AREN 2110 CLASS NOTES

APPLICATIONS OF THERMODYNAMICS TO CURRENT ISSUES

HEATING BUILDINGS

Reference for much of this material: MacKay, David (2008) "Sustainable Energy – without the hot air," UIT, Cambridge, UK.

Issues:

1. as much as 30% of the electricity generated in the US is used in buildings. Just **heating and cooling for buildings may account for 45 kwh/d/person**
2. fossil fuels used to produce most of the world's electricity are no infinite
3. furthermore, as they get scarcer, the cost will increase and the supply become less reliable
4. burning fossil fuels may have unknown and negative impacts on climate

Goal: Reduce energy use in buildings

Analysis

If a building were perfectly sealed (no losses or gains) no energy would be required to maintain temperature (ignoring insolation and heat input from people, appliances, lights, etc.) So power to heat building must make up for losses which are determined by the temperate difference between the indoors and outdoors (**ΔT**) and the characteristics of the building that allow heat losses (**leakiness**)

$$\textbf{Power to heat a building} = \frac{\boldsymbol{average\ \Delta T * Leakiness}}{\boldsymbol{efficiency\ of\ heating\ system}} \qquad \textbf{(I)}$$

2 mechanisms account for losses:

HEAT LOSSES

1. <u>CONDUCTION:</u> account for heat loss or gain by Newton's Law of cooling

$$\dot{\boldsymbol{Q}} = -\boldsymbol{k} * \boldsymbol{A} * \Delta \boldsymbol{T}\ \textbf{(W)}$$

where K = thermal conductivity ($W/m^2/K$), A = surface area through which heat loss/gain occurs (m^2), $\Delta T = T_{indoors}\text{-}T_{outside}$ (K).

2. VENTILATION: accounts for different in enthalpy of cold air entering building and warm air leaving through cracks, leaks, holes, or active ventilation with make-up air.

$$\dot{Q} = \dot{m} * C_P * \Delta T \quad \textbf{(W)}$$

Where ΔT is as define above, C_P = the specific heat of air (kJ/kg-K) and $\dot{m}$ = mass flow rate of infiltrating and exfiltrating air (kg/s), assuming steady-state conditions.

Conventional heat transfer analysis uses a volumetric specific heat constant, C, where C = ρC_P (kJ/m^3-K)

$$\dot{Q} = \dot{V} * C * \Delta T \quad \textbf{(W).}$$

Replacing $\dot{V}$ with Air Changes per Hour or ACH (hr^{-1}) x building air volume V (m^3)

$$\dot{Q} = \frac{1000}{3600} * C * ACH * V * \Delta T \quad \textbf{(W).}$$

Often the interest is energy, Q, not power, where

$$Q = \dot{Q} * \Delta t$$

Assuming factors K*A and C*ACH*V are constant for a building, Δt is the duration over which the temperature difference ΔT occurs, and the product **ΔT* Δt** called the **TEMPERATURE DEMAND**, is of interest.

Note that the units of K*A and C*ACH*V are W/^{o}C, so they can be combined such that

LEAKINESS = K*A + C*ACH*V

A common unit of temperature demand is the degree day. For example, if a house is maintained at 18 ^{o}C and the average outside temperature over a week is 8 ^{o}C, then the temperature demand = (18-8 ^{o}C)*7 days = 70 degree-days (^{o}C*day).

Combining Leakiness and Temperature Demand gives the energy lost from a building (the numerator in I)

Total energy lost = Leakiness (W/^{o}C)*Temperature Demand (^{o}C*day)

for units of energy lost (note that you can convert watt-days to get a unit of kwh, for example).

EFFICIENCY OF HEATING

Efficiency of heaters is the coefficient of performance, COP, where

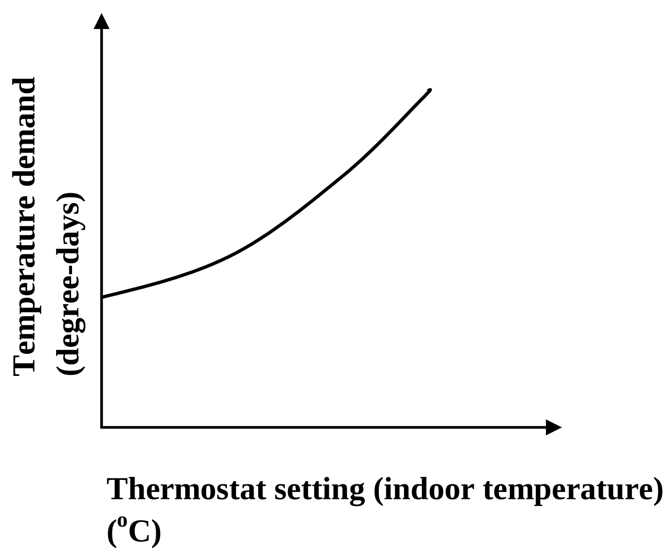
$$COP = \frac{heat\ energy\ delivered}{energy\ consumed}$$

REWRITE I as energy using formulas

$$\textbf{Energy to heat a building} = \frac{\Delta \boldsymbol{T} * \Delta \boldsymbol{t} * (\boldsymbol{K} * \boldsymbol{A} + \boldsymbol{C} * \boldsymbol{ACH} * \boldsymbol{V})}{\boldsymbol{COP}} \qquad \textbf{(II)}$$

REDUCING ENERGY CONSUMPTION FOR HEATING BUILDINGS

I. Reduce TEMPERATURE DEMAND (ΔTΔt) by setting back thermostat temperature



As indoor temperature set point increases, (ΔTΔt) increases significantly. Setting thermostat back by 3 – 5 ^{o}C (5 – 9 oF) can reduce temperature demand by 30 – 40% in a temperate climate.

II. Reduce ventilation and conduction losses (LEAKINESS)

A. Ventilation
   a. Seal window and door frames, and other gaps in building envelope
   b. Recirculate indoor air through furnace

B. Conduction
   a. Add insulation
   b. Use non-conductive materials on walls, roof, floors
      i. Double/triple pane windows
      ii. Thick walls
   c. Design
      i. Low surface area: volume ratio

Comparing losses for different types of buildings, normalize losses per unit floor area: W/^{o}C-m^2

Leakiness losses compared

Leakiness losses from:	(W/^{o}C-m^2)
Old house	4
Old house after adding insulation and sealing	3
New home using "sustainable" standards (UK)	1.1

Note that relatively costly upgrades to old house may reduce losses by 25% - not as high as "free" benefit of turning down thermostat.

III. Increase heating system efficiency (COP)

Type of heater	COP	Power required to heat building (W)
High efficiency boiler	0.9	$(K*A + C*ACH*V)*\Delta T/\mathbf{0.9}$
Heat pump	3 – 9 typically	$\sim(K*A + C*ACH*V)*\Delta T/\mathbf{6}$

Using heat pump may reduce power required for heating by a factor of greater than 6, depending on heat pump COP. Therefore, it may be more efficient to use

natural gas to produce electricity and use the electricity to run a heat pump, compared with burning natural gas to heat a boiler in individual buildings.
For heat pump, recall that for ideal (Carnot) heat pump:

$$COP_{HP,Carnot} = \frac{1}{\left(\frac{T_H}{T_L} - 1\right)}$$

So for a fixed value of T_H, the COP increases as T_L increases., which is a rationale for **using groundwater as the low temperature reservoir**, with a relatively constant temperature between 10 and 15 ^oC, compared with air, which may be -10 ^oC in the winter.

Concerns with groundwater as a heat source for heat pumps:

- Soil has relatively low thermal conductivity, so heat transfer to coils may be slow.
- If every building had a heat pump, could significantly lower groundwater temperature (freeze??) in areas with a high density of buildings.

Also, **lowering thermostat setting (T_H) has a double benefit for a heat pump**. It reduces leakiness losses AND it increases heat pump efficiency.