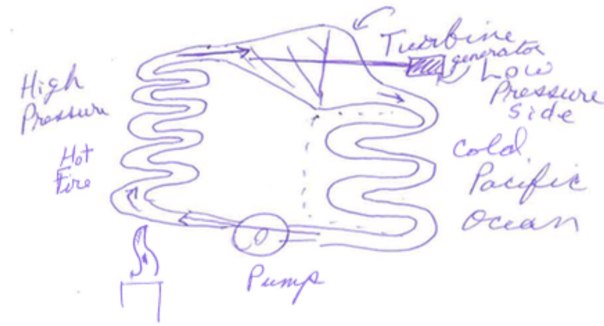
Big Exam #2 Use both sides. Put your name at the end

#1. Rankine Cycle (steam turbine):

a) Explain how a Rankine Cycle works. I should have said, “with a good drawing.” Please be able to draw heat engines and explain how they work, and answer these following questions for all heat engines.

b) Explain where we put work into the cycle, and where we get work out. Heat is not work. **<u>Heat is flow of thermal energy</u>** by conduction, convection, or radiation. **<u>Work</u>** is the integral of force over distance, or **<u>Pressure over volume (for fluids).</u>**



c) Mechanically speaking, how is the work produced greater than the work you put in, and how does this not violate the first law of thermal physics (conservation of energy)? Because the heat causes the water to boil, we have much more volume in expanding through the turbine, than in compressing the water. We conserve energy, not work. Heat is also put in and put out. More heat is put in than is given off, thus perfectly compensating for the increased work out.

d) You design a natural gas combined cycle using a 35% efficiency Brayton cycle with a 25% efficiency Rankine cycle. What is the total efficiency of your power plant? ~51%, most everyone got this right.

#2 Your friend who left his 100 W incandescent light on for a year. This choice resulted in:

a) How much money did this choice cost him?

b) How much CO_2 was emitted if the electricity was generated with an old coal-fired Rankin Cycle facility? About what mass of coal was used to generate this electricity? There are a number of simple things to remember for many questions:

- In California, electricity is ~ $0.15/kWh.
- The carbon (not carbon dioxide) intensities of Natural gas, Petroleum, and Coal are about 15, 20, 25 grams of Carbon / MJ. You can use this to figure things out completely. However, you can also work it out to see that for coal, you produce ~ 1 kg of CO_2 per kWh. Please do this: start with 25 g/MJ: Multiply by ~3.7 (for addition of oxygen), 3.6 (MJ => kWh), and 3 (efficiency)
- then NG in a NGCC is about 1/3 of that… why? Please prove to yourself.
- Really, the problem with coal is that it’s a solid, so:
  a) You can’t use it in a CC because it will destroy the turbine blades.
  b) It has all kinds of nasty crap (like mercury and sulfur) embedded in it.

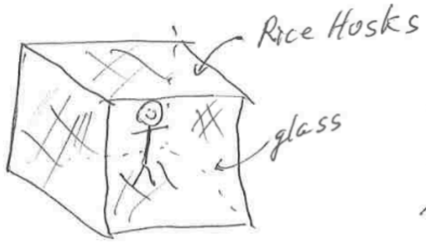
#3 Humans put out about 100 W while at rest. Imagine your house is a cube, 10 feet on a side, raised on stilts, so 5 surfaces are the same, and one is glass, facing South. You have R30 walls and R5 glass (Double pane, Low E glass + draped cover).

a) What is the amount of free temperature you obtain with one person living in the house?
b) If I set the thermostat at 68° F, what temperature outside will turn the thermostat on?
c) This house (without any sunlight) is placed in Minneapolis with 8000° F-degree days. How many barrels of oil (5.8 M BTU/bbl) are consumed in the year.? State any reasonable assumptions.
d) If I insulate the walls with straw (thermal conductivity ~ 0.05 W/m-K). How thick do the walls have to be in order to have an insulating factor of R30?

OK, this problem was informative in that it conveyed to all of us that you didn't learn this stuff and were surprised that it was on the big exam (see solutions below). I ask your forgiveness for putting this problem on BE #3, and am especially sorry if you were sad over the weekend as a result. This problem was the result of my trying to accommodate material that DH covered when we shared the class in to something that I am responsible for alone 2015 (actually, I toned the problem down from the 2015 midterm). I need to balance my respect for DH as a great friend and physicist with an understanding that when I make a class my own, I need to feel good with the content. Let's try something more fundamental. This is on your PS #3, and due on Wednesday. It is also representative of what I'm expecting you to be able to do on the midterm on Friday:

#3 Humans put out about 100 W while at rest. I build a house that is a cube in the air on stilts. The walls are insulated with 25 cm of rice hulls (~ 0.05 W/m-K), and I stay inside.

a) What is the free temperature from me living in the house? That is, what is the equilibrium temperature difference between the inside and outside of the building when I'm living inside?
b) This house (without any sunlight) is placed in Minneapolis with 8000° F-degree days. How many barrels of oil (5.8 M BTU/bbl) are consumed in the year.? State any reasonable assumptions.
c) *Extra Challenge for someone who has extra time!:* Let's say that one of the walls is a sheet of glass that is very thin and perfectly transparent. Repeat the above calculation for this consideration.



R is in $\frac{ft^2 - {}^\circ F - h}{BTU}$

So to get thermal transmittance, we need $\sum \frac{A}{R} = UA$

$$UA = \sum \frac{A}{R} = \frac{500\,ft^2\ BTU}{30\,ft^2\cdot{}^\circ F\cdot h} + \frac{100\,ft^2\ BTU}{5\,ft^2\cdot{}^\circ F\cdot h} \approx 37\,\frac{BTU}{h\cdot{}^\circ F}$$

a) Free Temp: $P = \frac{dQ}{dt} = UA\,\Delta T$, $\Delta T = \frac{P}{UA} = \frac{100\,W\ h}{37\ BTU}\,{}^\circ F$

because a $W \approx 3.4\,\frac{BTU}{hr}$ $\Delta T \approx 10^\circ F$

b) $68^\circ F - 10^\circ F \approx 58^\circ F$

c) degree days/year $= \sum^{8760} (65^\circ F - T_{outside})(1h)/24$, but our heater doesn't turn on until $58^\circ F$ outside or $7^\circ F$ below $65^\circ F$, so we have $7^\circ F \cdot 365\,day$ = 2555 °F days **less** or 8000 °F days − 2555 °F days = 5445 °F days

c) $E = P\cdot t = UA\,\Delta T\,\Delta t$

$$= \frac{37\ BTU}{h\cdot{}^\circ F}\cdot 5445\ {}^\circ F\ days \cdot \frac{24h}{day}$$

$= 4.8$ MBTU ≈ 0.8 Barrels of oil.

d) $P = UA\,\Delta T = A\cdot K\cdot\frac{\Delta T}{\Delta L}$

UA for 1 wall

$$\frac{100\,ft^2\ BTU}{30\,{}^\circ F\cdot h\cdot ft^2} = \frac{100\,ft^2\ .05\,W}{\Delta L\ \ m\,K}$$

$3.4\,\frac{BTU}{hr}$; $\sim 0.09\,m^{2}$; $1.8\,{}^\circ F$

what a mess!

$$\Delta L \approx \frac{5\cdot 3.4\cdot 0.09\,m\cdot 3}{1.8\quad 10} \approx 25\,cm \quad 25\,cm$$