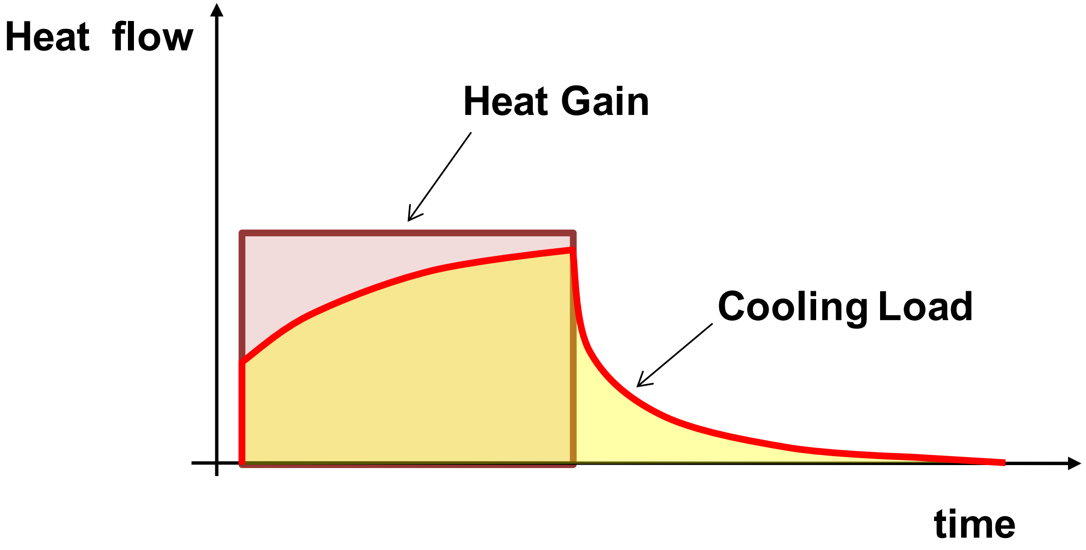
# Simplified dynamic calculation methods: cooling load, method of the equivalent temperature, overview on the quasi-steady state method, schematic of cooling systems

# Heat gain and cooling load

These models are based on the shift in time of the heat gain which occurs in a certain time step due to the thermal inertial of the building structures.

The cooling load is the effective load considering the effect of the building structures in terms of thermal inertia as storage and later released of the thermal energy embedded in the structures



# Method based on equivalent difference temperature

For each hour of the day, the following equation can be written:

$$q_p = q_g + q_{d,window} + q_{d,opaque} + q_s + q_{IG} + q_{inf}$$

- $q_g$: convective heat flow due to the incoming and outgoing air rates in the room
- $q_{d,window} + q_{d,opaque}$: conduction heat flow
- $q_s$: solar radiation
- $q_{IG}$: Internal gains
- $q_{inf}$: Infiltration gains

Ventilation gain:

$$q_g = G_a\, c_p\, (t_{imm} - t_i)$$

Infiltration gain:

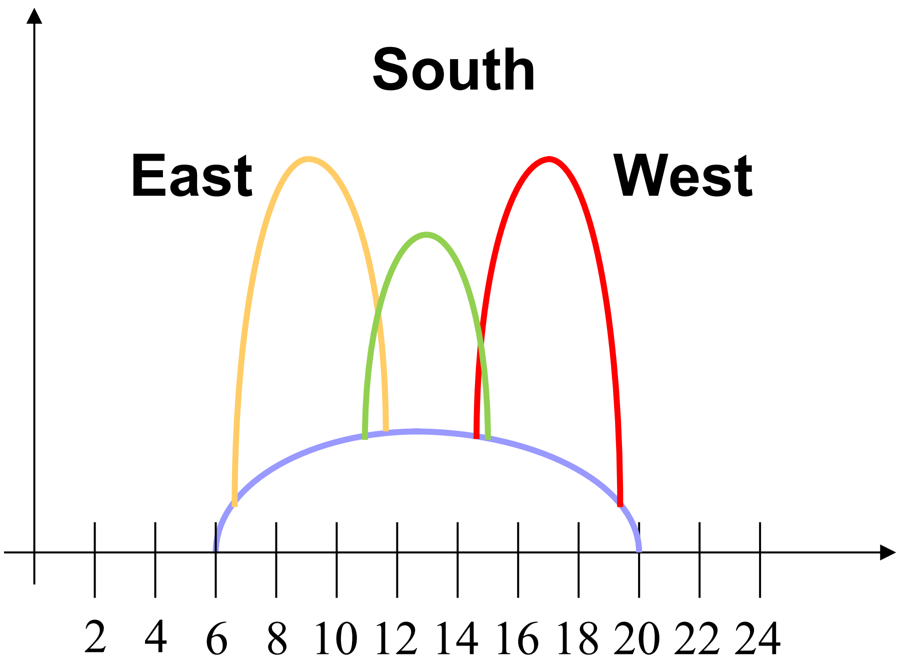
$$q_{inf} = G_a\, c_p\, (t_e - t_i)$$

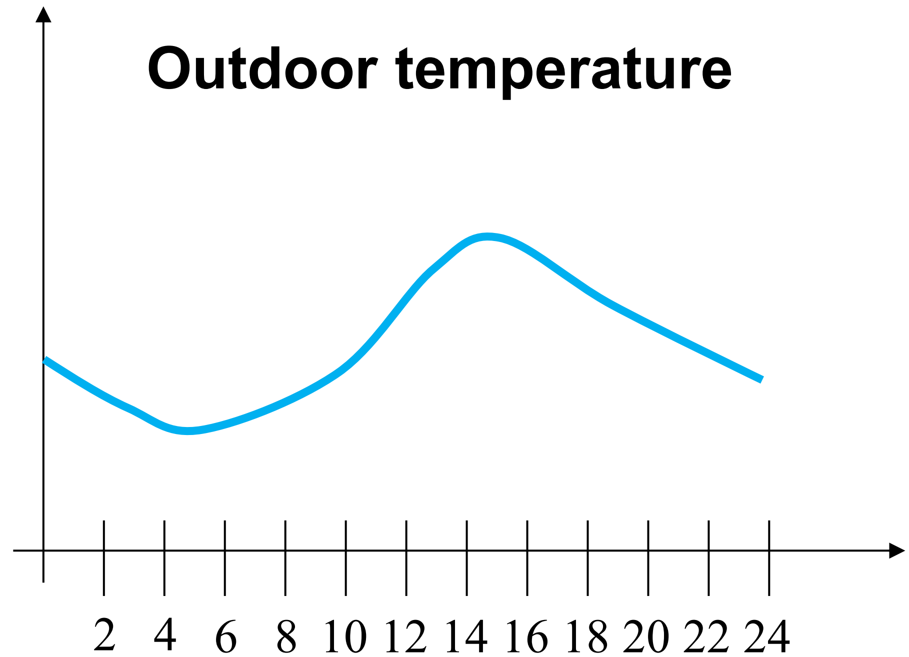
Windows are supposed to have no capacity:

$$q_{d,window} = \sum_{k=1}^{f} U_k S_k (t_e - t_i)$$

# Cooling load of opaque structures

# Solicitation: sol-air temperature



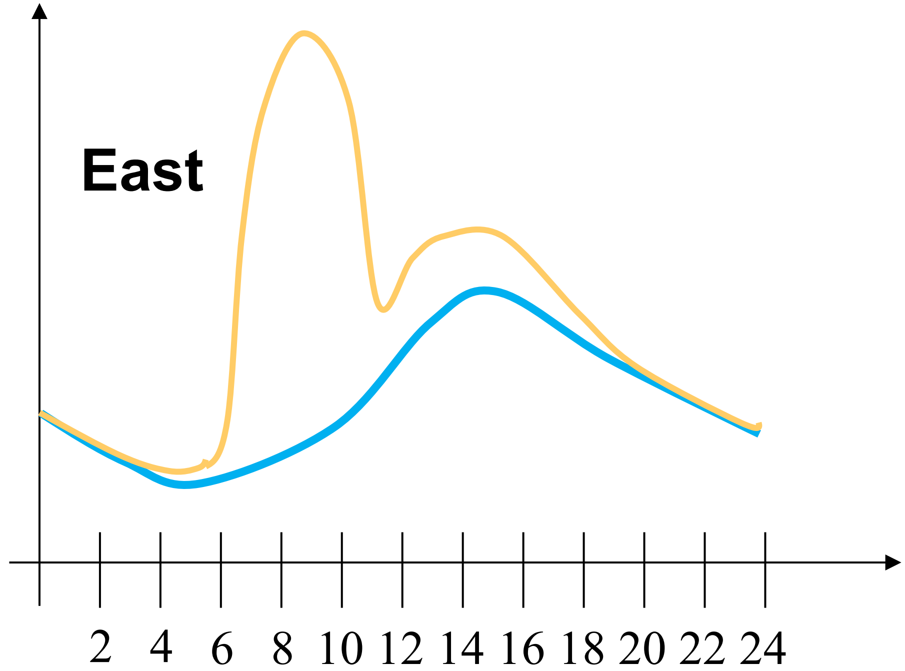



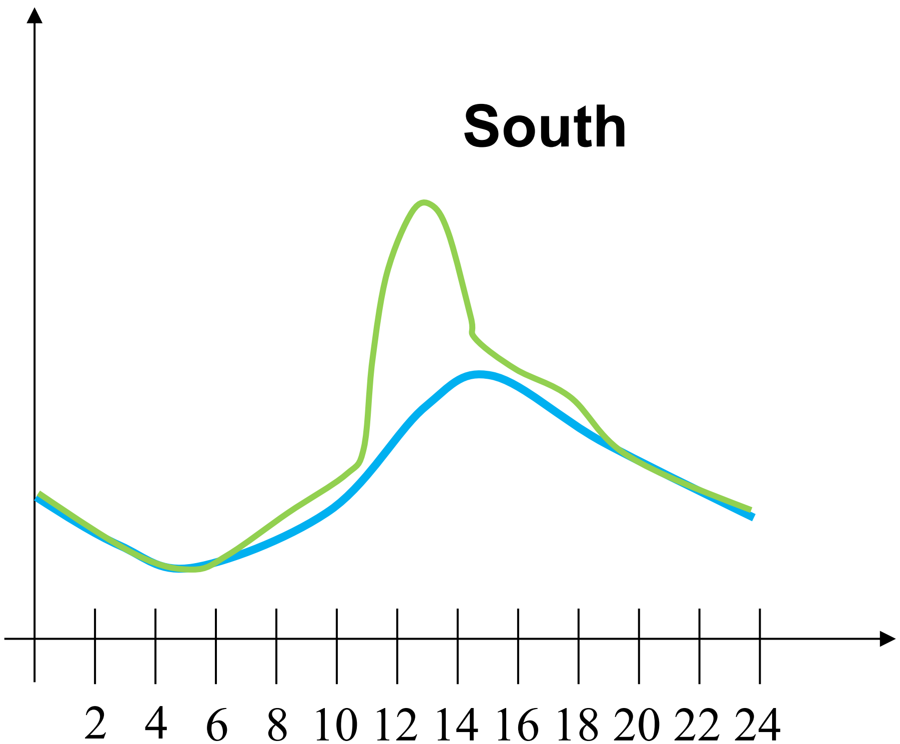

**Solar radiation in the different orientations (clear sky coinditions)**

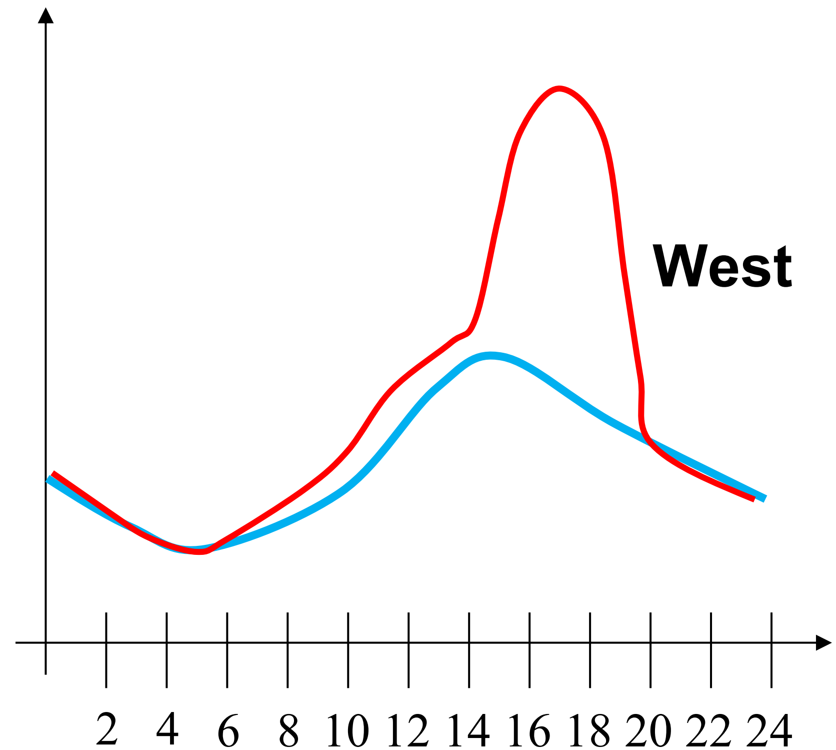
**Outdoor air temperature**

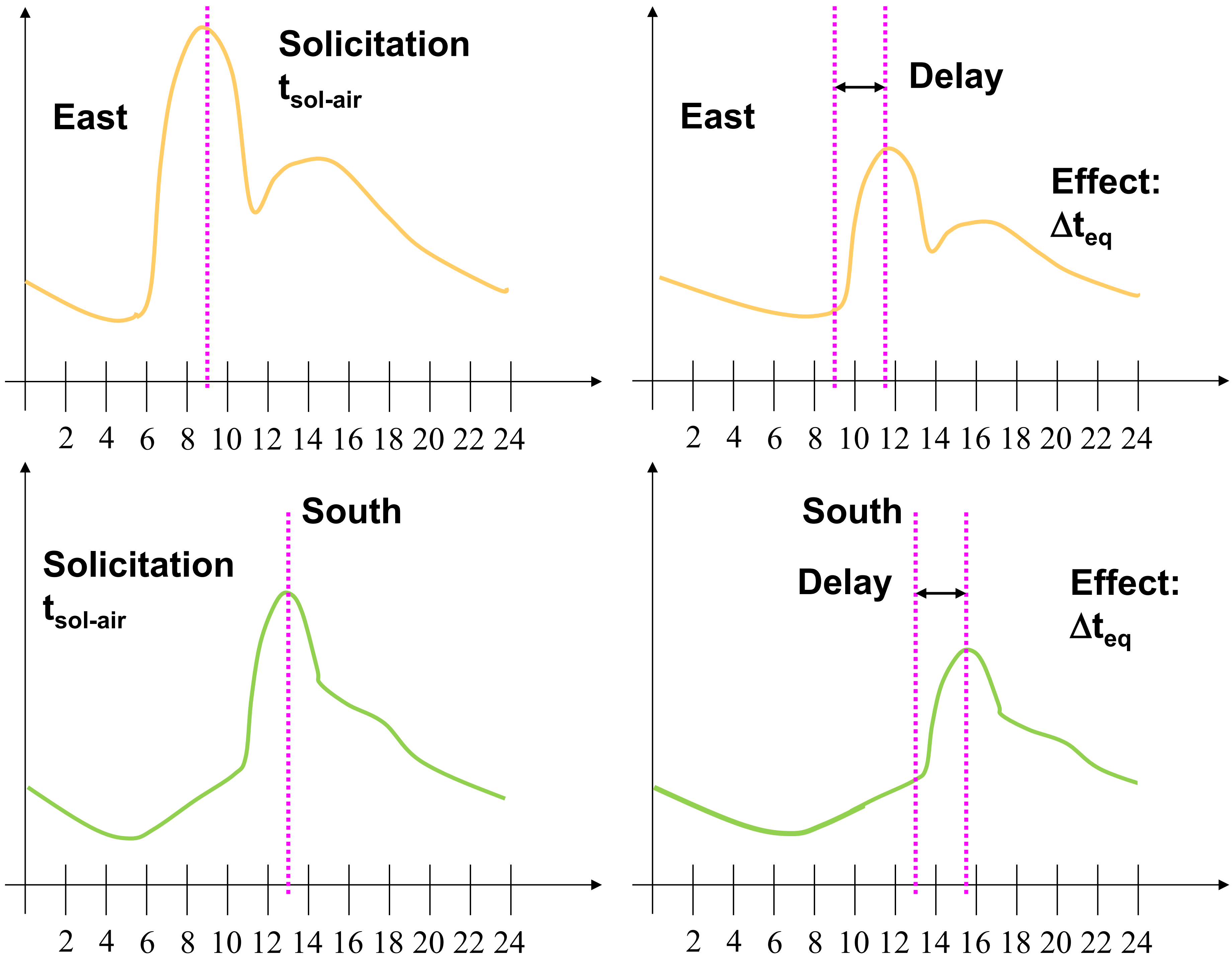
## Sol-air temperature:

$$t_{sol\text{-}air} = t_a + a \cdot I \cdot f_h / h_c$$

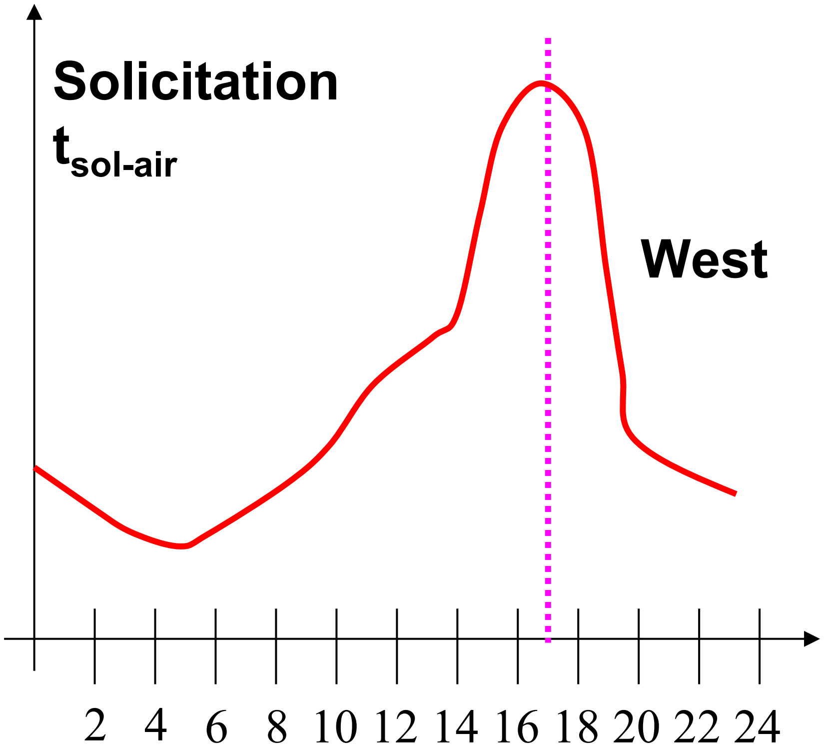


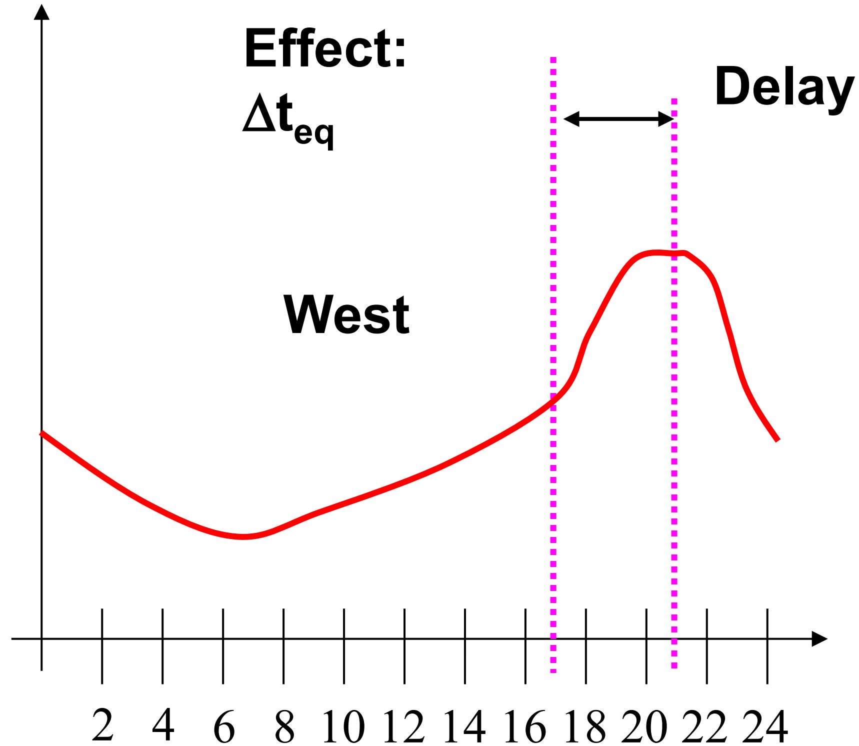





East
Solicitation
$t_{sol-air}$
2 4 6 8 10 12 14 16 18 20 22 24
East
Delay
Effect:
$\Delta t_{eq}$
2 4 6 8 10 12 14 16 18 20 22 24
South
Solicitation
$t_{sol-air}$
2 4 6 8 10 12 14 16 18 20 22 24
South
Delay
Effect:
$\Delta t_{eq}$
2 4 6 8 10 12 14 16 18 20 22 24



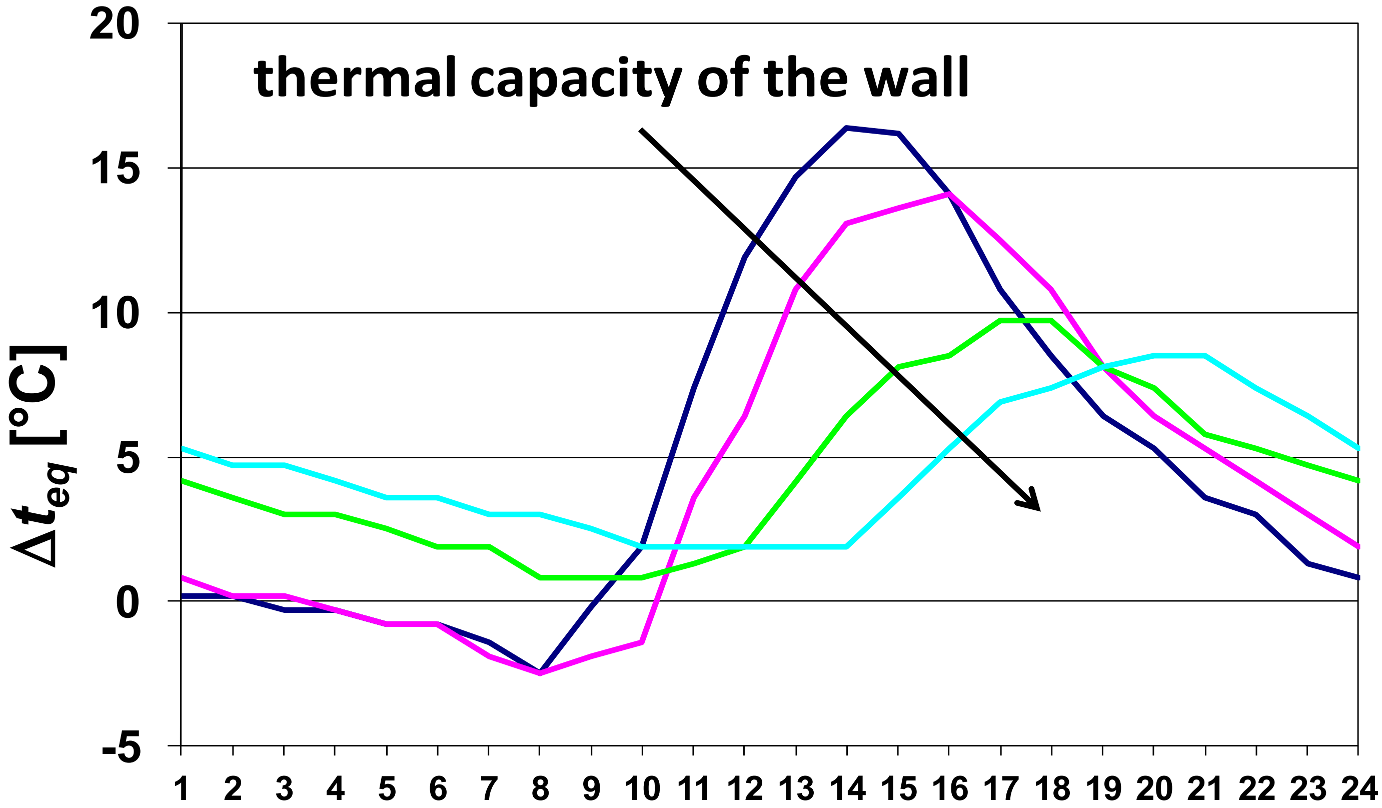




Depending on the orientation and colour of the wall, on the hour of the day and on the specific mass of the wall per surface area ($m_f$):

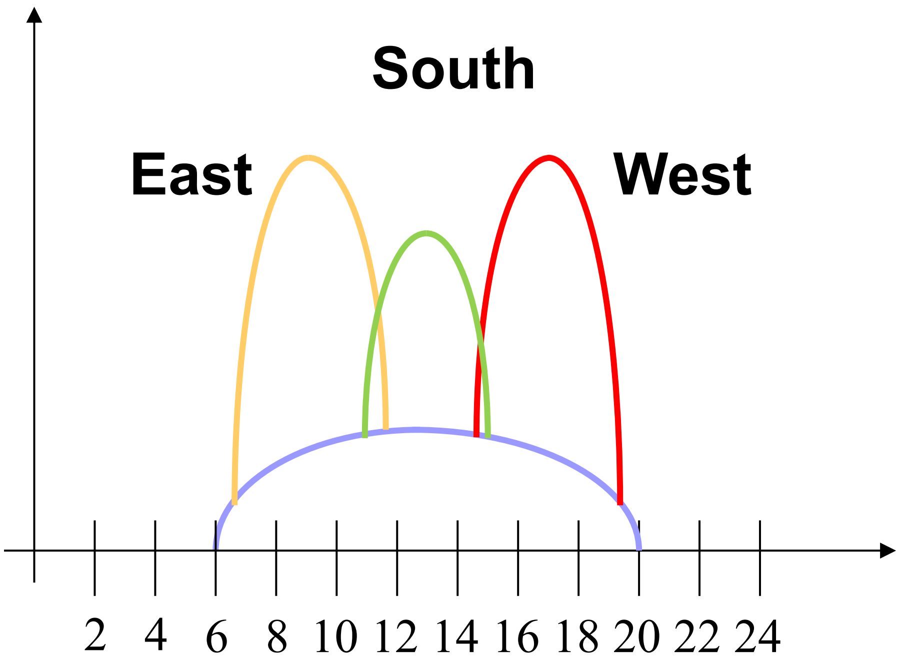
$$q_{d,opaque} = \sum_{i=1}^{o} U_i S_i \Delta t_{eq,i}$$

$$m_f = \sum_{q} \rho_q s_q$$

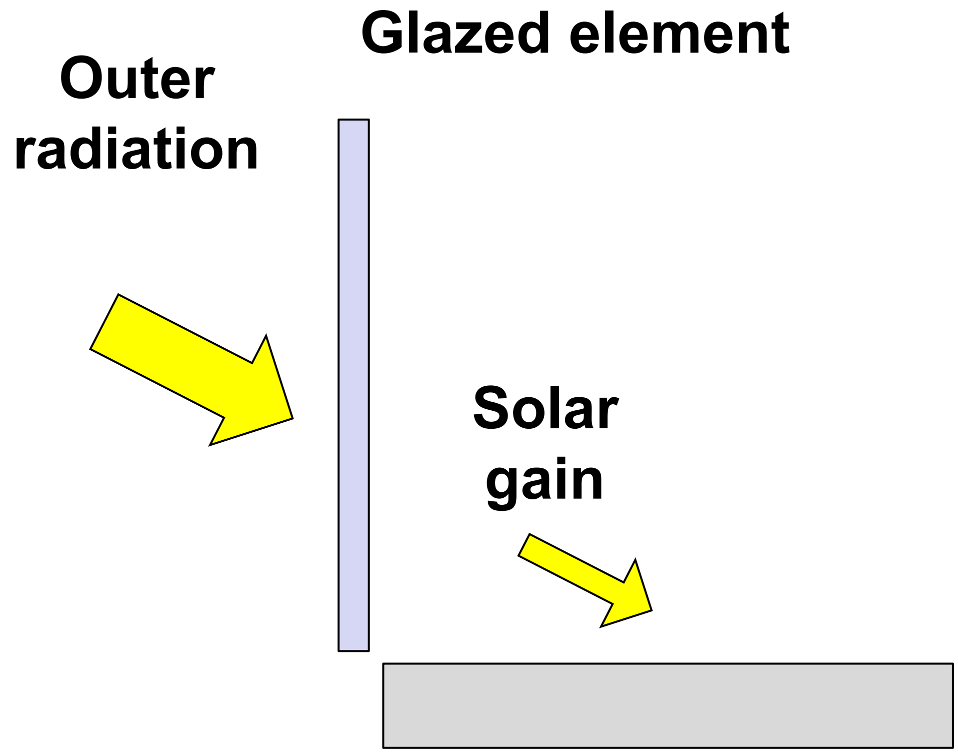
The $\Delta t_{eq,i}$ is the equivalent temperature difference and it includes the sol-air temperature and the shift in time of the thermal capacity of the wall



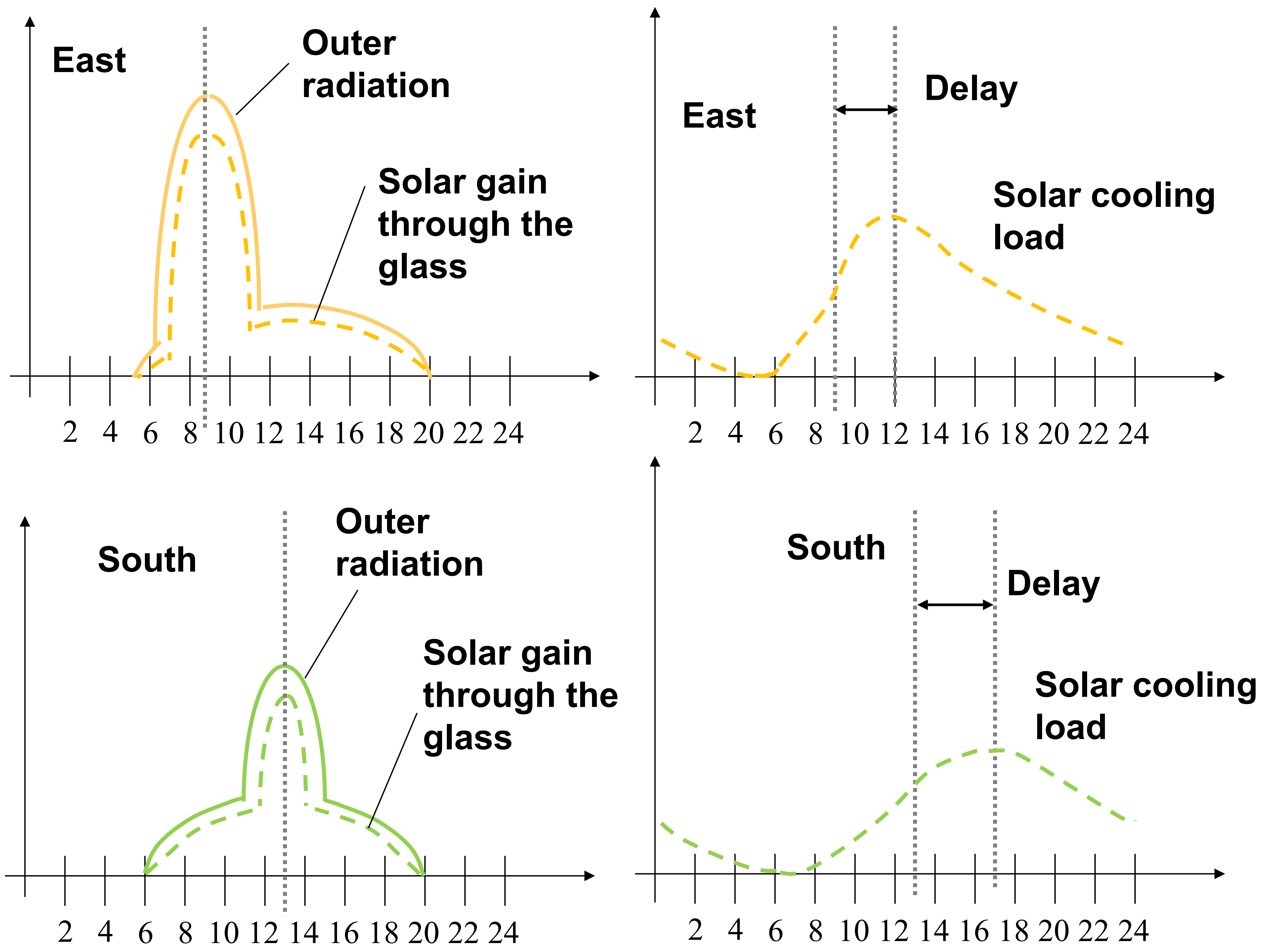
# Solar cooling load from glazed elements

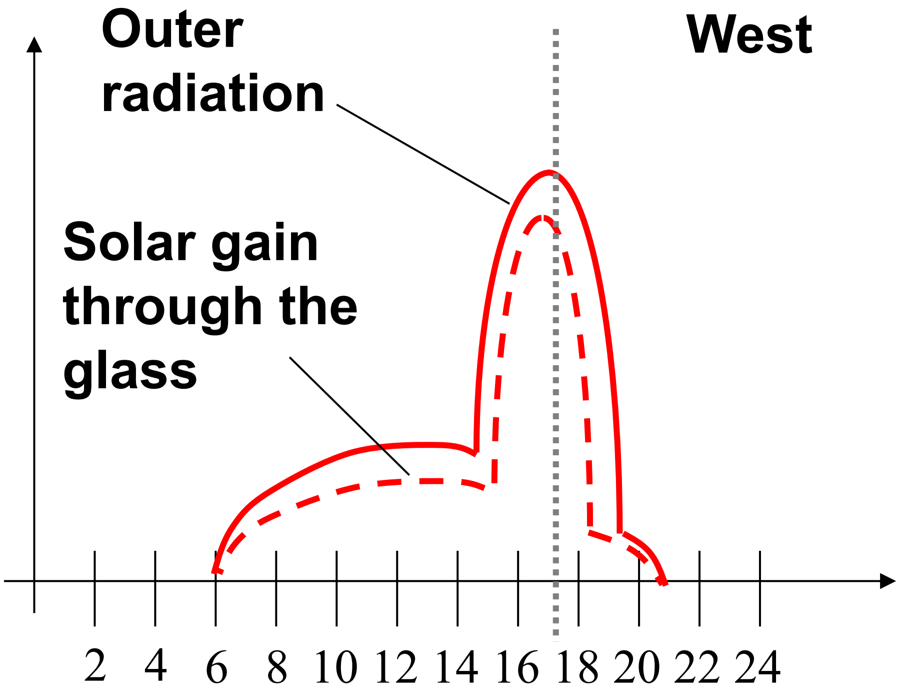



Solar radiation in the different orientations (clear sky coinditions)

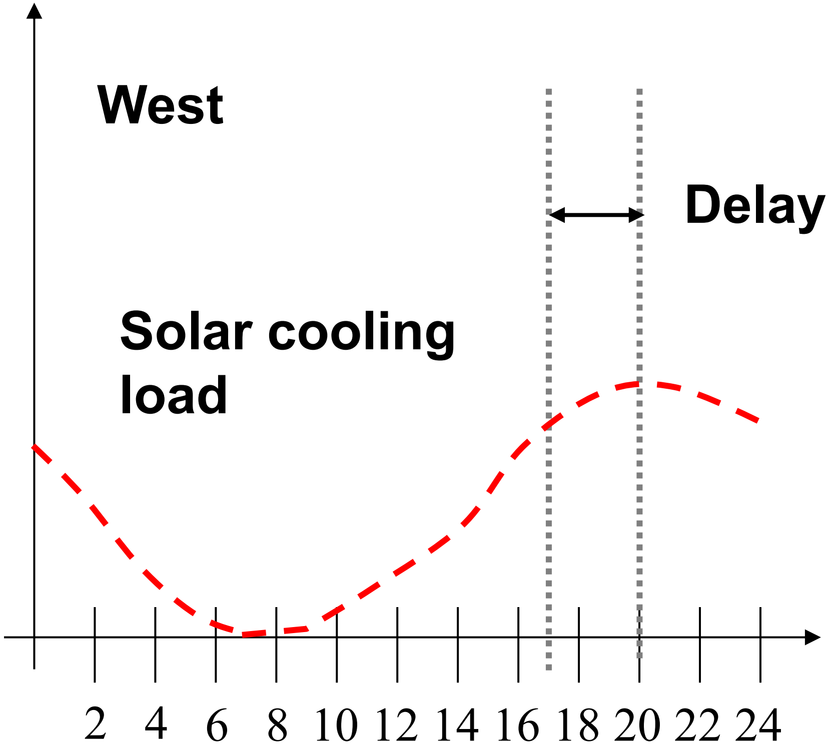



Thermal inertia of the room


East
Outer radiation
Solar gain through the glass
2 4 6 8 10 12 14 16 18 20 22 24
East
Delay
Solar cooling load
2 4 6 8 10 12 14 16 18 20 22 24
South
Outer radiation
Solar gain through the glass
2 4 6 8 10 12 14 16 18 20 22 24
South
Delay
Solar cooling load
2 4 6 8 10 12 14 16 18 20 22 24



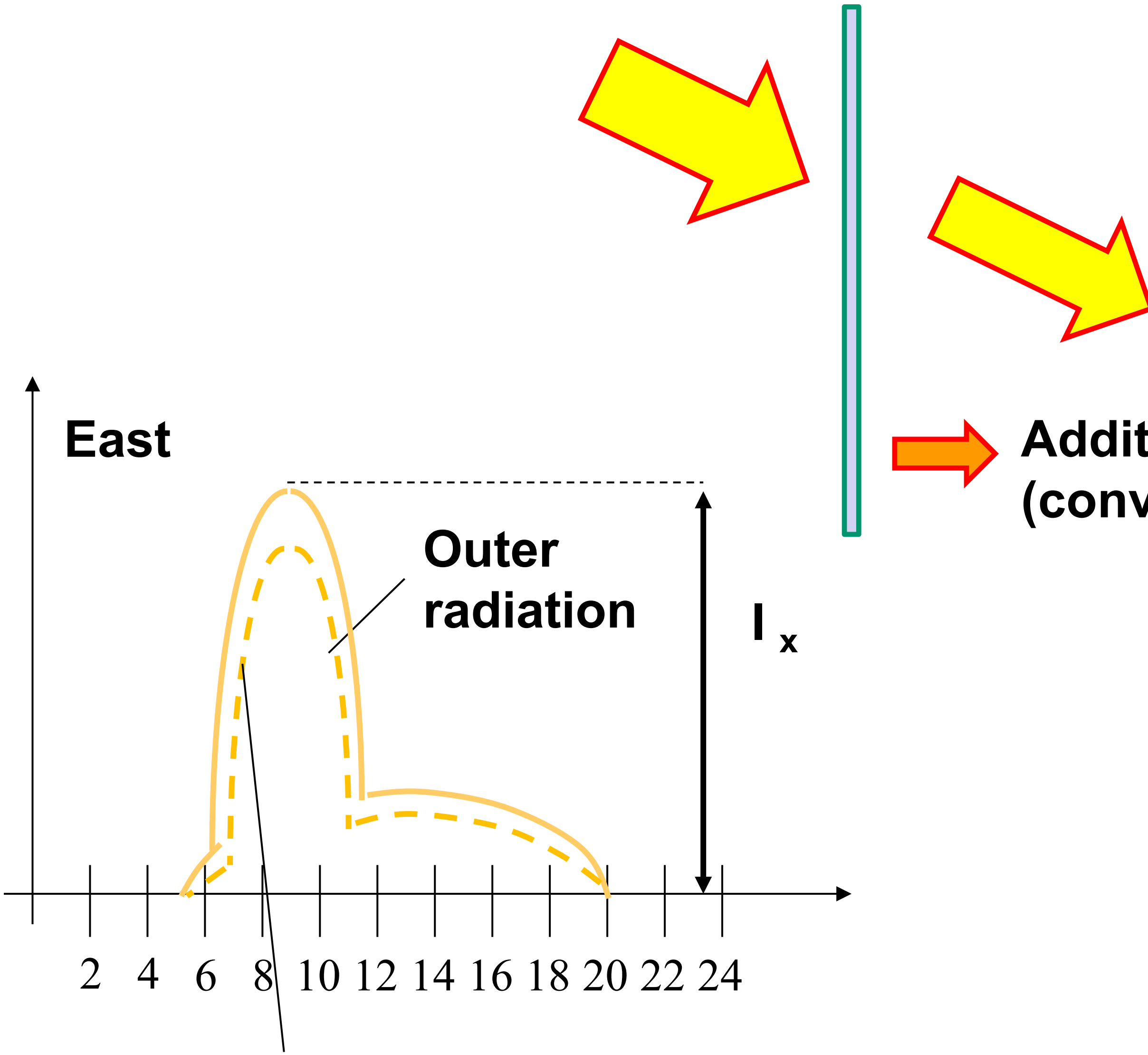
Outer radiation
West
Solar gain through the glass
2 4 6 8 10 12 14 16 18 20 22 24

West
Delay
Solar cooling load
2 4 6 8 10 12 14 16 18 20 22 24

**It is the ratio between the solar factor of the analyzed glass and solar factor of a reference one (clear glass, 3 mm):**

$$C_s = \frac{I_{gl}}{I_{ref,gl}}$$

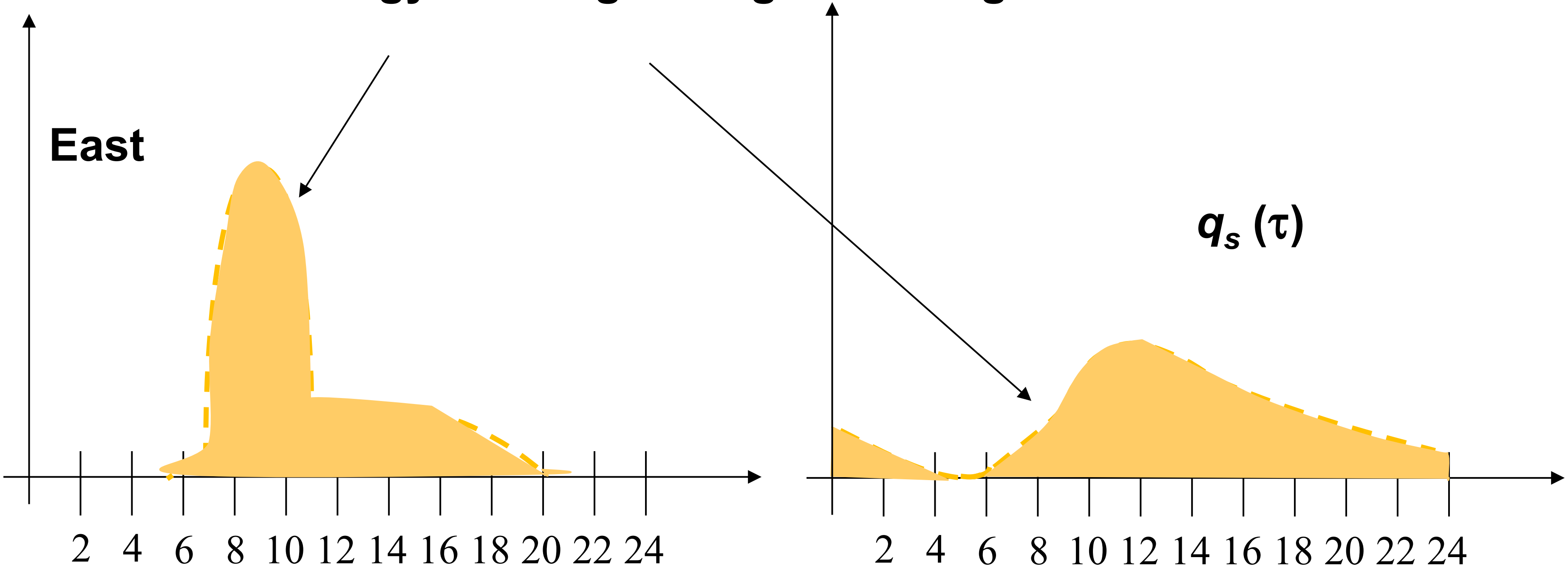



**Transmitted**

**Additional indirect load (convection + radiation)**

**Solar radiation through the reference glass Cs = 1**

**Same energy entering through 1 m² of glazed area**




**Solar cooling load ($q_s$): evaluated for each orientation as a function of the thermal inertia of the room (hour by hour).**

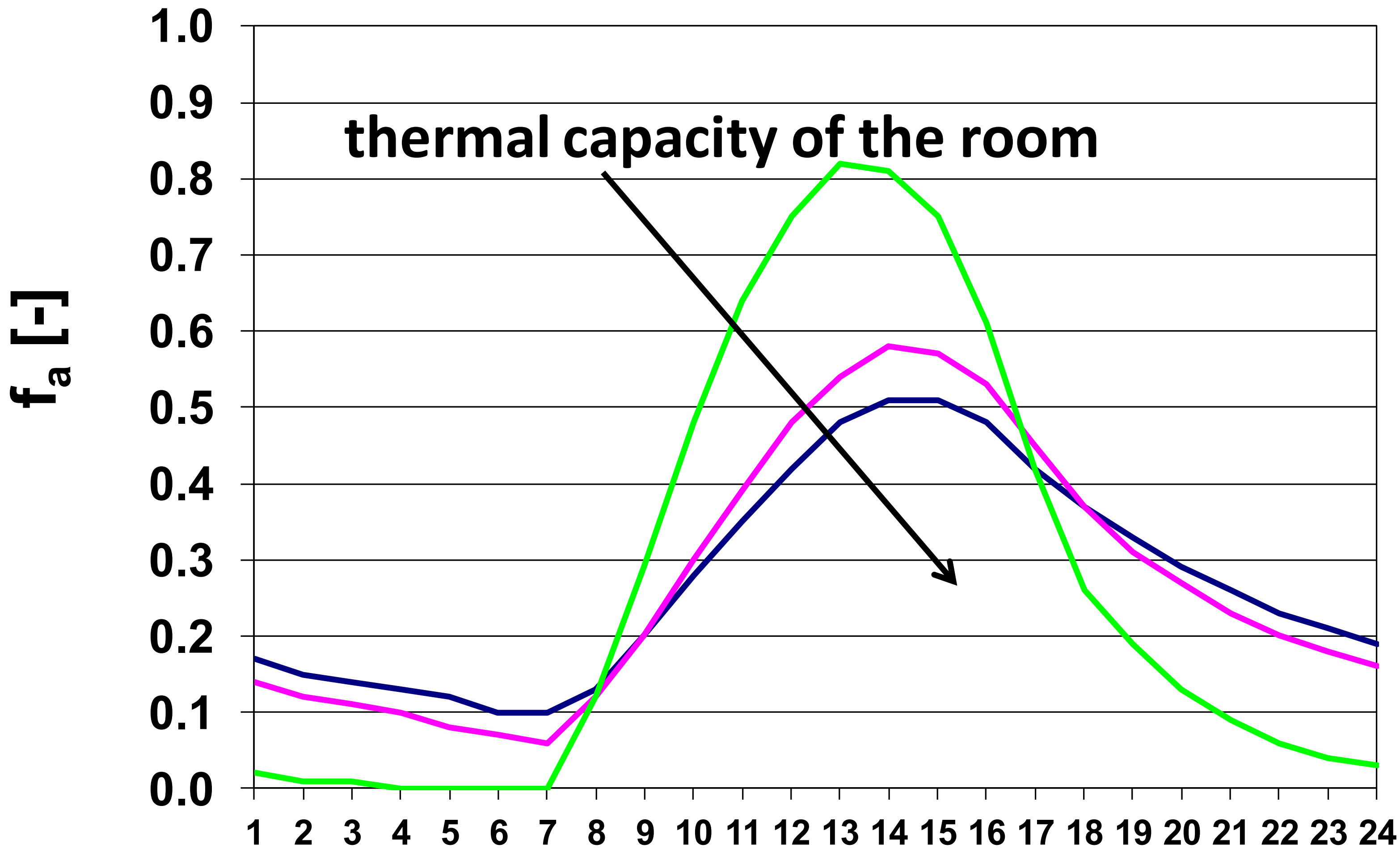
**Attenuation factor:** $f_a(\tau) = \dfrac{q_s(\tau)}{I_x}$ → **Referred to the maximum incident solar radiation for the considered orientation**

**Considering the area of the glass and the actual characteristics of the glass (Cs):**

$$q_s(\tau) = S\, I_x\, f_a(\tau)\, C_s$$

The effect of solar radiation through glazing components:

$$q_s = \sum_{k=1}^{f} S_k I_{x,k} f_{a,k} C_{s,k}$$



The thermal capacity of the room $M_R$ is calculated as:

$$M_R = \frac{\sum_j m_{f,j} S_j + 0.5 \cdot \sum_r m_{f,r} S_r}{S_f}$$

$S_f$ → Floor area

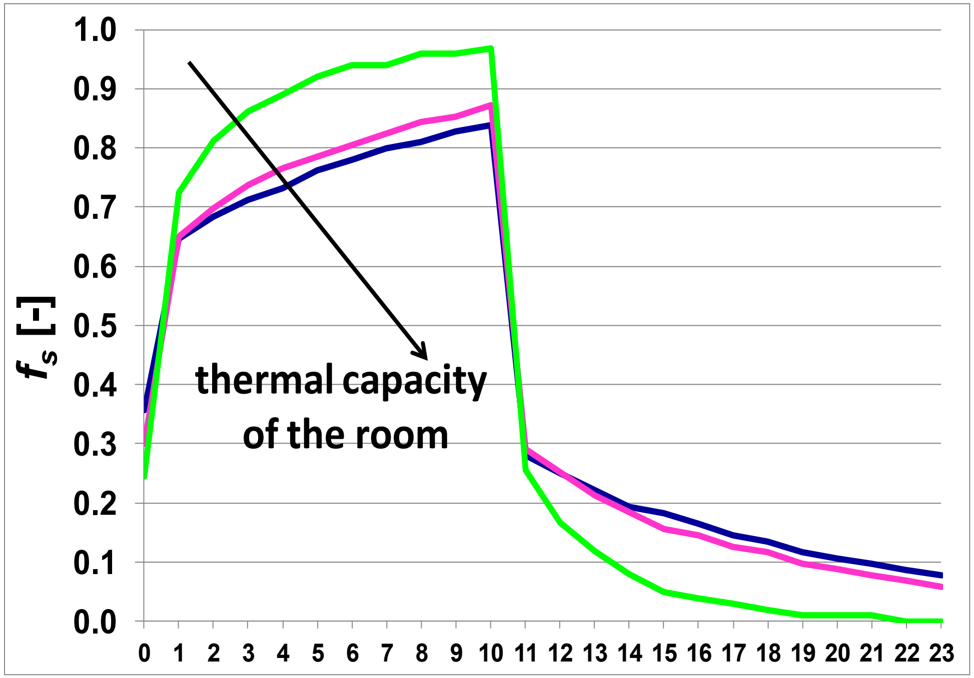
The thermal inertia of the *j*-th generic wall facing outside has to be considered as a whole, while the *r*-th internal wall is counted for half of the thermal capacity

Internal gains:

convective and radiant gains are considered together

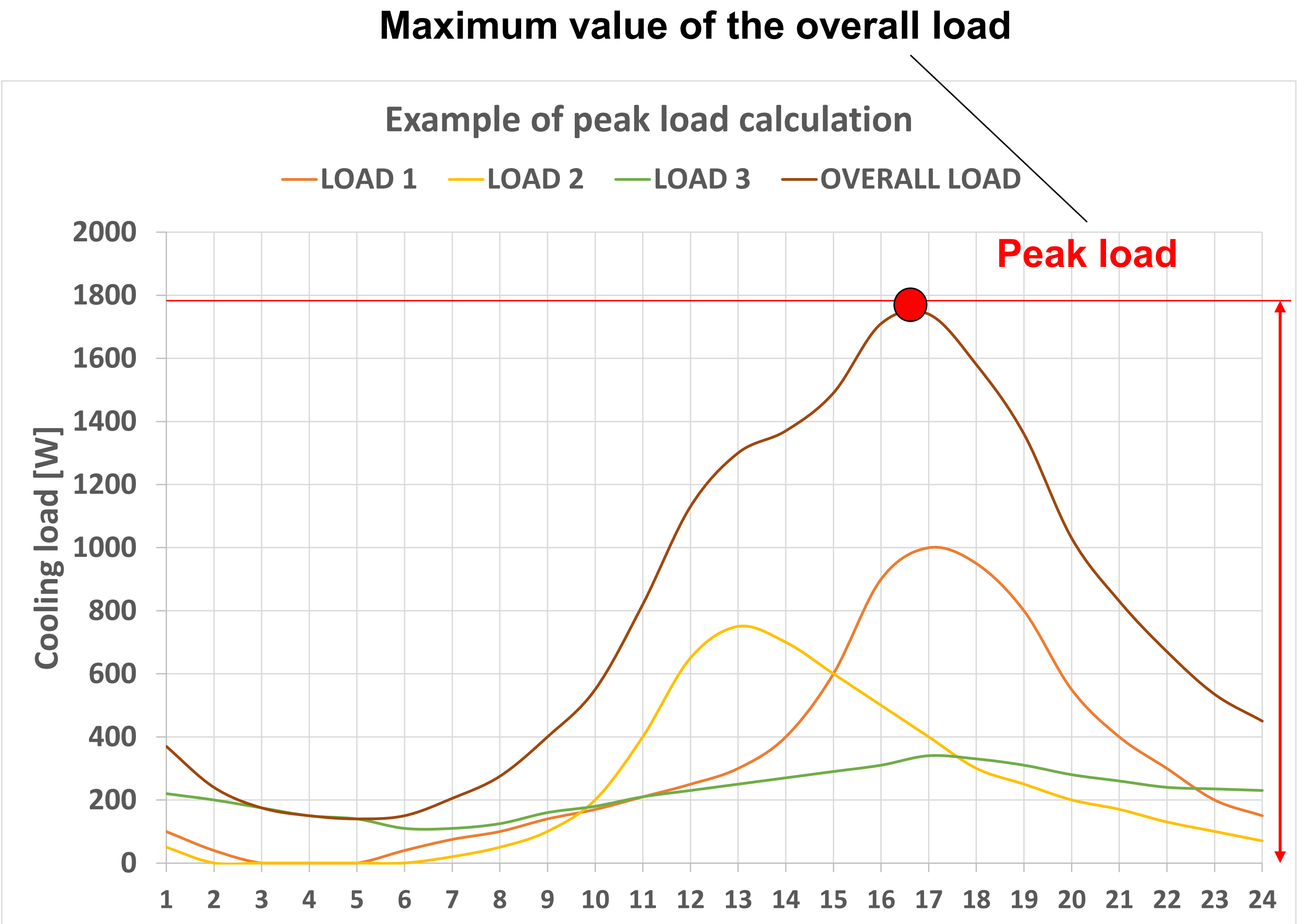
$$q_{IG} = \sum_{j} f_{s,j}\left(q_{I,j} + q_{C,j}\right)$$

internal gain storage factor




The storage factor begins (time step 0) when the internal gain starts

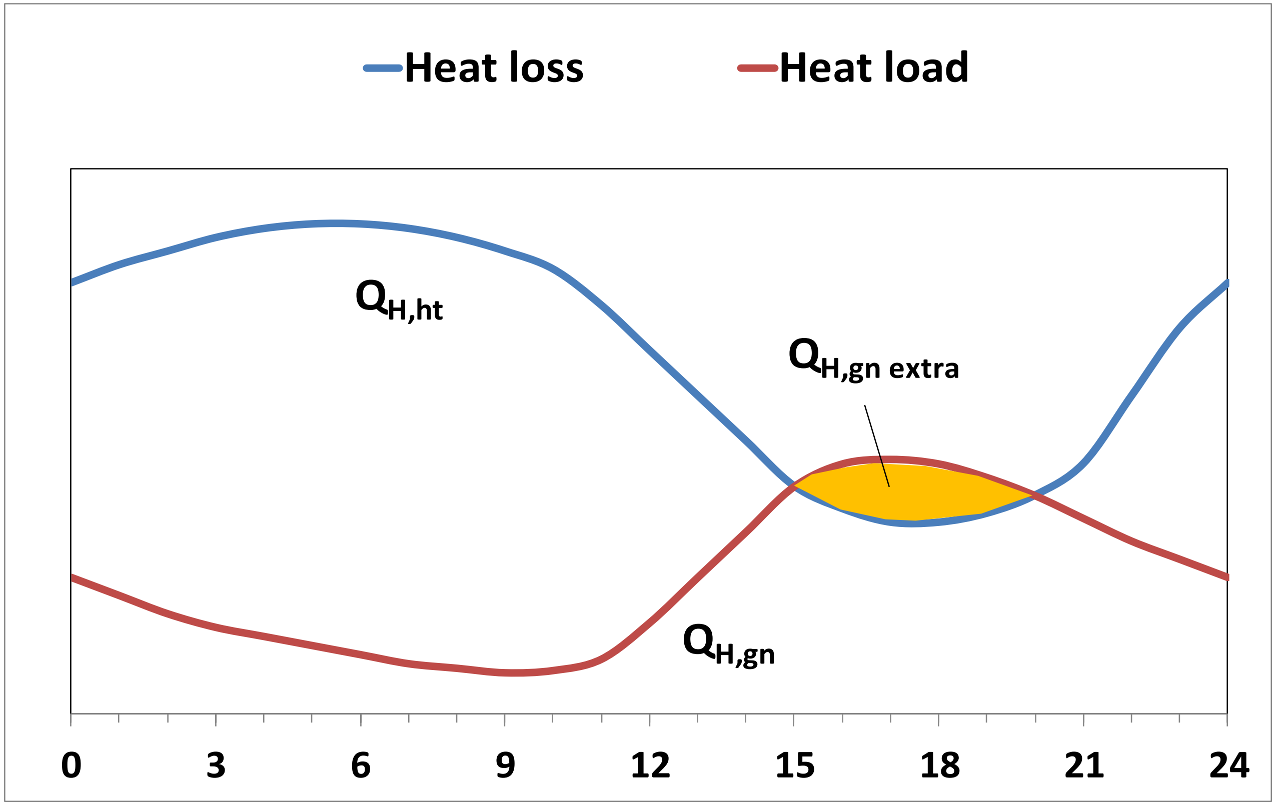
# Peak load evaluation



# Overview on the quasi-steady state method

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} Q_{H,gn}$$

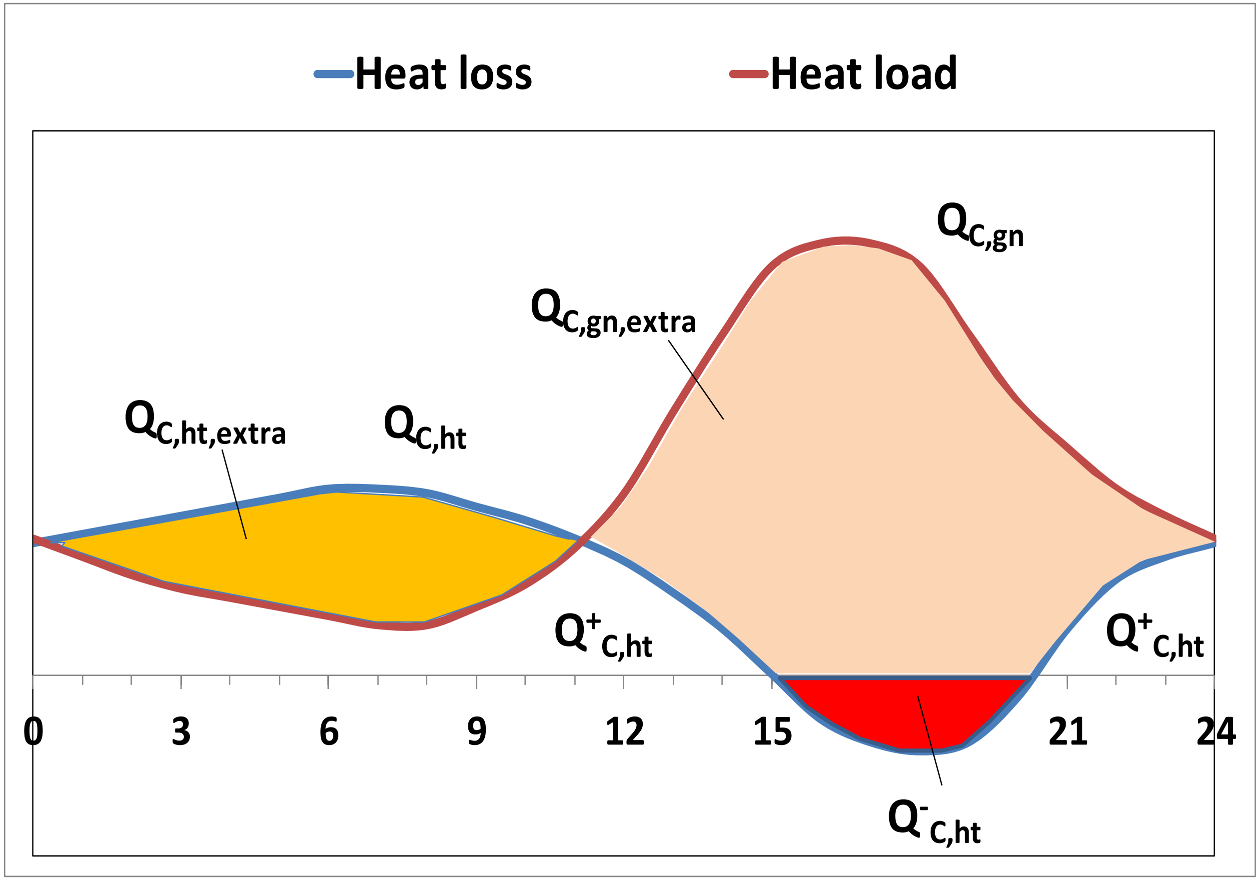
**Heating**




$$\eta_{H,gn} = \frac{Q_{H,gn} - Q_{H,gn,extra}}{Q_{H,gn}}$$

## Cooling

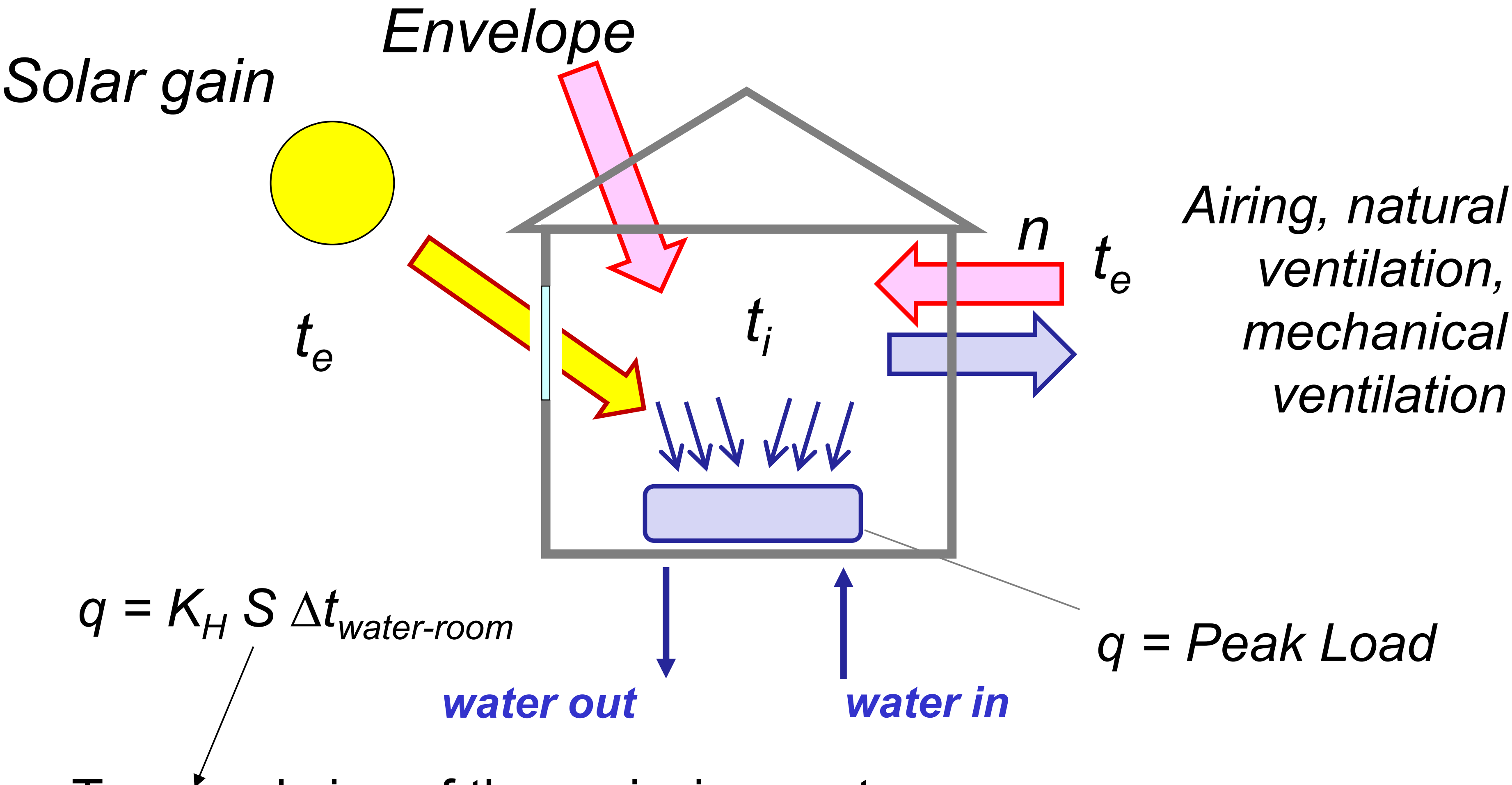
$$Q_{C,nd} = Q_{C,gn} - \eta_{C,ht} \cdot Q_{C,ht}$$




$$\eta_{C,ht} = \frac{Q_{C,ht} - Q_{C,ht,extra} - |\, Q^{-}_{C,ht} \,|}{Q_{C,ht} - |\, Q^{-}_{C,ht} \,|}$$

# Types of HVAC systems

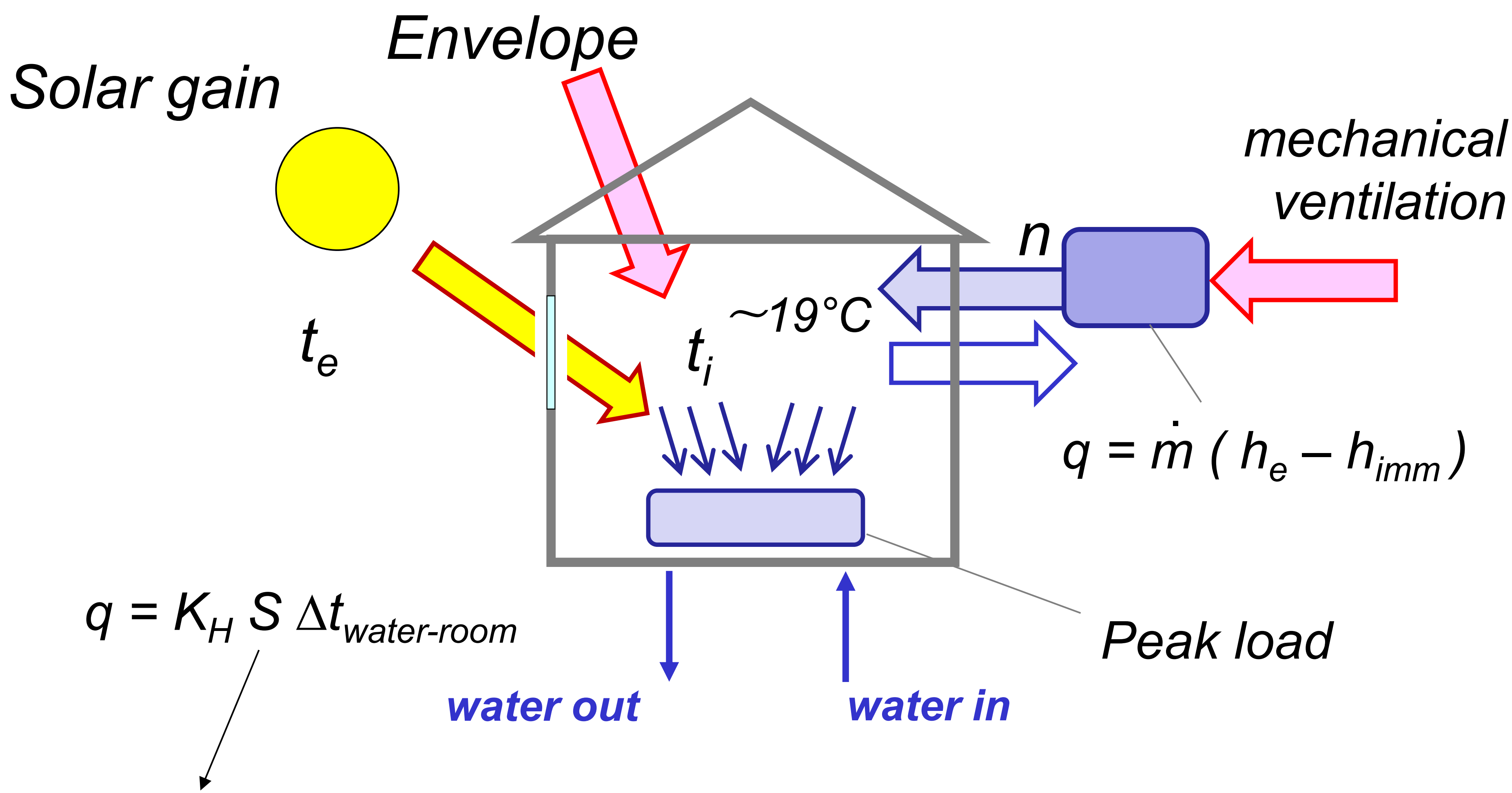
## 1. Water based cooling




- Type and size of the emission system
- Average water temperature in the emission system (dehumidification needed)

# Types of HVAC systems

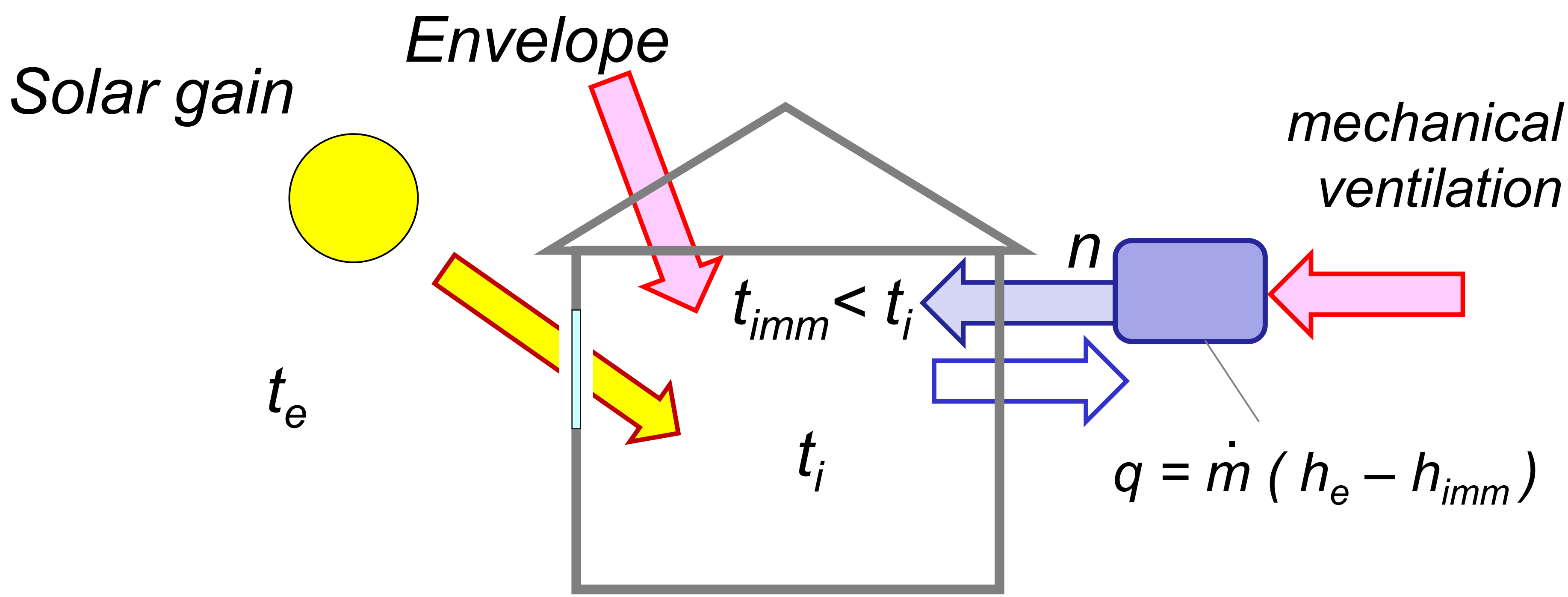
## 2. Air and water based cooling




- Type and size of the emission system
- Average water temperature in the emission system

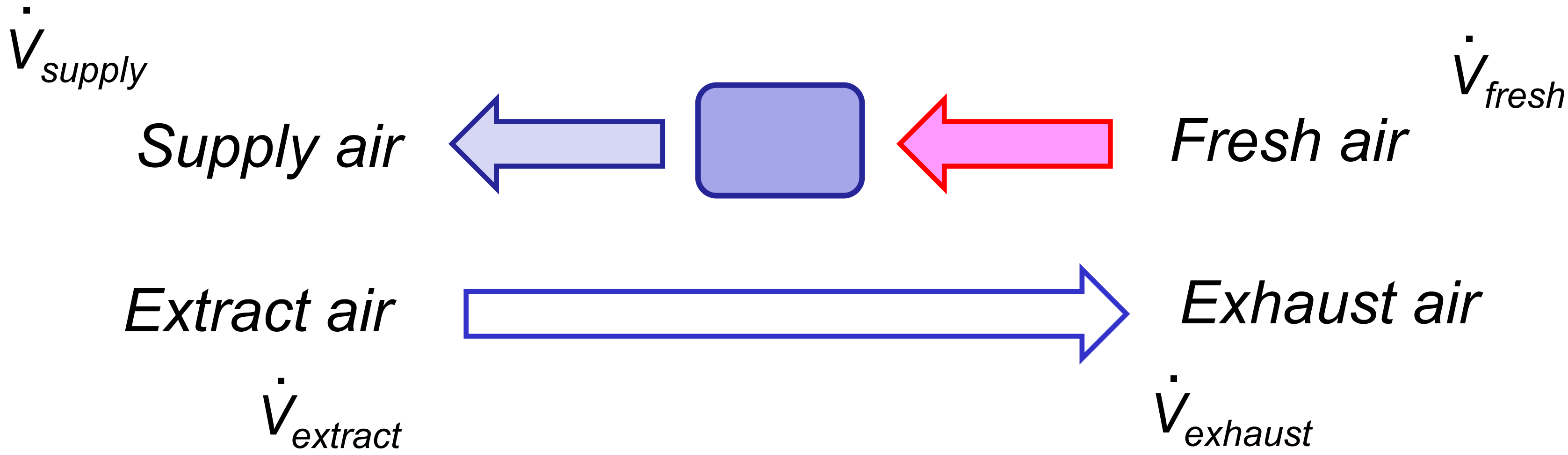
# Types of HVAC systems

## 3. Full air cooling




The air enters the room with lower temperature ($t_{imm}$) than $t_i$. Depending on the flow rate and $t_{imm}$, there are 2 possible solutions.

**1) No recirculation:** $\dot{V}_{fresh} = \dot{V}_{supply} \cong \dot{V}_{exhaust}$




**2.) With recirculation:** $\dot{V}_{fresh} < \dot{V}_{supply} \cong \dot{V}_{extract}$