11 PASSIVE COOLING

1. FUNDAMENTALS

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PASSIVE COOLING

- heat flows from high temperature areas to low temperature areas
- reverse flow can only be induced by feeding additional energy into the thermal system
- passive cooling seeks to use natural heat flows whenever possible
- strategies:

  reduce heat gains (internal and external)

  open a high-to-low temperature heat flow path to divert the excess heat (heat removal into a suitable heat sink)

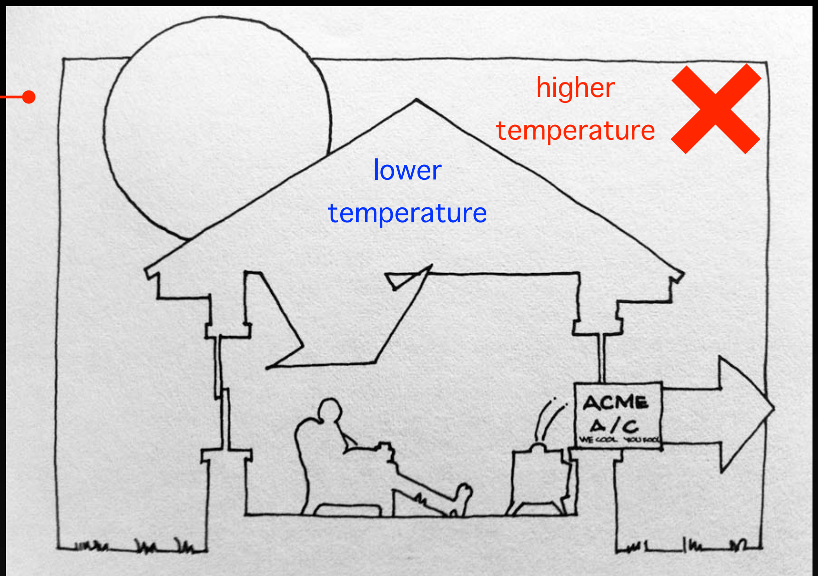

Figure 2.9. Cooling with a mechanical heat sink.

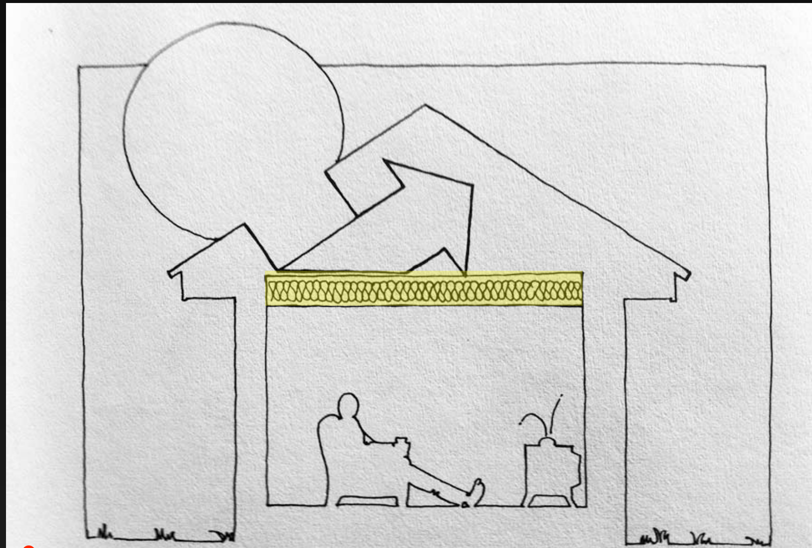

Figure 2.7. Cooling by avoiding heat gain.

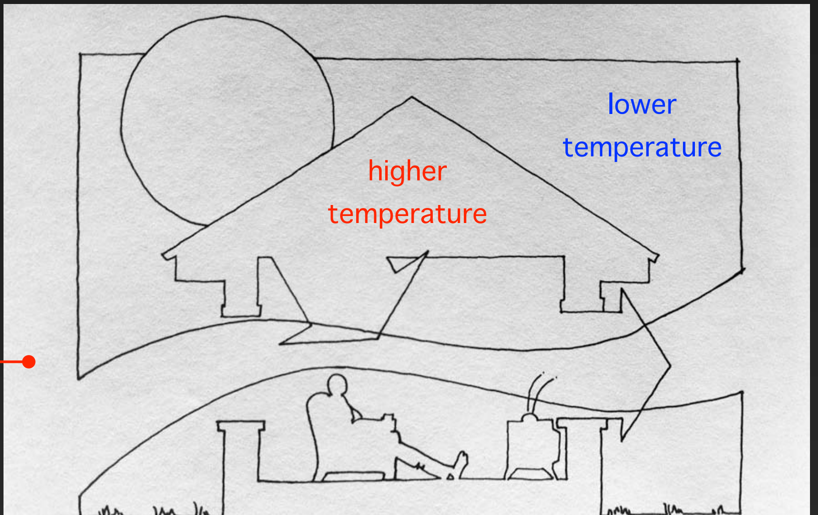

Figure 2.8. Cooling with the ambient as a heat sink.

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PASSIVE COOLING

- available natural heat sinks:

  ambient air (ventilation)

  evaporative cooling (adiabatic)

  radiative cooling (deep night sky)

- although limited in their capacity:
- important first steps towards reducing cooling loads
- hence: passive cooling

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2. SPECIFICS OF COOLING

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SPECIFICS OF COOLING

- crucial to passive heating: access to solar energy during winter
- crucial to passive cooling: availability of heat sinks for heat rejection and redirection
- important limiting factor: humidity

  high humidity limits evaporative cooling to high temperatures

  haze blocks radiative cooling to the night sky

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SPECIFICS OF COOLING

- crucial to passive heating: reducing heat losses by means of

  thermal insulation

  low infiltrations

- crucial to passive cooling: blocking heat gains by

  solar radiation (windows!)

  internal heat sources

  latent sources (humidity)

  ... AND USING HEAT SINKS

- temperature differential beween indoor and outdoor air is smaller for cooling purposes

  hence: smaller impact of conduction and infiltration

3. COOLING MECHANISMS

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COOLING MECHANISMS

- relative humidity: measure of concentration of water vapour
- expressed as a percentage of the water vapour air can hold at a particular temperature
- sensible heat: associated with change in air temperature
- latent heat: associated with change in the moisture content of air
- dewpoint temperature: temperature at which water vapour begins to condensate (relative humidity 100%)

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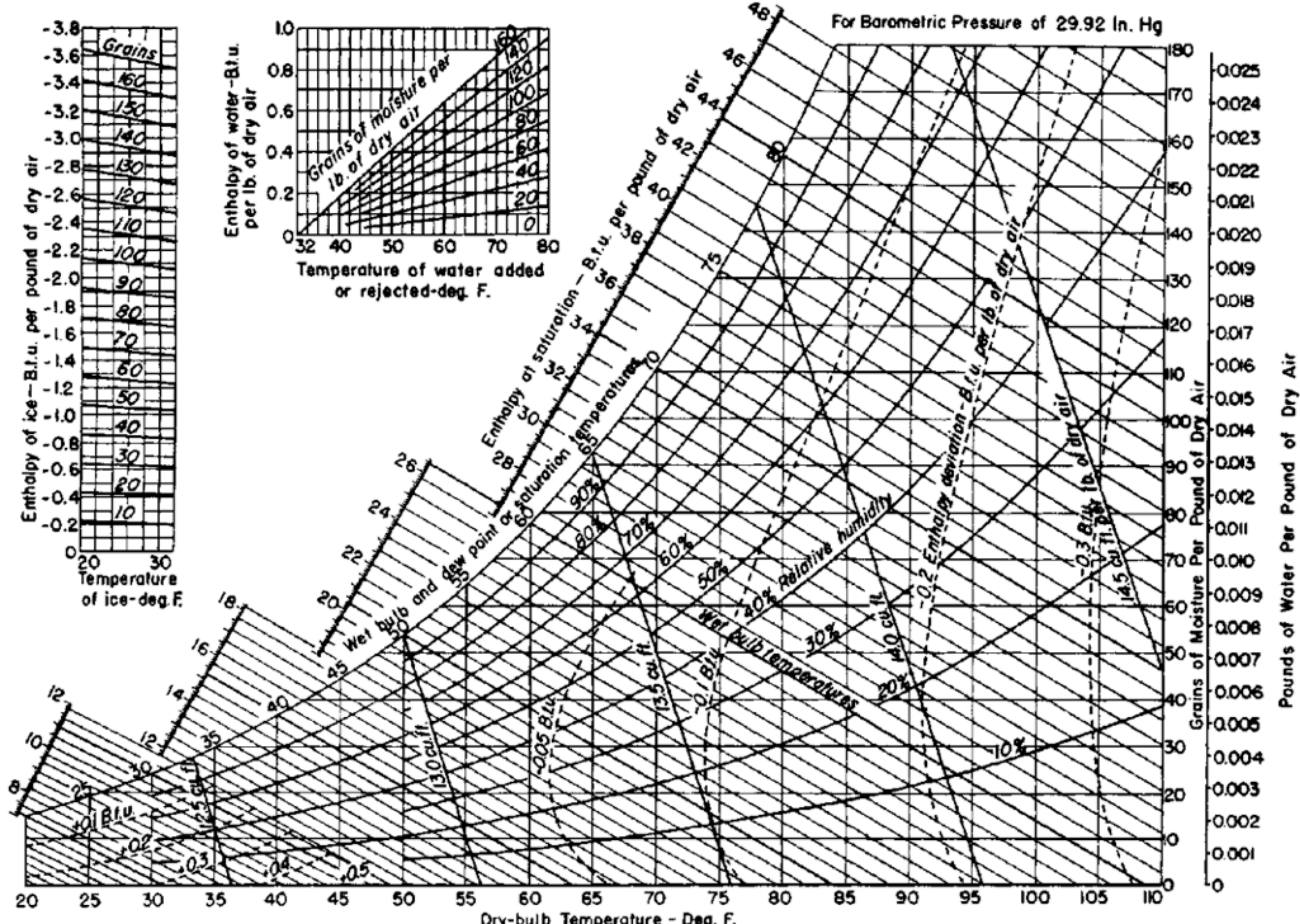

psychrometric chart

COOLING MECHANISMS

- average residential building:

  60 to 80% sensible heat gains

  40 to 20% latent heat gains

- cooling strategies need to deal with both types of loads

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4. THERMAL COMFORT IN HOT CLIMATES

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THERMAL COMFORT

- human thermal comfort:

  when heat flows in the human thermal system are balanced

  when the internal body temperature is near 37° C

- permanent internal heat production of 100 W

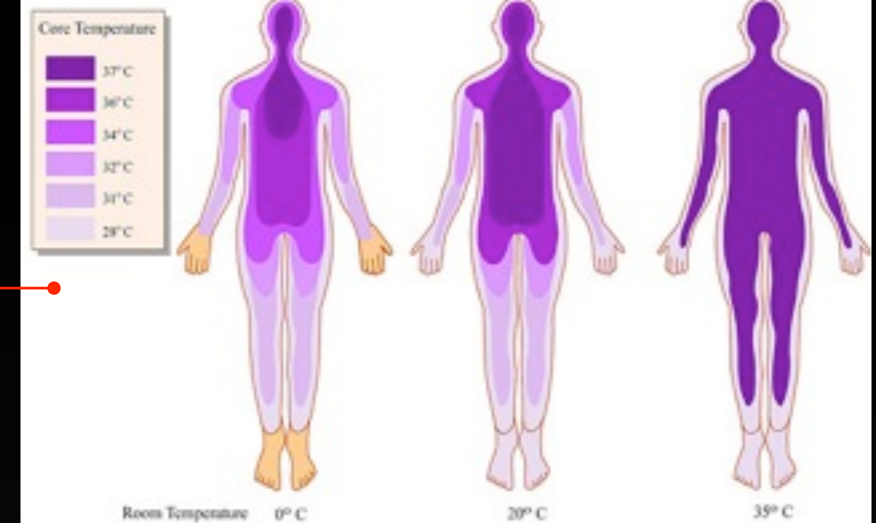
- feeling hot: when heat is absorbed and produced faster than it is lost

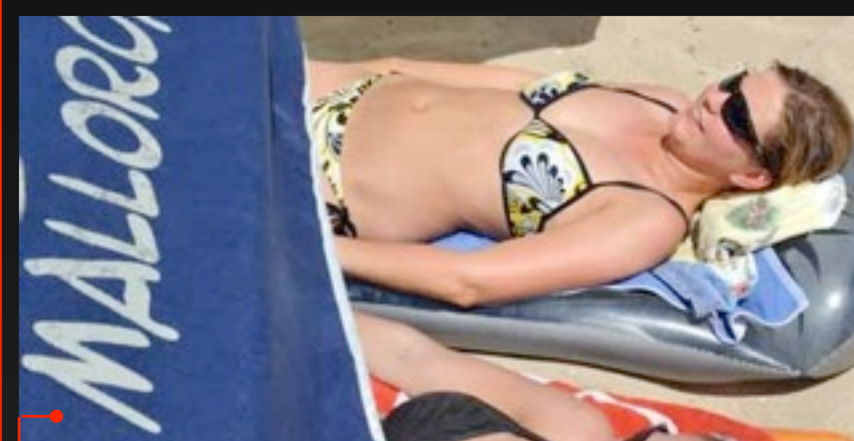
- in that case, bodily responses set in like:

  perspiration (evaporative cooling)

  additional blood flow to skin surface

  lethargic feeling to reduce activity





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THERMAL COMFORT

- environmental determinants of comfort:

    air temperature

    relative humidity

    air motion

    mean radiant temperature (MRT)

- any combinations of these are liable to produce the required comfort

5. REDUCTION OF COOLING LOADS

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REDUCTION OF COOLING LOADS

- main heat flows in a building:

  conduction through the building envelope

  ventilation

  unintended infiltration

  solar heat gains through windows

  internal heat generation

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REDUCTION OF COOLING LOADS
CONDUCTION

- thermal conduction: sensible loads dependent on differential between indoor and outdoor air temperatures

- conduction cooling loads thus increased by solar gains on the outside surface of the envelope (increased temperature differential)

- influencing factors:

  temperature difference across the envelope's section (delta T)

  insulating characteristics of the section

  thermal capacitance of internal masses

- control of conduction heat gains through:

  adding insulation

  reducing the surface area (A/V-ratio)

  reducing the temperature of the exteriour surface

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REDUCTION OF COOLING LOADS
INFILTRATION, VENTILATION

- infiltration, ventilation cooling load are the result of the flow of warmer and more humid air into the building (both sensible and latent heat components)

- when internal heat and solar gains drive the indoor temperature above the outdoor temperature, infiltration and ventilation may reduce cooling loads

- since infiltration is hardly controllable it should be curtailed (infiltration barrier)

- however, ventilation (natural or forced) needs be controllable to allow for minimum hygienic air exchange and for necessary cooling

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REDUCTION OF COOLING LOADS
SOLAR LOADS

- solar loads affect both opaque and glazed surfaces
- however, gains through glazed surfaces significantly exceed those through opaque walls
- hence, orientation and size of transparent or translucent surfaces are to be carefully designed
- since solar gains through windows are desirable in winter, glazed surfaces should be adaptive (solar protection)
- horizontal, east and west oriented glass produces the largest cooling loads, south oriented the least
- external shading is the most efficient method to reduce solar loads

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REDUCTION OF COOLING LOADS
INTERNAL HEAT GAINS

- internal heat gains are due to:

  presence of people

  mechanical and electrical equipment

- sensible gains: e. g. light bulb

- latent gains: e. g. human respiration, bathing, gas combustion (water vapour)

- excess lighting due to solar shading increases cooling loads significantly (paradox)

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6. VENTILATION FOR COOLING PURPOSES

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VENTILATION FOR COOLING PURPOSES

- ventilation provides cooling by carrying away heat by means of moving air (natural or forced movement)
- may involve either the building (open system) or the human body (closed system)
- prerequisite: outdoor air temperature must be below indoor air temperature (building cooling)
- atmosphere is a heat sink with virtually unlimited capacity
- buildings can be ventilated at night when the ambient air is cool to take advantage of the storing effect of thermal masses (heat sink)

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VENTILATION FOR COOLING PURPOSES

- main ventilation mechanisms available:

    wind-driven ventilation

    stack-effect ventilation

    forced ventilation (electric fans)

    solar chimneys

    ceiling and space fans

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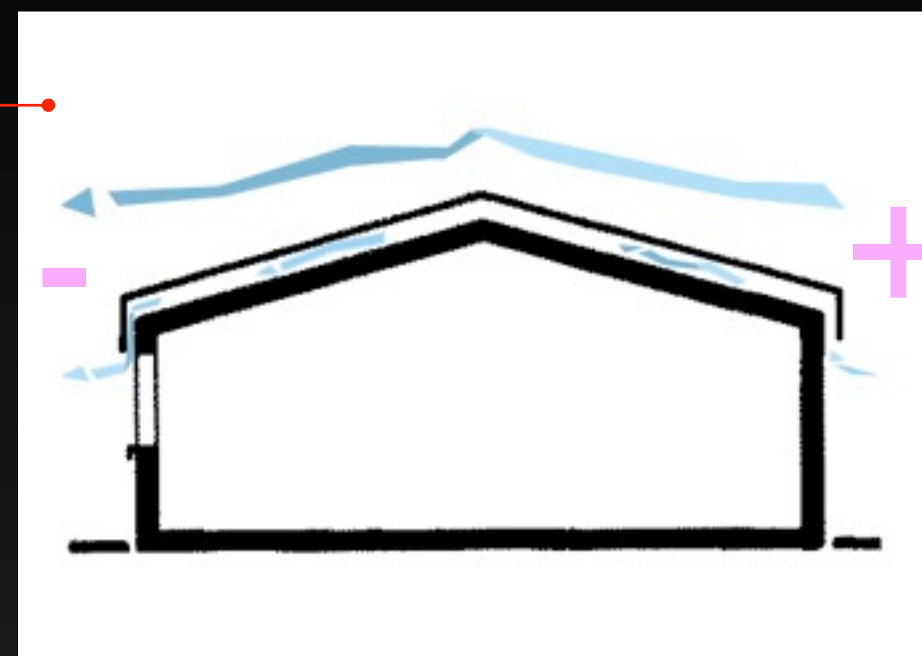
VENTILATION FOR COOLING PURPOSES
WIND-INDUCED VENTILATION

- air movement is induced by air pressure differential between windward and leeward sides of the building
- amount of wind-induced flow is proportional to window area
- fully-opening windows (casement, awning windows) are convenient
- architectural features like wind towers (e. g. malqaf, badgir) may benefit the cooling effect



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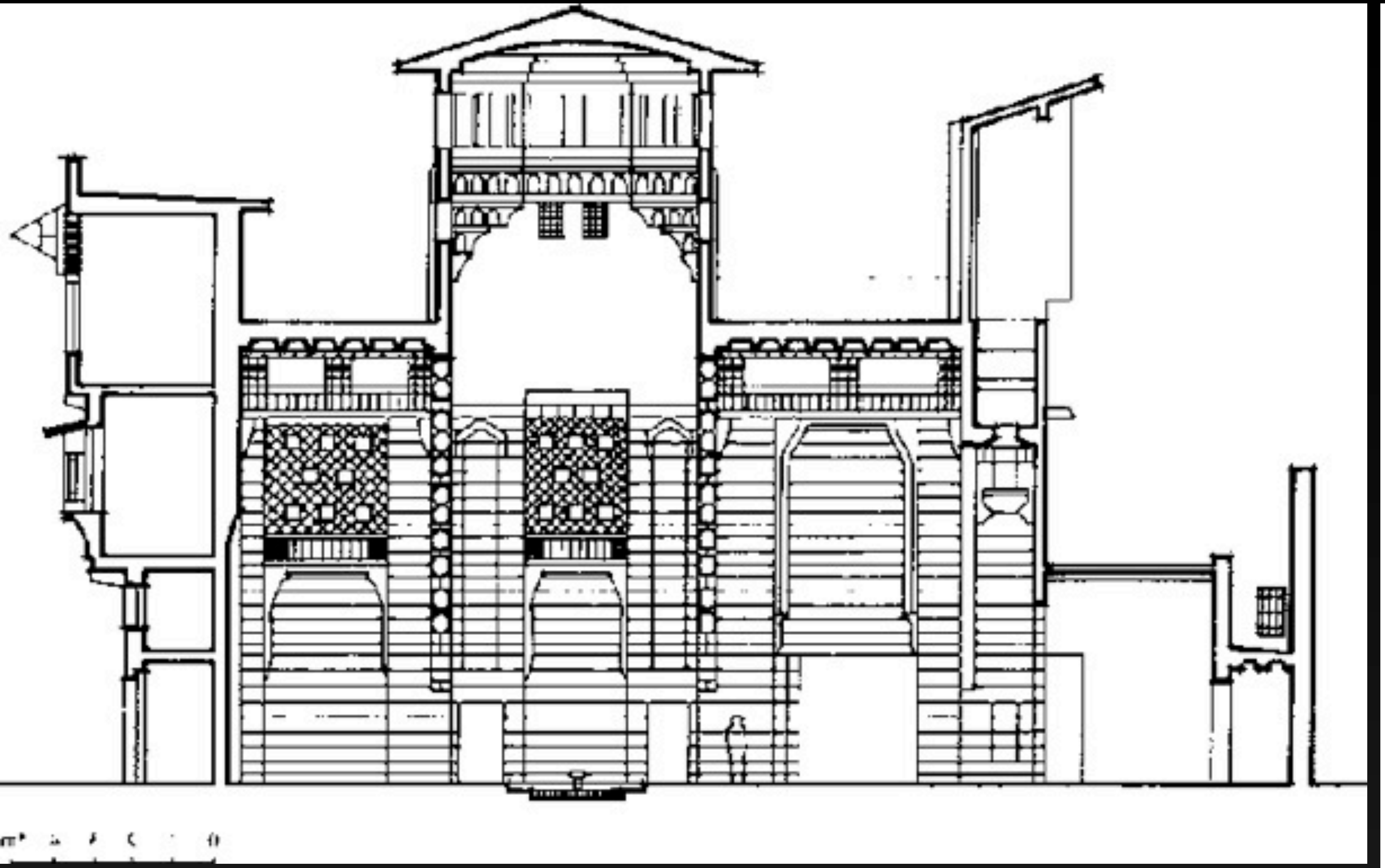
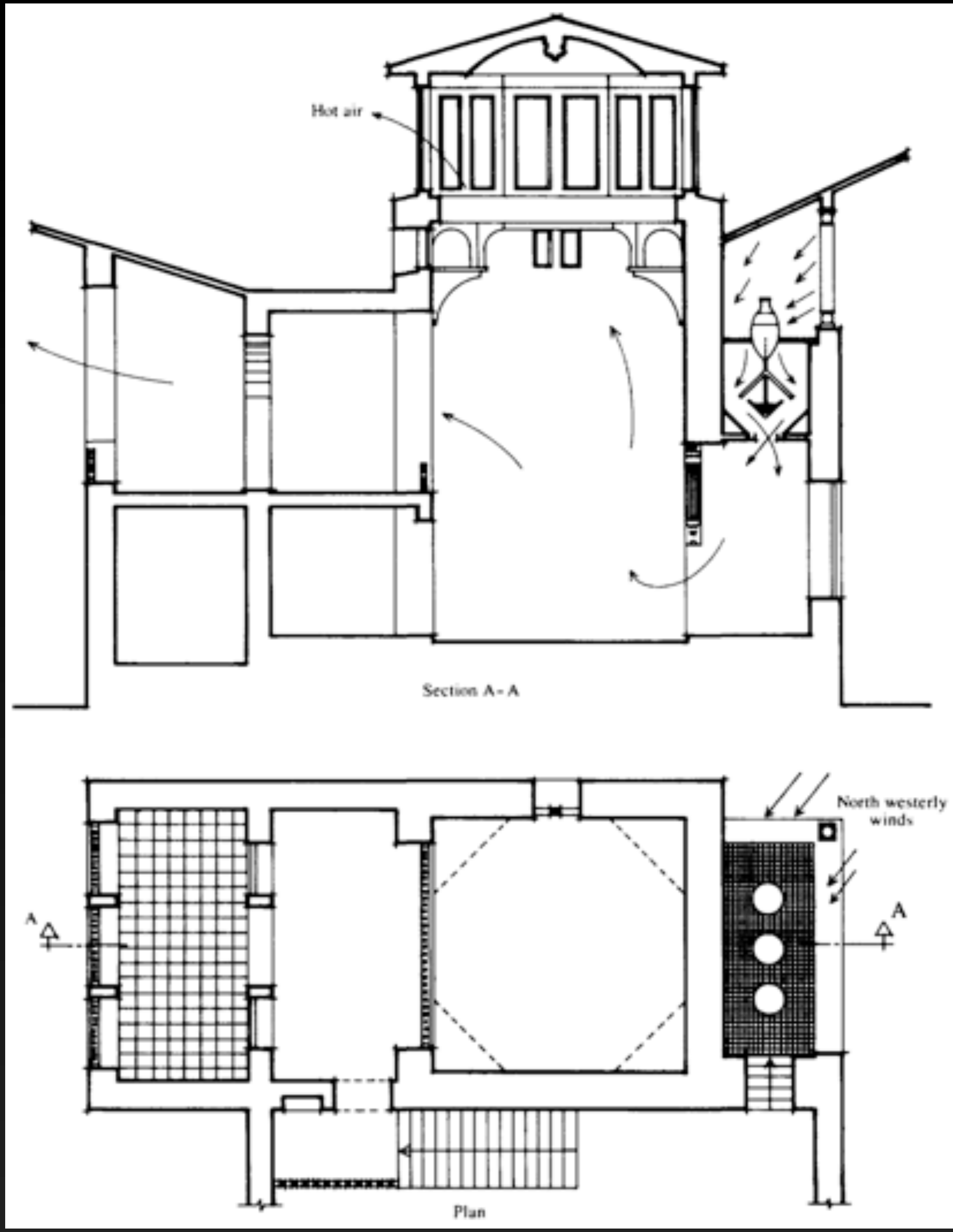


traditional type of malqaf ventilation



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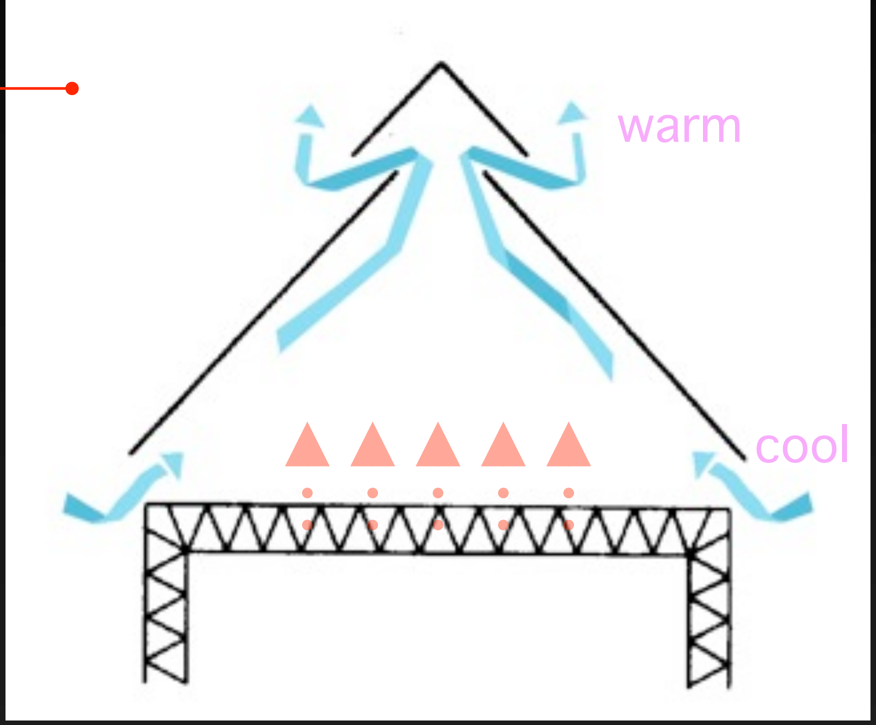
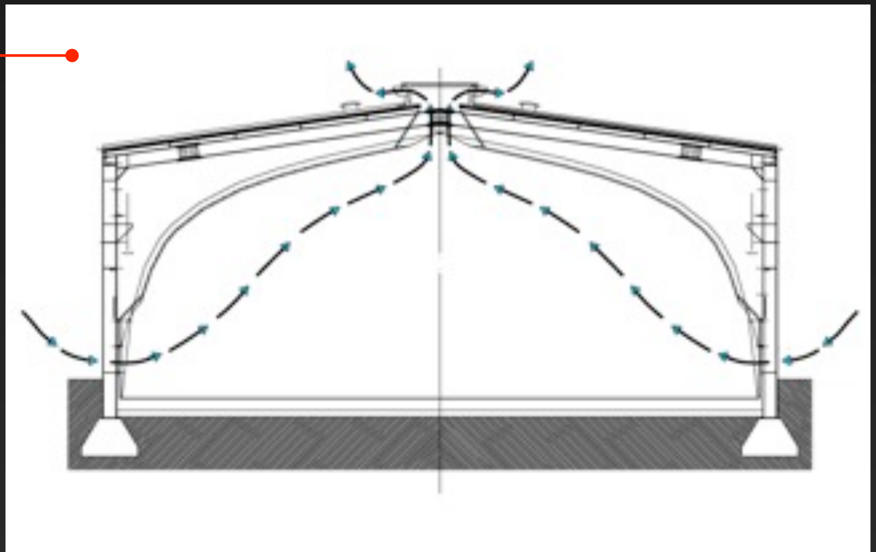
VENTILATION FOR COOLING PURPOSES
STACK-EFFECT VENTILATION

- warmer air lis lighter and thus more buoyant than cooler air
- the temperature differential (stacking) induces a forced upward flow
- comparatively weak form of ventilation with small flow volumes
- especially adequate for large hall-like spaces





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VENTILATION FOR COOLING PURPOSES
FORCED VENTILATION

- most consistently effective means of providing ventilation

- relatively small amount of energy required for operation

  interiour fans provide air circulation inside:

    remove heat from the occupants

    without changing the indoor air temperature

- potential problems: excess air speed and noise

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VENTILATION FOR COOLING PURPOSES
INTERIOUR THERMAL MASS COOLING

- extensively used to:

  store excess heat during the day

  release it at night

- however: lack of large temperature differential
- driving force: day-to night variation in ambient temperature (benefits the cooling effect)
- hence: increased air circulation during nighttime required (nocturnal ventilation)
- thermal masses increase nighttime indoor temperatures (as compared to lightweight construction)
- exposed thermal mass surfaces required

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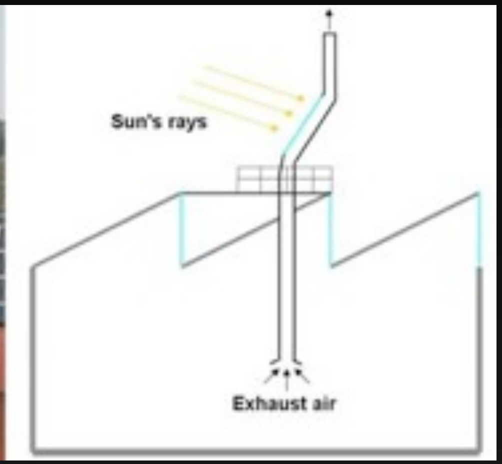
VENTILATION FOR COOLING PURPOSES
SOLAR CHIMNEYS

- solar chimneys are **stack-effect ventilators**
- driving force: passive solar heat
- also called: **solar-enhanced ventilators**
- **inlet** draws air from indoors
- **outlet** discharges to the outdoors
- as indoor air evacuates, (cooler) outdoor air flows into the building



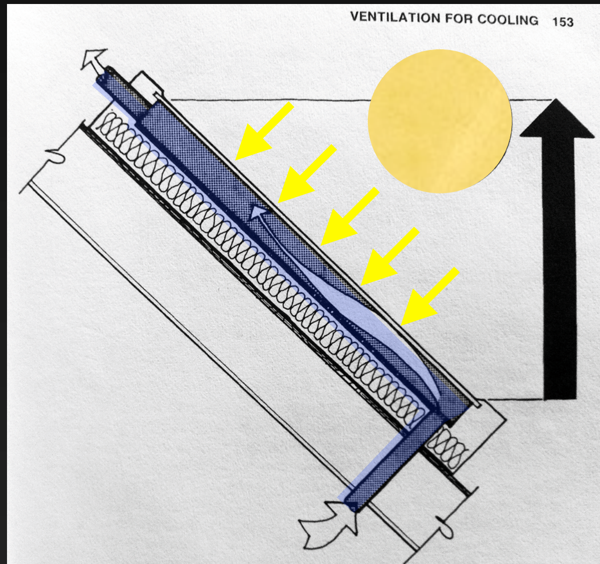


Figure 6.17. Solar chimney.

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7. EVAPORATIVE COOLING

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EVAPORATIVE COOLING

- by evaporation of water the sensible heat content decreases
- heat is absorbed by the phase change of water (liquid to gaseous)
- hence, moisture content of the air rises
- dry ambient air is beneficial to this process
- limit of the cooling process: when relative humidity reaches the saturation point (100%)
- direct evaporative cooling: misting of the inlet air

8. RADIATIVE COOLING

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RADIATIVE COOLING

- outer space has a constant temperature near **absolute zero**, i. e. -273° C
- although warmer, the sky all the same provides a **suitable natural heat sink** for cooling
- heat is rejected through **radiation heat transfer**
- a **temperature differential** is necessary for this effect to develop
- **unobstructed direct line** between radiant objects is required (to ‚see' each other)
- clear, dry climates are beneficial

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RADIATIVE COOLING

- architectual applications:

sleeping on terraces

roof pond cooling

water surface radiates heat to the night sky

open water ponds or

large bags of water (sprayed)

movable insulation panels during daytime

closing of the umbrellas in the courtyard of the Mosque in Madinah in the evening in order to benefit from the nightly radiation to the cool deep sky

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9. HEAT PUMPS

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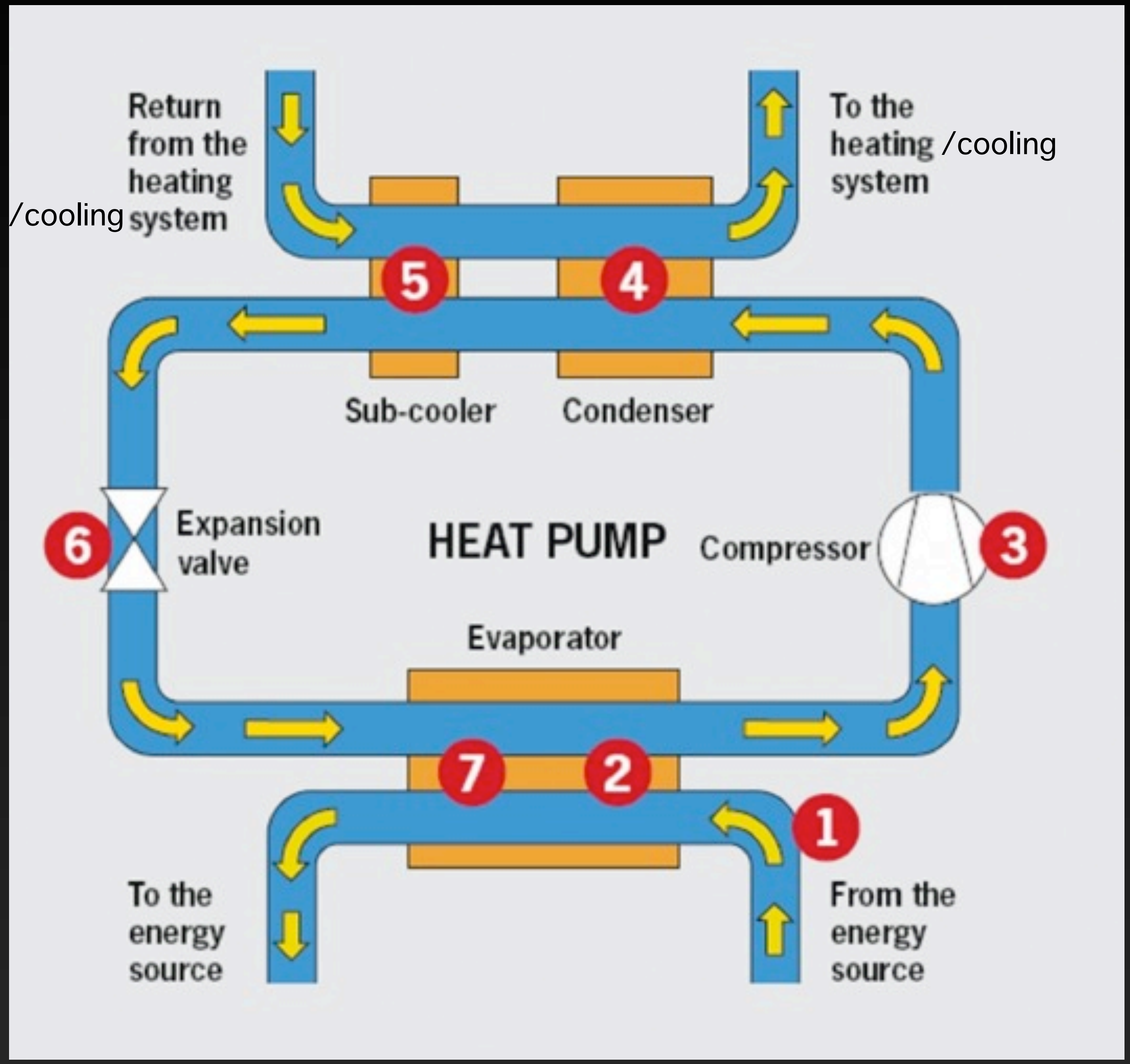
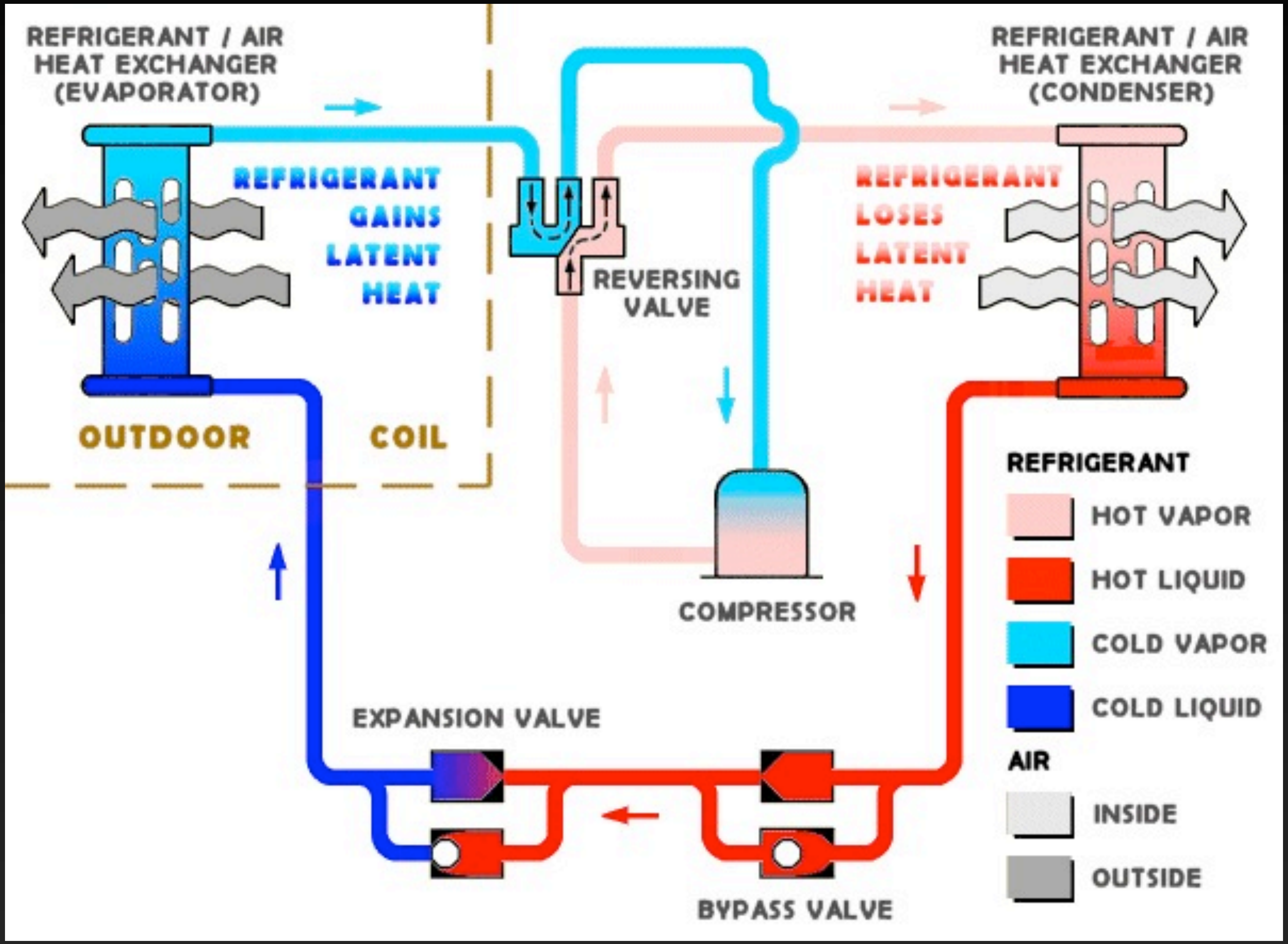


basic working principle of a heat pump for cooling or heating purposes



basic working principle of an air-source heat pump for cooling or heating purposes

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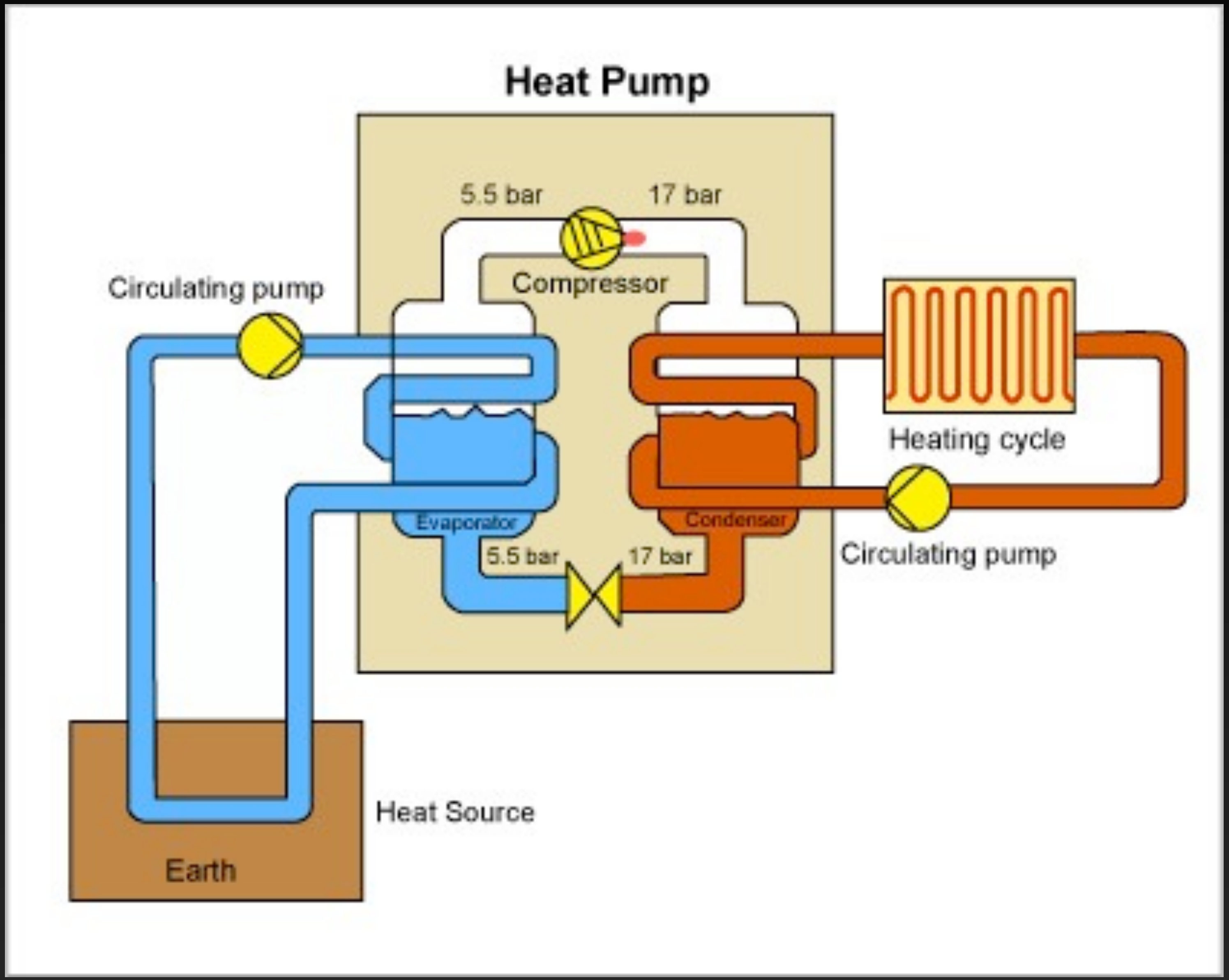

basic working principle of a water-source heat pump for cooling or heating purposes

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11 Passive Cooling

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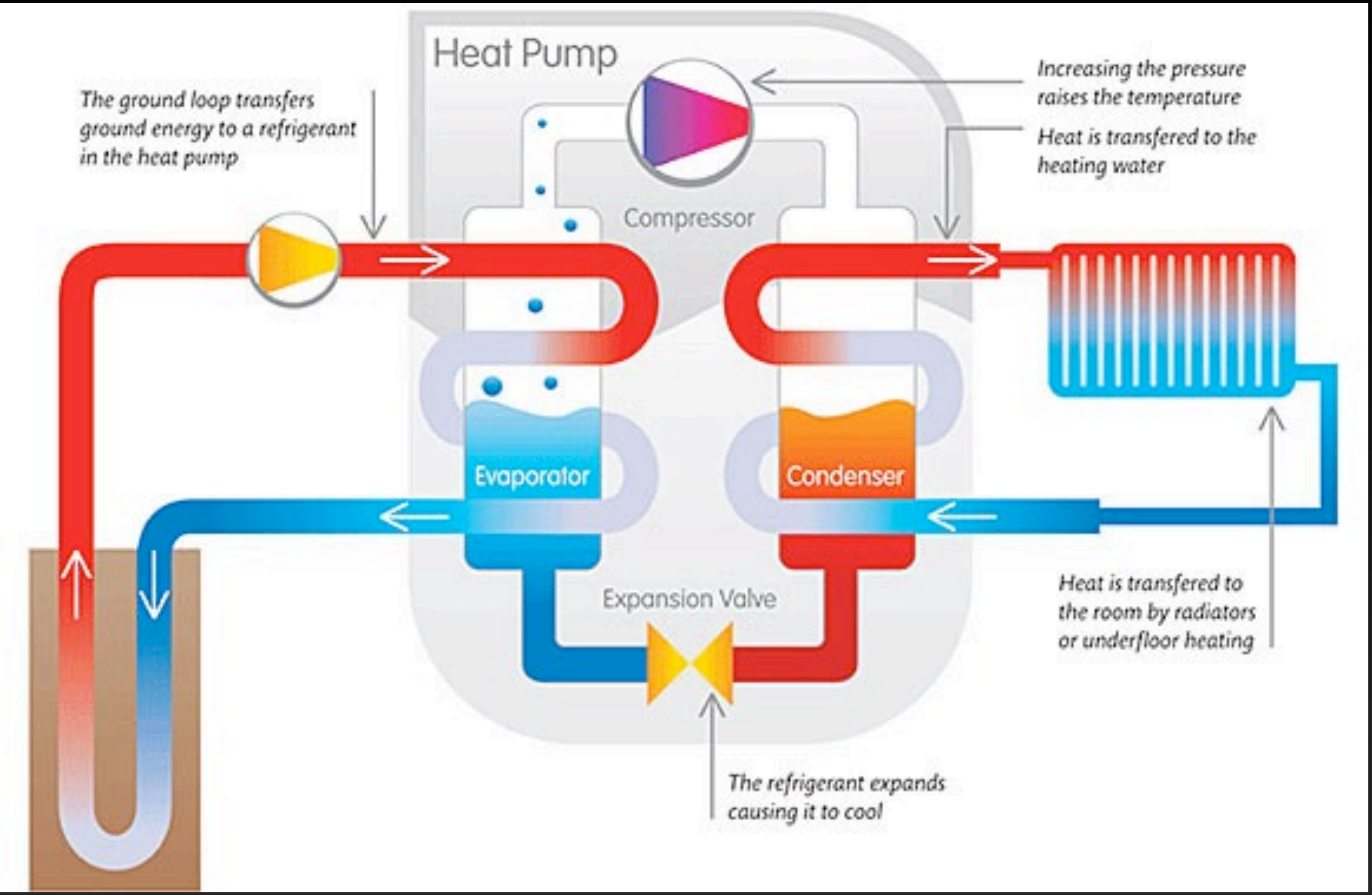

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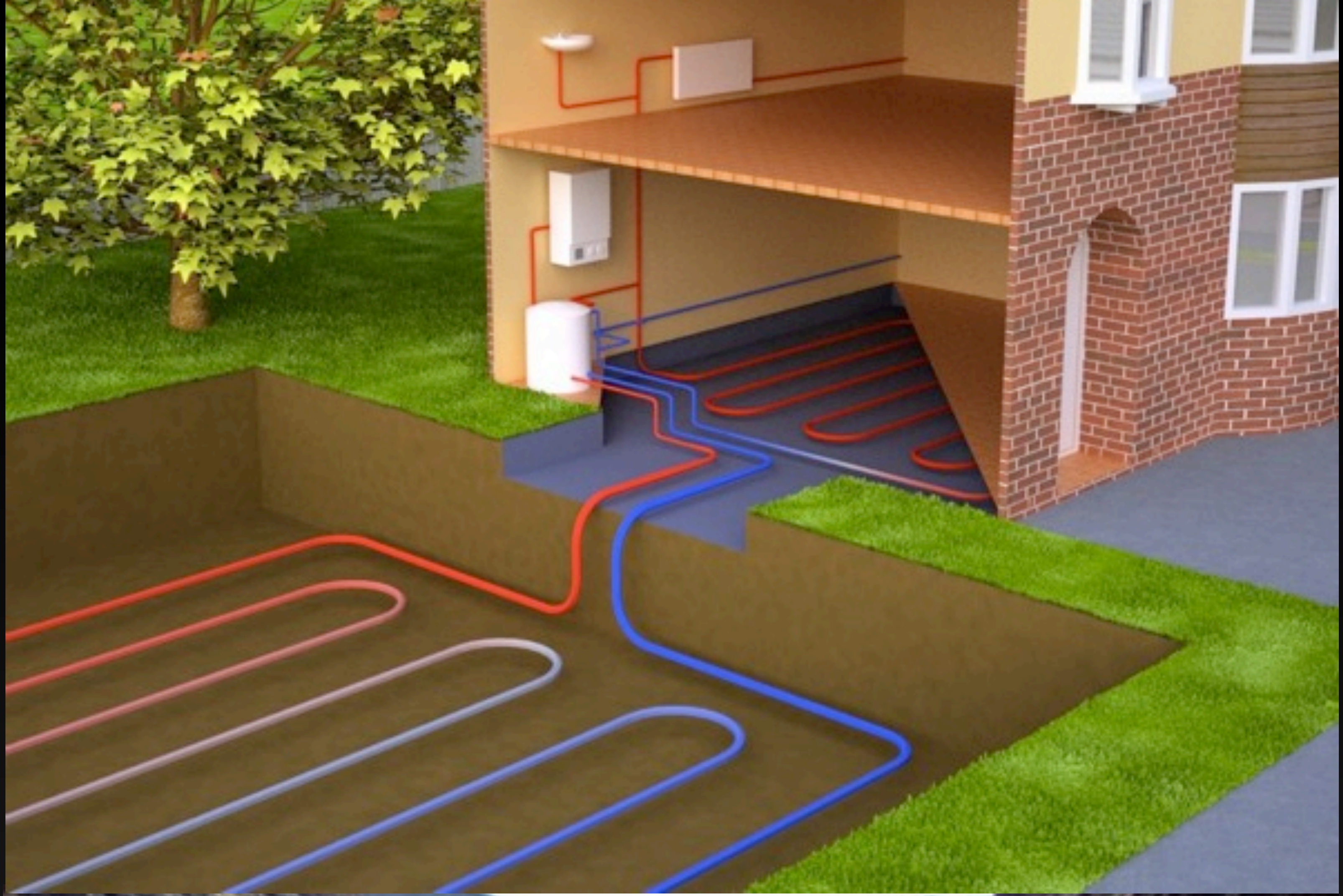

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