COOLING LOAD CALCULATION

Heat Gain and cooling load

Most of the dynamic 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. As a matter of fact usually there is a clear division between the heat gain, which is defined as the actual thermal solicitation, and the load that a cooling system has to extract (i.e. the cooling load), which 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 (Figure 1). Therefore cooling load is the rate at which heat must be removed from the space to maintain a constant space air temperature. The sum of all space instantaneous heat gains at any given time does not necessarily (or even frequently) equal the cooling load for the space at that same time. The integral of energy of the heat gain over one day has to be the same of the cooling load.

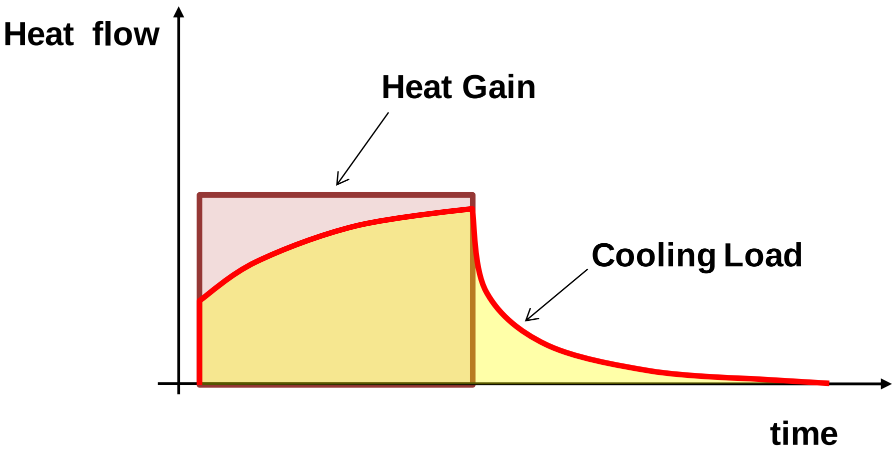

Figure 1: Graphical view of a step-wise constant heat gain and related cooling load

Method based on equivalent temperature difference

This is one of the oldest methods which is in use by practitioners for determining the sensible cooling load of a room. It is based on the superposition of different solicitations may be summed based on the superposition technique.
For each hour of the day, the following equation can be written:

$$q_p = q_g + q_{d,window} + q_{d,opaque} + q_s + q_{IG} + q_{inf} \quad (1)$$

The convective heat flow q_g due to the incoming and outgoing air rates in the room can be calculated via these two equations equation (equation 2 for the mechanical ventilation and equation 3 for infiltration):

$$q_g = G_a \, c_p \, (t_{imm} - t_a) \quad (2)$$

$$q_{inf} = G_a \, c_p \, (t_e - t_a) \quad (3)$$

As for the conduction through elements, windows are supposed to have no capacity, therefore for each k-th surface the following heat flow can be calculated:

$$q_{d,window} = \sum_{k=1}^{f} U_k S_k (t_e - t_i) \qquad (4)$$

As for the conduction through walls different behaviour of the structures are supposed, depending on the latitude of the site, on the orientation and on the colour of the wall, on the hour of the day and on the specific mass of the wall per surface area (m_f). Depending on the combination of these parameters, for each i-th surface the following heat flow can be calculated:

$$q_{d,opaque} = \sum_{i=1}^{o} U_i S_i \Delta t_{eq,i} \qquad (5)$$

where the $\Delta t_{eq,i}$ is the equivalent temperature difference which includes the sol-air temperature and the shift in time of the thermal capacity of the wall, as reported in Figure 2.a. As for the thermal capacity of outer walls, the following equation is used:

$$m_f = \sum_{q} \rho_q s_q \qquad (6)$$

where ρ_q is the density of each layer composing the wall and s_q its thickness.

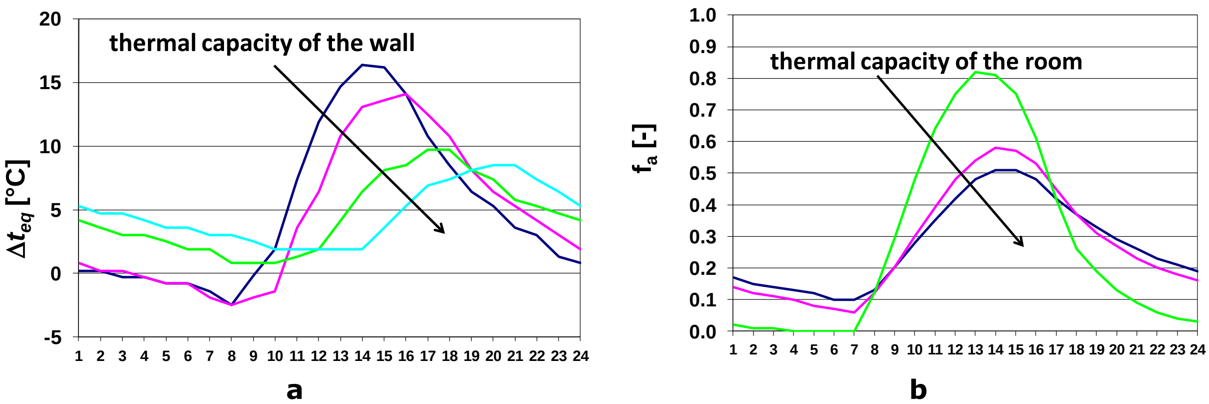

Figure 2: Equivalent difference of temperature for a clear grey South wall (a) and attenuation factor for the solar radiation entering the room as a function of the thermal capacity of the room for a window facing South (b)

The effect of solar radiation through glazing components can be evaluated by means of the following equation:

$$q_s = \sum_{k=1}^{f} S_k I_{x,k} f_{a,k} C_{s,k} \qquad (7)$$

where $I_{x,k}$ is the maximum solar radiation on the considered orientation passing through the reference glass (depending on latitude, time of the year and orientation), $C_{s,k}$ is the shading coefficient, and $f_{a,k}$ is the attenuation factor of the room, which is calculated based on the overall thermal inertia of the room. The thermal capacity of the room M_R is calculated as

$$M_R = \frac{\sum_j m_{f,j} S_j + 0.5 \cdot \sum_r m_{f,r} S_r}{S_f} \quad (8)$$

where 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. The overall weight of the room is divided by the floor area S_f. As an example, in Figure 2.b the attenuation factor for a window facing South is shown as a function of the room mass.
As for the internal gains, convective and radiant gains are considered together and multiplied by the internal gain storage factor $f_{s,j}$, as follows:

$$q_{IG} = \sum_j f_{s,j} \left(q_{I,j} + q_{C,j} \right) \quad (9)$$

The storage factor depends on the duration of the presence of the internal gains and on the specific mass of the room M_R. The storage factor begins (time step 0, as reported in Figure 3) when the internal gain starts.

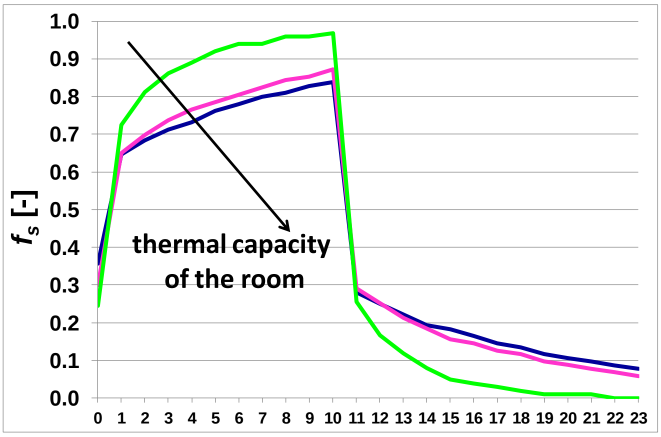

Figure 3: Storage factor for 10 hours internal gains in a room as a function of the thermal capacity of the room

The method is easy to implement and has been widely used. Some lacks in accuracy derives by the fact that the mass involved in dumping the solar radiation and in storing the internal gains do not consider the position of insulation material on the outer walls. A more detailed method is the one presented hereafter.

QUASI STEADY STATE MODEL FOR THE ENERGY DEMAND

The quasi-steady state model has been the basis for the standard ISO EN 13790, for determining sensible heating and cooling demand. The reference calculation step could be monthly or seasonal.
The building energy need for space heating and cooling in the reference period for a room with this method is based on a single equation, respectively equation (10) for the heating period and equation (12) for the cooling period. The average values of the weather conditions are considered (average solar energy and mean outdoor temperature). As shown in detail hereafter, due to the use of a parameter which considers intrinsically the thermal behaviour of the structures via the time constant of the room, the method is called quasi steady state.
This method is the basis of the energy certifications in Europe and it is the most widely used. It is more accurate for determining the energy demand in heating season rather than in cooling season, mainly due to the difference between indoor and outdoor temperatures.

4.3.1 Building energy demand for space heating

The building energy need for space heating in the reference period for a room ($Q_{H,nd}$) for conditions of continuous heating, is calculated as given by the following equation:

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} Q_{H,gn} \tag{10}$$

where $Q_{H,ht}$ is the total heat transfer for the heating mode, $Q_{H,gn}$ gives the total heat loads (solar radiation and internal loads) for the heating mode and $\eta_{H,gn}$ is the dimensionless gain utilization factor.
This last coefficient considers the fact that not all the heat loads can be fruitfully used. As shown in Figure 4, during a typical day in heating season the building has losses, which are typically higher in night time (lower outdoor temperatures) and lower during the day (higher temperatures). As for heat loads, they have usually a peak during the day, due to the solar radiation. As shown before, when a heat gain occurs it needs some time before it appears clearly and, at the same time, when it stops it needs some time in order to disappear. This delay time is due to the thermal inertia of the room, i.e. by the time constant of the room (defined as a combination of the capacitance of the building and its overall resistance), since the heat gain has to be first partially stored and then released by the structures.
Considering again Figure 4, the heat load $Q_{H,gn}$ is useful if it is lower than the amount of heat loss, therefore the heating energy demand is represented by the area between the two profiles. When the heat load exceeds the heat loss the surplus of heat gain $Q_{H,gn,extra}$ is not useful, hence it cannot be included in the calculations. Therefore the efficiency in the use of internal gains can be calculated as:

$$\eta_{H,gn} = \frac{Q_{H,gn} - Q_{H,gn,extra}}{Q_{H,gn}} \tag{11}$$

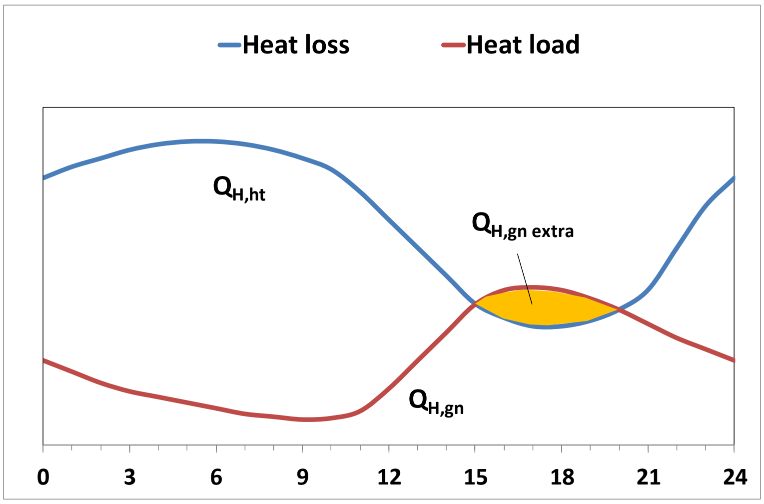

Figure 4: Heat losses and heat gains in an average day in winter period

4.3.2 Building energy demand for space cooling

The building energy need for space cooling in the reference period for a room ($Q_{C,nd}$) for conditions of continuous cooling, is calculated as given by the following equation:

$$Q_{C,nd} = Q_{C,gn} - \eta_{C,ht} \cdot Q_{C,ht} \tag{12}$$

where $Q_{C,gn}$ gives the total heat gains (solar radiation and internal loads) for the cooling mode, $Q_{C,ht}$ is the total heat transfer for the cooling mode and $\eta_{C,ht}$ is the dimensionless utilization factor for heat losses.

The definition of the utilization factor for the heat losses can be understood by using Figure 5. In the cooling period the heat load has a peak during the day, mainly due to solar radiation. The shape of the heat load curve is smoothed, due to the effect of the structures and the time constant of the room. The heat loss shape is similar to the one in winter time, but the average value is lower due to the reduced temperature difference between indoor and outdoor in summer time and, in the afternoon, it becomes negative, since the outdoor temperature is higher than the indoor temperature. The negative heat loss is called $Q^{-}_{C,ht}$ and it becomes an extra load to be removed by the cooling system, which has to face the amount of energy $Q_{C,gn,extra}$ + $|Q^{-}_{C,ht}|$ (pink and red areas in Figure 5). During night time the heat loss might exceed the heat load, thus leading to a free cooling. In any case the surplus of heat loss ($Q_{C,ht,extra}$) cannot be used, hence the useful part of the heat loss for free cooling is $Q_{C,ht}$ - $Q_{C,ht,extra}$ - $|Q^{-}_{C,ht}|$.

Therefore, the utilization factor for heat losses can be calculated as the useful part of heat loss and the overall amount of heat loss ($Q_{C,gn}$ - $|Q^{-}_{C,ht}|$):

$$\eta_{C,ht} = \frac{Q_{C,ht} - Q_{C,ht,extra} - |Q^{-}_{C,ht}|}{Q_{C,ht} - |Q^{-}_{C,ht}|} \tag{13}$$

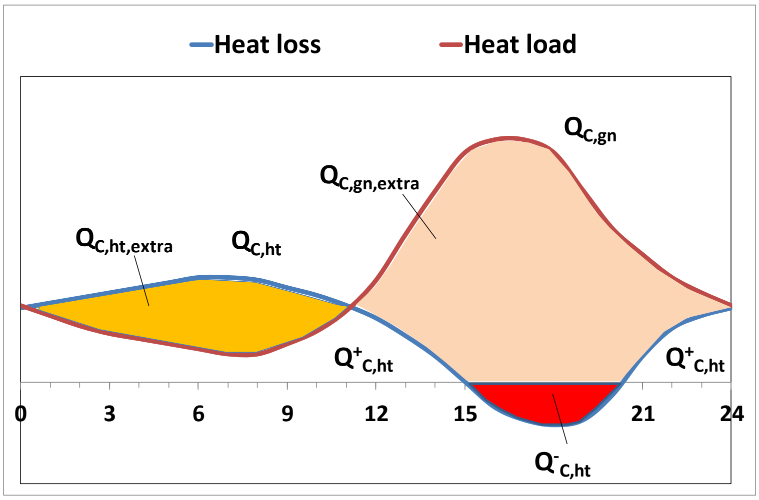

Figure 5: Heat losses and heat gains in an average day in summertime