MEBS6008 Environmental Services II

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Heat Pumps

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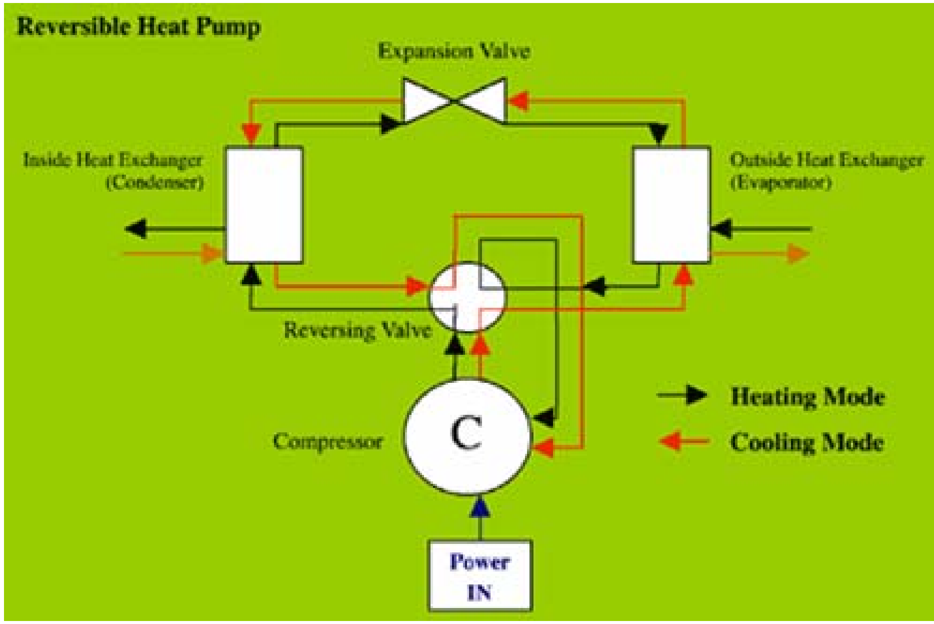
Content

Heat Pumps Systems

- ✓ What is a heat pump?
- ✓ Basic Types of Heat Pump Cycles.
- ✓ Heat Sources and Heat Sinks.
- ✓ Different Types of Heat Pumps.
- ✓ Criteria for evaluation on Performance of Heat Pumps.
- ✓ Comparison of Heat Pump and Other Heating Sources.

What Is a Heat Pump?

- ✓ A heat pump is a self-contained, packaged cooling-and-heating unit with a reversible refrigeration cycle (reversing the functions of two heat exchangers).
- ✓ Heat sources : ground, well water, surface water, gray water, solar energy, air, internal building heat.
- ✓ They can also include heat rejecters (cooling towers), supplementary heaters (boilers and steam heat exchangers), solar collection devices, and thermal storage.
- ✓ Other uses including domestic and service water heating, pool heating, industrial process heating

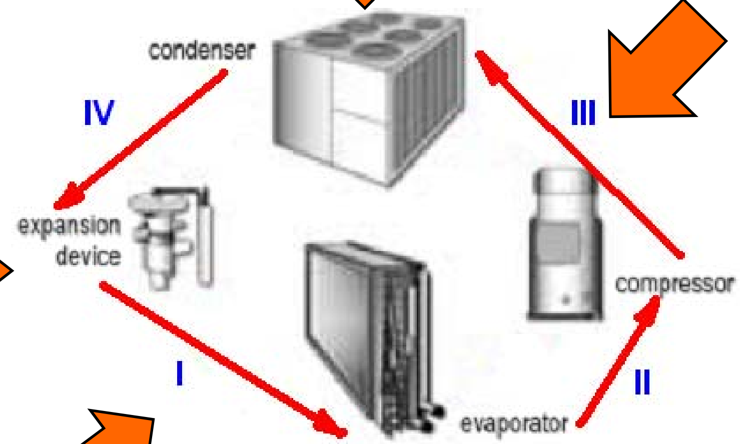


Review of a Typical Vapour Compression Cycle - Cooling

Refrigerant condenses into a liquid.

Hot, high-pressure refrigerant vapor

Expansion device reduces the pressure of refrigerant

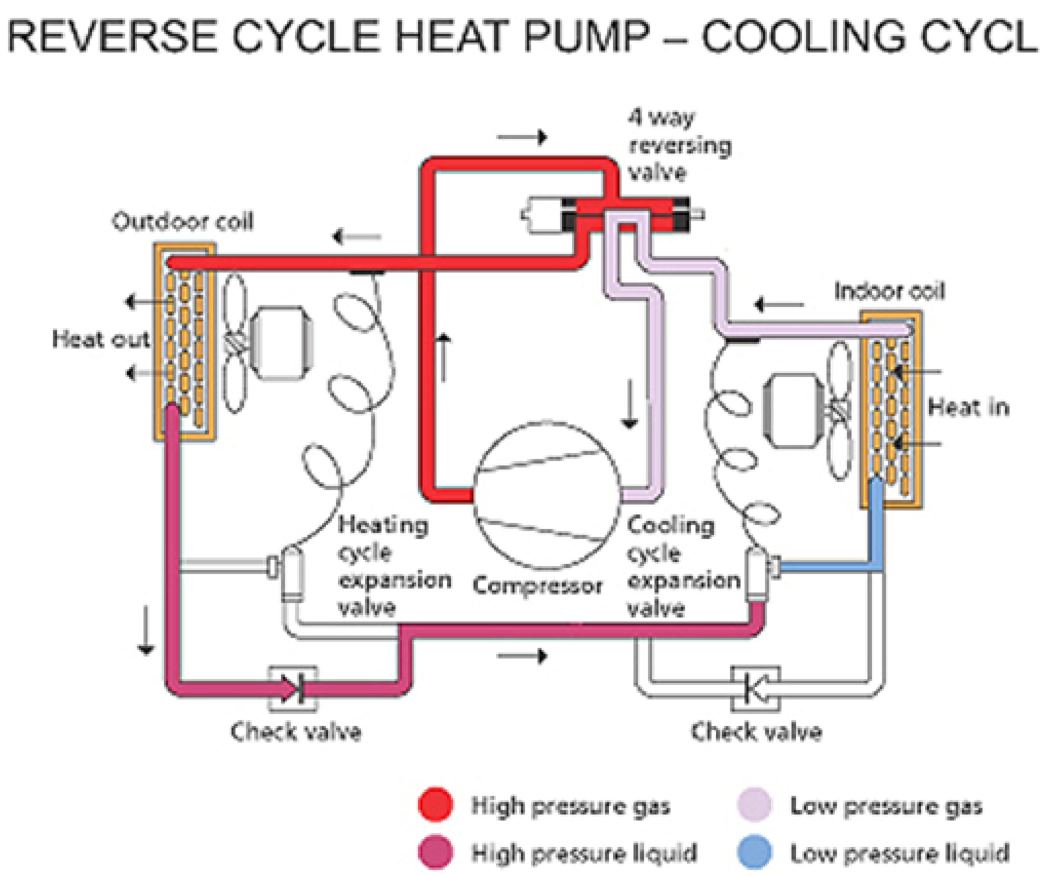


Compressor increases pressure & temperature of refrigerant vapor.

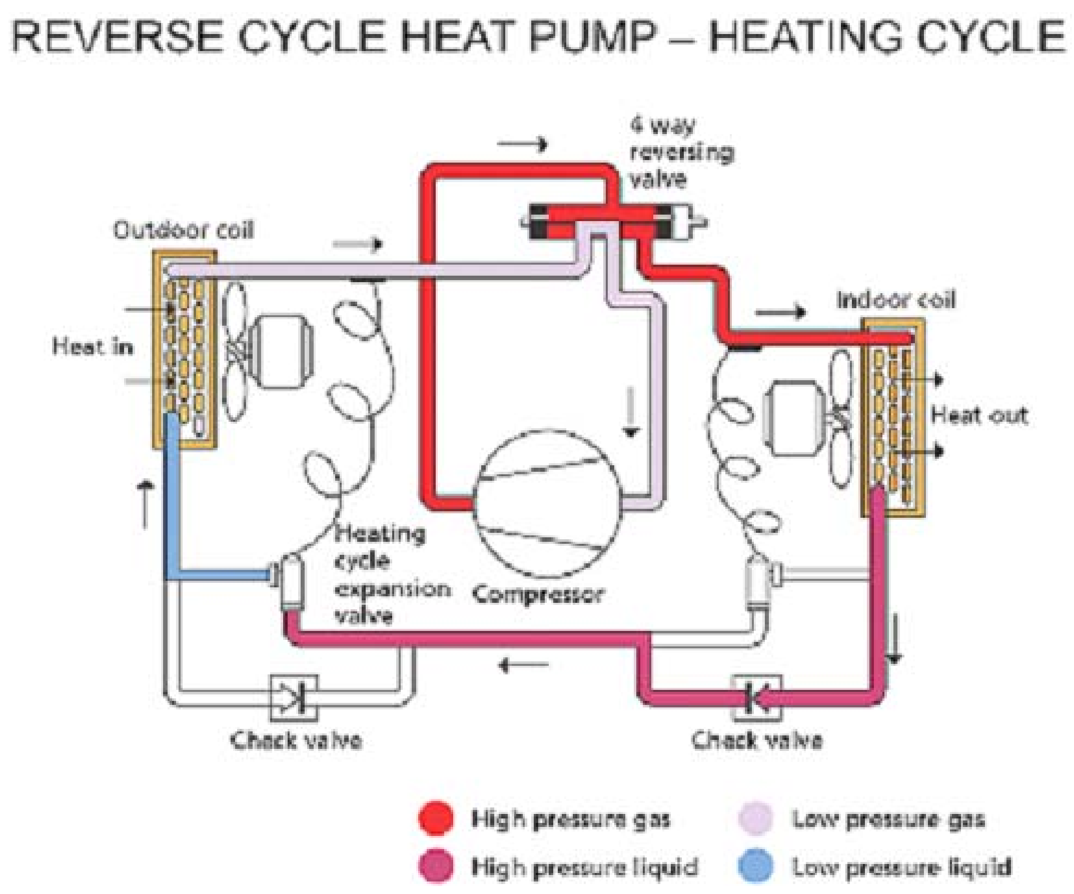
Refrigerant :a cool, low-pressure mixture of liquid and vapor.

Heat is transferred from the relatively warm air or water to refrigerant -> causing liquid refrigerant to boil.

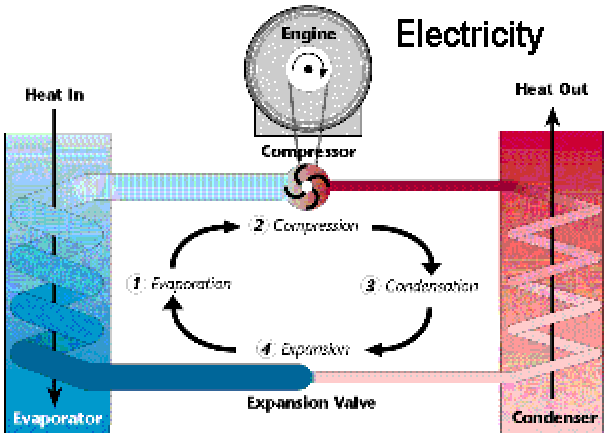
Heat Pump at Cooling Mode



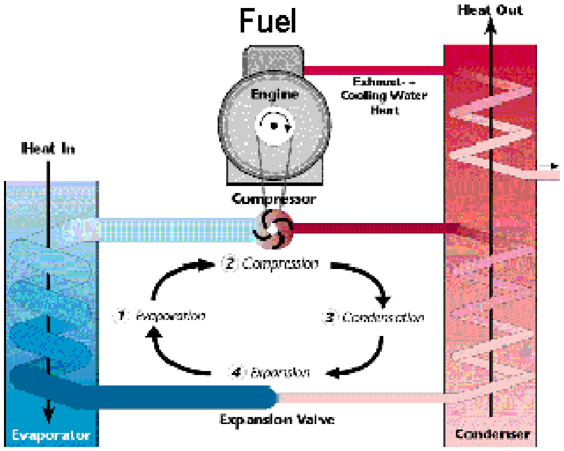
Heat Pump at Heating Mode



Heat Pump driven by Electric Motor & Gas Engine



Closed cycle, electric-motor-driven vapour compression heat pump

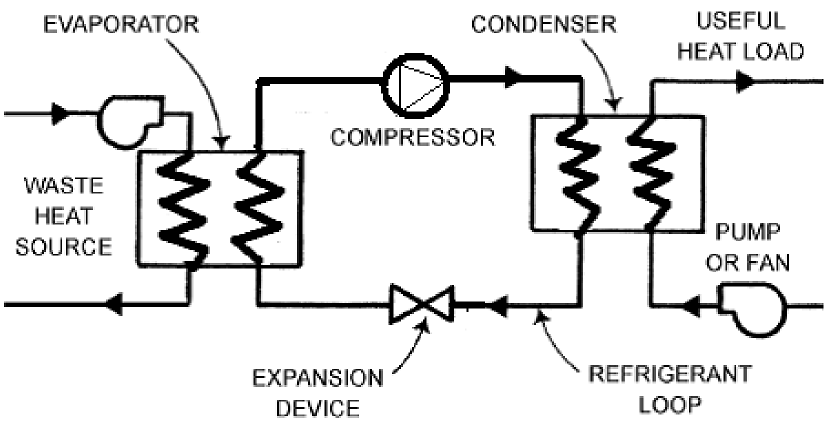


Closed cycle, engine-driven vapour compression heat pump.

Basic types of heat pump cycles

Basic types of heat pump cycles

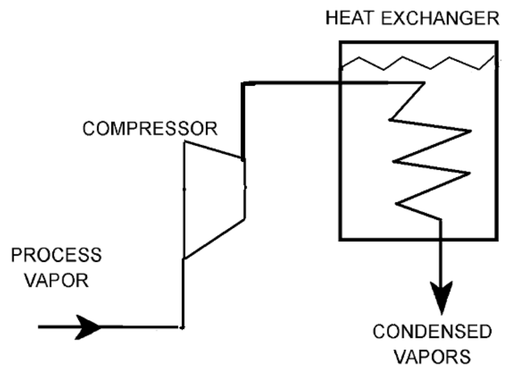
Closed vapor compression cycle



- ✓ This is the most common type used in both HVAC and industrial processes.
- ✓ It employs a conventional, separate refrigeration cycle that may be single-stage, compound, multistage, or cascade.

Basic types of heat pump cycles

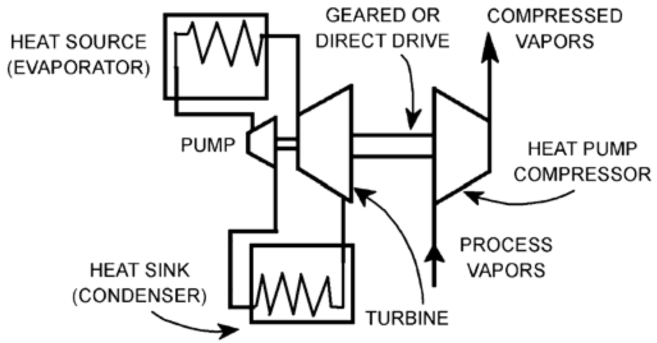
Mechanical vapor recompression cycle with heat exchanger



- ✓ Process vapor is compressed to a temperature and pressure sufficient for reuse directly in a process.
- ✓ Energy consumption is minimal, because temperatures are optimum for the process.

Basic types of heat pump cycles

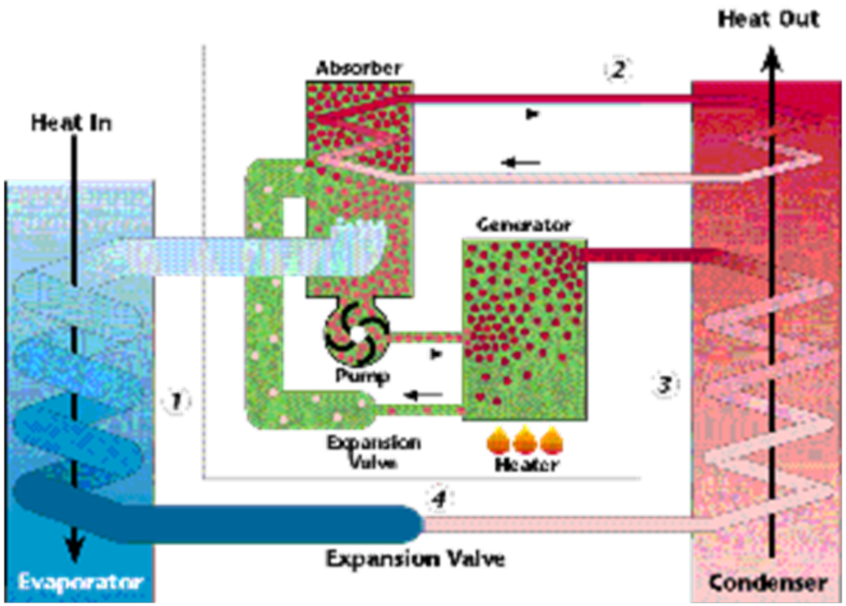
Heat-driven Rankine cycle



- ✓ This cycle is useful where large quantities of heat are wasted and where energy costs are high.
- ✓ The heat pump portion of the cycle may be either open or closed

Basic types of heat pump cycles

Vapour Absorption Cycle



- ✓ Compression of the working fluid is achieved thermally in a solution circuit which consists of an absorber, a solution pump, a generator and an expansion valve.
- ✓ Low-pressure vapour from the evaporator is absorbed in the absorbent. **This process generates heat.** The solution is then enters the generator, where the working fluid is boiled off with an external heat supply at a high temperature.
- ✓ The working fluid (vapour) is condensed in the condenser while the absorbent is returned to the absorber via the expansion valve.

Heat Sources and Heat Sinks

HEAT SOURCES AND SINKS

Air

- ✓ Extended-surface, forced-convection heat transfer coils transfer heat between the air and the refrigerant.
- ✓ Sizing depends on outdoor air temperature and consideration in frost formation.
- ✓ Heating capacity is heavily temperature dependent.
- ✓ Accumulated frost inhibits heat transfer. Defrost frequency depends on climate, air-coil design, and the hours of operation. Say after 20 min of operation.
- ✓ Early designs :Fin spacing of 5 to 6 mm to minimize the frequency of defrosting.
- ✓ With effective hot-gas defrosting, fin spacing of 1.3 to 2.5 mm is permitted.

HEAT SOURCES AND SINKS

Water

- City water
  - seldom used
  - cost and municipal restrictions.
- Surface or stream water
  - Limit temperature drop across evaporator in winter to prevent freeze-up.
  - Heat exchangers be submerged in open ponds, lakes or streams.
- Industrial waste process water
  - Spent warm water in laundries, plant effluent, and warm condenser water as heat source.
- Sewage
  - Temperatures > surface or groundwater (USA)
  - Secondary effluent (treated sewage) is usually preferred
  - Untreated sewage need heat exchanger

HEAT SOURCES AND SINKS

Water

- Groundwater (well water)
  - relatively high and nearly constant temperature.
  - The water temperature is a function of source depth and climate
  - The use is non consumptive (only the water temperature changes).
  - Possibility of scale formation and corrosion
  - Heat exchanger to separate well water from the equipment.
  - Filtering and settling ponds for specific fluids.
  - Costs of drilling, piping, pumping, disposal of used water.
  - Information on well water availability, temperature, chemical and physical analysis is available from U.S. Geological Survey offices in USA (Hong Kong ?)

HEAT SOURCES AND SINKS

Ground

- ✓ Heat transfer through buried coils.
- ✓ Soil composition (wet clay to sandy soil), has a predominant effect on thermal properties and expected overall performance.
- ✓ Thermal diffusivity is the ratio of thermal conductivity to the product of density and specific heat. It values depends on soil data.
- ✓ The soil moisture content influences its thermal conductivity.

HEAT SOURCES AND SINKS

Solar Energy

- ✓ As the primary heat source or in combination with other sources.
- ✓ Air, surface water, shallow groundwater, and shallow ground-source systems all use solar energy indirectly.
- ✓ Using solar energy directly can provide a higher temperature resulting in an increase in the heating coefficient of performance.
- ✓ Direct system places refrigerant evaporator tubes in a solar collector.
- ✓ An indirect system circulates either water or air through the solar collector

Different Types of Heat Pumps

AIR-SOURCE HEAT PUMP SYSTEMS
(Air-to-Air Heat Pumps)

Different Types of Heat Pumps

AIR-SOURCE HEAT PUMP SYSTEMS (Air-to-Air Heat Pumps)

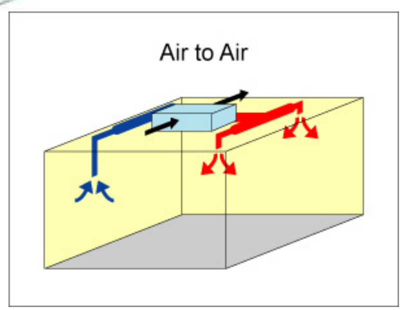
- ✓ Since air is readily available everywhere, they are the most widely used in residential and many commercial buildings.
- ✓ The cooling capacity : 1 and 30 tons (3.5 and 105 kW).
- ✓ Air-source heat pumps can be classified as individual room heat pumps (without ductwork) and packaged heat pumps (rooftop heat pumps and split heat pumps).

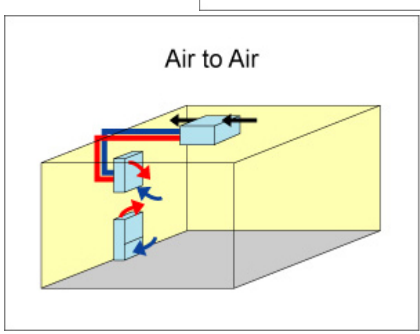
Roof top package unit

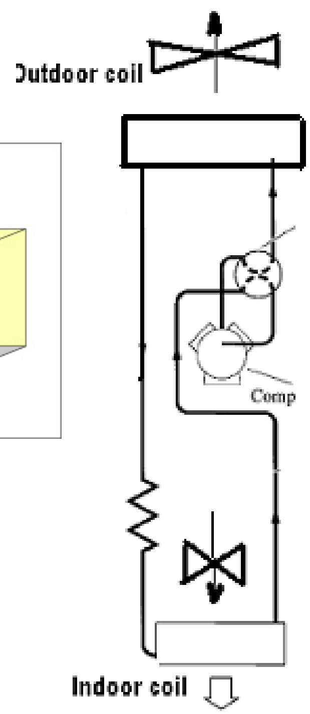
Split System Heat Pump

Different Types of Heat Pumps

AIR-SOURCE HEAT PUMP SYSTEMS (Air-to-Air Heat Pumps)







Most air-source heat pumps consist of :

- ✓ Outdoor Single or multiple compressors
- ✓ Indoor coils where heat is extracted from or rejected to the outdoor air
- ✓ Expansion valve
- ✓ Reversing valves that change the heating operation to a cooling operation and vice versa
- ✓ An accumulator to store liquid refrigerant, and other accessories

Different Types of Heat Pumps

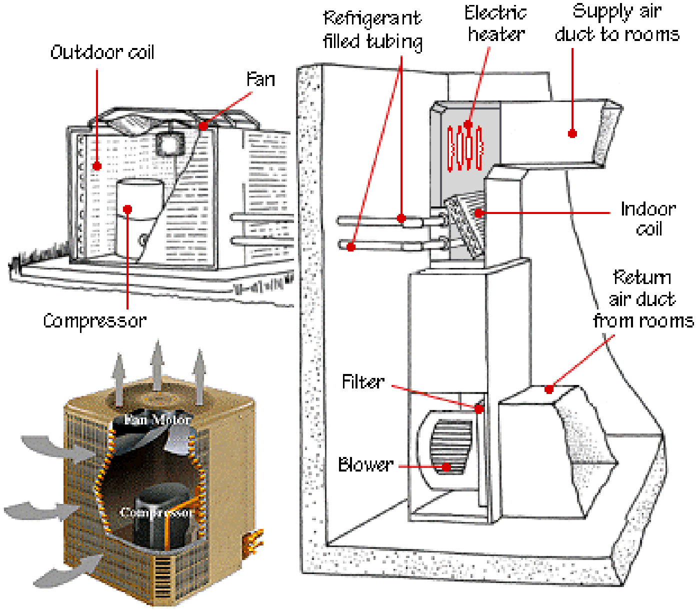
AIR-SOURCE HEAT PUMP SYSTEMS (Air-to-Air Heat Pumps)

Indoor Coil

- ✓ An indoor coil heats and cools the indoor supply air.
- ✓ For heat pumps using halocarbon refrigerants, the indoor coil is usually made from copper tubing and corrugated aluminum fins.

Outdoor Coil

- ✓ An outdoor coil always deals with outdoor air: it acts as a condenser or an evaporator.
- ✓ Outdoor coil is usually made of copper tubing and aluminum fins for halocarbon refrigerants.
- ✓ Plate or spine fins are often used instead of corrugated fins to avoid clogging by dust and foreign matter.



Different Types of Heat Pumps

AIR-SOURCE HEAT PUMP SYSTEMS (Air-to-Air Heat Pumps)

Reversing Valve

- ✓ Guide the direction of refrigerant flow when cooling operation is changed over to heating operation or vice versa.
- ✓ The rearrangement of connections between ways of flow—compressor suction, compressor discharge, evaporator outlet, and condenser inlet—causes the functions of the indoor and outdoor coils to reverse.

Compressor.

- ✓ Reciprocating and scroll compressors are widely used in heat pumps.

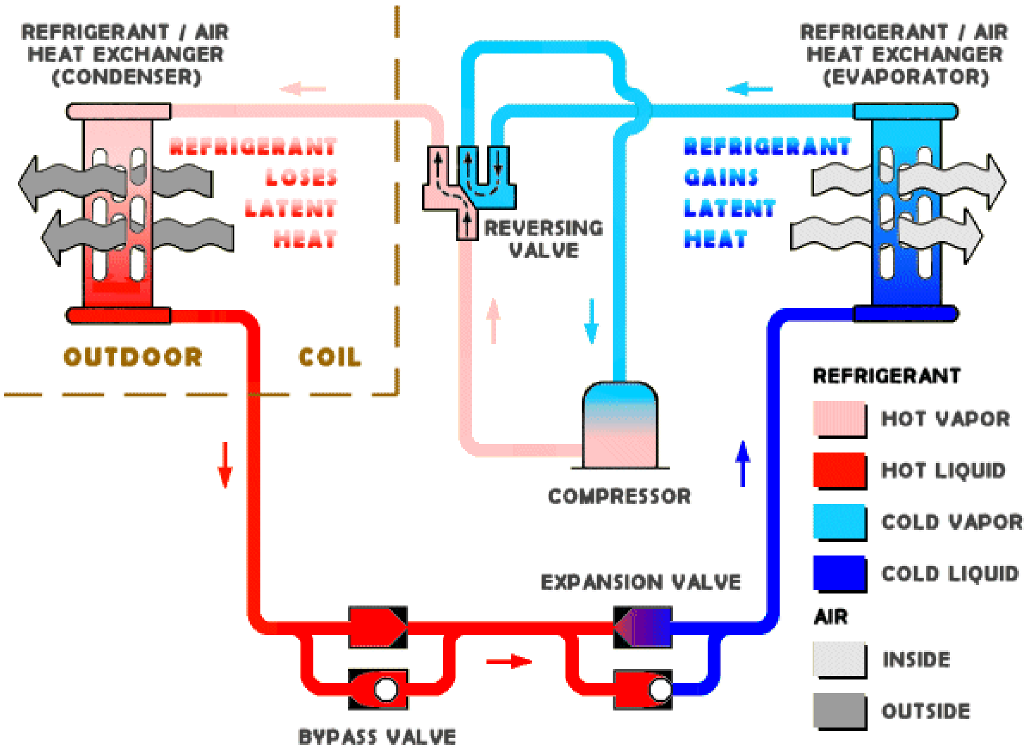
Expansion Device

- ✓ The most common types are thermal expansion valves (TXV), electronic expansion valves, and capillary tubes.
- ✓ TXV have the added capability of metering the quantity of refrigerant flowing through the cycle to match the load to enhance the efficiency of the cycle.

Different Types of Heat Pumps

AIR-SOURCE HEAT PUMP SYSTEMS (Air-to-Air Heat Pumps)

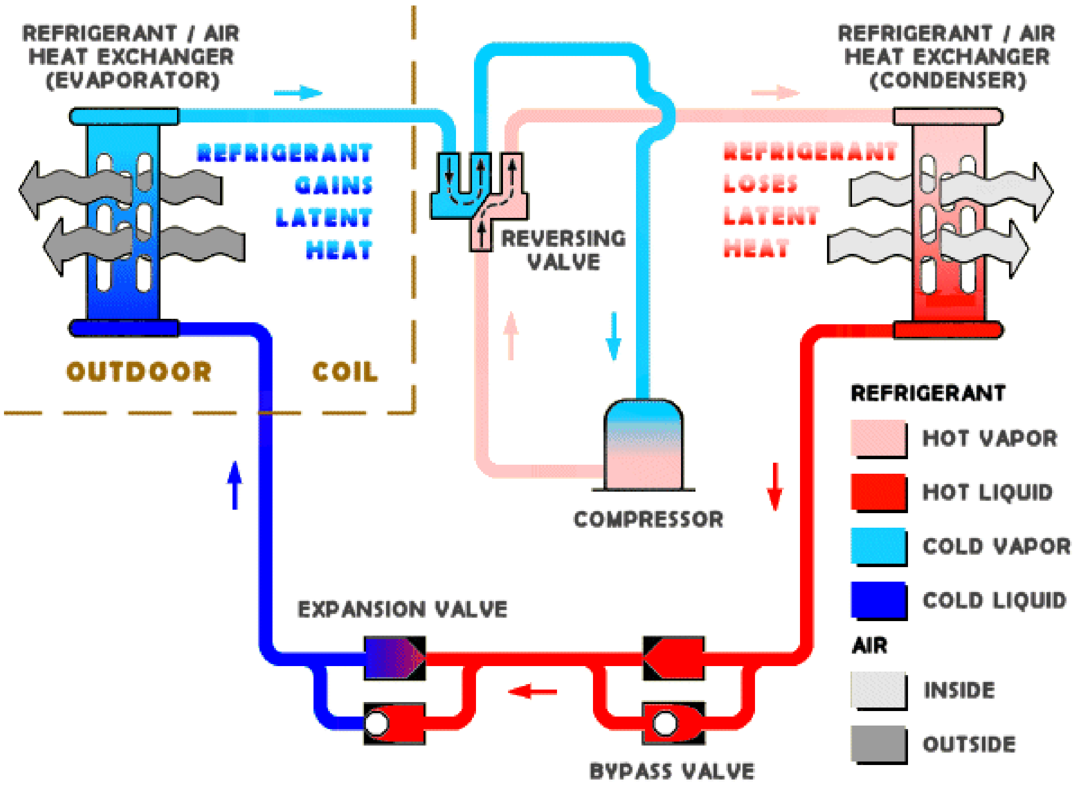
Air-source heat pump in cooling mode.



Different Types of Heat Pumps

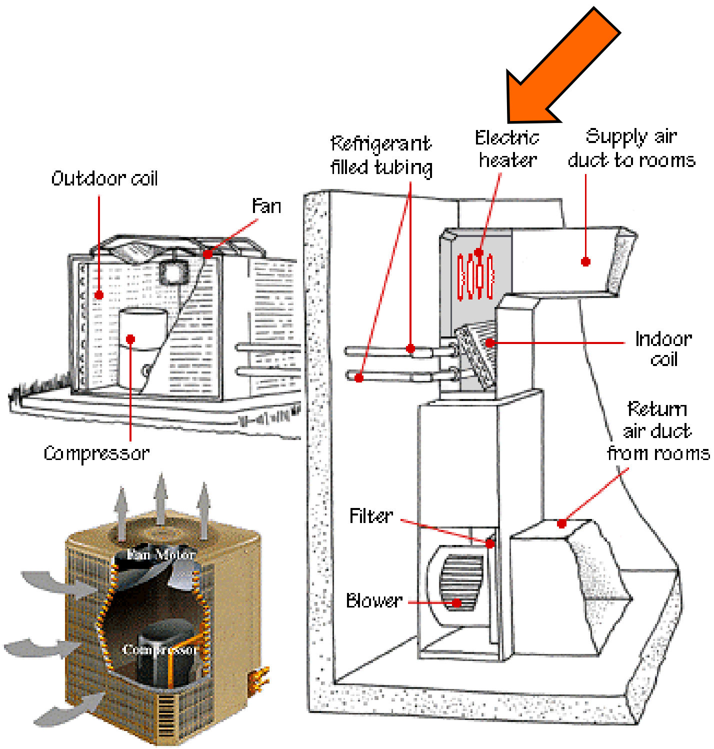
AIR-SOURCE HEAT PUMP SYSTEMS (Air-to-Air Heat Pumps)

Air-source heat pump in heating mode



Different Types of Heat Pumps

AIR-SOURCE HEAT PUMP SYSTEMS (Air-to-Air Heat Pumps)



- ✓ When discharge air temperature sensor detects a drop in air temperature further below preset limits, supplementary heater (electric) would be energized

ASHRAE/IESNA Standard 90.1-1999

- ✓ Heat pumps with internal electrical resistance heaters shall operate only when the heating load **cannot be met** by heat pump.

Different Types of Heat Pumps

AIR-SOURCE HEAT PUMP SYSTEMS (Air-to-Air Heat Pumps)

Cycling Loss in Air-to-Air Heat Pumps

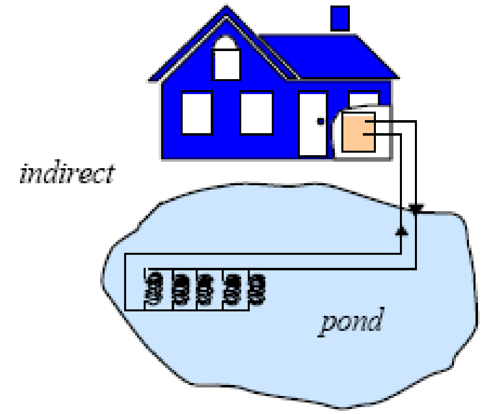
- ✓ For split packaged air-source heat pumps with an on/off control for compressor, during the off period, refrigerant tends to migrate from the warmer outdoor coil to the cooler indoor coil in summer and from warmer indoor coil to the cooler outdoor coil during winter.
- ✓ When the compressor starts again, the transient state performance shows that a 2 to 5 mins operating period of reduced capacity before the heat pump can operate at full capacity.
- ✓ Such a loss due to cycling of the compressor is called cycling loss.

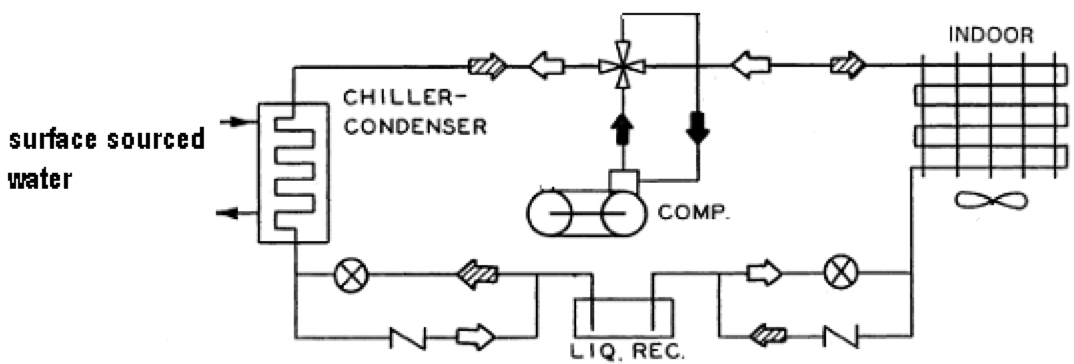
Water-to-Air Heat Pumps

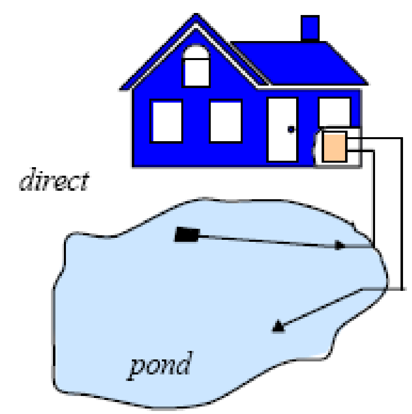
Different Types of Heat Pumps
Water-to-Air Heat Pumps

Surface water heat pumps

- ✓ They use surface water from either a lake, pond, or stream as a heat source or sink.
- ✓ Similar to the ground-coupled and groundwater heat pumps, these systems can either circulate the source water directly to the heat pump or use an intermediate fluid in a closed loop.







Different Types of Heat Pumps
Water-to-Air Heat Pumps

Internal-source heat pumps

- ✓ They use the high internal cooling load generated in modern buildings either directly or with storage.
- ✓ These include water loop heat pumps.

Wastewater-source heat pumps

- ✓ Sanitary waste heat or laundry waste heat.
- ✓ The waste fluid can be introduced directly into the heat pump evaporator after filtration, or from a storage tank.
- ✓ An intermediate loop may also be used for heat transfer between the evaporator and the waste heat source.

Different Types of Heat Pumps
Water-source heat pumps

Horizontal units

- ✓ Installation in ceiling plenums, especially for spaces where floor space is at a premium.

Horizontal Model

Vertical units

- ✓ Installation in separate spaces such as closets or maintenance rooms.
- ✓ Larger vertical units are generally used in spaces that are more open, such as cafeterias and gymnasiums

Vertical Model

Different Types of Heat Pumps
Water-source heat pumps

Console units

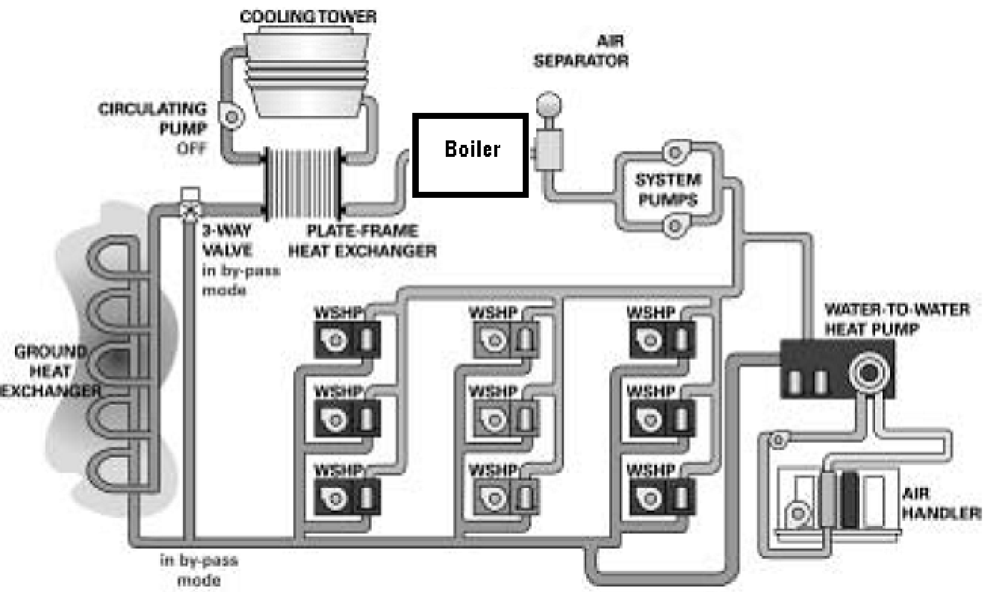
- ✓ Under windows, in perimeter spaces, where ducted systems cannot be used and floor space is not a constraint.
- ✓ Typical applications include offices, apartment buildings.
- ✓ Because of their rugged design, they are typically used in schools.

Vertical-stack units

- ✓ In multistory buildings such as hotels, apartments (a minimum amount of floor space is available).
- ✓ Designed for corner installation
- ✓ Stacked above each other to minimize piping and electrical installation costs.

Different Types of Heat Pumps

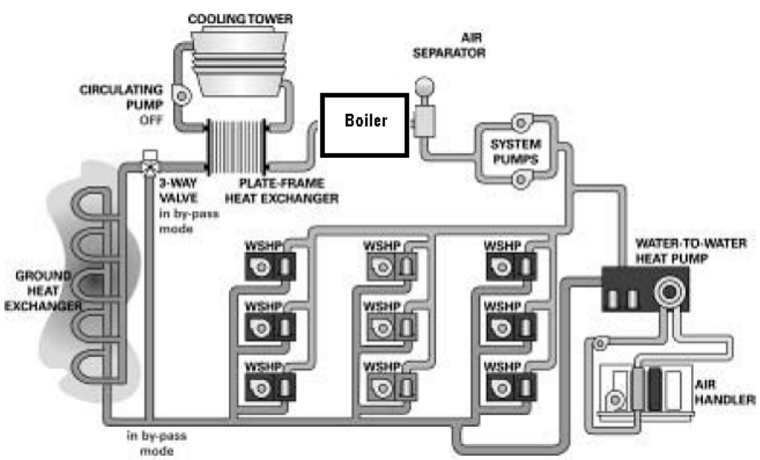
Water-source heat pumps



- ✓ Hot weather : a cooling tower rejects heat to outdoor air, maintaining a leaving-water temperature of 32°C.
- ✓ Cold weather: a boiler adds heat to water loop, maintaining a leaving-water temperature of 16°C.
- ✓ Mild weather: sunny side and interior of building in cooling mode (reject heat into water loop). Shady side in heating mode (absorb heat from water loop).
- ✓ Heat rejected by the units in cooling mode can be used to offset the heat absorbed by the units in heating mode.
- ✓ Between 16°C and 32°C, neither the boiler nor the cooling tower operates.

Different Types of Heat Pumps

Benefits of using water-source heat pump

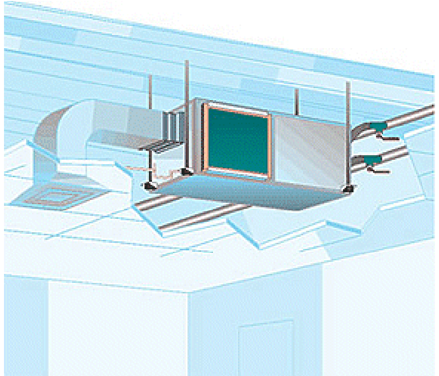


- ✓ In the heat recovery mode => saves energy by reducing the operating time of cooling tower and boiler.
- ✓ Allowing different space with dissimilar cooling and heating requirements (each independently controlled space is served by its own heat pump and own thermostat).
- ✓ The same equipment to provide cooling & heating.
- ✓ Though Cooling tower & Boiler in the system, need only one set of water pipes => reduce system installation cost.
- ✓ If one heat pump fails and to be replaced, it does not affect the operation of the rest in system.

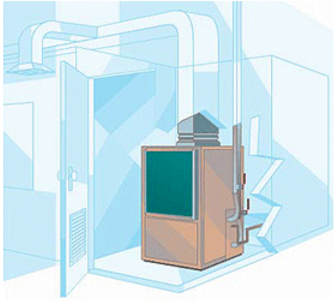
Different Types of Heat Pumps

Key issues associated with water source heat-pump system.

- ✓ Most commercial buildings have a separate, ducted ventilation system for outdoor air for ventilation.
- ✓ Heat pump is located in occupied space containing compressor fans and resulting in high noise level.
- ✓ Proper maintenance of the heat pumps requires that they be located in accessible areas.



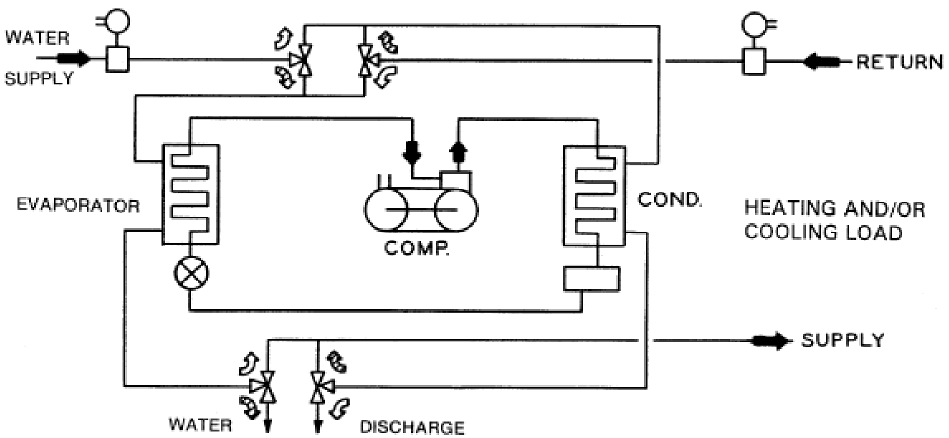
Horizontal GHP unit installation above a dropped ceiling



Vertical GHP unit installation in a mechanical utility closet

Water-to-Water Heat Pumps

Different Types of Heat Pumps
Water-to-Water Heat Pumps



- ✓ Heating-cooling changeover can be done in the refrigerant circuit, but it is often more convenient to perform the switching in the water circuits.
- ✓ Direct admittance of the water source to the evaporator or through a heat exchanger (or double-wall evaporator) to avoid contaminating the closed chilled water system.

Different Types of Heat Pumps
Water-to-water Heat Pump

Unit Selection Procedure

Determine the system design conditions for source and load-side(s) of the equipment

Entering liquid temperatures for the source-side can be 30F to 120F

Entering liquid temperatures for the load-side 45F to 120F.

Define the selection parameters.

Entering water temperature,

Fluid flow rate, and

Fluid pressure drop.

Determine unit requirements.

Total cooling capacity/total heating

Staging of capacity to satisfy cooling requirements.

Pressure drop reduction through the load-side of multiple units, even when a single unit might meet capacity.

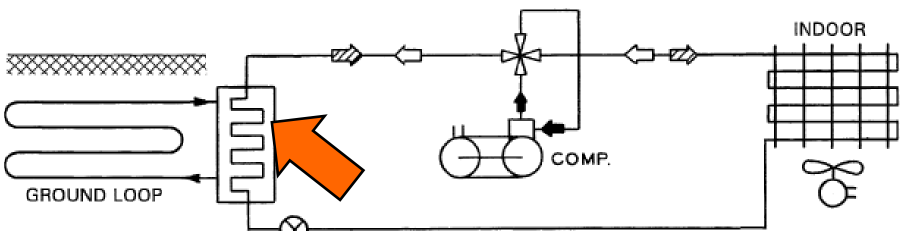
Antifreeze will be required in the fluid loop if source-side leaving water temperature falls below $1^{o}C$.

Ground-Coupled Heat Pumps

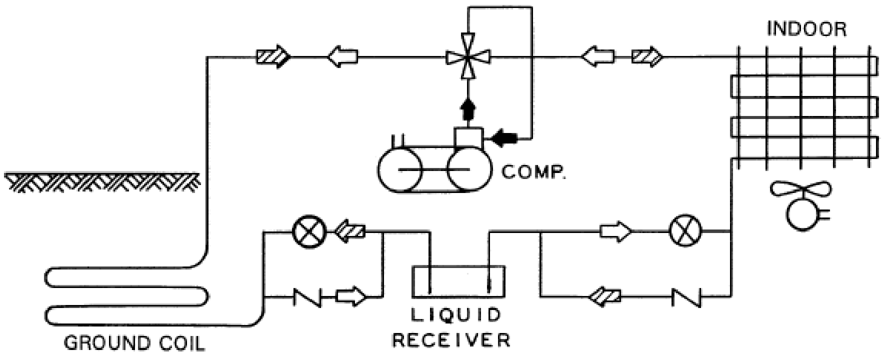
Different Types of Heat Pumps
Ground Source Heat Pumps

Ground as a heat source and sink.

In systems with refrigerant-to-water heat exchangers, a water or antifreeze solution is pumped through horizontal, vertical, or coiled pipes embedded in the ground.

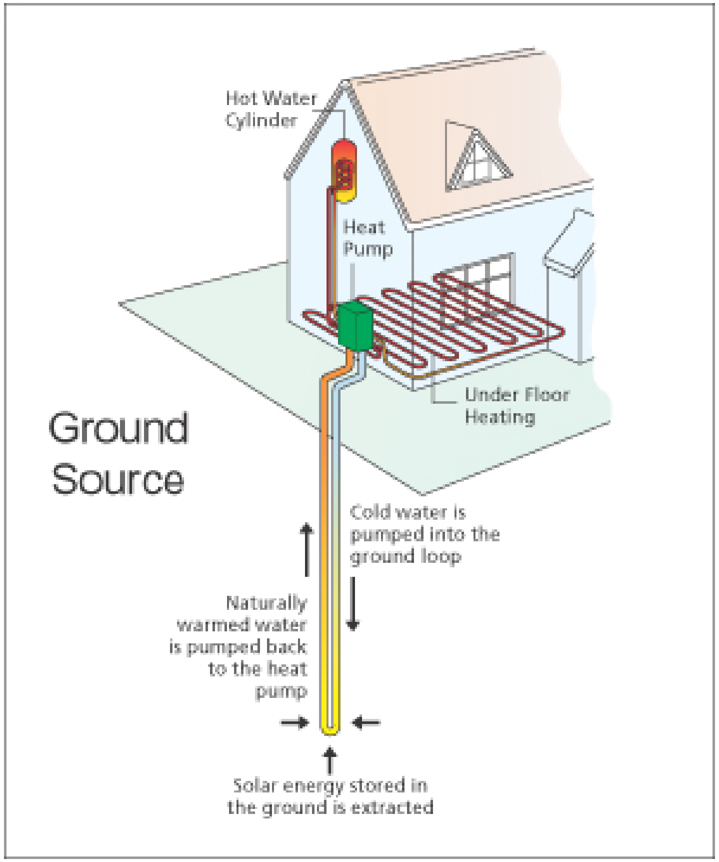


Direct expansion ground-coupled heat pumps use refrigerant in direct expansion, or flooded evaporator circuits for the ground pipe coils.



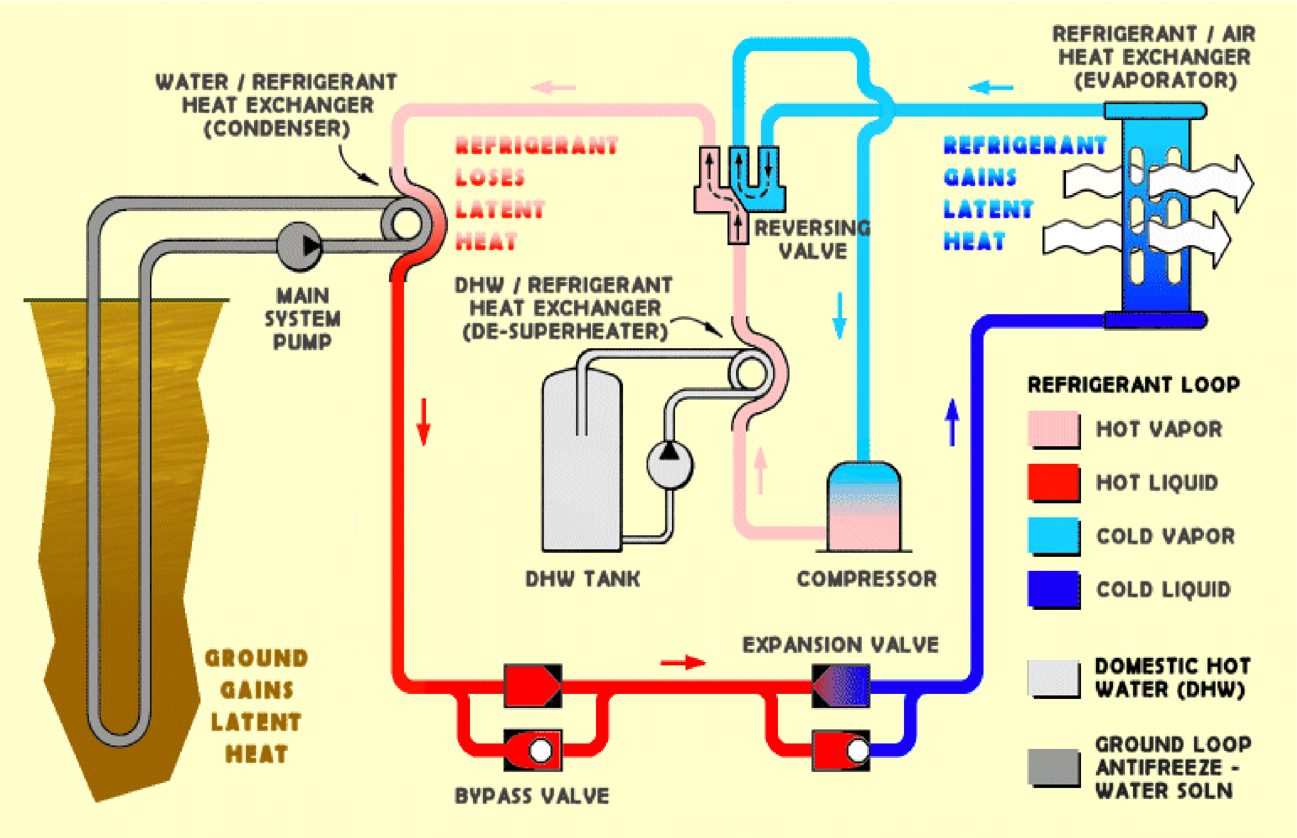
Different Types of Heat Pumps

Ground Source Heat Pumps



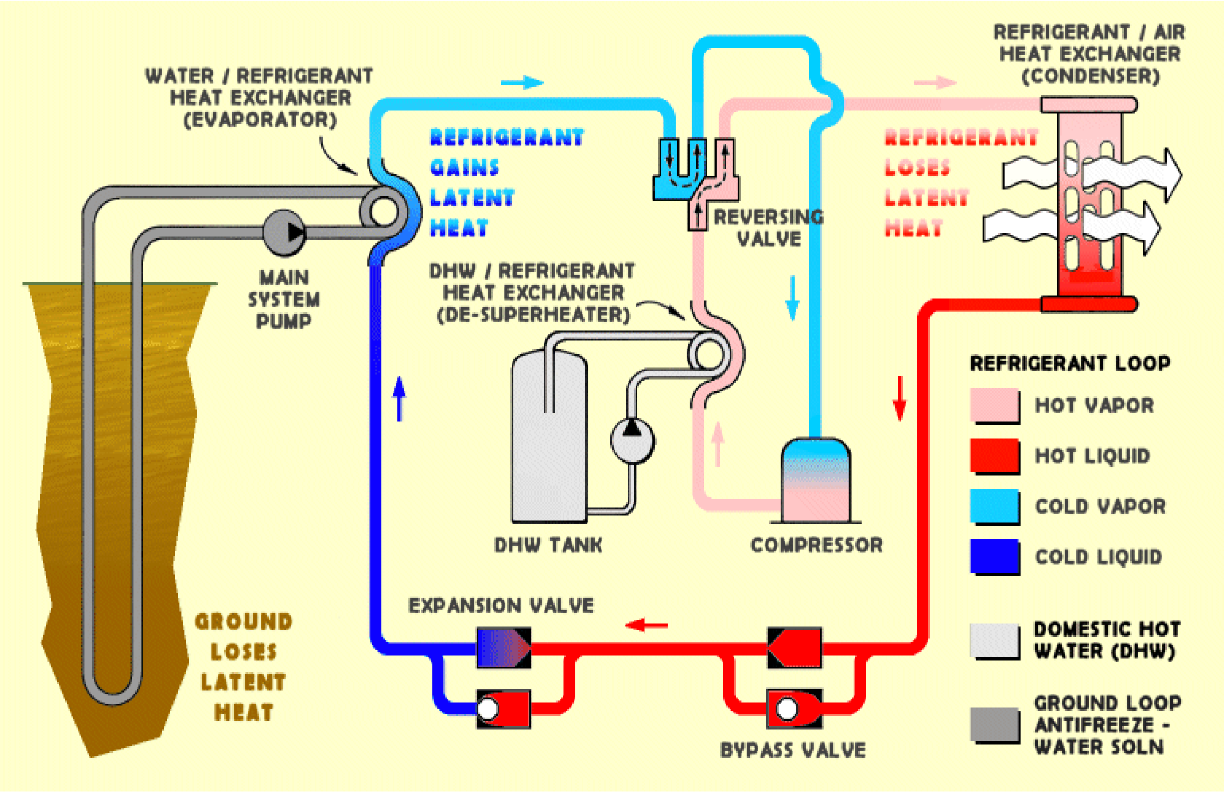
- ✓ Soil types, moisture content, composition, density, and uniformity close to the surrounding field areas affect the success of this method of heat exchange.
- ✓ With some piping materials, the material of construction for the pipe and the corrosiveness of the local soil and underground water may affect the heat transfer and service life.
- ✓ In a variation of this cycle, all or part of the heat from the evaporator plus the heat of compression are transferred to a water-cooled condenser.
- ✓ This condenser heat is then available for uses such as heating air or domestic hot water.

Different Types of Heat Pumps
Ground Source Heat Pumps



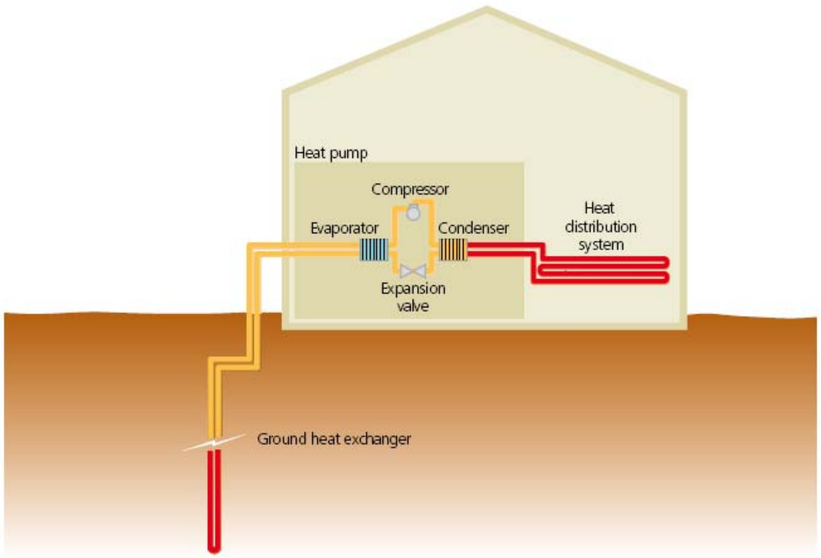
Ground-source (geothermal) heat pump in cooling mode

Different Types of Heat Pumps
Ground Source Heat Pumps



Ground-source (geothermal) heat pump in heating mode.

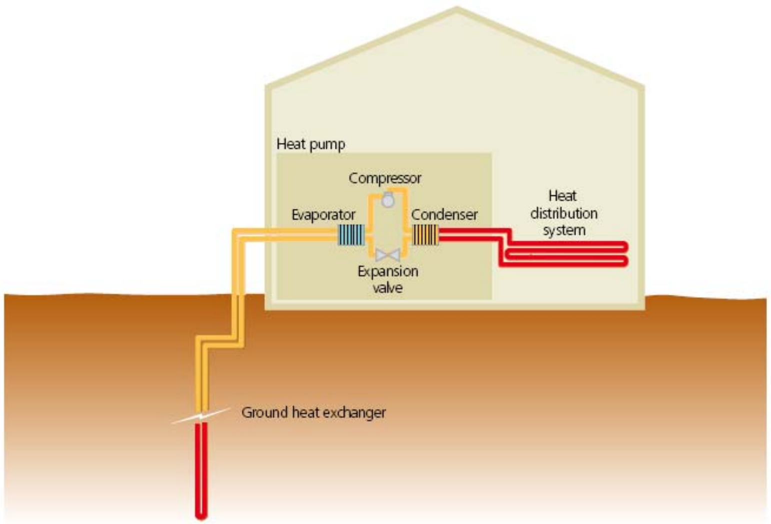
Different Types of Heat Pumps
Ground Source Heat Pumps



- ✓ A ground-source heat pump uses the earth as the heat rejecter and heat adder.
- ✓ These systems take advantage of the earth's relatively constant temperature, and use the ground or surface water as the heat rejecter and heat adder.
- ✓ Ground-source heat pump systems don't actually get rid of heat—they store it in the ground for use at a different time.

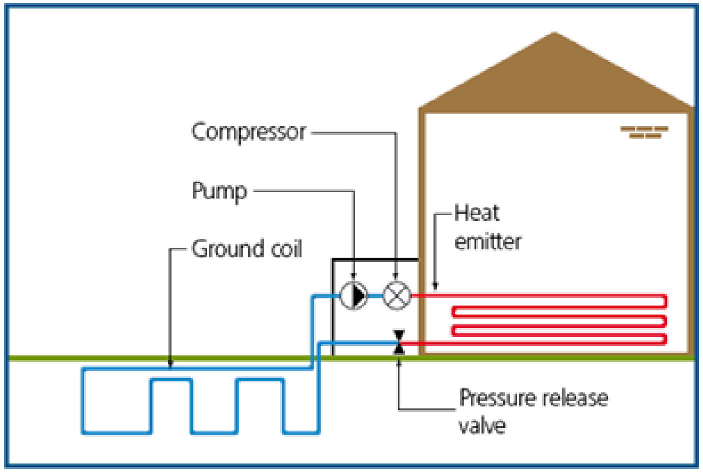
Different Types of Heat Pumps

Ground Source Heat Pumps



- ✓ During the summer, the heat pumps absorb heat from the building and store it in the ground.
- ✓ When the building requires heating, this stored heat can be recaptured from the ground.
- ✓ In a perfectly balanced system, the amount of heat stored over a given period of time would equal the amount of heat retrieved.

Different Types of Heat Pumps
Ground Source Heat Pumps



- ✓ Neither cooling tower nor boiler needed that saves initial cost & floor space.
- ✓ Operating-cost savings comparing to the traditional cooling-tower-and-boiler system.
- ✓ High installation cost for heat exchanger.
- ✓ Installation requires excavation, trenching, or boring, and few qualified contractors for installing the ground heat exchanger.
- ✓ High-density polyethylene pipes that are buried in the ground at a depth

Different Types of Heat Pumps

Ground Source Heat Pumps

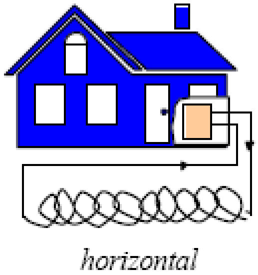
There are several types of Ground Coupled Systems.

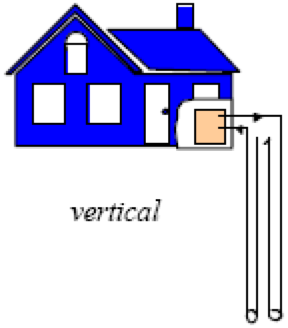
<u>**Closed-loop systems**</u>
Horizontal and vertical heat pump

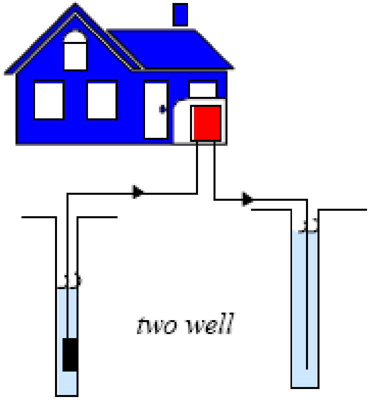
<u>**Open-loop system**</u>
Groundwater heat pump

Which should be selected depends on the climate, soil conditions, available land, and local installation costs at the site. excavation costs

All of these approaches can be used for residential and commercial building applications.



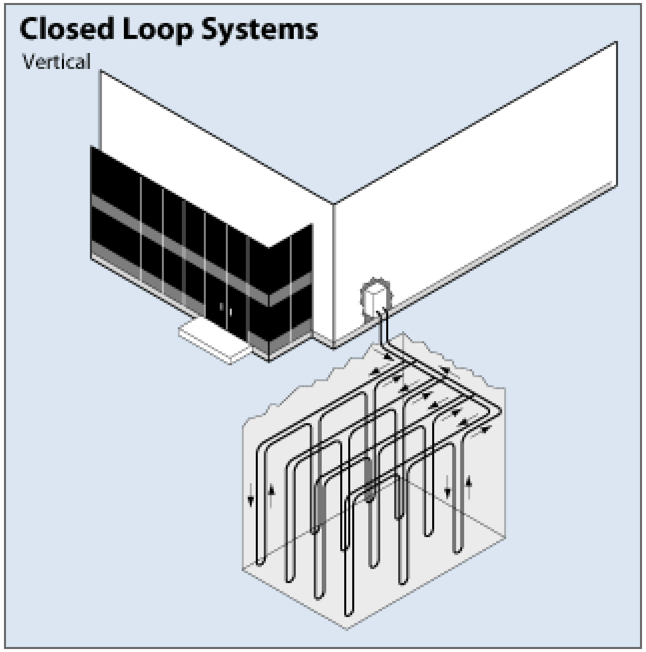




Different Types of Heat Pumps
Ground Source Heat Pumps

Vertical

- ✓ Large commercial buildings and schools often use vertical systems because the land area required for horizontal loops would be prohibitive.
- ✓ Vertical loops are also used where the soil is too shallow for trenching, and they minimize the disturbance to existing landscaping.
- ✓ For a vertical system, holes (approximately 100 mm diameter) are drilled about 6m apart and 30m –120m deep.
- ✓ Into these holes go two pipes that are connected at the bottom with a U-bend to form a loop.

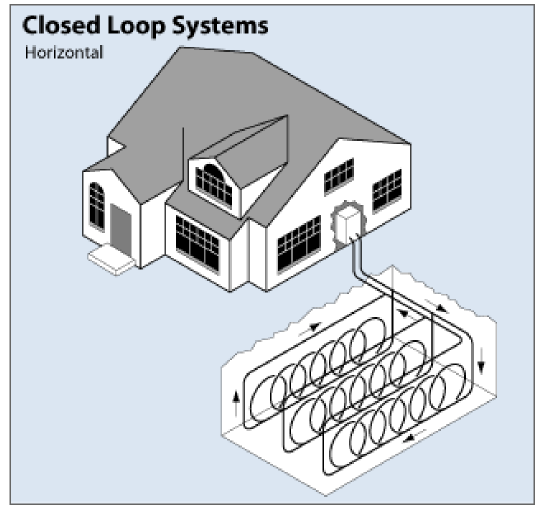


Different Types of Heat Pumps

Ground Source Heat Pumps

Closed-Loop (Horizontal)

- ✓ Trenches at least 1.2m deep.
- ✓ The most common layouts either use two pipes, one buried at 1.8m, and the other at 1.2m, or two pipes placed side-by-side at 1.5m in the ground in a 0.6m wide trench.
- ✓ The Slinky™ method of looping pipe allows more pipe in a shorter trench, which cuts down on installation costs.



Slinky

Different Types of Heat Pumps

Ground Source Heat Pumps

Thermal conductivity of different soil types

- ✓ It indicates the heat transfer rate between ground loop and the surrounding soil for a given temperature gradient.
- ✓ It determines the length of pipe and hence installation cost and the pumping energy.
- ✓ Heat transfer capability tends to increase as soil texture becomes increasingly fine, with loam mixtures having an intermediate value between sand and clay.
- ✓ Its value is greatly improved if the soil is saturated with water. This effect is much greater for sandy soils than for clay or silt, since coarse soils are more porous and therefore hold more water when wet.

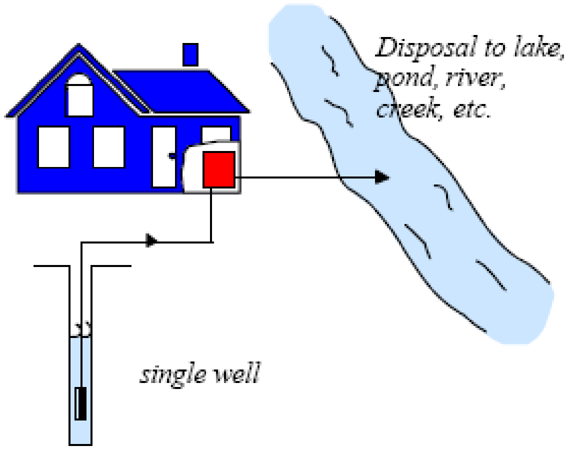
Texture Class	Thermal Conductivity Btu/ft hr °F
Sand	0.44
Clay	0.64
Loam	0.52
Saturated sand	1.44
Saturated silt or clay	0.96

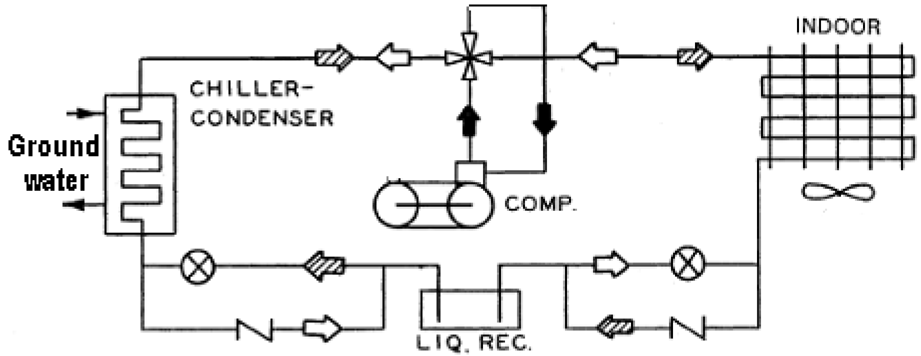
Soil Thermal Conductivity Btu/(hr ft °F)	Number of U-Tubes	Effective Depth of U-Tubes vert. feet	Total U-Tube Vert. Length vert. feet
0.55	16	199	3,180
0.7	15	188	2,820
0.85	14	187	2,620
1.0	12	202	2,420
1.2	12	188	2,260
1.35	12	180	2,160
1.5	10	212	2,120

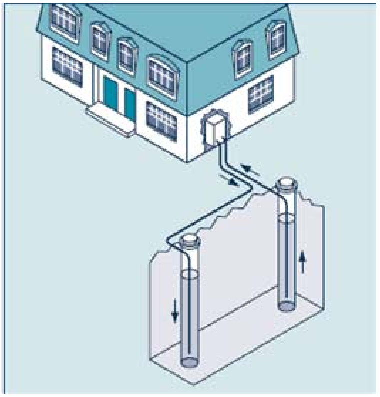
Different Types of Heat Pumps
Water-to-Air Heat Pumps

Groundwater heat pumps

- ✓ They use groundwater from wells as a heat source and/or sink.
- ✓ This option is obviously practical only where there is an adequate supply of relatively clean water, and all local codes and regulations regarding groundwater discharge are met.







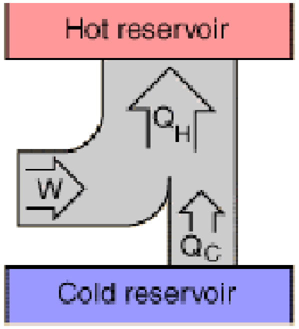
Criteria for evaluation on Performance of Heat Pumps

Coefficient of Performance

The coefficient of performance (CP) for a heat pump is the ratio of the energy transferred for heating to the input electric energy used in the process.

$$\text{Coefficient of Performance} = \frac{Q_H}{W}$$

All real refrigerators and heat pumps require work to get heat to flow from a cold area to a warmer area.



There is a theoretical maximum CP, that of the Carnot cycle :

General definition

Limit for ideal Carnot case

$$CP = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C} \Rightarrow \frac{T_H}{T_H - T_C}$$

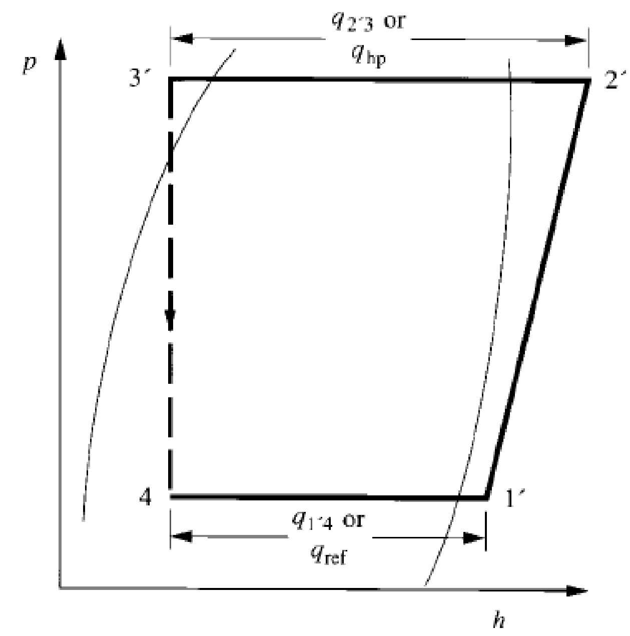
Ideal coefficient of performance

A system rated in heating at 6.5kW, with a rated power consumption of 1.8kW => CoP of 3.61.

$$CoP = \frac{6.5}{1.8} = 3.61 \text{ or } (361\%)$$

Coefficient of Performance

A heat pump cycle comprises the same processes and sequencing order as a refrigeration cycle except that the refrigeration effect $q_{1'4}$ or q_{rf}, and the heat pump effect $q_{2'3'}$,both in J/kg, are the useful effects.



$$\mathrm{COP_{ref}} = \frac{h_{1'} - h_4}{W} = \frac{q_{1'4}}{W_{in}}$$

where

h_4' h_1' = enthalpy of refrigerant entering and leaving evaporator, respectively, J /kg

Win = work input, J/kg

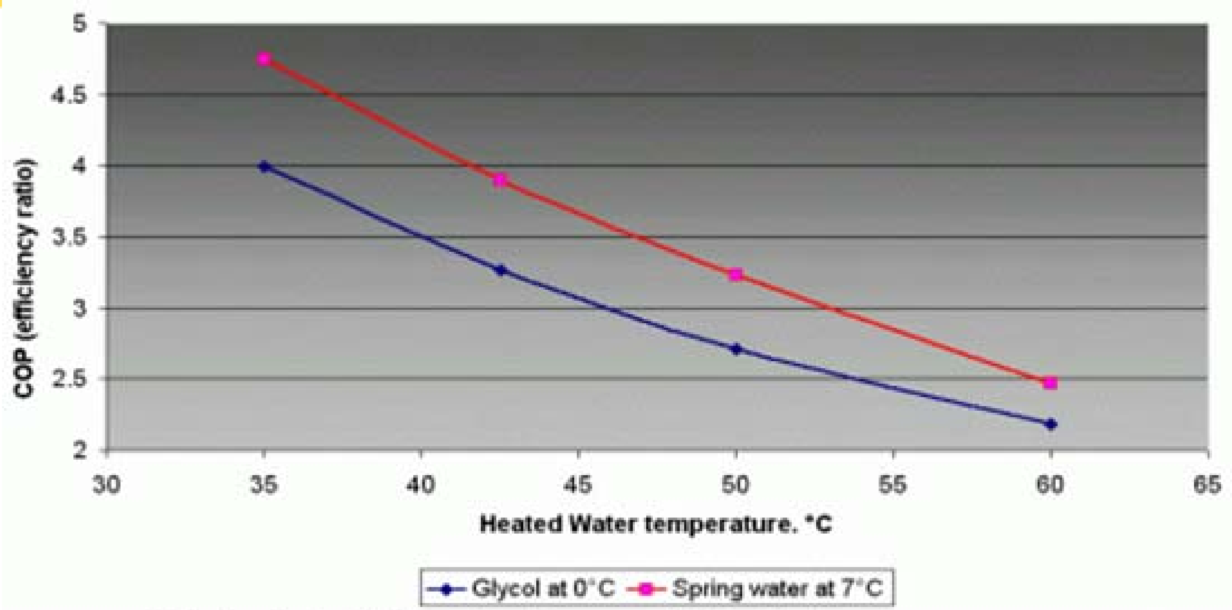
The coefficient of performance of the heating effect in a heat pump system COP_{hp} is

$$\mathrm{COP_{hp}} = \frac{q_{2'3'}}{W_{in}}$$

Coefficient of Performance

System		CoP/(η)	CO_2 emission kg/kW/h (useful)
Vapour Compression Cycle –			
Electric:	Air to Air	2.5 - 3.0	0.14 - 0.17
	Air to Water	2.7 - 3.2	0.13 - 0.15
	Water to Air	3.7 - 4.2	0.10 - 0.11
	Water to Water	4.0 - 4.5	0.09 - 0.10
	Ground to Air	3.2 - 3.7	0.11 - 0.13
	Ground to Water	3.5 - 4.0	0.10 - 0.12
Engine Driven:	Gas Fired	1.2 - 2.2	0.09 - 0.15
	Oil Fired	1.5 - 2.0	0.14 - 0.18
Absorption Cycle:	Gas Fired	1.2 - 1.5	0.13 - 0.16
	Oil Fired	–	0.18 - 0.22
LPHW Boilers:	Gas	0.7 - 0.9 (η)	0.22 - 0.28
	Oil	0.7 - 0.9 (η)	0.30 - 0.39

Coefficient of Performance



Variation in Coefficient of Performance (COP) with heated water temperature

- ✓ It is to keep the heated water temperature as low as possible.
- ✓ To attain a COP of 4, it is necessary to keep the heated water down to 35°C.
- ✓ This is only possible with a good underfloor heating system.
- ✓ If radiators are used, then they must be significantly oversized (e.g. doubled) to keep the temperature down as far as possible.
- ✓ The red line shows how much the efficiency improves if spring water is used.

Energy Efficiency Ratio (EER)

The output of a heat pump in cooling mode.
The rated capacity is divided by the rated total power input.

$$EER = \frac{\text{Cooling Output (kW)}}{\text{Total energy consumed by the system, including fans, pumps and controls (kW)}}$$

For example, a system that is rated in cooling at 6.5kW, with a rated power consumption of 1.8kW will have an EER of 3.61.

$$EER = \frac{6.5}{1.8} = 3.61 \text{ or } (361\%)$$

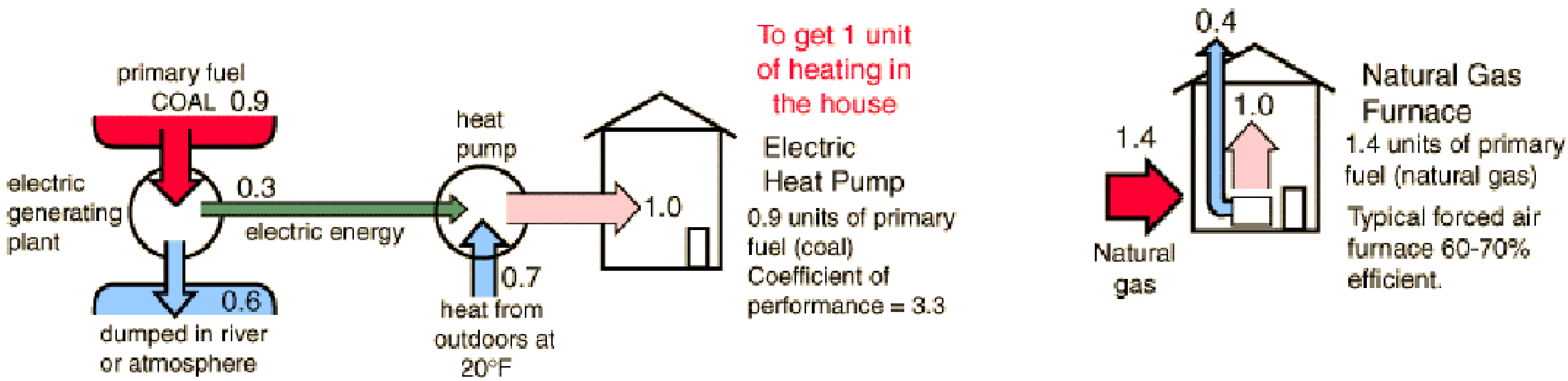
Ground Source Heat Pumps – Efficiency Recommendation

Efficiency Recommendation

Product Type	Recommended		Best Available[a]	
	EER	COP	EER	COP
Closed Loop	14.1 or more	3.3 or more	25.8	4.9
Open Loop[b]	16.2 or more	3.6 or more	31.1	5.5

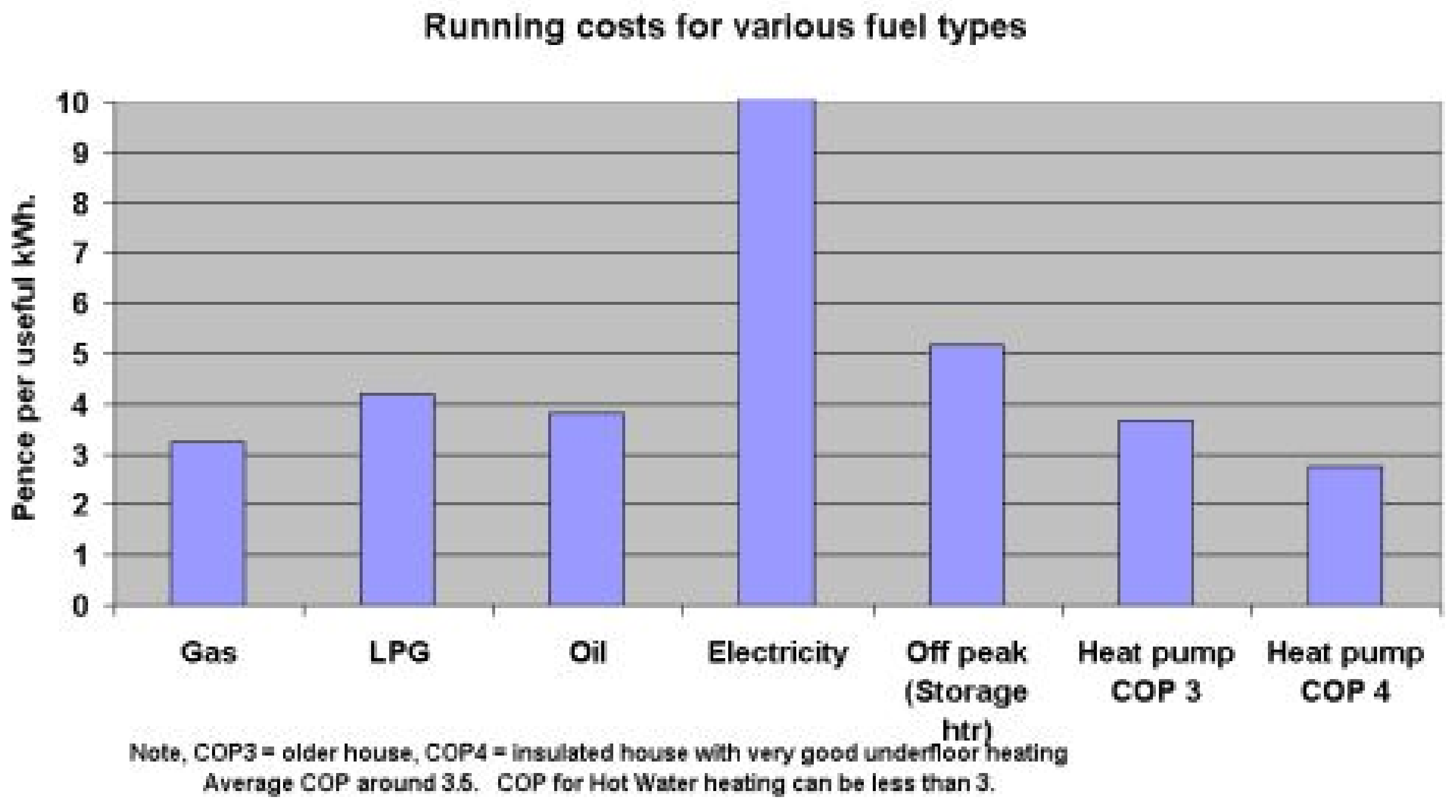
Comparison of Heat Pump and Other Heating Sources

Comparison of Heat Pump and Other Heating Sources



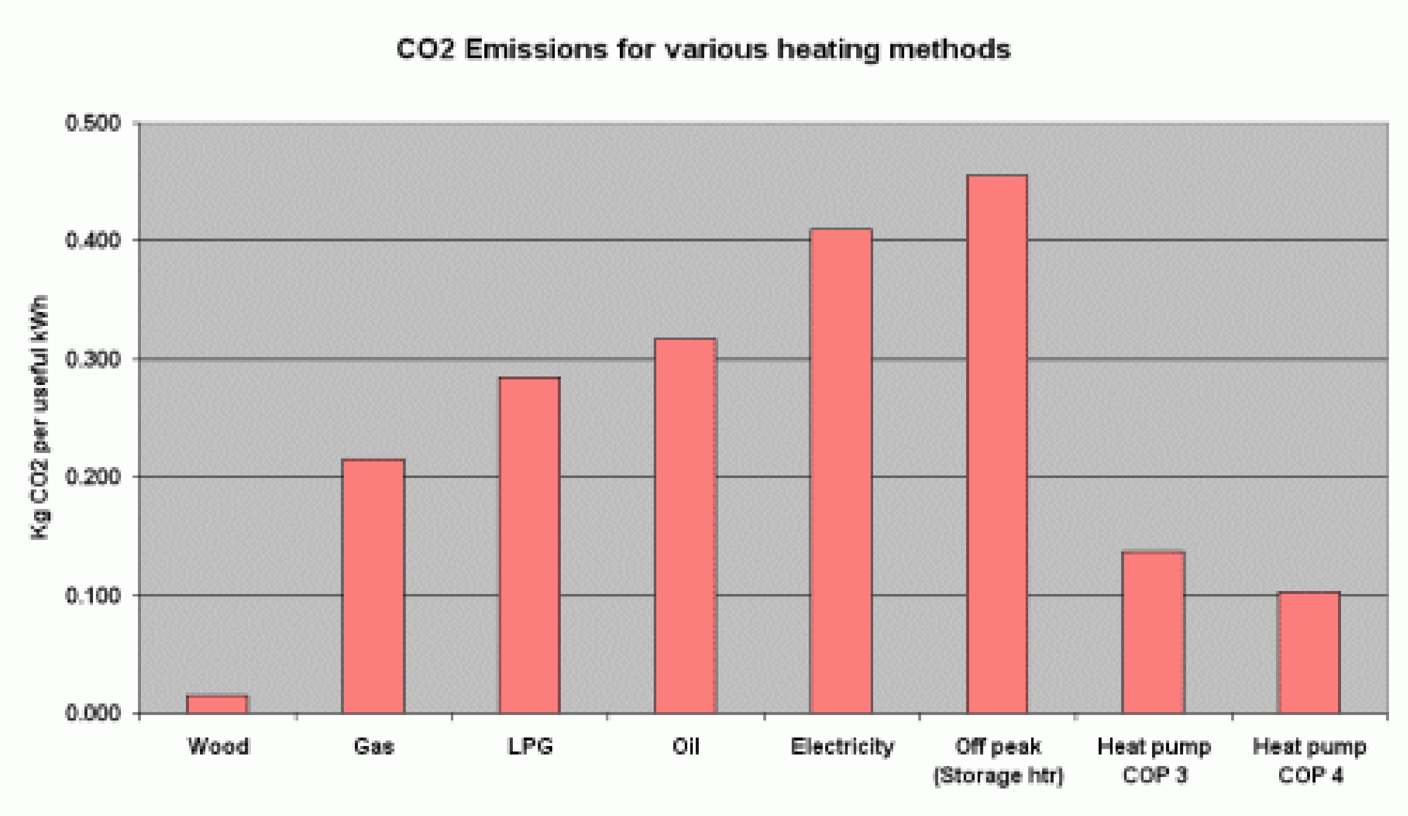
To heat directly by electric energy by means of electric resistance heaters would require about three units of primary fuel to get one unit of heat in to the house. This is not a good use or our energy resources.

Comparison of Heat Pump and Other Heating Sources



Gas condensing boiler efficiency 89%
Oil boiler efficiency 85%
LPG condensing boiler efficiency 88%
Electricity 100% efficient at point of use. Off peak 85% at point of use. (Note, the efficiency for off-peak heating is less than 100% since unnecessarily high temperatures at night are inevitable. This varies from 60% in a badly insulated house to 95% in a super-insulated house.)

Comparison of Heat Pump and Other Heating Sources



Comparison of Heat Pump and Other Heating Sources

System	Capital cost installed (£)	Energy consumed (kWh)	Annual running cost[1] (£)	Annual CO_2 emissions[4] ($kgCO_2$)
Ground source heat pump	1,800	7,825	420	3,600
All electric[2] (efficiency 100 per cent)		18,680	545 – 1,100	8,590
Regular oil-fired boiler, pre 1998 (efficiency 70 per cent)[3]	1,280	26,686	380	7,210
Regular oil-fired boiler, 1998 or later (efficiency 79 per cent)[3]		23,646	340	6,390
Gas-fired condensing boiler (efficiency 85 per cent)		21,976	365	4,260

Question and Answer