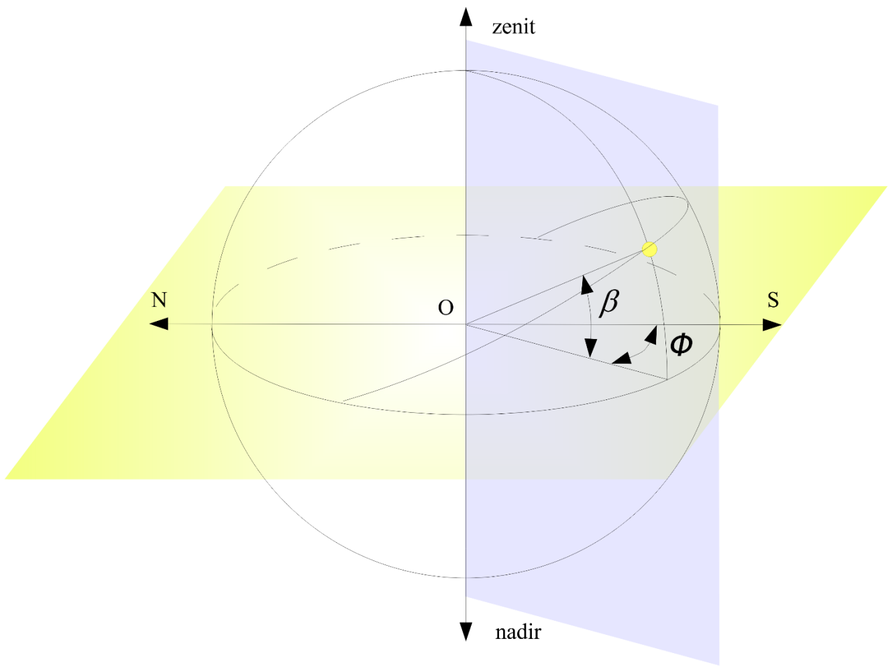
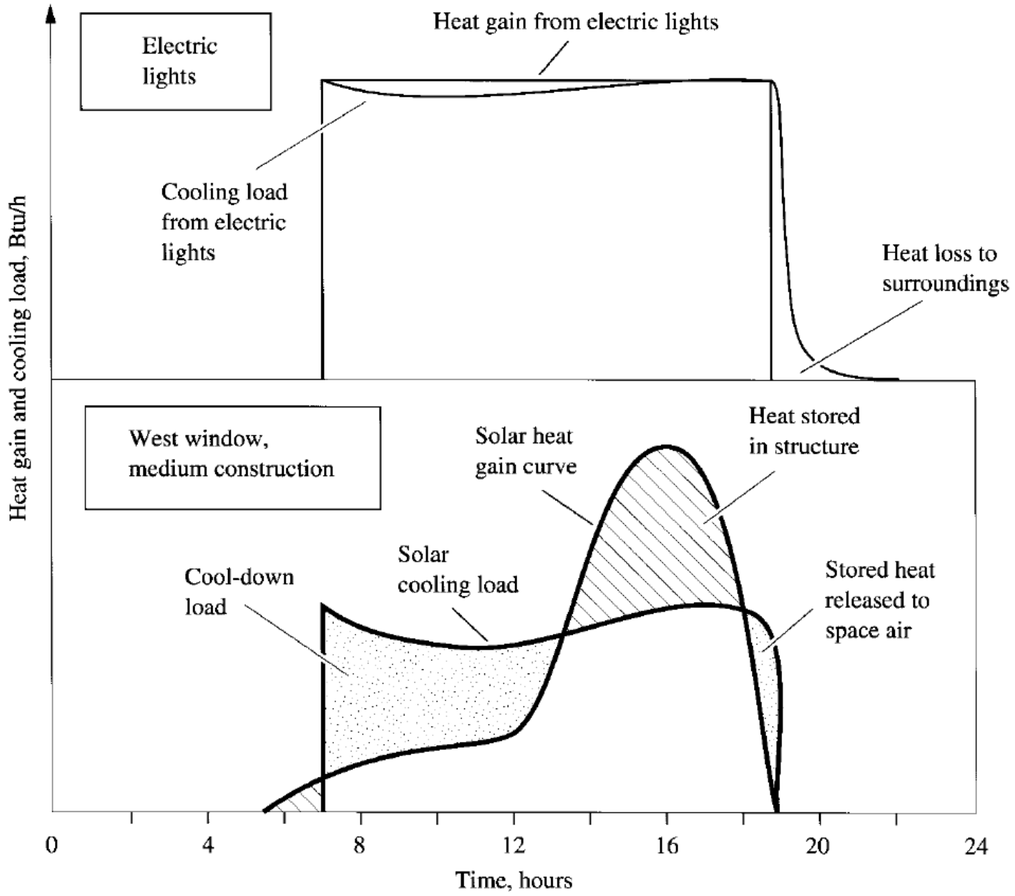
BUILDINGS HVAC SYSTEM
Solar Angles

Solar angles, horizontal coordinates

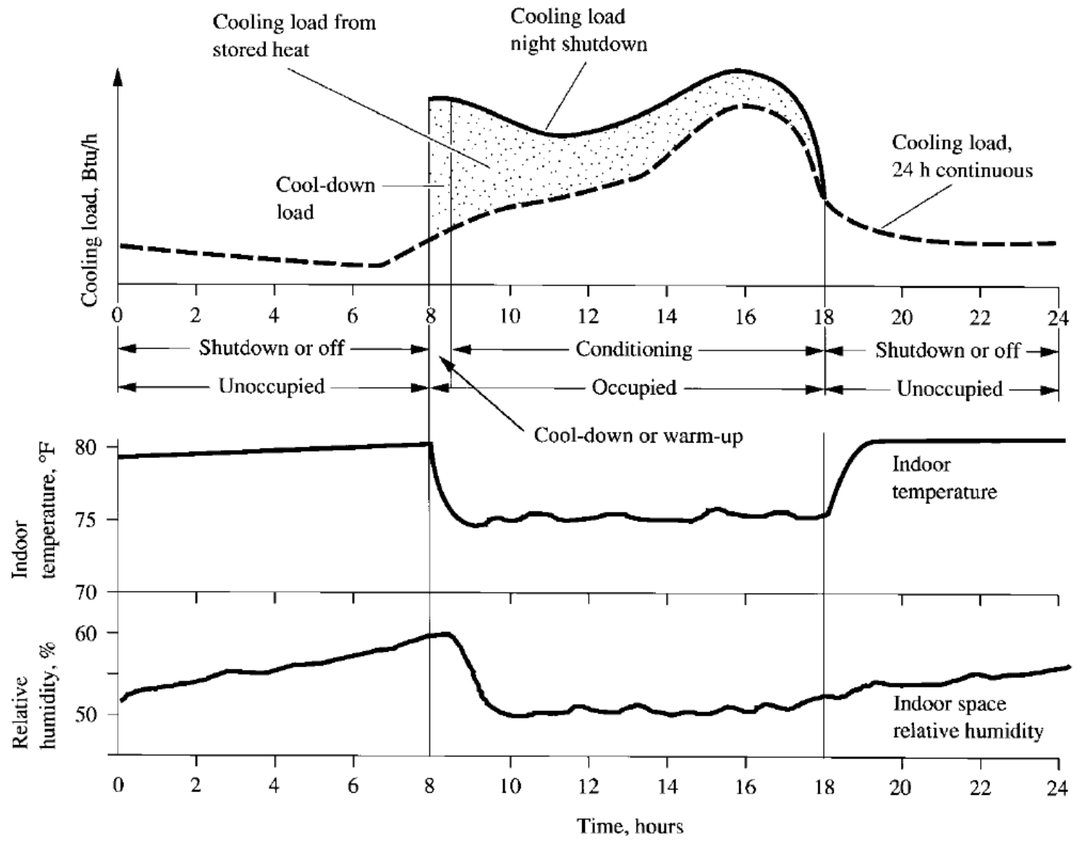
- The reference is the observation horizontal plan
- We identify the solar angles
- θ_z : zenith angle
- β : solar height
- ϕ: solar azimuth, positive in west direction



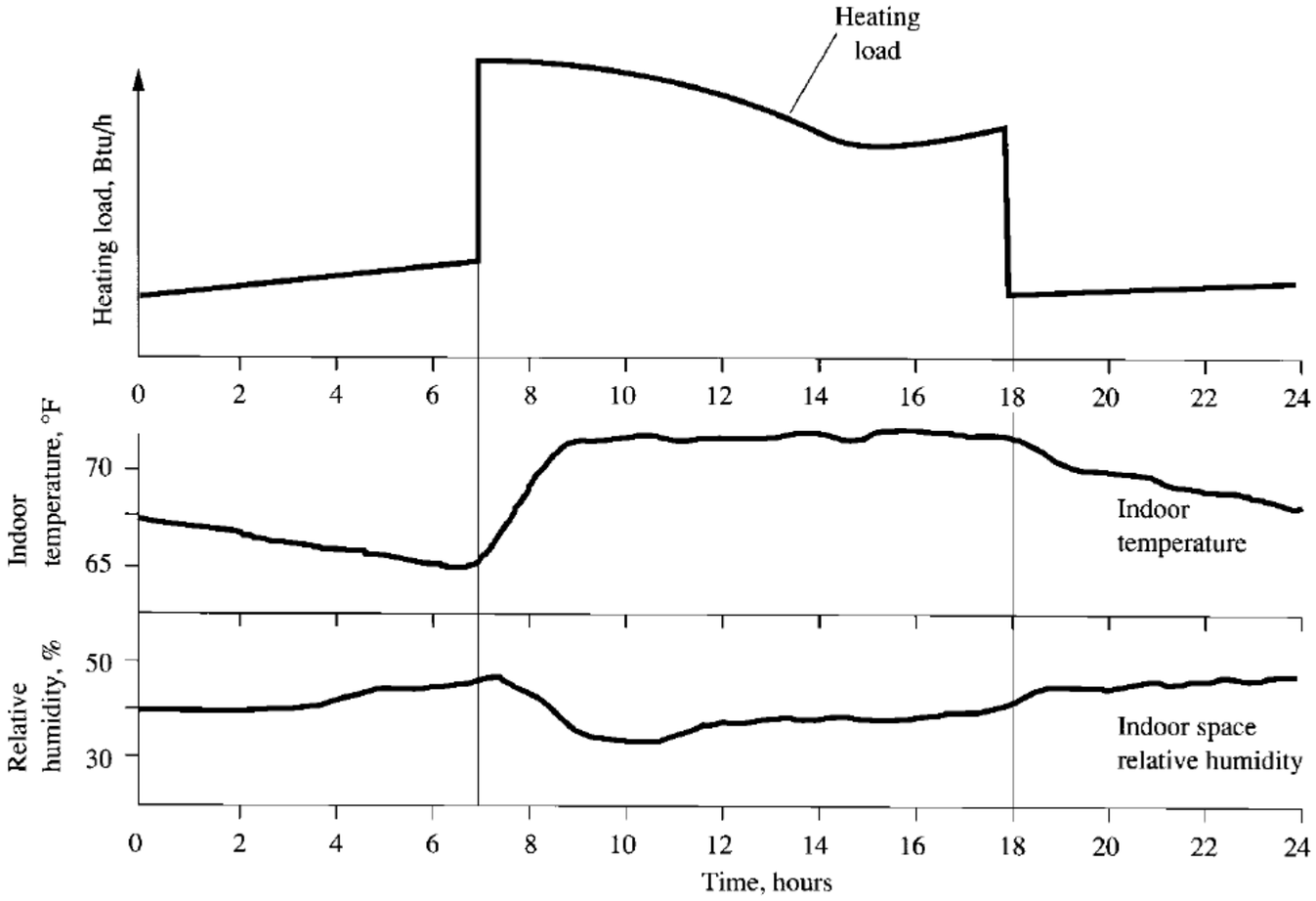
Heat Gains and Cooling Loads



Summer operation



Winter operation



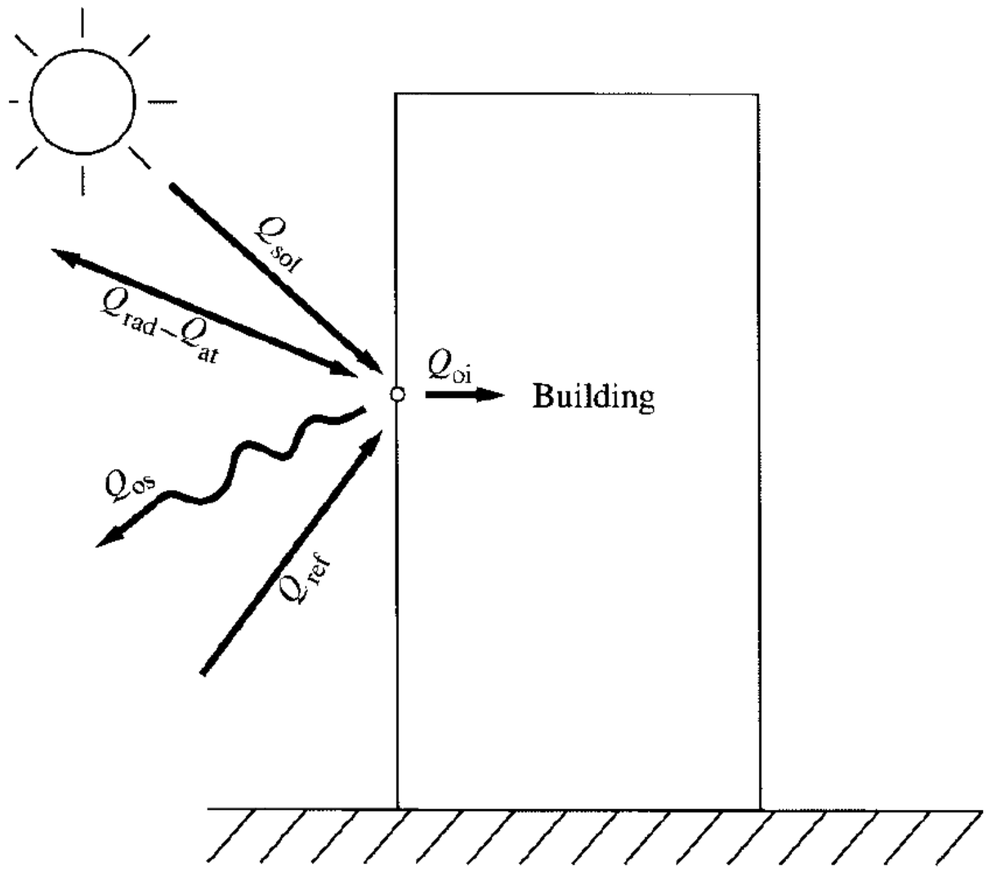
Surface Balance

$$Q_{sol} + Q_{ref} = Q_{os} + (Q_{rad} - Q_{at}) + Q_{oi}$$

$$Q_{sol} = \alpha \cdot [A_s \cdot (I_D + I_d) + A_{sh} \cdot I_d]$$

$$Q_{ref} = A \cdot \alpha_{os} \cdot I_{ref}$$

$$Q_{os} = h_c \cdot A \cdot (T_{os} - T_o)$$



Sol-Air Temperature

- Q_{ref} offset by $Q_{rad} - Q_{at}$

$$Q_{sol} + Q_{ref} = Q_{os} + (Q_{rad} - Q_{at}) + Q_{oi}$$

$$Q_{sol} = Q_{os} + Q_{oi}$$

$$Q_{oi} = h_o \cdot A \cdot (T_{sol} - T_{os})$$

$$\alpha_{os} \cdot I_t = h_o \cdot (T_{os} - T_o) + h_o \cdot (T_{sol} - T_{os})$$

- Sol-air temperature

$$T_{sol} = T_o + \frac{\alpha_{os} \cdot I_t}{h_o}$$

Heat Balance Equation

- For a surface a heat balancing equation can be written

$$q_{i,t} = [h_{ci}(T_{r,t} - T_{i,t}) + \sum_{j=1}^{k} h_{ij}(T_{j,t} - T_{i,t})A_i + S_{ir,t} + L_{ir,t} + E_{ir,t} + O_{ir,t}$$

- h_{ci}convective heat transfer surface *i*
- h_{ij} radiative heat transfer
- $T_{r,t}$ room temperature
- $T_{i,t}$ *i*th surface temperature
- $T_{j,t}$ *j*th surface temperature
- $S_{ir,t}$ solar radiation
- $L_{ir,t}$ electric lights
- $E_{ir,t}$ radiative energy from equipment absorbed *ith surface*
- $O_{ir,t}$ radiation from occupants absorbed on the surface

sensible cooling load

$$Q_{rs,t} = \sum_{i}^{m} h_{ci}\left(T_{r,t} - T_{i,t}\right)A_i \; + \dot{V}_{if}\rho c_{pa}\left(T_{o,t} - T_{r,t}\right) + S_{c,t} \; + L_{c,t} + E_{c,t} + O_{c,t}$$

- h_{ci}convective heat transfer surface *i*
- $\dot{V}_{if}$ volumetric flow rate infiltration
- $T_{o,t}$ outdoor temperature
- $S_{c,t}$ solar radiation from windows
- $L_{c,t}$ electric lights
- $E_{c,t}$ convective energy from equipment absorbed *ith surface*
- $O_{c,t}$ sensible heat from occupants

Heat Balance Method

- Impossible to solve equations without computer
- Different methods developed
  - Transfer function method
  - Radiant time series
  - Finite difference
  - CLTD/SCL/CLF Method, cooling load temperature difference
  - TETD/TA Method total eqivalent temperature difference
- CLTD/SCL/CLF Method
  - CLTD: Cooling Load Temperature Difference
  - SCL: Solar Cooling Load
  - CLF: Cooling Load Factor

CLTD

- Space sensible cooling load

$$Q_{rs,w} = U \cdot A \cdot CLTD$$

- *U* overall heat-transfer coefficient
- *A* area of exterior wall, roof, or window
- *CLTD* cooling load temperature difference (usually in °F)
- *CLTD* tables reported for specific conditions
- Possible correction for different temperatures

$$CLTD_{corr} = CLTD + 78 - T_r + T_{om} - 85$$

Space Cooling due to Fenestration

- The data is split according to the exposition of the window

$$Q_{rs,s} = Q_{sun} + Q_{sh} = A_s \cdot SCL_s \cdot SC + A_{sh} \cdot SCL_{sh} \cdot SC$$

Q_{sun} space cooling load from solar heat gain through sunlit area of window glass

Q_{sh} space cooling load from solar heat gain through shaded area of window glass

A_s, A_sh sunlit and shaded area

SC shading coefficient

SCL_s solar cooling load for sunlit glass facing specific direction

SCL_{sh} solar cooling load for shaded area as if glass is facing north

Internal Cooling Loads

- Sensible internal heat hain contains the radiative component and is multiplied by a factor

$$Q_{int,s} = q_{int,s} \cdot CLF_{int}$$