Midterm #1. If you see ** before a problem, it means "do this problem last if you have time."

1. Internal Combustion Engines still power automobiles after more than 100 years!
   a) What is the name of the heat engine cycle used by most cars?
   b) With a rough drawing explain how this engine works.
   c) Please explain where mechanical work is put into the engine and where work is put out by the engine. Physical work is the integral of *force* over *dx*, or *Pressure* over *dV*. Like in the last big exam, many people mistook "work" for "energy" and talked about heat flow. Physical work is put into the engine by compressing the "charge" (air + fuel), although you could also rightly argue that it requires physical work during intake to pull in the charge, and exhaust to push the exhaust out. Work is done *by* the engine during the expansion of the burning charge during the power phase. The many wrong answers on both the BE and the MT indicates that we need to rethink how we're communicating. It seems people didn't read the BE corrections and I'm curious why this didn't happen.
   d) What happens in the engine that allows the output work to be greater than the work put in? Because there is an explosion, the pressure is much higher during the expansion than during the compression, so much more work is put out in the expansion of the power phase than is used for compression.
   e) How does getting more work out not violate the 1st law of thermal physics? We don't conserve work, we conserve energy. Thus by putting in heat (in the form of chemical potential energy of fuel), we are able to put more work out than is put into the engine, but the *energy* in (work + heat) is equal to the *energy* out.
   f) ** Burning gasoline has a temperature of above 1500 C. If the outside temperature is 20 C. Estimate the maximum theoretical efficiency we could get from a gasoline engine. Make sure you use *absolute* temperatures when doing efficiency calculations.
   g) **We calculated the Veyron to get a maximum efficiency of about 30%. Why so low? It's not sufficient to say that there is lots of waste heat – that's just repeating the question and there is always waste heat given off by a heat engine. There are many reasonable answers to this question. Maybe the most important is that the exhaust temperature of the Otto cycle under full power is much much much higher than room temperature, so that the Carnot Efficiency cannot be realized.

2. As a society, we built large electrical grids.
   a) What was the benefit in building large grids? This question was premature (I apologize), and we will learn more about this in the coming week. Grid allows economy of scale as we see the efficiency of large turbines is way better. It allows centralized production of pollutants in a place where no one lives, or powerless, voiceless people live, like poor minorities (Environmental Justice issues address who gets rich and who suffers from an action, policy or technology). Because electricity must be used as soon as it's generated or stored (which is expensive), a large grid evens out the high-power spikes in consumption each home has and makes it better for everyone. All this may change in the near future with inexpensive photovoltaic generation and batteries. It is likely that the way the grid operates will change in the coming decade.
   b) Why was AC electricity necessary to make these large grids efficient? Please be complete. This has several parts: power loss is proportional to I^2 and power transmitted = IV, so we want to transmit power at very high voltages. We need to raise and lower voltages, and a transformer does this well with AC because it's a *changing* magnetic field that induces voltage in a coil.
   c) Please explain how a transformer works.
   d) We build most of our electrical generation facilities on the beautiful coast where land is expensive. Why don't we build them in the desert where no one wants to live?

3. I have 10 lights in my house – but I like it bright. I only use 100 W incandescent bulbs because they are way cheaper than LED lights! I keep the house lit up nicely for about 6 hours every evening. For this class, it is crucially important that we know the formula P = E/t or W/t. Units of energy are J or kWh. Power are W, or kWh/year or something like that. Watts / year is neither: it would be the rate of power *increase*. Understand that Watts is the *rate of energy use*, or power. Lots of you still are not comfortable with this. Please make sure you've mastered it by the next exam.
   a) How much does this choice cost me financially each year?
   b) Estimate the amount of carbon dioxide this choice puts into the atmosphere if the marginal electricity in California is generated by Natural Gas Combined Cycle. Marginal electricity is probably a new term to you, but you likely solved the problem without knowing it completely. When you turn something on, it is the generator that is turned on or turned up to accommodate the increased load, or the generator that is turned off when you turn something off. So even if 99% of the electricity is generated from (near) carbon free solar, but 1% is single cycle coal is necessary to meet the complete load, *every single consumer* is responsible for *coal's* cost and emissions (of 1 kg of CO_2 emitted per kWh of electricity used), because if any one person turned off their use, it would be the coal plant that would be turned down. More on this in the coming week.
   c) Estimate the mass of Natural Gas burned in this process. This can be done with energy density of natural gas, or just balance the chemical equation using 16g of methane to 44g of CO_2.
   d) **We know that the US consumes about 100 EJ of total primary energy per year. *Starting with this fact* and demographic and energy choices we know about in the USA, estimate the average rate of electricity consumption for the USAmerican in Watts.

4. I'm making an adobe wall 4 m long, 2 m high, and 75 cm thick. The thermal conductivity of earth in metric units is ~1.5. If it drops to freezing at night and you like to keep it at about 20 C (68F) inside.

a) Please estimate the power you'll lose through the wall.

b) **If I put in a nice 2m x 2m window of very thin glass, how much power will I lose through this window? No one wanted to do a radiative and/or convective approximation. The thin window means there is no conductive resistance: The inside of the window is the same temperature as the outside of the window. Heat is radiated through and conductive heat loss is limited by convective losses. This is a hard problem, I was hoping you'd get part of it. You might want to see the second BE.