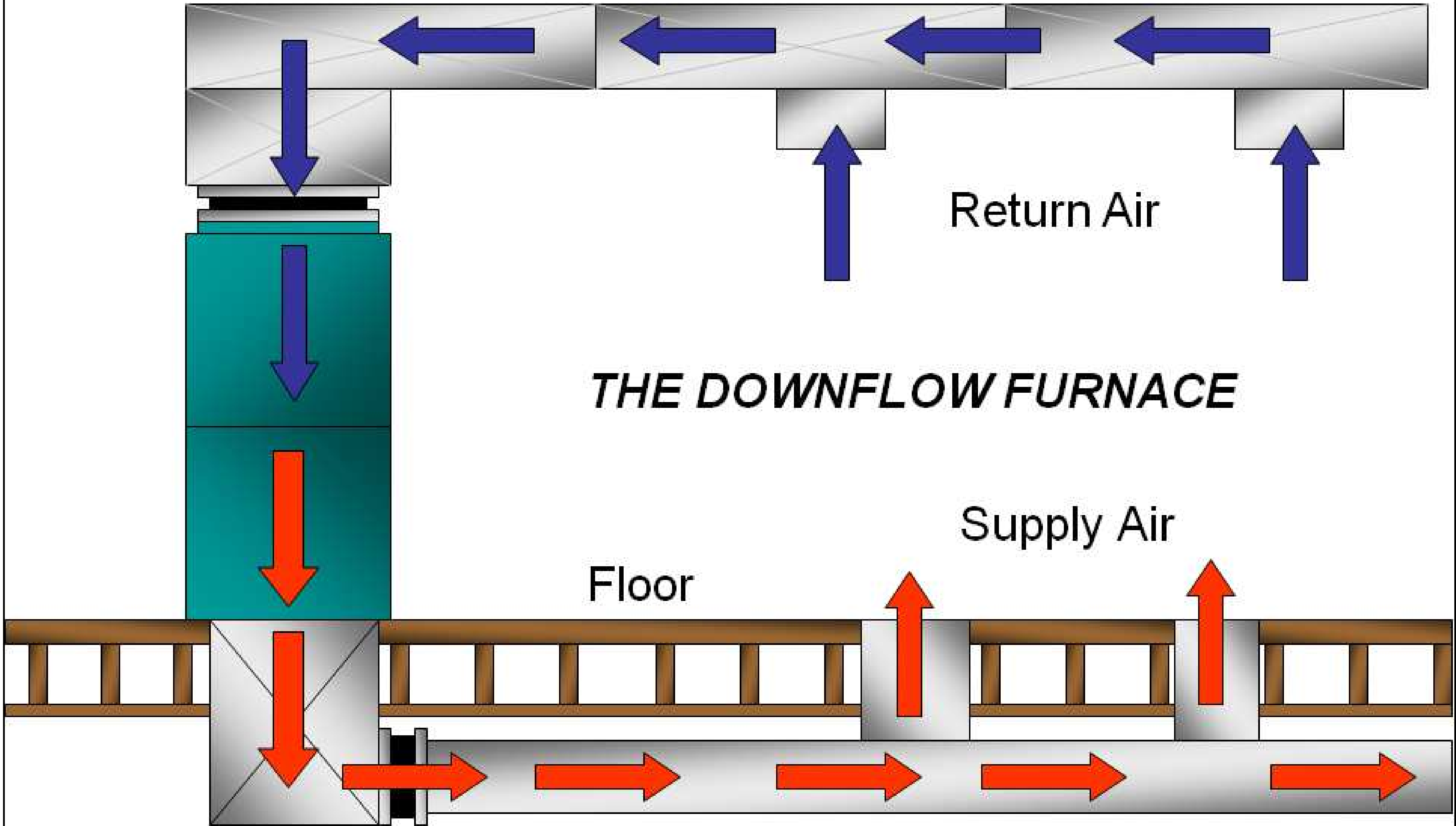
(Source: Delmer Cengage Learning)

Low boy furnace



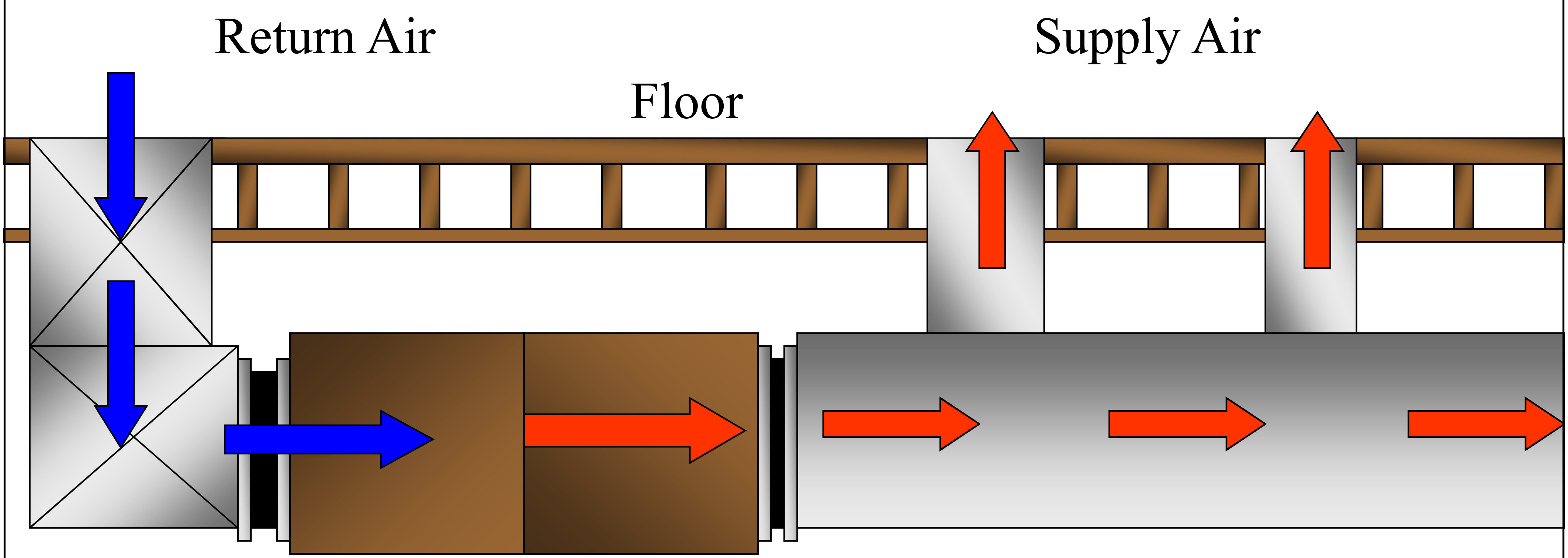
(Source: Delmer Cengage Learning)

Downflow furnace



(Source: Delmer Cengage Learning)

Horizontal furnace installed in a basement

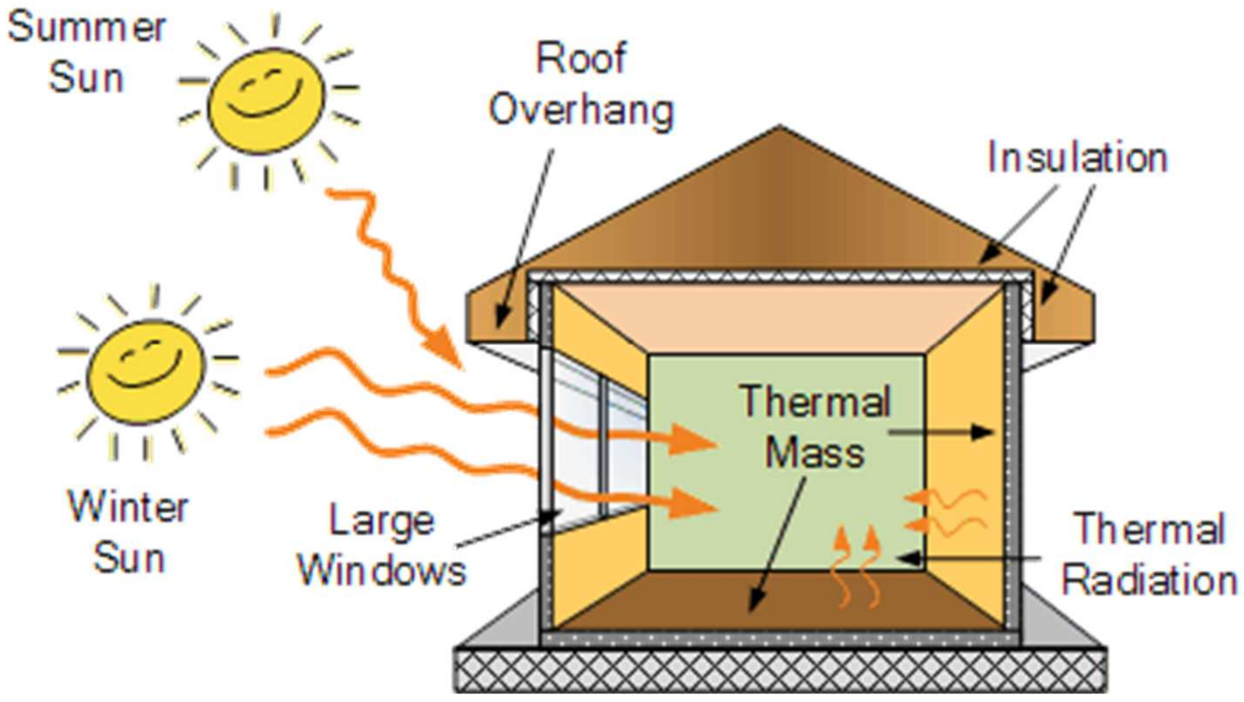


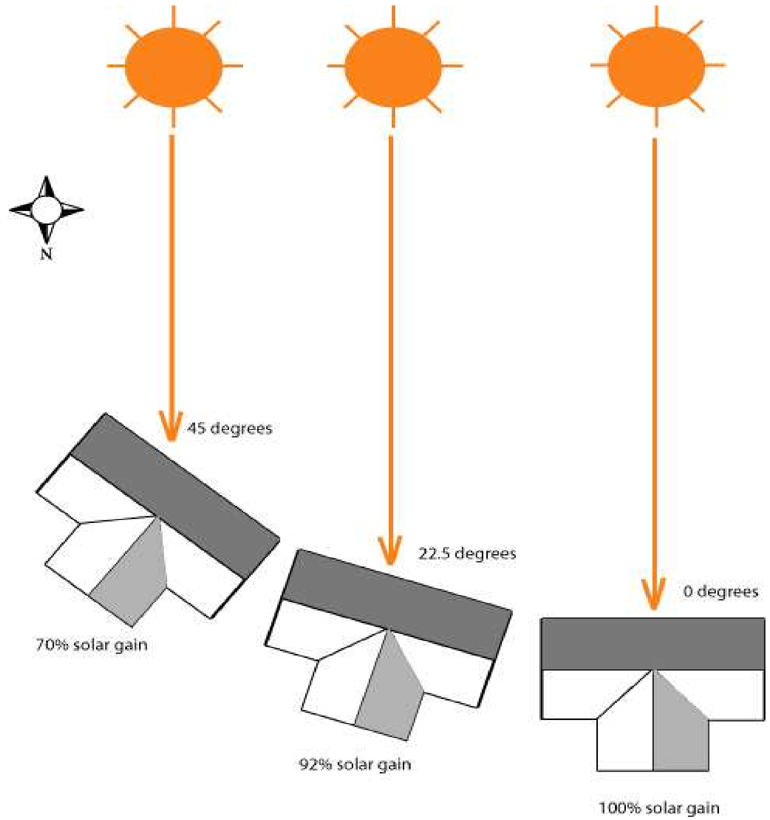
(Source: Delmer Cengage Learning)

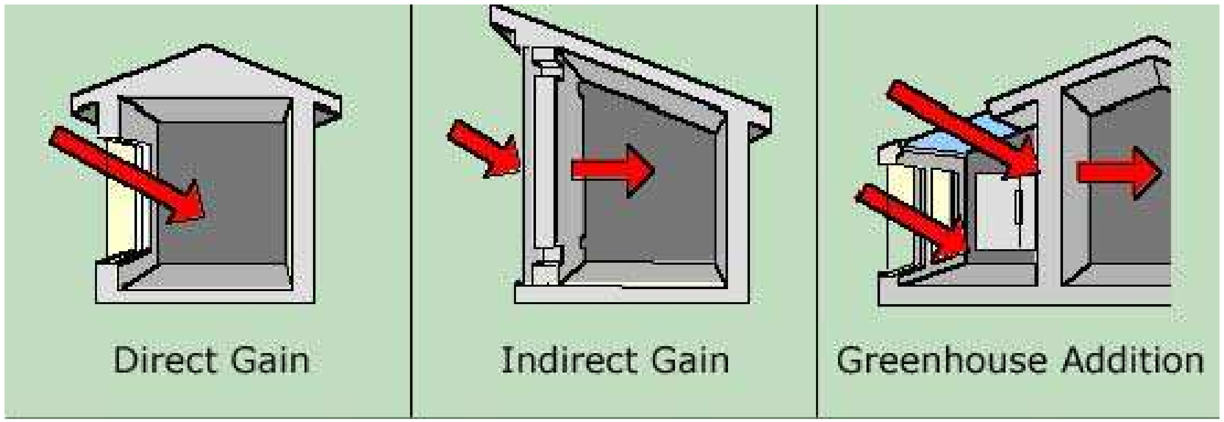
Solar heating

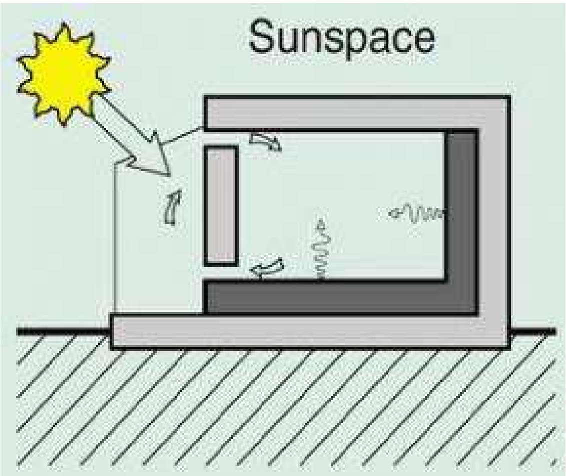
- Two types of systems to capture solar energy and convert it to thermal energy (heat)
  - 1. Passive solar heating
    - Use no fans or mechanical devices to transfer heat from one area to another. Some materials in the system absorb radiant energy during the day, convert it to thermal energy, and radiate the thermal energy after dark
  - 2. Active solar heating
    - Include solar collectors, devices that absorb radiant energy from the sun. The collectors are usually installed on the roof or south side of a building

Passive solar heating design









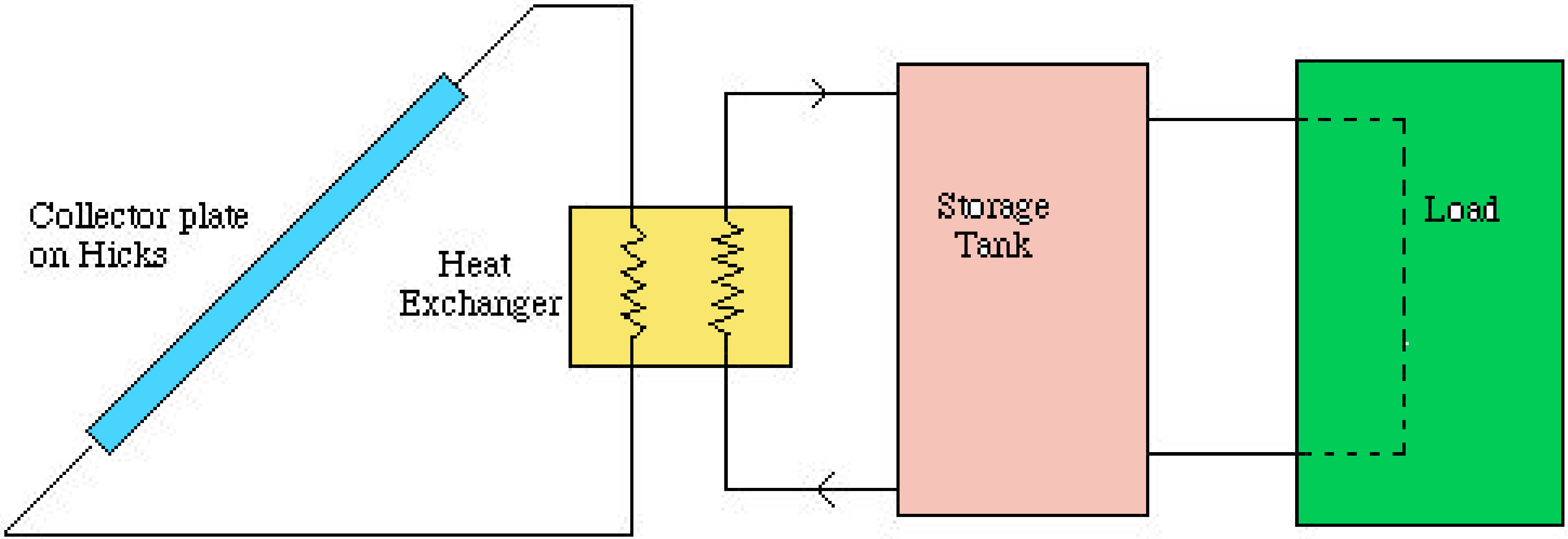
(See also: Passive solar heating http://www.yourhome.gov.au/passive-design/passive-solar-heating)

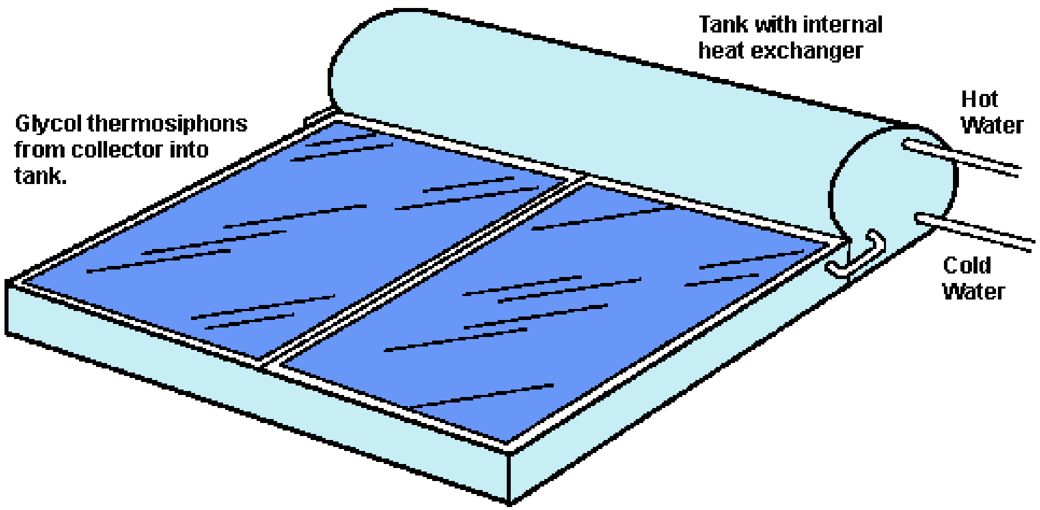
Solar heating

- Active solar, also called 'solar thermal'
- Common applications
  - Solar hot water (domestic or non-domestic)
  - Swimming pool heating
  - Space heating or air preheating
- Harness the solar heat to produce hot water
- Domestic solar water heating system usually comprises of solar collectors and a water tank

(See also: http://re.emsd.gov.hk/english/solar/solar_wh/solar_wh_to.html)

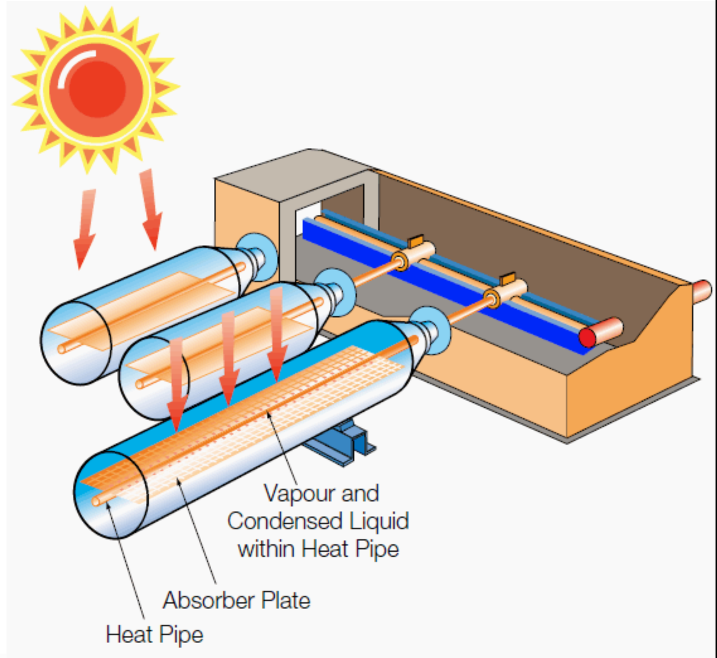
Solar hot water systems



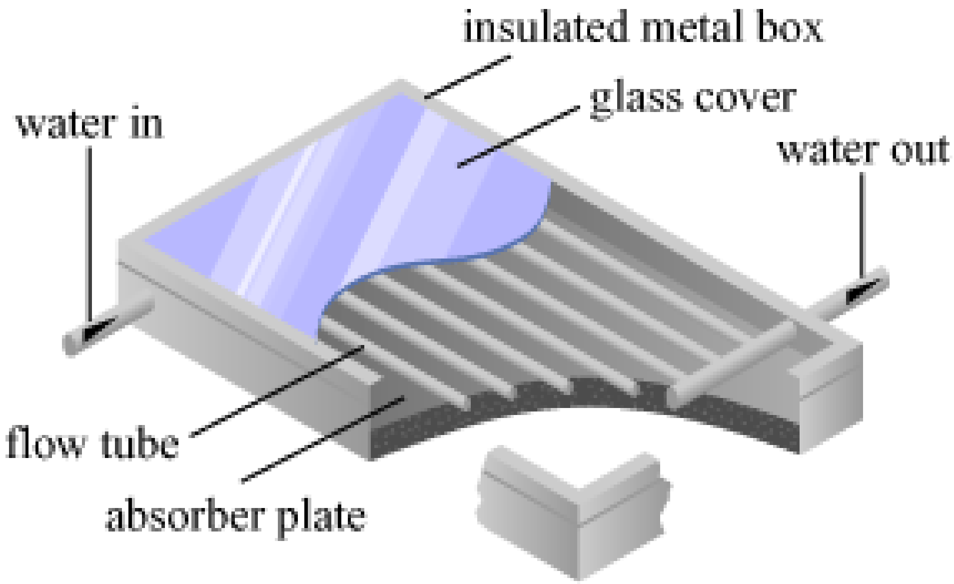


Simple domestic system
(with integral storage tank)

Examples of solar thermal systems



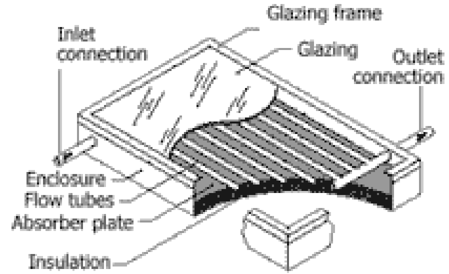
Flat-plate solar collector



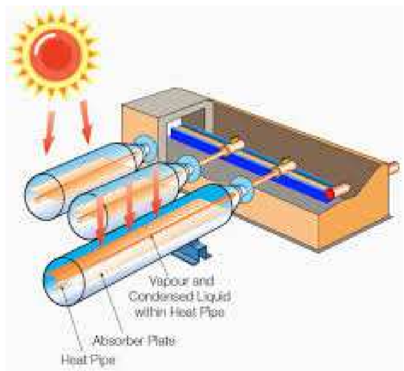
Evacuated-tube solar collector

Solar heating

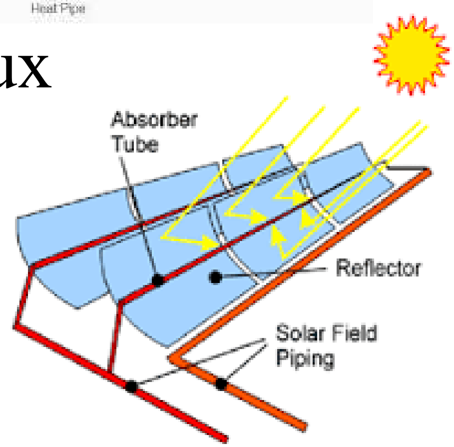
- Types of solar collectors
  - <u>Flat-plate solar collector</u>



    - Main components: glazing panel, absorber, flow tubes, insulation
  - <u>Evacuated-tube solar collector</u>

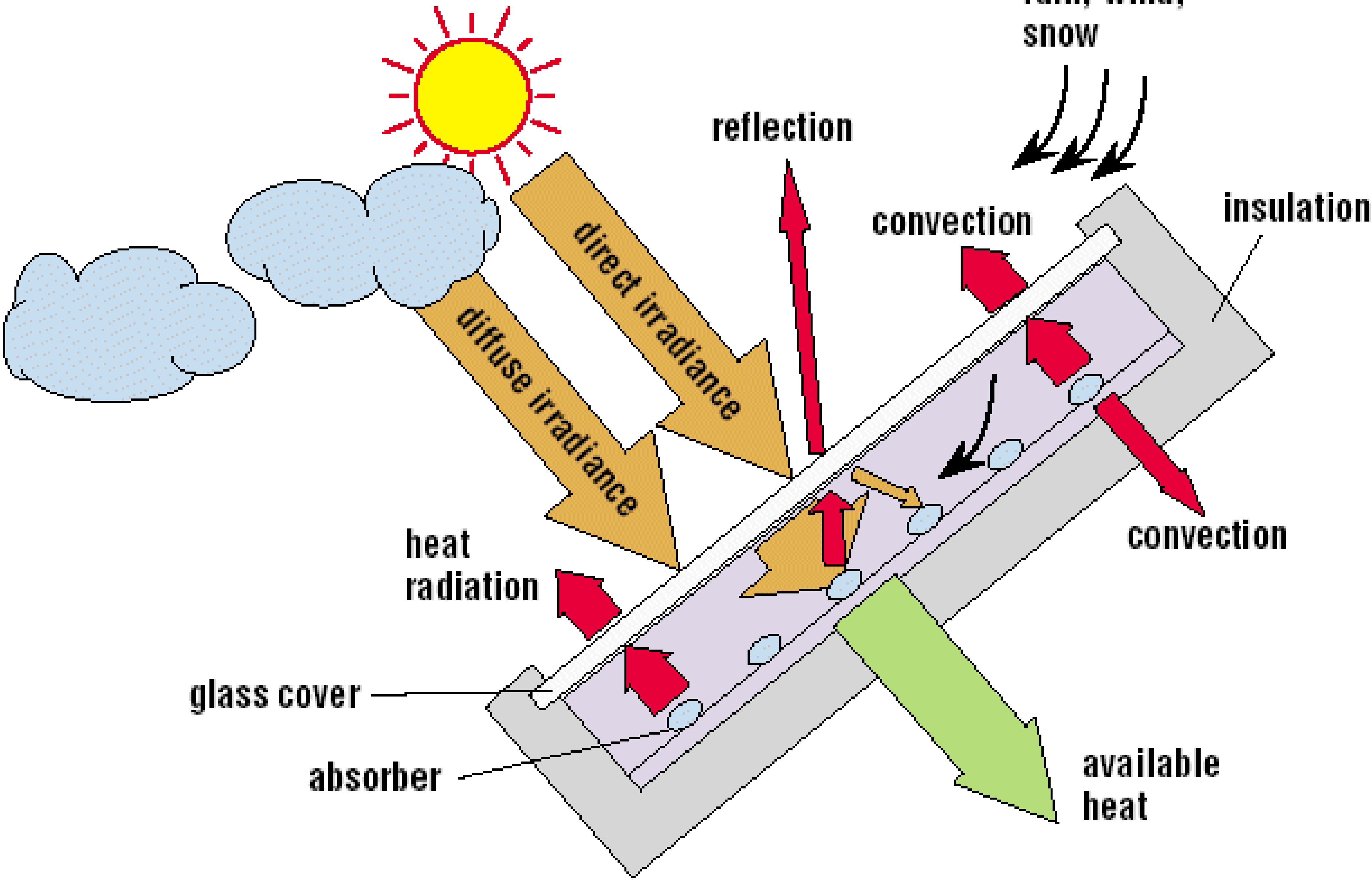


    - Water-in-glass type or with heat pipe
  - <u>Concentrating solar collector</u>
    - Smaller receiver area to increase the solar flux
    - Such as parabolic trough, dish concentrator, multifaceted mirror type



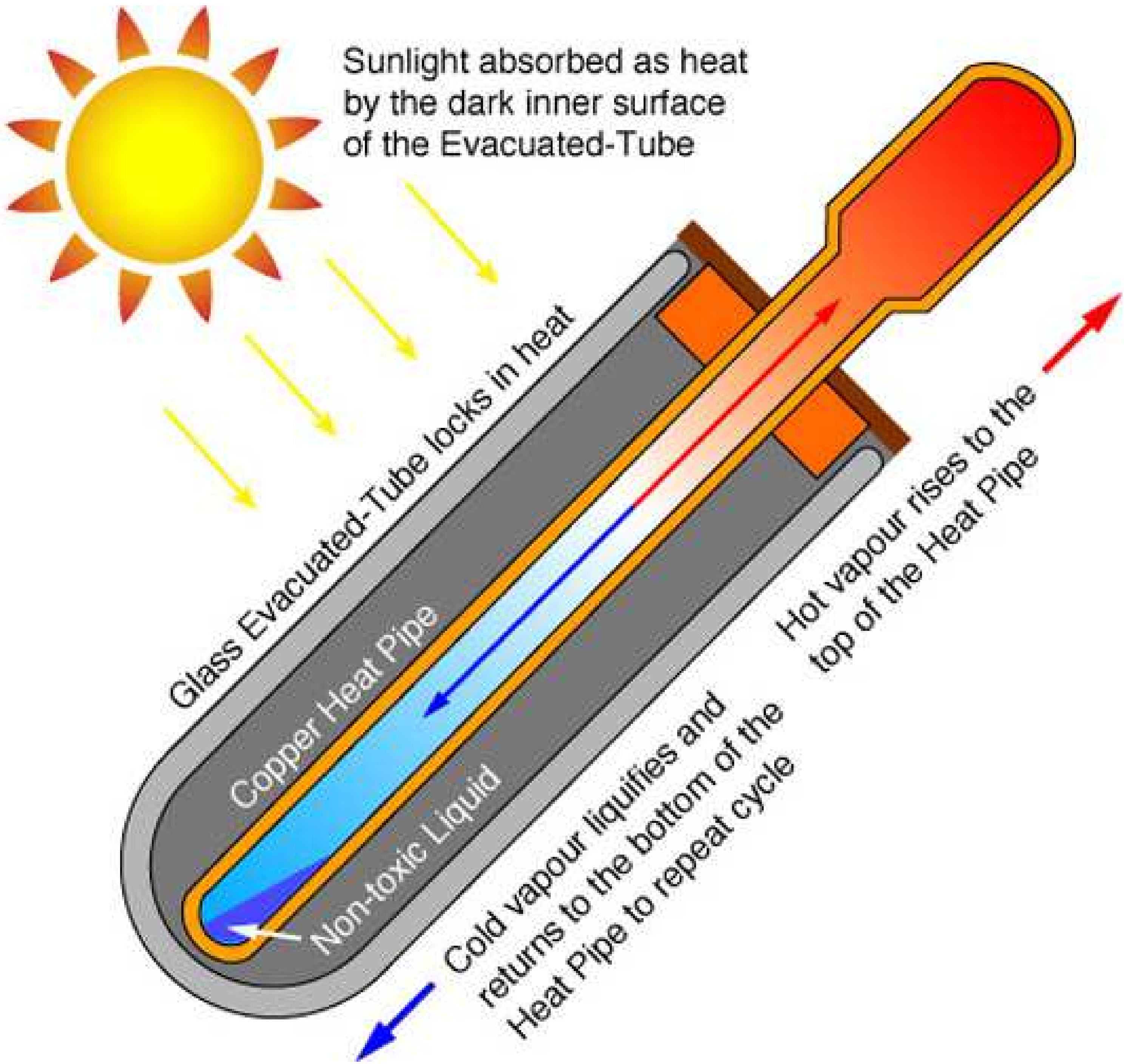
(Further info: http://re.emsd.gov.hk/english/solar/solar_wh/solar_wh_to.html)

Heat transfer processes at a flat-plate solar collector



(Source: http://www.volker-quaschning.de/articles/fundamentals4/index.php)

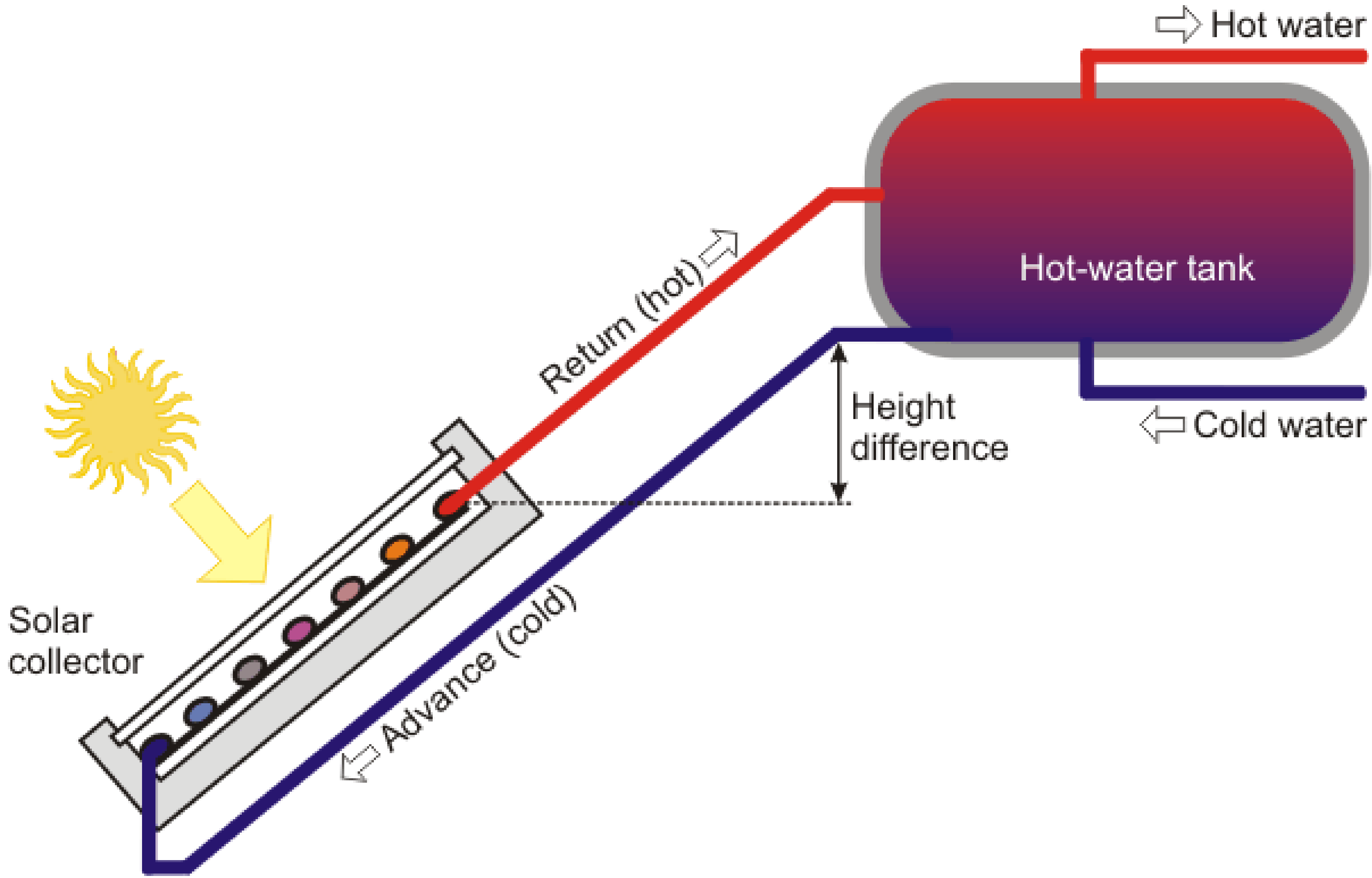
Principle of an evacuated tube collector with heat pipe



(Source: http://dogstarsolar.net/about/solar-evacuated-tubes/)

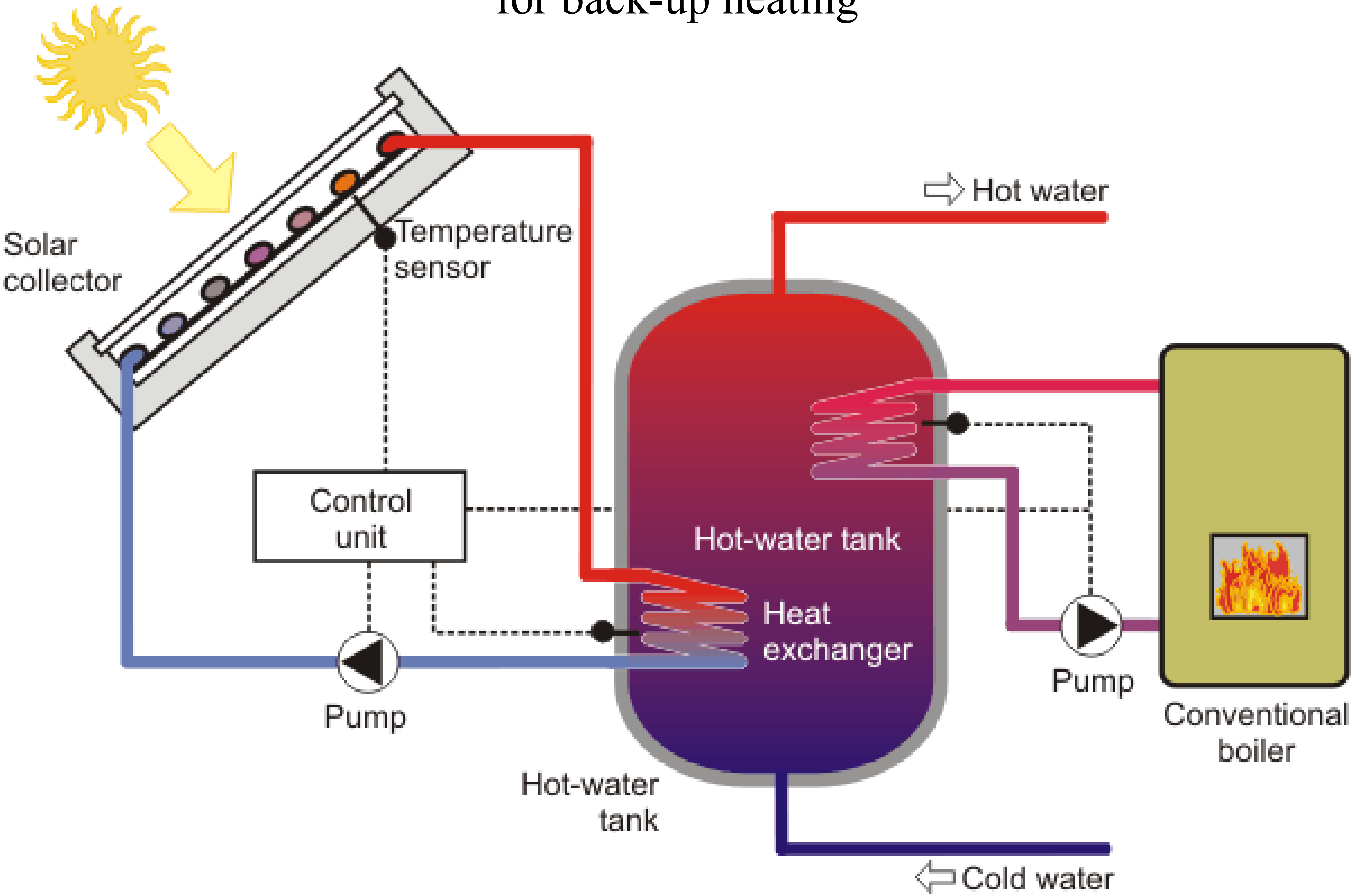
Evacuated-tube solar hot water system in a hotel in Lhsa, Tibet
(photo taken by Dr Sam C M Hui)

A thermosyphon system



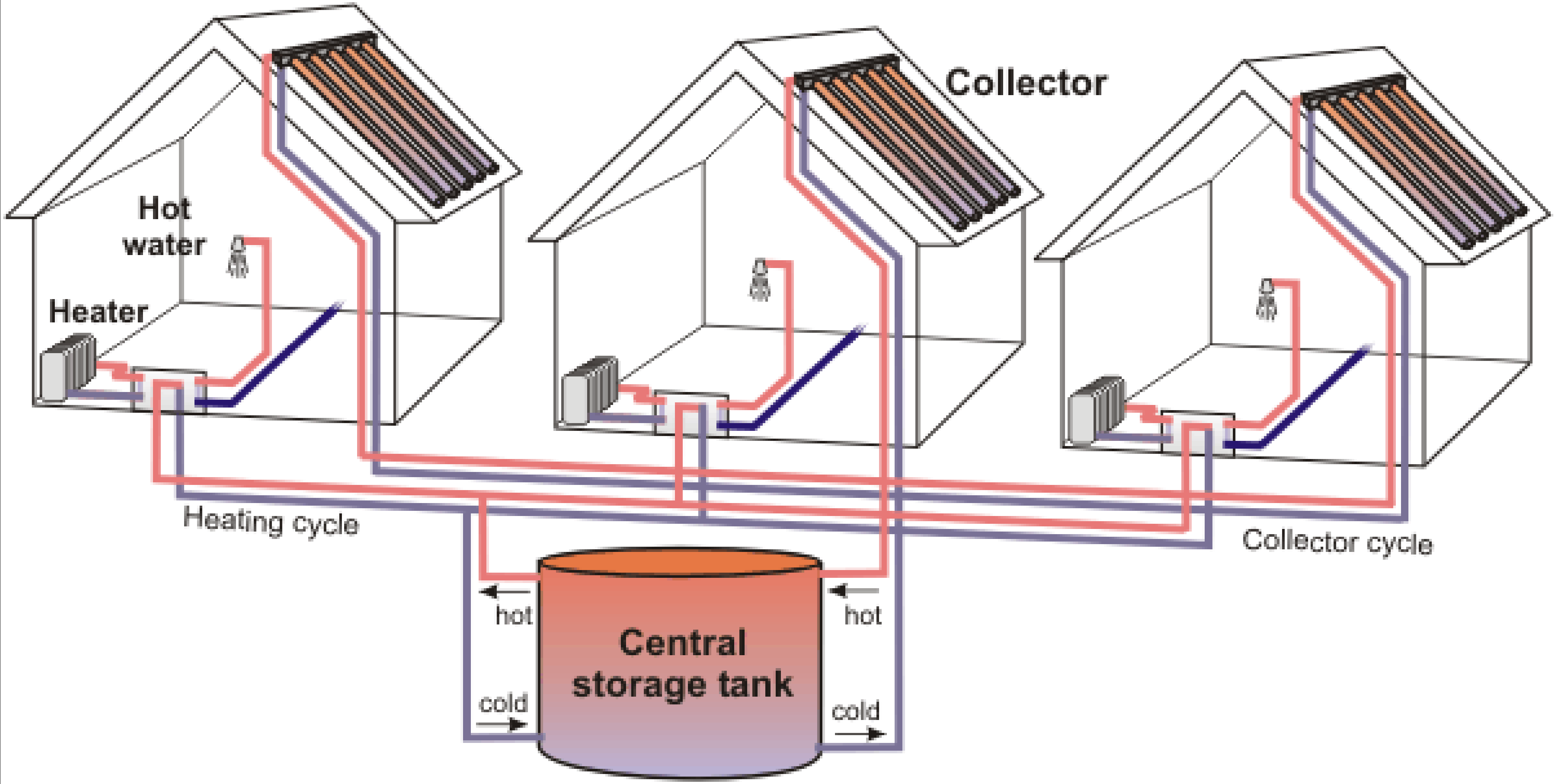
(Source: http://www.volker-quaschning.de/articles/fundamentals4/index.php)

A double-cycle system with forced circulation with a conventional boiler for back-up heating



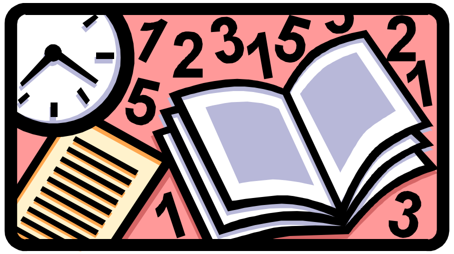
(Source: http://www.volker-quaschning.de/articles/fundamentals4/index.php)

A solar district heating system



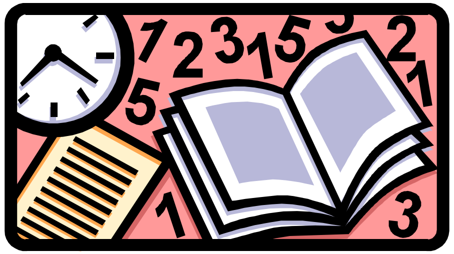
(Source: http://www.volker-quaschning.de/articles/fundamentals4/index.php)

Further Reading



- Hall, F. and and Greeno, R., 2013. *Building Services Handbook*, 7th ed., Butterworth-Heinemann, Oxford, U.K.
  - - Chapter 4 Heating Systems
- Heating http://www.arca53.dsl.pipex.com/index_files/heat.htm
  - Factors that Influence the Choice of Heating System http://www.arca53.dsl.pipex.com/index_files/heat5.htm
  - Heating Emitters http://www.arca53.dsl.pipex.com/index_files/emitters1.htm
  - Types of Boilers http://www.arca53.dsl.pipex.com/index_files/boil1.htm
  - Design of Heating Systems http://www.arca53.dsl.pipex.com/index_files/htgdes.htm

References



- CIBSE, 2006. *How to Design A Heating System*, CIBSE Knowledge Series: KS8, Chartered Institution of Building Services Engineers, London.
- CIBSE, 2016. *CIBSE Guide B1 Heating*, Chartered Institution of Building Services Engineers, London.
- Oughton, D. and wilson, A., 2015. *Faber and Kell's Heating and Air-conditioning of Buildings*, 11th edition, Routledge, Abingdon, Oxon and New York.
  - Part C: Heating of Buildings