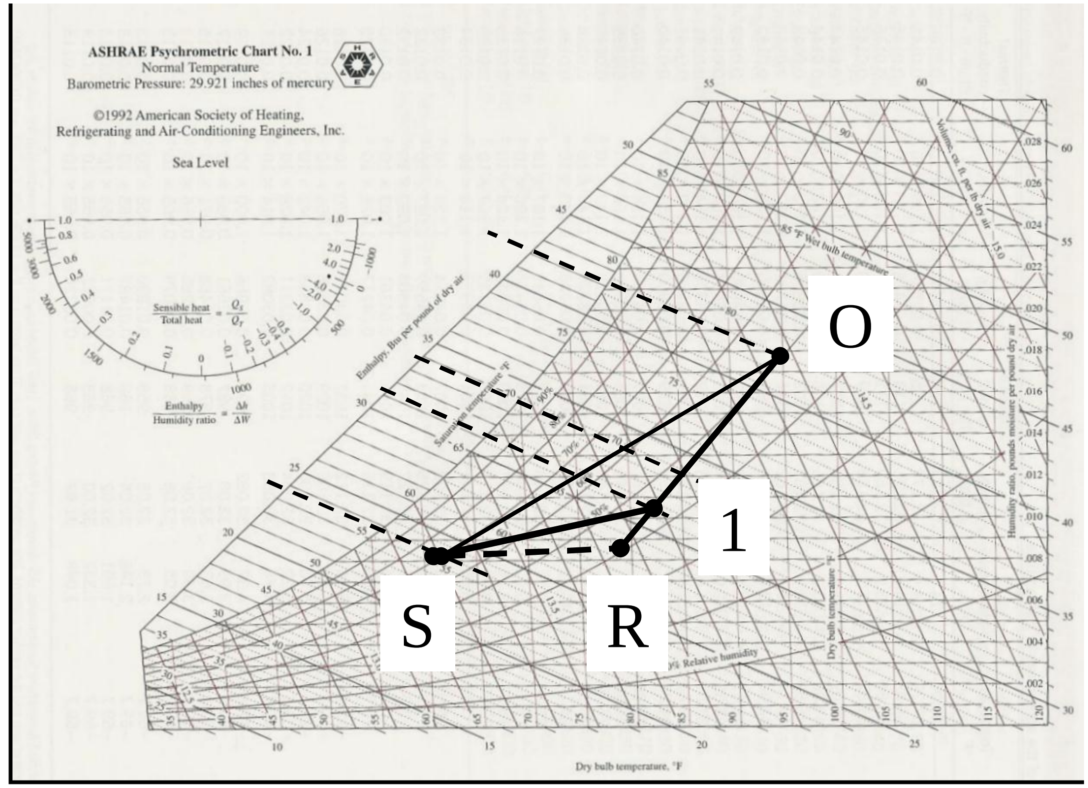
# Problem set 5 (PS5) Due Monday February 20

**PS5-1** A laboratory involving animal research must use either 100 percent outdoor air or 25 percent outdoor air with high-performance filters for the return air. Gravimetric efficiency must be at least 99 percent in the size $0–5 \times 10^{-6}$ m. The computed heat gain of the laboratory is 3 tons with a sensible heat factor (SHF) of 0.7. The cooling and dehumidifying unit requires a fixed air-flow rate of 350 cfm per ton. Inside conditions are 78 F db and 40 percent relative humidity, whereas outdoor conditions are 95 F db and 50 percent relative humidity. (a) Investigate the feasibility, and find the required amount of air and the size of the cooling unit when 100 percent outdoor air is used. (b) Find the required amount of air and the size of the cooling unit when 25 percent outdoor air is used and the remainder is recirculated through the high-performance filters. (c) Design the filter system using the data of Fig. 4-9 and Table 4-6 so that the maximum pressure loss is 0.125 in. water with clean filters.

**PS5.2** Replace the concrete block construction in the wall of figure 5-4a with a 2x6 stud wall and calculate the overall coefficient for the wall taking into account the different conditions at the studs and between the studs. Structural lumber is actually .5 in smaller than the nominal dimensions. A 2 x 6 “two by 6” is actually 1.5 in x 5.5 in.

Problems 5-15 and 5-36 from the McQuiston Text

# PS5.1




a) $q_{coil} = \text{Tons} \times 200\ \text{BTU/ton} = m_s \Delta h_{coil}$

$$m_s = \frac{350\ \text{cfm} \times \text{Tons}}{v}$$

substituting

$$\text{Tons} \times 200 = \frac{350\ \text{cfm} \times \text{Tons}}{v} \times \Delta h_{coil}$$

$$\Delta h_{coil} = \frac{200 \times v}{350\ \text{cfm}} = 7.8\ \text{BTU/lb}$$

$$h_R = h_O - \Delta h_{coil} = 42.4 - 7.8 = 34.7\ \text{BTU/lb}$$

this enthalpy gives 85 F supply

which will not cool

b) with 25 % outside air, 75 % return air,

$h_1 = 31.4\ \ \text{BTU/lb}$

$h_s = 31.4 - 7.8 = 23.7\text{BTU/lb}$ and $66^O$ F,

will cool

$$q_{space} = m_s (h_S - h_R)$$

$$m_s = \frac{3 \times 200}{28 - 23.7} = 135.5\ \text{lb/min}$$

$$V_s = 134.5\ \text{lb/min} \times 13.5\ \text{ft}^3/\text{lb} = 1829\ \text{cfm}$$

$99\% \Rightarrow \text{M} - 200$

$$Q_{24x24x12} = Q_{table}\left(\frac{\varphi p_{limit}}{\varphi p_{table}}\right)^{.5} = 1200\left(\frac{.125}{.4}\right)^{.5}$$

$Q_{24x24x12} = 670\text{cfm per M200 filter element}$

$Q_{24x24x8} = 514\ \text{cfm per M200 filter element}$

$$\text{No. Required} = \frac{1829\text{cfm to be filtered}}{670\ \text{cfm per 24x24x12 element}} = 2.72$$

$$\text{No. Required} = \frac{1829\text{cfmtobefiltered}}{514\ \text{cfm per 24x24x8 element}} = 3.55$$

PS5-2

| | resistance hr ft$^2$ F/ Btu | |
|---|---|---|
| | at studs | between studs |
| 1. outside (15mph) | .17 | .17 |
| 2. facebrick | .44 | .44 |
| .5 in air gap | .90 | .90 |
| 1.5 x 5.5 stud | 6.71 | - |
| 5.5 in insualtion | - | 20.83 |
| 7. .5 in gypsum (foil) | .45 | .45 |
| 8. inside | .68 | .68 |
| Total Resistance | 5.223 | 23.47 |

5.5 insualtion

Table 5-1a, Insulation

$$R = \frac{1}{C} = \frac{1}{.048} = 20.83$$

2x6 stud

Table 5 – 1a, Wood

$$R = \frac{\Delta x}{k} = \frac{5.5}{\frac{.74 + .9}{2}} = 6.71$$

.5 air gap

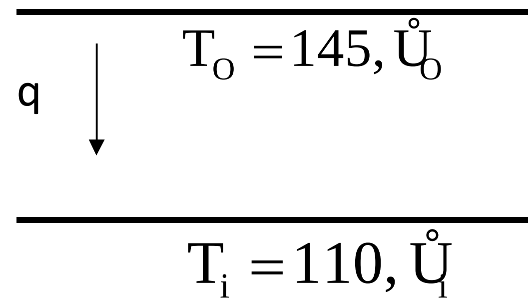
Table 5 – 2a

vert., horiz., Ů = .82, R ≈ .9

$$U = \frac{U_{at}A_{at} + U_{between}A_{between}}{A_{total}}$$

$$U = \frac{\frac{1.5}{5.223} + \frac{22.5}{23.47}}{24} = \frac{.287 + .959}{24} = .0519 \text{ Btu/ ft}^2 \text{ hr F}$$

compared to .171 and .140 for block construction for $\text{Ů}_o = .9, \quad \text{Ů}_i = .9$ 5-15




$$\text{Ů} = \frac{1}{\frac{1-\text{Ů}_o}{\text{Ů}_o} + \frac{1}{F_{io}} + \frac{1-\text{Ů}_i}{\text{Ů}_i}} = \frac{1}{2\frac{1-.9}{.9}+1} = .82$$

$$Q_{rad,.9} = \text{Ůů}\left(T_O^4 - T_i^4\right) = .82 \times .1713 \times 10^{-8}\left((145+460)^4 - (110+460)^4\right)$$

$$Q_{rad,.9} = 39.8 \text{ Btu/ft}^2 \text{ hr}$$

$$\text{Ů} = \frac{1}{\frac{1-\text{Ů}_o}{\text{Ů}_o} + \frac{1}{F_{io}} + \frac{1-\text{Ů}_i}{\text{Ů}_i}} = \frac{1}{1+\left(\frac{1-.05}{.05}\right)} = .0256$$

$$Q_{rad,.05} = \text{Ůů}\left(T_O^4 - T_i^4\right) = .0256 \times .1713 \times 10^{-8}\left((145+460)^4 - (110+460)^4\right)$$

$$Q_{rad,.05} = 1.145 \text{Btu/ft}^2 \text{ hr}$$

actual case : Horizontal, Down, t = large, $T_{ave} = 128, \Delta T = 35$

Table 5 – 2a Horizontal, Down,

$R_{.9} = .92, R_{.05} = 4.55$

Table 5 - 3a. Horizontal, Down, t = 3.5 in, Tave = 90, $\Delta T = 10$

$R_{.9} = 1., R_{.05} = 8.19$

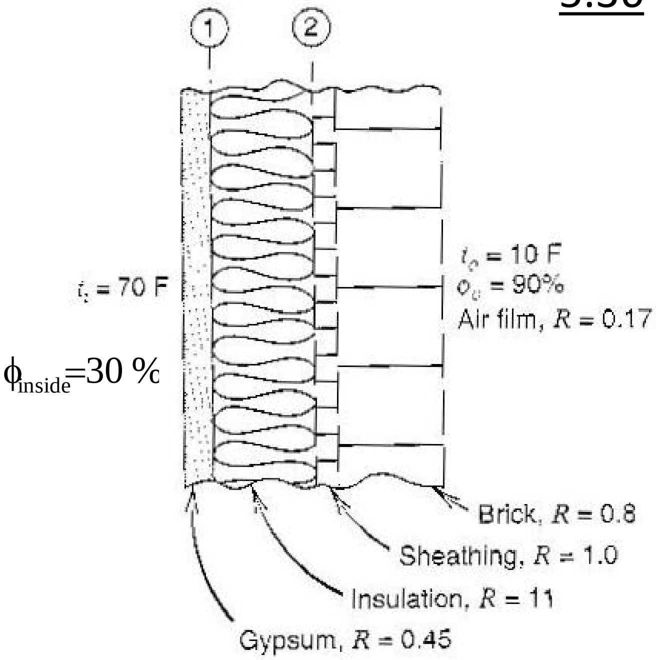
Table 5 - 3a. Horizontal, Down, t = 3.5 in, Tave = 50, $\Delta T = 30$

$R_{.9} = 1.22, R_{.05} = 9.6.$

$$q_{conv,.9} = \text{Uφφ} = \frac{1}{\sum R}\text{φT} = \frac{35}{.92+.92} = \frac{35}{1.84} = 19 \text{ Btu/ft}^2\text{hr}$$

$$q_{conv,.05} = \text{Uφφ} = \frac{1}{\sum R}\text{φT} = \frac{35}{4.55+4.55} = \frac{35}{9.10} = 3.85 \text{ Btu/ft}^2\text{hr}$$

<u>5.36</u>




$R$ in units of (hr – ft$^2$ – F)/Btu

| | R |
|---|---|
| inside | .68 |
| gypsum | .45 |
| insulation | 11.0 |
| sheathing | 1. |
| brick | .8 |
| outside | .17 |
| total | 14.03 |

$$\phi = \frac{p_v}{p_g} = \frac{p_v}{.3631} = 30\%$$

$$p_v = .1089$$

$$@\ p_v = .1089, \quad T_{dewpoint} = 37\text{ F}$$

$$q = U\varphi\varphi = \frac{1}{\sum R}\varphi T = \frac{70-10}{14.03} = 4.277\text{ Btu/ft}^2\text{hr}$$

$$\varphi T_{inside} = q \times R_{inside} = 4.277\text{ Btu/ft}^2\text{ hr} \times .68 = 2.19\text{ F}$$

$$\varphi T_{gypsum} = q \times R_{gypsum} = 4.277\text{ Btu/ ft}^2\text{hr} \times .45 = 1.92\text{ F}$$

$$\varphi T_{iinsualtion} = q \times R_{insulation} = 4.277\text{ Btu/ ft}^2\text{hr} \times 11. = 65.17\text{ F}$$

$$T_1 = T_i - \varphi T_{inside} - \varphi T_{gypsum} = 65.17\text{ F}$$

$$65.17\text{ F} > T_{dewpoint} \Rightarrow \text{no condensation}$$

$$T_2 = T_i - \varphi T_{inside} - \varphi T_{gypsum} - \varphi T_{insualtion} = 18.09\text{ F}$$

$$18.09\text{F} < T_{dewpoint} \Rightarrow \text{condensation}$$

vapor barrier at surface 1