Environmental Engineering (HVAC) - List of Equation

1) Ventilation

Basic principles

$$I = \frac{\dot{V}_o}{V_r}$$

$$I_S = \frac{\dot{V}_s}{V_r}$$

$$C\ [\text{ppm}] = C\ [\text{mg/m}^3]\frac{24{,}44}{M}$$

$$\dot{G}d\tau + \dot{V}c_s d\tau = \dot{V}c\ d\tau + V_r dc$$

$$\dot{V} = \frac{\dot{G}}{c - c_s} = \frac{\dot{G}}{PEL - c_s}$$

$$\dot{V} = \frac{\dot{Q}}{\rho c\left(t_i - t_s\right)}$$

$$\dot{V} = \frac{\dot{M}_w}{\rho\left(x_i - x_s\right)}$$

Thermal environment

$$q = q_m - w = \pm q_c \pm q_r + q_{ev} \pm q_{res} \underbrace{\pm q_{con}}_{0}$$

$$w = \eta \cdot q_m$$

$$PMV = f\left(t_a, MRT, w, RH, I_{cl}, q_m\right)$$

$$DR = f\left(t_a, MRT, Tu\right)$$

$$t_o = \frac{h_c t_a + h_r t_r}{h_c + h_r}$$

$$t_o = \frac{t_a + t_r}{2} \quad \text{for } w < 0{,}2 \text{ m/s}$$

Psychrometrics

$$\varphi = \frac{p_v}{p_{v,s}}$$

$$x = 0.622 \frac{\varphi p_{v,s}}{p - \varphi p_{v,s}}$$

$$h = c_a t + x\left(l + c_v t\right) = 1.01t + x\left(2500 + 1.86t\right)$$

Mixing of two airflows

$$M_1 x_1 + M_2 x_2 = (M_1 + M_2) x_m$$

$$M_1 h_1 + M_2 h_2 = (M_1 + M_2) h_m$$

Heat exchangers

$$\dot{Q}_{hc} = \dot{V} \rho c \left(t_2 - t_1\right)$$

$$\dot{Q}_{cc} = \dot{Q}_{sen} + \dot{Q}_{lat} = \dot{V} \rho c \left(t_1 - t_2\right) + \dot{V} \rho l \left(x_1 - x_2\right) = \dot{V} \rho \left(h_1 - h_2\right)$$

$$\dot{Q}_{hum} = \dot{V} \rho l \left(x_1 - x_2\right)$$

$$\dot{M}_{w,hum} = \dot{V} \rho \left(x_1 - x_2\right)$$

Natural ventilation

$$\dot{M} = \frac{\dot{Q}}{c\left(t_{ex} - t_s\right)}$$

$$\Delta p = hg\left(\rho_o - \rho_i\right)$$

$$M_{ex} = M_s = M$$

$$\mu_{ex} A_{ex} \rho_{ex} w_{ex} = \mu_s A_s \rho_s w_s \quad \leftarrow \quad w_s = \sqrt{\frac{2\Delta p_s}{\rho_s}}; w_{ex} = \sqrt{\frac{2\Delta p_{ex}}{\rho_{ex}}}$$

$$\frac{\Delta p_s}{\Delta p_{ex}} = \frac{\mu_{ex}^2}{\mu_s^2} \frac{\rho_{ex}}{\rho_s} \frac{A_{ex}^2}{A_s^2}$$

$$\Delta p = \Delta p_s + \Delta p_{ex}$$

$$B = \frac{t_{oz} - t_o}{t_{ex} - t_o}$$

Mechanical ventilation

$$\dot{Q}_{hc} = \dot{Q}_{hl,vent} + \dot{Q}_{hl,tran} = \dot{V} \rho c \left(t_i - t_o\right) + \dot{V} \rho c \left(t_{sup} - t_i\right) = \dot{V} \rho c \left(t_{sup} - t_o\right)$$

$$\dot{Q}_{hl,tran} = UA\left(t_i - t_o\right)$$

Heat recovery

$$\Phi = \frac{t_{rec} - t_o}{t_i - t_o}$$

$$\Phi_{\min} = 73\%$$

Duct design

$$\mathrm{Re} = \frac{wd}{\nu}$$

$$\frac{w_s}{w_{\max}} = 0{,}817$$

$$\Delta p = \lambda \frac{l}{d}\frac{w^2}{2}\rho + \sum \zeta \frac{w^2}{2}\rho = K \cdot \dot{V}^2$$

$$K = \left(\frac{\lambda \cdot l}{d} + \sum \zeta\right)\frac{8 \cdot \rho}{\pi^2 \cdot d^4}$$

$$\lambda = \frac{64}{Re}$$ for laminar flow

$$\lambda = f\left(\mathrm{Re}, \varepsilon/d\right)$$ for turbulent flow

$$\lambda \cong 0.02$$ for galvanized steel and fully developed turbulent flow

$$d_h = \frac{4A}{O} = \frac{4ab}{2(a+b)} = \frac{2ab}{a+b}$$

Fans

$$P = \frac{\dot{V}\Delta p}{\eta_{\mathrm{tot}}}$$

$$SFP = \frac{P}{\dot{V}} = \frac{\Delta p}{\eta_{tot}}$$

$$E_{tot} = \int_0^{\tau} P d\tau = \sum_0^n P = \frac{\dot{V}\Delta p}{1000 \cdot \eta_{tot}}\tau = SFP \cdot \dot{V} \cdot \tau$$

$$\Delta p = p_{t2} - p_{t1} = \Delta p_{t1} + \Delta p_{t2} = \Delta p_{l1} + \Delta p_{l2} + p_{d2}$$

$$p_t = p_s + p_d$$

$$p_d = \frac{w^2}{2}\rho$$

Fan laws

$$\dot{V}_2 = \dot{V}_1 \frac{n_2}{n_1}$$

$$\Delta p_2 = \Delta p_1 \left(\frac{n_2}{n_1}\right)^2 \frac{\rho_2}{\rho_1}$$

$$P_2 = P_1 \left(\frac{n_2}{n_1}\right)^3 \frac{\rho_2}{\rho_1}$$

2) Heating

Heating Load

$\dot{q} = -\lambda \cdot \nabla T$ Fourier's law

$$U = \frac{1}{R_{si} + \sum_{n=1}^{m} R_n + R_{se}} = \frac{1}{R_{si} + \sum_{n=1}^{m} \frac{\delta_n}{\lambda_n} + R_{se}}$$ heat transfer coefficient for all external walls

$$B' = \frac{A_g}{0,5 \cdot P}, \quad d_t = w + \lambda_{ground} \cdot \left(\mathrm{R_{si}} + \mathrm{R_f} + \mathrm{R_{se}}\right)$$

$$d_t \geq B' \Rightarrow U = \frac{\lambda_{\mathrm{ground}}}{0,457 \cdot B' + d_t}$$ heat transfer coefficient of ground

$$\Phi_{\mathrm{T,i}} \approx \left(H_{\mathrm{T,ie}} + \sum H_{\mathrm{T,ia(...)}} + H_{\mathrm{T,ig}}\right) \cdot \left(\theta_{\mathrm{int,i}} - \theta_{\mathrm{e}}\right)$$ total heat load for heated space

$$H_{\mathrm{T,ie}} = \sum_k \left[A_{\mathrm{k}} \cdot \left(U_{\mathrm{k}} + \Delta U_{\mathrm{TB}}\right) \cdot f_{\mathrm{U,k}} \cdot f_{\mathrm{ie,k}}\right]$$

$$H_{T,ia(...),k} = \sum_k (A_k \cdot U_k \cdot f_{ia(...),k})$$

$$H_{T,g} = \left[A_{floor} \cdot \left(U_g\right) + O_g \cdot \left(\Psi_g\right)\right] \cdot G_w$$

$$\Phi_{V,i} = \rho \cdot c_p \cdot q_{V,\min,i} \cdot \left(\theta_{\mathrm{int},i} - \theta_e\right)$$

$$q_{V,\min,i} = n_{\min,i} \cdot V_i$$

Heating Surfaces

$$\dot{Q} = \dot{m} \cdot c \cdot (t_{w1} - t_{w2})$$

$$\frac{Q_{REAL}}{Q_{NOMINAL}} = \frac{k \cdot S_L \cdot \left(t_{wm} - t_i\right)}{k_N \cdot S_{LN} \cdot \left(t_{wmN} - t_{iN}\right)} \approx \left[\frac{t_{wm} - t_i}{t_{wmN} - t_{iN}}\right]^n = \left[\frac{(\Delta t) sk}{(\Delta t)_N}\right]^n$$

$$c = \frac{t_{w2} - t_i}{t_{w1} - t_i}$$

$$c \geq 0,7 \Rightarrow \Delta t = \frac{t_{w1} + t_{w2}}{2} - t_i$$

$$c < 0,7 \Rightarrow \Delta t_{\ln} = \frac{t_{w1} - t_{w2}}{\ln \frac{t_{w1} - t_i}{t_{w2} - t_i}}$$

Heating Systems

$$k_v = \dot{V} \cdot \sqrt{\frac{100}{\Delta p_{Valve}}} \cdot \sqrt{\frac{\rho}{1000}} \Rightarrow \Delta p_{Valve} = \left(\frac{\dot{V}}{k_v}\right)^2 \cdot \frac{\rho}{10}$$ Kv value

$$\dot{Q} = \dot{m} \cdot c \cdot (t_{w1} - t_{w2}) \Rightarrow \dot{m} = \frac{\dot{Q}}{c \cdot (t_{w1} - t_{w2})}$$

$$\dot{m} = \dot{V} \cdot \rho = S \cdot w_{opt} \cdot \rho = \frac{\pi \cdot d_{opt}^{\ 2}}{4} \cdot w_{opt} \cdot \rho \Rightarrow d_{opt} = \sqrt{\frac{4 \cdot \dot{m}}{\pi \cdot \rho \cdot w_{opt}}}$$

$$V_{EV} = 1{,}3 \cdot V_o \cdot n \cdot \frac{1}{\eta}$$ Expansion Vessel

Heating Source

$$\eta_k = \frac{\text{Performance}}{\text{Power Consumption}} = \frac{Q_{EXIT}}{Q_{INPUT}}$$ direct method

$$\eta_k = 100 - \sum Z_i$$ indirect method

$$\text{Coefficient of performance (COP)} = \frac{\text{What we want}}{\text{What we pay}}$$ for heat pumps

Hot Water Preparation

$$Q_{HW} = Q_{HWt} + Q_{HWz} = (1+z) \cdot Q_{HWt} = \frac{(1+z) \cdot V_{HW} \cdot \rho \cdot c \cdot (t_2 - t_1)}{3600 \cdot 1000}$$

$$O_{HW,\text{tank}} = \frac{\Delta Q_{\max}}{c^* \cdot (t_2 - t_1)}$$

$$P_{HW} = \left(\frac{\Delta Q_{s,i}}{\tau_i}\right)_{\max}$$