4.401/4.464 Environmental Technologies in Buildings

Christoph Reinhart

L17 HVAC systems for small buildings

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Thermal Module

- [x] Thermal Mass & Heat Flow
- [x] Insulating Materials + Window Technologies
- [x] Shading + Integrated Façade Design
- [x] Ventilation
- [x] Internal Gains & Load Calculations
- [x] HVAC for Small Buildings
- [ ] HVAC for Large Buildings

Course Project Workflow

- ❑ Provide a project narrative; analyze the climate; set your project targets
- ❑ General: Generate a Rhino model that uses the daylighting layers for representation and daylighting analysis as well as a set of separate zone layers for energy.
- ❑ For energy set up a simple simulation model in DIVA4 (with surrounding context) and determine orientation, WWRs and suitable upgrades levels (lighting, insulation and shading)
- ❑ To add PV using the DIVA/ArchSim PV module.
- ❑ Show space layouts in plan on a separate layer.

HVAC Systems

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General Considerations

- So far we have concentrated on quantifying and optimizing energy loads in buildings for heating, lighting, cooling, and internal gains using basic building design and passive systems concepts.
- Now we are looking at the mechanical heating & cooling systems that are required to meet these loads.

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General Considerations

- Internal gains and lighting loads are nearly always met with electricity in which case thermal loads and energy use are identical.
- Mechanical heating and cooling systems have a maximum capacity, i.e. a maximum output at any particular point in time.
- If heating or cooling loads are temporarily higher than the system capacity the building 'under-heats' (should not happen) or overheats (may happen once in a while).
- If a system is always running significantly under its maximum capacity it always runs at part load and accordingly has been oversized which might result in unnecessarily high initial investment costs and non-optimized system part loads.

General Considerations

- Is your building envelope or internal load dominated? You need cooling in the latter case.
- The closer you work with your HVAC engineer and the better you are able to predict the temporal load curve of your building, the more informed will be your choice when designing your HVAC system.
- Variables to consider include:
  - thermal behavior of your building (thermal mass, solar gains, occupancy patterns)
  - peak loads
  - part load curves for your equipment
  - size of system units
  - return air/water temperature

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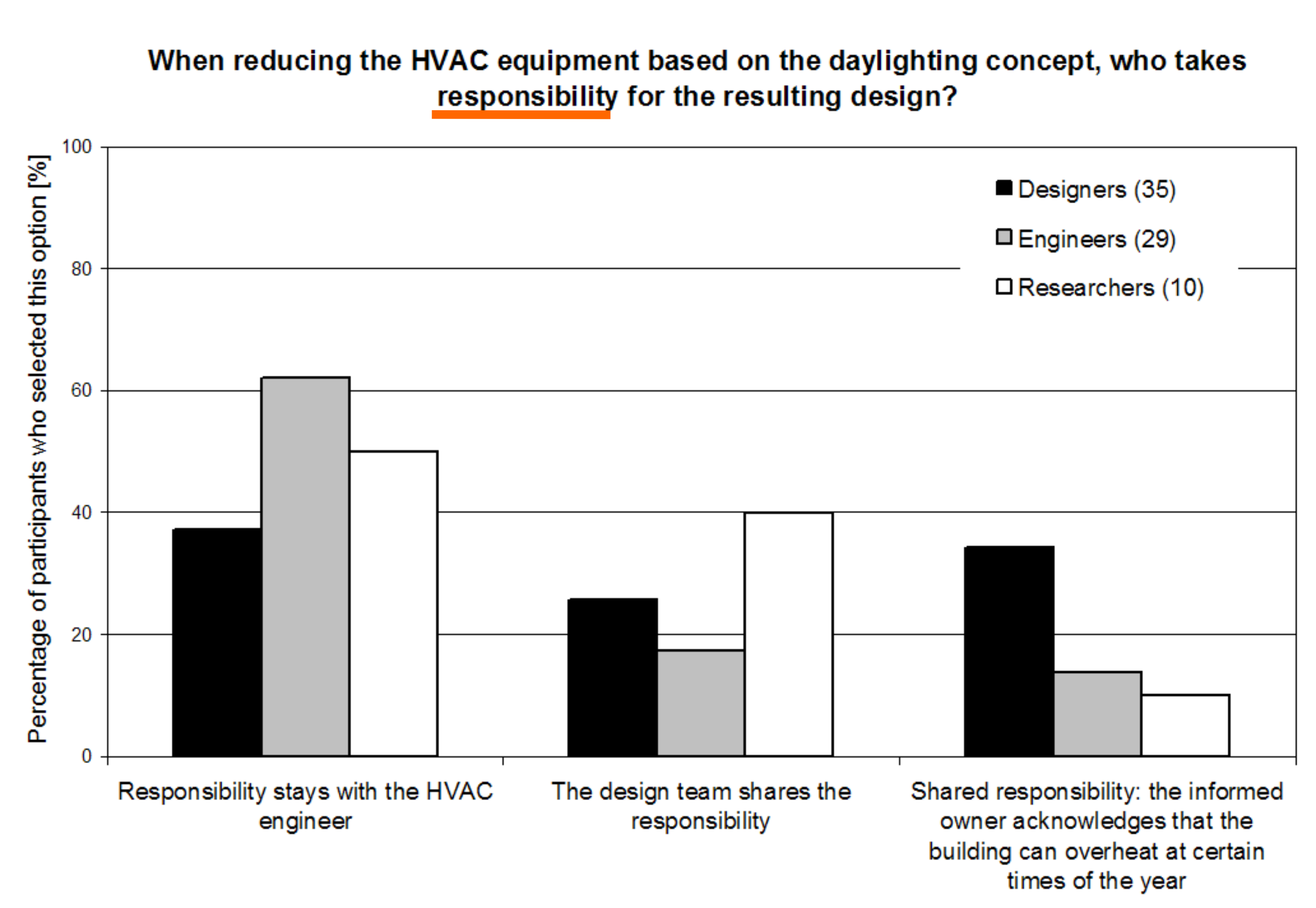
Potential Conflict



This image is from Anca D. Galasiu & Christoph F. Reinhart, "Current daylighting design practice: a survey," Building Research & Information, 36:2, 159-174. This journal is available online at https://www.tandfonline.com/doi/abs/10.1080/09613210701549748.

- The compensation of the HVAC engineer is usually linked to the cost of the purchased equipment.
- ASHRAE sizing methods do not consider solar gains for heating capacity.

Integrated Project Delivery

"Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. IPD principles can be applied to a variety of contractual arrangements and IPD teams can include members well beyond the basic triad of owner, architect, and contractor. In all cases, integrated projects are uniquely distinguished by highly effective collaboration among the owner, the prime designer, and the prime constructor, commencing at early design and continuing through to project handover."

--American Institute of Architects, 2007

Note: IPD in building design is linked to the concept of a Building Information Model (BIM).

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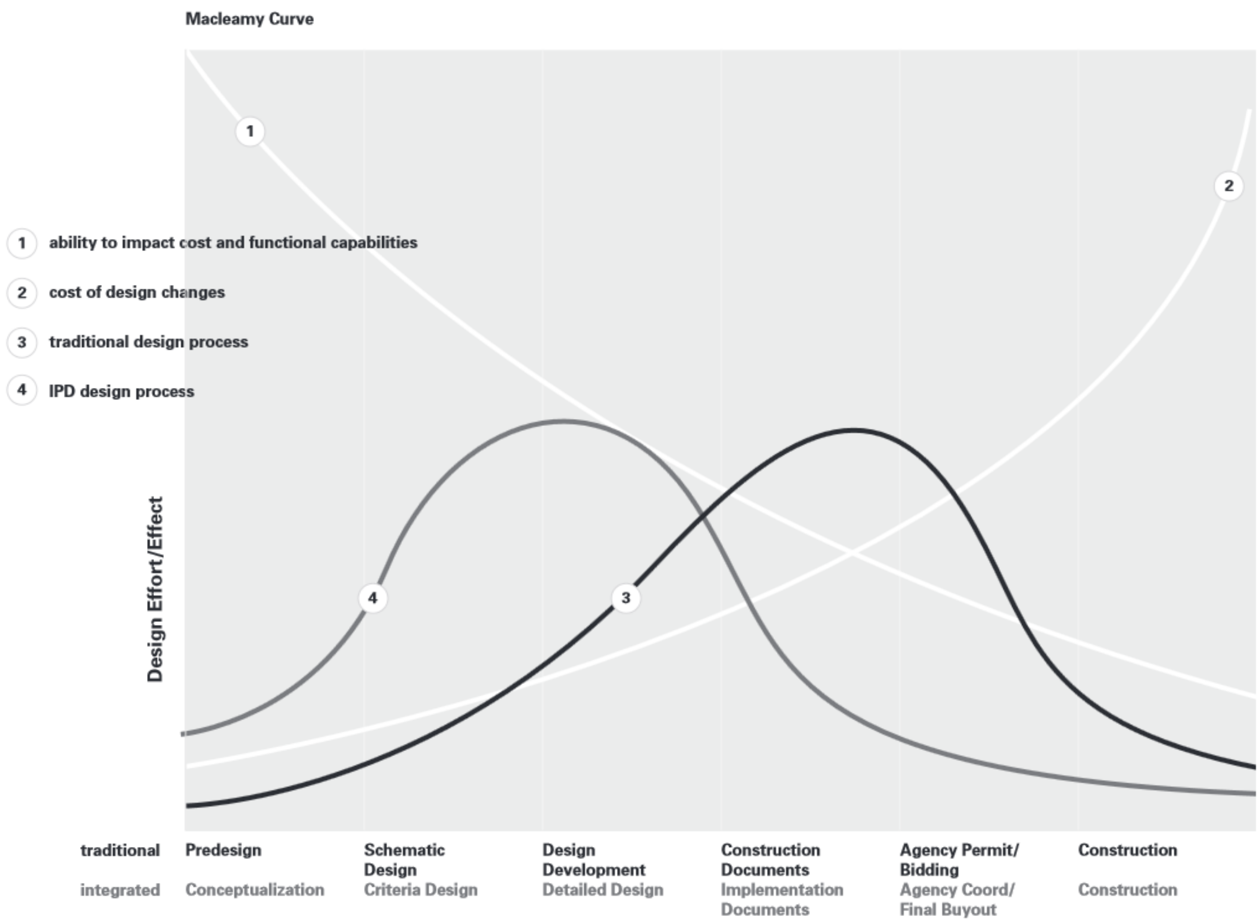
MacLeamy Curve



Introduced in the Construction Users Roundtable's "Collaboration, Integrated Information, and the Project Lifecycle in Building Design and Construction and Operation" (WP-1202, August, 2004)", the "MacLeamy Curve" illustrates the concept of making design decisions earlier in the project when opportunity to influence positive outcomes is maximized and the cost of changes minimized, especially as regards the designer and design consultant roles.

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Heating

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What was the first heating system?

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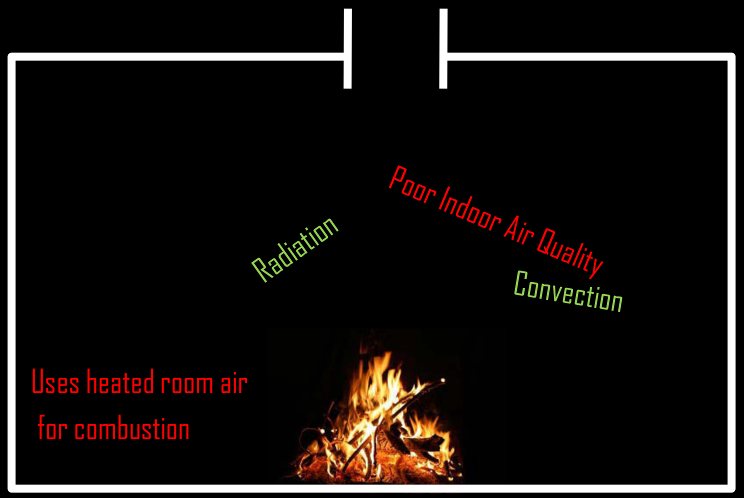
Heating with Wood



Open Fire

Chimney (efficiency ~ 10%)

- ❑ Basic Physics: Controlled combustion of a medium and delivery of heat to a space through a combination of heat transfer mechanisms

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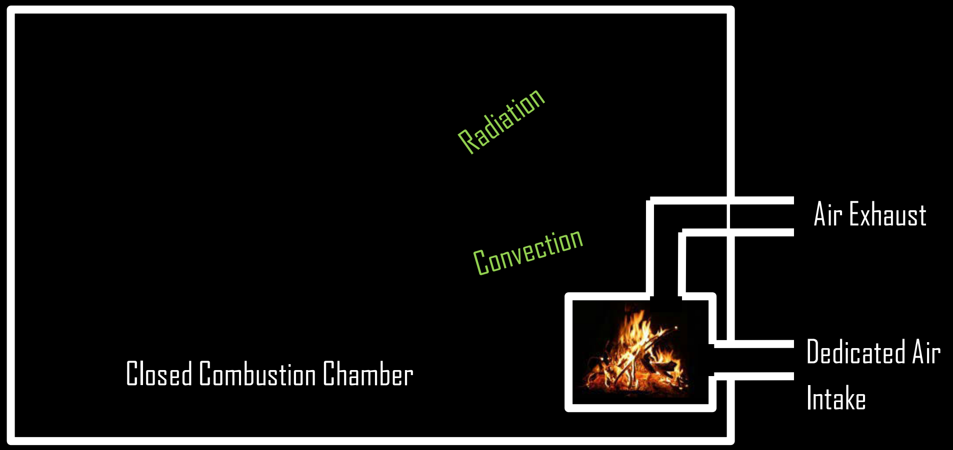
Heating with Wood



Retrofitted Fireplace

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Heating with Wood

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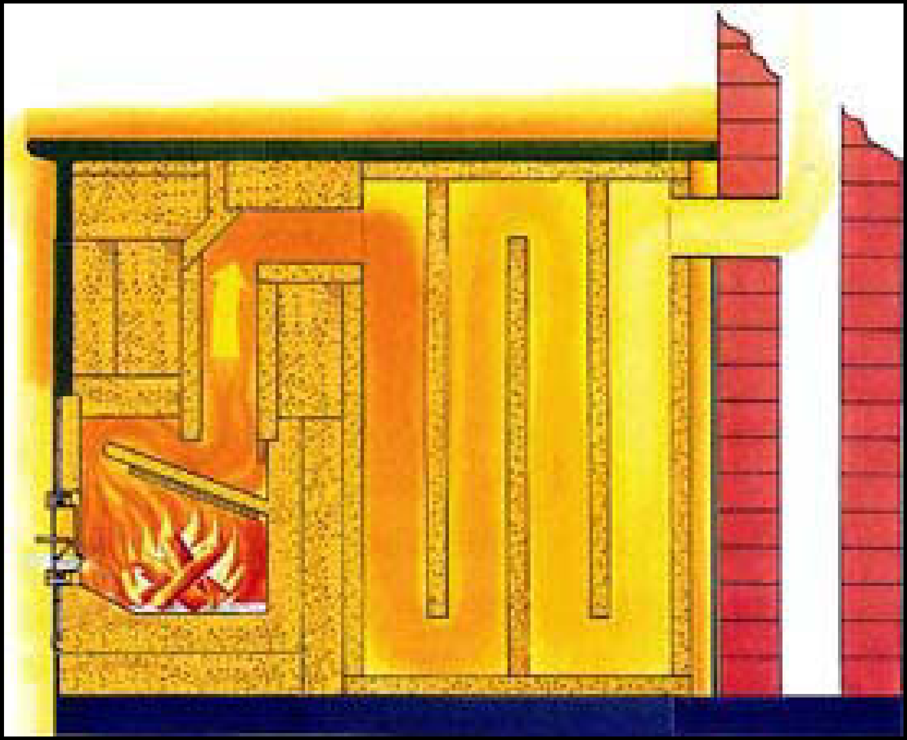

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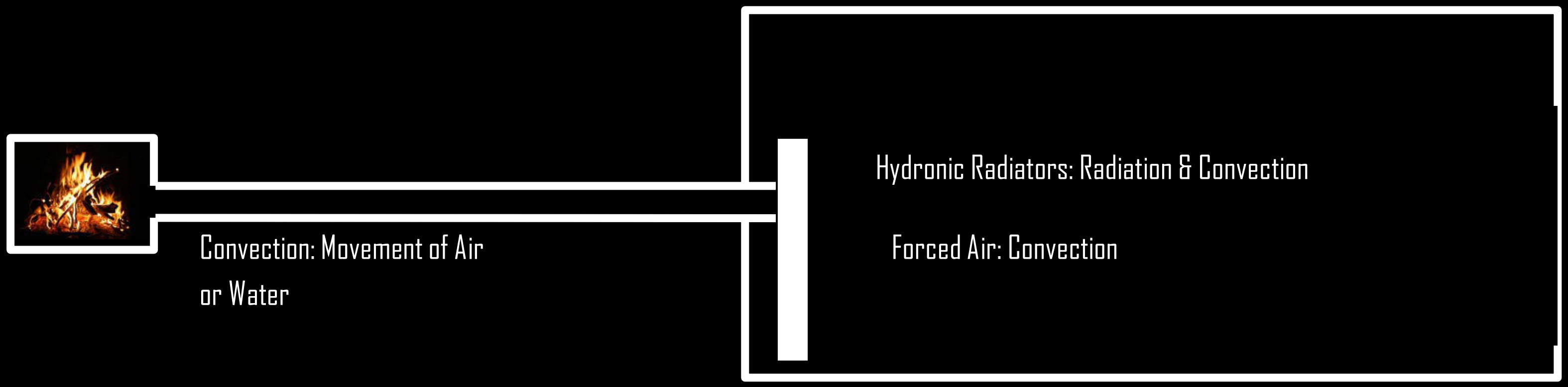
Central Heating

- Separating the combustion process from the space.
- Requires a distribution system.



Central Heating System

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Heating Systems

- A heating system consists of three components.

Source Energy	Heating System	Distribution System
Solar Wood Oil Gas Biomass Electricity	Furnace Solar collector Baseboard heater Heat pump	Air Water Electricity

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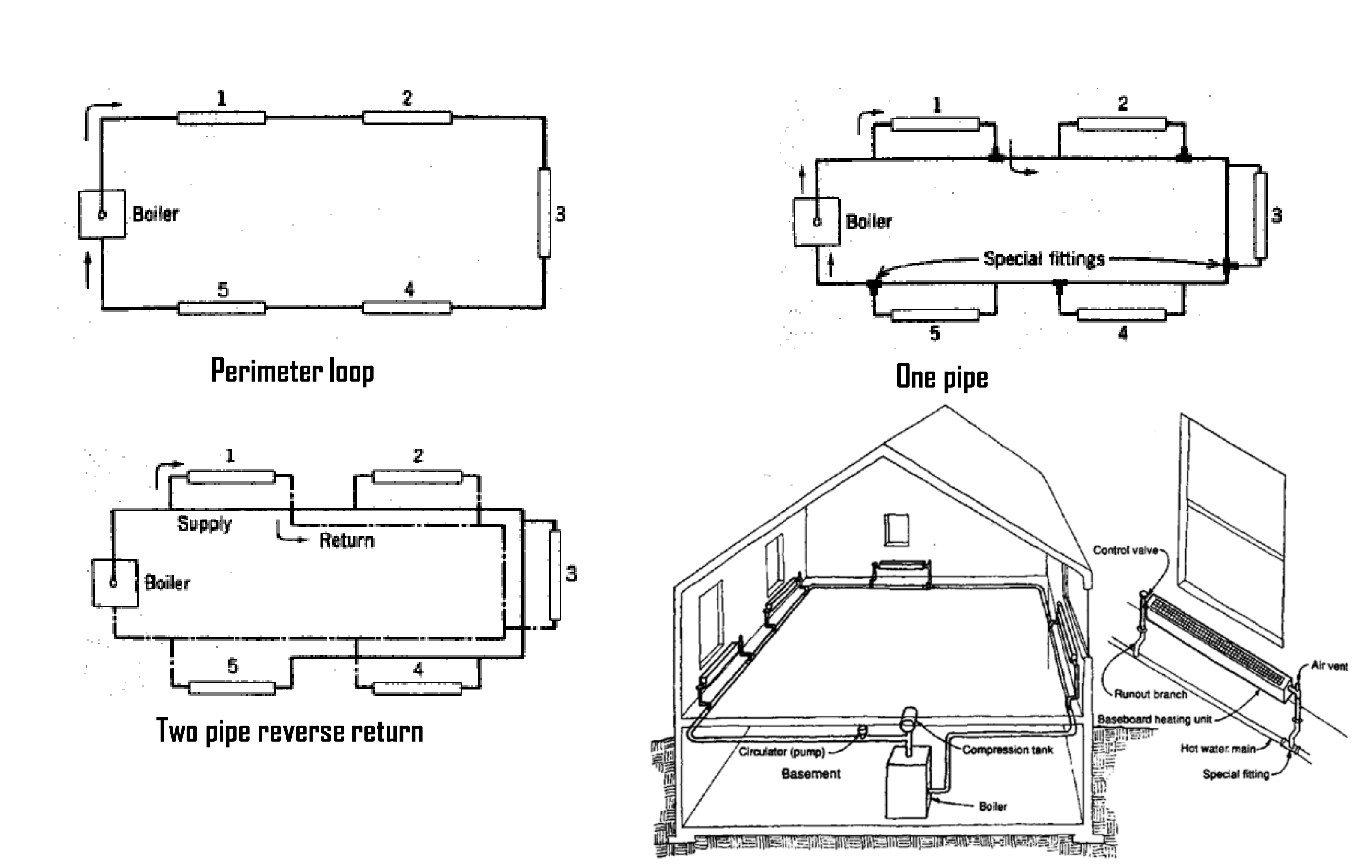
Pros and Cons of Various Heating Distribution Systems

System	Advantage	Disadvantage
Air	• Ventilation, cooling and humidity control	• Space requirements
Water	• Limited space requirements • Radiant heating and cooling	• No ventilation • No humidity control
Electricity	• Space requirements • Flexibility; easy to control, cheap to install	• No ventilation • No humidity control • High operation costs

Examples of hydronic heating distribution systems



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- ❑ To consider: pipe expansion, air vents and water drains, pipe insulation

Radiant Panels

Radiant floor

Radiant ceiling

❑ A radiant floor has a larger heat exchange surface than a conventional radiator and may hence operate at a lower temperature.

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Condensing

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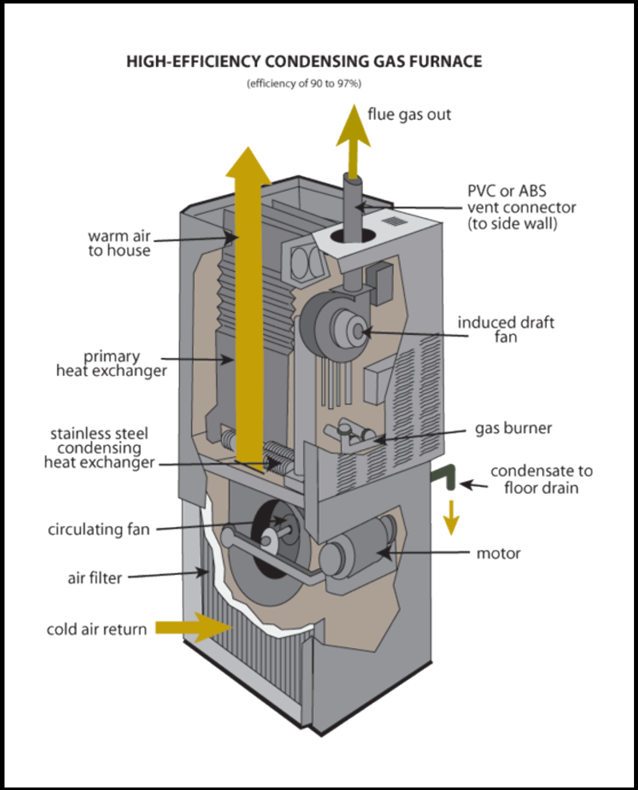

- As opposed to a regular furnace, a high-efficiency or condensing furnace extracts so much heat from the exhaust gases that water vapor in the exhaust condenses. Such furnaces must be designed to avoid the corrosion that this highly acidic condensate might cause.
- No chimney is required.
- Typical price premium for a high-efficiency furnace is \$1000. Assuming a \$200 utility rebate, \$100 federal incentives, 15% efficiency gain, the payback time lies around 3.5 years or less.
- Variable-speed DC motor fans reduce noise and save electricity.

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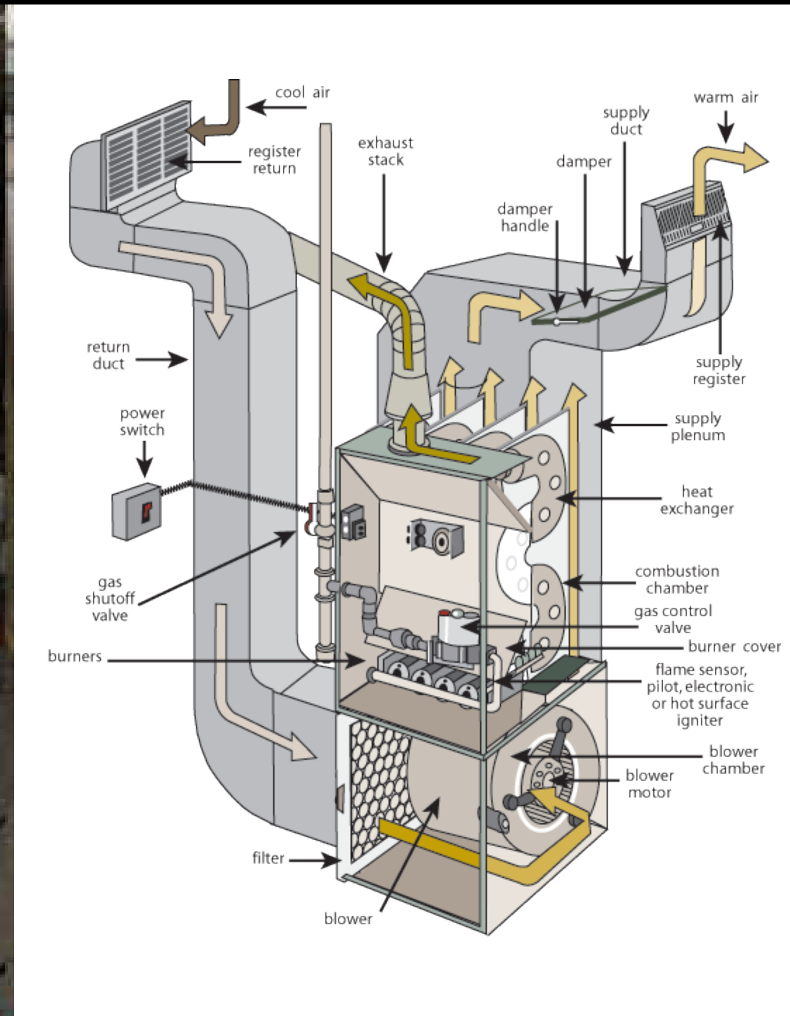
Condensing Furnace



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Heating with Pellets

Wood pellets

Pellet stove

Tanker delivering pellets

- Ideally a byproduct of sawmilling, very dense, low humidity content (<10%)
- Due to regular shape and consistent burning efficiency suitable for automatic feeding.
- Both room furnaces and central heating.
- Requires local provider and distribution system.
- CO_2 content depends on the harvesting process of the underlying biomass.

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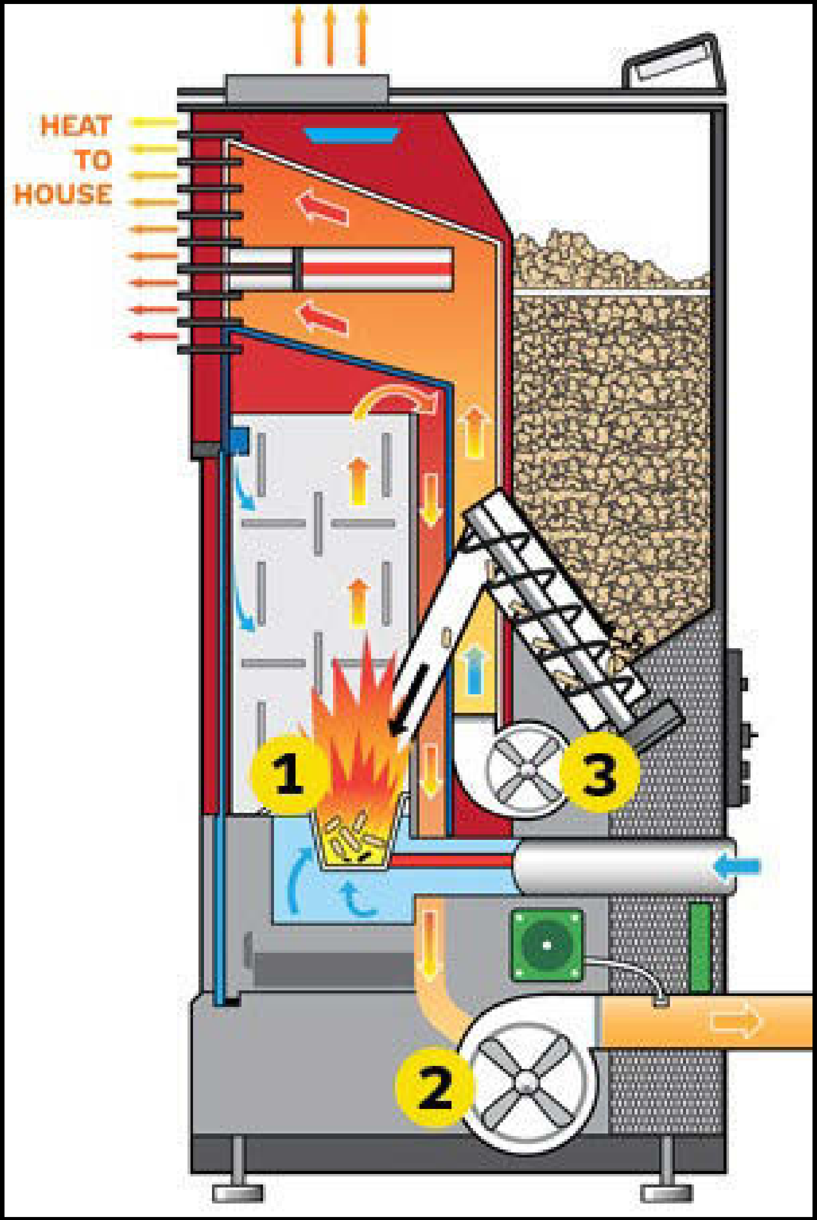
Pellet Stove Diagram



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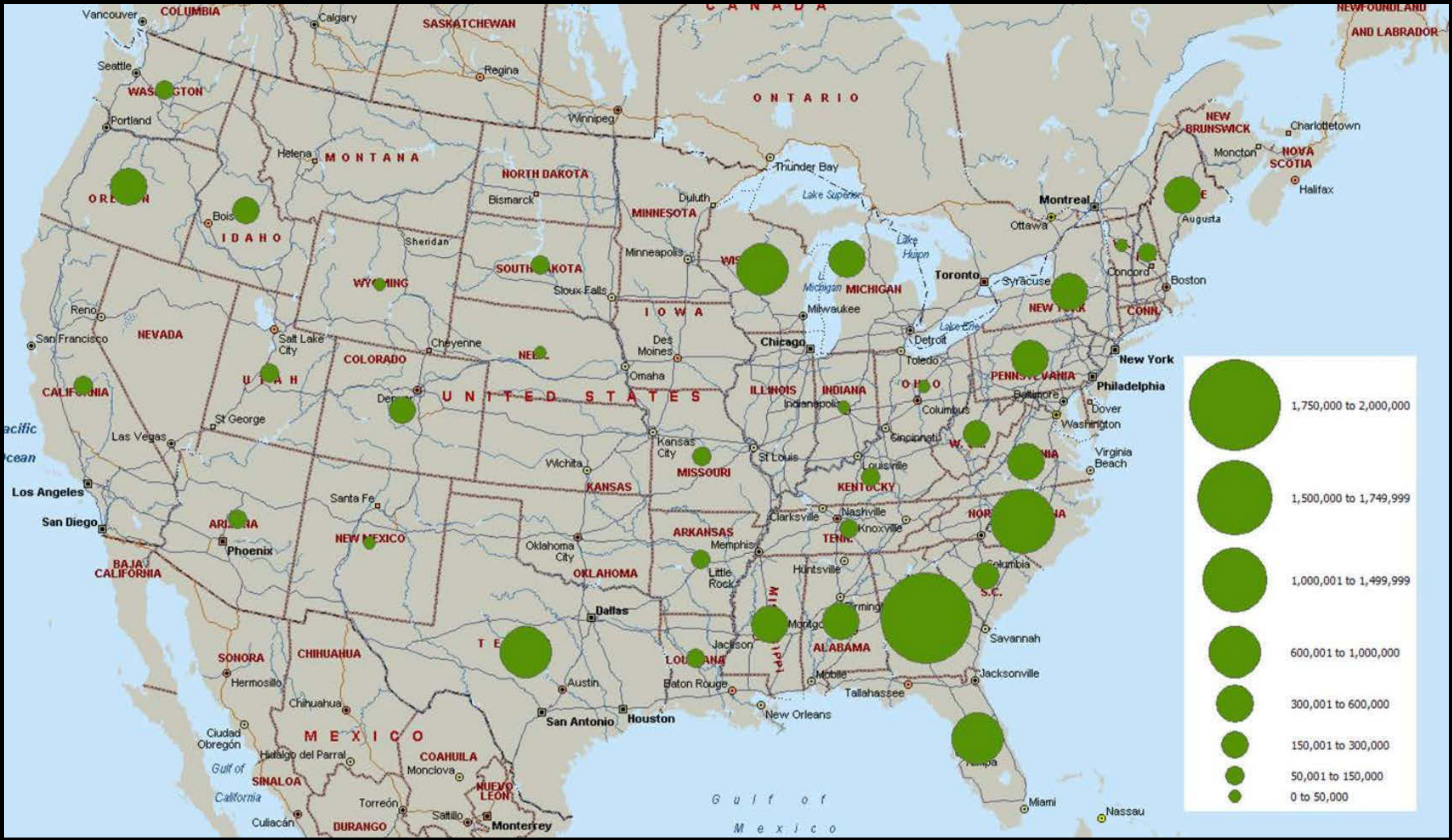
US Market Penetration (2014)



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- States with the highest penetration of wood pellets lack a natural gas infrastructure.

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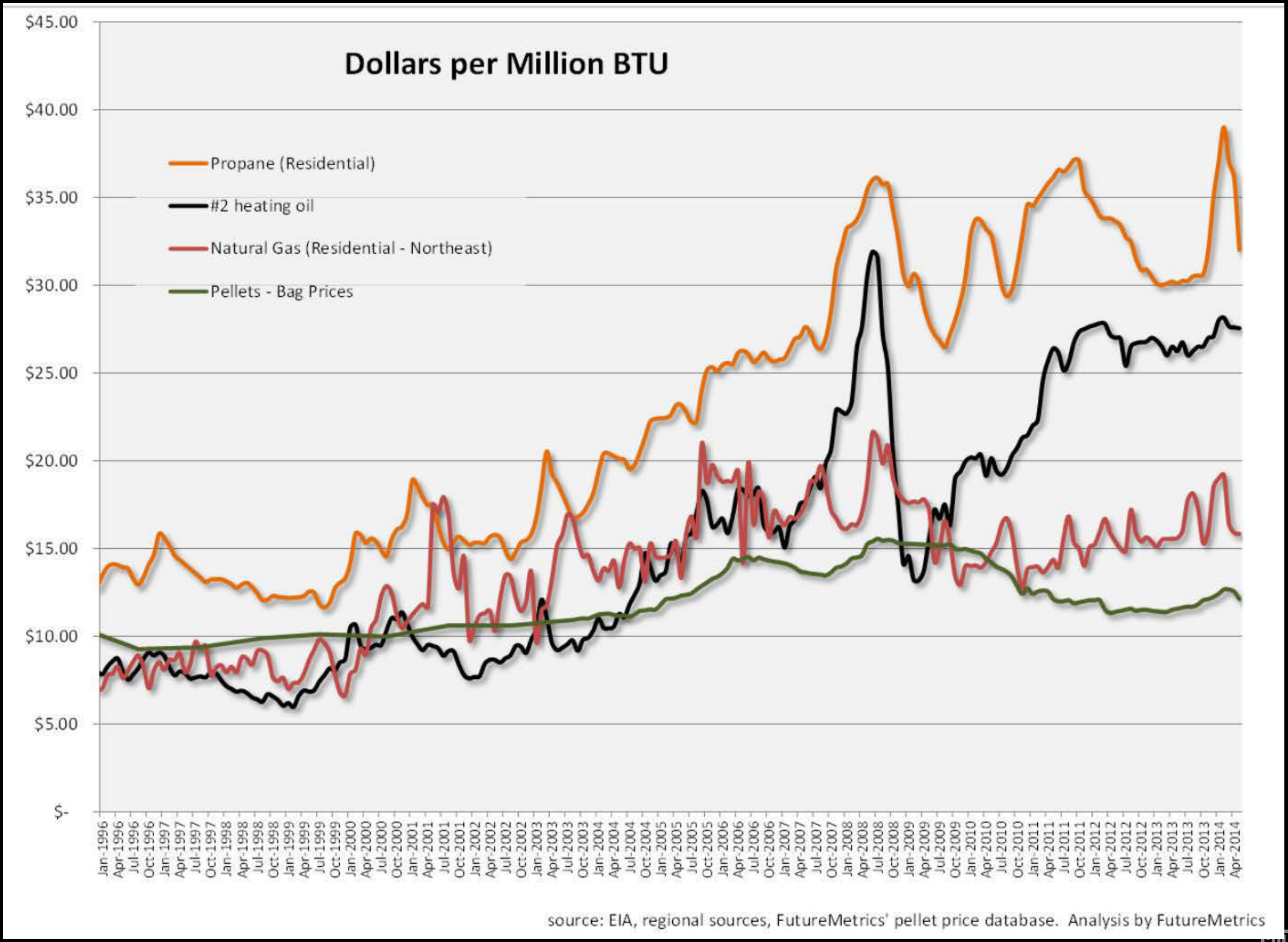
Economics (ballpark)



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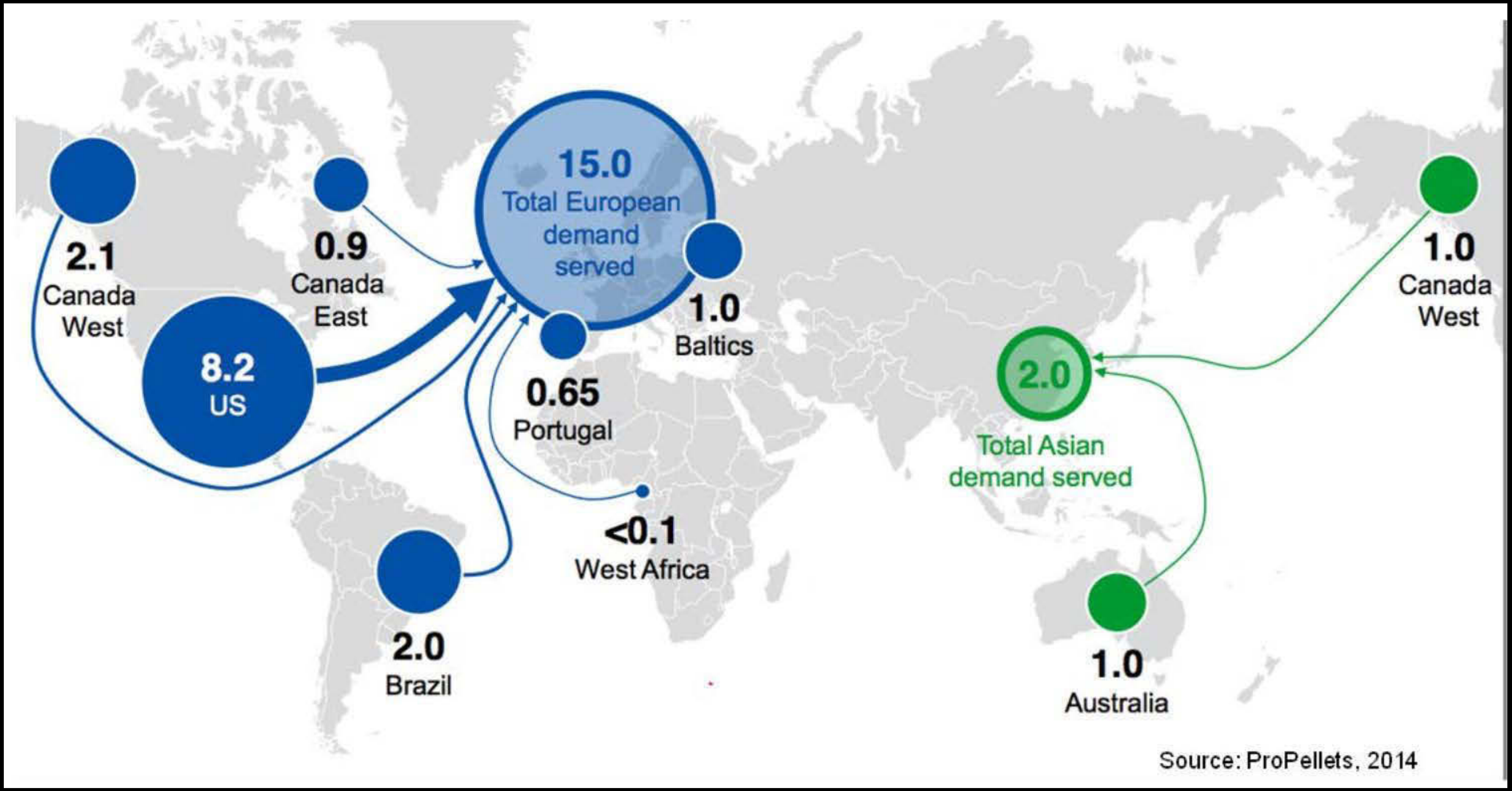
International Pellet Markets



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Heating with Electricity

Electric baseboard heater

Air Source Heat Pump

- Resistance heater: 1 kWh electric equals 1 kWh thermal
- Heat pump: 1 kWh electric yields > 1 kWh thermal

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Heat Pumps

A heat pump is a mechanical heating and cooling system driven by electricity. It is based on a compressive refrigeration system that can run 'both ways'. Compressive refrigeration relies on liquefaction and evaporation of a refrigerant.

Heat Source

Heat Sink

$$T_{source} < T_{Sink}$$

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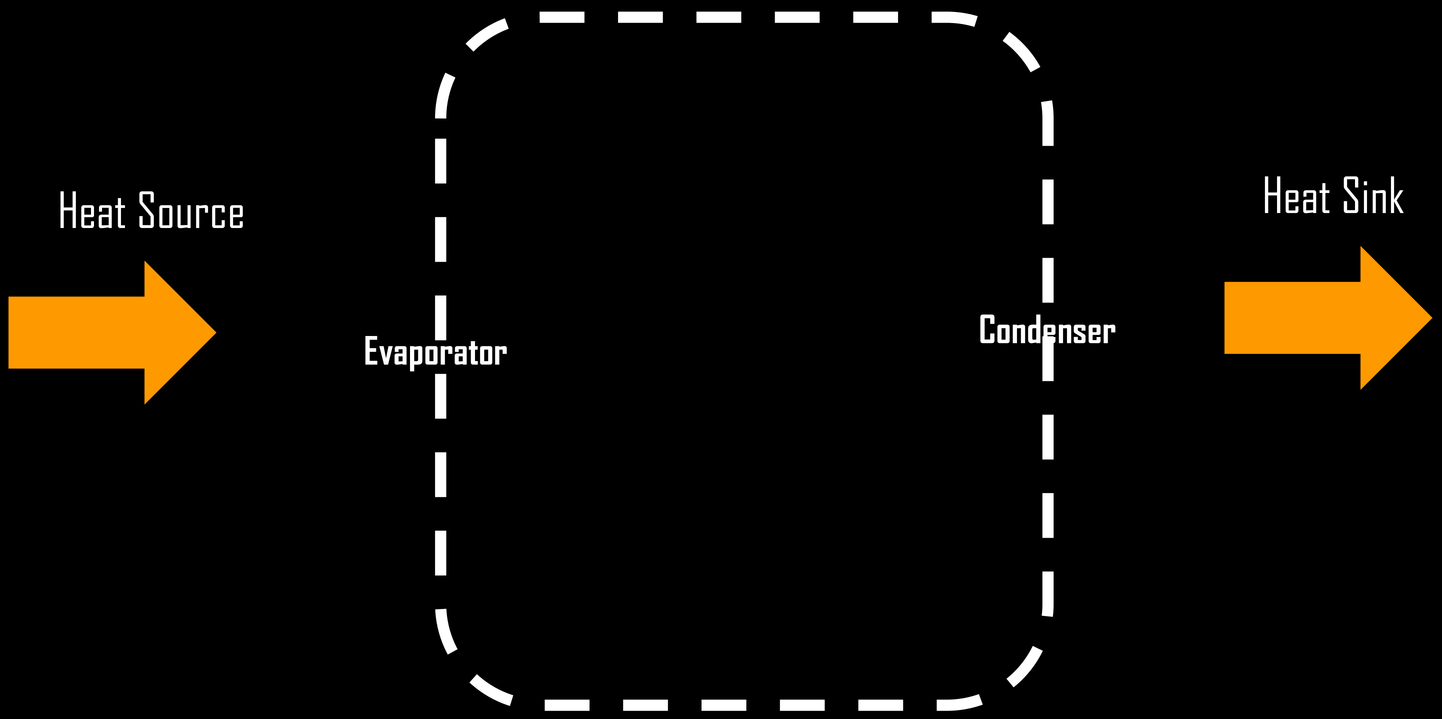
Heat Pumps

A heat pump is a mechanical heating and cooling system driven by electricity. It is based on a compressive refrigeration system that can run 'both ways'. Compressive refrigeration relies on liquefaction and evaporation of a refrigerant.



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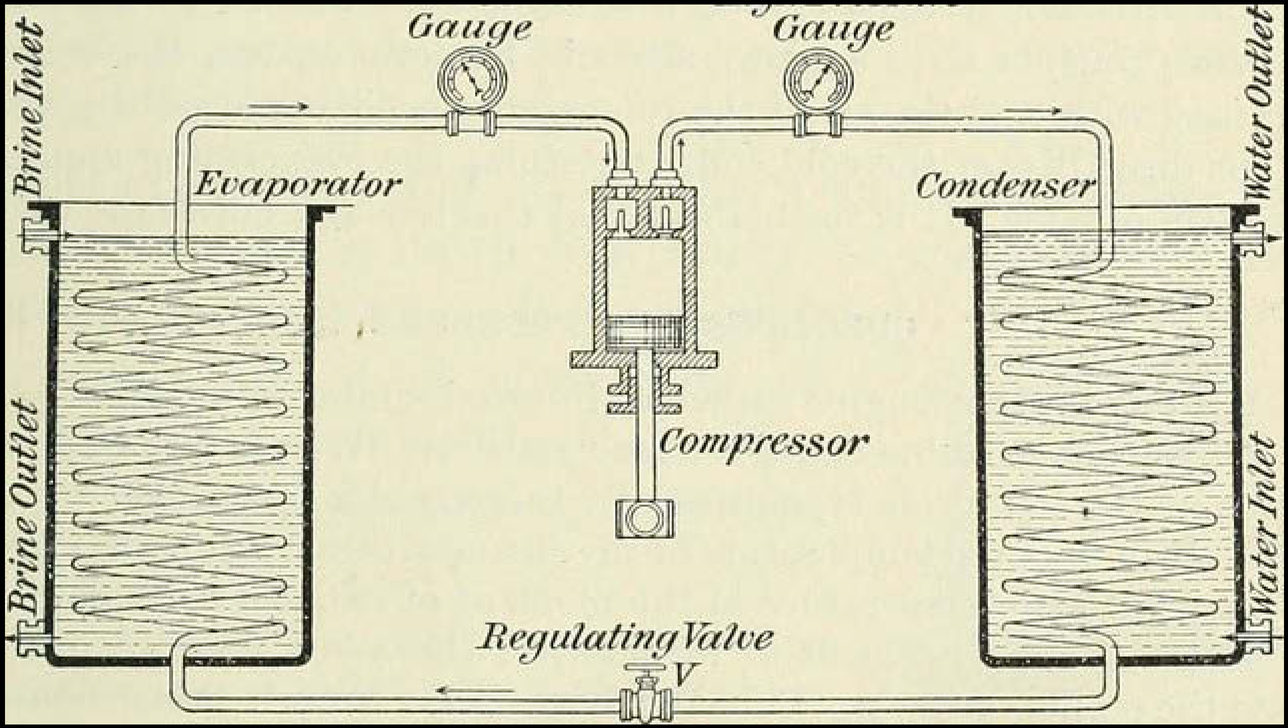
Heat Pumps

Heat In



Heat Out

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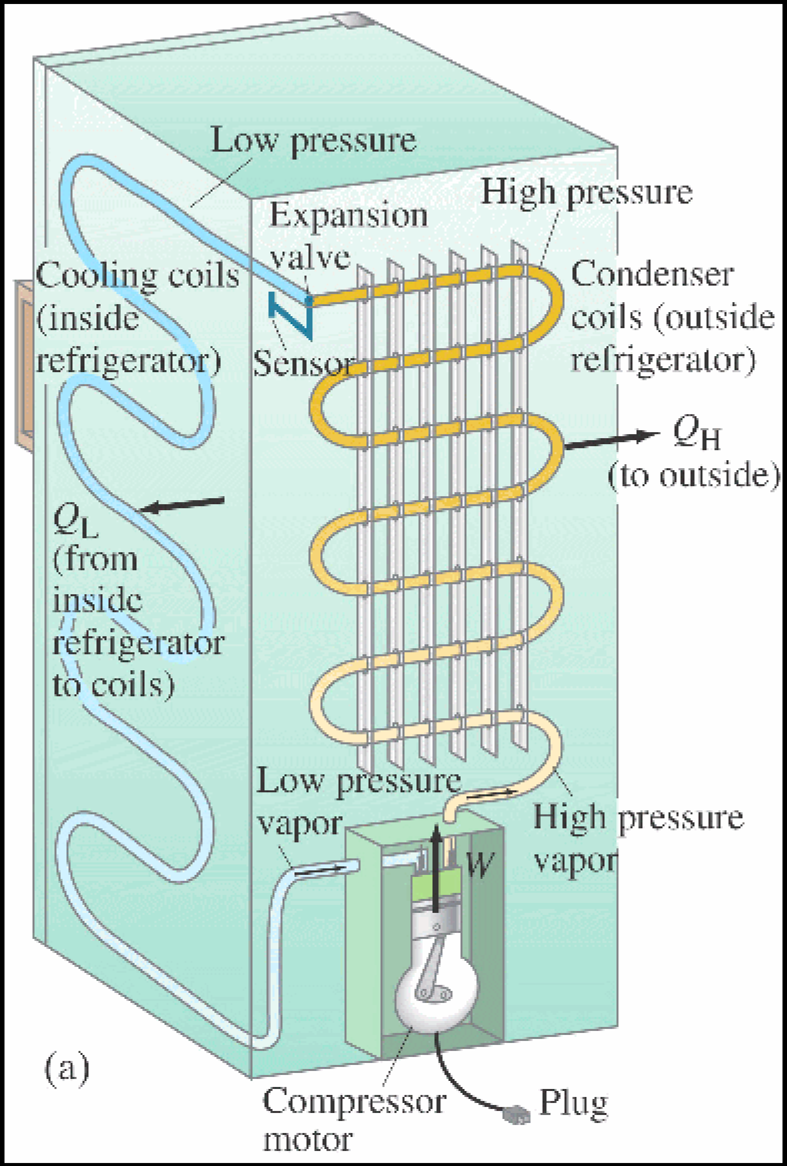
Refrigerator



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Can you cool a room with an open fridge?

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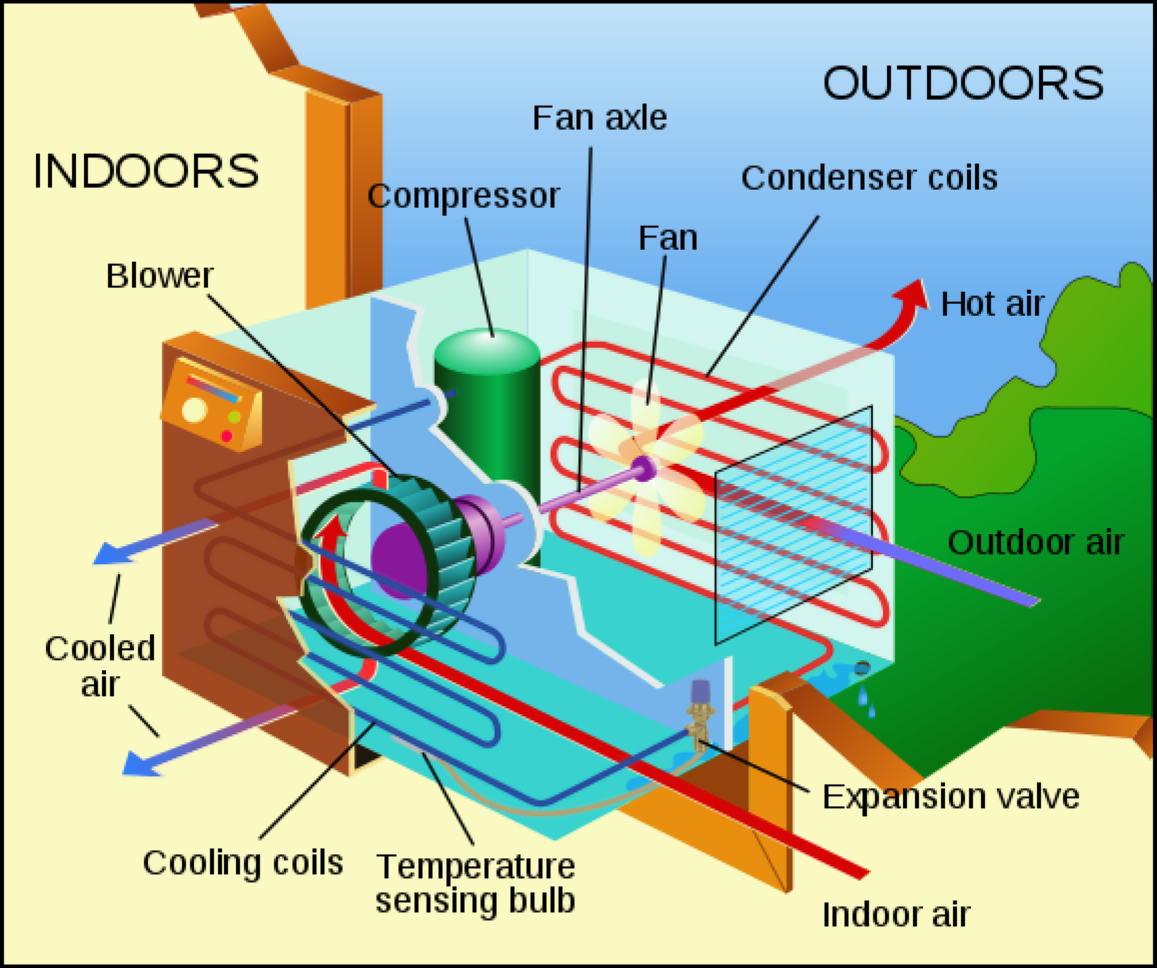
Typical Through-The-Wall AC Unit



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Refrigerants

- Up until the mid-1990s chlorofluorocarbon (CFC) gases were used which are strong greenhouse gases.

- In the mid-1990s CFCs were banned and replaced with hydrochlorofluorocarbons (HCFCs).

- In 2010s HCFCs are being replaced with hydrofluorocarbons (HFC)

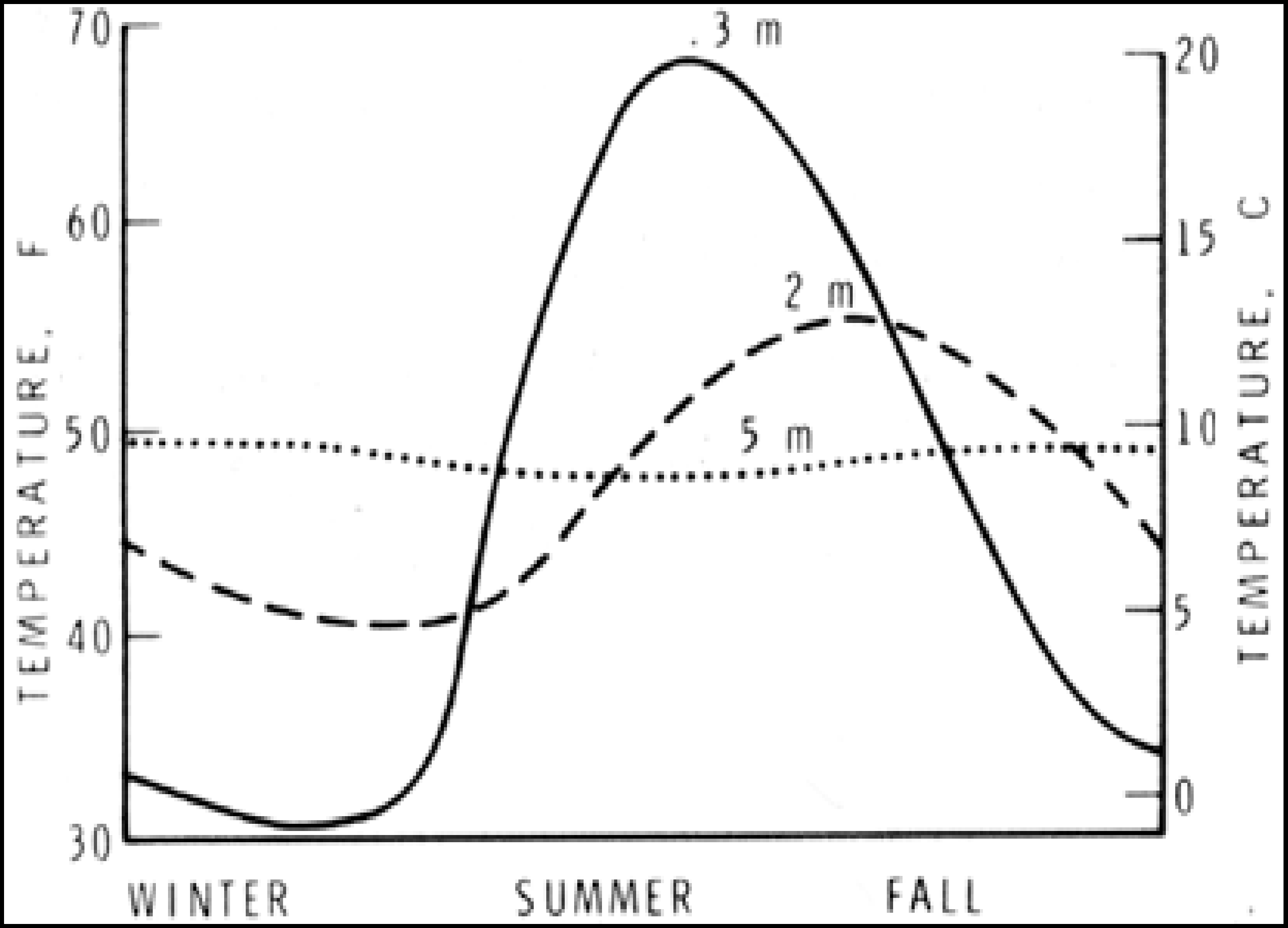
Heat Pumps

- Heat pumps typically draw heat from the ambient air or the ground making them either air source or ground source heat pumps.

- Heat pumps can be reversed into a cooling device. In fact, ground source heat pumps should be used for both heating and cooling as the ground temperature otherwise keeps on rising or falling with time.

- Mini split (air to air heat pump) systems are becoming increasingly popular in the US and abroad.

Ground Temperatures



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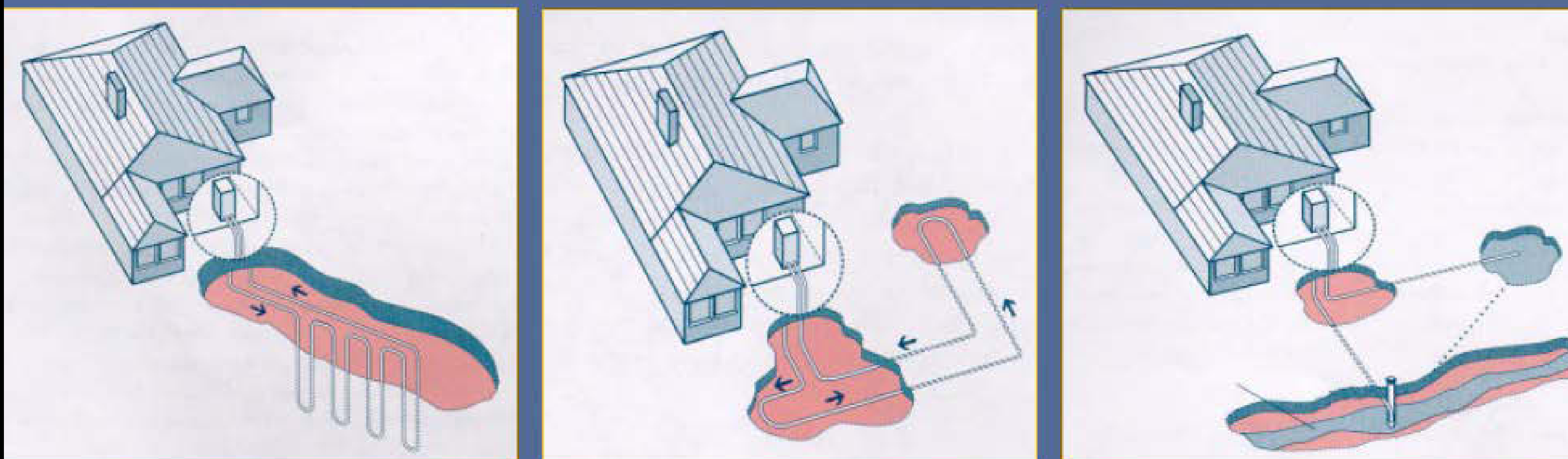
- The temperature of undisturbed ground oscillates around the annual mean air temperature.

Types of Earth Connection

Vertical (GCHP)	Horizontal (GCHP)	Groundwater (GWHP)
Rocky ground	Most land used	Aquifer+Injection
More expensive	Less expensive	Least expensive
Little land used	Small buildings	Regulations
High efficiency	Temp. varies	Fouling



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- Plastic tubing usually used for outside heat exchanger.

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Horizontal Ground Source Heat Pump

- ❑ Installation depth about 1.5 m.

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Heat Pump Example

Blackstone Building (architecture: Bruner Cott)

❑ Ground source heat pumps should be used for both heating and cooling as the ground temperature otherwise keeps on rising or falling with time.

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Ground Source Heat Exchanger

Lamparter Building
Weilheim, Germany

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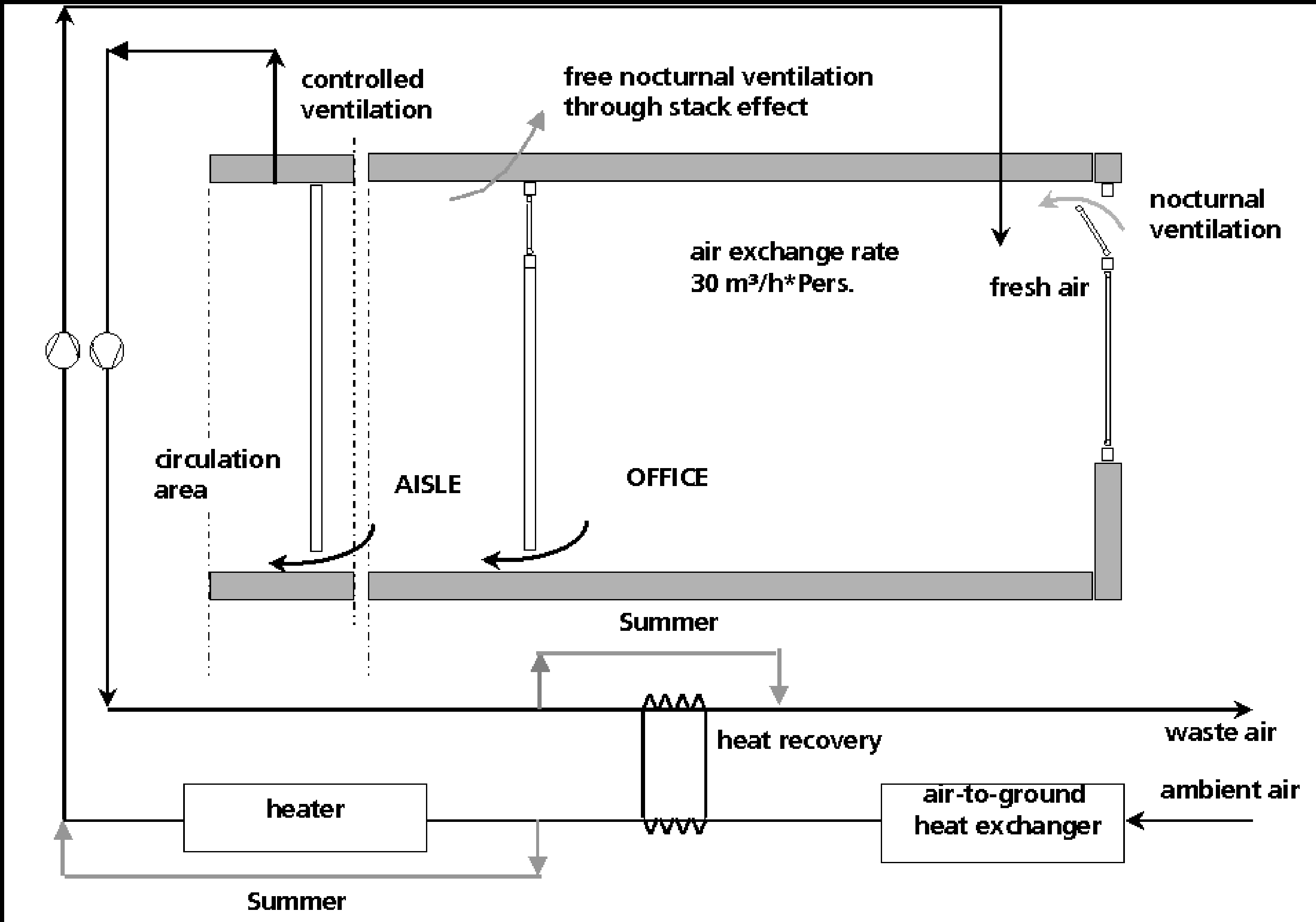
Ground Source Heat Exchanger

- ❑ Preconditions incoming air in summer and winter.
- ❑ Moisture control can be an issue. Underground air ducts should therefore be accessible for cleaning.

Photo courtesy of Fraunhofer ISE. Used with permission.

Environmental Concept



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Heat Pump – General Considerations

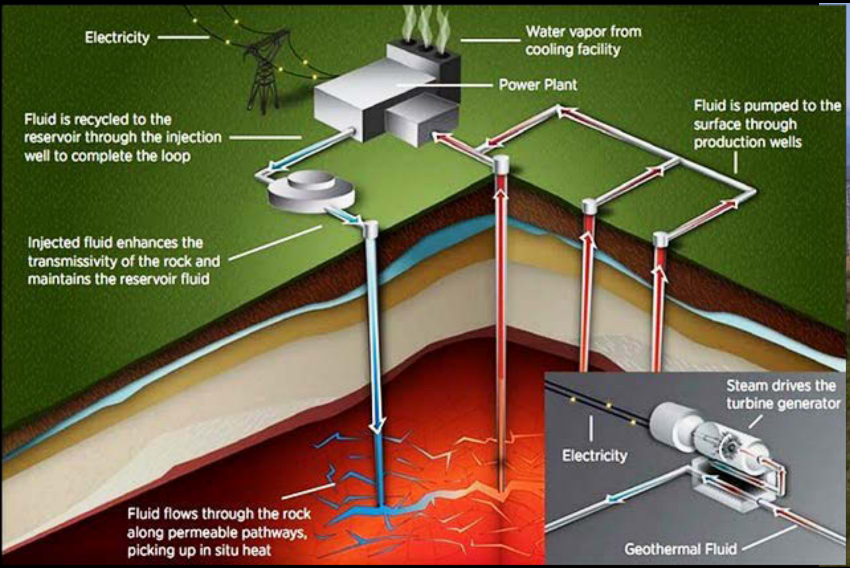
- Historically, utilities tend to promote heat pumps since they tend to run under capacity in the winter.

- Nowadays heat pumps are promoted as the goal is to reach an all electric energy supply system. As the electric grid is getting decarbonized, heat pumps are again considered to be a viable, energy-saving technology.

- Heat pumps work well with radiant heating systems as they provide low temperature energy.

Geothermal

Contractors and developers frequently refer to ground source heat pumps as "geothermal." Geothermal is the direct use of a high temperature heat stored in the earth. One has to go deep. The geothermal gradient of temperatures through the crust is 25–30° C per kilometer.



Sonoma Power Plant

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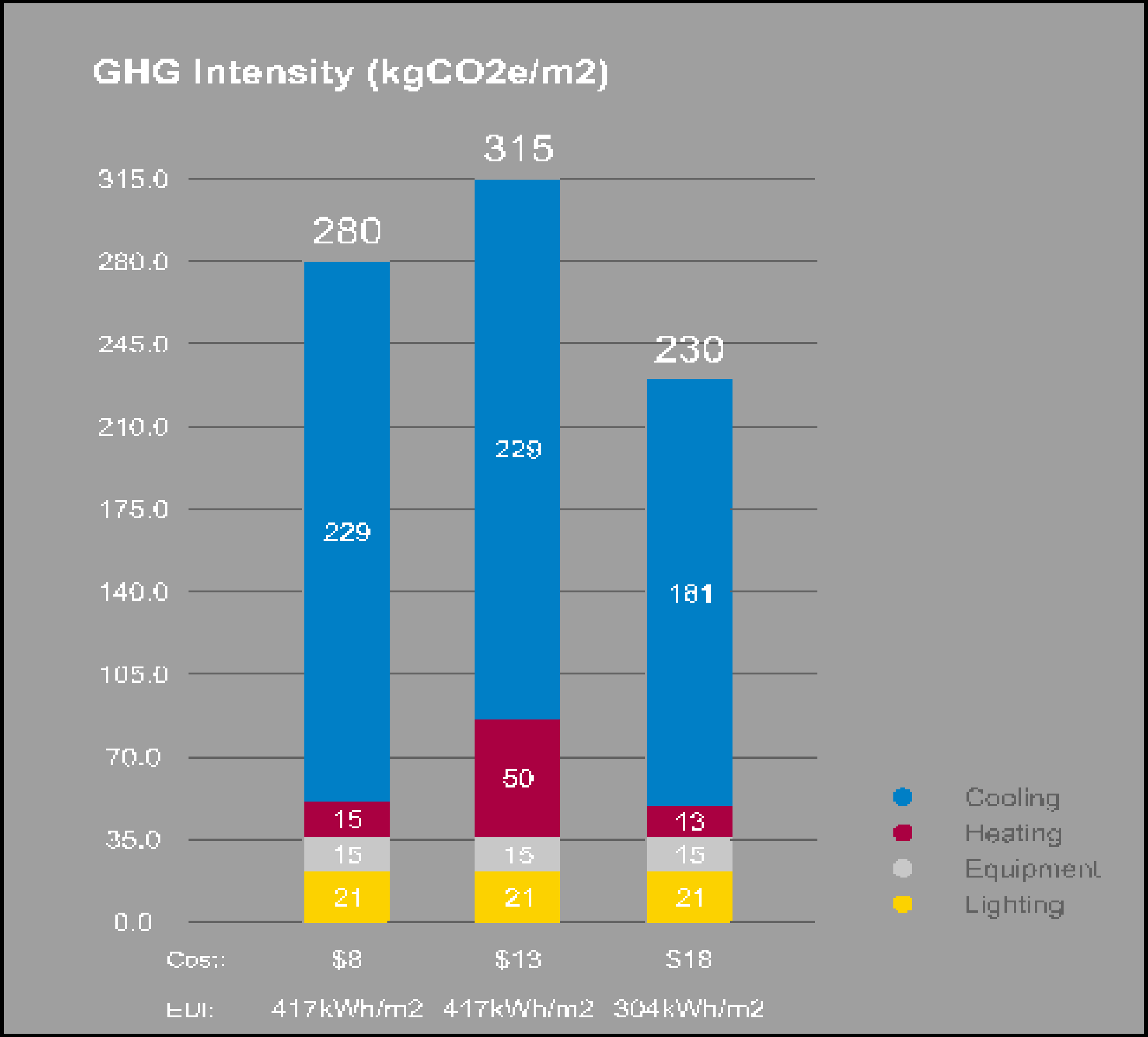
Simulation Game Choices



Boiler Heating DX/AC

Baseboard Heating, DX/AC

GSPH for Heating and Cooling

Cooling

Who grew up in a house without air–conditioning?

Willis Carrier (1876-1950)

Public domain image courtesy of
Carrier Corporation on Wikipedia.

- 1902 in Buffalo, NY, inventor of air conditioning
- Air conditioning performs four functions:

1.) control temperature

2.) control humidity

3.) control air circulation and ventilation

4.) cleanse the air.

According to Carrier Corp., "The world started to become aware of air conditioned theaters when Carrier brought a centrifugal chiller to the Rivoli Theater in New York's Times Square in 1925."

Photo courtesy of Joseph at Cinema Treasures. License: CC BY.

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Cooling – General Considerations

- In 1950 air conditioning was still considered a luxury. Now it is being viewed as a necessity and even a safety issue (e.g. in cars).

- Type A office space is air conditioned by definition.

- Load considerations and the afternoon peak. Highest demand in the summer (even in the Northeast).

Cooling Systems

There are two main types of mechanical cooling systems:

- Compressive Refrigeration relies on liquefaction and evaporation of a refrigerant.

- In absorption refrigeration the refrigerant is distilled water and the absorber is lithium bromide (salt solution).

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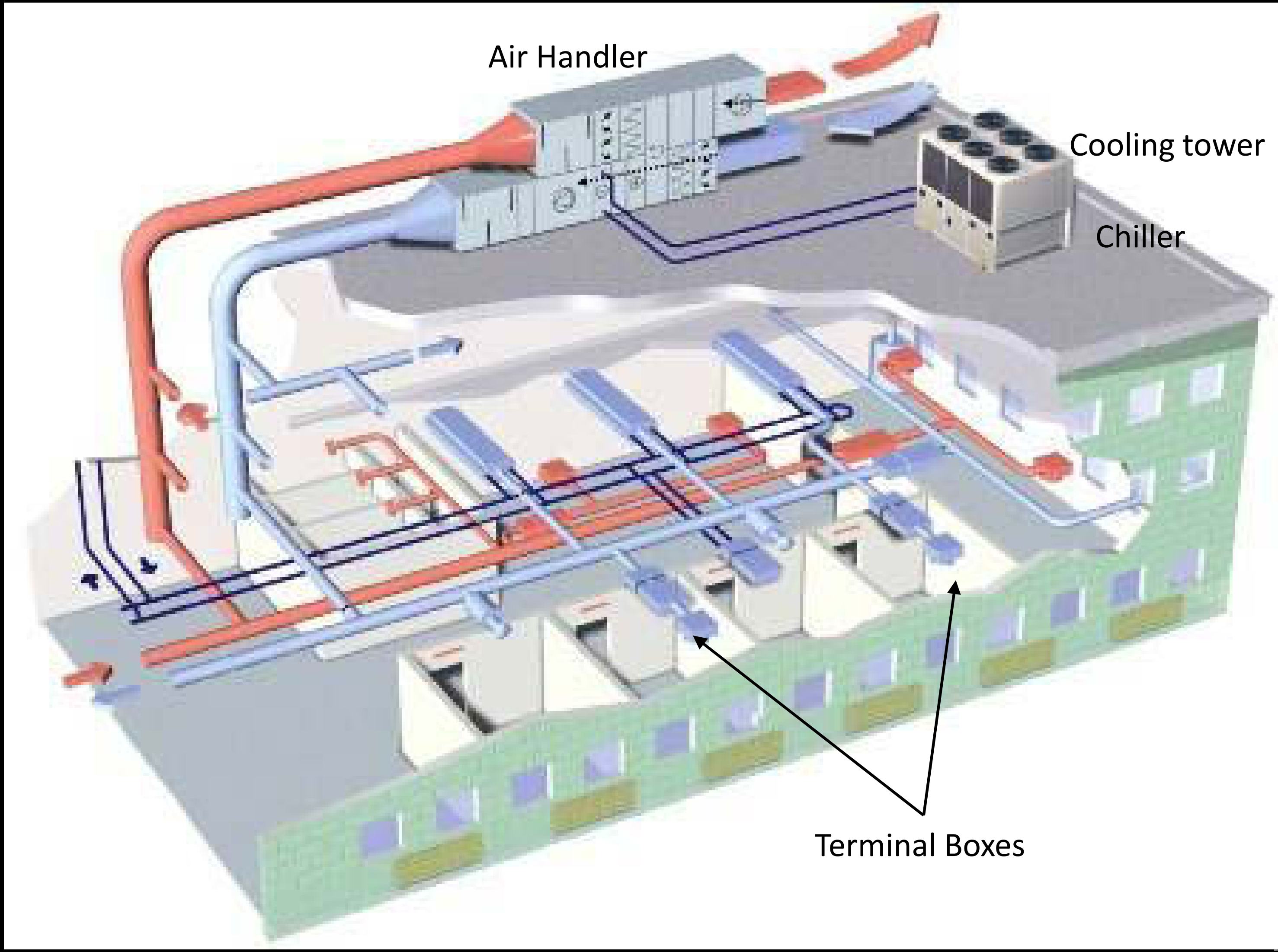
Interaction between HVAC Equipment and the Building



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Air Handling Unit

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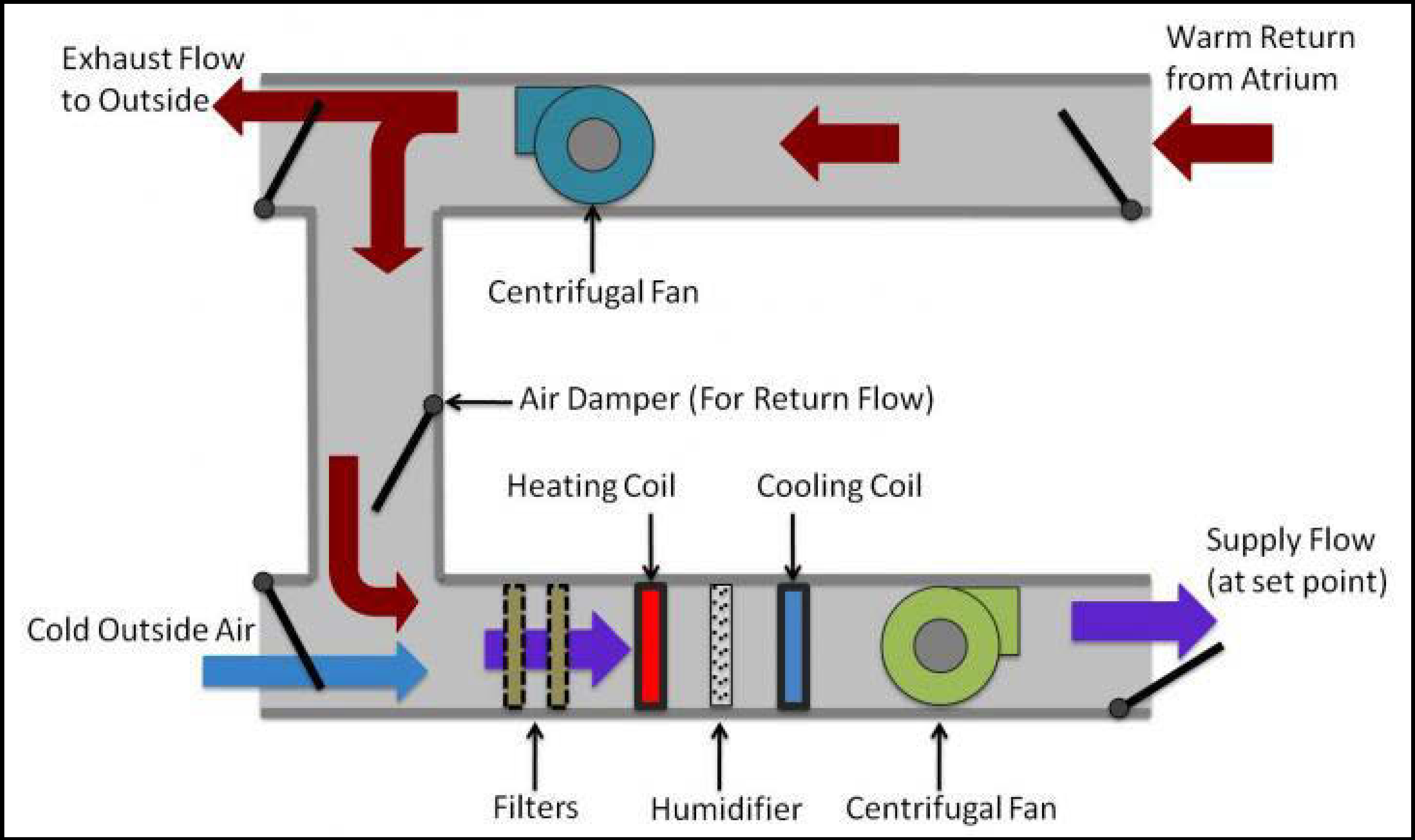
Air Handling Unit



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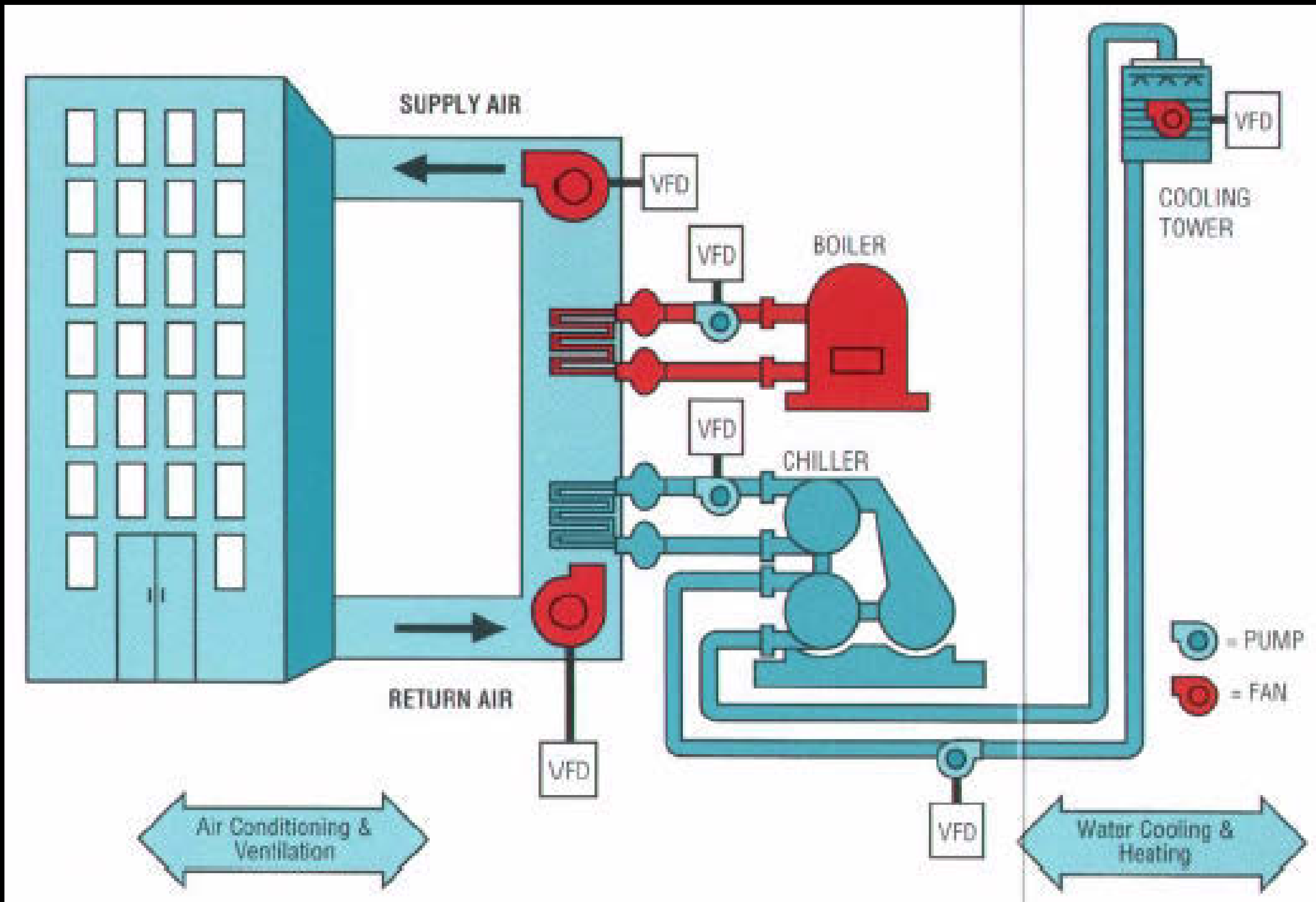
Schematic Relationship HVAC System & Building



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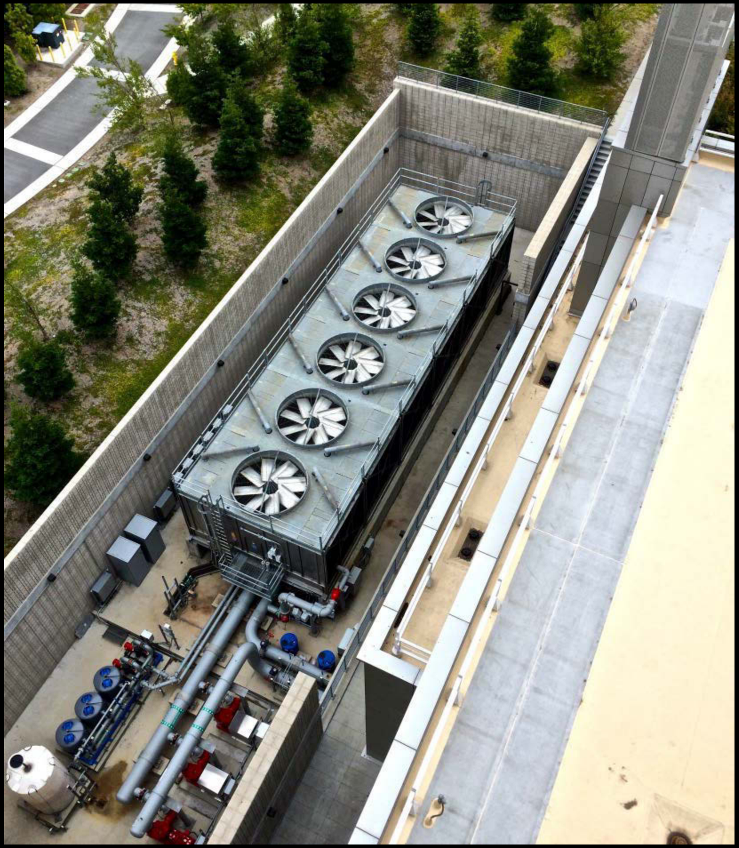
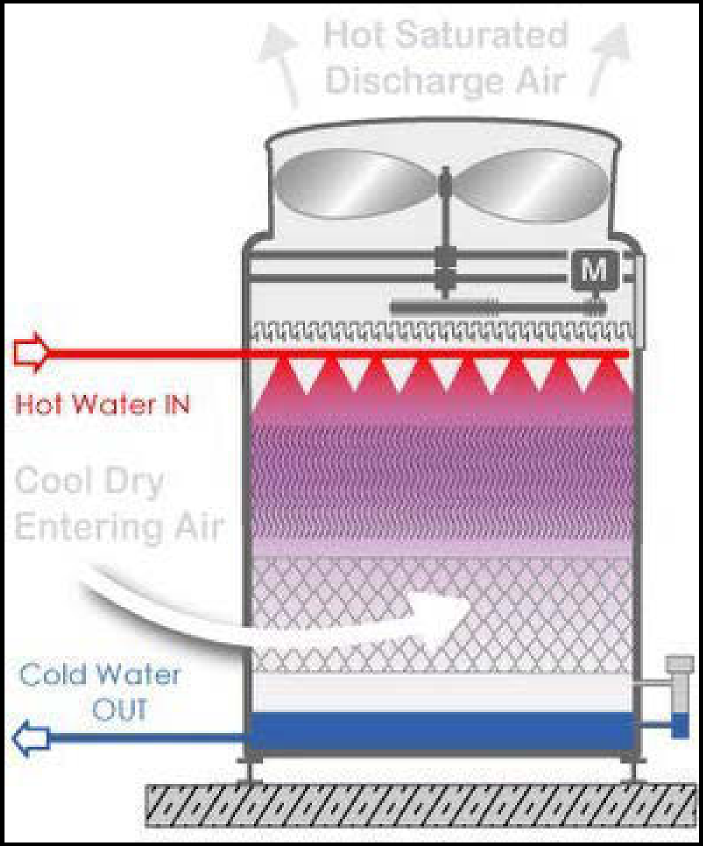
Cooling Towers & Condenser Water Systems





- Cooling towers reject waste heat from the condenser of a chiller to the environment.
- Condenser water systems include chillers, cooling towers, and the associated equipment required to circulate water from the chiller condensers to the cooling towers.

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Centrifugal Chiller

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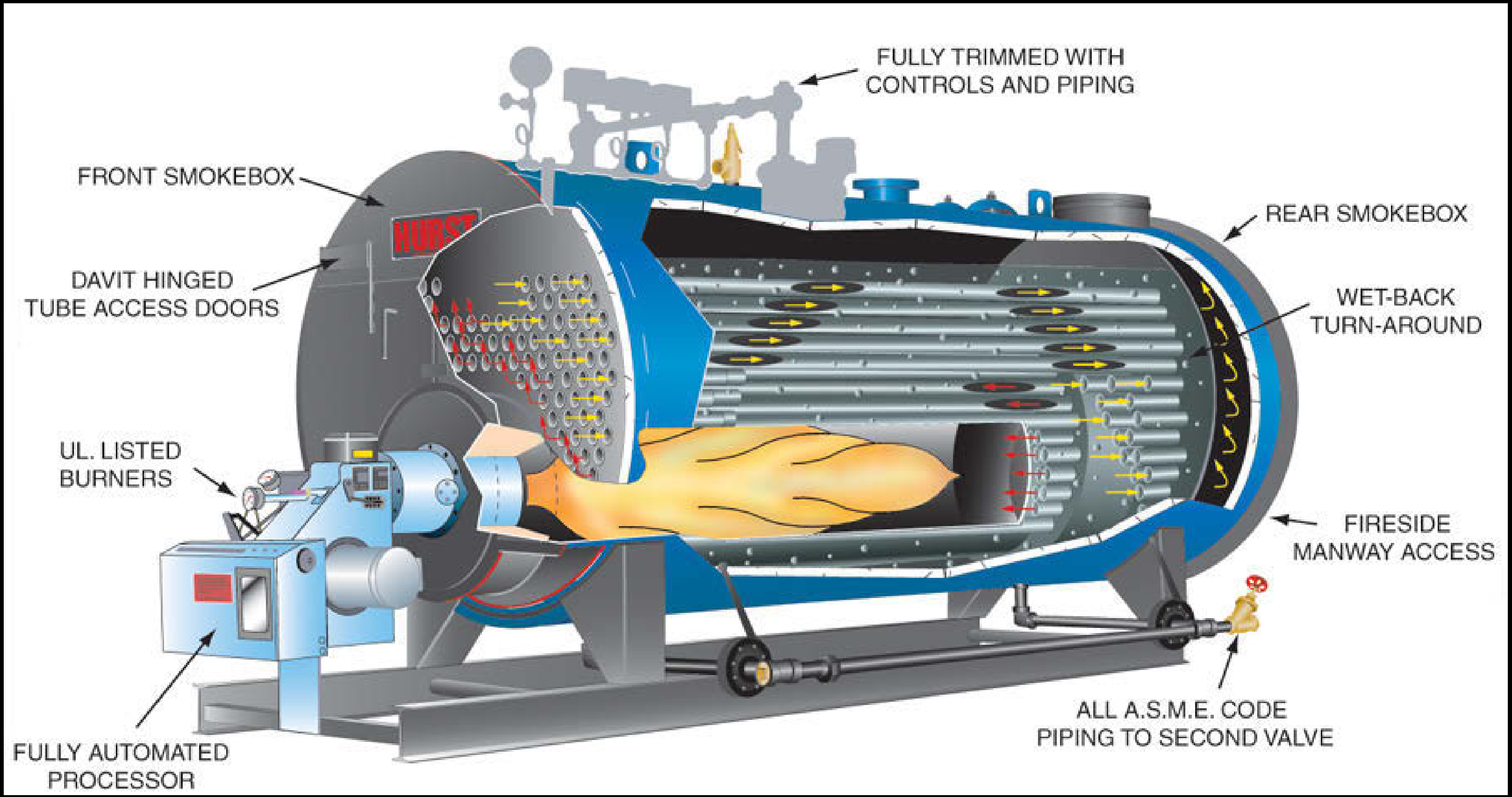
Boilers & Hot Water Systems



- Boilers are used to generate hot water or steam that can be used for heating, domestic hot water and humidification.
- Hot water systems take the hot water or steam that is produced by the boilers and distribute it through pipes to various devices, which can include AHUs, ATUs, FCUs, humidifiers, and sterilizers.

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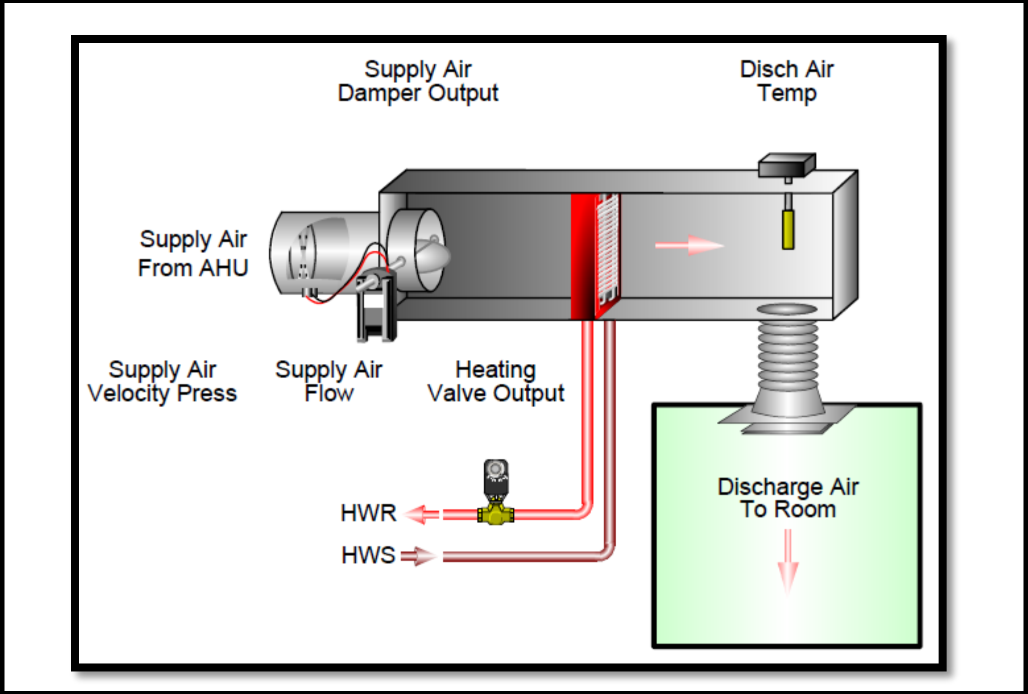
Air Terminal Boxes



- Air terminal boxes (ATUs) receive air from an AHU and control airflow and sometimes temperature of the supply air into a specific room or zone to maintain the desired space temperature.

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This looks like a lot of space…

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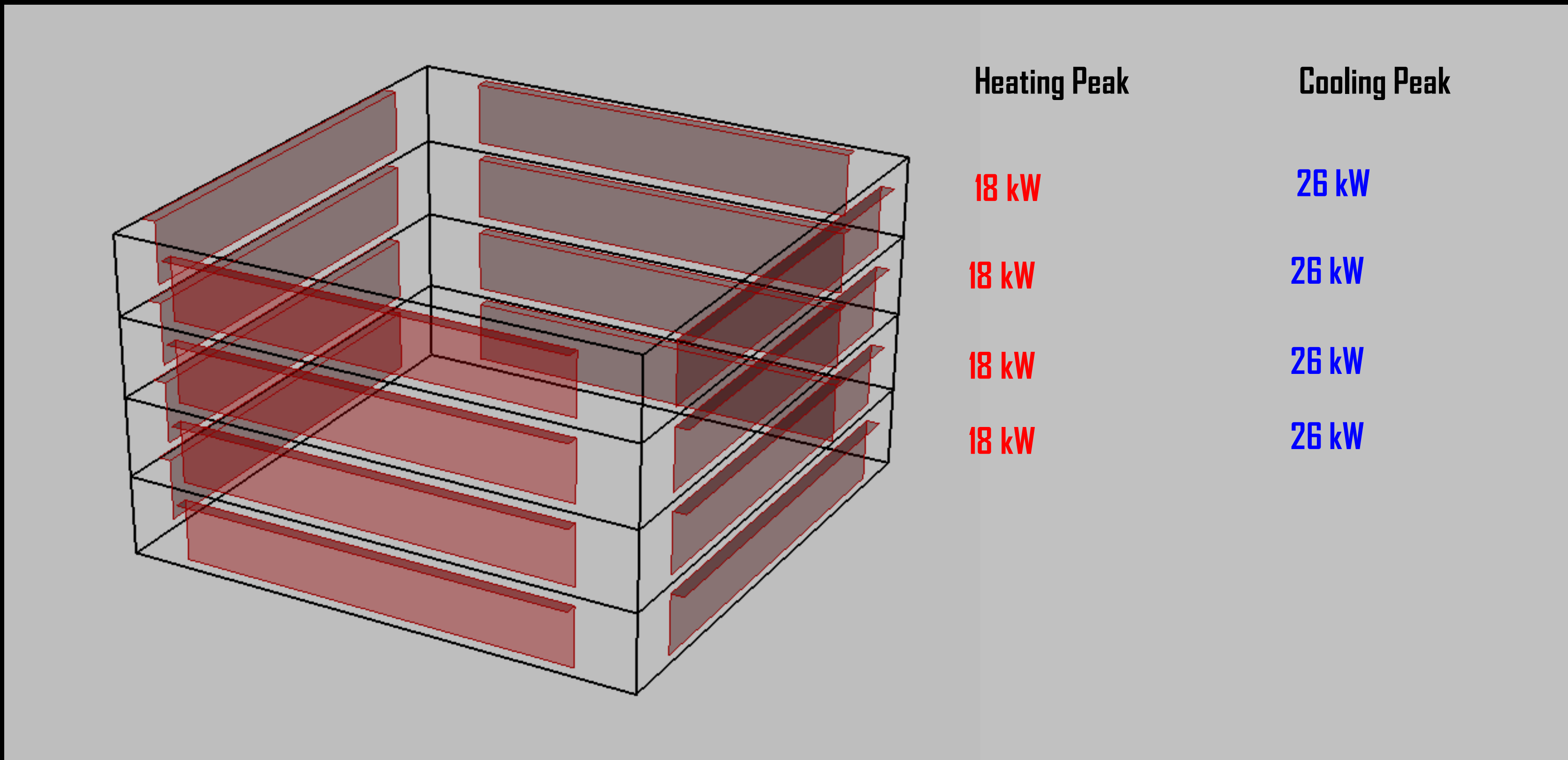
How much space are we talking about?

Example Calculations



- Office building in Boston run via the simulation game.
- Hourly peak loads for each floor file are around 18 kW for heating and 26 kW for cooling.
- How big do the resulting ducts have to be assuming an "all-air" system to condition the space and provide fresh air supply for all occupants?

Fresh Air Supply

- Each floor has an occupant density of 0.2 persons per m^2. With a total floor area on each story of 20 m x 20 m = 400 m^2 this results in 80 occupants per floor.

- Each occupant requires 10 l/s and so we need 800 l/s = 0.8 m^3/s floor each floor.

- A 0.1 m^2 duct typically deliver around 0.13 m^3/s. This means that each floor needs around six 0.1 m^2 supply ducts or 0.6 m^2.

- For a central, roof mounted AHU the main supply duct needs to have a minimum size of 4 floor x 0.6 m^2/floor = 2.4 m^2.

- Assuming a similarly sized return duct, the duct size requirements for fresh air supply at 2 x 2.4 m^2 = 4.8 m^2

Condition Requirements

- The set point temperatures for heating and cooling are 20° C and 26° C, respectively. The maximum and minimum supply air temperatures are 32° C and 13° C to ensure occupant comport.
- This means that under peak conditions:

$$\text{Peak Load} = (V' \times c \times r) \times (T_{supply} - T_{space})$$

where:
V' = required volume flow [m^3/s]
ρ= Density of Air 1.2 kg/m^3
c = Specific Heat Capacity of Air (20Deg C) ~ 1000 J/kg K

Heating

$$18\ \text{kW} = (V' \times 1200\ \text{J/m}^3\text{K} \times (32°\ \text{C} - 20°\ \text{C})$$

$$V' = 1.3\ \text{m}^3/\text{s}$$

Required supply duct size per floor = 1.3 m^3/s / 0.13 m^3/s
= 10 ducts with size of 0.1 m^2 = 1 m^2

Cooling

$$-26\ \text{kW} = (V' \times 1200\ \text{J/m}^3\text{K} \times (13°\ \text{C} - 26°\ \text{C})$$

$$V' = 1.7\ \text{m}^3/\text{s}$$

Required supply duct size per floor = 1.7 m^3/s / 0.13 m^3/s
= 13 ducts with size of 0.1 m^2 = 1.3 m^2

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Duct Size

❑ The size of the air supply system is dictated by the required cooling air supply of 1.3 m^3 per floor. The total main duct space required for supply and return air is thus:

Main duct size = 4 x 2 x 1.3 m^2 = 10.4 m^2

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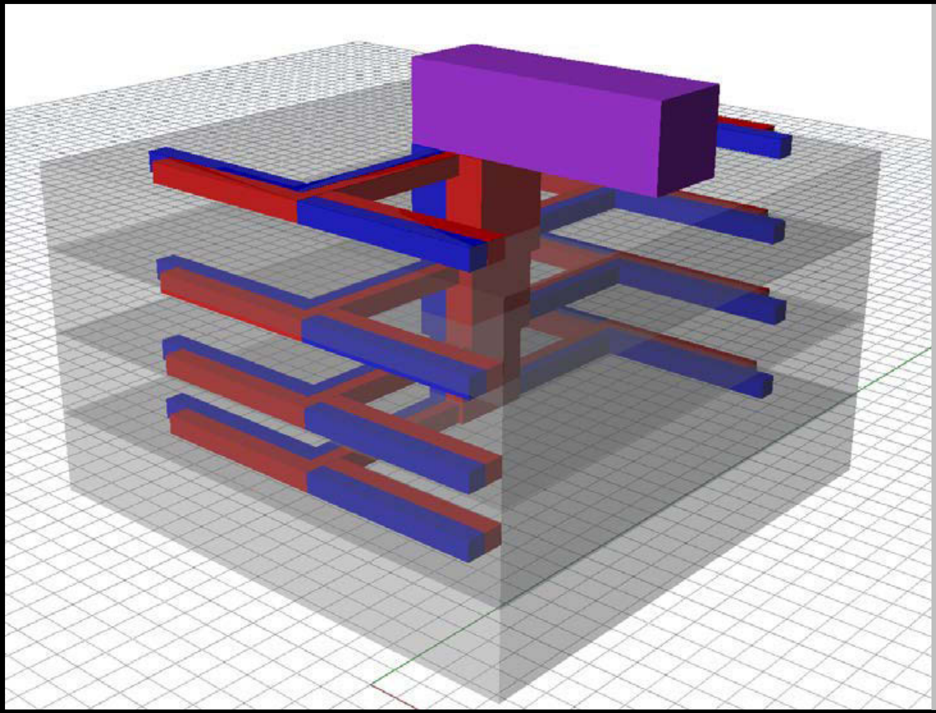
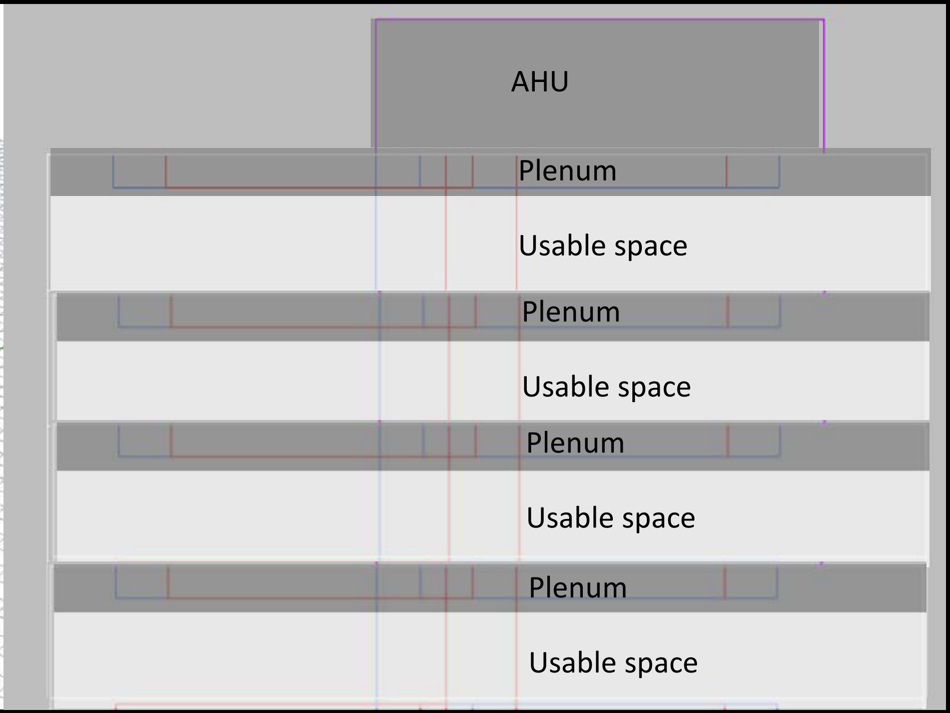
Simple HVAC Design





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MIT Campus – Looking up

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Cooling Tower

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- In larger buildings a secondary loop consisting of water is used to cool the evaporator coil. The water is transported from the cooling unit to the roof of the building and then cooled by evaporation.

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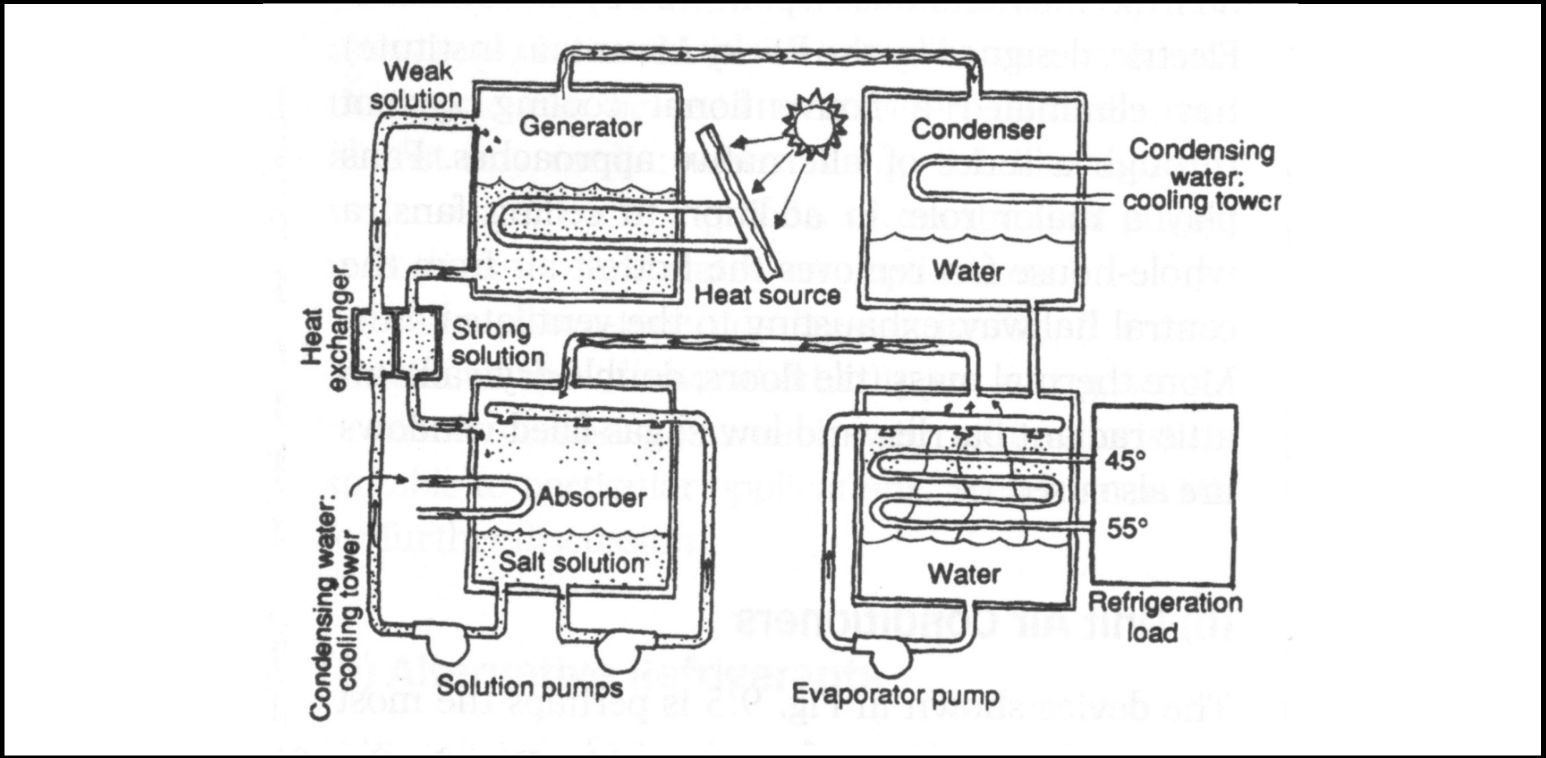
Absorption Refrigeration Cycle



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- Thermally driven cooling system where heat is used to regenerate the salt solution.
- Less efficient than compressive refrigeration but can already work at low thermal heat (60° C), i.e. high grade energy (electricity) used to run a compressor is replaced with low grade energy (heat).
- The heat to concentrate the salt solution can come from natural gas (direct fired) or waste heat (indirect fired) or even the sun.

Evaporative Condensers

- Water is sprayed on the condenser to make heat transfer more efficient.

- Used in mid-sized commercial buildings where the condensing coil can be less than 60 feet (20 m) from the compressor and evaporator coil.

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Questions?

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