

Heating systems

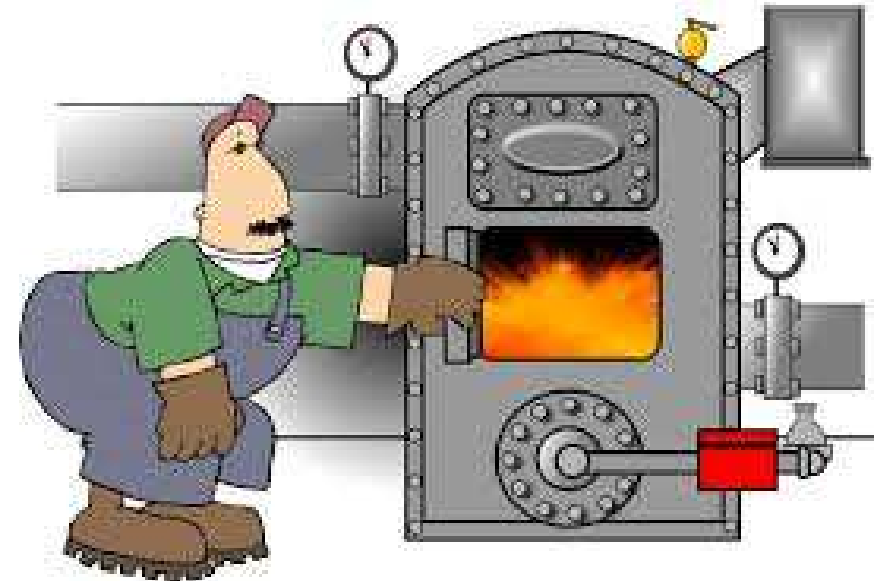


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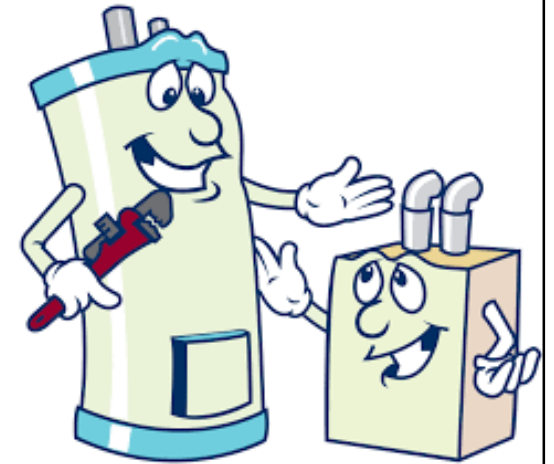
- System types and components
- Design of heating systems
- Boilers
- Warm air furnaces
- Solar heating



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

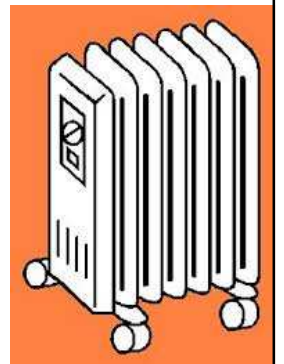
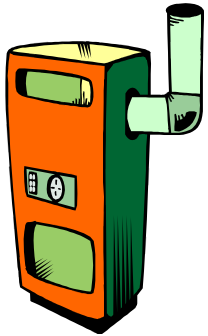
| | | |
|----------------------------|--|--|
| Heat source | Natural gas Liquefied petroleum gas Oil (petroleum) Coal Electricity | Solar thermal Biomass, biofuels Combined heat and power (CHP) Heat pump (air, water or ground-source) Waste heat |
| Distribution medium | Water (low, medium or high temperature) 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 |

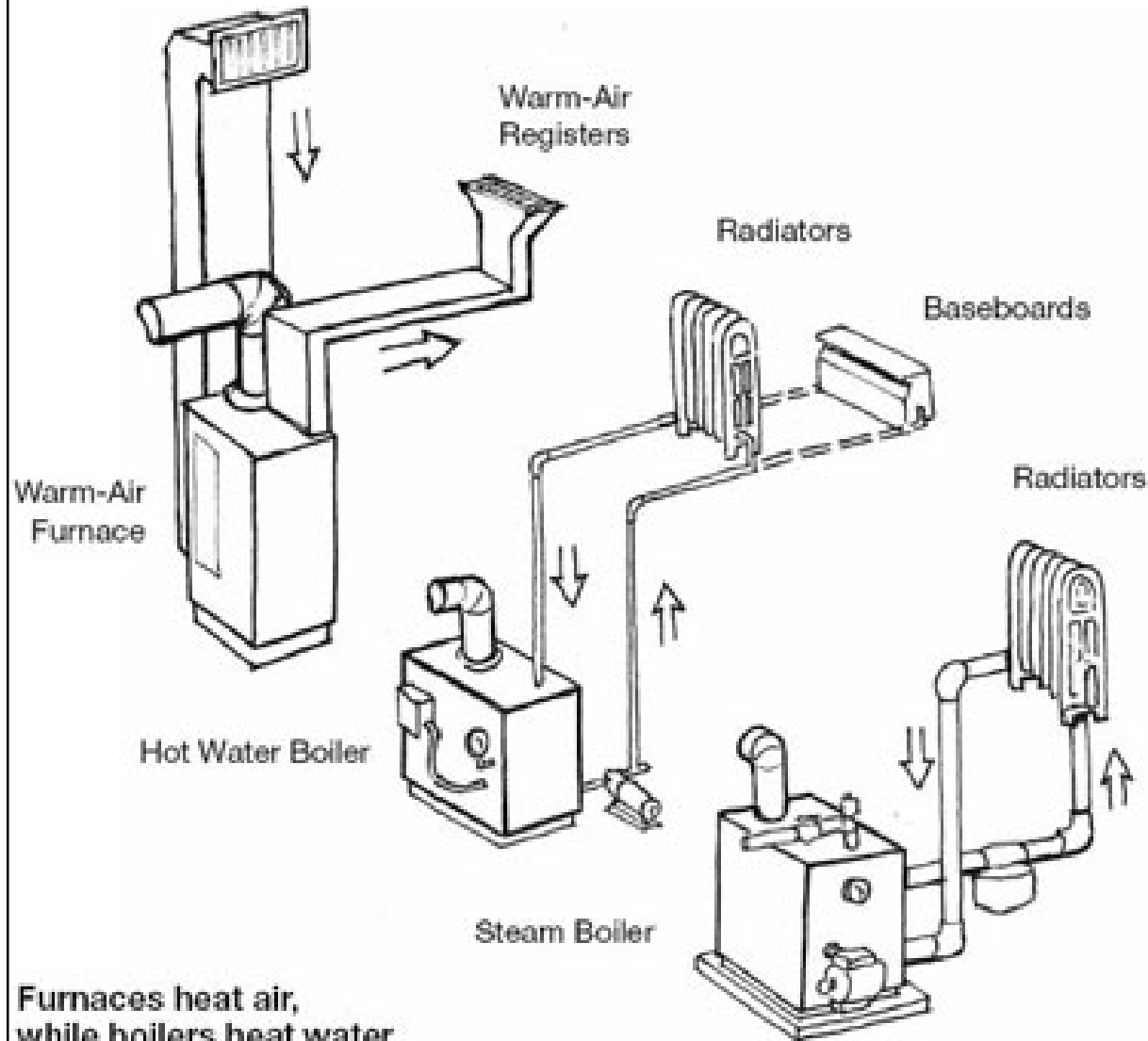
System types and components



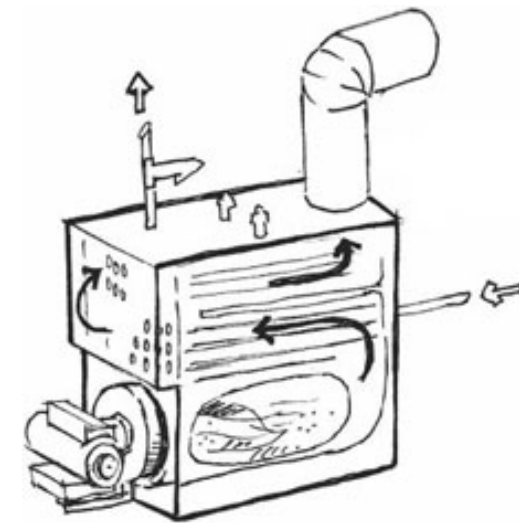
- Common types of heating systems:
 - 1. Heating systems using boilers (water is heated)
 - 2. Warm air furnaces and packaged heating units (air is heated)
 - 3. Heat pumps (reverse cycle of refrigeration cycle) (air, water or ground-source)
 - 4. Individual space heaters (e.g. electric, gas, radiant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



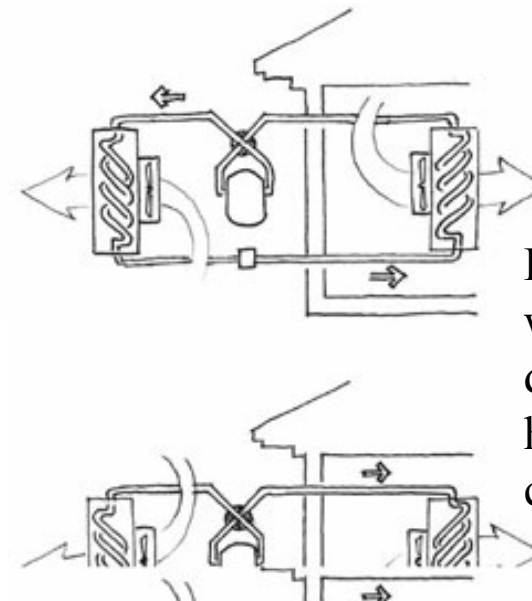
Types of heating systems



**Furnaces heat air,
while boilers heat water.**



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



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

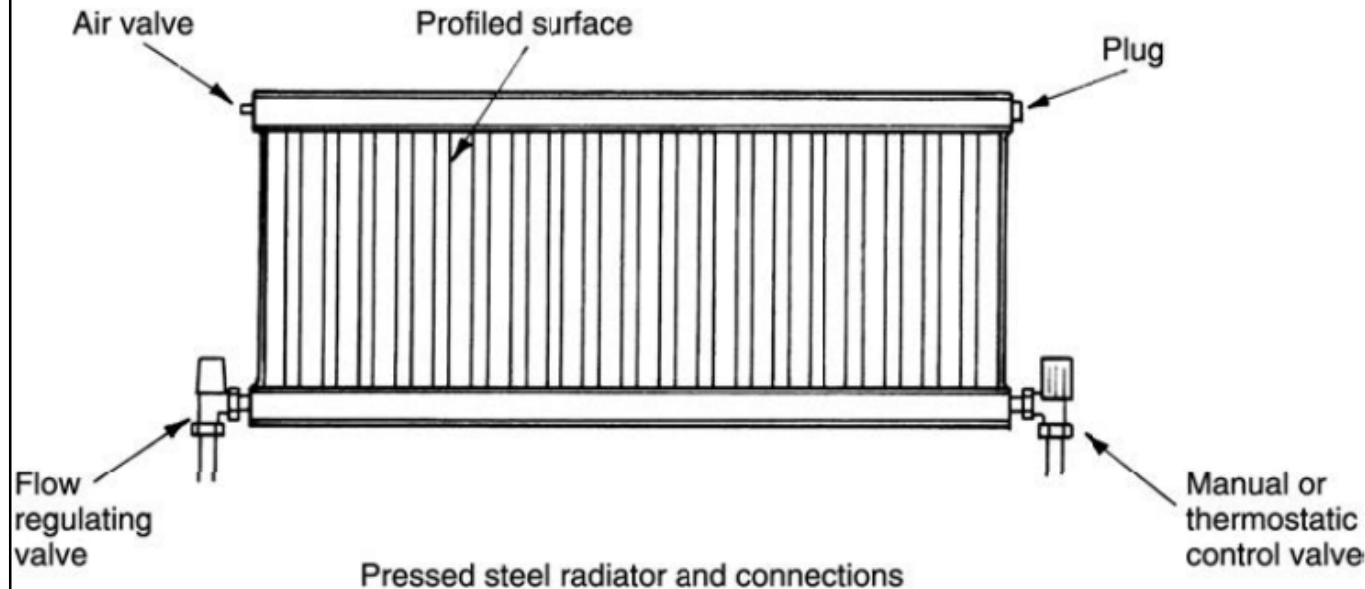
Centralised versus non-centralised systems

| | 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

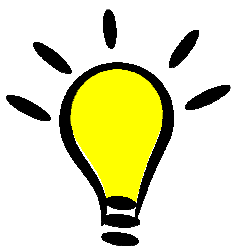
| | Design points | Advantages | Disadvantages |
|----------------------------------|--|--|---|
| Radiators | Output up to 70% convective. Check for limit on surface temperature in some applications, e.g. hospitals | Good temperature control. Balance of radiant and convective output gives good thermal 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

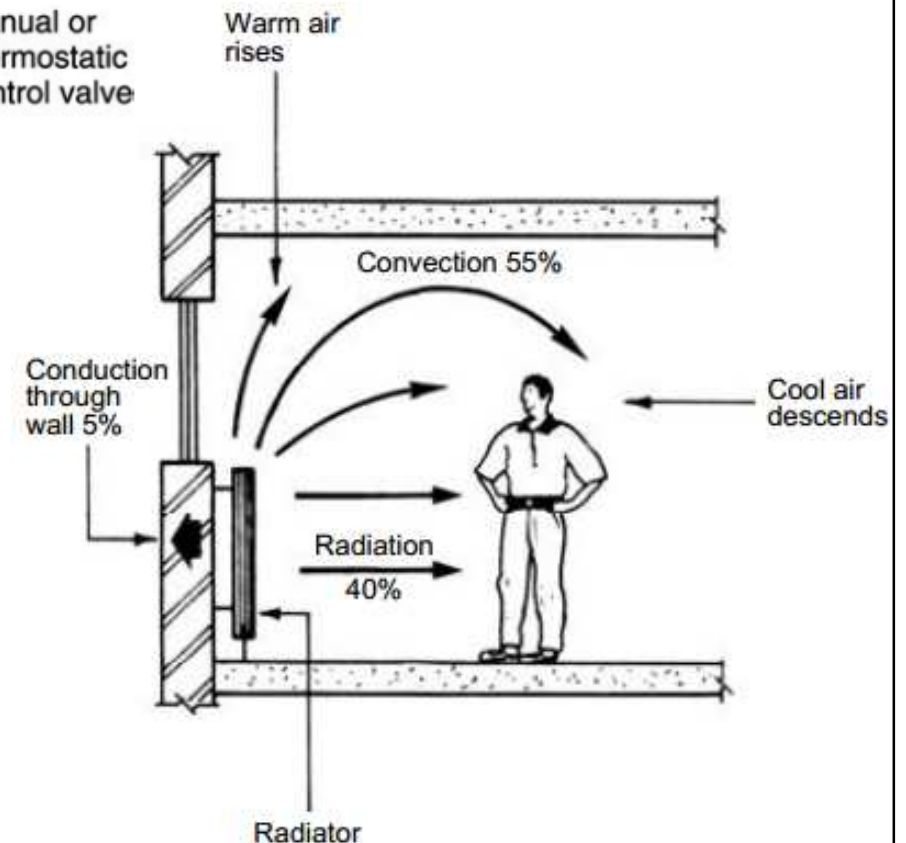


Heat energy transfer:

- Radiation
- Convection
- Conduction

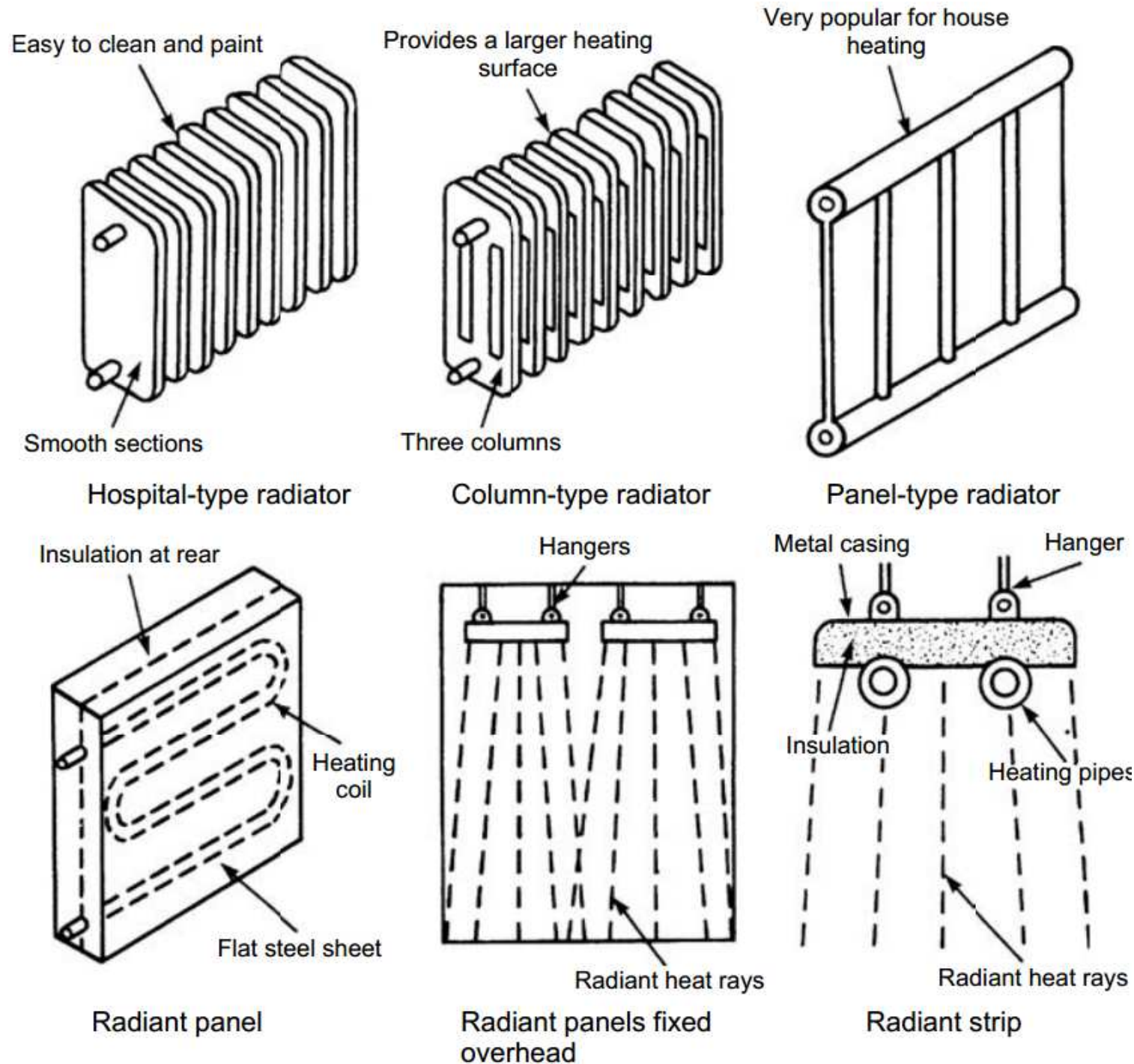


Despite the name, radiator, no more than 40% of the heat transferred is by **radiation**. The remainder is **convected**, with a small amount **conducted** through the radiator brackets into the wall.

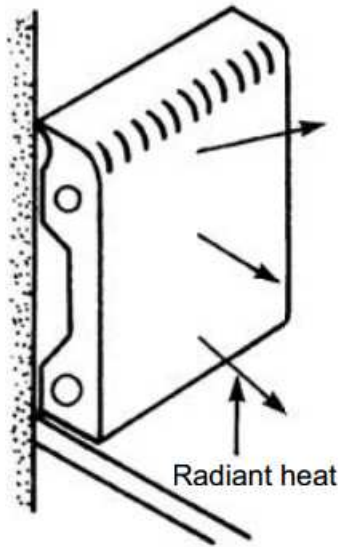


(See also: Heat Emitters http://www.arca53.dsl.pipex.com/index_files/emitters1.htm)

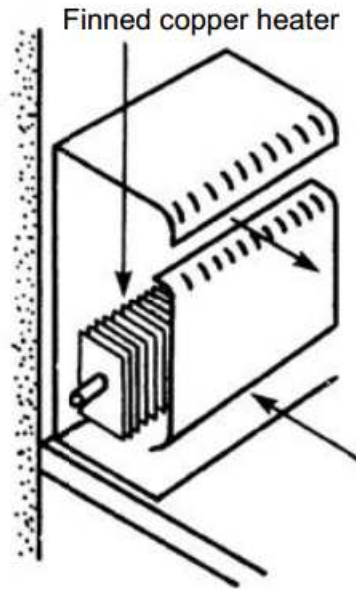
Different types of radiators



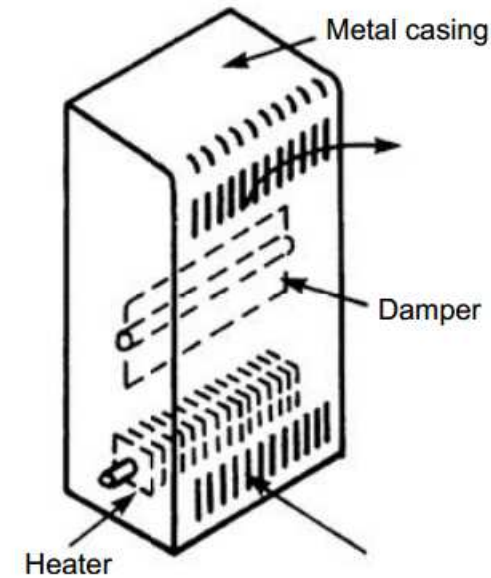
Examples of radiant and convector skirting heaters



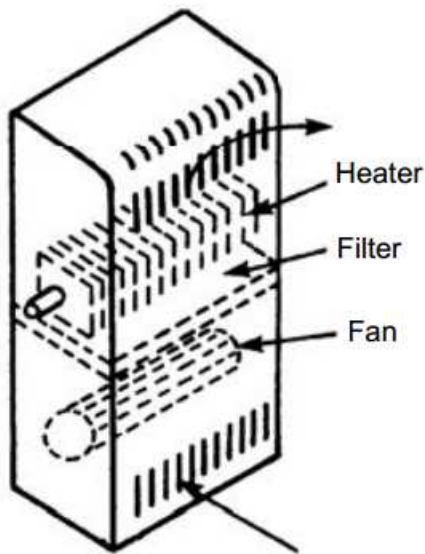
Radiant skirting heater



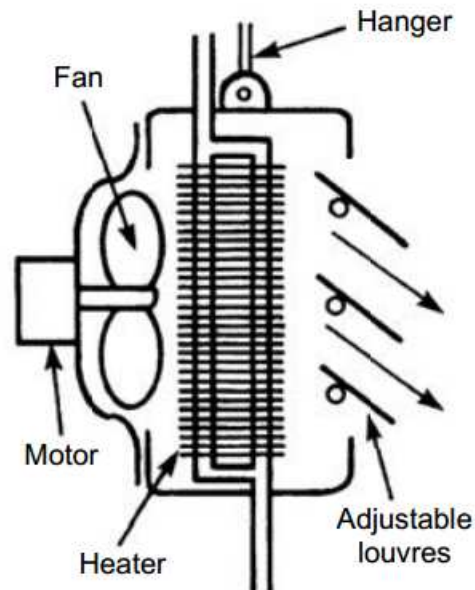
Convector skirting heater



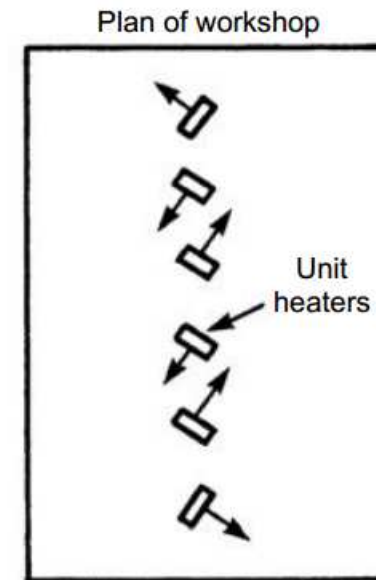
Natural convector



Fan convector



Overhead unit heater

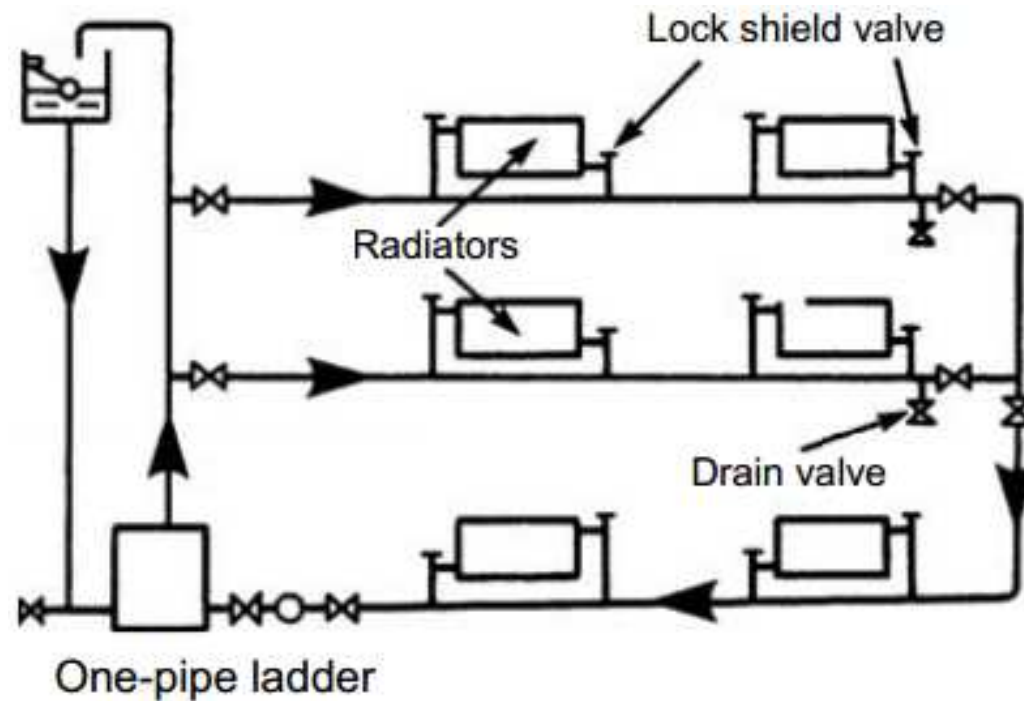
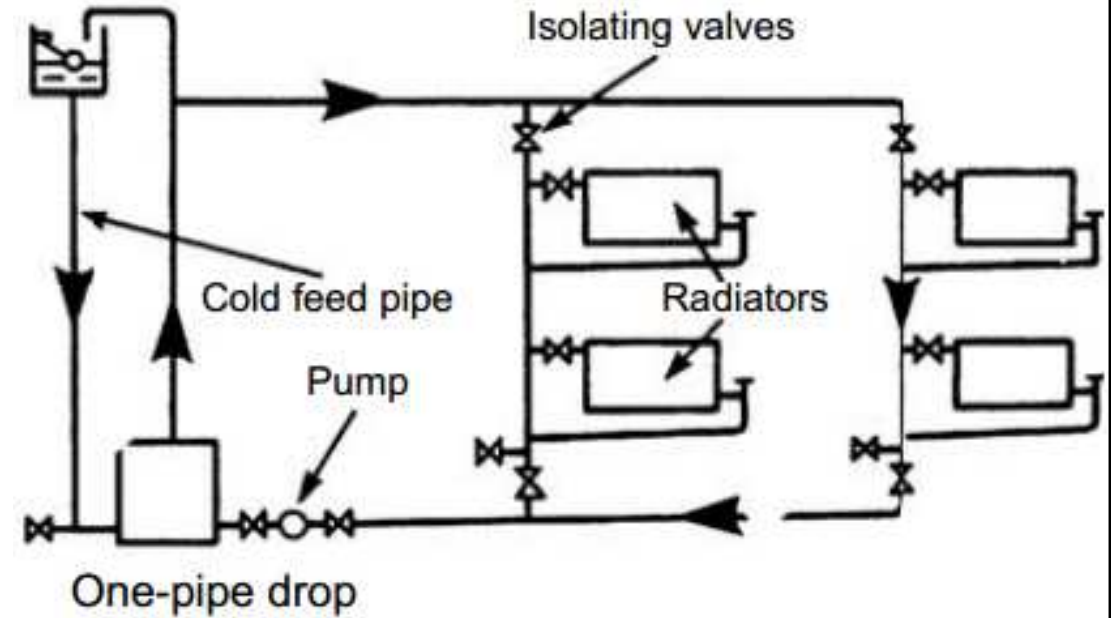
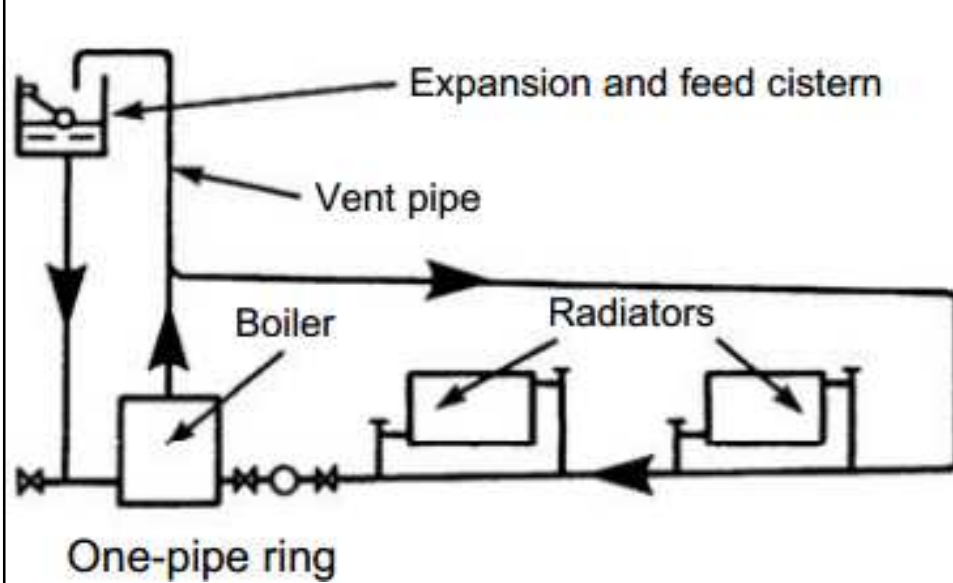


Method of siting overhead unit heaters

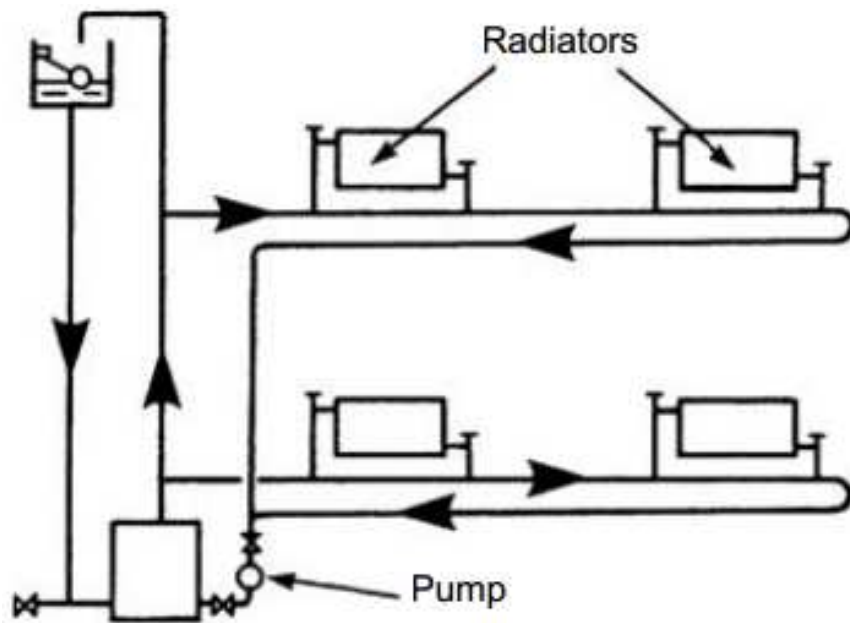
Characteristics of heat distribution media

| Medium | Principal characteristics |
|-------------------------------------|---|
| Air | <u>Advantages</u> : no intermediate medium or heat exchanger is needed; there is no risk of water leak. <u>Disadvantages</u> : 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. |

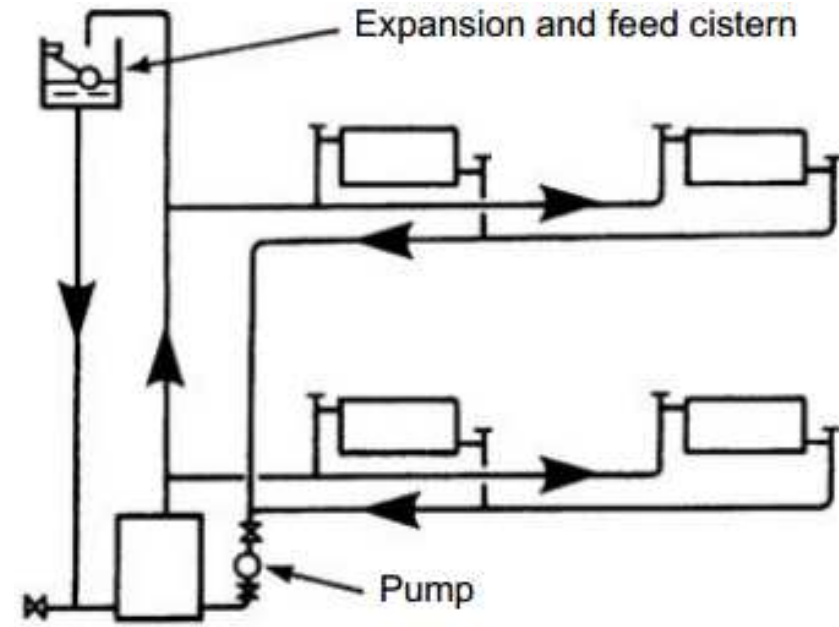
Pipe layout options of low-temperature hot water heating systems



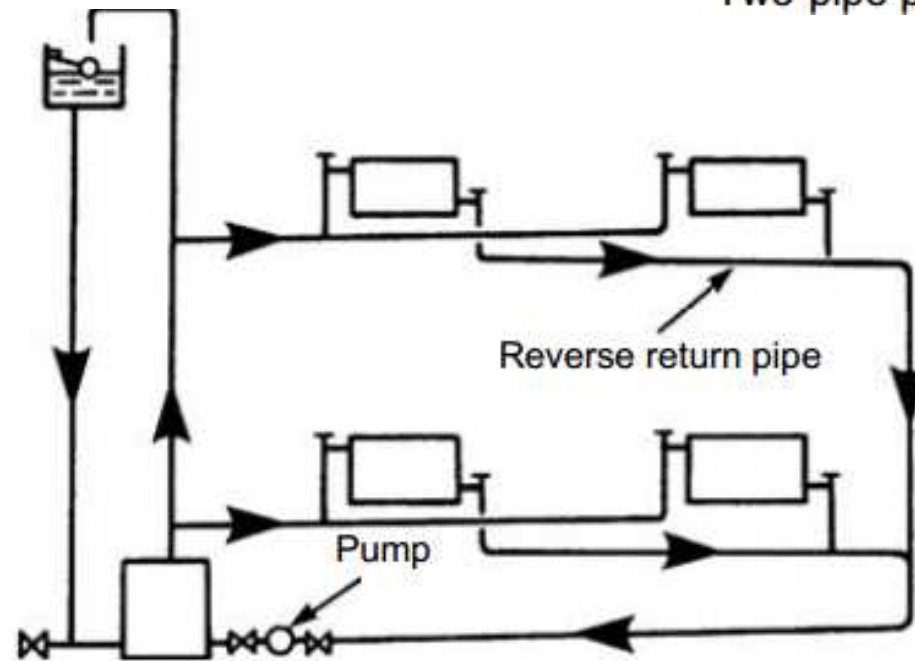
One- and two-pipe parallel systems



One-pipe parallel

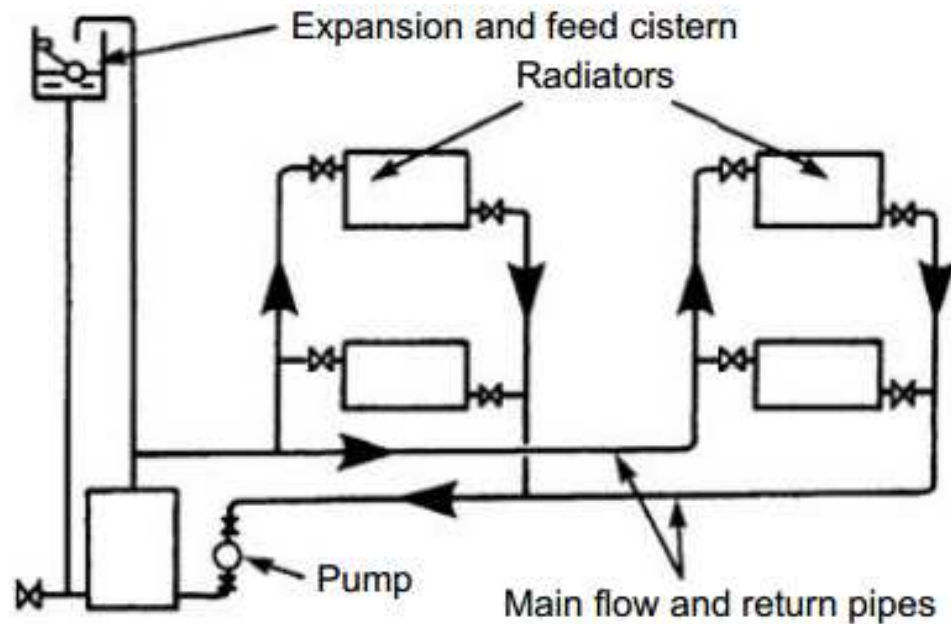


Two-pipe parallel

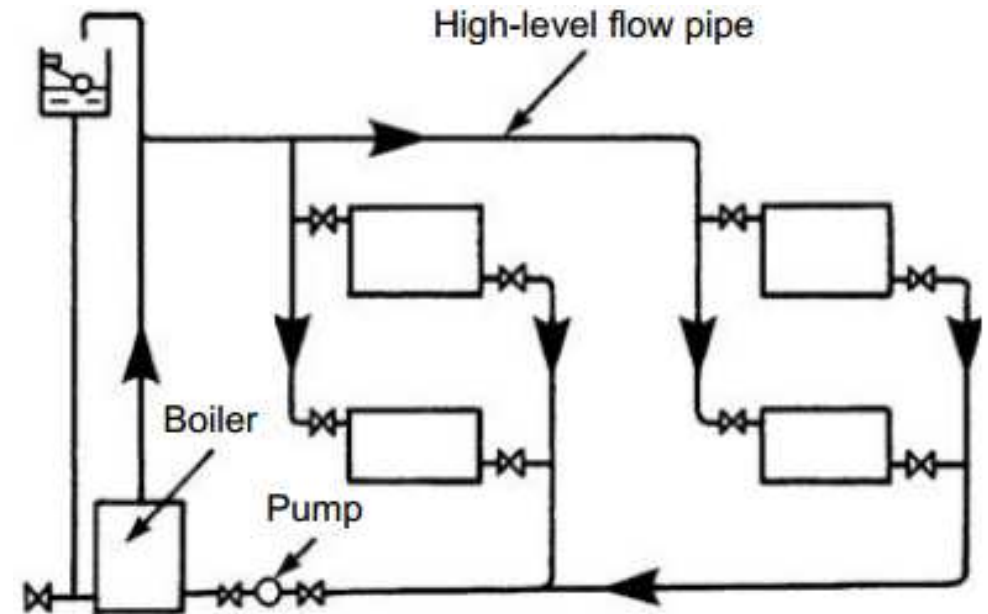


Two-pipe reverse return

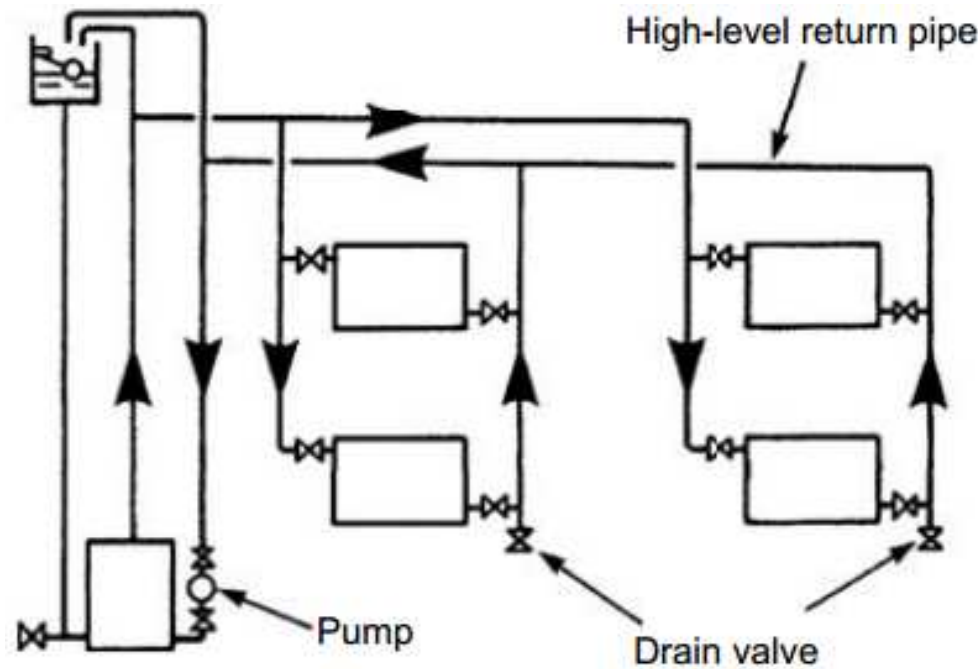
Two-pipe upfeed, drop and high-level return systems



Two-pipe upfeed



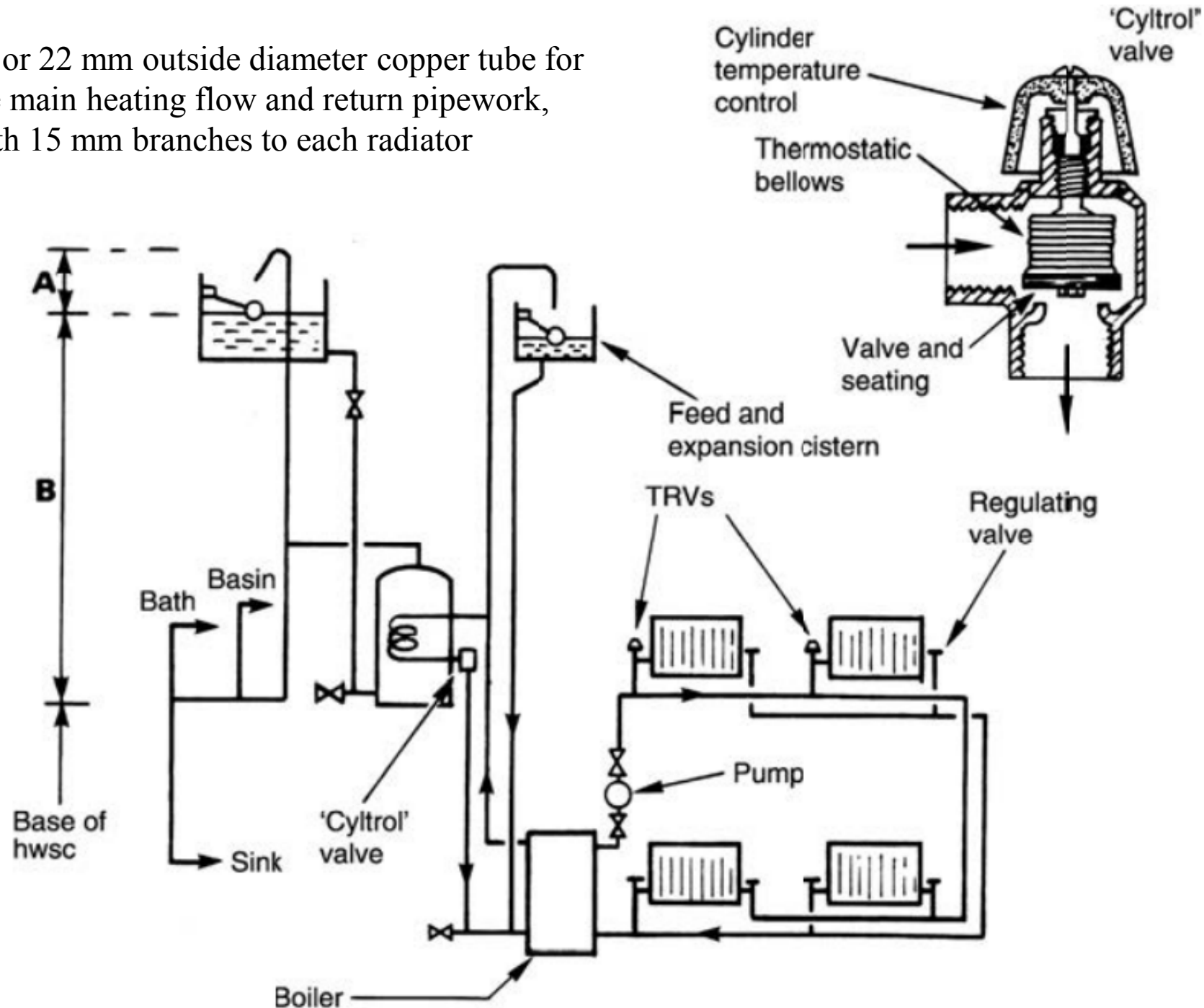
Two-pipe drop



Two-pipe high-level return

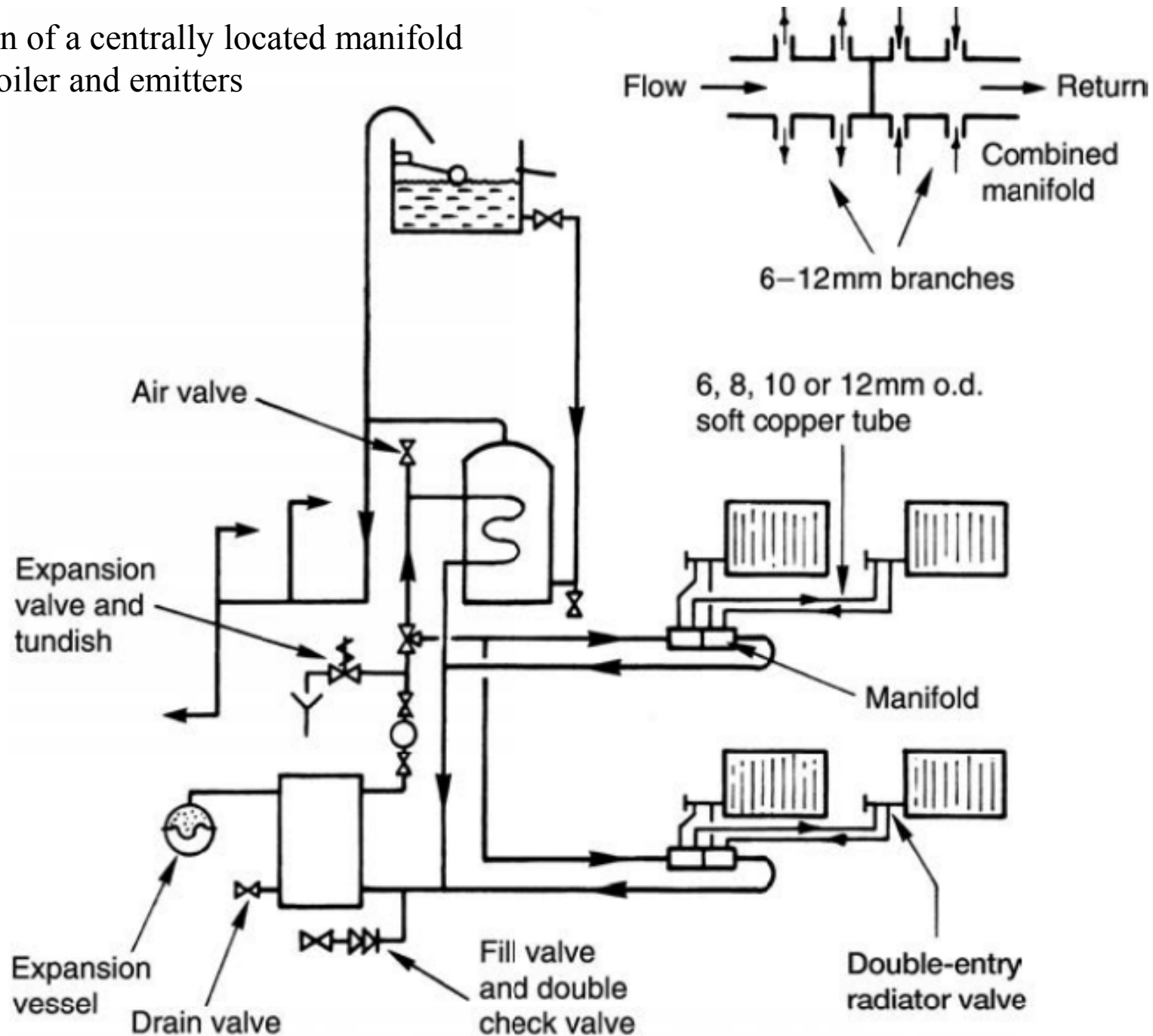
Small bore hot water heating system

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

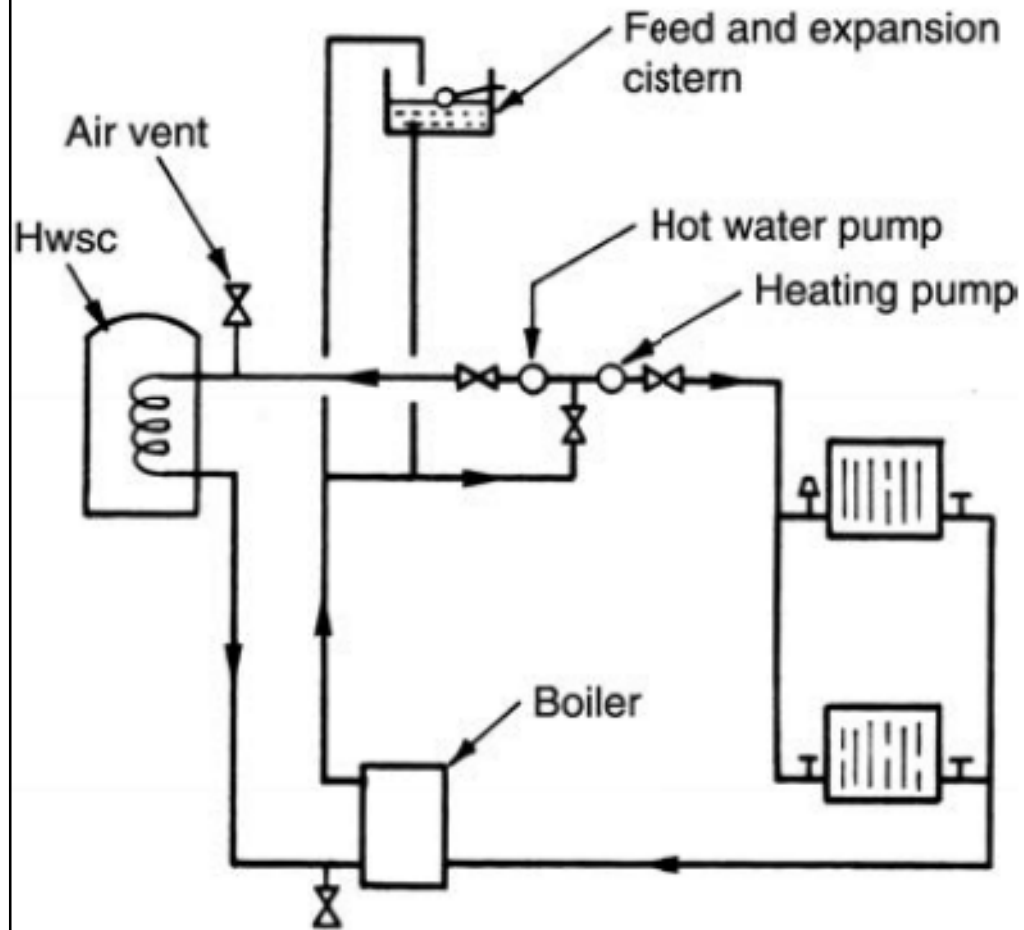


Microbore hot water heating system

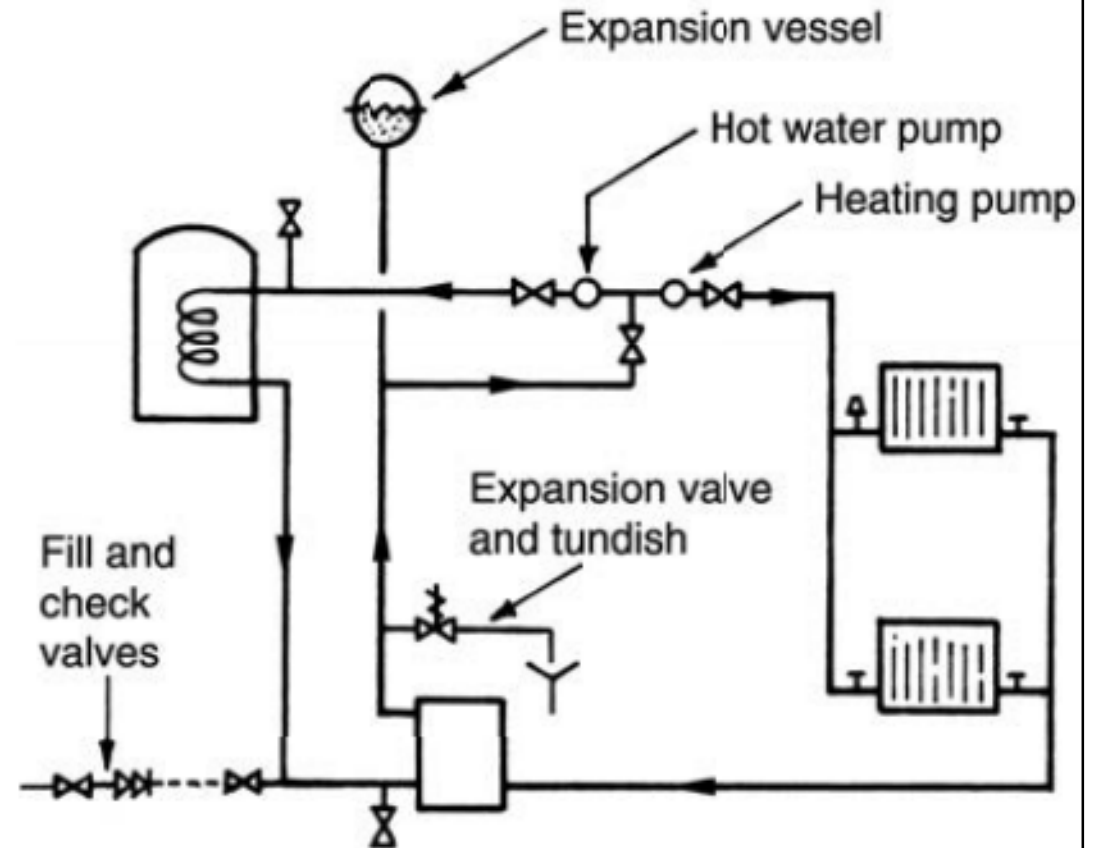
Application of a centrally located manifold between boiler and emitters



Open-vent and sealed systems



Conventional open-vent system



Typical sealed system

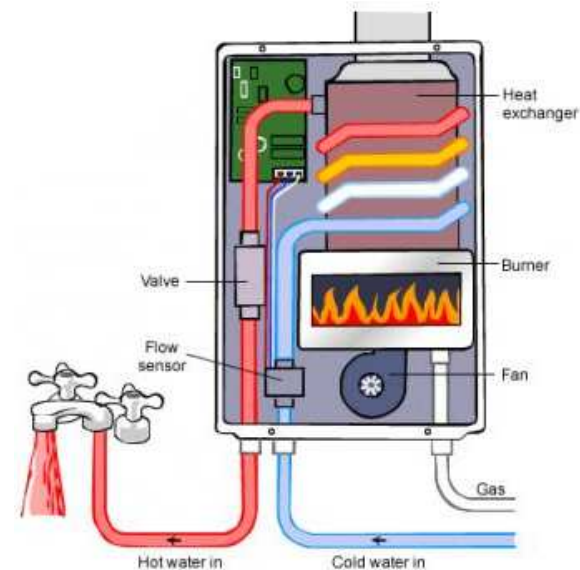
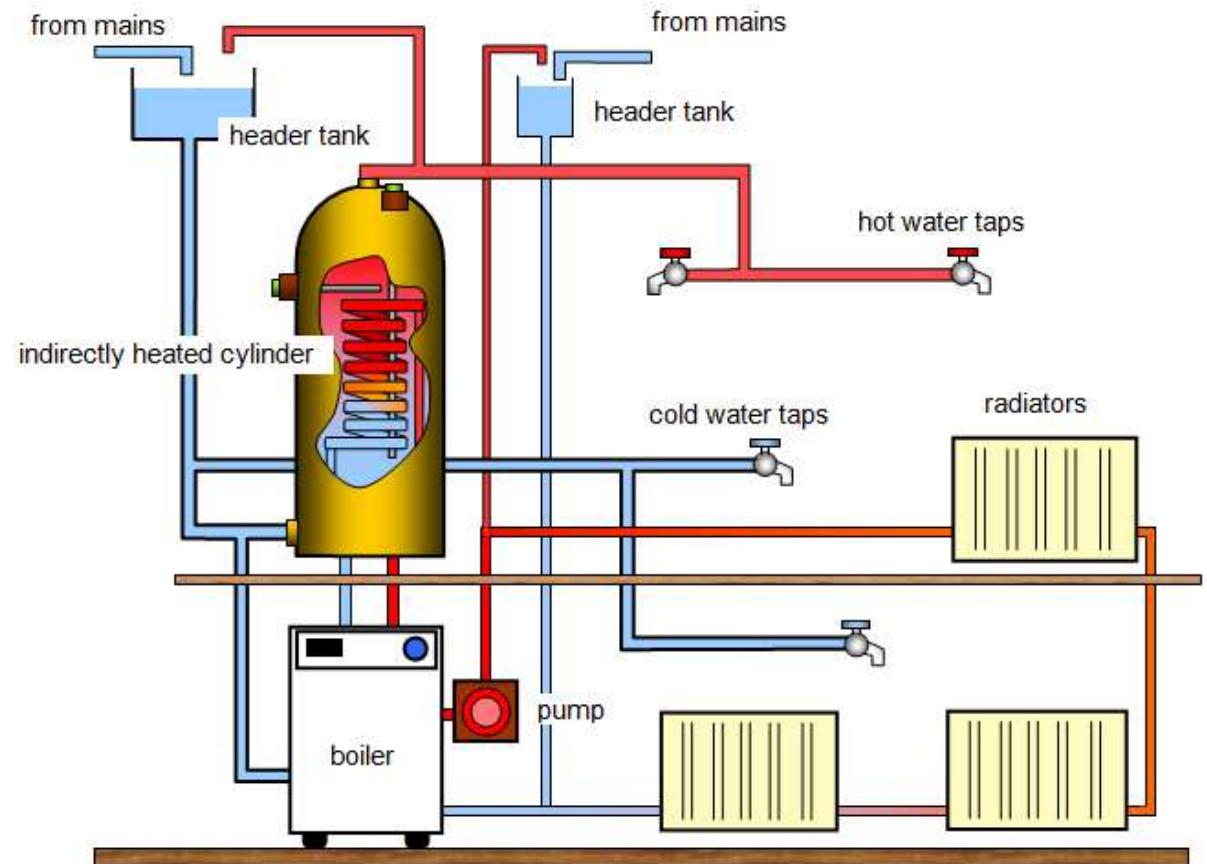
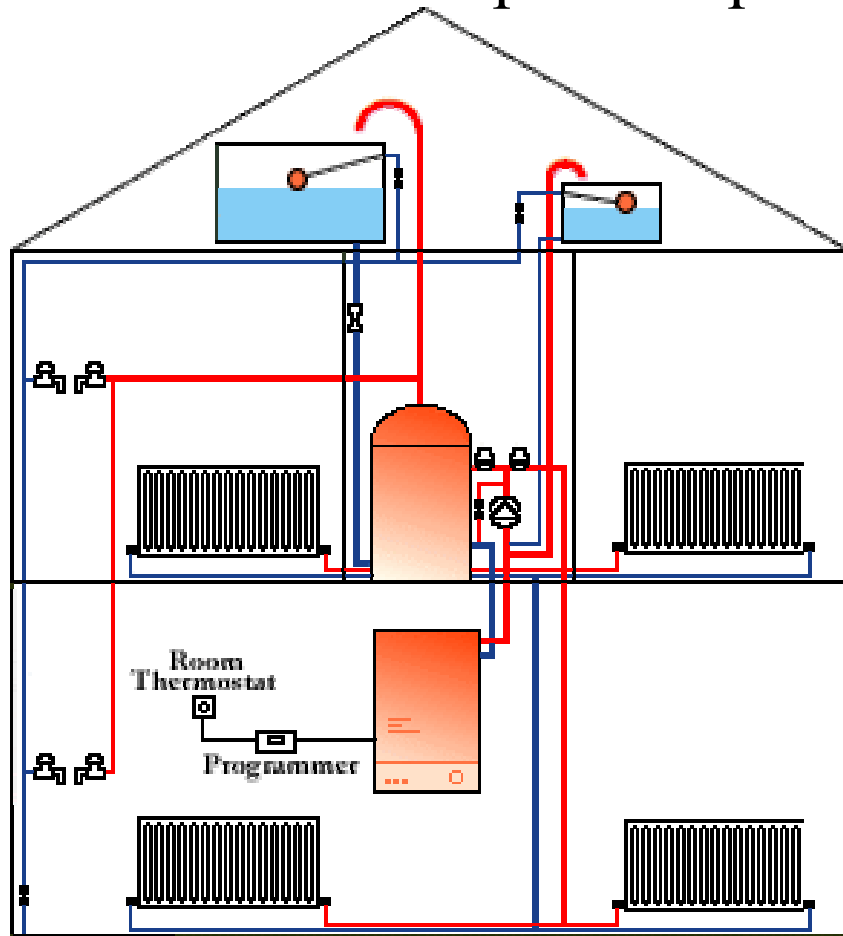
Design of heating systems



- 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 |

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)

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

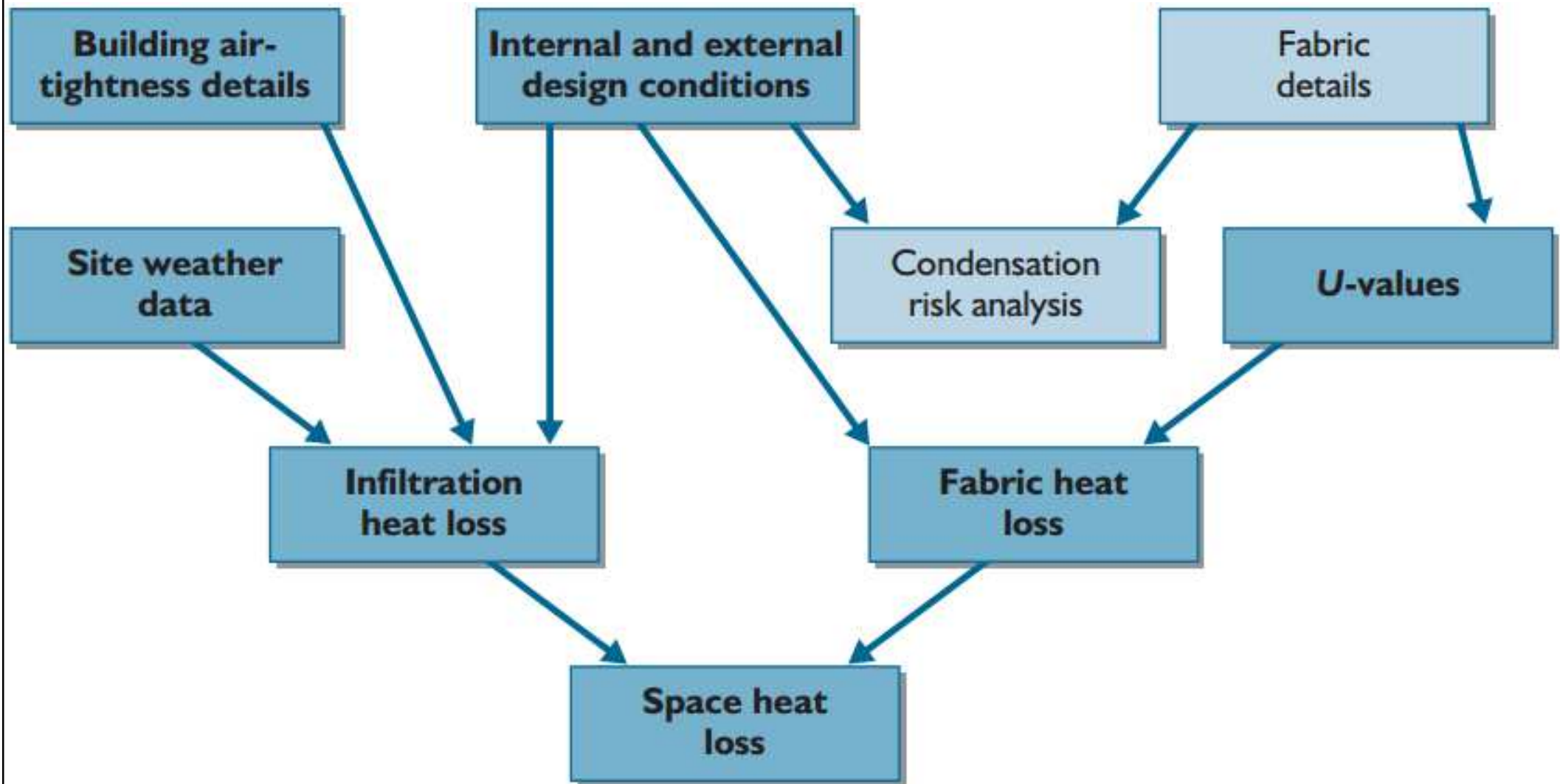
Step 10: system analysis and control performance

Step 11: Final value engineering and energy targets assessment

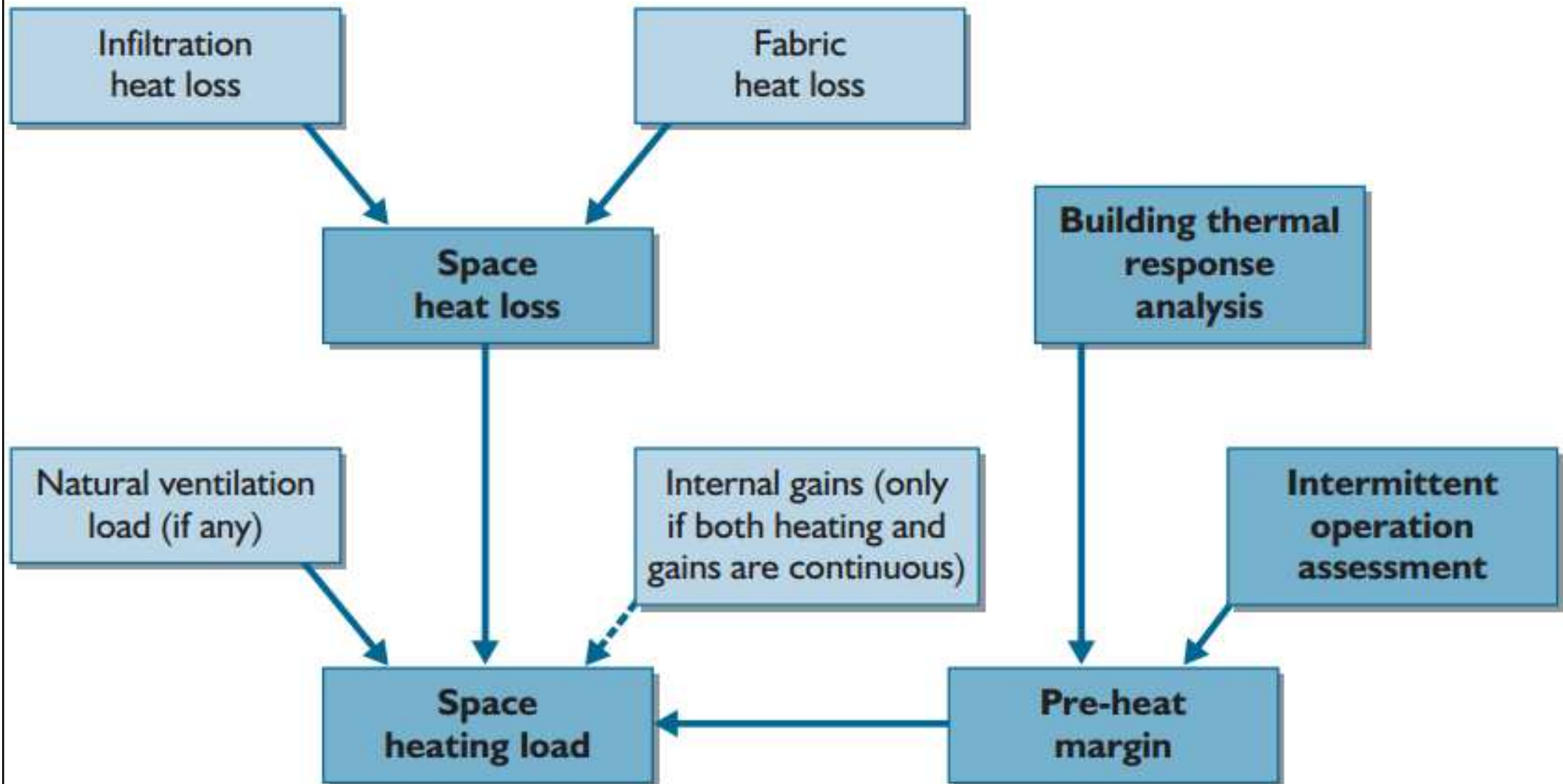
Step 12: design review

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

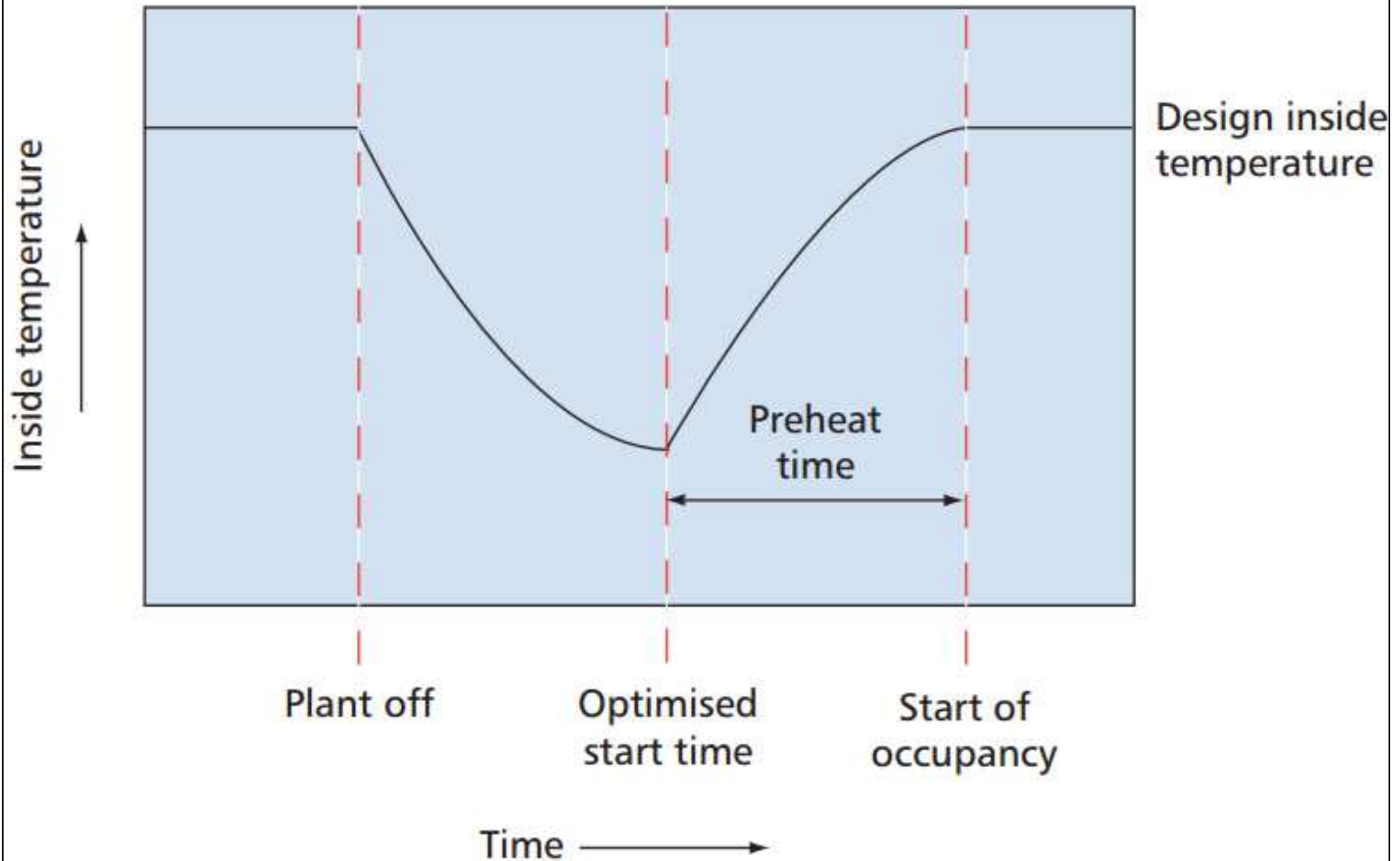
Key steps to establish individual space heat losses



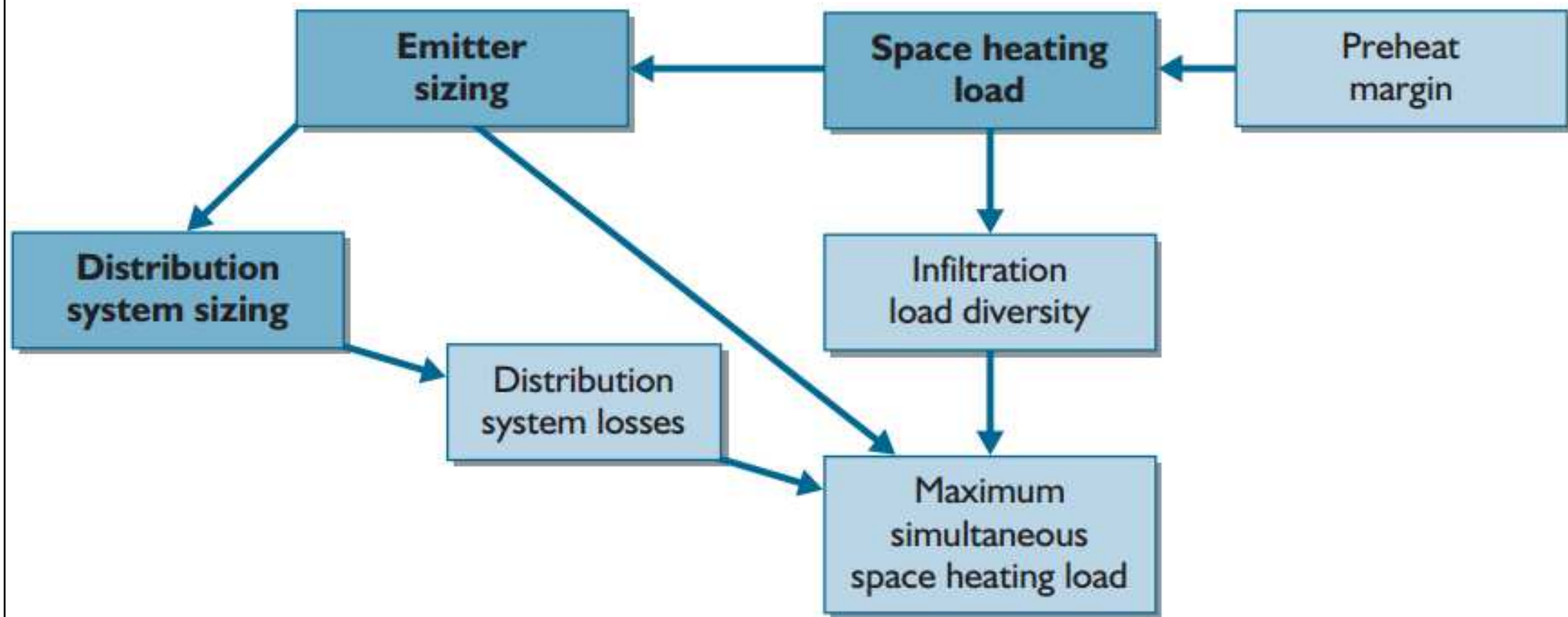
Key steps to establish space heating loads



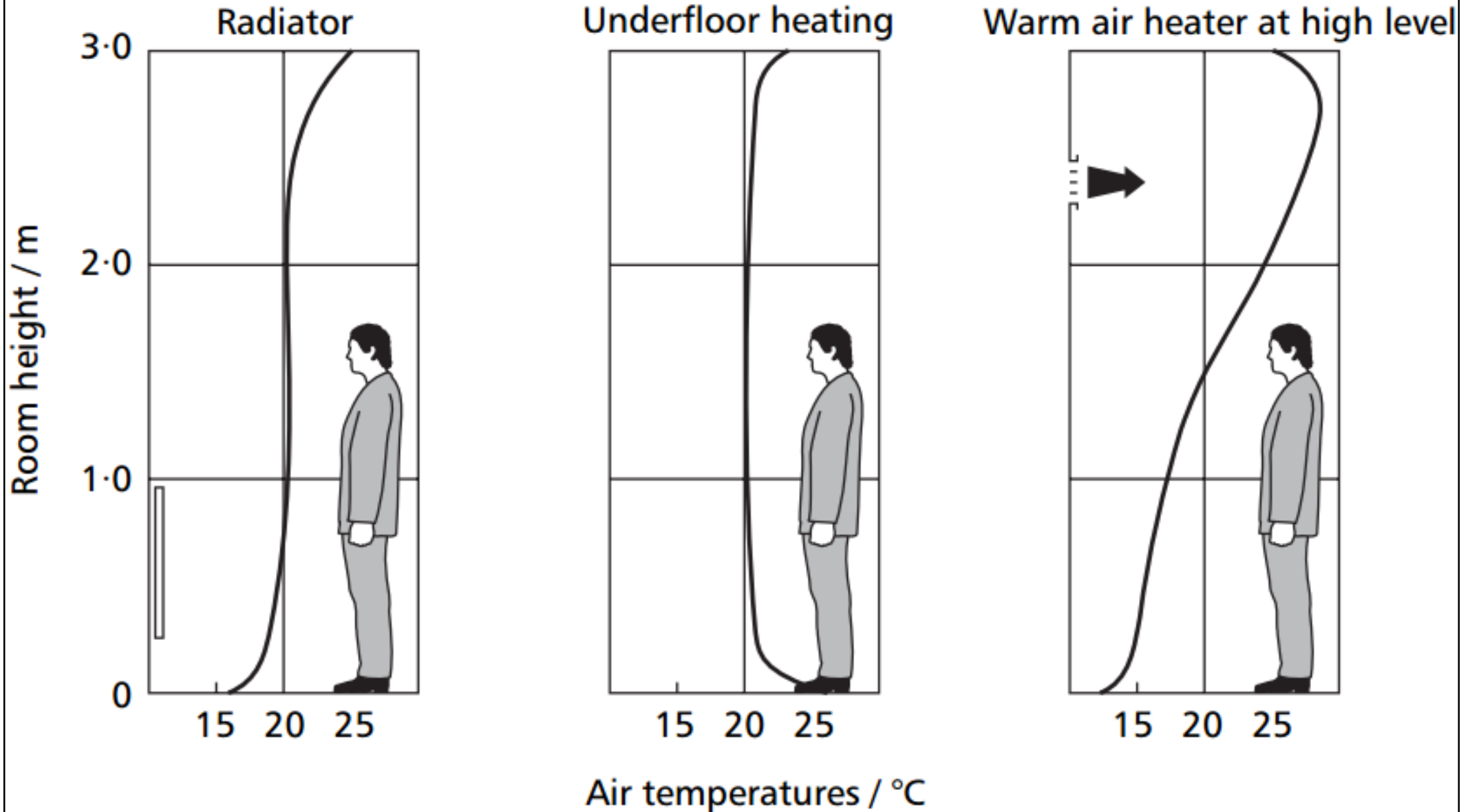
Preheat time before the start of the occupied period



Key steps for emitter and distribution system sizing

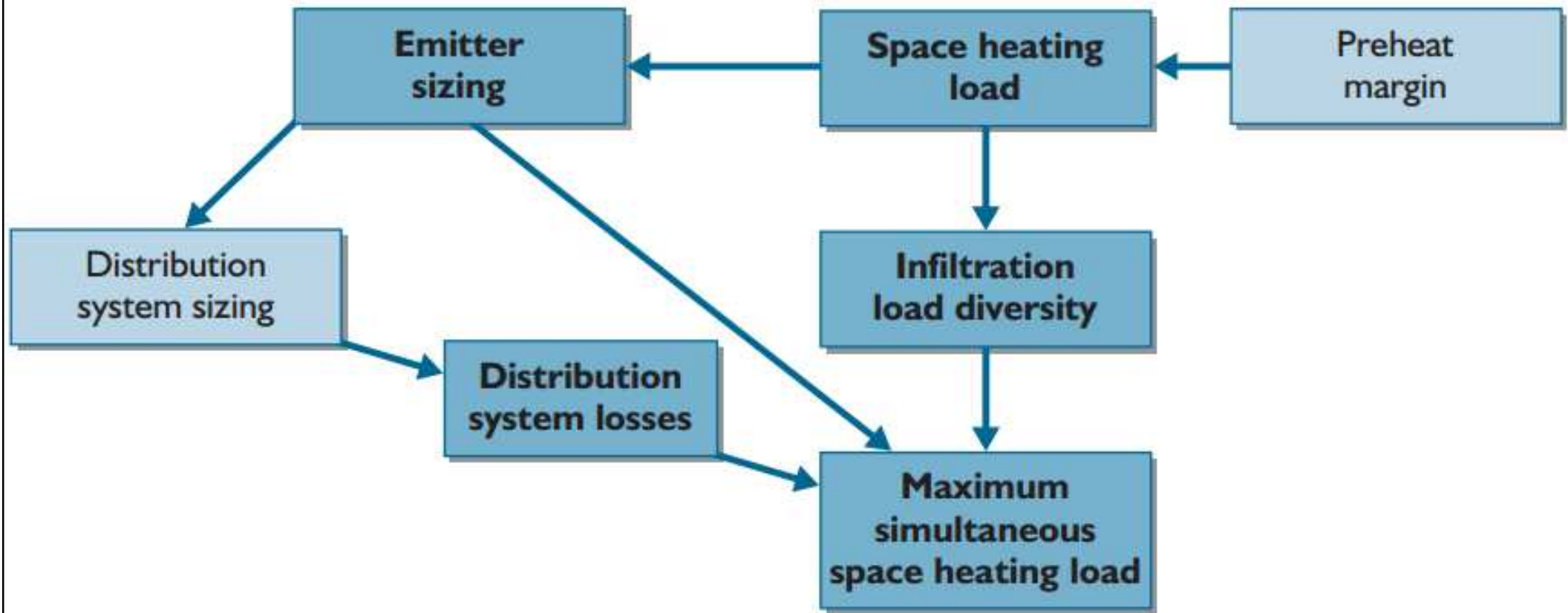


Vertical air temperature gradients for different heating types

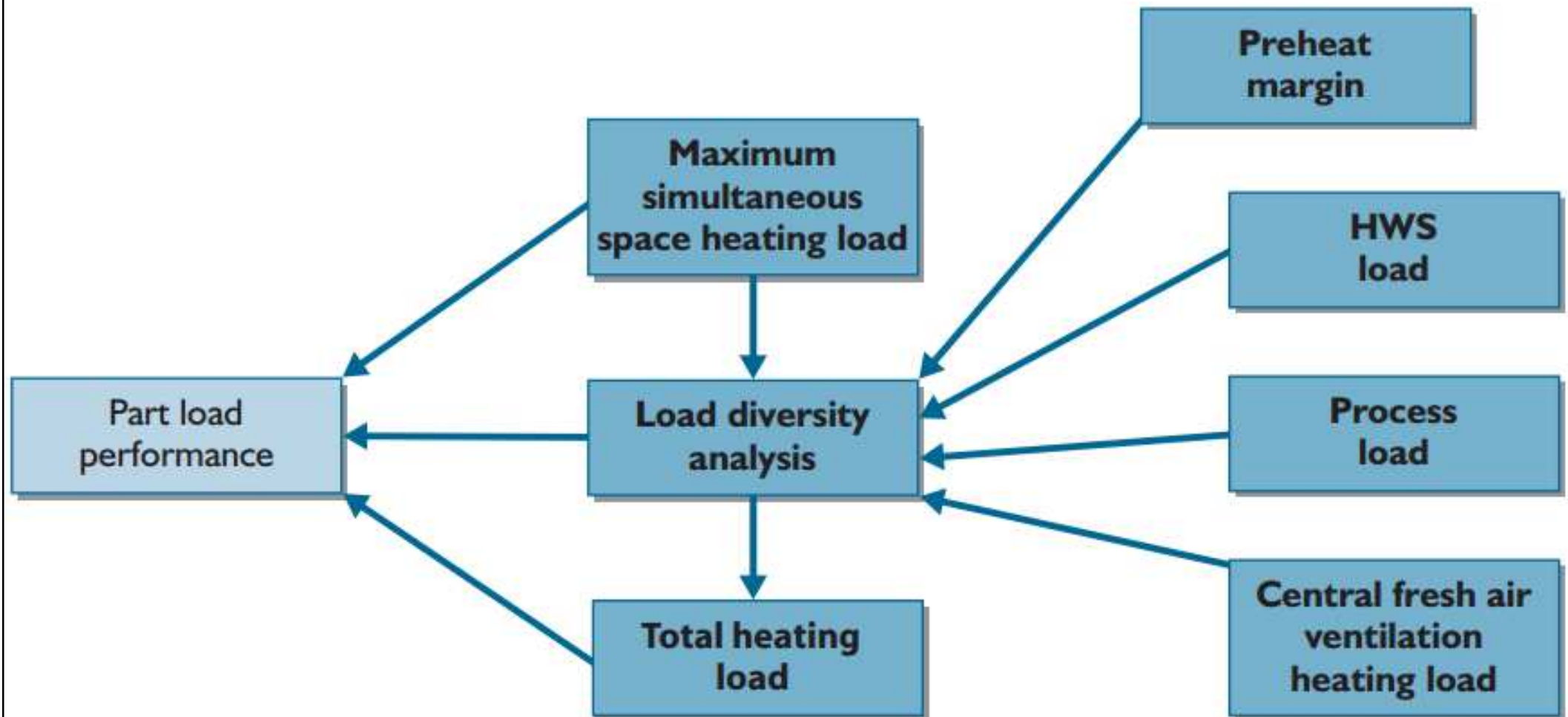


Which one do you think is more comfortable?

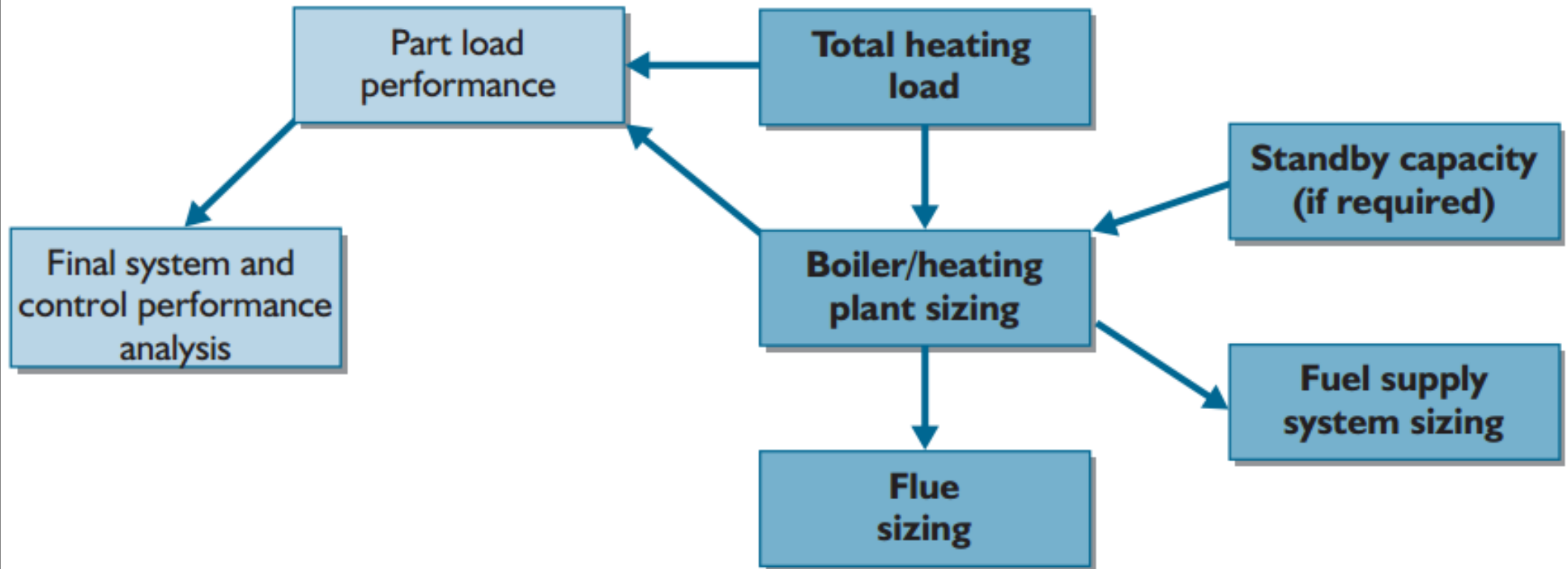
Key steps to establish the maximum simultaneous space heating load



Key steps to establish the total heating load



Key steps for boiler/heating plant sizing and selection



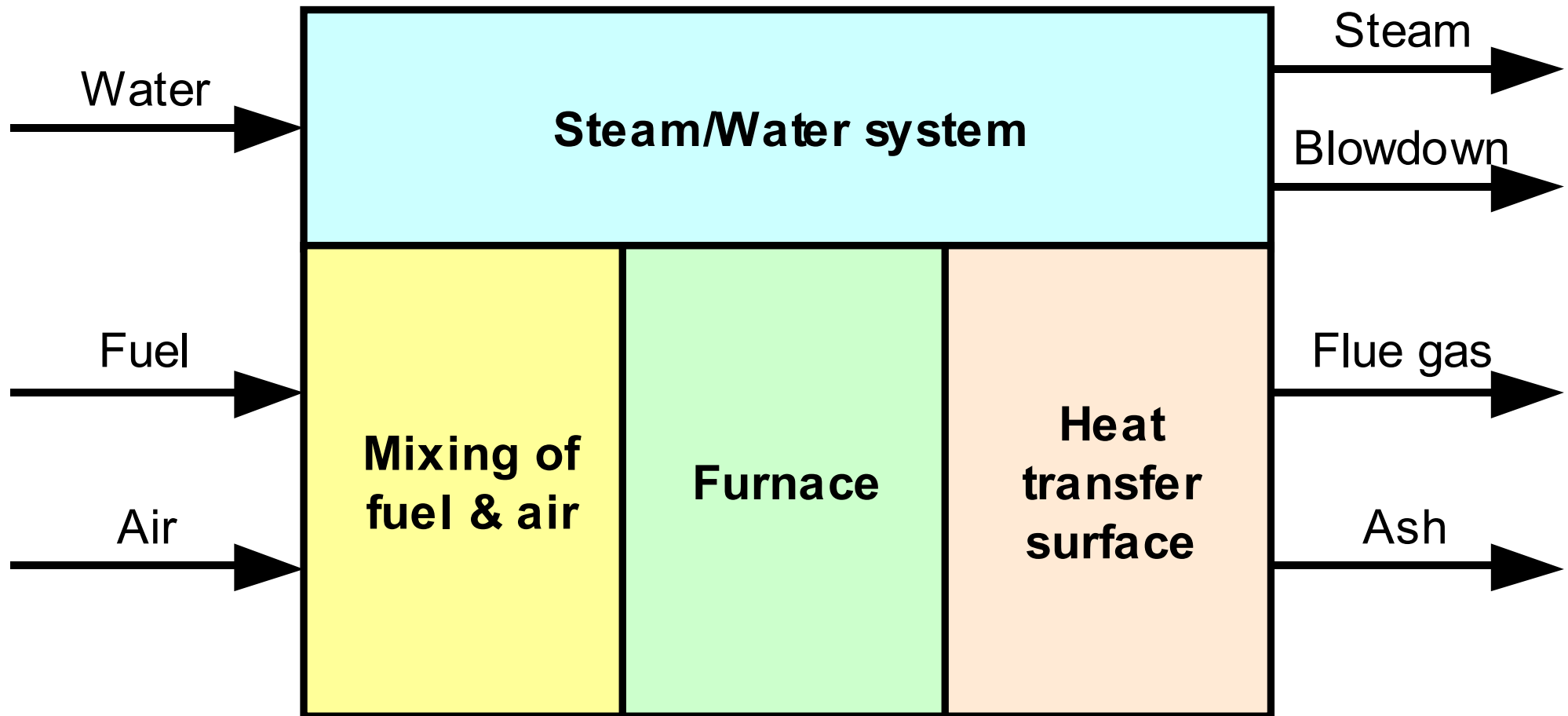
Boilers



- **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% |
| <i>Overall thermal efficiency</i> | 82.5% |

Boilers

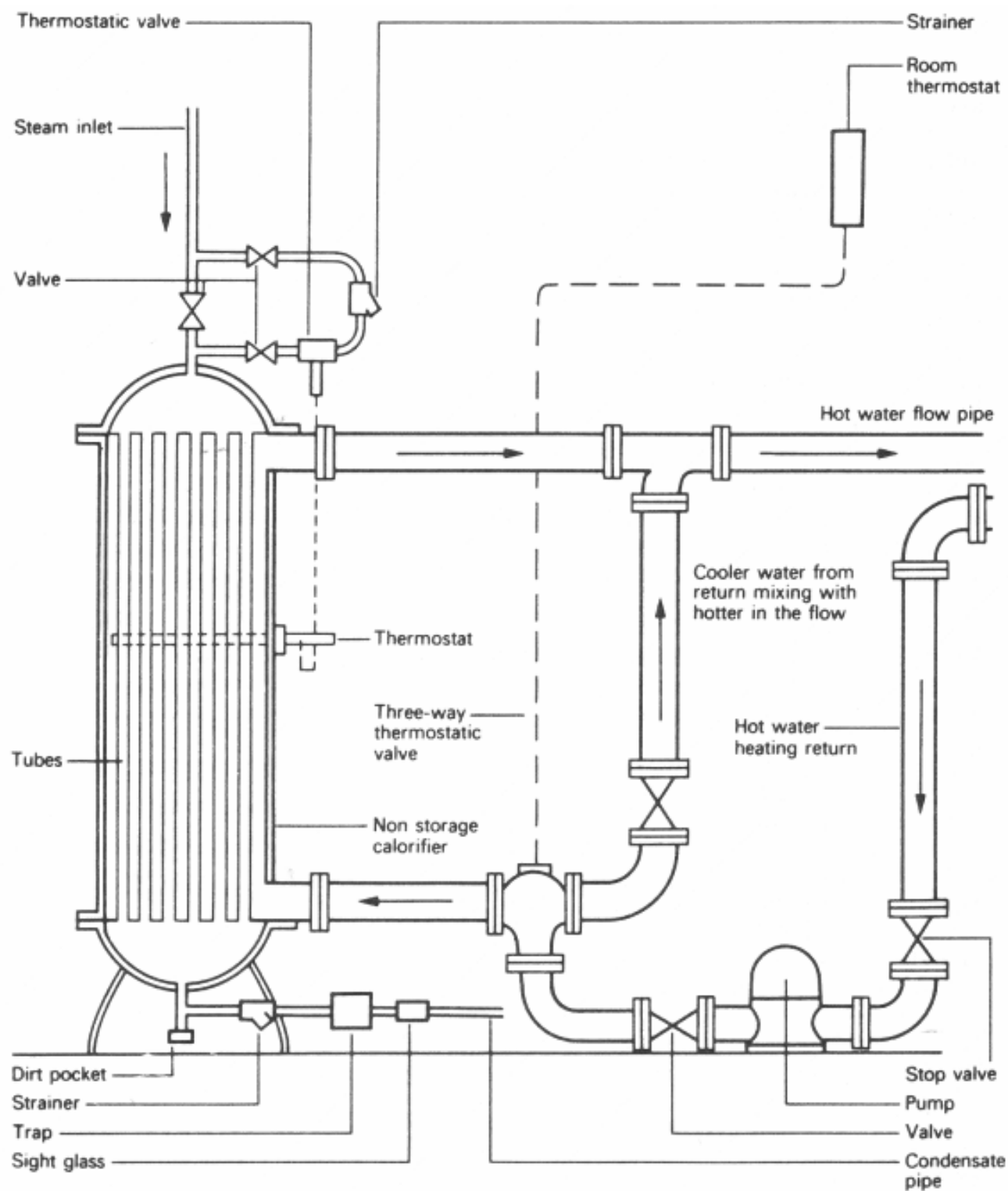


- **Steam boilers** (high and low pressure)
 - High-pressure >100 kPa
 - Reduce size of boiler & steam piping (due to density)
 - But decrease boiler efficiency
 - Good for heat load at long distance
 - Low-pressure ≤ 100 kPa
 - Simpler in both design & operation
 - No pressure-reducing valves are required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

Boilers



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



Non-storage
type calorifier

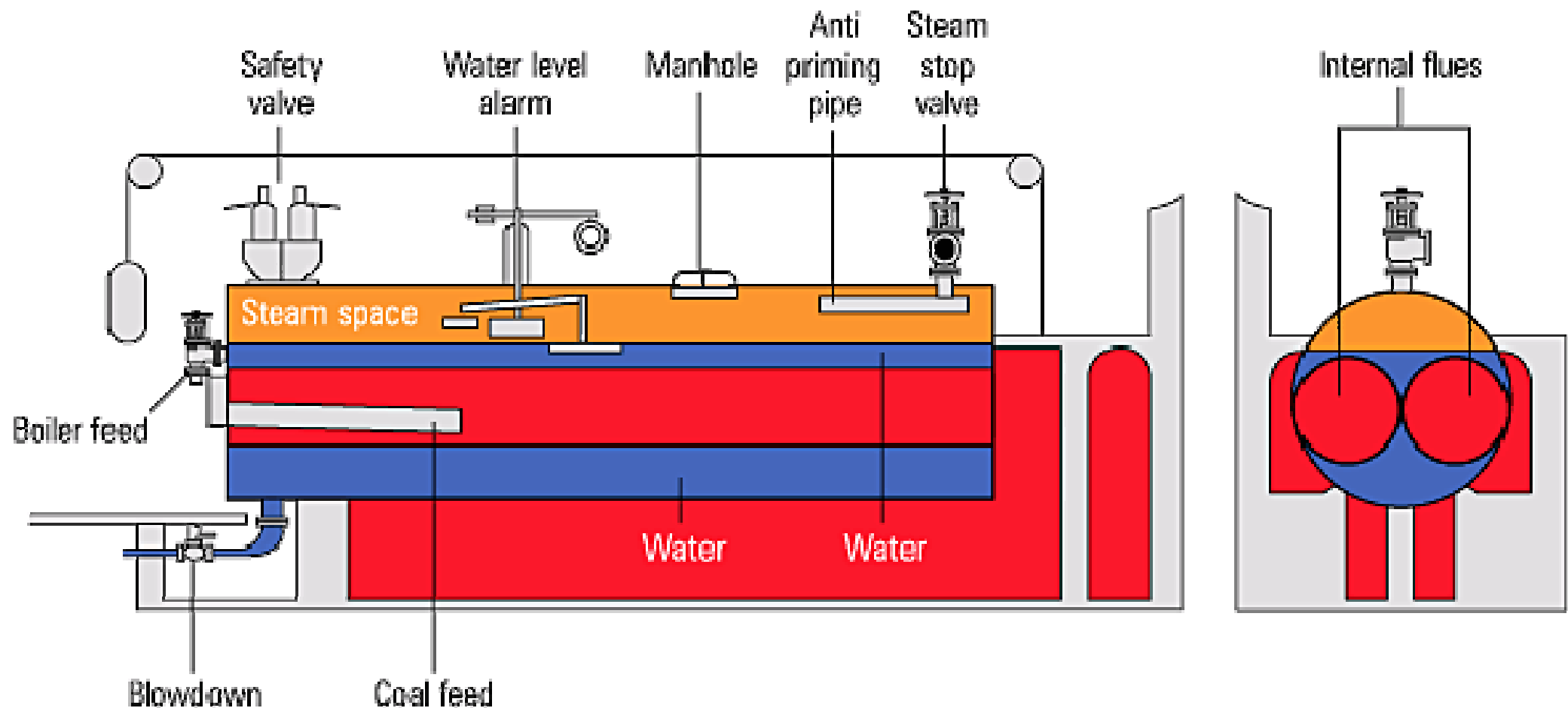
Boilers



- **Shell boilers**

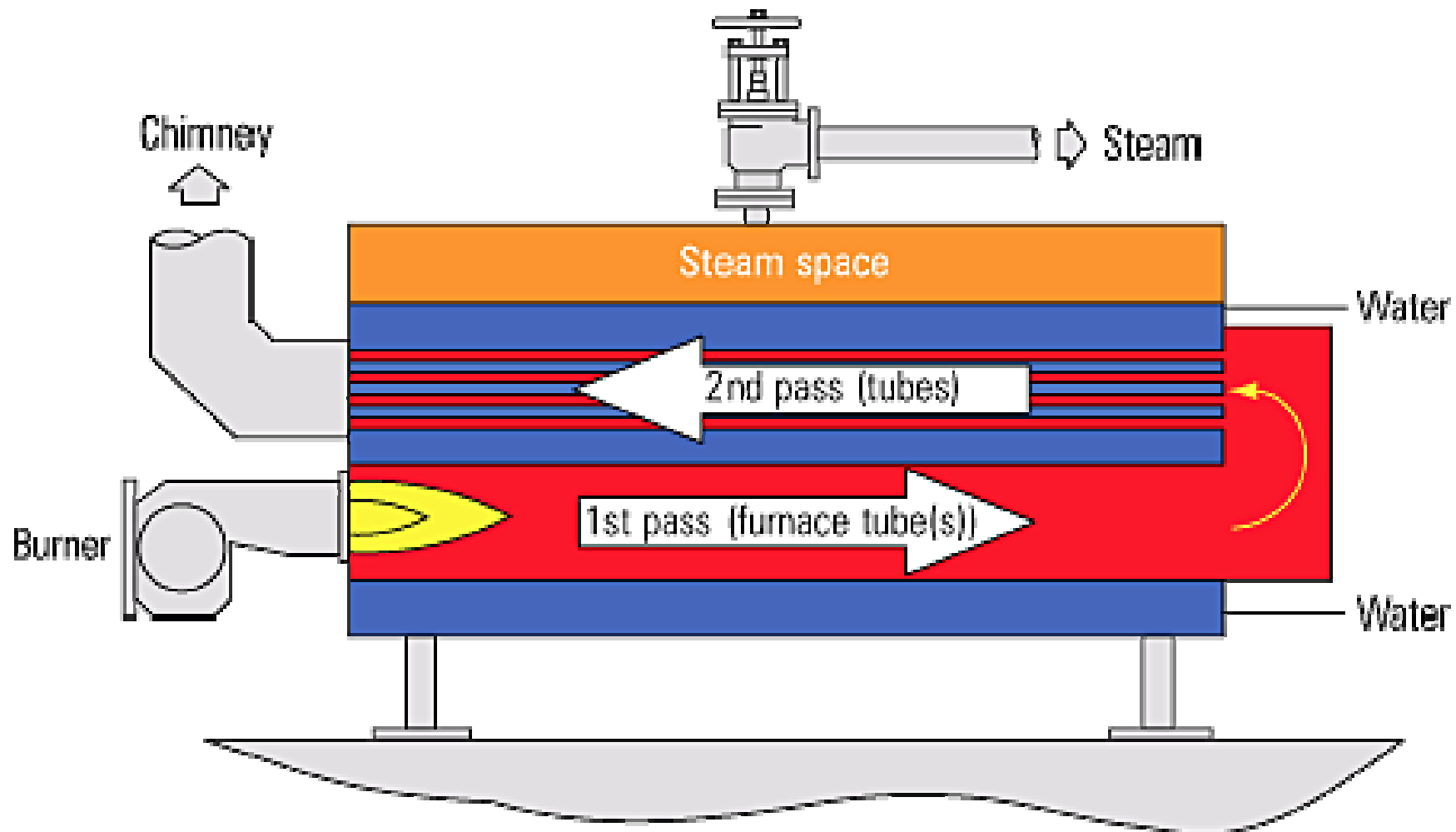
- The heat transfer surfaces are all contained within a steel shell
- Also known as ‘fire tube’ or ‘smoke tube’ boilers
 - Products of combustion pass through the boiler tubes, which in turn transfer heat to the boiler water
- Typical types of shell boilers:
 - Lancashire boiler
 - Economic boiler (two-pass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

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 |

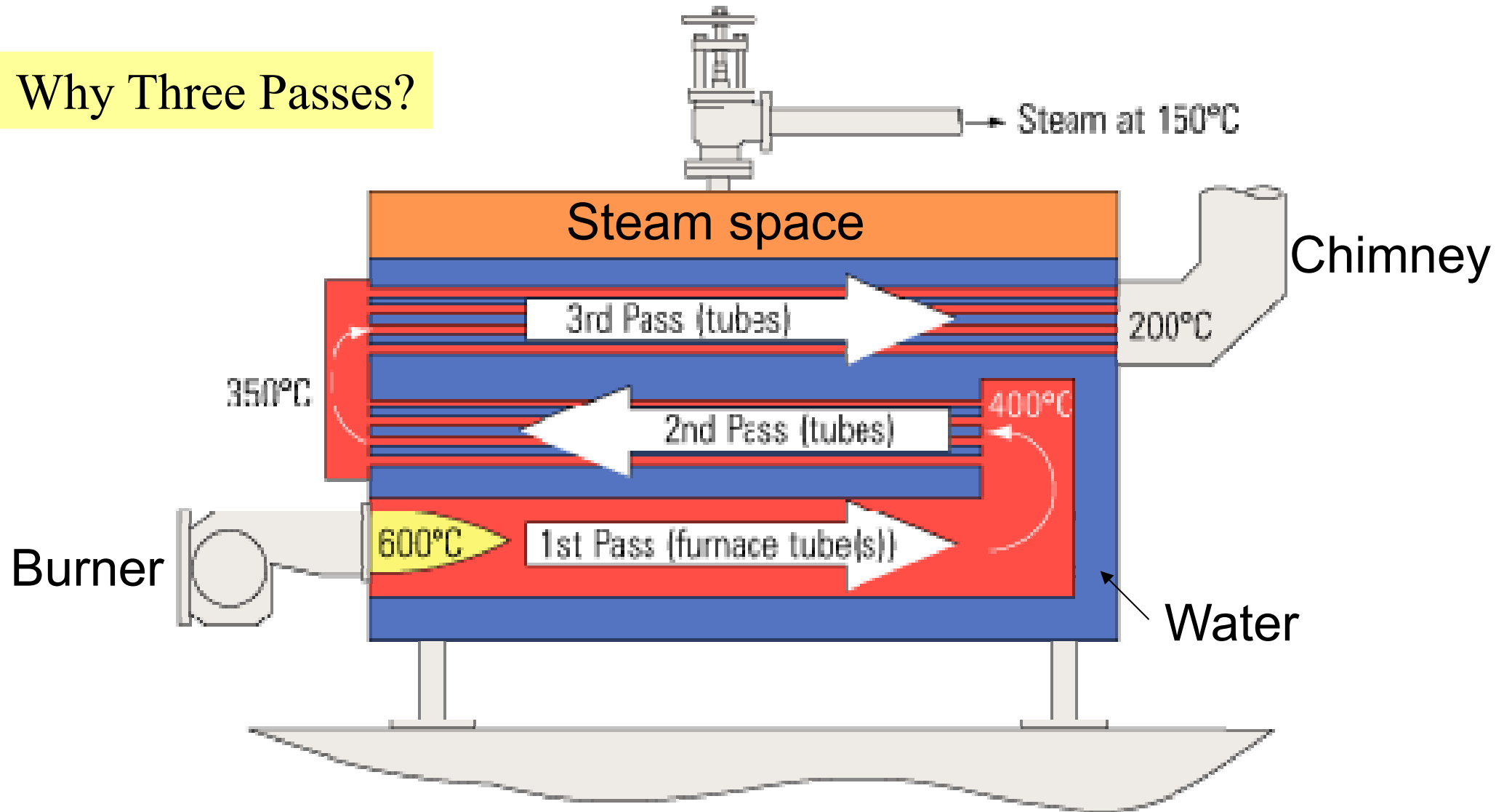
Economic boiler (two-pass, dry back)



| 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 |

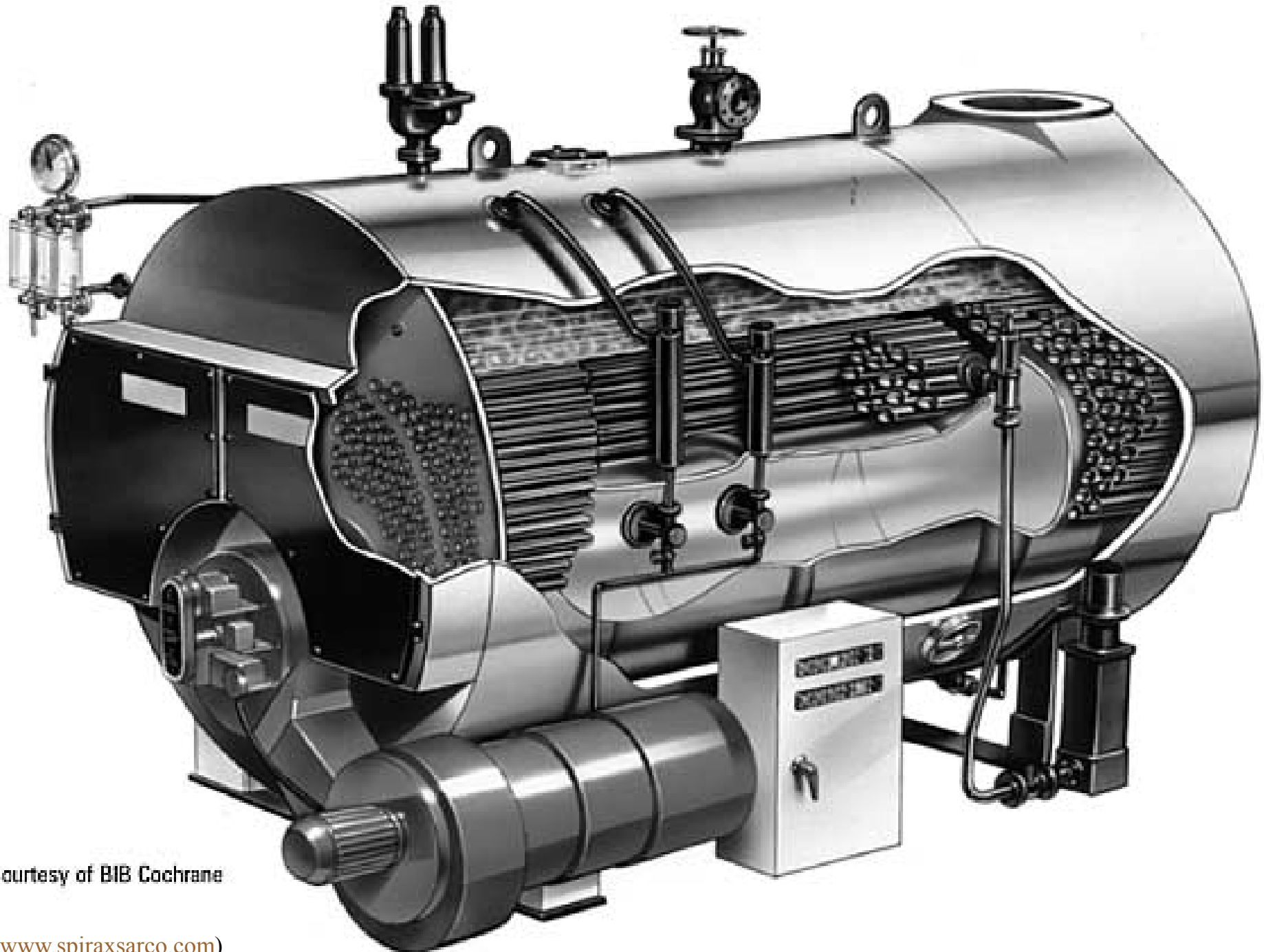
Economic boiler (three-pass, wet back)

Why Three Passes?



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

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



Courtesy of B&B Cochrane

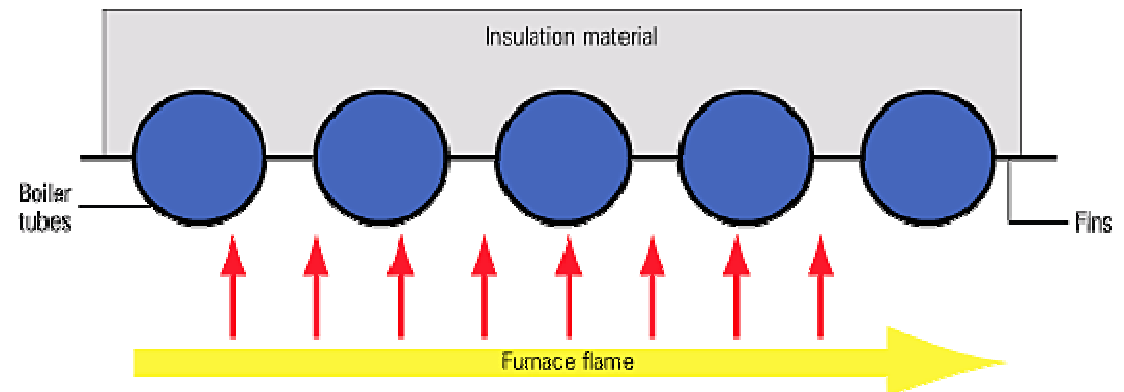
(Source: www.spiraxsarco.com)

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



Boilers



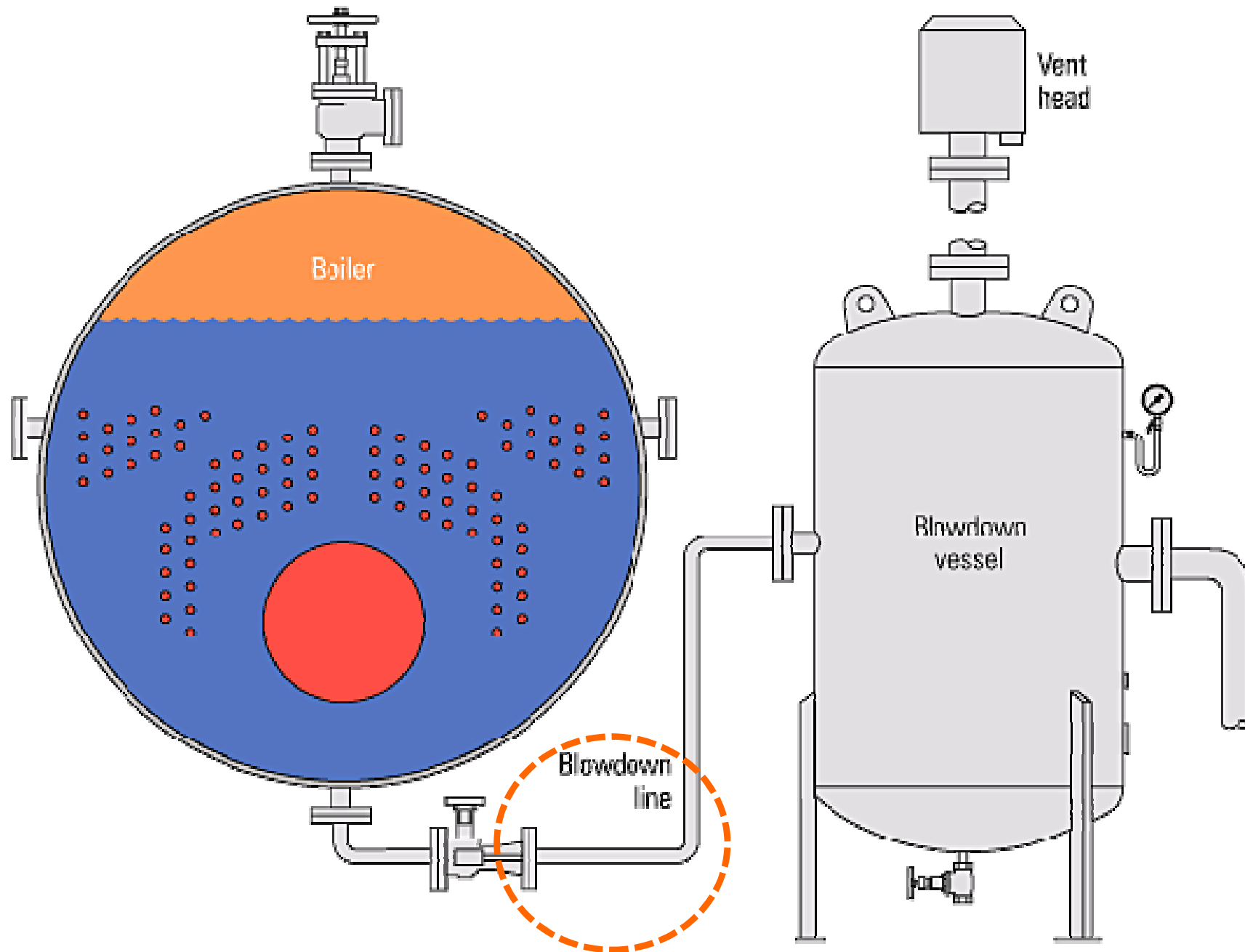
- Three types of commonly used boiler ratings:
 - ‘From and at’ rating
 - Widely used as a datum by shell boiler manufacturers
 - Shows the amount of steam in kg/h which the boiler can create ‘from and at 100°C’, at atmospheric pressure
 - kW rating
$$\text{Steam output (kg/h)} = \text{Boiler rating (kW)} \times \frac{3\,600 \text{ s/h}}{\text{Energy to be added (kJ/kg)}}$$
 - 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

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

| | |
|--|----------------|
| Serial Number | 32217 |
| Model Number | Shellbol Mk.II |
| Output | 3,000 kg/h |
| Design pressure | 19 bar |
| Maximum working pressure | 18 bar |
| Hydraulic test pressure | 28.5 bar |
| Date of test | 26/03/91 |
| Design standard | BS EN 12953 |
| Class | 1 |
| Inspection authority | British Engine |
| Manufactured by Boilermakers Ltd. | |



Boiler blowdown (to remove suspended solids)



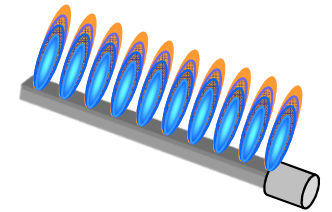
Warm air furnaces



- 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)

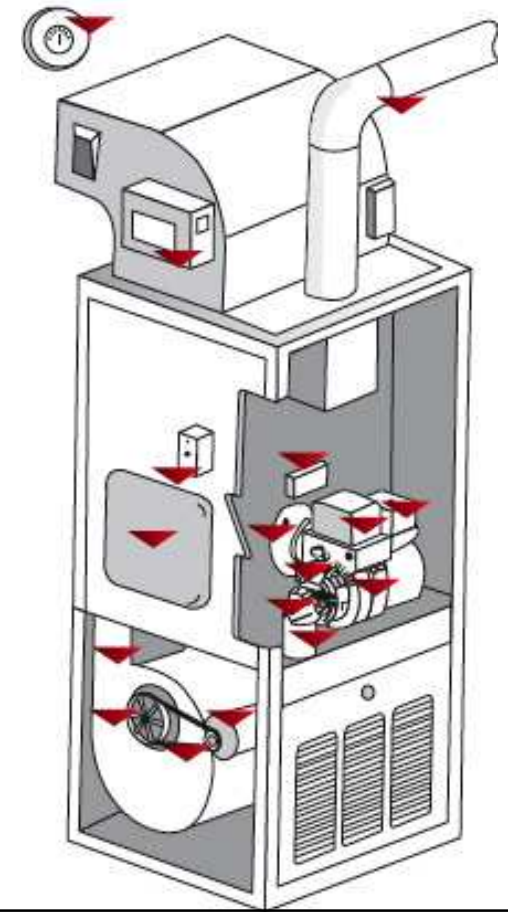
- Combustion requires fuel, oxygen and heat



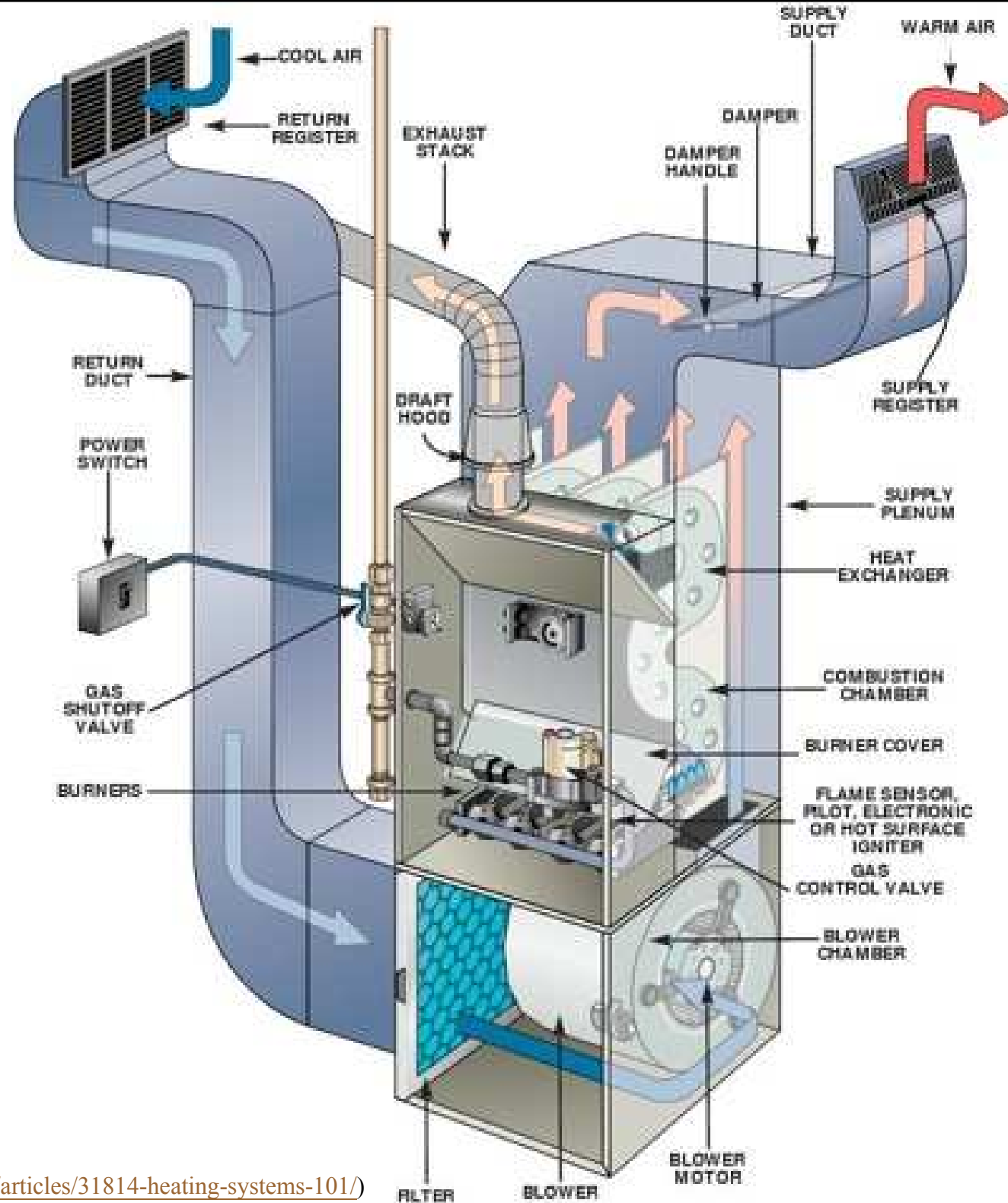
Warm air furnaces



- 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

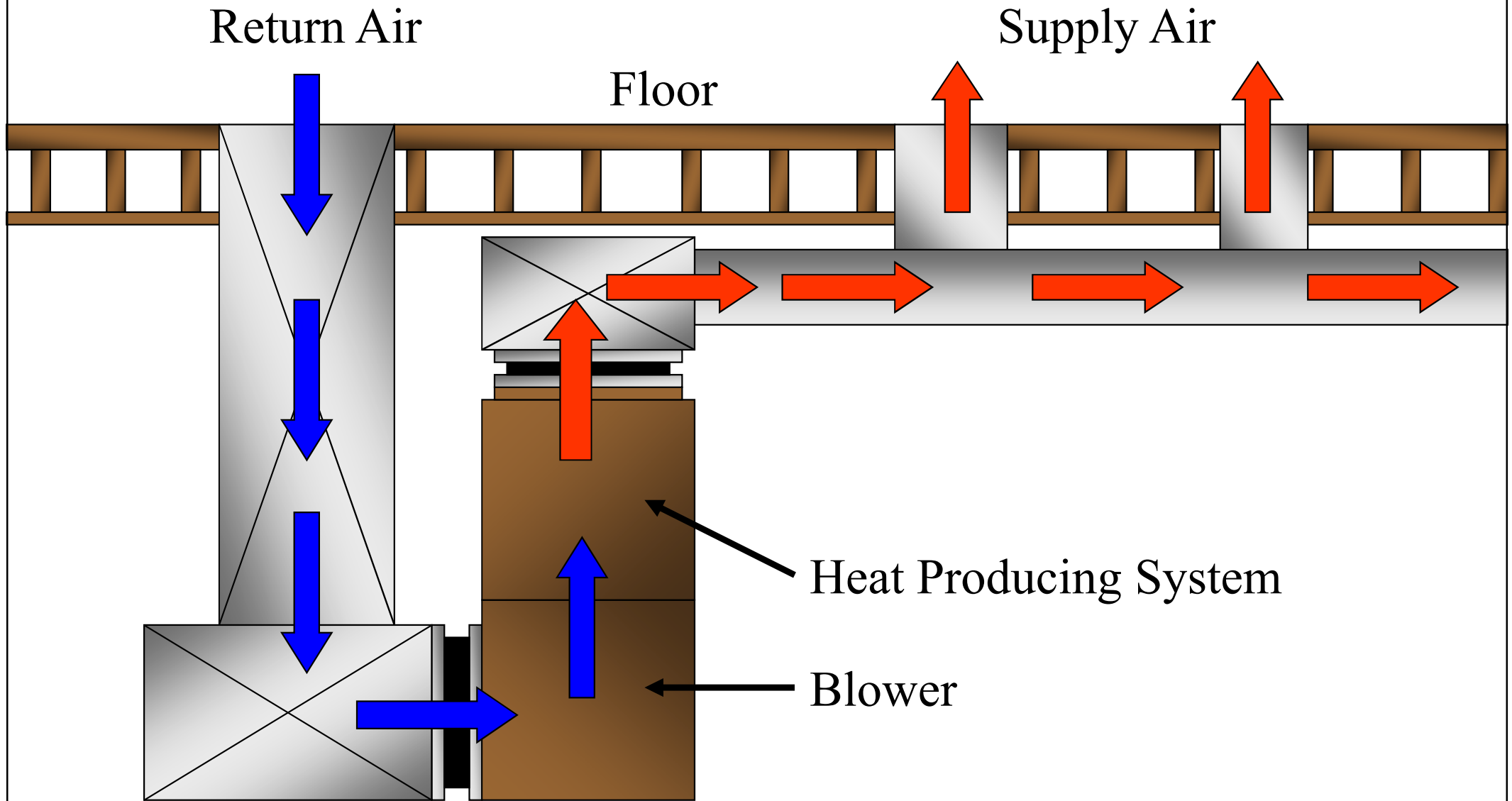


Warm air furnaces

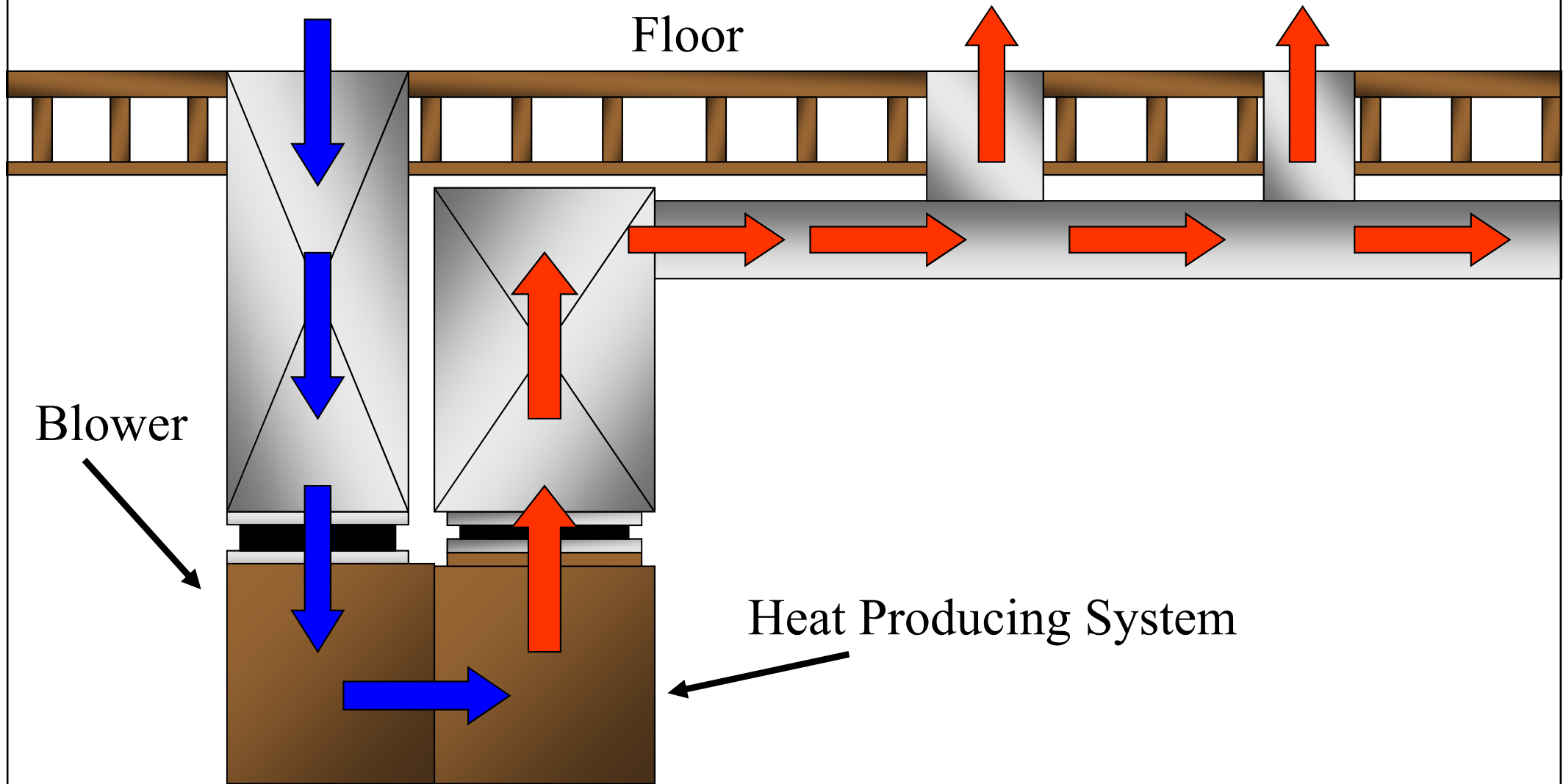


- Types of furnaces
 - Upflow – Stands vertically, top air discharge
 - Low Boy – Used where there is little headroom
 - Both supply and return are at the top
 - Blower located behind the furnace
 - Downflow – Stands vertically, bottom air discharge
 - Horizontal – Left or right discharge
 - Multipoise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

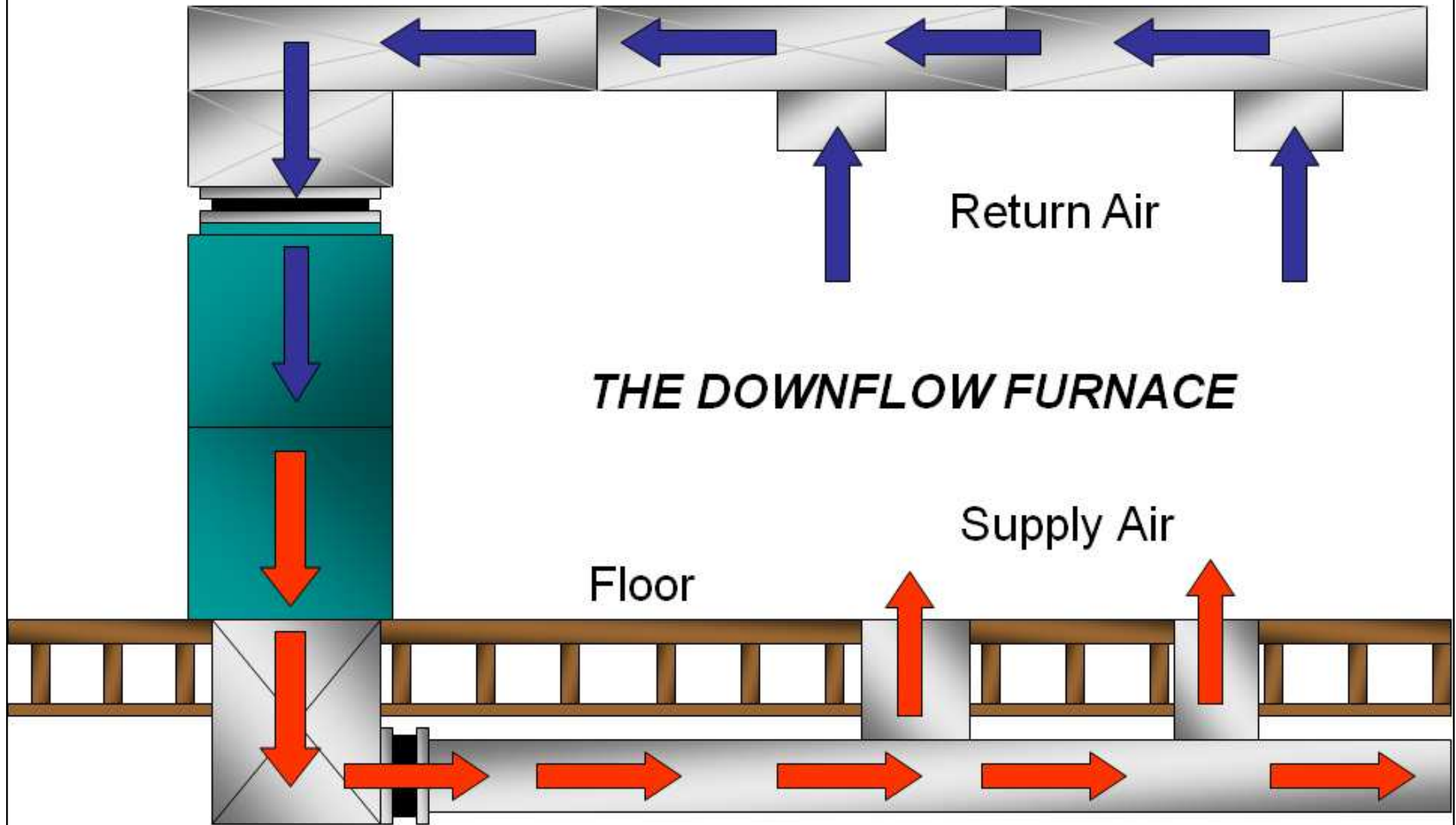
Upflow furnace



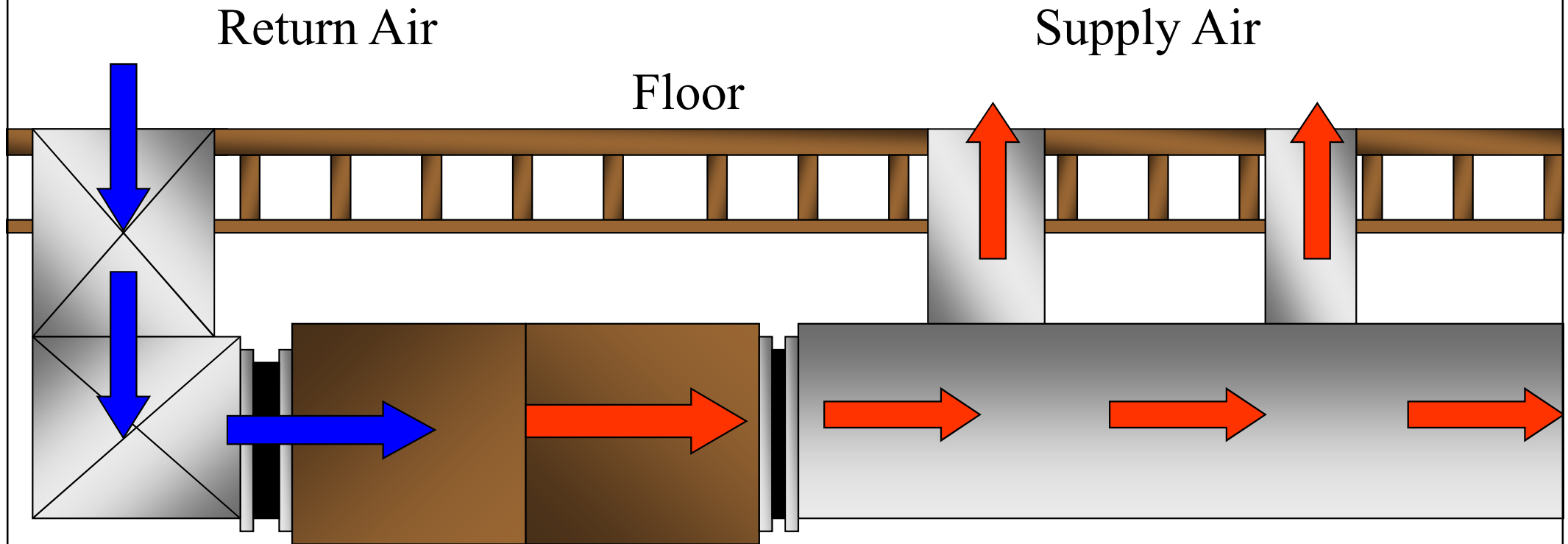
Low boy furnace



Downflow furnace



Horizontal furnace installed in a basement

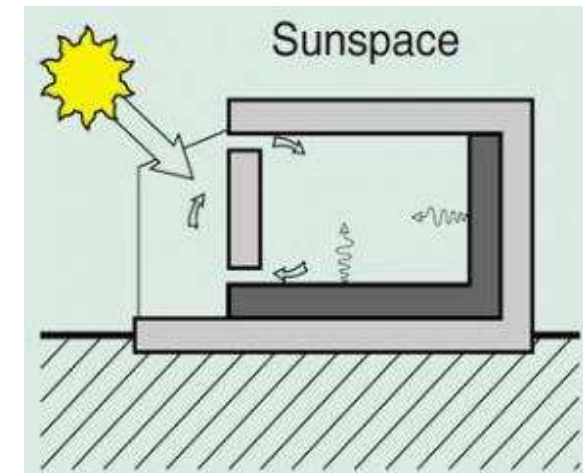
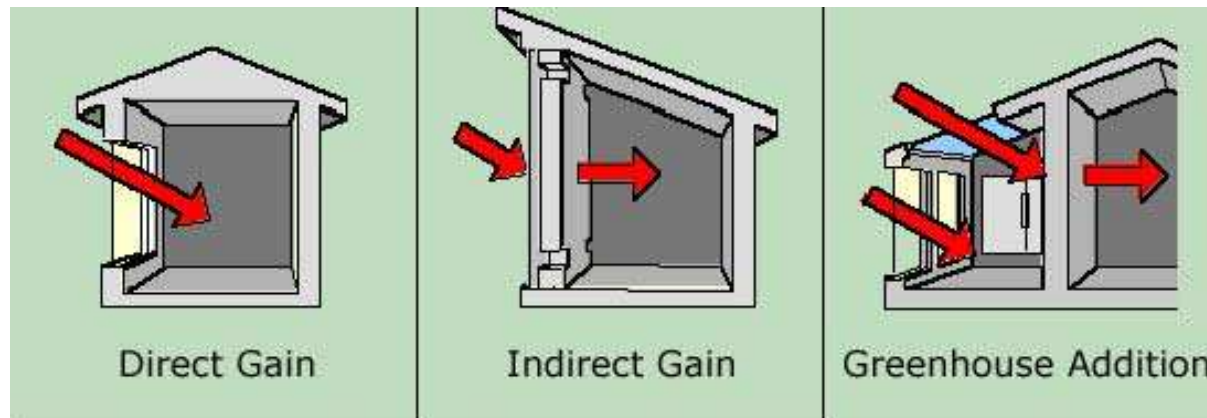
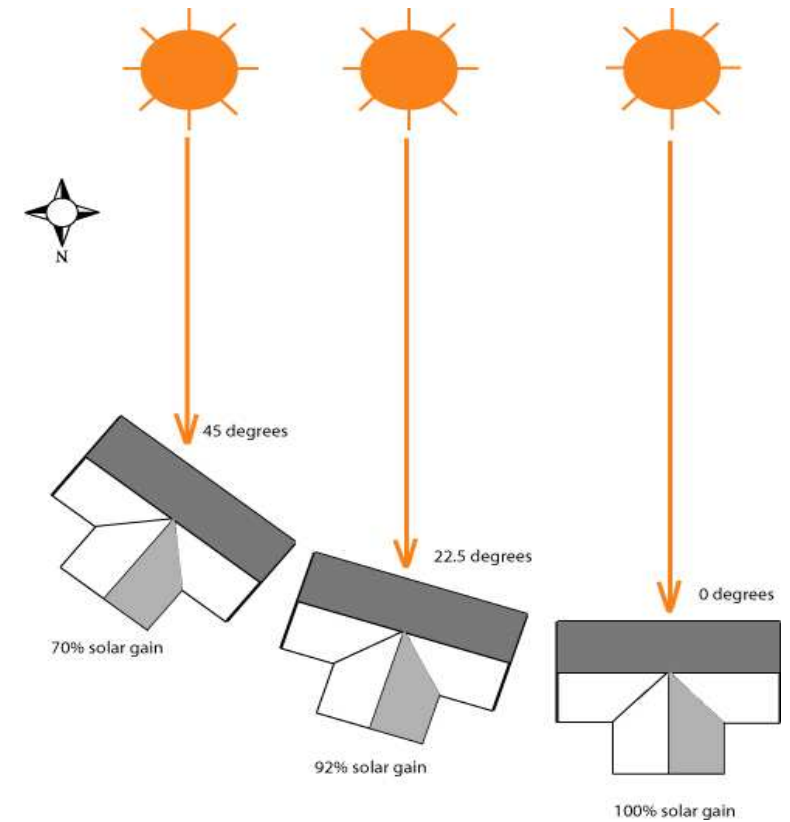
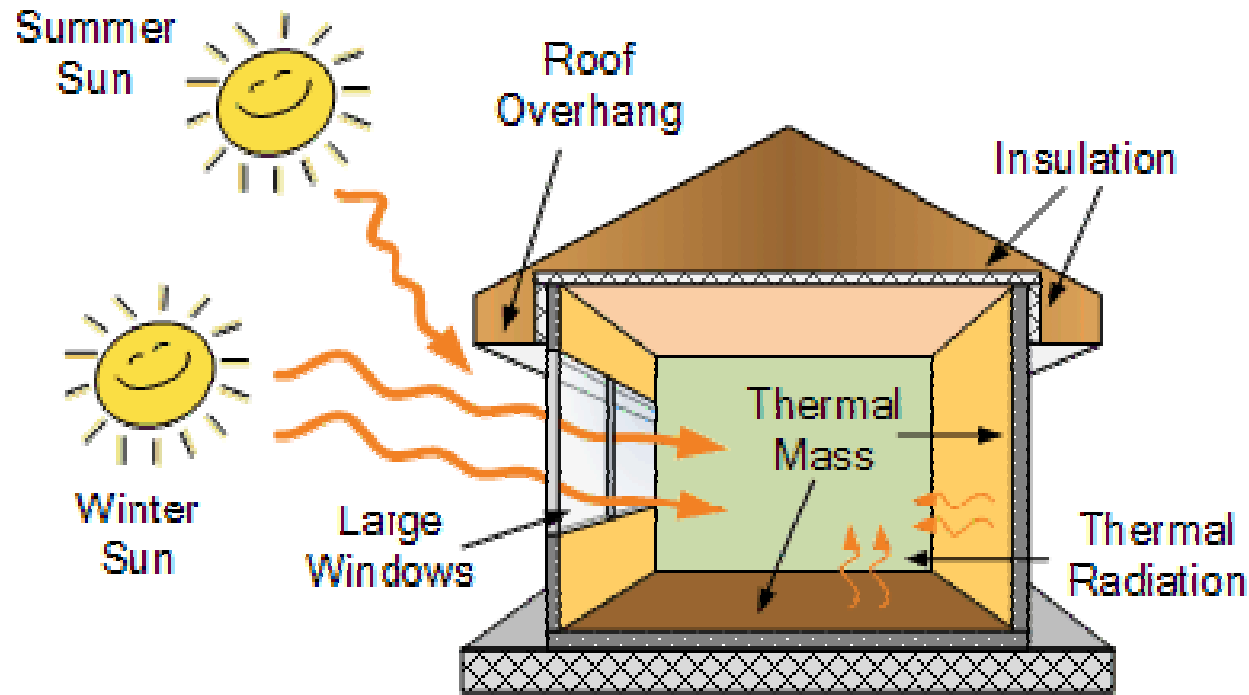




Solar heating

- 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

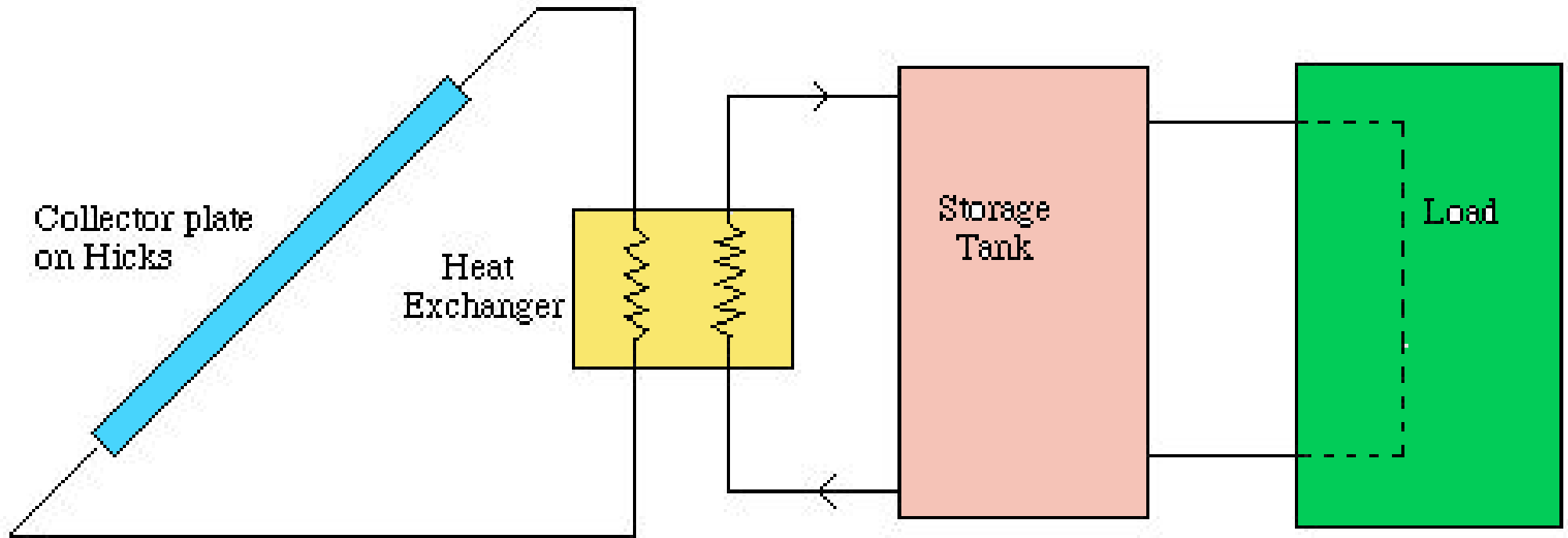




Solar heating

- **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

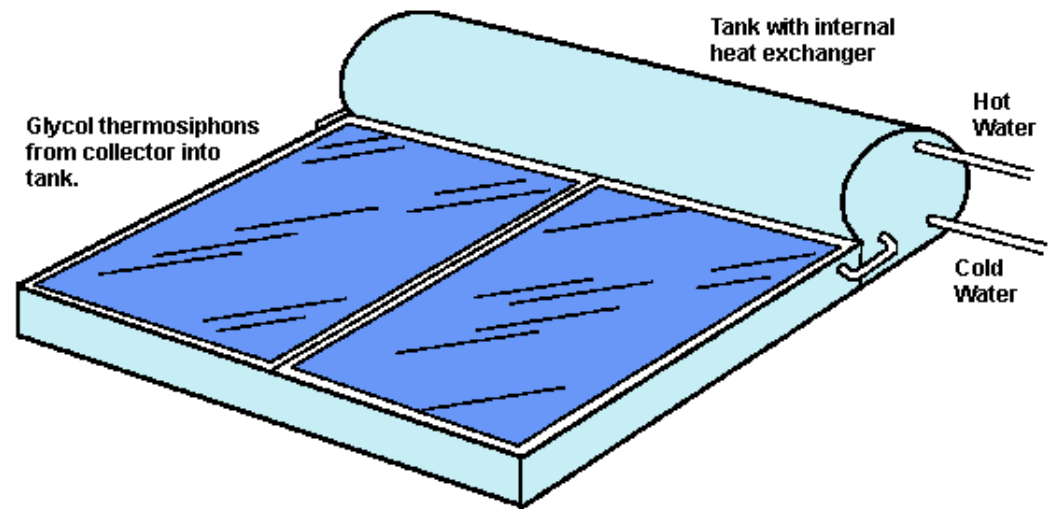
Solar hot water systems



Flat board type



Vacuum glass pipe type

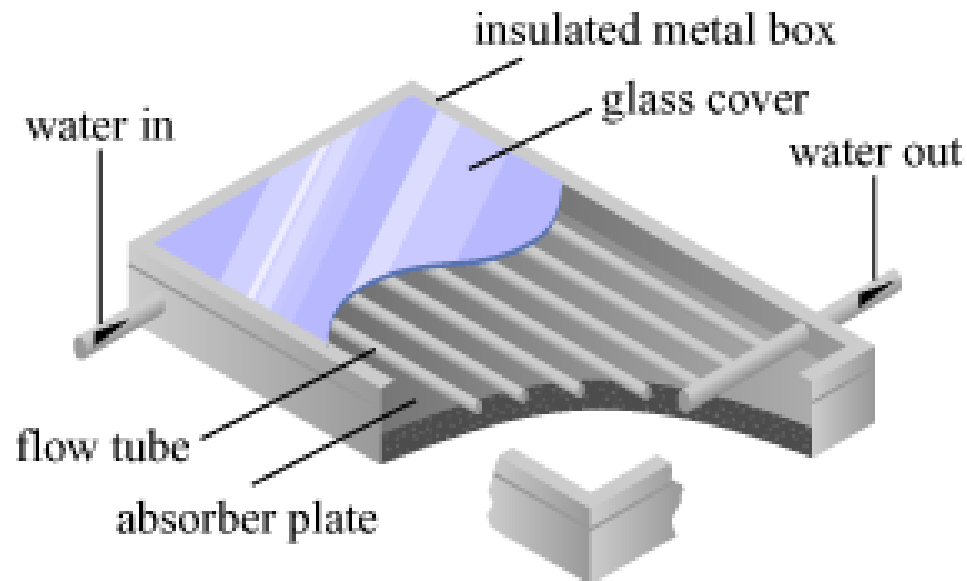
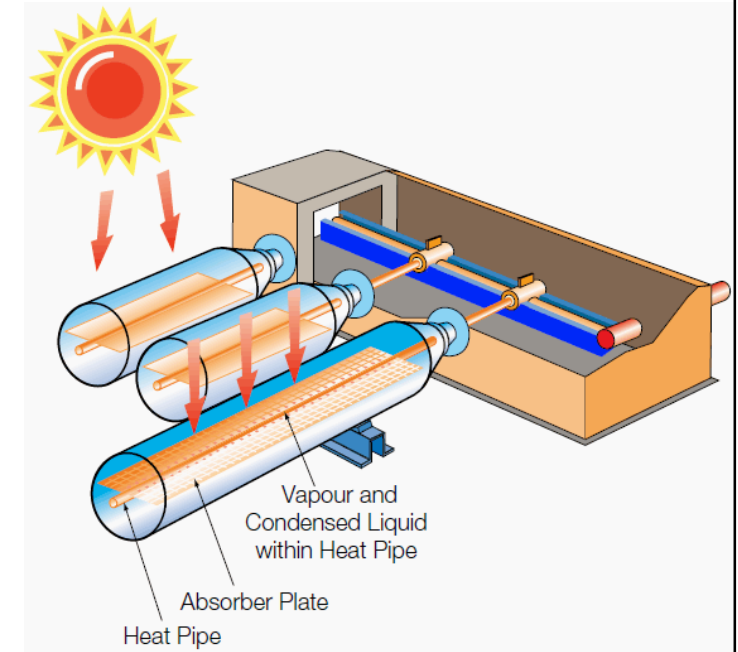


**Simple domestic system
(with integral storage tank)**

Examples of solar thermal systems



Flat-plate solar collector



Evacuated-tube solar collector

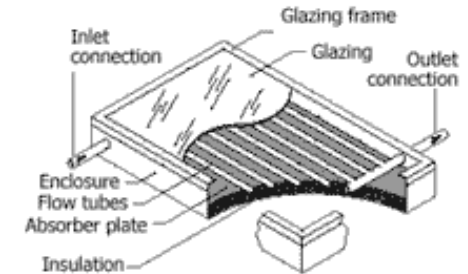
Solar heating



- Types of solar collectors

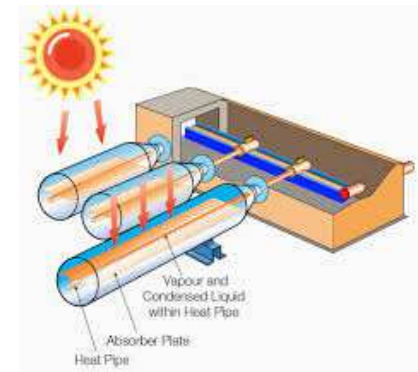
- Flat-plate solar collector

- Main components: glazing panel, absorber, flow tubes, insulation



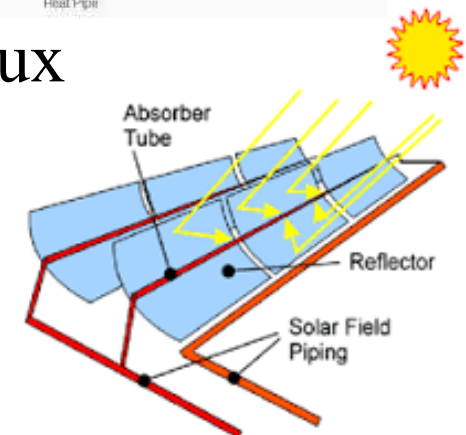
- Evacuated-tube solar collector

- Water-in-glass type or with heat pipe

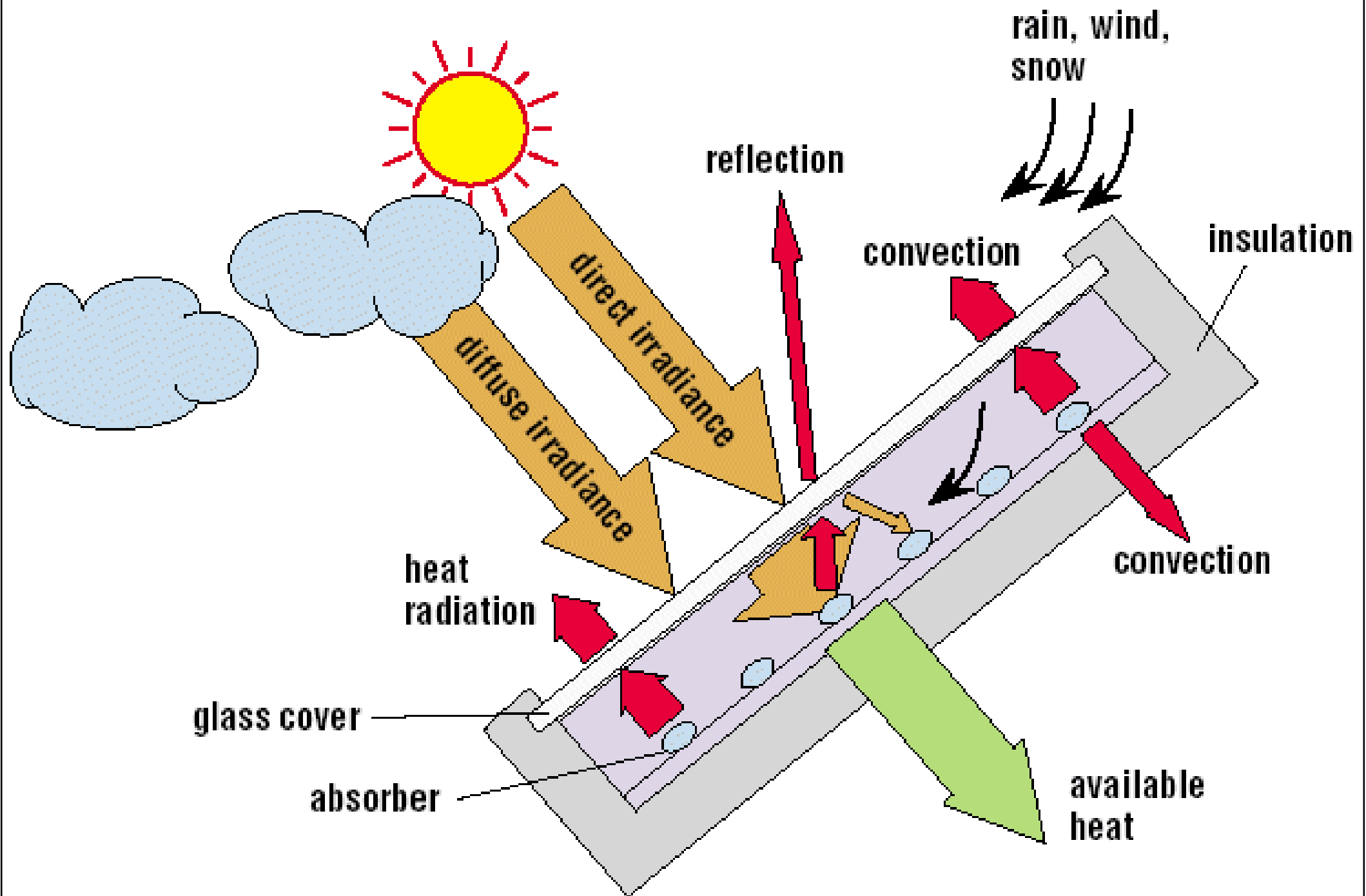


- Concentrating solar collector

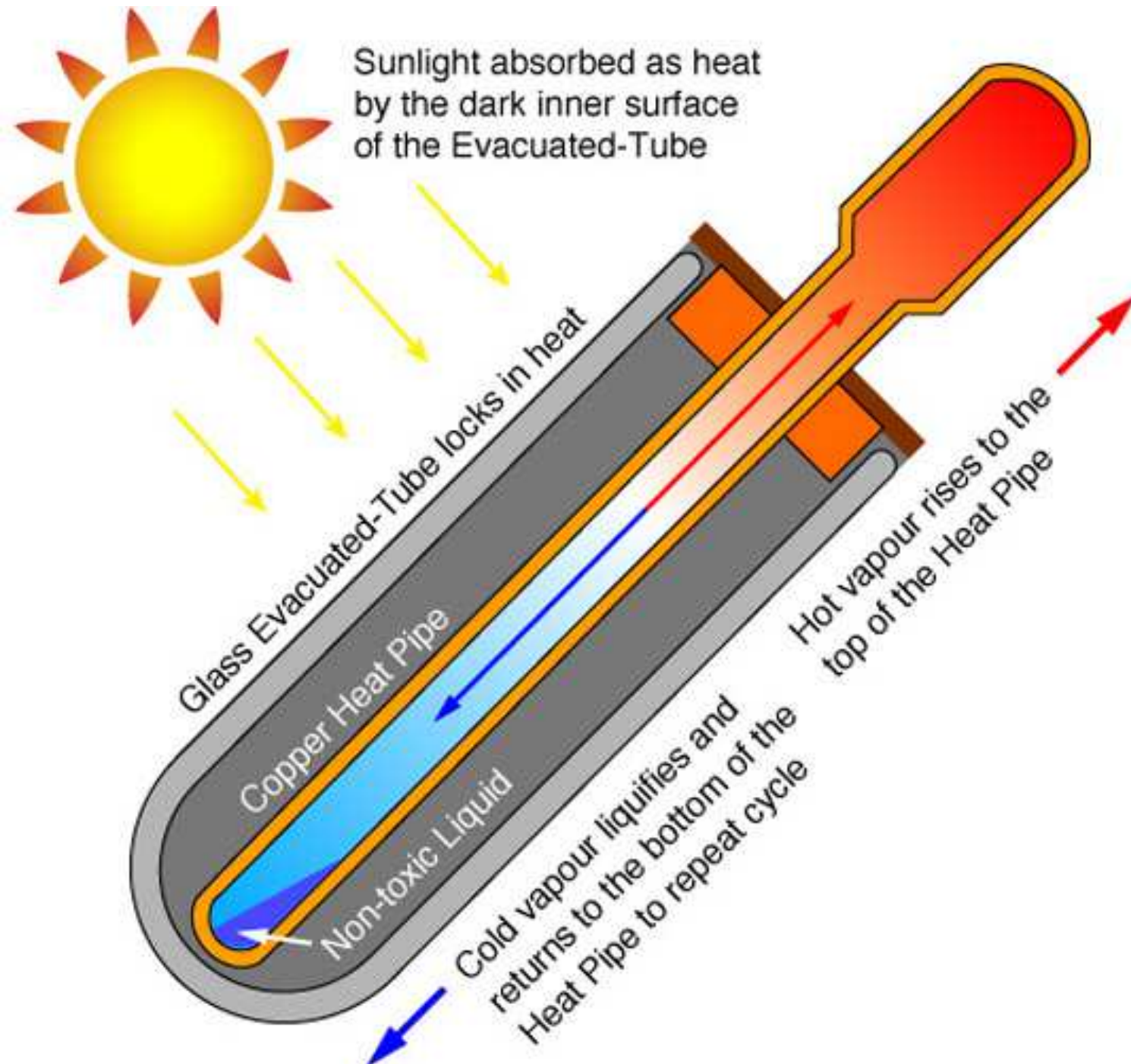
- Smaller receiver area to increase the solar flux
 - Such as parabolic trough, dish concentrator, multifaceted mirror type



Heat transfer processes at a flat-plate solar collector



Principle of an evacuated tube collector with heat pipe

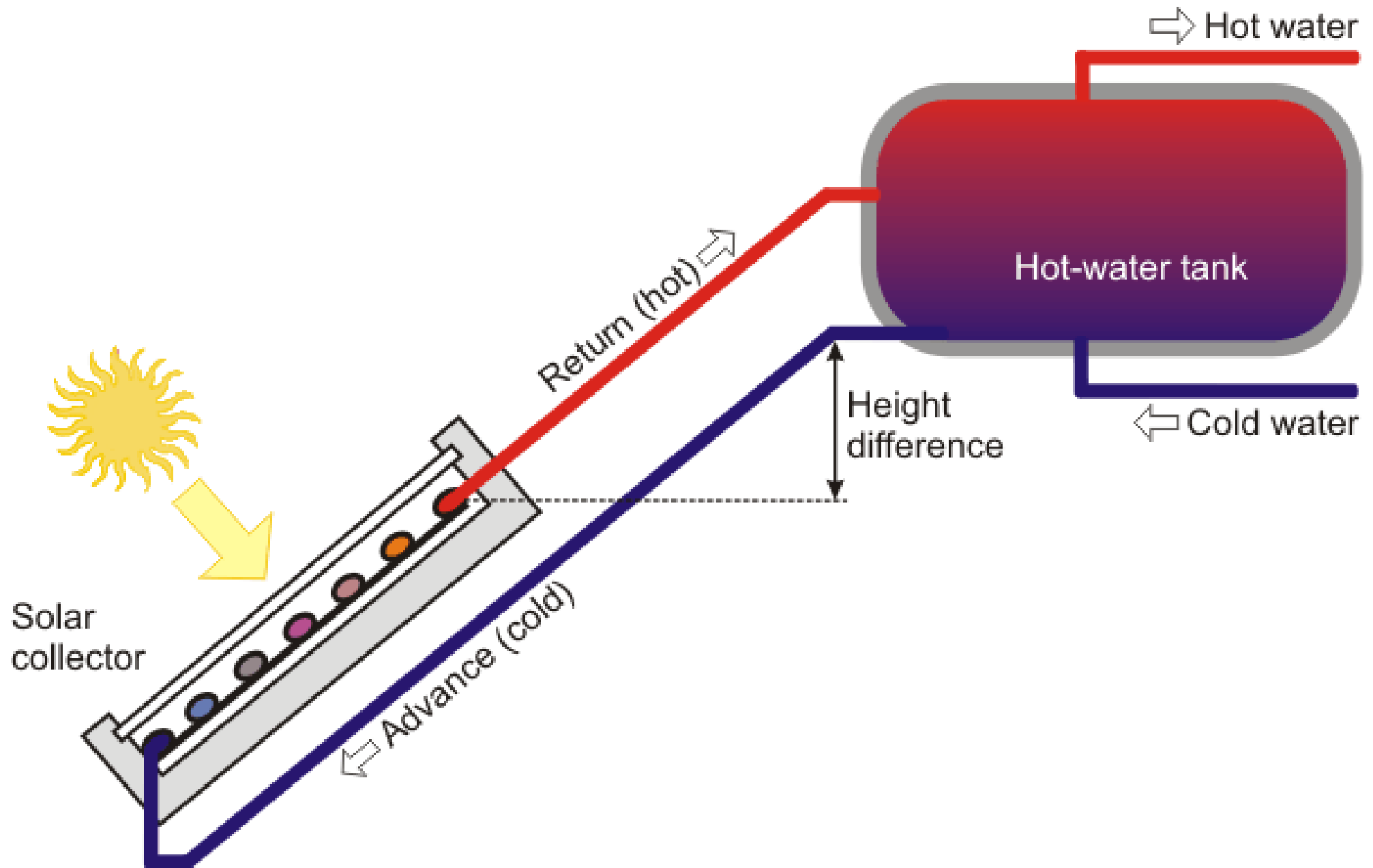


Why Tibet is
good for using
solar energy?

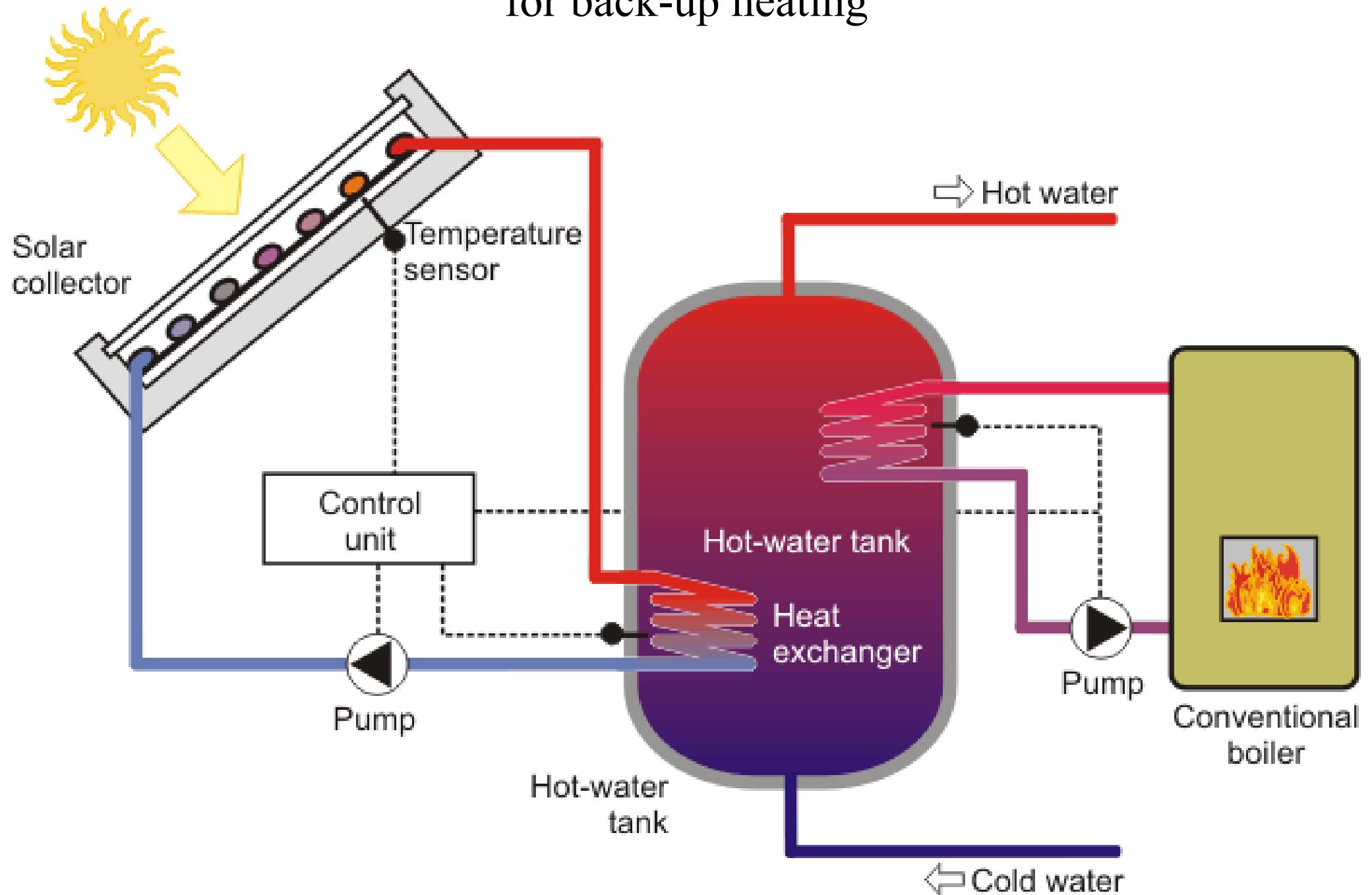


Evacuated-tube solar hot water system in a hotel in Lhasa, Tibet
(photo taken by Dr Sam C M Hui)

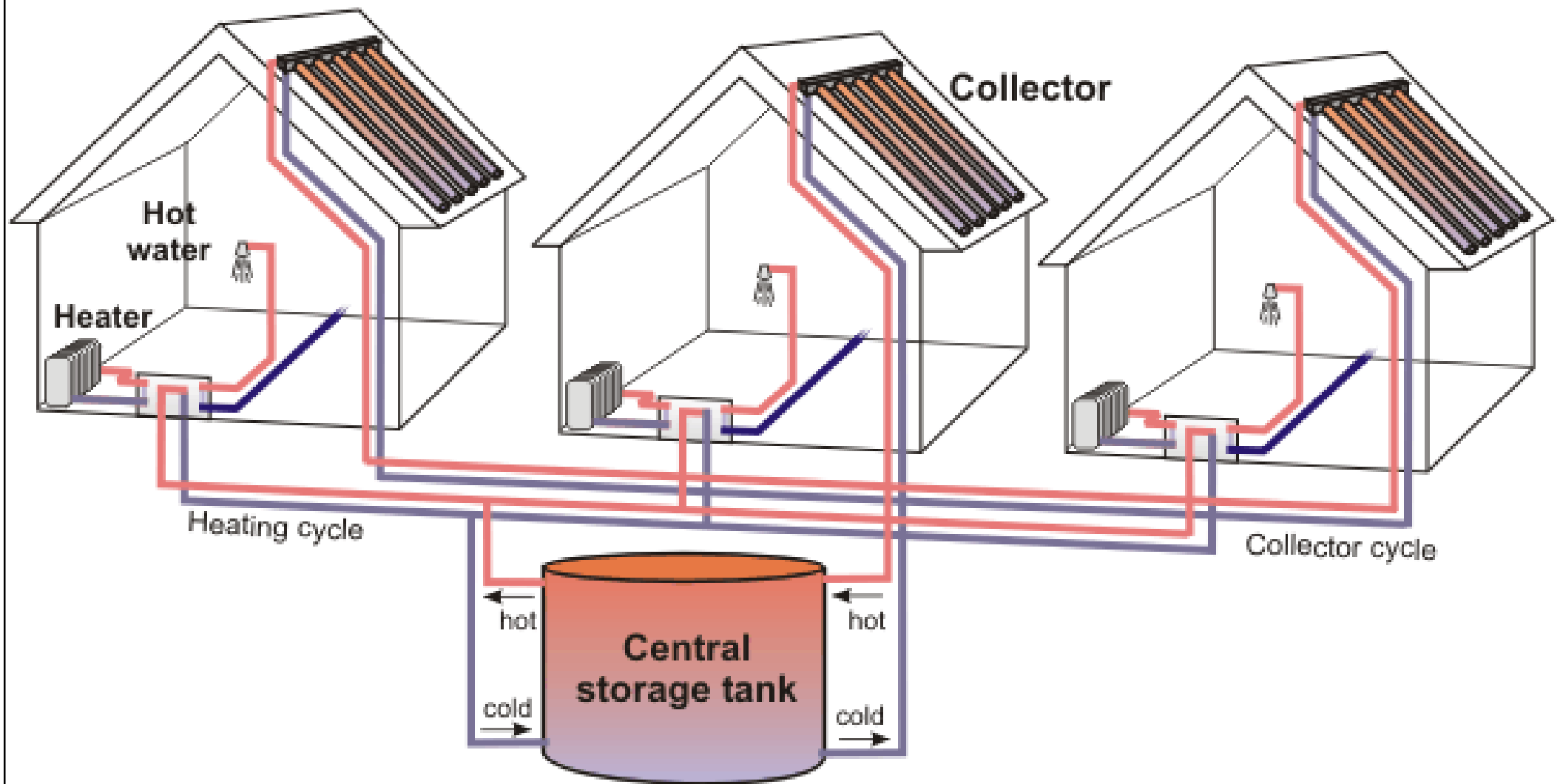
A thermosyphon system

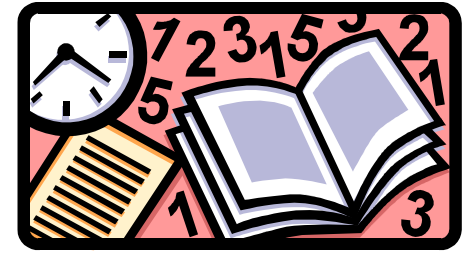


A double-cycle system with forced circulation with a conventional boiler for back-up heating



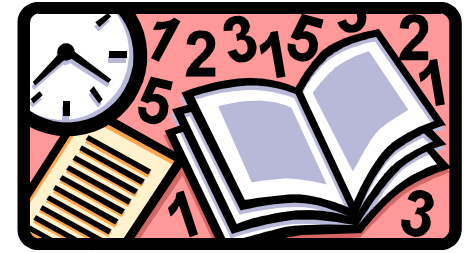
A solar district heating system





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



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- 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