The Science of Being Hot

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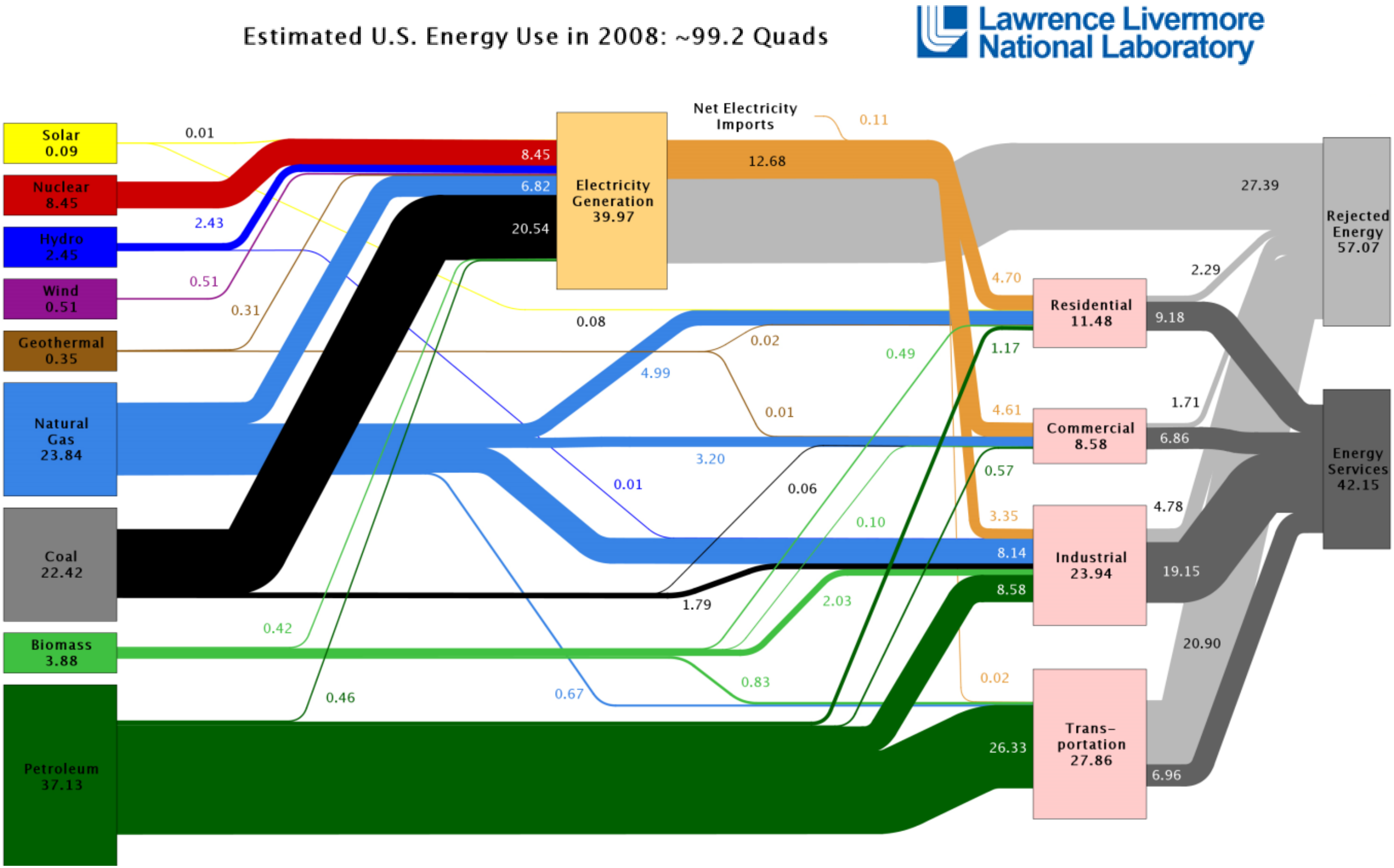
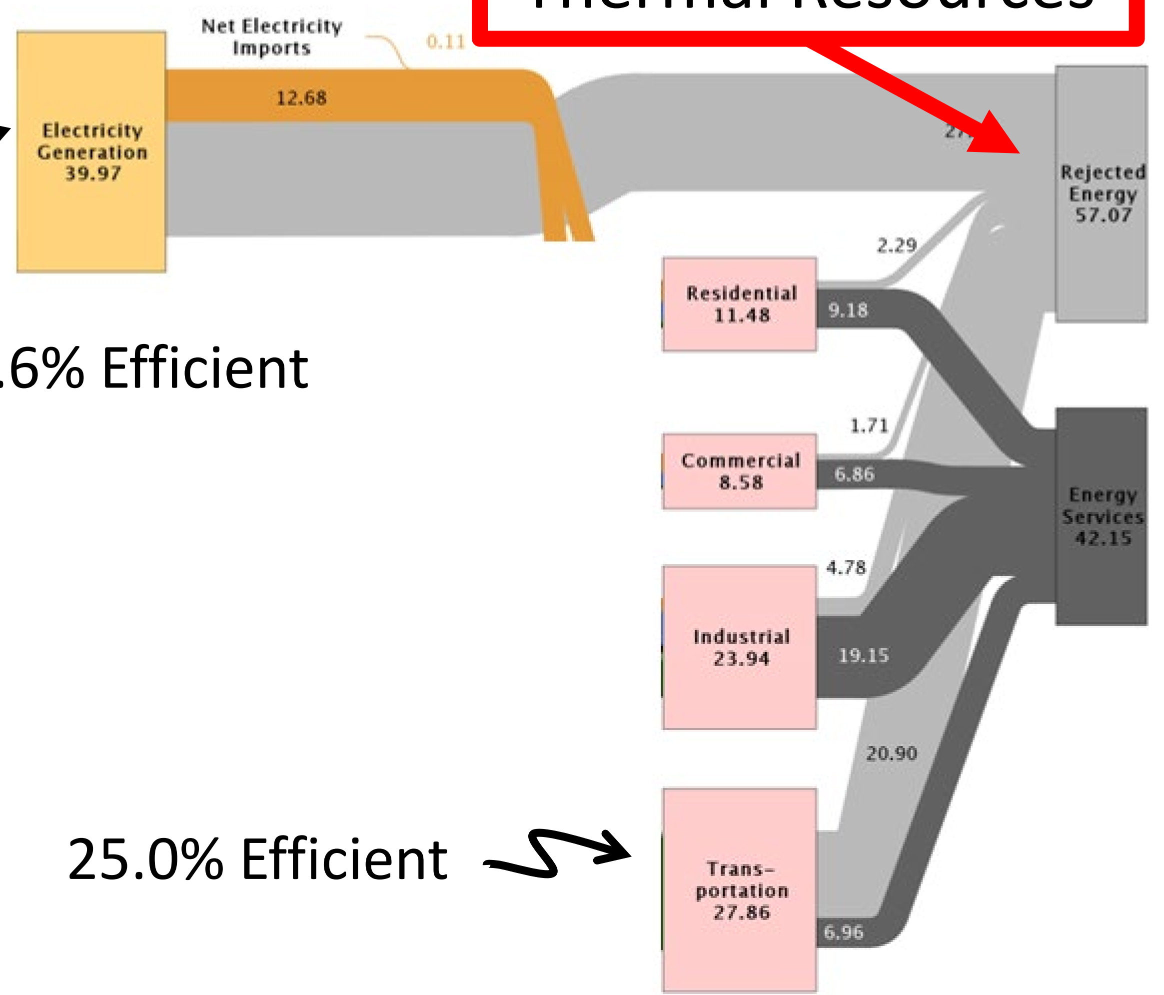
Energy Balance of the USA



How efficient are we?

Analysis #3
Waste Management
Analysis #4
Thermal Resources



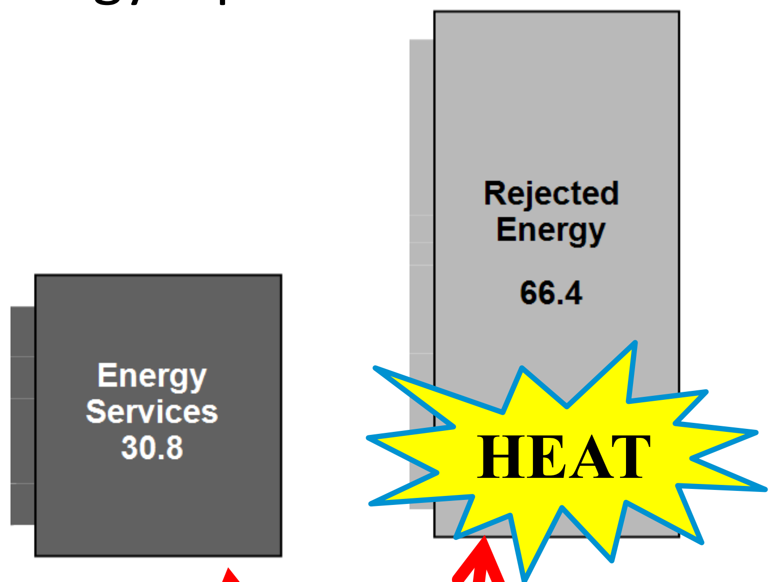
34.6% Efficient

25.0% Efficient

Energy Efficiency = Do more with less

31.6% of all energy inputs

68.3% of all energy inputs



Drives our economy:
$18.75 Trillion GDP

Goal:
Keep (or grow) GDP

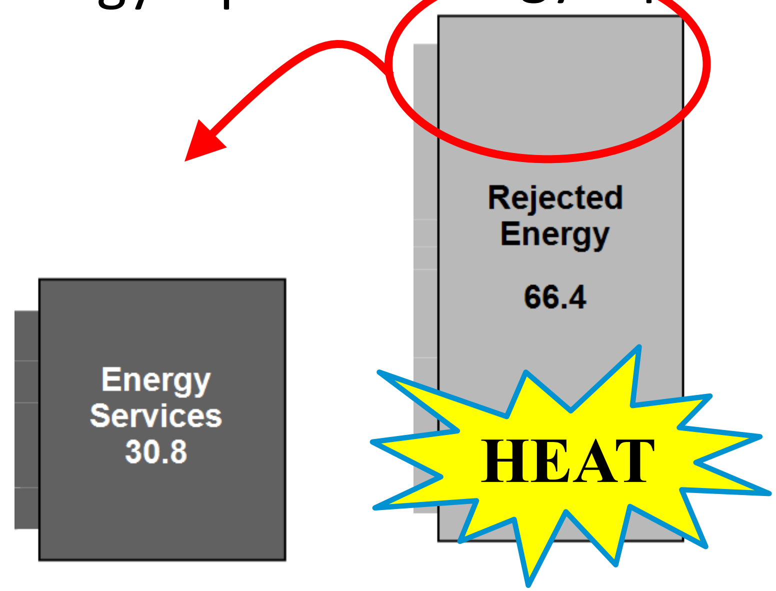
Reducing Energy Services:
Being efficient with my resources

Reducing Rejected Energy:
Being efficient with my equipment

Energy Efficiency = Do more with less

31.6% of all energy inputs

68.3% of all energy inputs

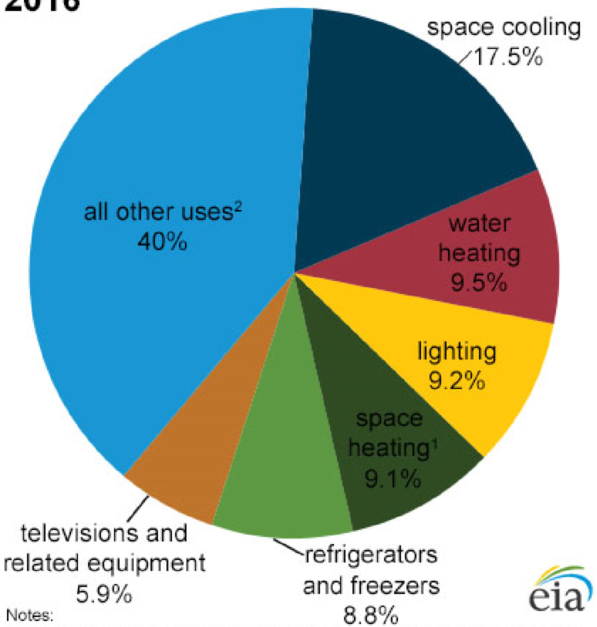


Drives our economy:
$18.75 Trillion GDP

Innovation:
Shifting ***Rejected Energy*** into ***Energy Services***
for additional economic capacity

Why study heating and cooling?

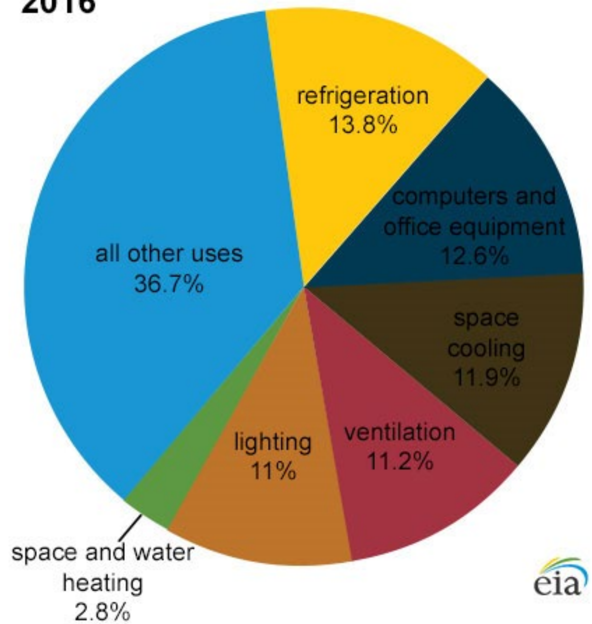
U.S. residential sector electricity consumption by major end uses, 2016



Notes:
[1]Includes consumption for heat and operating furnace fans and boiler pumps.
[2]Includes miscellaneous appliances, clothes washers and dryers, computers and related equipment, stoves, dishwashers, heating elements, and motors not included in the uses listed above.

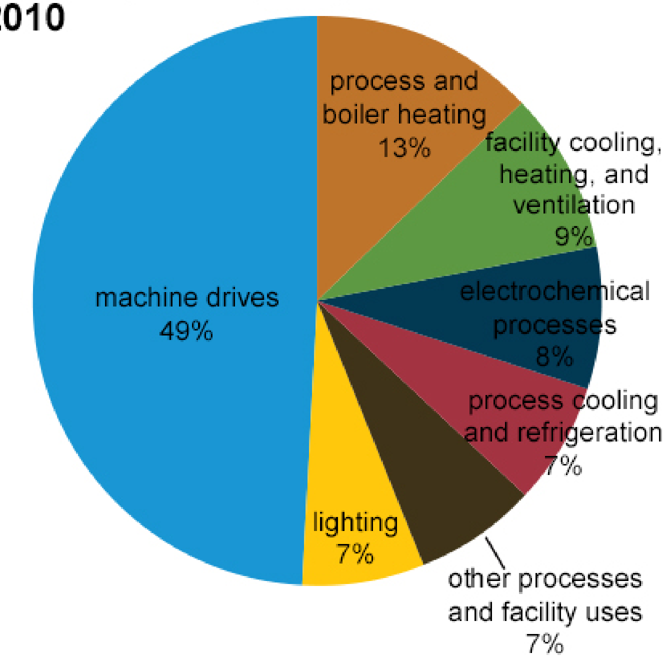
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2017*, Table 4, January 2017

U.S. commercial sector electricity consumption by major end uses, 2016



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2017*, Table 5, January 2017

U.S. manufacturing electricity consumption by major end uses, 2010



Source: U.S. Energy Information Administration, *Manufacturing Energy Consumption Survey 2010*, Table 5.1, March 2013

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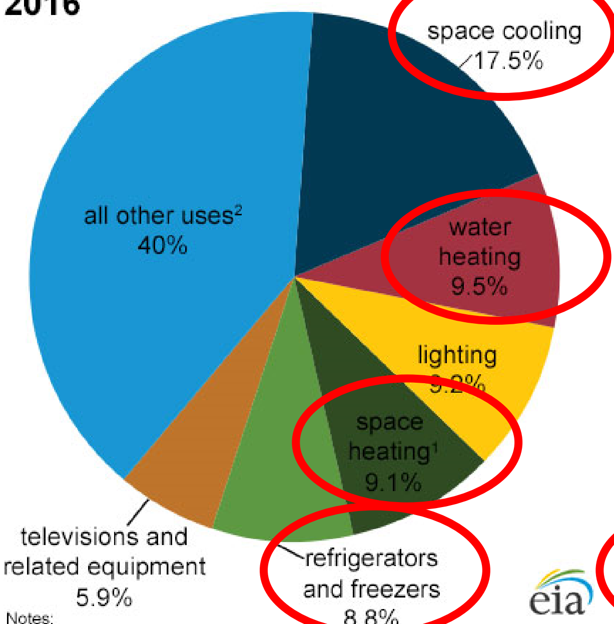

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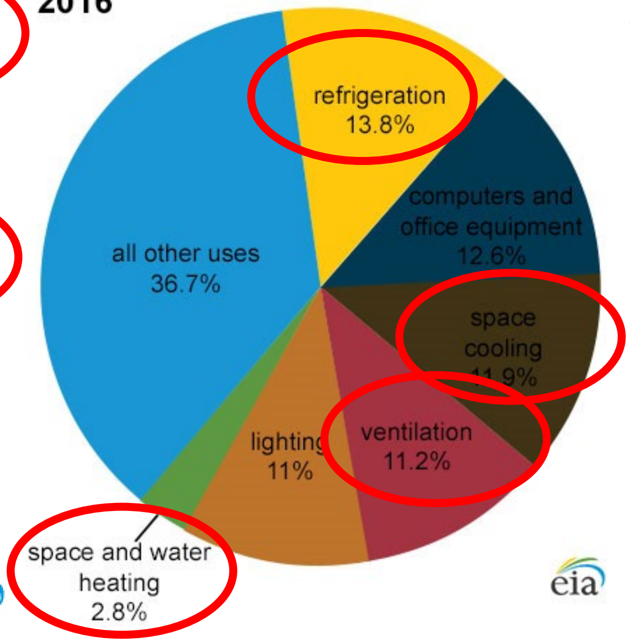

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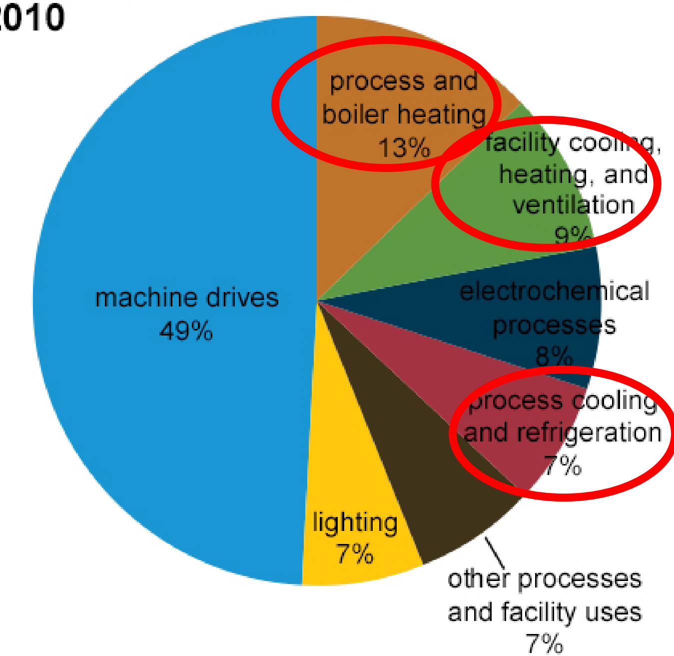

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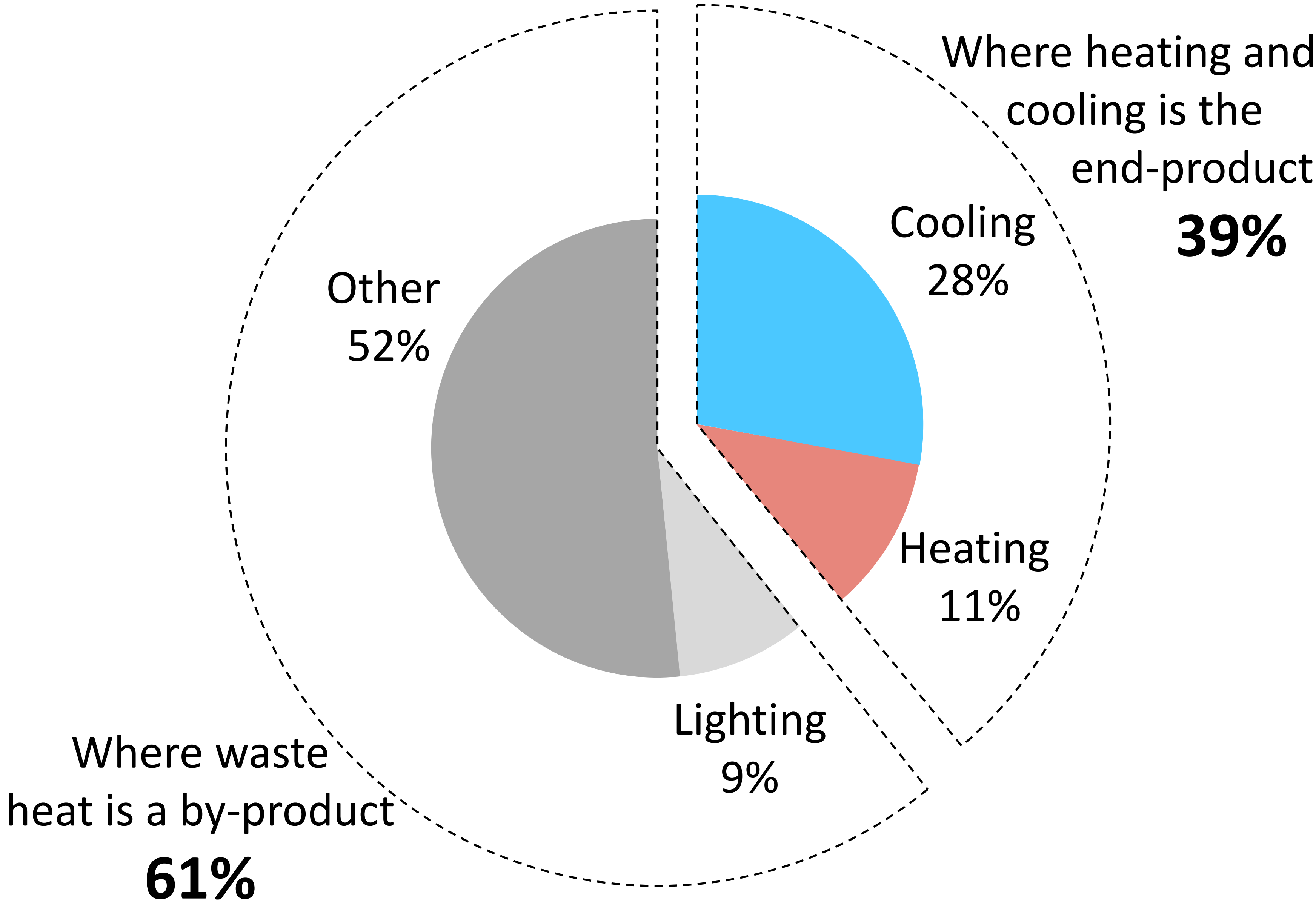
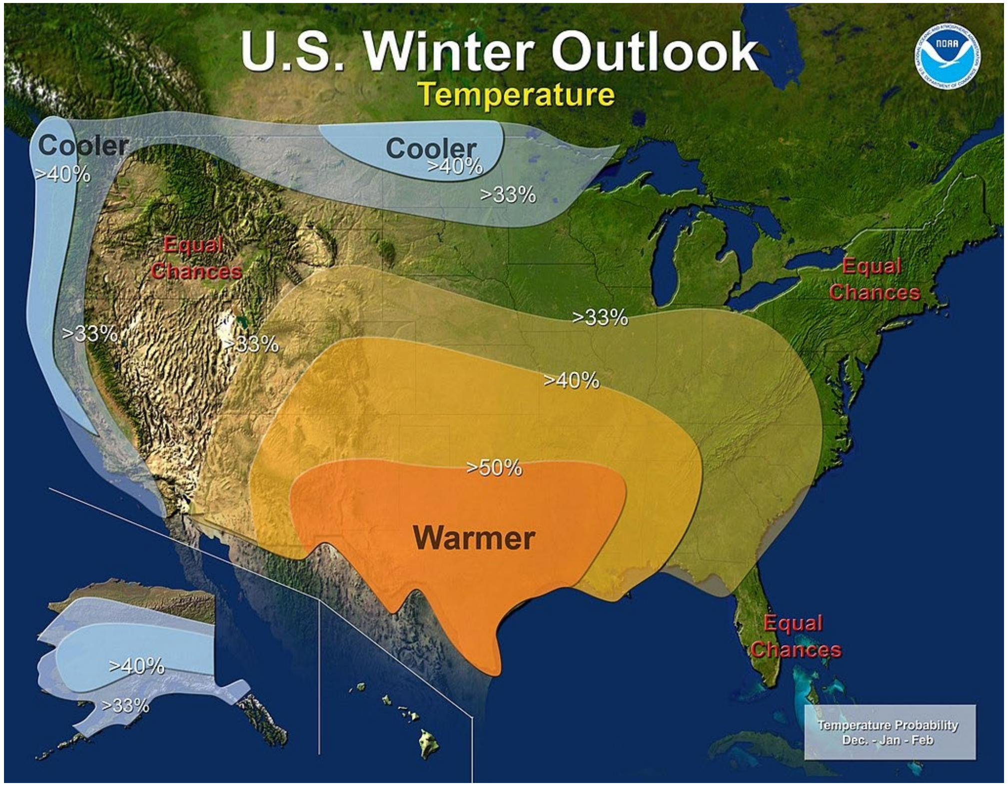
Why study heating and cooling?



What is Heat? – It’s all relative!

- Heat is energy *transferred* from one body to another by thermal interactions
- Heat is not a property of a system or body
- I cannot say “This laptop has heat”
- I can say “This laptop is hotter than my leg. Ouch!”

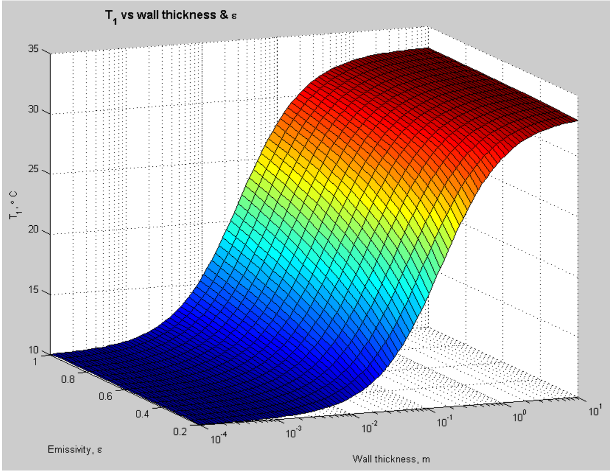


Heat Transfer

“Hot” is something that has relatively more heat

“Cold” is something that has relatively less heat

“Heat Transfer” the motion of heat from the hotter thing to the colder thing.



Heat always moves from hot to cold.

Cold never moves.

Engineers care about enthalpy

Calculating enthalpy is complicated:

$$\mathbf{d}\boldsymbol{H} = \boldsymbol{C_p}\,\mathbf{d}\boldsymbol{T} + \boldsymbol{V}\,(\mathbf{1} - \boldsymbol{\alpha}\,\boldsymbol{T})\,\mathbf{d}\boldsymbol{p}$$

Engineers care about enthalpy

Calculating enthalpy is complicated:

Change to **Temperature** you're trying to get to

Temperature you're at

Change in Enthalpy

$$\mathbf{d}\boldsymbol{H} = \boldsymbol{C_p}\,\mathbf{d}\boldsymbol{T} + \boldsymbol{V}\,(\mathbf{1} - \boldsymbol{\alpha}\,\boldsymbol{T})\,\mathbf{d}\boldsymbol{p}$$

Pressure

Heat Capacity (includes humidity)

Volume (how much)

Constant

Frequently we only refer to ***temperature*** when discussing heat.

Sometimes we refer only to ***pressure*** when discussing heat

These are useful shorthand but gross simplifications.

Heat implies pressure

$$P\,V = n\,R\,T$$

Pressure	Volume	Moles or number	Temperature
(Variable)	(Constant)	(Constant)	(Variable)

RESULT:

High Temperature == High Pressure

Or, anytime I have high temperature, I also have high pressure

High pressure can be dangerous! (2007 NYC)

http://commons.wikimedia.org/wiki/Category:2007_New_York_City_steam_explosion

People care about comfort

Temperature is different from comfort.

Predictive Mean Vote is a measure of comfort. It includes:

Physical factors:

metabolic rate

clothing level,

Environmental factors:

air temperature,

radiant temperature,

air speed

humidity

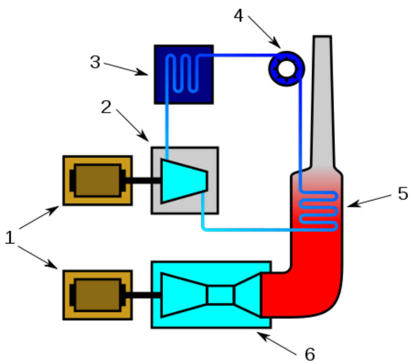
It is used for modeling and building design.

It is not used for operations.

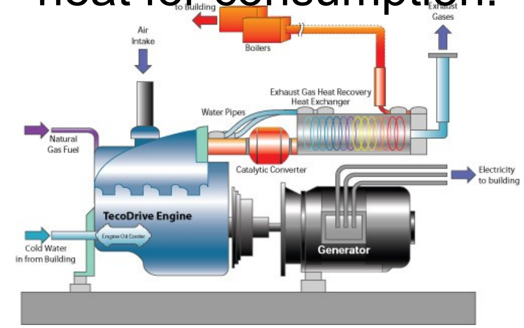
Lets build a system – Generation:

Generation | Transportation | Consumption | Recycling

Combined Cycle:
Using waste heat from one process to preheat the next process

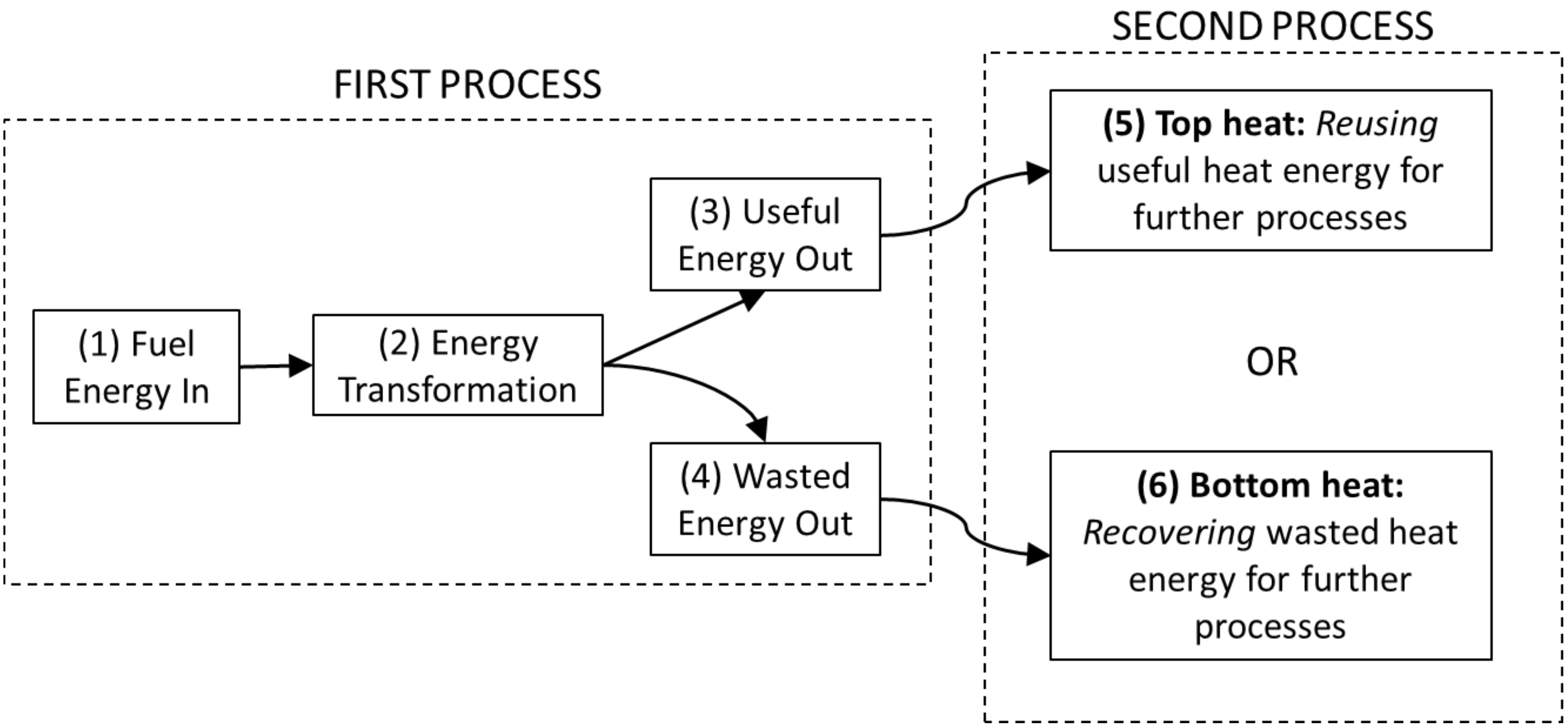


Co-generation and Combined Heat and Power (CHP)
Generating both electricity and heat for consumption.



Efficiencies of all these technologies can exceed 80%

Generating Heat: Top vs. Bottom Cycling



Example of Top Heat:

Cooking sausages on a grill

- Charcoal is used primarily for heat.

Example of Bottom Heat:

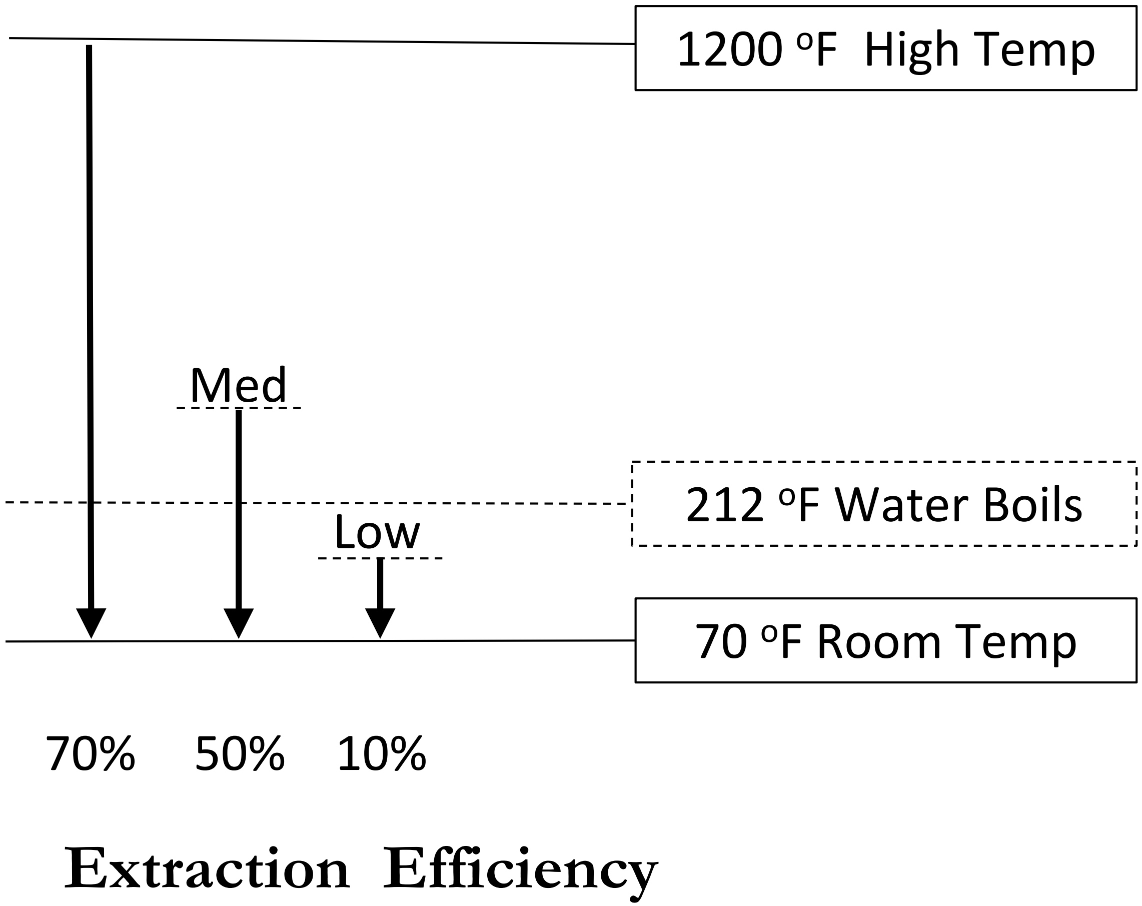
Cooking sausages on a car engine

- Primary use of energy is for Transportation
- Secondary use of energy is for heating the sausages.

http://www.wikihow.com/Cook-Food-on-Your-Car%27s-Engine

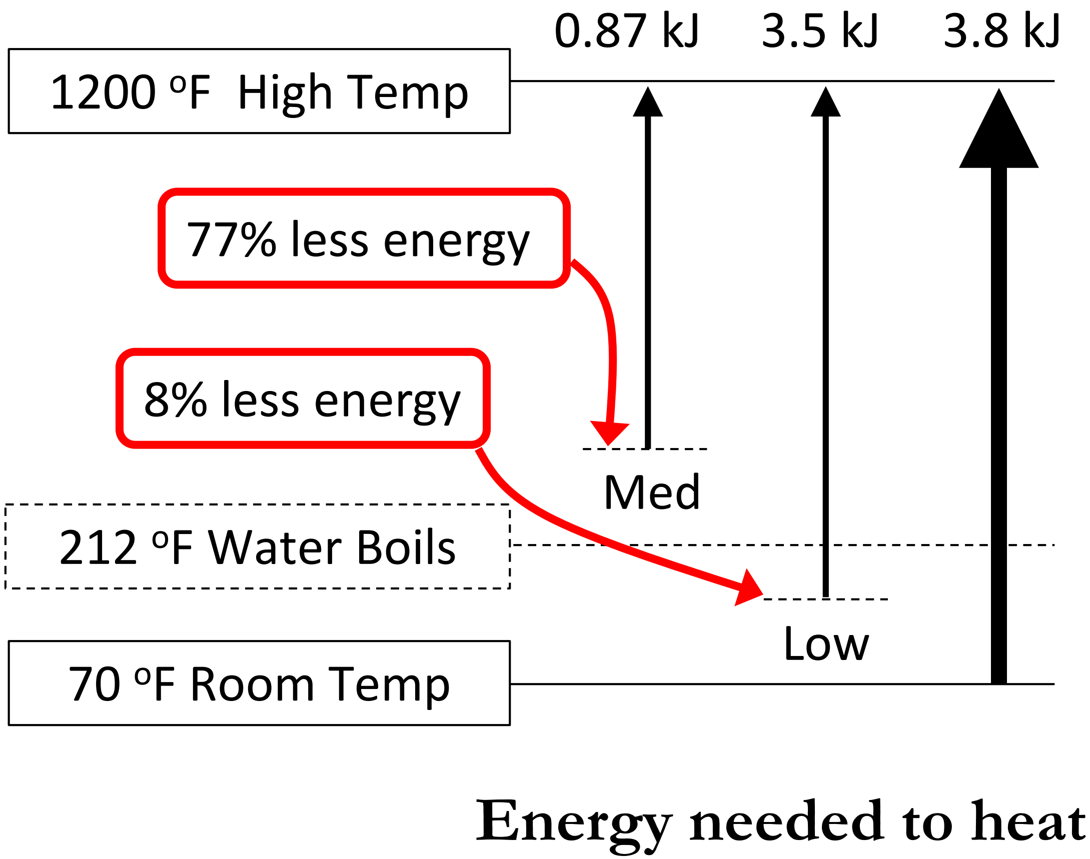
Quality of Heat: Based on Temperature ***Difference***

- The larger the temperature difference, the more valuable it is! (or the higher the ***quality*** of the heat)



Value of Preheating

- The higher the starting temperature, the less energy you need to heat it.



Transport heat via hot water and steam

Generation → **Transportation** → Consumption → Recycling

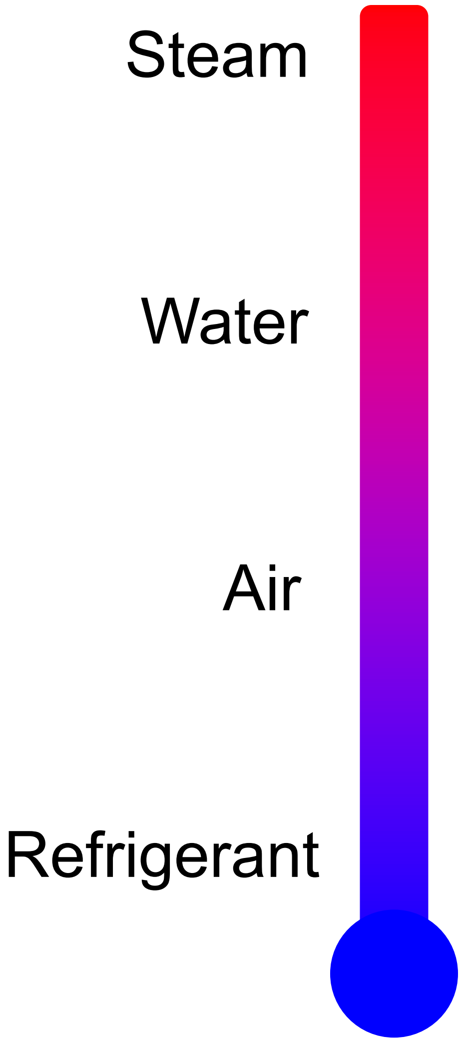
STEAM

- High quality heat
- Good for running processes

WATER

- Low quality heat
- Good for pre-heating

Common Fluids



The type of fluid you used to transport heat depends on the temperature

Each fluid has a different heat storage capacity (heat capacity), melting point and boiling point.

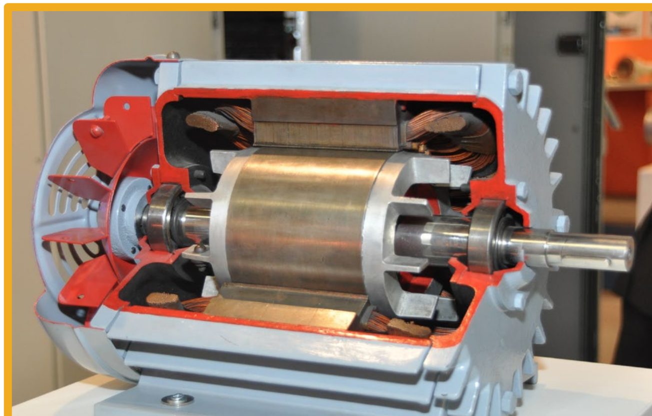
Fluids are chosen based on those attributes.

Other fluids (aka, refrigerants)

R-Name	Chemistry Type	Heat Capacity	Global warming potential	Boiling Point (ºC)
Water/ Steam	H2O		0.2	100
R-12	CFC		10,900	-28
R-22	HCFC		1,810	-40
R-134	HCFC		1,430	-26
R-410A	HFC		2,088	-51
R-744	CO_2		0	-78

Consumption of heat and electric energy

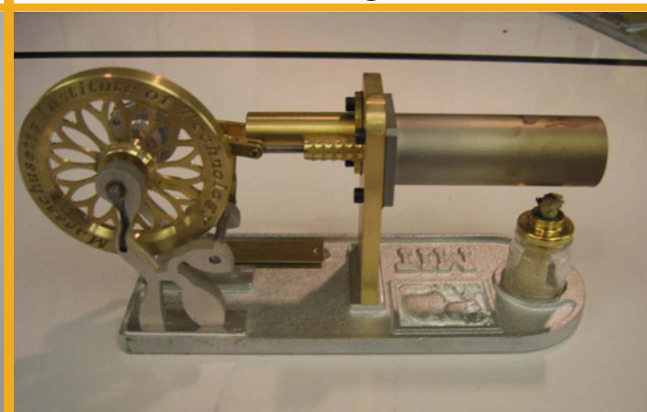
Generation → Transportation → **Consumption** → Recycling



Electric Engine

Jet Engine

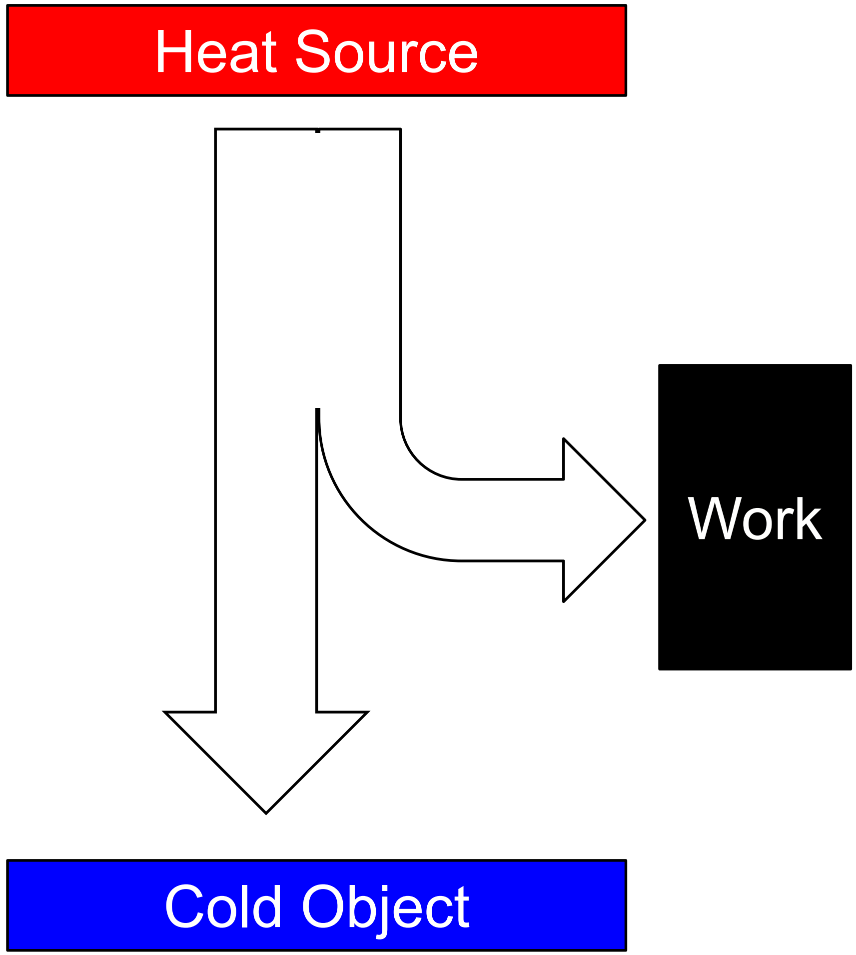
Internal Combustion Engine



Heat - Stirling Engine

Heat Engine – Turning heat energy into motion

(1) This is the source of heat, such as a fire that creates the steam



(3) This is the mechanical work that is generated by the ***thermal gradient*** of the heat

(2) This is where the heat flows to, such as a condenser. This is also called wasted heat

Common words associated with heating

$$\text{Efficiency} = \frac{\text{Useful Heat Energy Out}}{\text{Heat Energy In}}$$

Joule / BTU / Therms = Measurement of Heat energy

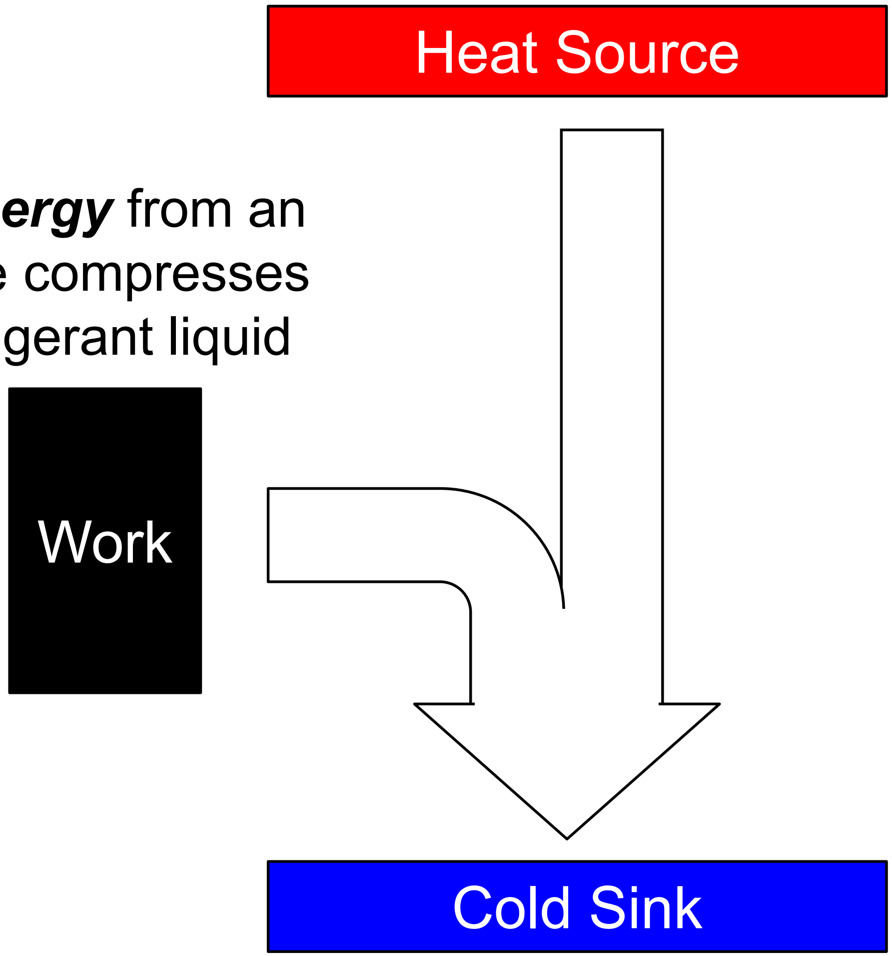
(For some reason, we don't use kWh for heat)

PSI = pounds per square inch, or pressure

Turning motion into heat

(3) Heat energy from the surroundings flow into the cooler liquid

(1) ***Energy*** from an engine compresses a refrigerant liquid



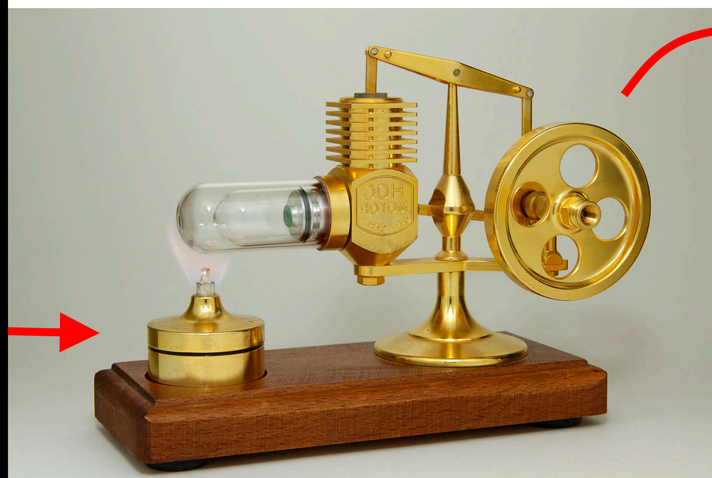
(2) When the liquid expands, it is cooler than its surroundings

You can use heat to cool things!

Engines convert an energy source to mechanical motion

(1)
The Fuel:
HEAT

A Stirling Engine



(2)
The Output:
ROTATION

An air conditioner compressor

(3)
The Result:
COLD AIR!

Common words on cooling

COP: Coefficient of Performance $= \dfrac{\text{Heat Removed}}{\text{Energy Consumed}}$

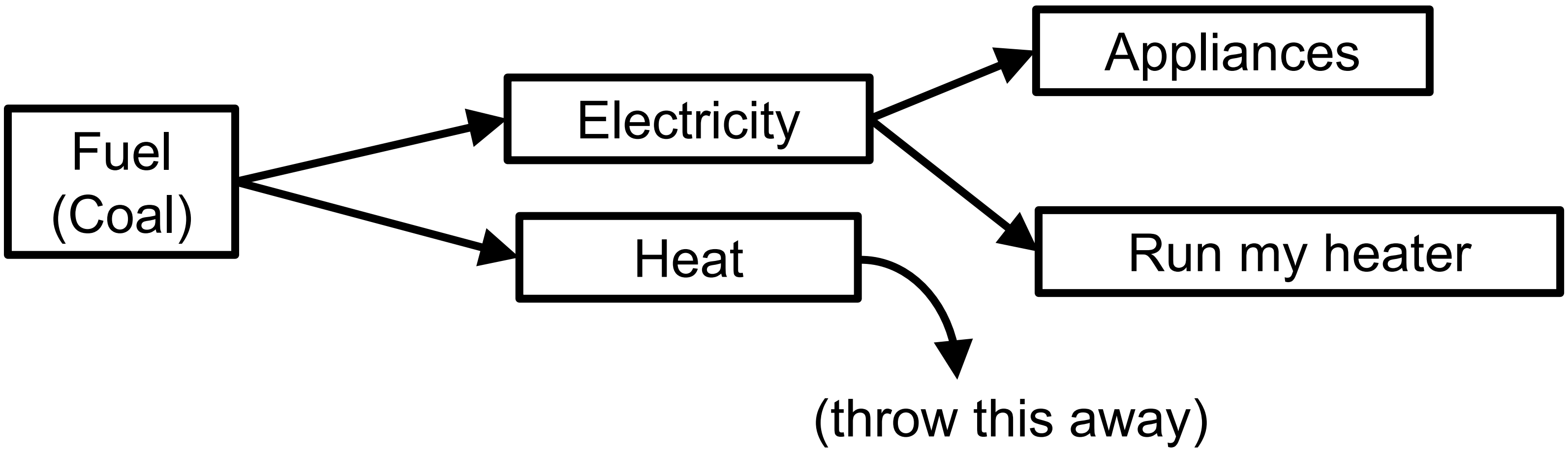
Common "Heat Sinks" or "Cold Sinks"

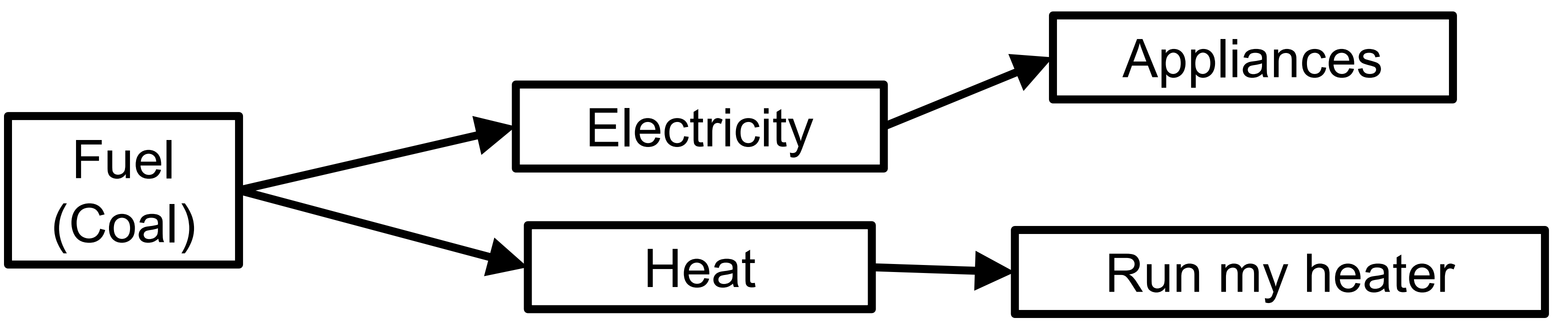
- Water Tower
- Ground Source Heat Pump

Refrigerants:

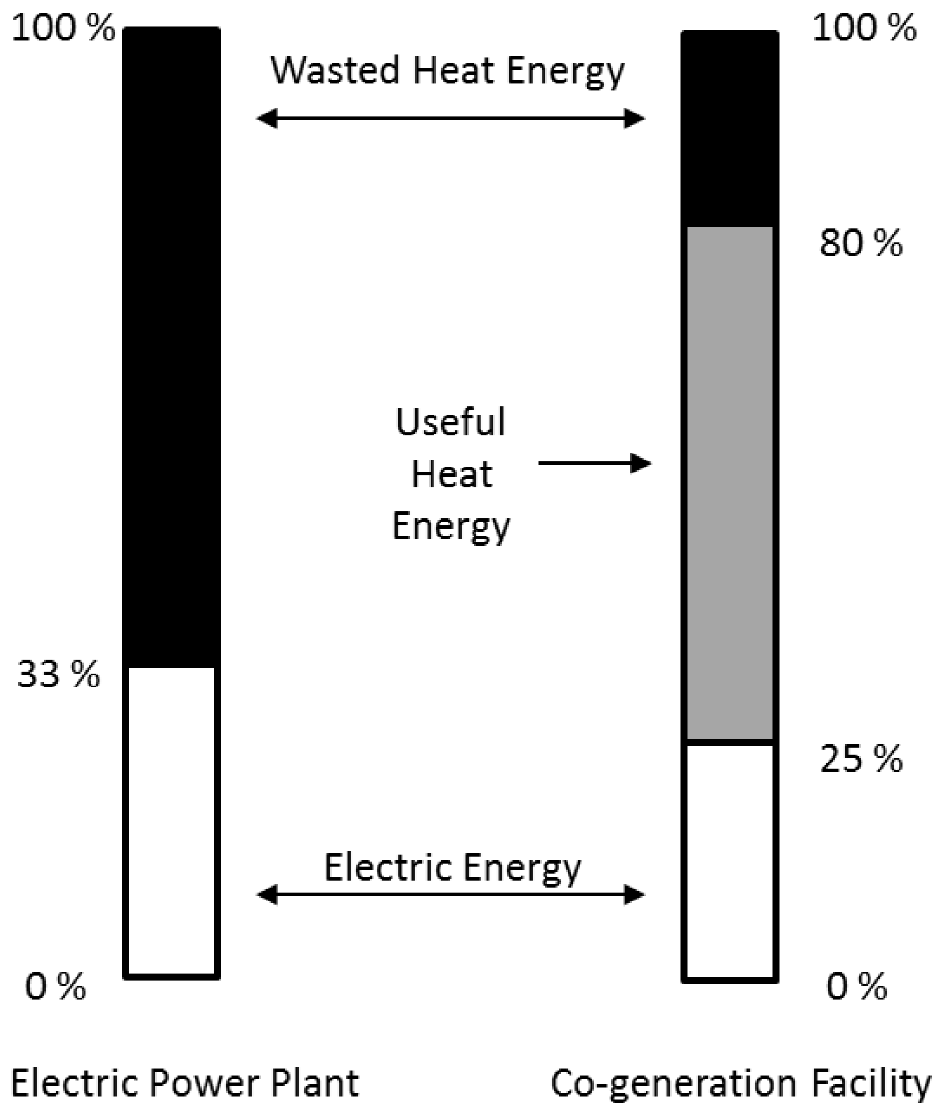
- A fluid that is used to transfer the heat from source to sink
- Classification, based on R-number, by chemistry

Which has less waste?



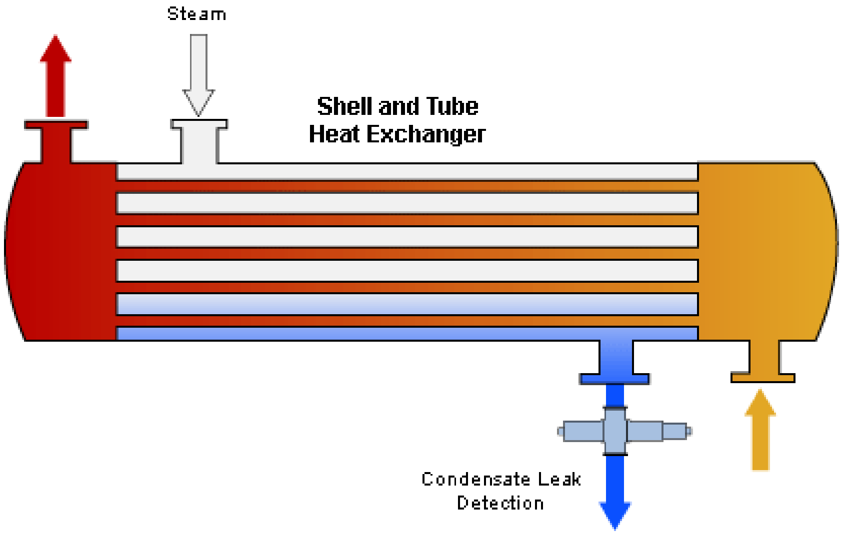


Fuel utilization of Co-Generation



Heat Exchanger

The device that transfers heat between the hot and cold fluids



Insulation / Weatherization

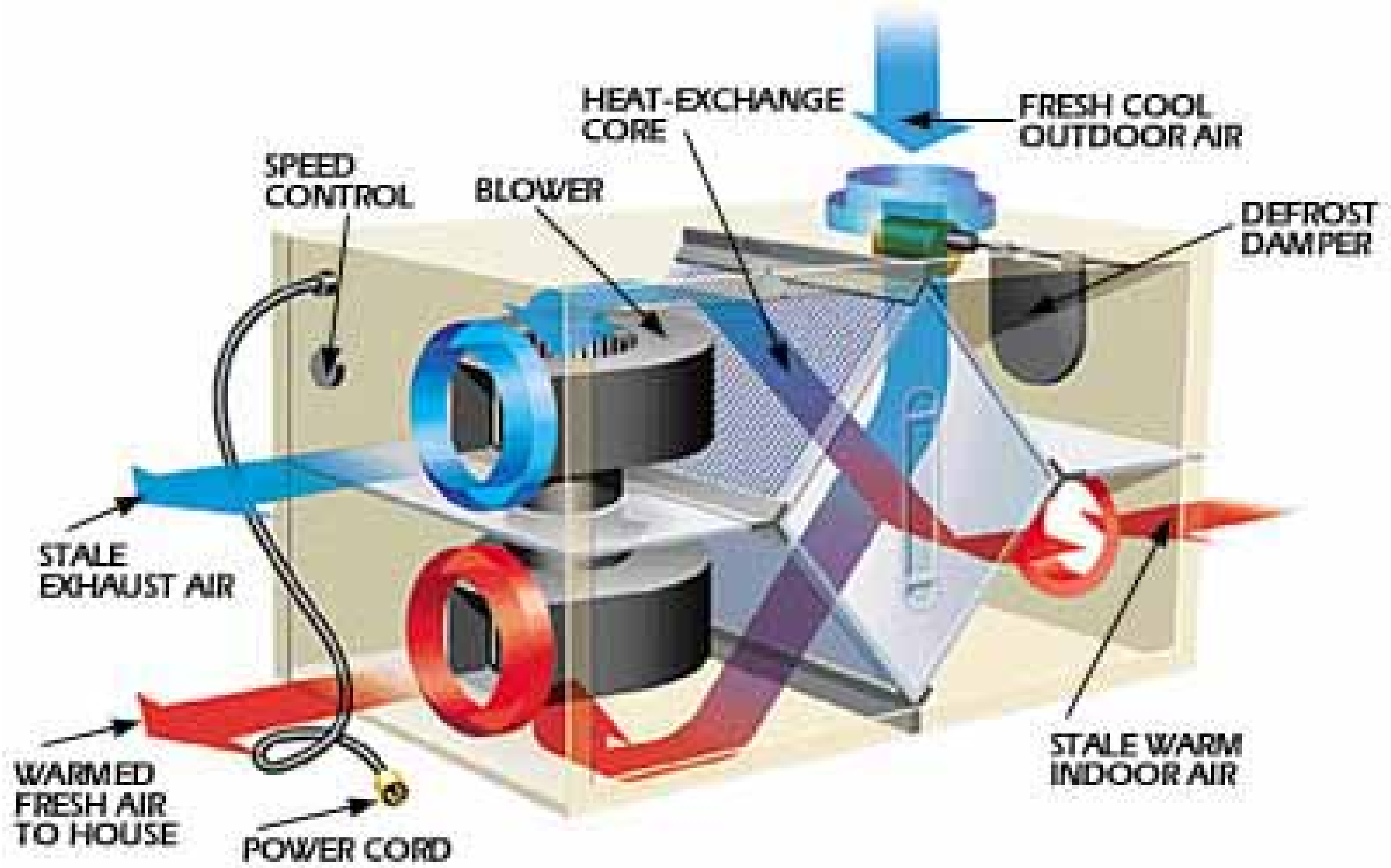
- The more heat an object can store, the less passes through it. Hence insulation.
- R values – Thermal Resistance. The higher the better
- Totally different R-Values from Refrigerants!!!

Material	R Value (per inch)
Brick	R-0.2
Glass	R-0.14
Wood	R-0.7 to R-1.4
Cement	R-2
Fiberglass batts	R-3.1
Vacuum insulated panel	R-30 to R-50

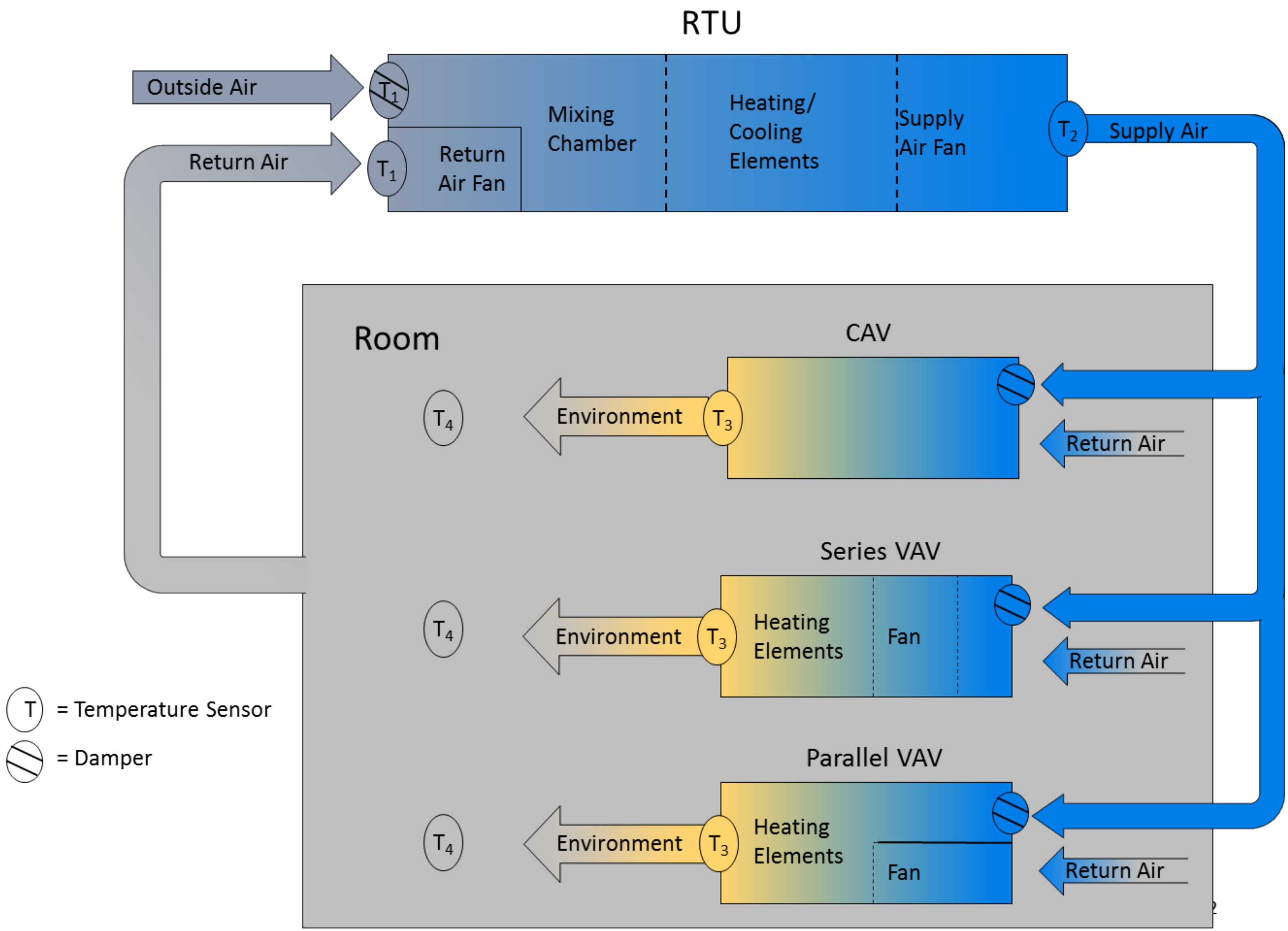
Consumption of heat and electric energy

Generation → Transportation → Consumption → **Recycling**

Air-to-air re-heat before recirculation



The HVAC airflow cycle for a building



5 questions

Applications that …

… need heat	… remove heat	… maintain heat
• Metallurgy • Kilns • Cooking	• Data centers • Exhaust fans • Refrigeration	• Thermal Comfort • Hot / Cold water • Heat lamps

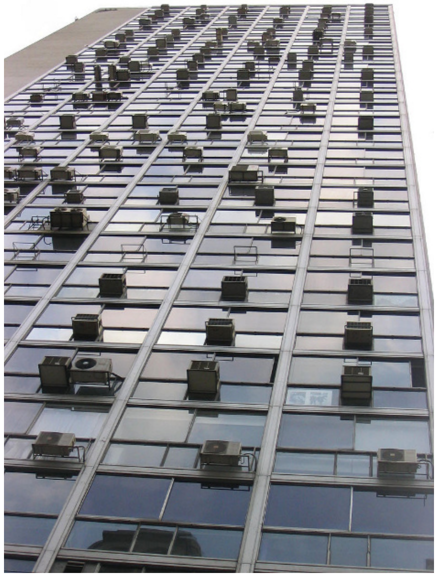
District Energy ties all three together

Issue #1 Water Management of heat

- Water is one of the best coolants in existence. It is cheap, abundant and ubiquitous.
- Yet water is one of the most expensive resources to transport.
- Heat management and water management are tied together.

Should factories be built next to rivers to lower cost of transporting water? Or far away from rivers to maintain the environment?

Issue #2 Who controls comfort?



Some say individuals who have control over their own comfort is better service

Others say a central, building-wide system is more energy efficient.

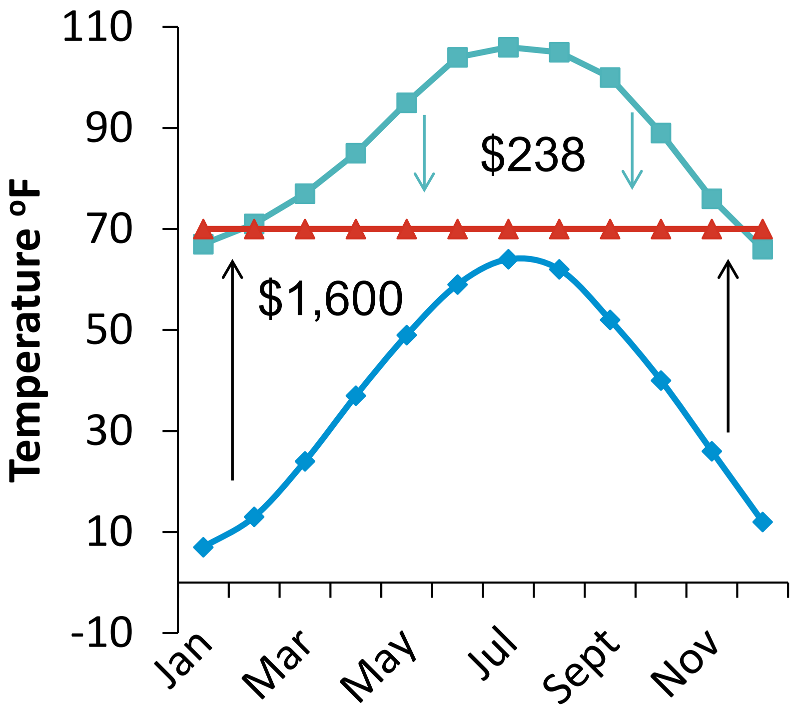
How does one decide which strategy to pursue – to maximize choice or maximize control?

Issue #3 Cost to heat vs. cost to cool

Room temperature is a comfortable 70 ^{o}F

The average January temperature in Minnesota is 7 ^{o}F. They spend approximately $1,600 per year to heat their homes by 64 ^{o}F.

The average July temperatures in Arizona is 106 ^{o}F. They spend approximately $238 per year to cool their homes by 36 ^{o}F.



Should people live in warm or cold climates?

Issue #4 Thermal Pollution

"Thermal Shock" – The changing of the temperature of an environment very quickly.

Too hot: factory releasing steam into the atmosphere, affecting birds and insects.

Too cold: constructing a dam that gathers water in a lake, cooling the natural temperature of a warm river.

Should thermal pollution be regulated? If so, how should it be monitored and enforced?

Issue #5 Messaging and Education

Heat energy is just another form of energy. It can be manipulated akin to electric and mechanical energy, etc. Yet it is frequently overlooked as a resource.

How can and should one explain the importance of heat management to the general public?

Thank You