PHYS-310 Heat Transfer, Efficiency, Electricity, Problem Set #3:

1) Humans put out about 100 W while at rest. I build a house that is a cube of length 3 m 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? Using the conductive power through 6 walls in parallel, I get about 9°C.

   b) This house (without any sunlight) is placed in Minneapolis with 8000° F- days ~ 4444 °C days per year. How many barrels of oil (5.8 M BTU/bbl ~ 6.1 GJ/bbl) are consumed in the year.? State any reasonable assumptions. With our free temperature of 9°C, get about 3300 °C*days per year, leaving about 1150°C*days per year. I get about 0.7 barrels per year.

   c) What's the "R-value" of this 25 cm of this wall material in English units of ft^2-F-h/Btu. This is actually kind of important, because when we buy insulation in the USA it's in English "R" values (consult section 11.1 of DH's book) we use in ft^2-°-h/BTU. Using equations 11.1 and 11.3, we can see that the resistance value is R = L/k, which makes sense: the resistive value of insulation is the inverse of the thermal conductivity times the thickness. For 25 cm of rice husks, we get R = 5 m^2-K/W. In converting this to English Units we get about 28 ft^2-°-h/BTU, or an R28, not bad. You should try to cancel the units nicely at least once to prove it to yourself, but look it up next time.

   d) Let's say that one of the walls is a sheet of glass that is very thin and perfectly transparent. Repeat calculation a) for this consideration. Linearizing radiative heat (11.12 – 11.14) we get an effective (metric) R value of (1/5.7) m^2-K/W. So, through this window of 9 m^2, we'd lose about 60 W per °C of temperature difference, meaning our 100 W through this window alone would leave a free temperature of only 1.6°C, meaning we've lost almost all our free temperature. If we look at 11.10, we can see that the effective R value of convection is even less, so we're in big trouble. I'll make the assumption that the thermal resistances to convection and radiation are equal, yielding a total thermal loss rate of 120 W/ °C of temperature difference and only about 0.8 °C of free temperature or about 300°C days of free temperature per year, lowering our 4444 °C days per year to 4144 °C days per year. 43 GJ of heat is needed in a year, or about 7 Barrels of oil: Close the blinds on your windows to save heat!!

2) Entropy is created when heat flows from hot to cold. In the idealized Sterling Engine, and in the idealized Carnot Cycle, one can imagine that no heat flows from hot to cold. Therefore, these engines create no entropy. No heat is lost without doing work! Work turns heat to energy, reducing entropy, while heat flowing from hot to cold increases entropy. So, if work is created (reducing entropy) we must have some waste heat (to create that much entropy). Starting with a change of entropy of zero and the conservation of energy, please derive the Carnot efficiency. We recognize that if some heat Q flows from hot to cold, entropy Q/T_{Hot} is destroyed and Q/T_{Cold} is created… thus more entropy is created than destroyed… however, if as the heat flows from hot to

cold, it goes through a heat engine, some heat changes to work, then the Q out of your engine into the cold is now Q-W and the entropy gained when the heat flows into the cold reservoir is now only $(Q-W)/T_{Cold}$ so the entropy gained is less. The most we could hope for would be to gain *zero* entropy. Thus, we just set $(Q-W)/T_{Cold}$ equal to Q/T_{Hot}. Then it's just some algebra and you isolate the first law efficiency: W/Q and find it is equal to $1 - (T_{Cold}/T_{Hot})$.

3) Solution to this is problem #1 in PS 3 for 310, 2015: http://sharedcurriculum.wikispaces.com/file/view/PS3_310_Solutions_S15.pdf/548892038/PS3_310_Solutions_S15.pdf

Remember our Bugatti Veyron? http://www.youtube.com/watch?v=LO0PgyPWE3o Please reconsider the subject of efficiency:

a) What was the efficiency you calculated? This is called the "first law efficiency" because it follows directly from the first law of thermal physics. This is also of course the *actual* efficiency of the vehicle.
b) What is the maximum possible efficiency (Carnot Efficiency) you could hope for given the extremes of temperature between ambient outside temperature and the hottest hot of the combustion (you'll have to look this up… but I wasn't able to find it for a Veyron. You could look it up for the general Otto Cycle.)
c) What portion of this maximum theoretical efficiency did you achieve? This portion is called the "second law efficiency" because the Carnot Efficiency comes from adhering the second law of thermal physics.
d) Even a perfect, frictionless Otto Cycle doesn't achieve the Carnot Efficiency. Please see: http://web.mit.edu/16.unified/www/SPRING/propulsion/notes/node25.html and investigate the efficiency of the Otto Cycle – what is the key factor? Why are diesel engines a little more efficient than the Otto Cycle? Well, there are a few reasons we will investigate later, but please find one of them now.
e) What is the second law efficiency for a perfect Otto Cycle (achieving perfect Otto Cycle efficiency for the temperatures and compression ratios you find)?
f) What portion of the maximum possible Otto Cycle efficiency does your Veyron actually achieve?

4) Running a Natural Gas Combined Cycle

Let's say you're in charge of a NGCC for Southern LA. You control the flow of NG to the Brayton Cycle turbine and you can monitor the (a) electrical current, (b) the torque (how hard the turbine has to push the generator to keep it going), (c) the spinning frequency of the turbine, and the (d) output voltage. At 5:30 PM, everyone gets home and turns on their electrical appliances – especially air conditioners..

a) When this happens, what do you notice about measurements in (a) – (d) above? As you noticed when you turned the hand generators and the electrical load increases (a) the current goes up, (b) increasing the torque because of the increased current pushing backwards on the rotating coils. If you don't increase the fuel into the generator, (c) the rate of turning will slow, lowering the frequency, and (d) the output voltage decreases because of the reduction of the rate of change of magnetic flux through the rotating coils. BROWN OUT!
b) How do you respond with the flow of NG to the Brayton Cycle Turbine? What does this do? You slam in some additional fuel. This increases the power in and the torque you

provide to the generator, reestablishing the speed and voltage at a higher current.! All is well, you have responded so that your generation facility "met load"!

c) After your action, how do measurements (a) – (b) compare to how they were before everyone came home? Explained above.

5) Transmission

Solution is question 5 in PS#3 from 2015:
http://sharedcurriculum.wikispaces.com/file/view/PS3_310_Solutions_S15.pdf/548892038/PS3_310_Solutions_S15.pdf

Why do we need Transformers?

a) Please explain how transformers reduce transmission losses, and include consideration of High Voltage, AC/DC, and resistive heat losses in a wire.

Let's say you're on a task force to address the power loss to Bakersfield from Diablo. The power lines were made a long time ago and since then, Bakersfield's demand for electricity during peak hours has doubled.

b) If the power use has doubled, by what factor will the amount of heat loss in the cables increase?

c) On extra hot days, there will be an extra thermal load on the wires. What problem occurs when the wires heat up? How would this change the transmission losses?

d) Long wires have considerable inductance and capacitance. How does this affect heating loses? Please ignore this answer, and this question as well… because it isn't really in the inductance of the transmission wires that we lose electricity. The losses in long distance AC transmission comes in the fact that there is inductive coupling between the wires and the rest of the world. In a sense, it's like your wires are the primary coil of a transformer and the rest of the world is the secondary coil… there is only weak coupling (like when I took the iron out of the coils in the transformer in class). However, there is *some* coupling. So as your current sloshes back and forth through the long distance cables, it creates a changing magnetic field, which induces current (and lost heating) in everything in the area! This doesn't happen with DC transmission lines, which is why DC transmission lines lose less energy!

e) You find a way to increase the transmission voltage by a factor of 5. By what factor will this change the transmission losses?

Please read more about what transmission lines are made of at
http://en.wikipedia.org/wiki/Electric_power_transmission