Thermal comfort

Thermal comfort and in general IEQ (Indoor Environmental Quality) is extremely important in buildings. As a matter of fact the article 1 of EPBD (Energy Perfomrance of Buildings Directive) [1] declares: "the objective of the European Energy Directive for Buildings is to promote the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as *indoor climate requirements* and cost-effectiveness".
IEQ is the combination of different parameters affecting our well-being indoor: thermal comfort, IAQ, visual comfort and acoustics. Today people spend about 90% of their time inside (home, work, travels, public premises) and 10% outside, hence we are exposed to indoor conditions (Figure 1).

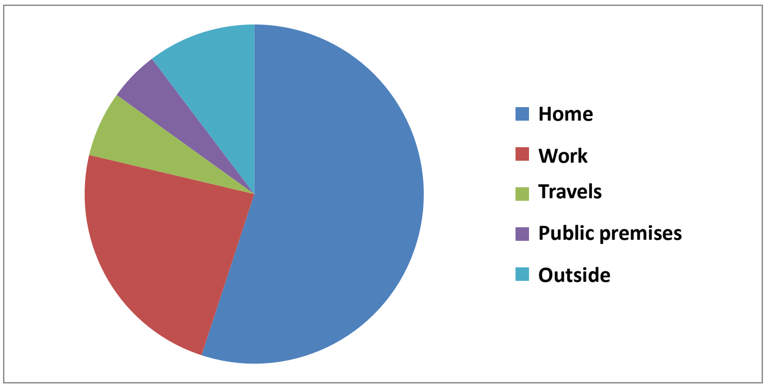

Figure 1: Sharing of time spent by people today

Although all the above-mentioned parameters affect the comfort and productivity of people, in this course we will focus on the thermal comfort in terms of the inner temperatures of a building. We will focus on the parameters affecting comfort conditions, on how to consider them inside building dynamic simulations and looking at dynamic behaviour of buildings. Last we will see how to define the comfort in a so called naturally ventilated building, i.e. a building where we have no air conditioning system for cooling. In fact we have to keep in mind that heating is mandatory but cooling is not.
It is important to underline that we are interested in thermal comfort in moderate environments, i.e. environments which are not too warm or too cold (these conditions are also known as severe conditions), as usually happens in civil and industrial spaces without processes involving heat sources. An example of severe warm environments is represented by foundries and for severe cold environments refrigerating rooms.

Global thermal comfort conditions

Introduction

The factors affecting the thermal comfort in moderate environments can be summarised as:

- air temperature
- surface temperatures
- air velocity

- relative humidity
- type of clothing
- activity level

All these factors affect the thermal balance of the human body with the surrounding space. As a whole, we usually exchange mostly sensible heat (ca. 80%) rather than latent heat (ca. 20%) as represented in Figure 2. As a matter of fact, the relative humidity affects slightly the thermal comfort and can be considered almost negligible if it is between 30% and 70%, as it usually is inside moderate environments. The relative humidity is more important for the vapour content in the rooms and the problems connected to surface and interstitial condensation.
When considering the different losses, we can subdivide the heat loss mainly through the skin (ca. 88%) and through lungs (ca. 12%). Hence, overall, we might assume that the heat transfer of the body can be assumed to be convective and radiative (Figure 3). Since the air velocity has to be kept low in the rooms in order to avoid draught risks, the convection heat transfer can be assumed to depend on air temperature.

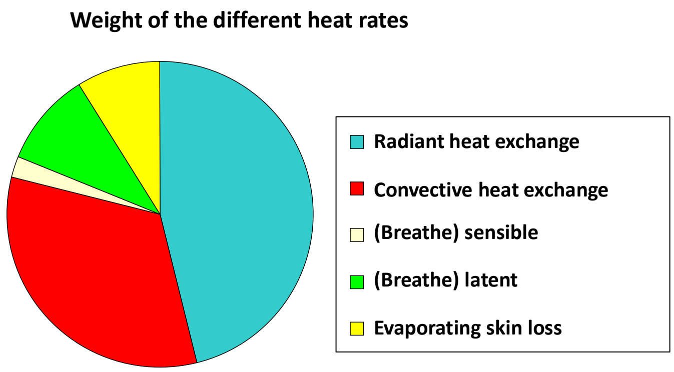

Figure 2: Sharing of heat losses of a human body

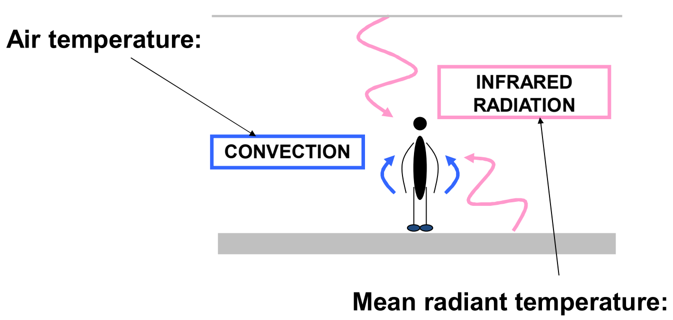

Figure 3: Main mechanisms of heat transfer between the human body and the surrounding: convection (air temperature) and infrared radiation (mean radiant temperature)

Mean radiant temperature

The effect of the temperature of the different surfaces surrounding a person can be summarised by mean of a single quantity, the mean radiant temperature (t_{mr}). The mean radiant temperature is the uniform temperature of a black cavity which leads to the same infrared radiant heat exchange between the human body and surrounding surfaces. In the case of radiantly grey surfaces with emissivities close to one, the mean radiant temperature can be expressed, in the absolute scale, as:

$$T_{mr} = \left[\sum_{k=1}^{n} F_{p-k} \cdot T_{s,k}{}^{4} \right]^{0.25} \tag{1}$$

where $F_{p\text{-}k}$ are the view factors between the human body and the surfaces and $T_{s,k}$ their absolute temperatures; view factors can be determined by means of graphs [2] or, for computerised calculations, by means of algorithms based on spherical trigonometry [6].
The mean radiant temperature in moderate environments can be also calculated more easily:

$$T_{mr} = \Sigma\ (F_{p\text{-}k}\ T_{s,k}) \tag{2}$$

The mean radiant temperature is a function of the position it is measured or evaluated through detailed calculations. An example will show the effect of position of a person in a room for determining the mean radiant temperature (Figure 4). First of all it has to be underlined that the indoor conditions for the global comfort are related to the barycentre of a person which is conventionally at 0.6 m for a seated person and at 1.1 m for a standing person.

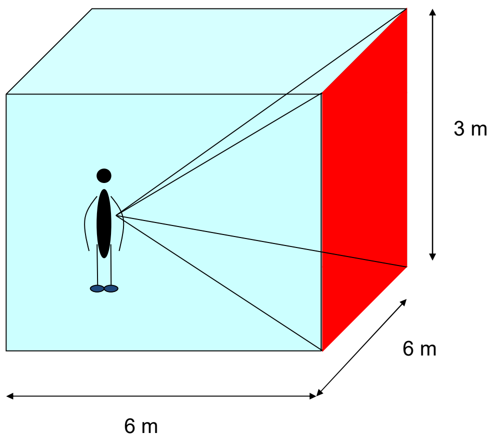

Figure 4: Example of calculation of mean radiant temperature calculated in different locations in the room

In the room of Figure 4 let us consider a seated person (0.6 m height) in the centre of the room (position 1), close to a corner far from the wall West (position 2) and close to the West wall (position 3) as shown in Figure 5. Let us consider to increase the temperature of West surface while maintaining the same temperature on the other walls fixed at 26°C. By increasing the West wall temperature of 5°C from 30°C to 45°C in Figure 6 the view factor are reported, as well as the mean radiant temperature. As can be seen, the increase of 5°C in the West wall leads to 0.5°C increase in the mean radiant temperature in position 1 (column 1), 0.2 °C in the opposite corner of the room (position 2, second column) and 1.1°C increase in the closest location (position 3, third column). The West wall temperature of 30°C leads to 0.8°C from position 2 to position 3 (row 1). If the West temperature is 35°C the difference in the mean radiant temperature between positions 2 and 3 is equal to 1.6°C (row 2). If the West temperature is 40°C the difference in the mean radiant temperature between positions 2 and 3 is equal to 2.4°C (row 3). If the West temperature is 45°C the difference in the mean radiant temperature between positions 2 and 3 is equal to 3.3°C (row 4).

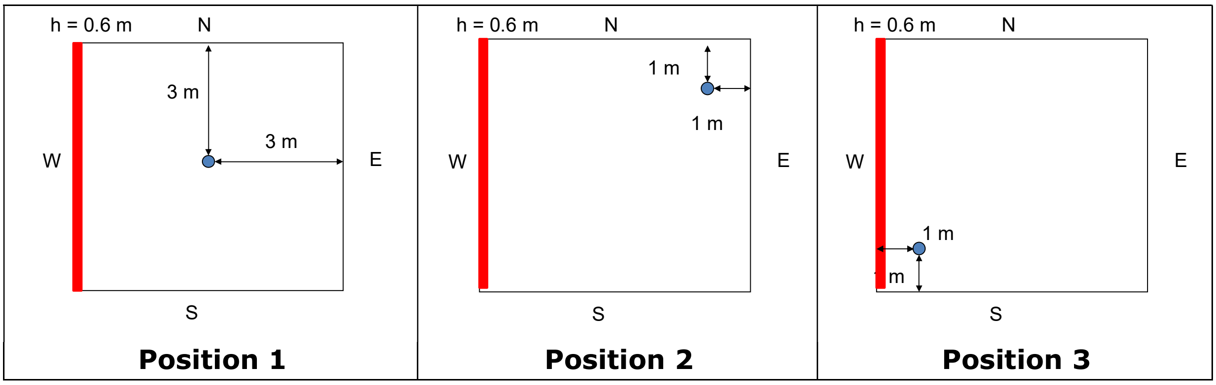

Figure 5: The 3 examined cases with detailed calculations of view factors:

Nord	0.095	26.0	2.47
Est	0.095	26.0	2.47
Sud	0.095	26.0	2.47
Ovest	0.095	30.0	2.85
Soffitto	0.2087	26.0	5.43
Pavimento	0.4114	26.0	10.70
			26.4

Position 1 with wall temperatrure West of 30°C

Nord	0.2184	26.0	5.68
Est	0.2214	26.0	5.76
Sud	0.0154	26.0	0.40
Ovest	0.0478	30.0	1.43
Soffitto	0.1544	26.0	4.01
Pavimento	0.3426	26.0	8.91
			26.2

Position 2 with wall temperatrure West of 30°C

Nord	0.015	26.0	0.40
Est	0.048	26.0	1.24
Sud	0.219	26.0	5.68
Ovest	0.219	30.0	6.55
Soffitto	0.155	26.0	4.01
Pavimento	0.344	26.0	8.91
			26.8

Position 3 with wall temperatrure West of 30°C

Nord	0.095	26.0	2.47
Est	0.095	26.0	2.47
Sud	0.095	26.0	2.47
Ovest	0.095	35.0	3.33
Soffitto	0.2087	26.0	5.43
Pavimento	0.4114	26.0	10.70
			26.9

Position 1 with wall temperatrure West of 35°C

Nord	0.2184	26.0	5.68
Est	0.2214	26.0	5.76
Sud	0.0154	26.0	0.40
Ovest	0.0478	35.0	1.67
Soffitto	0.1544	26.0	4.01
Pavimento	0.3426	26.0	8.91
			26.4

Position 2 with wall temperatrure West of 35°C

Nord	0.015	26.0	0.40
Est	0.048	26.0	1.25
Sud	0.219	26.0	5.70
Ovest	0.219	35.0	7.67
Soffitto	0.155	26.0	4.03
Pavimento	0.344	26.0	8.93
			28.0

Position 3 with wall temperatrure West of 35°C

Nord	0.095	26.0	2.47
Est	0.095	26.0	2.47
Sud	0.095	26.0	2.47
Ovest	0.095	40.0	3.80
Soffitto	0.2087	26.0	5.43
Pavimento	0.4114	26.0	10.70
			27.3

Position 1 with wall temperatrure West of 40°C

Nord	0.2184	26.0	5.68
Est	0.2214	26.0	5.76
Sud	0.0154	26.0	0.40
Ovest	0.0478	40.0	1.91
Soffitto	0.1544	26.0	4.01
Pavimento	0.3426	26.0	8.91
			26.7

Position 2 with wall temperatrure West of 40°C

Nord	0.015	26.0	0.40
Est	0.048	26.0	1.25
Sud	0.219	26.0	5.70
Ovest	0.219	40.0	8.76
Soffitto	0.155	26.0	4.03
Pavimento	0.344	26.0	8.93
			29.1

Position 3 with wall temperatrure West of 40°C

Nord	0.095	26.0	2.47
Est	0.095	26.0	2.47
Sud	0.095	26.0	2.47
Ovest	0.095	45.0	4.28
Soffitto	0.2087	26.0	5.43
Pavimento	0.4114	26.0	10.70
			27.8

Position 1 with wall temperatrure West of 45°C

Nord	0.2184	26.0	5.68
Est	0.2214	26.0	5.76
Sud	0.0154	26.0	0.40
Ovest	0.0478	45.0	2.15
Soffitto	0.1544	26.0	4.01
Pavimento	0.3426	26.0	8.91
			26.9

Position 2 with wall temperatrure West of 45°C

Nord	0.015	26.0	0.40
Est	0.048	26.0	1.25
Sud	0.219	26.0	5.70
Ovest	0.219	45.0	9.86
Soffitto	0.155	26.0	4.03
Pavimento	0.344	26.0	8.93
			30.2

Position 3 with wall temperatrure West of 45°C

Figure 6: Different cases to show the effect of the positions 1, 2 and 3 (one per column) with different temperatures on the West wall while the other walls are ocnsidered at the same temperature (26°C). West wall with 30°C (row 1), West wall with 35°C (row 2), West wall with 40°C (row 3) and West wall with 45°C (row 4).

Usually these calculations are time consuming and in the previous steps of the design there are no many particulars on the exact positions in the rooms. Hence usually it is more common in building simulations the calculation of the mean radiant temperature is carried out in a simplified way, by using the weighted average temperature on surface areas of the mean surface temperatures:

$$T_{mr} = \frac{\sum_{k=1}^{n} S_k \cdot T_{s,k}}{\sum_{k=1}^{n} S_k} \qquad (3)$$

Considering the same room of Figure 4, the weighting factors are in this case 0.25 for the floor and the ceiling and 0.125 for all other surfaces. In this case the mean radiant temperature is 26.5 if the West surface has a temperature of 30°C, 27.1°C if the West surface has a temperature of 35°C, 27.8°C if the if the West surface has a temperature of 40°C, and 28.4°C if the West surface has a temperature of 35°C.
The mean radiant temperature is calculated as the effect of the infrared heat exchange between the inner surfaces and the person. The solar radiation entering from the glazing elements is taken into account in the thermal balance of the room and the inner surface temperatures are increased by the incoming solar radiation (Figure 7.A). The output of a room balance (as weill be seen during the course) gives as results, the inner temperatures (surface temperatures) and the room load. This leads to the calculation of the mean radiant temperature T_{mr}* which is calculated with the resulting temperatures of the surfaces /Figure 7.B). The solar radiation impinging on a human body has an additive effect, i.e. the person is not only influenced by the infrared radiation of the inner surfaces, but also by the incident direct solar radiation which represent an increase of the heat flux. This leads to an increase of mean radiant temperature ΔT_{mr} which has to be added to the calculated mean radiant temperature:

$$T_{mr} = T_{mr}^* + \Delta T_{mr} \qquad (4)$$

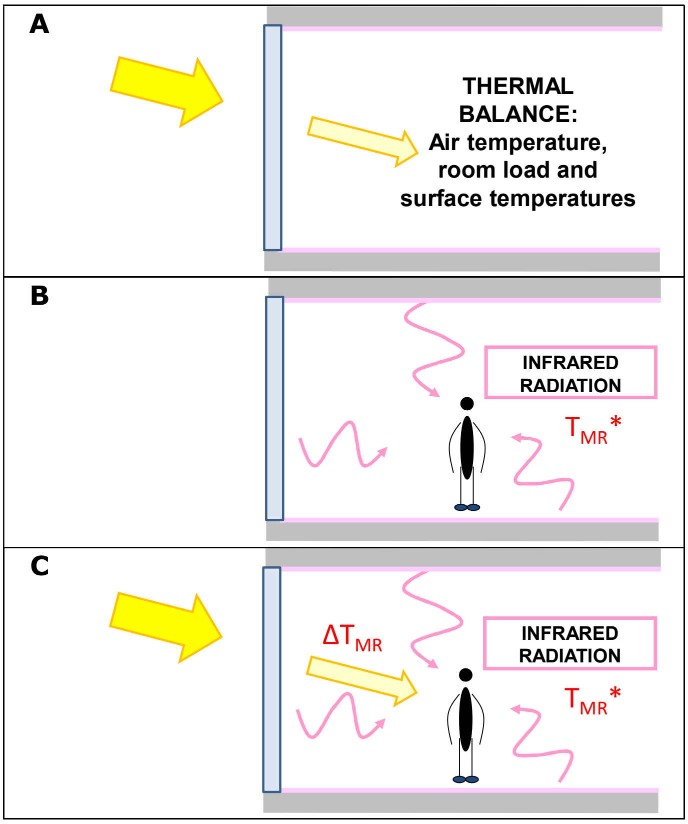

Figure 7: Steps of calculation of the mean radiant temperature in case of an additional heat flux (ΔT_{mr}) due to direct solar radiation entering the room and impinging on a human body.

Operative temperature

An important parameter, used in the study of thermal comfort, is the operative temperature t_o, which is a weighted value of air temperature t_a and mean radiant temperature t_{mr}, calculated as:

$$t_o = \frac{h_c \cdot t_a + h_r \cdot t_{mr}}{h_c + h_r} \tag{5}$$

where h_c and h_r are the convective and the radiant heat exchange coefficient between human body and the surroundings. If the air velocity is less than 0.2 m/s and the difference between the mean radiant temperature and the air temperature is less than 4°C, the operative temperature can be calculated, with a good approximation, as the average value between these two temperatures. The operative temperature is taken as a parameter involved in defining thermal comfort conditions in all the above mentioned standards.

Methabolic rate

Basal metabolic rate (BMR) is the rate of energy expenditure per unit time by all endothermic animals, including humans.
In thermal comfort (ISO 7730 [3]) it is defined via the unit "met" (1 met = 58.2 W/m^2), which is equal to the rate of energy produced per unit surface area of an average person seated at rest. The surface area of an average person is 1.8 m^2. As already mentioned a person resting has an activity level of 1 met, while working in office (sedentary activity) is usually assumed to have a standard value of 1.2 met. In Figure 8 different values of metabolic rates are reported.

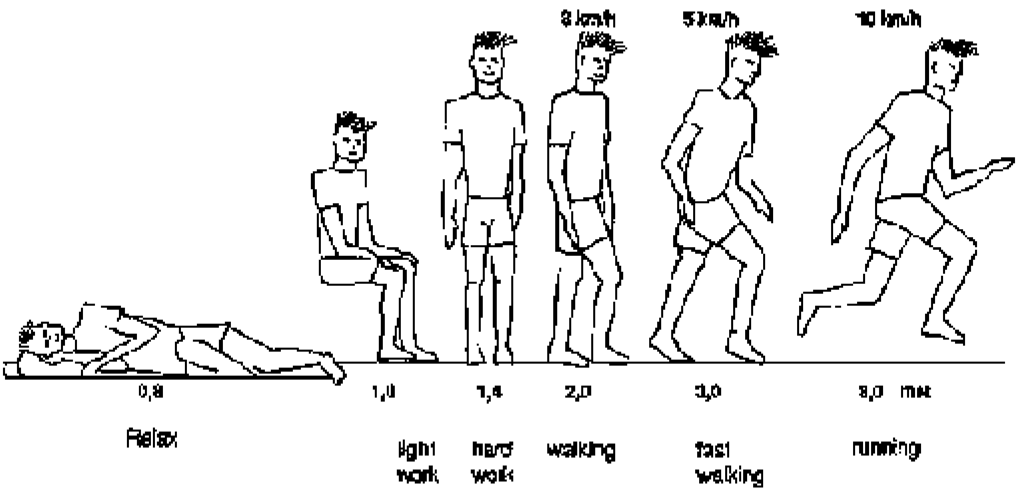

Figure 8: Metabolic rate of different activities (1 met = 58 W/m²) [7]

Clothing resistance

Clothing affects our perception of comfort, due to the contribution that conduction makes to the heat exchange process. This depends on the thermal conductivity of the materials in immediate contact with the skin. The comfort perception is hence depends on how people are dressed. To a certain extent, we can control comfort by adequate clothing, although in air conditioned spaces the change in clothing resistance is more limited than in naturally ventilated buildings [8], as shown later.
The insulation effect of clothing can be expressed by a clothing-value, named "clo" in ISO7730 [3] (1 clo = 0.155 m² K/W). Again the reference surface area of an average person of 1.8 m^2 has to be considered. In Figure 9 different values of clothing resistances are reported.
Usually in building simulations the usual value of clothing resistance in cooling conditions is 0.5 clo and in heating conditions is 1.0 clo. In particular cases (e.g. in case of dressing codes required), the values have to be evaluated accordingly.

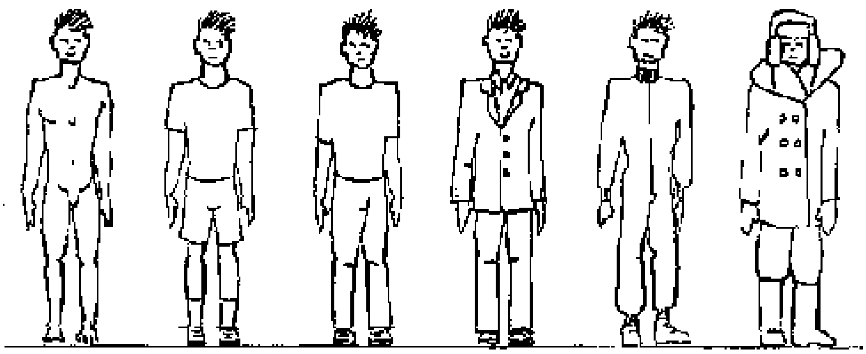

Figure 9: Insulation values of different kind of clothing (1 clo = 0.155 m²K/W). Source: [7]

Comfort parameters in conditioned spaces

Comfort parameters and ISO EN 7730

The influence of the parameters affecting comfort has been widely studied and evaluation criteria have been defined [2, 3, 4, 5]. The Fanger's approach easily allows to predict users reactions (*PMV* and *PPD*), as a function of the activity level by the metabolic rate M (expressed in met), clothing thermal resistance R_{cl} (expressed in clo), mean radiant temperature t_{mr} of the surrounding surfaces, dry-bulb temperature t_a, as well as relative air velocity v_a and relative humidity of the air:

$$PMV = f(M, t_a, t_{mr}, R_{cl}, v_a, RH) \qquad (6)$$

$$PPD = 100 - 95 \cdot e^{\left[-\left(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2\right)\right]} \qquad (7)$$

The *PPD* (Percentage People Dissatisfied) is quite intuitive and represent the percentage of people who are not satisfied about comfort conditions in a room. The *PMV* (Predicted Mean

Vote) is less intuitive and ranges between -3 for "very cold" and +3 for "very hot". There is a strict relationship between PMV and PPD (Figure 10).
As already mentioned before, the main parameters which affect comfort in buildings are operative temperature, clothing resistance and metabolic rate. Depending mainly on these three parameters the PPD and/or PMV can be evaluated. As shown in Table 1 three classes of comfort level have been defined in ISO 7730: class A (with more restrictive parameters), class B (intermediate class) usually used in new civil buildings and class C (less restrictive parameters) which cabin be used as reference in existing buildings (buildings built up 2007).

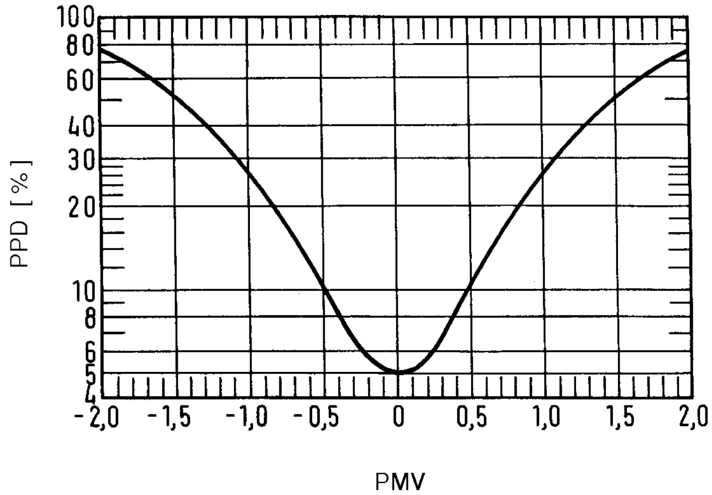

Figure 10: Percentage of people unsatisfied PPD as function of the predicted mean vote PMV. Source: [2]

Besides the so called global comfort parameters there are also local discomfort conditions to check. These are the draft risk, the radiant asymmetry and the difference of temperature between head and feet, but we will not investigate these local discomfort conditions in the course.

Table 1: Definitions of classes of comfort in EN ISO 7730 [2]

Class	PPD	PMV
A	< 6%	-0.2 < PMV < 0.2
B	< 10%	-0.5 < PMV < 0.5
C	< 15%	-0.7 < PMV < 0.7

The Standard EN 16798

The standard is a revision of EN 15251:2007. This standard specifies different types and categories of criteria, which may have a significant influence on the energy demand. For the thermal environment criteria for the heating season (cold/winter) and cooling season (warm/summer) are listed. The criteria in EN 15251 were, however, mainly for dimensioning of building, heating, cooling and ventilation systems. They may not be used directly for energy calculations and year-round evaluation of the indoor thermal environment. Studies have shown that occupant expectations in natural ventilated buildings may differ from conditioned buildings, which will be part of this standard.
The new standard specifies how design criteria shall be established and used for

dimensioning of systems. It defines how to establish and define the main parameters to be used as input for building energy calculation and short- and long-term evaluation of the indoor environment. The standard gives default criteria for design and energy calculations (in an informative Annex) although specifying national criteria may be introduced at national level. The national values may specify different criteria for design compared to criteria for energy calculation. The national annex may also specify different criteria for different building types (offices, schools, hospitals, etc.). The standard does not require certain criteria to be used. This is up to national regulations or individual project specifications.
The standard provides four different types of comfort levels, named categories (Table 2). Categories are similar to the classes definition of EN ISO 7730: category I corresponds to class A (high level of comfort), category II corresponds to class B (medium level of comfort), and category III corresponds to class C (moderate class of comfort). Category IV is a category which is below class C and represent low comfort level. The categories are related to the level of expectations the occupants may have. A normal level would be "Medium". A higher level may be selected for occupants with special needs (children, elderly, handicapped, etc.). A lower level will not provide any health risk but may decrease comfort. This level can be reached occasionally and for very short periods.

Table 2: Definitions of categories of comfort in EN 16798 [2]

Category	PPD	PMV
I	< 6%	-0.2 < PMV < 0.2
II	< 10%	-0.5 < PMV < 0.5
III	< 15%	-0.7 < PMV < 0.7
IV	< 25%	-1.0 < PMV < 1.0

Criteria for the thermal environment in heated and/or mechanical cooled buildings shall be based on the thermal comfort indices PMV-PPD, with assumed typical levels of activity and typical values of thermal insulation for clothing (winter and summer). Based on the selected criteria a corresponding design operative temperature interval shall be established. The values for dimensioning of cooling systems shall be the upper values of the comfort range during cooling season (summer) and values for dimensioning of the heating system shall be the lower values of the comfort range. The design criteria in this section shall be used for both design of buildings (dimensioning of windows, solar shading, building mass etc.) and HVAC systems.

The occupied zone: area where to evaluate the comfort parameters

The requirements for the indoor environment shall be satisfied in the so called occupied zone. This means that all measurements dealing with comfort criteria shall be related to this zone. The total area of a room can be used to evaluate the requirements, but the comfort criteria are not guaranteed beyond the occupied zone. The occupied zone is dependent on the geometry and the use of the room and shall be specified case by case as shown in Figure 11: based on the different cases the dimensions defined in Table 3 have to be chosen accordingly.

Table 3: typical dimensions for the occupied zone related to Figure 11. Source [9]

Distance from the inner surface of		Typical range (m)	Default value (m)
Floors (lower boundary)	A	0,00 to 0,20	0,05
Floors (upper boundary)	B	1,30 to 2,00	1,80
External windows and doors	C	0,50 to 1,50	1,00
HVAC appliances	D	0,50 to 1,50	1,00
External walls	E	0,15 to 0,75	0,50
Internal walls	F	0,15 to 0,75	0,50
Doors, transit zones etc.	G	Special agreement	-

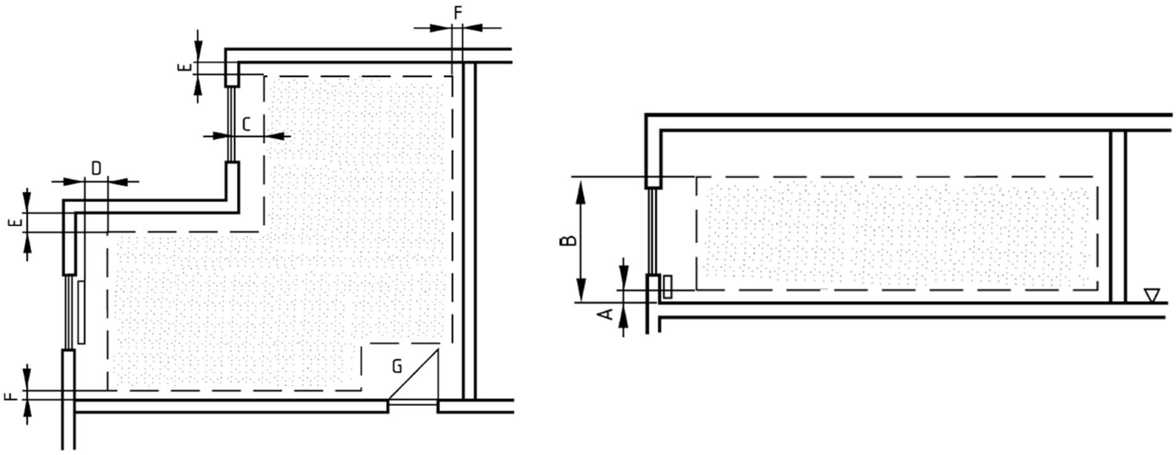

Figure 11: Possible definitions of the occupied zone. The defined areas dimensions are reported in Table 3. Source [9]

Adaptive comfort conditions for unconditioned buildings

The adaptive comfort approach is mainly addressed to the cooling season, since for the dimensioning of the heating system the same criteria as for mechanically, cooled and heated buildings shall be used.

Adaptive comfort builds on the principle that people experience differently and adapt, up to a certain extent, to a variety of indoor conditions, depending on their clothing, their activity and general physical condition. Therefore, contrary to the conventional cooling which is based on pre-calculated temperatures and humidity levels, the adaptive approach is based on a non fixed set of conditions, taking into account thermal perception and behaviour of the user, requiring her/him to take an active role in controlling her/his indoor environment [10]. Thermal adaptation is the physiological, psychological or behavioural adjustment of building occupants to the interior thermal environment in order to avoid or to limit thermal discomfort. In naturally ventilated buildings these are often in response to changes in indoor environment induced by outdoor weather conditions.

In buildings without mechanical cooling, the criteria for the thermal environment shall be specified using the adapted method that takes into account adaptation effects. This adaptive method only applies for occupants with sedentary activities without strict clothing policies where thermal conditions are regulated primarily by the occupants through opening and closing of elements in the building envelop (e.g. windows, ventilation flaps, roof lights, etc.). This method applies to office buildings and other buildings of similar type used mainly

for human occupancy with mainly sedentary activities, where there is easy access to operable windows and occupants can freely adapt their clothing to the indoor and/or outdoor thermal conditions.
The upper limits shall be used to design buildings and passive thermal controls (e.g. orientation of glazing and solar shading, thermal building capacity, size and adjustability of operable windows, etc.) to avoid overheating. It shall be evaluated if increased air velocity (with or without personal control) can improve thermal comfort.
The model of adaptive comfort considers the perception of an environment by occupants. The basic concept is to consider the capability of people to adapt to an environment by playing on the different variables.
The concept of adaptation to an environment is based on the expectations of the occupants who play an active role in managing the indoor climate, reducing or neglecting the HVAC.
There are three mechanisms behind the theory:

1. Behavioural.
   It includes all actions of the user (conscious or not) for the interaction with the thermal balance of the body. These actions can be subdivided into:
   - Personnel (by putting/removing clothing)
   - Technological (opening windows, control of solar radiation)
   - Cultural (e.g. resting in the warmest hours of the day)
2. Physiological.
   It depends on the capability of a person to acclimate in a different environment by reducing the metabolic rate. This mechanism is more frequent in populations facing constantly with severe climatic conditions.
3. Psycological.
   There are different perception of sensory information due to past experiences. The personal comfort sensation can differ from the one which can predicted by the theory of Fanger due to the habit to face frequent warm solicitation

One of the main important parameters in this approach is the possibility to change the clothing resistance. As a matter of fact it has to be underlined that a change of met = 0.1 clo corresponds to 0.7°C of change in the perceived operative temperature.

Table 4: Typical clothing resistances [clo] and corresponding variations in the perceived operative temperatures [K]

Garment Description	Thermal Insulation clo	Change of Operative Temp. K
Panties	0,03	0,2
T-shirt	0,09	0,6
Short sleeves shirt	0,15	0,9
Normal shirt, long sleeves	0,25	1,6
Shorts	0,06	0,4
Normal trousers	0,25	1,6
Light skirts (summer)	0.15	0,9
Heavy skirt (winter)	0,25	1,6
Thin sweater	0,20	1,3
Light, summer jacket	0,25	1,6
Normal jacket	0,35	2,2

A preliminary study done by Humphreys in 1978n [12] had already shown that in non-conditioned buildings the expectations are less restrictive than in cooled environments (Figure 12). Similar result has been achieved by De Dear and Brager in 2002 [13] as shown in Figure 13. As can be seen the difference between the actual comfort perceived by occupants was in agreement with the one evaluated via the Fanbger's approach in air-conditioned spaces (Figure 13.a). On the other hand, in naturally ventilated buildings the comfort perceived by occupants was completely different from the one evaluated by Fanger's theory, showing that occupants of free-running buildings perceive comfort at higher temperatures compared to the ones deriving by PMV and PPD approach.

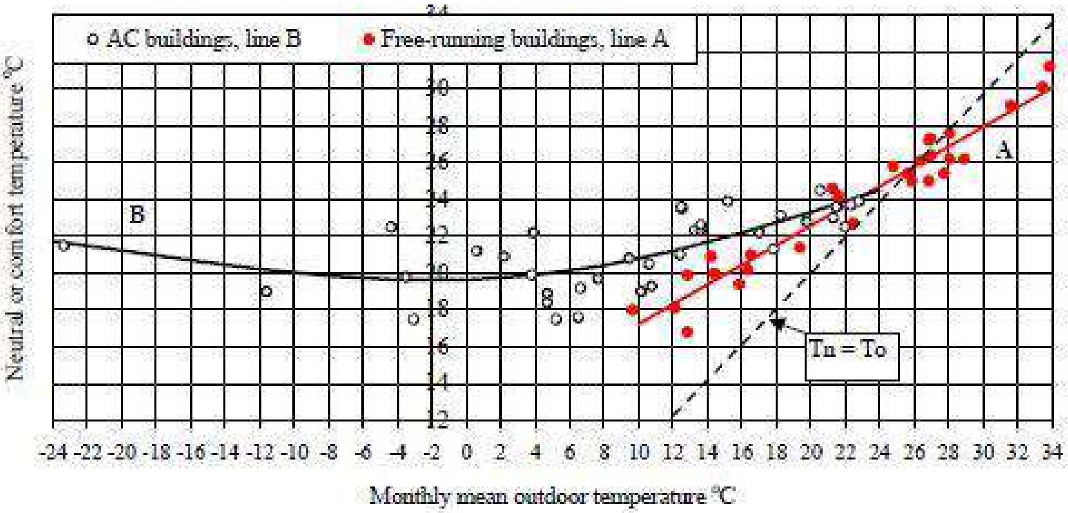

Figure 12: Finding s of Humphreys showing that in free-running buildings the expectations were different compared to air conditioned buildings in cooling [12].

Based on the adaptive comfort theory, currently two possible comfort criteria can be followed, as defined in the standards ASHRAE 55 [11] and EN 16798 [9]. They both give a range of acceptable indoor operative temperature according to outdoor temperature which has been shown to be the most important parameter affecting thermal comfort in unconditioned buildings. The difference in the two standards is the reference outdoor temperature, which is the monthly outdoor temperature in ASHRAE 55 (Figure 14) and the weekly mean running temperature in EN 16798 (Figure 15). These charts can be used both for previous calculations by means of dynamic simulations and for checking indoor environmental conditions with in situ measurements over a long period.

In Figure 16 there is a representation of possible maximum operative temperatures in naturally ventilated buildings as a function of the outdoor air average temperature in the warmest month. The example wants to show the possible limits for a naturally ventilated building in different locations in the World according to ASHRAE 55.

In Figure 17, instead, the possible values of the weekly mean running temperature defined in EN 16798 considering the TRY of Venice.

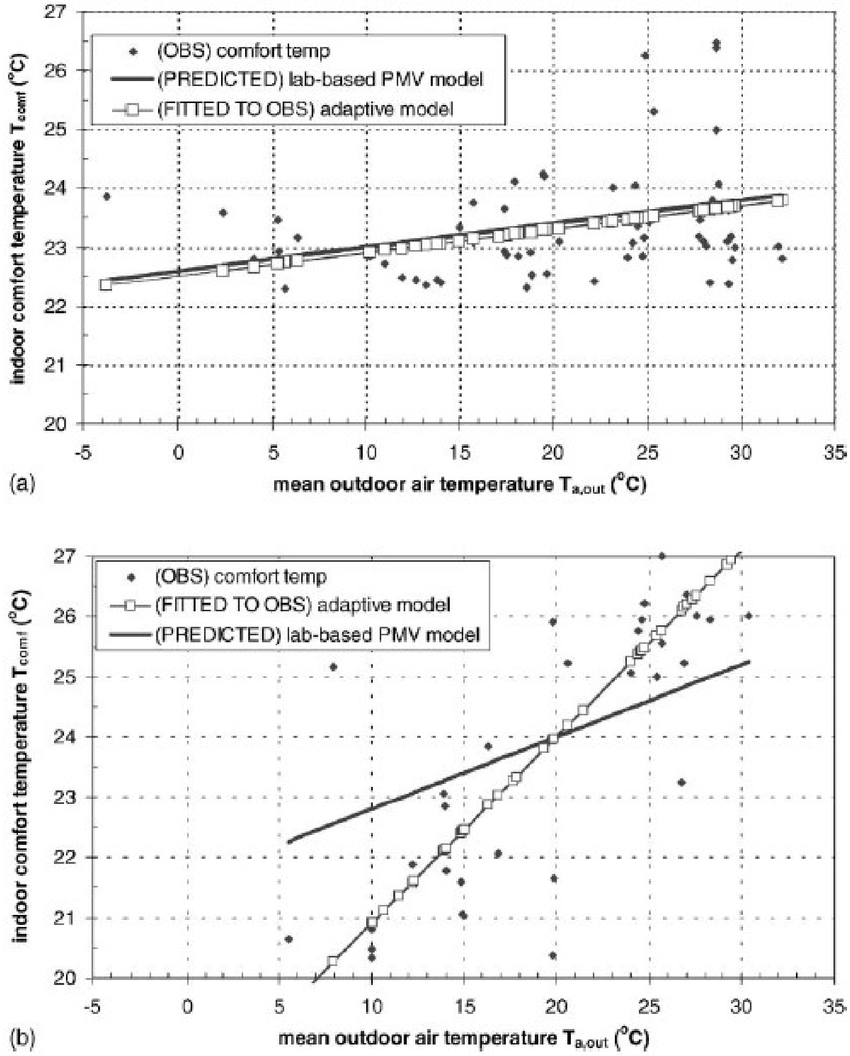

Figure 13: Finding s of De Dear and Brager in 2002 [13].

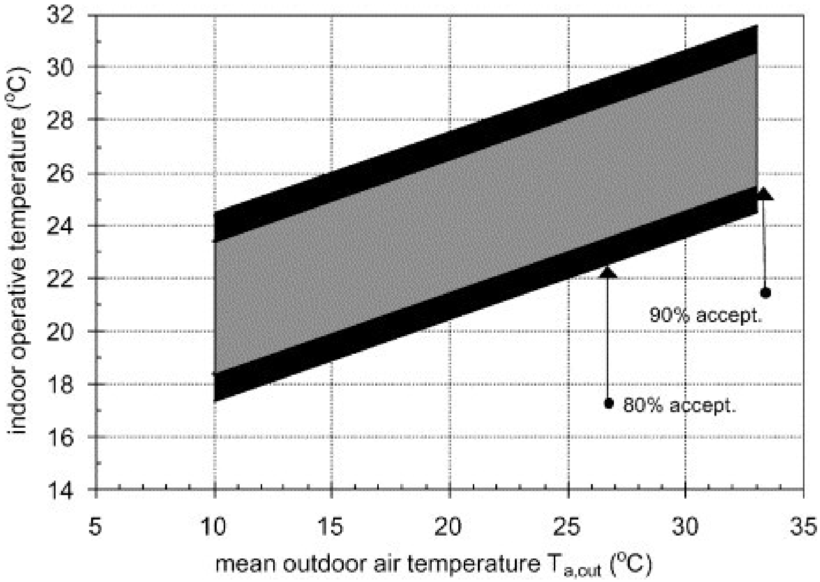

Figure 14: Acceptable range of operative temperature as function of the mean monthly outdoor temperature. Source: [11]

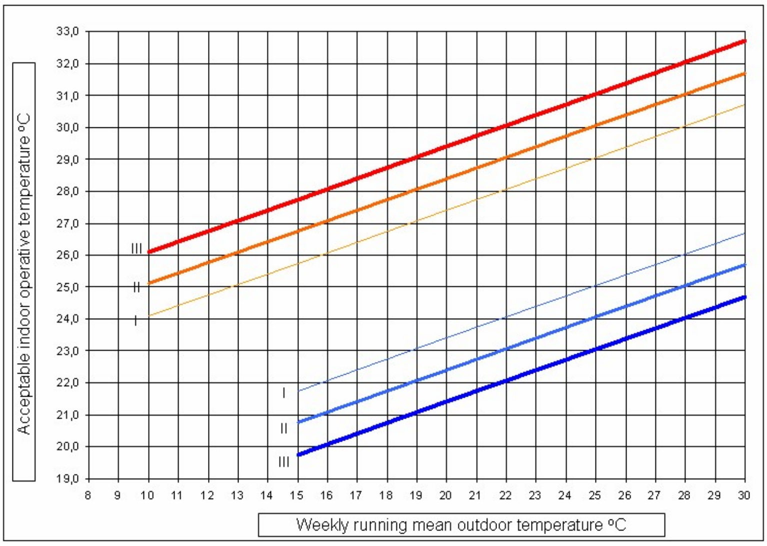

Figure 15: Acceptable range of operative temperature as function of the weekly running mean outdoor temperature. Source: [9]

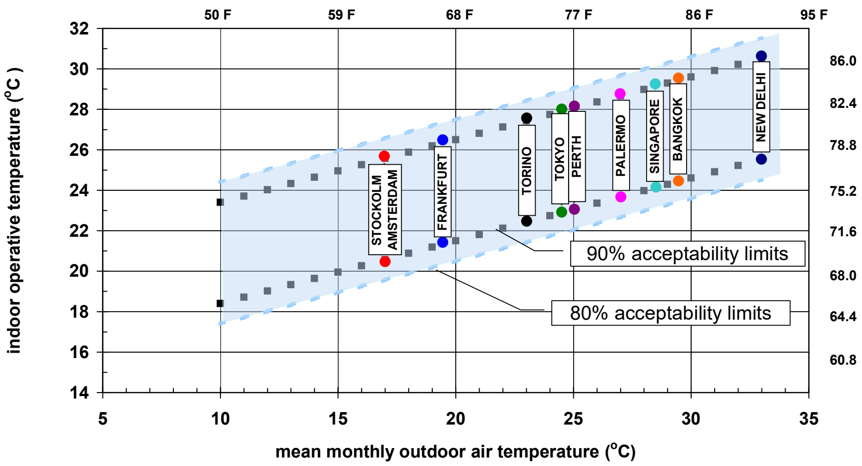

Figure 16: Example of inner operative temperatures as a function of outdoor average temperature in the warmest month in different countries according to ASHRAE 55.

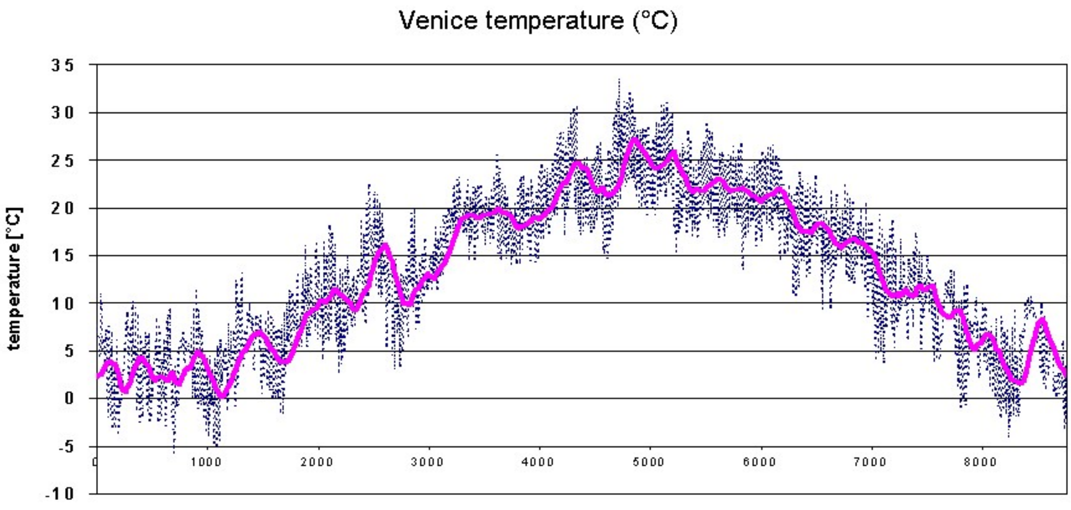

Figure 17: Example of the weekly mean running temperature defined in EN 16798 considering the TRY of Venice

The concept of mixed mode of a building

We have seen that there are two main philosophies for designing buildings in cooling conditions. The approach of air-conditioned buildings, where basically the indoor temperature is almost stable (Fanger's approach), and the naturally ventilated buildings where we may accept a certain variation of indoor temperatures over the day, according to the adaptive comfort model. The different approaches can be seen in Figure 18; as can be seen the potential temperatures of a building are in between the outdoor environmental conditions (curve 1) and full air conditioned (horizontal line 5). The first option is to work on external microclimate (shadows, plants, water) to limit the external solicitation (curve 2). The second option to further reduce the variation of building temperatures is to work on the climate balance of structure, i.e. to design the building to be a naturally ventilated building (curve 3). Usually naturally ventilated buildings are present in mild climates and many times it is not possible to ensure the comfort conditions even considering the adaptive approach of the different standards [9] and [11].
An interesting alternative to run a building always with a cooling plant (Curve 5) may be the possibility to make a hybrid approach between the naturally ventilated buildings (curve 3) and the fully air-conditioned buildings (curve 5). The approach is called as mixed mode and the qualitative trend is represented by the intermediate curve 4. The mixed mode approach is in principle quite intuitive, as it is based on the assumption that it is possible to decide to work with natural ventilation unless the indoor temperatures are lower than 26°C and, when the indoor temperature tends to increase, it is possible to close the windows and switch on the cooling system. This may allow an interesting energy saving compared to the full air-conditioned approach.

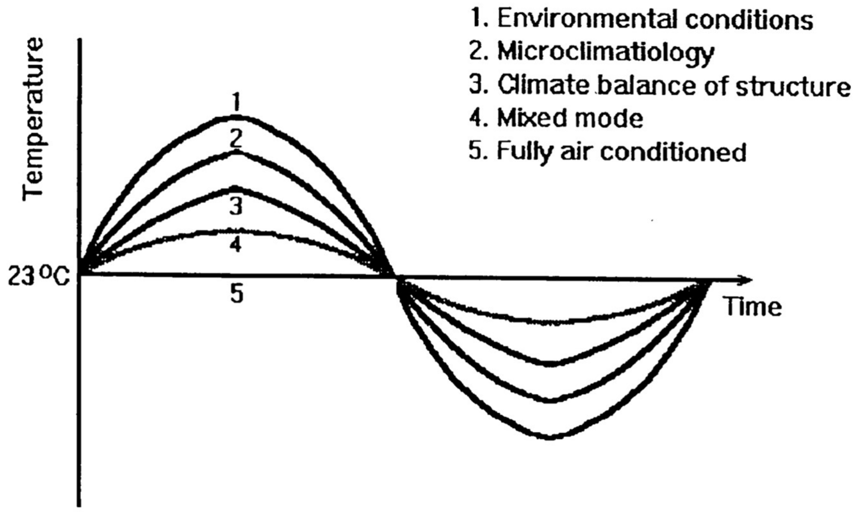

Figure 18: Simplified explanation of the different approaches in cooling season to limit the indoor temperatures in a building. Source [14]

The mixed mode approach is shown in Figure 19, where it is possible to see for a certain location the potential of saving considering the frequency of outdoor temperature and the possibility to use the cooling system for e limited period of time.

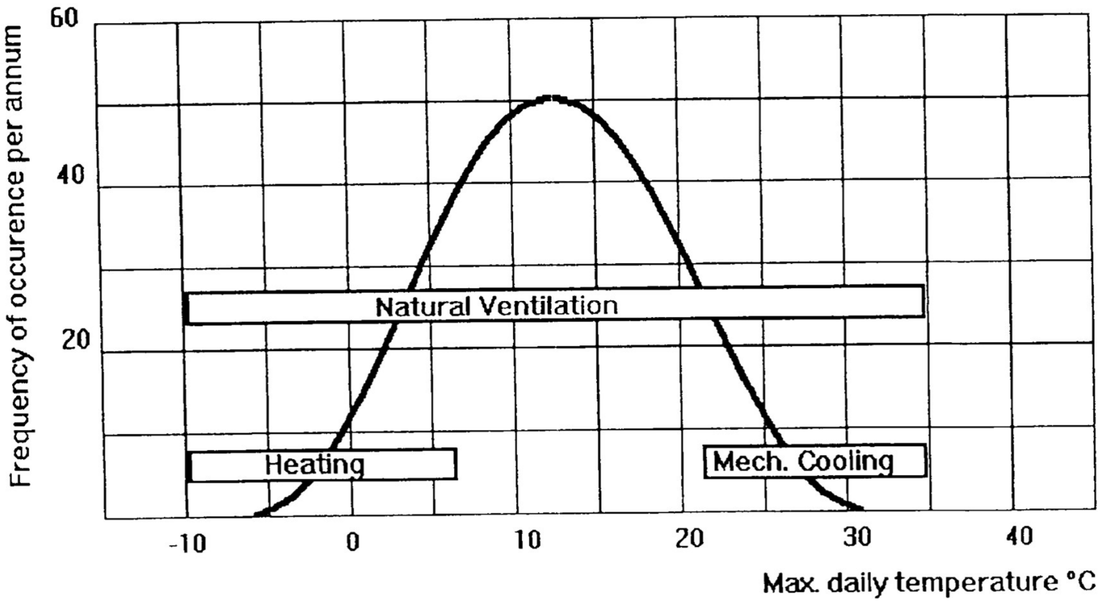

Figure 19: Simplified explanation of the different approaches in cooling season to limit the indoor temperatures in a building. Source [14]

References

[1] 2002/91/CE. EPBD Energy Perofmance Building Directive. 2002.

[2] FANGER P. O. *Thermal comfort: analysis and applications in environmental engineering*, McGraw Hill, New York, N.Y., 1972.

[3] ISO. *ISO 7730-2006, Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria Standard on requirements for moderate environments*. International Organization for Standardization. Geneva (CH), 2005.

[4] ASHRAE. *ANSI/ASHRAE Standard 55-2010, Thermal environmental conditions for human occupancy*. American Society of Heating Refrigerating and Air-conditioning Engineers, Inc. Atlanta, 2010.

[5] CEN. *CR 1752, Ventilation for Buildings: Design Criteria for the Indoor environment*. CEN, Brussels (B). 1998.

[6] BONAVITA F., BRUNELLO P., ZECCHIN R. *Metodo di calcolo dei fattori di forma tra corpo umano e superfici interne di un ambiente*, Condizionamento dell'aria, riscaldamento, ventilazione, anno XXXIII, n. 2, PEG Editrice, Milan. 1989.

[7] AA VV. Climate responsive Building (SKAT, 1993)

[8] DE CARLI M., OLESEN B.W., ZARRELLA A., ZECCHIN R. (2007). People's clothing behaviour according to external weather and indoor environment. BUILDING AND ENVIRONMENT, voi. 42(12), p. 3965-3973, ISSN: 0360-1323. doi: 10.1016/j.bulldenv.2006.06.038

[9] Standard EN 16798-1. Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6. 2019.

[10] DE DEAR R., BRAGER G. S. *Developing an adaptive model of thermal comfort and preference*. ASHRAE Transactions, Vol. 104 (1), 1998.
[11] ASHRAE. *ANSI/ASHRAE Standard 55-2010, Thermal environmental conditions for human occupancy*. American Society of Heating Refrigerating and Air-conditioning Engineers, Inc. Atlanta, 2010.
[12] HUMPHREYS, M. A. (1978) 'Outdoor temperatures and comfort indoors', Building Research and Practice (J. CIB), vol 6, no 2, pp.92–105.
[13] DE DEAR R., BRAGER G. S. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. Energy and Buildings 34 (2002) 549–561
[14] CLEMENTS-CROOME Derek. *Naturally Ventilated Buildings: Building for the Senses, the Economy and Society*. Routledge.1998. ISBN: 0419215204, ISBN-13: 9780419215202