1. (20 pts) Consider the room ventilation configuration of Lecture 20 when we introduced the concept of recirculation. Suppose we use that room as a clean room and need to obtain a Class 10 clean room for 0.5-micron particles.

   (a) What is the maximum number concentration of 0.5-micron particles [number of particles/m^3] that we can tolerate for a Class 10 clean room? [Note: Use the table rather than the figure to avoid errors reading from the plot.]

   (b) The air cleaner in this clean room is a filter with \( \eta \) evaluated for 0.5-micron particles. The other parameters of the room and ventilation system are:

   - \( f = \) make-up air fraction = 0.050
   - \( c_a = \) ambient air (make-up air from outside) particle number concentration = 3650 (0.5-micron particles)/m^3
   - \( S = 735 \) (0.5-micron particles)/minute
   - \( A_s = \) surface area for wall adsorption = 220 m^2
   - \( k_w = \) wall adsorption coefficient = 0.025 m/minute
   - \( V = \) room volume = 300 m^3
   - \( Q = Q_s = \) supply air volume flow rate = 20 m^3/minute

   Calculate the number of room changes per hour. Then calculate the required filter efficiency \( \eta \) as a percentage to maintain a steady-state Class 10 clean room.

   (c) Estimate the annual heating cost of make-up air if this clean room is located in a city where there are 6500 heating degree days (°F days), oil is used to heat the make-up air at a cost of $2.60 per gallon, and the clean room is used 60 hours per week on average.

   (d) What would the air cleaner removal efficiency need to be in order to achieve a Class 1 clean room for 0.5-micron particles, all else being the same (cleaner efficiency \( \eta \) is the only thing that changes)? Also calculate the cost for this case.

2. (10 pts) In the book and in class, we give an “engineering equation” for the cost of make-up air for general ventilation,

   \[
   \frac{S_{heating}}{year} = \text{constant} \cdot \frac{D D_{t, \text{operating}} C_{fu} Q}{q_{fu}}, \text{ where constant} = 0.154
   \]

   In an “engineering equation” the units in the constant are already taken care of, but you must enter all the values in precisely specified units. As a mathematician, this kind of equation is not very “satisfying.”

   (a) Figure out the units of the constant 0.154 in the above equation. Write your answer as “constant = 0.154 xxxx” where “xxxx” is a bunch of units, like (BTU∙ft∙hr…) / (°F∙ft^3…) – whatever units are necessary to get the left hand side of the equation to be $/year when all the variables are entered in their specified units.

   (b) Re-write the above equation with all the units of the constant included. Your result will be a “normal” equation rather than an “engineering equation.” In other words, you can then enter the values of the variables with any units you choose, and then multiply be unity conversion factors to generate the final answer. This final equation may be more “satisfying” to some of you.

3. (15 pts) Two air cleaners are available for cleaning a hazardous gas from an air stream. The removal efficiencies are \( \eta_A = 95\% \) and \( \eta_B = 88\% \).

   (a) Calculate the overall efficiency if the two air cleaners are installed in series.

   (b) Calculate the overall efficiency if the two air cleaners are installed in parallel, but you will need to optimize how the flow is split between the two cleaners. Which flow split produces the best overall removal efficiency?

   (c) Recommend the best choice and briefly discuss.
4. (40 pts) Air (and some vapor contaminant) at SATP is drawn into a tapered canopy hood, and then goes through a combination air cleaner/damper, several long sections of pipe, and four elbows, as sketched. The air is exhausted by a fan.

- duct dia. = 380 mm
- duct length = 195 ft
- duct roughness = 0.43 mm
- $C_{o, \text{hood}} = 0.38$
- $C_{o, \text{cleaner/damper}} = 3.37$
- elbows are 7-gore, 90° CD3-10 with $R/D = 2.5$
- $\rho_{\text{air}} = 1.184 \text{ kg/m}^3$
- $\nu_{\text{air}} = 1.562 \times 10^{-5} \text{ m}^2/\text{s}$

A fan is purchased, and the manufacturer gives the following performance data for the fan:

<table>
<thead>
<tr>
<th>$Q$ (SCFM)</th>
<th>Fan head (inches water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.2</td>
</tr>
<tr>
<td>1240</td>
<td>5.1</td>
</tr>
<tr>
<td>2480</td>
<td>4.82</td>
</tr>
<tr>
<td>3720</td>
<td>4.02</td>
</tr>
<tr>
<td>4960</td>
<td>2.15</td>
</tr>
<tr>
<td>5950</td>
<td>0</td>
</tr>
</tbody>
</table>

I strongly suggest Excel or other software for this problem. **On the same plot**, plot two curves: (1) required fan pressure rise (Pascals) as a function of volume flow rate (SCFM), and (2) available fan pressure rise (Pascals) as a function of volume flow rate (SCFM). Predict the volume flow rate in SCFM and fan pressure rise (Pascals) at the operating point. In other words, match the fan’s performance capability to the requirements of this duct system.

5. (15 pts) Refer to the class example in Lecture 28 in which we compared lateral hoods (pickling copper in sulfuric acid). Repeat the analysis for this same tank and all other parameters, but use the push-pull system of Fig. 6.13. For consistency, use a blowing slot width of 3/16 inch. Calculate the required suction slot width, blowing volumetric flow rate, and suction volumetric flow rate. Finally, compare the required suction volumetric flow rate with that of the lateral exhaust hood on one side of the tank (as calculated in the class example problem).