HI-SMART

HI-SMART: HIGHER EDUCATION PACKAGE FOR NEARLY ZERO ENERGY AND SMART BUILDING DESIGN

MODULE #4

CHAPTER 1: METEOROLOGY

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CONTENT

4.1.1 METEOROLOGY

EXTERNAL TEMPERATURE

The most important characteristics of the external temperature are the mean, minimum, and maximum values. All characteristic numbers can be referenced to different periods. The daily mean value is the arithmetic mean of the temperatures continuously observed or measured every hour for 24 hours. The temperature average for a longer period (5 or 10 day periods, monthly, semi-annual, annual) is the algebraic average of the daily averages of the corresponding period.

The daily temperature fluctuation is the difference between the highest and lowest temperature observed within a day. We can talk about average daily (between average daily maxima and minima) and annual oscillations.

Normally, the temperature decreases with altitude, about 6.5 °C/km. Because warm air is lighter than cold air, this situation helps to create vertical airflows.

However, the lower layers may cool better, resulting in a different temperature stratification from the normal situation, which is called inversion: the colder, heavier air layers will be at the bottom, while the warmer, lighter air layers will be at the top. This stratification does not promote convection, so in such situations the transport of air pollutants is low, high concentrations are formed.

For different purposes different external temperature values are required.

EXTERNAL DESIGN TEMPERATURE

If the aim is to size a heating system, i.e. to determine the heat demand of a building or a room, then the coldest air condition during the year is the relevant criterion, as the system must be selected to provide the expected internal temperature under the most extreme conditions (at a given risk level).

In case of the approximate heat demand calculation methods generally used in practice, the design outdoor temperature is considered to be the value at which the design value of the temperature-dependent energy flows between the room and the environment is to be calculated assuming constant conditions. In this respect, Hungary is divided into three climate zones, to which the design temperature values of -15, -13, -11 °C (Figure 4.1.1.) are added. When designing buildings in the 10–10 km wide band from the boundary lines, you can freely choose which outdoor temperature you want to perform the calculation with. Where the effect of the urban heat island is strong (for example, in the centres of bigger cities), the designer and his client may agree that the sizing will be performed at -11 °C.

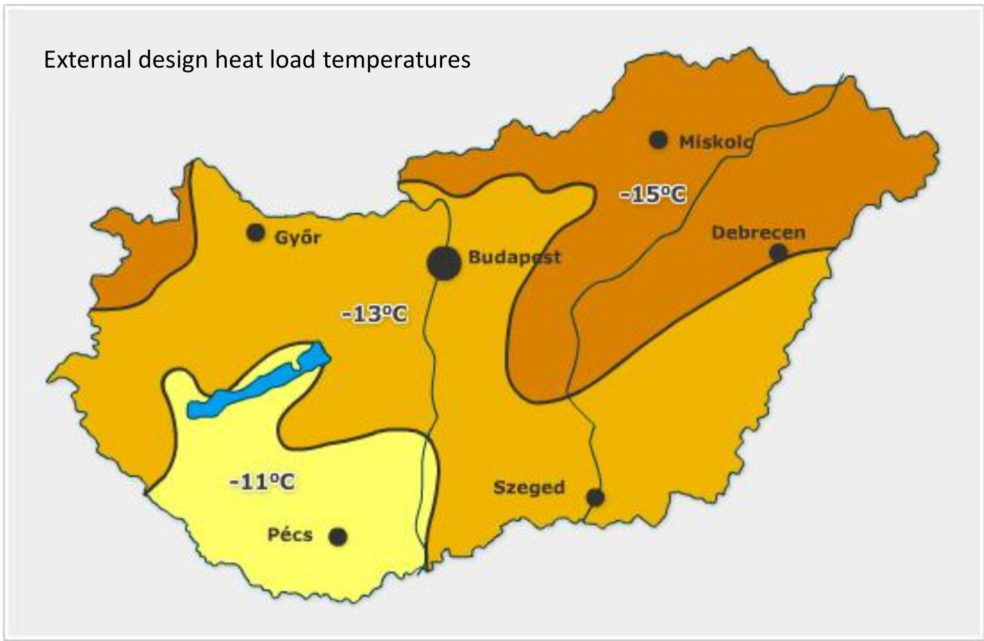

Figure 4.1.1.: External design heat load temperatures in Hungary

YEARLY EXTERNAL AVERAGE TEMPERATURE

In Hungary, the average annual temperature is highest in the South-Southeast, around 11-11.5 °C, and the lowest in the North-Northwest around 8-9 °C (Figure 4.1.2). The temperature difference between the warmest and coldest months is maximal in the Great Plain, in the central areas of the Trans-Tisza, reaching 24 °C, while in the high mountains, in some areas of the foothills, it remains below 20 °C.

The practical significance of the annual average temperature, which is not decisive from the point of view of heating or cooling, lies in the fact that it provides a good approximation of the annual average temperature of the upper layers of the soil.

One of the determining factors of heating energy demand is how the temperature difference between the room and the environment develops during the season. If we look at the whole season, the length of the heating season and the average temperature difference are proportional to the heat loss (using the simplification of excluding influencing factors other than the outside temperature, such as wind). If the internal setpoint temperature is constant, the average temperature difference depends only on the average of the outdoor temperature. However, as it is described in the next chapter the length of the heating season is influenced not only by meteorological factors but also by the design of the building itself. Therefore, the average outdoor temperature can only be given accurately with the knowledge of the building, but apart from low-energy and specially designed buildings, the simplified heating season is 180 days in Hungary and the corresponding seasonal average temperature is approximately 4 °C. Based on the average temperature of the season and the length of the heating season, the concept of the heating degree days can be defined.

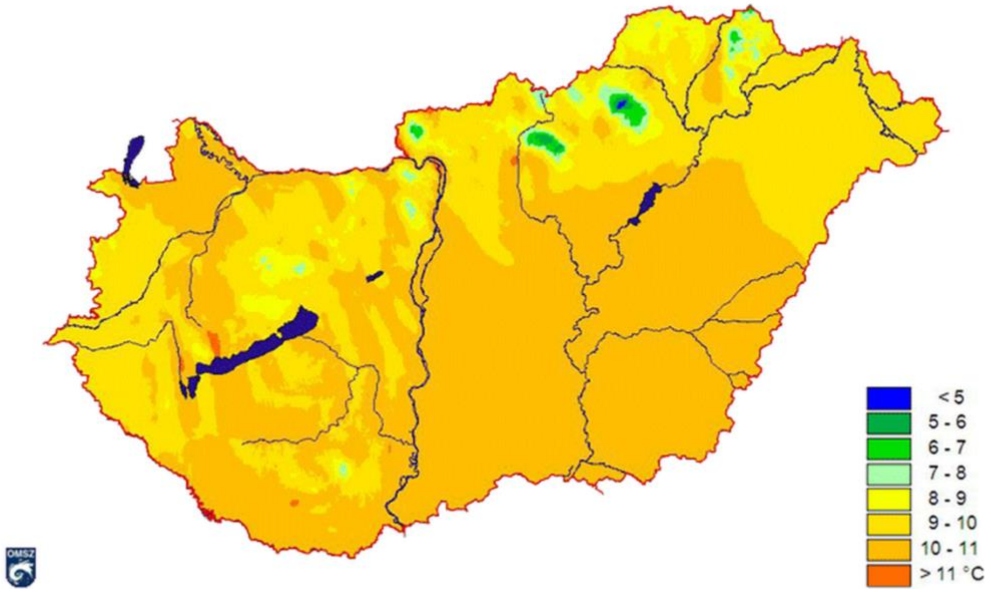

Figure 4.1.2.: Yearly average temperatures in Hungary

HEATING DURATION CURVE

In some cases, the heating demand is met by more than one heat generator in a joint (so-called bivalent parallel) or alternating (so-called bivalent alternative) operation, and the development of the temperature difference within the season is decisive for their operation schedule. An often-used solution is that in the coldest periods the so-called peak heat generators are put into operation because the primary heat generating equipment has been scaled to a lower load for economic reasons. Furthermore, the efficiency of some heat generating equipment at part load differs from the value characteristic of full load, and the frequency of part loads must be known in order to make an accurate energy assessment. Since the degree of load is roughly proportional to the temperature difference, the frequency of occurrence of outside temperatures is an important indicator which can be shown on a heating duration curve.

Figure 4.1.3 shows the annual heating duration curves for Budapest based on 30 year measurement data. The thick black curve shows the average temperature duration curve. At each intersection of the curve, it is possible to read the total number of days in a year with a given average temperature or less.

This type of processing is needed because it gives a monotonically increasing function, which is advantageous later when editing the heating degree days. The curve shows the number of days in a year with an average temperature below a certain outdoor temperature. Below 0 °C the curve becomes steeper and steeper. The number of days with an average temperature below -5 °C is below 10 days per year. It follows that the current heat demand only approaches the sizing value for a few days, the heat demand is much lower during most of the season. This also confirms that heat generators operate largely at partial loads.

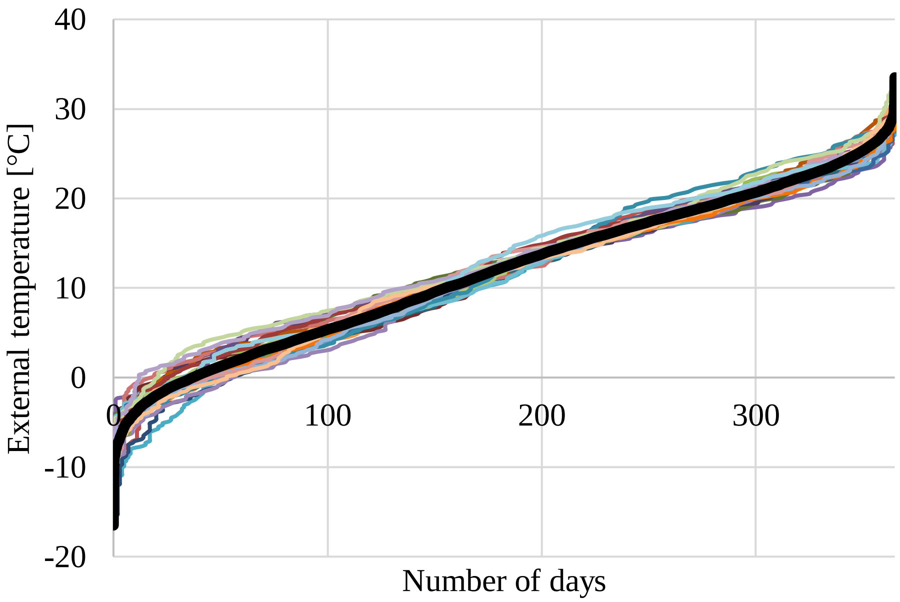

Figure 4.1.3.: Temperature duration curves in Budapest (1981-2010)

GROUND TEMPERATURE

Ground temperature in the near-surface layers is mainly determined by external factors on the surface, irradiation (depends on topography, slopes), surface absorption / emission factors, the shading effect of vegetation, the amount of water evaporating from the surface and evaporated by vegetation. Also depends on possible snow cover as well as the thermal conductivity of the ground. The temperature fluctuation of the surface and the layers close to the surface is large, in the deeper layers the temperature fluctuation decreases exponentially with the depth.

Moving towards the deeper layers, the role of surface factors decreases and the effect of the core heat of the ground becomes decisive. Beyond a depth of about 30 m, the temperature is constantly increasing, moving towards the interior of the Earth, regardless of the season. The extent of this is expressed by the geothermal gradient, the typical value of which is 3 °C/100 m on the ground average, and 5–7 °C/100 m in Hungary (see Figure 4.1.4).

Due to the high heat storage capacity of the ground and its relatively stable temperature, the transmission heat flows through the boundary structures in contact with the ground are smaller and more stable over time. The more stable ground temperature and the high heat storage capacity allow the ventilation air to be preheated in winter and pre-cooled in summer in the buried air ducts conducted in the ground. Also for some heat pump systems the source side is the ground layer close to the surface.

The properties of the uppermost (1-2 m) layers of the soil (vegetation cover, albedo, thermal conductivity, density, groundwater level) are decisive for the heat losses of the building and the efficiency of some soil collector systems (see Figure 4.1.5).

The depth range of 50-100 meters is the so-called drilling depth for ground source heat pump systems. The value of heat that can be extracted with ground probes is 50-80 W/m, i.e. 3-4 kW/probe for 50 m long probes and 6-8 kW/probe for 100 m long probes.

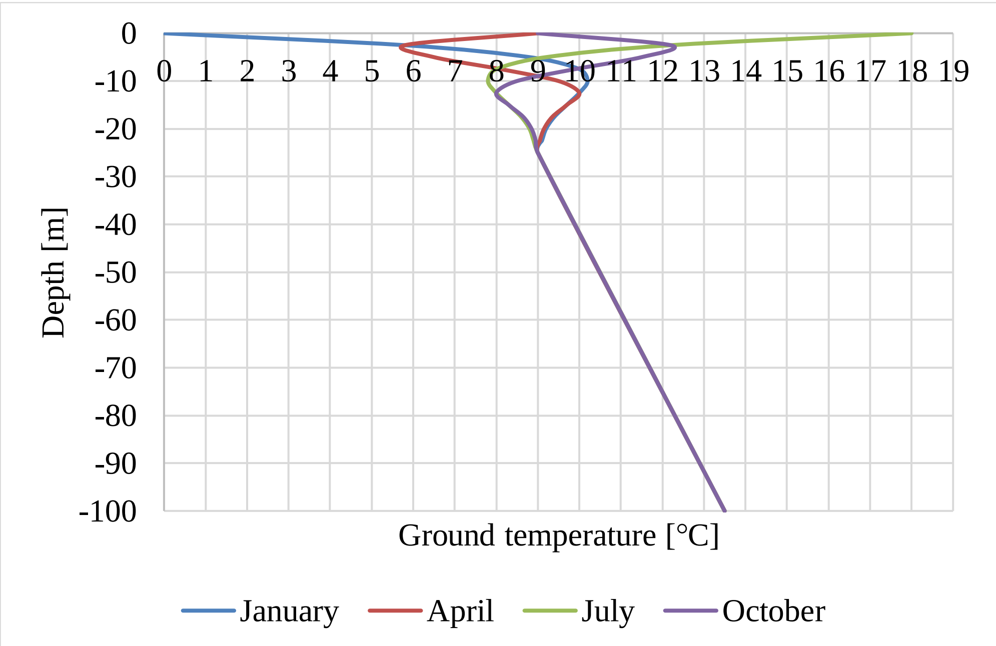

Figure 4.1.4.: Ground temperature in the function of depth and time of the year

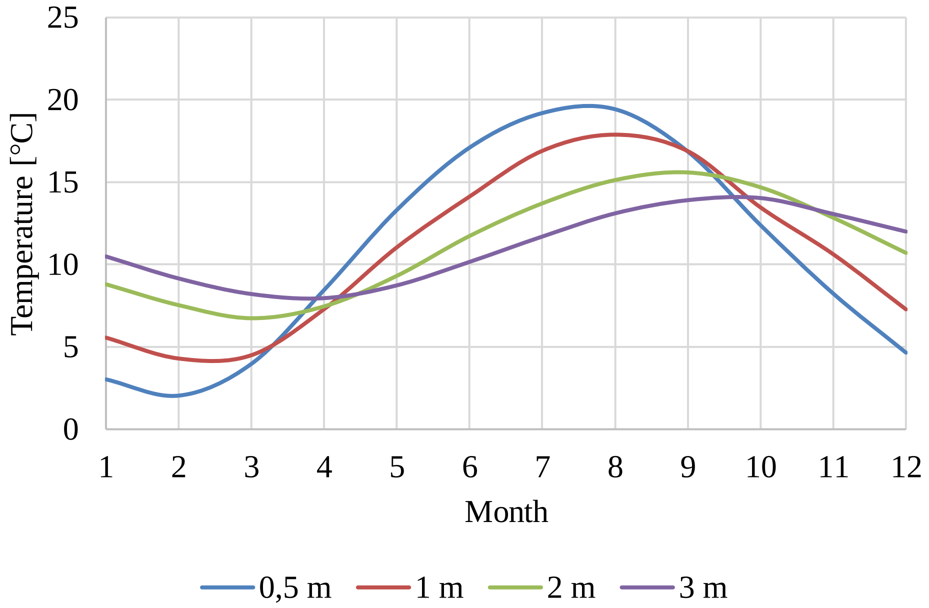

Figure 4.1.5.: Ground temperature in the function of depth and time of the year (close to the surface)

SOLAR RADIATION

RADIATION FUNDAMENTALS

Electromagnetic radiation: An energy flow from a source in any direction without a transmission medium, induced by the rapid oscillation of the electromagnetic field. It is transported by photons and propagates in space in the form of a wave. Oscillations can be characterized by the length of the waves.

Electromagnetic spectrum: All electromagnetic radiation can be arranged according to wavelength, then we get the electromagnetic spectrum, which is shown in Figure 4.1.6.

Shortwave radiation: The wavelength range (from 0.15 µm to about 3 µm) in which 99% of the energy emitted from the Sun falls.

Long-wavelength radiation: The wavelength range (3 µm to about 100 µm) in which 99% of the energy emitted from the Earth's atmosphere system falls.

Emission: Characterizes how efficiently a body radiates energy from a unit piece of its surface in a unit time relative to its maximum energy emission. Its value varies between 0 and 1, denoted by ε.

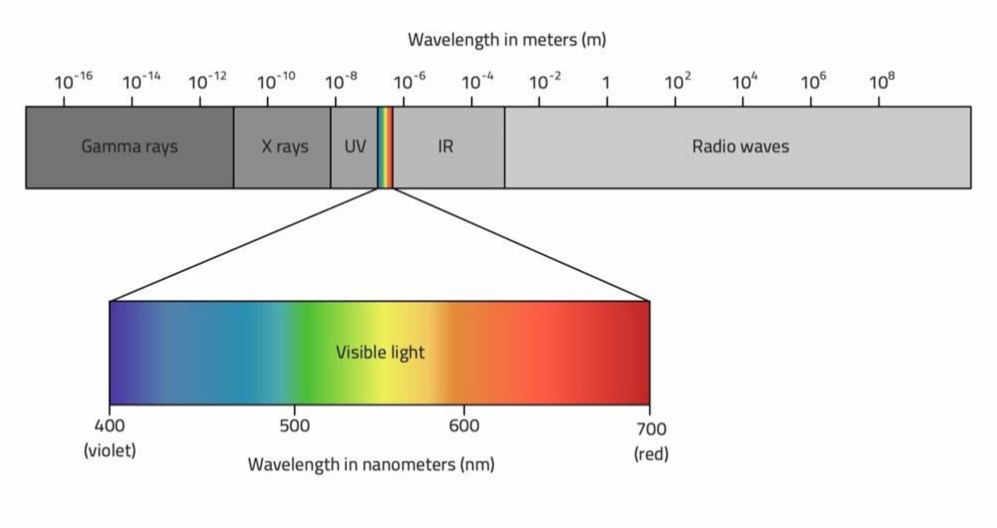

Figure 4.1.6.: The electromagnetic spectrum [https://www.radio2space.com/wp-content/webp-express/webp-images/uploads/2013s/07/components-of-electromagnetic-spectrum.jpg.webp]

Planck's Law: Planck's law states that the energy associated with a given wavelength is a function of wavelength and temperature. That is: $E\lambda = f(\lambda, T)$.

Kirchoff's law: It states that if a body emits e (λ, T) at a temperature T and a wavelength λ and absorbs a (λ, T) energy under the same conditions.

Black body: A body that emits the maximum possible energy from a unit piece of its surface at a given temperature in a unit time. The emission factor of such a body is $\varepsilon = 1$.

Stefan-Boltzmann's law: According to Stefan-Boltzmann's law, the total amount of energy radiated depends only on the absolute temperature of the radiating body, it is proportional to its fourth power:

$$E = \varepsilon \cdot \sigma_s \cdot T^4 = \varepsilon \cdot C_s \cdot \left(\frac{T}{100}\right)^4 \left[\frac{W}{m^2}\right] \qquad 1$$

where

σ_s – the absolute black body radiation constant (Stefan-Boltzmann constant, $5{,}67 \cdot 10^{-8}$ [W/m^2K^4])
C_s – the radiation factor of the absolute black body: 5,67 [W/m^2K^4]
T – temperature in [K]
ε – emission factor

Radiation intensity / flux: The amount of energy emitted, transmitted or absorbed per unit time. Sign: I or Φ. Unit: W, or specifically W/m^2.

Irradiation: the total radiant energy received by a surface unit over a period of time, measured in kWh / m^2 for the duration of irradiation (e.g. hour, day, year). Irradiation is actually the time integral of the radiation density incident on a surface.

Global radiation: all shortwave radiation from the upper half-space on the horizontal plane.

Diffuse radiation: all shortwave radiation from the upper half-space on the horizontal plane, except for the solid angle of the Sun's disk.

Direct radiation: shortwave radiation entering the surface perpendicular to the direction of the Sun from the spatial angle of the Sun's disk.

Global, direct, and diffuse radiation do not include radiation reflected by the earth's surface, which is characterized by albedo.

Albedo: In the of solar radiation, albedo (α) is the ratio of surface reflection to incoming shortwave radiation.

Daylight duration: the number that indicates how many hours the Sun has been shining during a period of time (hours, days, months, years, etc.). Sunshine means that the global radiation exceeds 120 W/m^2.

INCOMING SOLAR RADIATION

The energy yield of radiation is expressed in terms of radiation intensity (W/m^2). Outside the terrestrial atmosphere, the intensity of radiation fluctuates between 1300 and 1400 W/m^2 with an annual periodicity (extraterrestrial radiation). How much of this reaches a surface on the Earth's surface depends on the angle at which the radiation reaches the surface (since we can only count on the perpendicular component), i.e. it depends on the calendar and daily time (Figure 4.1.7), the orientation of the surface and tilt (Figure 4.1.8). It is also related to the angle of incidence how long the radiation must travel through the atmosphere (Figure 4.1.9), with a longer distance the intensity reaching the surface is lower. In the same way, the altitude of the site plays a role, as it affects the length of the journey in the atmosphere. The effects of water vapor, fog, clouds, poly-atomic gases, and atmospheric pollution are obvious - the latter alone can reduce the annual value of radiant energy yield by a few tens of percent.

The radiation reflected by the particles in the atmosphere – listed above – can no longer be characterized by such a definite directionality, this is diffuse radiation (in the case of a closed cloud, fog, almost only this arrives at the earth's surface). The particles absorb some of the radiation they receive and they themselves emit their own radiation at longer wavelengths. Finally, in some cases, radiation reflected from the surface (soil, snow, cover) can also play a significant role.

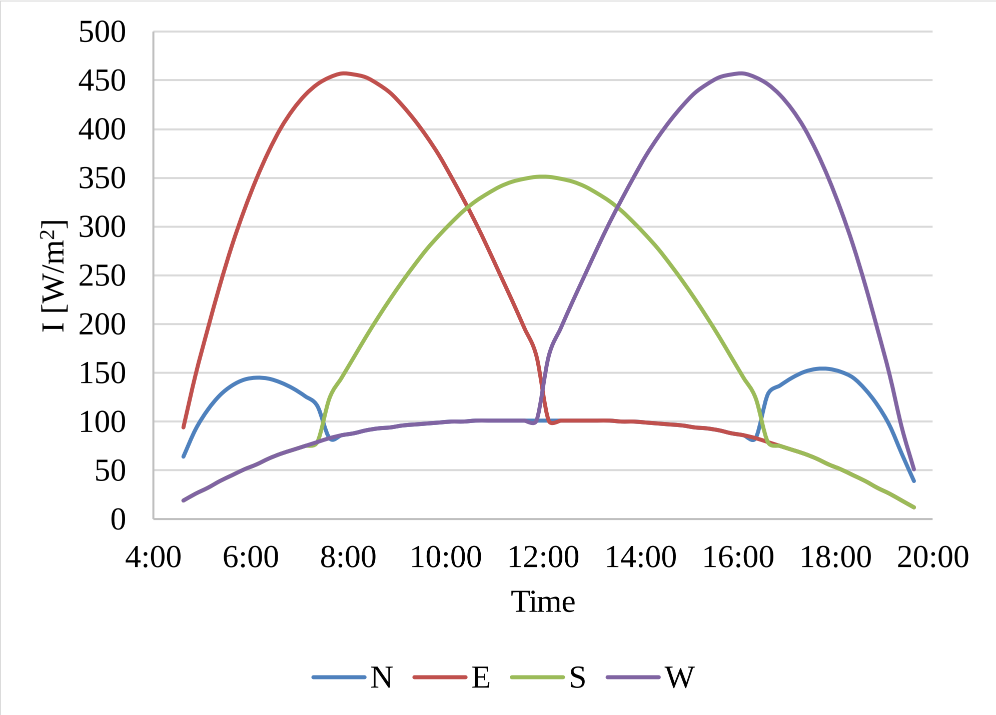

Figure 4.1.7.: Solar radiation intensity on vertical surfaces in June

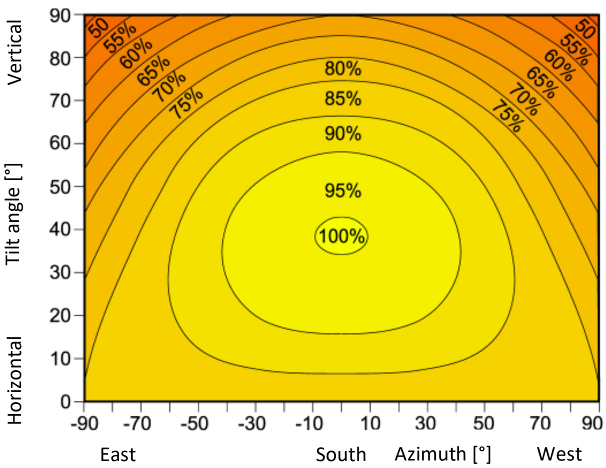

Figure 4.1.8.: Yearly incoming solar energy on tilted and oriented surface [Source: http://naplopo.hu/letoltes/naplopo-tervezessi-segedlet.pdf]

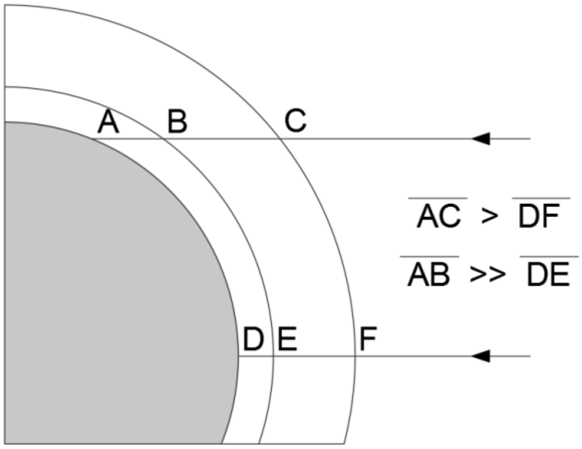

Figure 4.1.9.: Thickness of the atmosphere

Another important feature of radiation is irradiation, which is the total incoming energy over a period of time. For building energy calculations based on Hungarian statistical data, in case of surfaces with characteristic orientation and tilt angle, depending on the purpose, the data in Table 4.1.1, Table 4.1.2, Table 4.1.3 and Table 4.1.4 can be used.

Table 4.1.1.: Incoming solar radiation in the heating season for differently oriented and tilted surfaces

Purpose of the calculation	Tilt angle	Orientation				
		N	NE/NW	E/W	SE/SW	S
Incoming radiation in the heating season to calculate the net heating demand Q_{TOT} [kWh/m^2/a]	0°	325				
	30°	195	230	315	400	435
	45°	155	195	300	410	460
	60°	130	165	275	400	460
	90°	85	105	200	320	400

Table 4.1.2.: Average radiation intensity at the beginning of the heating season

Purpose of the calculation	Tilt angle	Orientation				
		N	NE/NW	E/W	SE/SW	S
Average radiation intensity at the beginning of the heating season to calculate the length of the heating season I_{winter} [W/m^2]	0°	100				
	30°	45	65	95	125	140
	45°	40	55	90	130	150
	60°	35	45	85	125	150
	90°	25	30	60	100	125

Table 4.1.3.: Maximal daily average radiation intensity in summer

Purpose of the calculation	Tilt angle	Orientation				
		N	NE/NW	E/W	SE/SW	S
Average radiation intensity on a hot summer day to calculate the risk of overheating I_{summer} [W/m²]	0°	245				
	30°	205	210	230	245	245
	45°	170	180	215	230	230
	60°	130	155	195	205	205
	90°	70	100	135	140	140

Table 4.1.4.: Incoming solar radiation in the cooling season for differently oriented and tilted surfaces

Purpose of the calculation	Tilt angle	Orientation				
		N	NE/NW	E/W	SE/SW	S
Incoming radiation in the cooling season to calculate the net cooling demand $Q_{TOT,summer}$ [kWh/m²/év]	0°	675				
	30°	530	560	635	685	700
	45°	420	485	595	650	660
	60°	310	405	530	590	595
	90°	170	260	370	400	375

GEOMETRY OF THE SUN'S PATH AND SHADOW CALCULATION

The Earth is in a position around the Sun (due to the skewness of the Earth's axis of rotation) twice a year (spring and autumn equinoxes) when the northern and southern hemispheres are equally sunlit. In the intervening periods, one hemisphere is more sunny than the other (this is the reason for the change of seasons), and extreme situations are the solstice days of winter and summer (Figure 4.1.10 and Figure 4.1.11).

Viewed from Earth, the position of the Sun in the sky is given by two angles. Solar altitude is the angle measured from the horizontal in the vertical plane, azimuth is the angle measured in the horizontal plane relative to a preferred direction. As a privileged direction, both south and north occur in various publications and aids. A schematic of the angles is presented in Figure 4.1.12.

Viewed from Earth, the angle of inclination of the apparent solar planes measured from the vertical is equal to the latitude of the given geographical location.

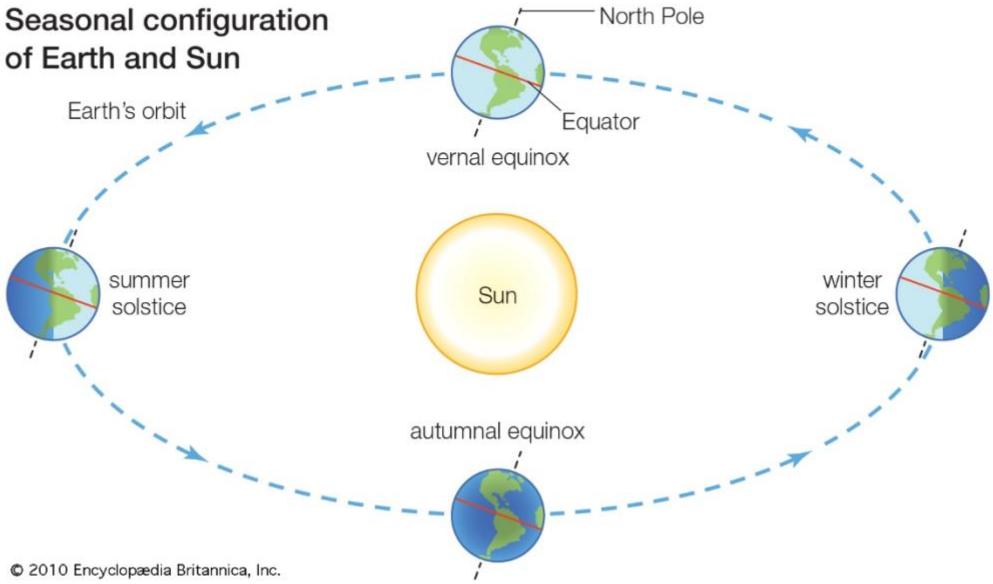

Figure 4.1.10.: Earth's orbit around the Sun (Source: https://cdn.britannica.com/68/91868-050-F9D480C2/Diagram-relation-position-Earth-Sun-season-Northern.jpg)

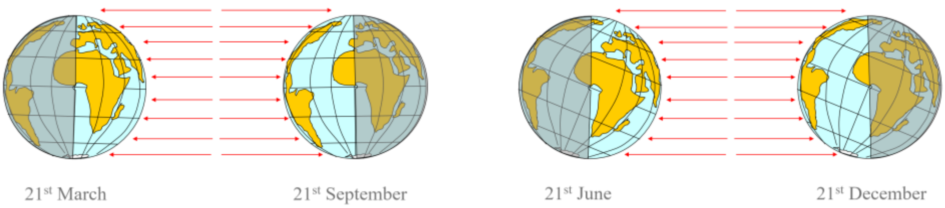

Figure 4.1.11.: Position of the Earth at the equinoxes and solstices

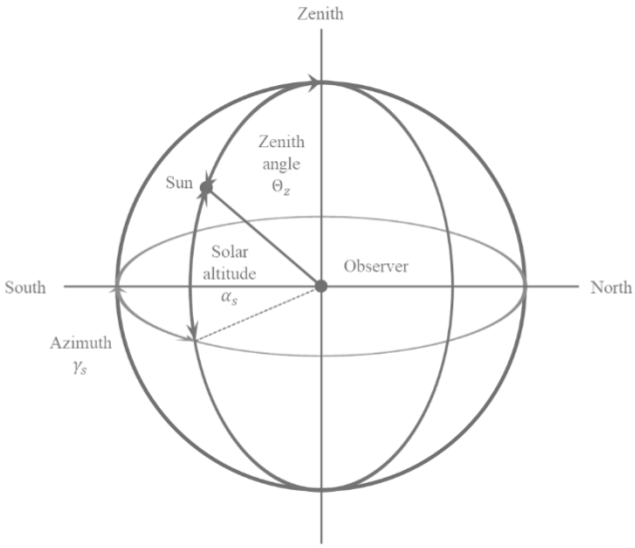

Figure 4.1.12.: Position of the Sun

For design purposes, we can map the apparent orbit of the Sun in the form of daytime diagrams. One version of this is the cylindrical projection. Following the movement of the Sun, he draws a line on the mantle of the cylinder with the gaze of the observer in the centre of the base circle (Figure 4.1.13), recording the date of observation and the points of the round clock (astronomical) times along the line. The cylindrical projection is obtained by cutting and spreading the cylinder along its northern component. In this, the curves belong to the representative days of the months, on the horizontal axis we can read the azimuth angles measured from the southern (privileged) direction, and on the vertical axis we can read the elevation angles. The day lines are crossed by the clock lines. From the chart, you can read the angles that indicate the position of the Sun for any day of the year and any hour of the day. A cylindrical sun path diagram is shown in Figure 4.1.14.

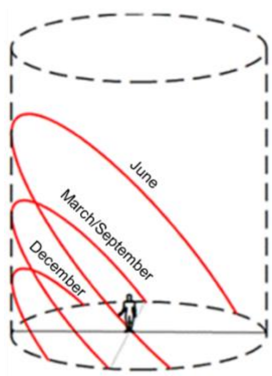

Figure 4.1.13.: Cylindrical sun path registration

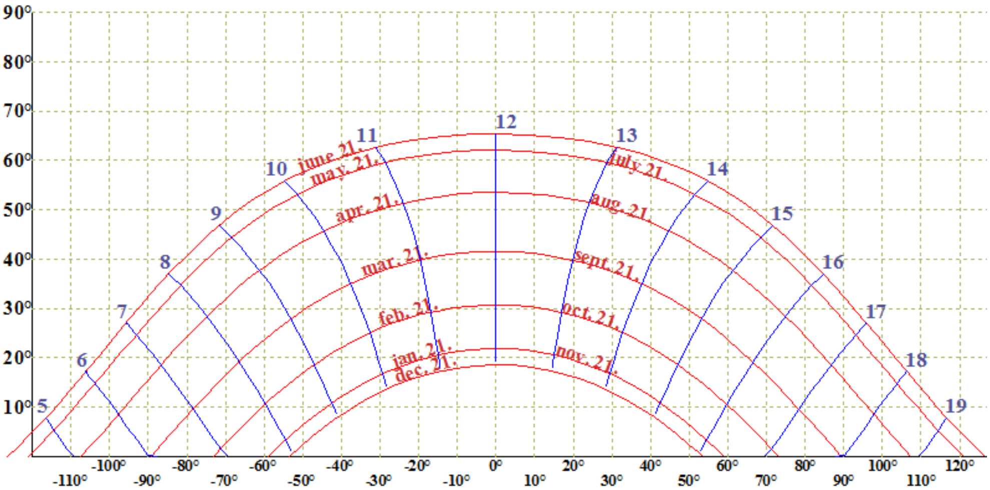

Figure 4.1.14.: Cylindrical sun path diagram

Another option of projecting the Sun's movement is spherical, of which in the stereographic projection. (The observer here observes the apparent movement of the Sun from the South Pole, his gaze draws the lines of the orbits on the spherical surface). In this diagram, the azimuth angles are seen along the circumference of the circle, and the solar altitude angles are written on the concentric circles. The curves also belong to the representative days of each month, and we also find the clock lines that cross them (Figure 4.1.15).

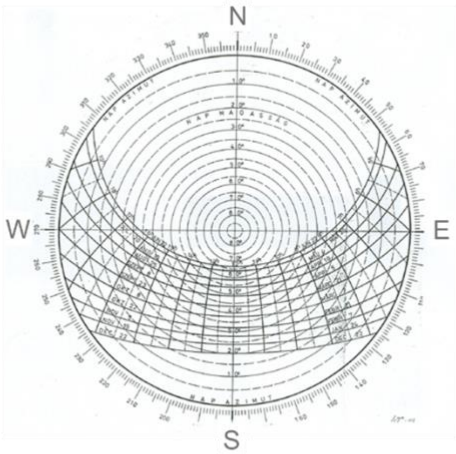

Figure 4.1.15.: Stereographical sun path diagram

On the clock charts, the clock time is the solar time: it is noon when the Sun is at the highest point of its orbit. However, this is point by point along the perimeter of the Earth, at different times per meridian. The clocks show the so-called zone times. The Earth's surface is divided into 24 spherical bisectors – each measuring 15 degrees longitude along the perimeter. The time shown by the clock in the centre line of a spherical duplex is the same as the astronomical time. In places east of the midline in the zone, the Sun is "early", to the west "late" by 4–4 minutes per longitude. It should be noted that the boundaries of the time zones are sometimes aligned with the administrative boundaries.

A further minor correction can be made due to the uneven orbital velocity of the Earth. Finally, a correction is needed if the clocks are adjusted sixty minutes ahead due to daylight saving time.

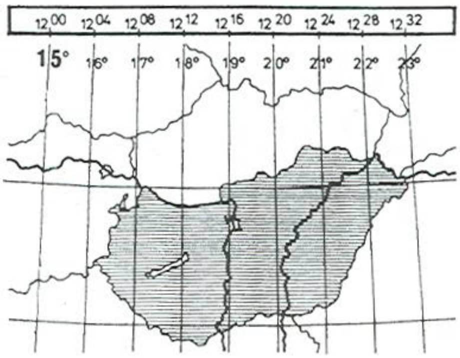

Figure 4.1.16.: Time correction due to the longitude lines in Hungary

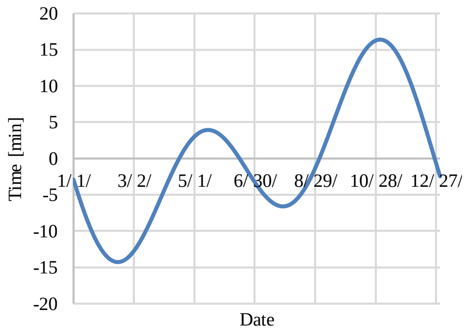

Figure 4.1.17.: Correction for the uneven movement of the Earth

To decide whether an energy-collecting surface (window, solar collector, PV panel) can be exposed to direct solar radiation on a given day and hour, additional geometrical considerations are needed: the question is whether there is anything between the surface under study and the Sun that prevents them from "See each other."

One such obstacle could be a ledge. Looking out of the window in a direction perpendicular to the façade plane, we see the edge of the ledge at some angle (measured in a vertical plane). If we turn to the side, this angle changes, it becomes smaller (Figure 4.1.18). Plotting this as a function of the angle of turn to the side gives a mapping of the edge of the ledge. Such edge-forming curves can be made in advance, specifying as a parameter the number of degrees below which we see the edge measured in a plane perpendicular to the plane of the façade.

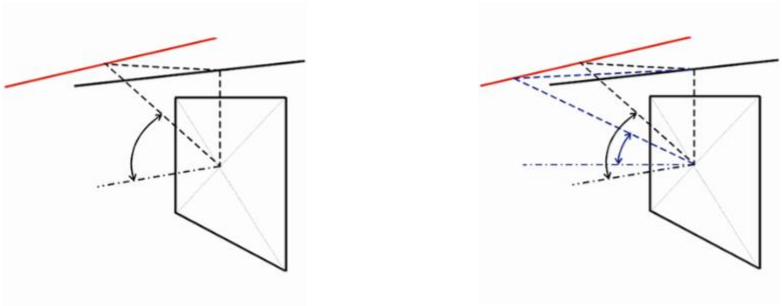

Figure 4.1.18.: Development of shadow edge curves

Between the Sun and the point under study, the thing hindering "mutual visibility" is bounded by horizontal edges – this can be represented by horizontal shadow edge curves (Figure 4.1.19). In the case of vertical edges, the shadow edge curve is also vertical in the shadow mask diagram (e.g., Figure 4.1.20). If this figure - the shadow mask - (drawn on a transparent substrate) is overlapped with a cylindrical clock diagram drawn on the same scale, it can be seen in which months and at what intervals the examined point is in shadow (Figure 4.1.21, Figure 4.1.22).

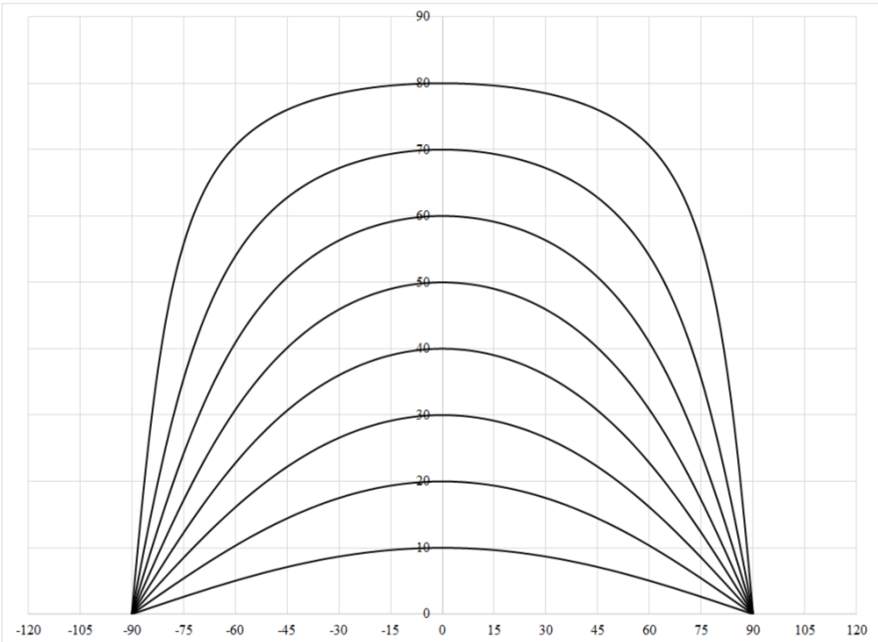

Figure 4.1.19.: Shadow edge curves for a cylindrical sun path diagram

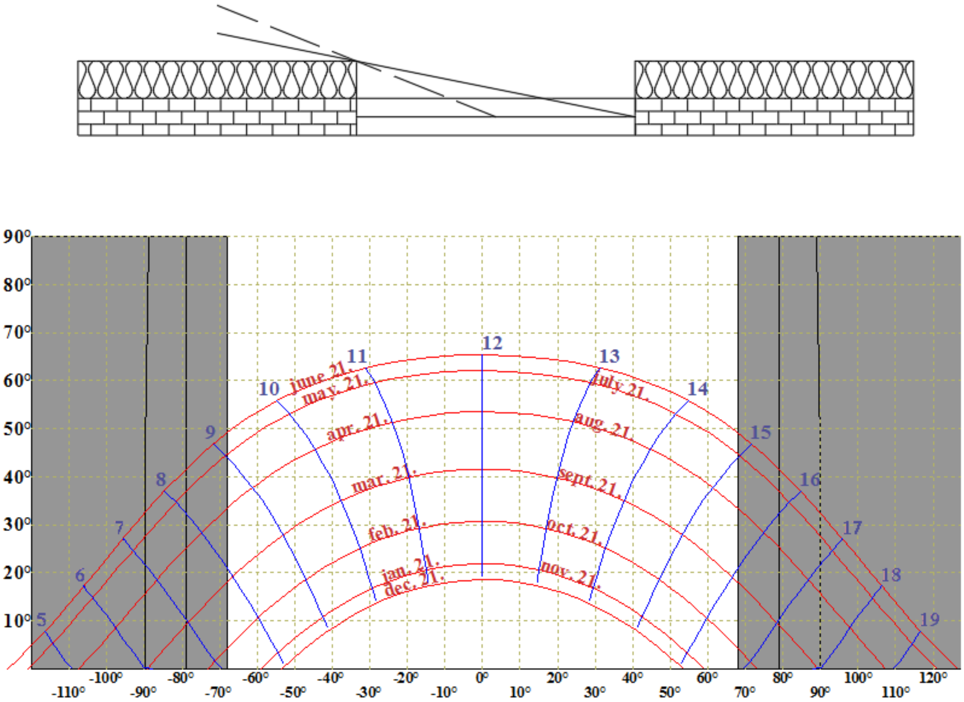

Figure 4.1.20.: The sky is not visible from the shadow edge outwards.

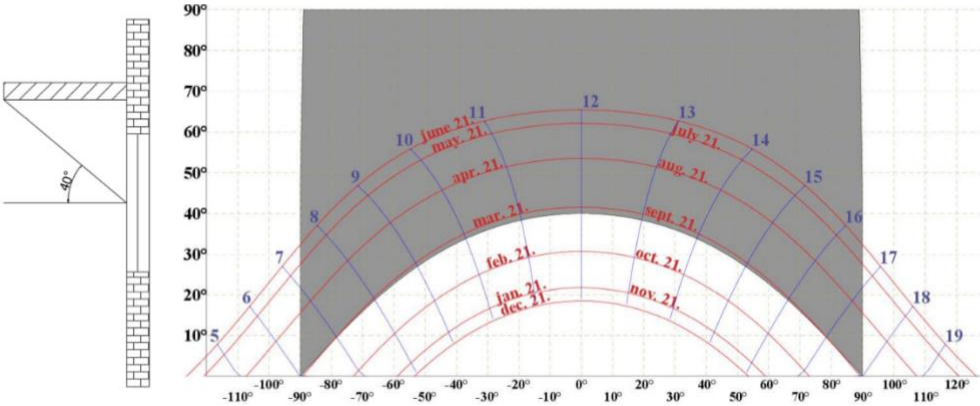

Figure 4.1.21.: The sky is not visible from the shadow edge upwards.

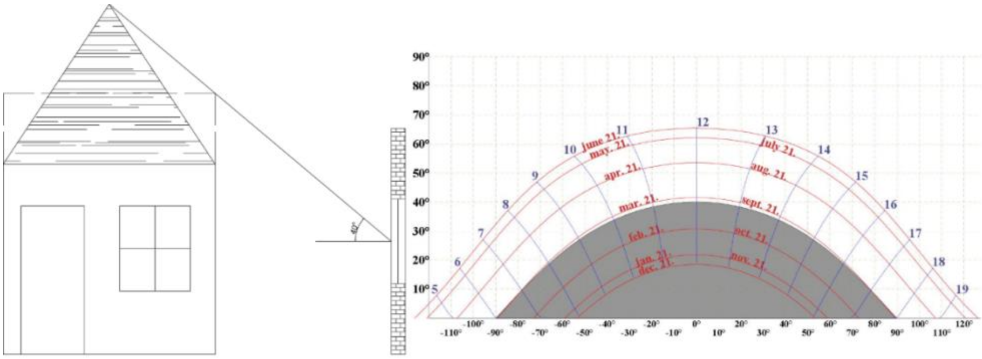

Figure 4.1.22.: The sky is not visible from the shadow edge downwards.

If the surface is oriented to the south, then the zero point of the horizontal axis of the shadow edge curves and the zero point of the axis of the sun path diagram are overlapping. If the orientation of the examined surface is different from the south, then the zero point of the horizontal axis of the shadow edge curves is overlapped with the point in the direction in which the normal of the wall – the azimuth of the wall – points (Figure 4.1.23).

In case of a stereographic sun path diagram, the shadow protractor plays a similar role, its curved lines show the angle at which the edge appears (measured in a vertical plane perpendicular to the façade), the diameter is laid through the centre of the stereographical sun path diagram so that the diameter lies in the façade line. The solid angle obscured by the obstacle is denoted by the curved lines (height) and the radians (angular range measured in a horizontal plane).

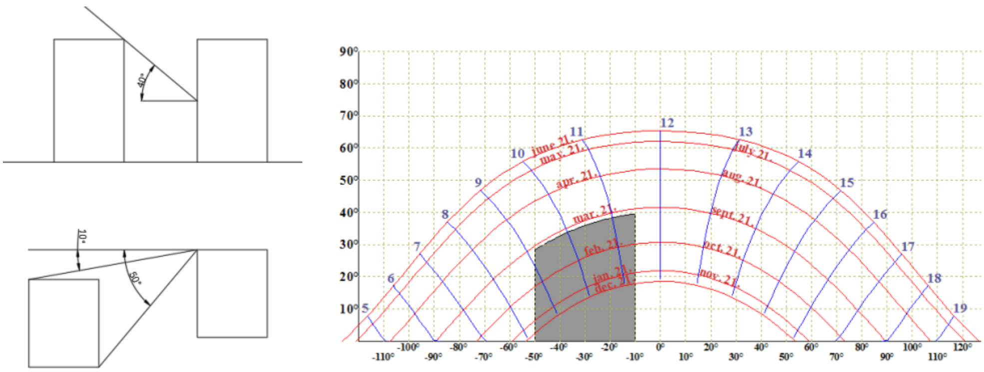

Figure 4.1.23.: By combining the horizontal and vertical shadow edges of different objects the shadow mask can be sketched.

Sky visibility can be represented in a coordinate system like a shadow protractor: rays indicate the edges of objects (the obscured horizontal angle range), and concentric circles indicate the edges delimiting the height (the obscured vertical angle range) when viewed from the center upwards. A similar image is obtained when photographing with an upwardfacing fisheye optic (Figure 4.1.24, the drawing and the photograph do not show the same space).

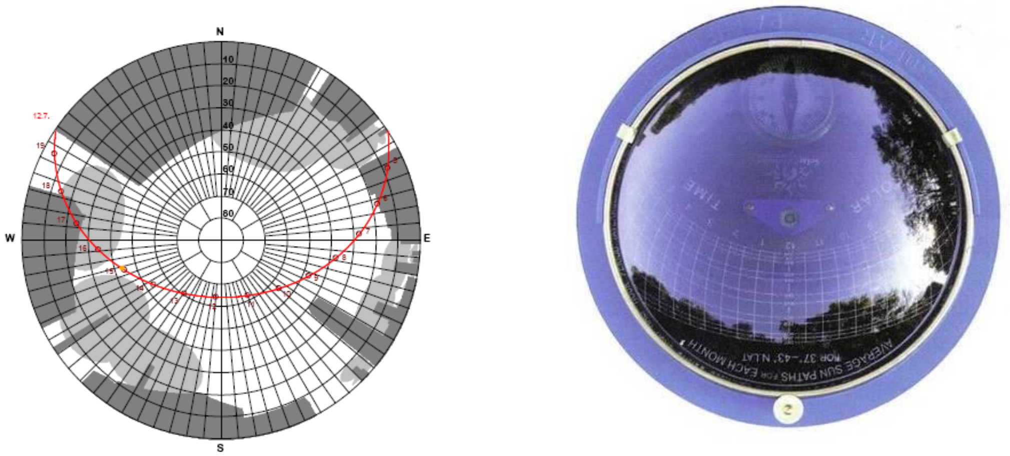

Figure 4.1.24.: Shadows displayed on a stereographical sun path diagram (Source: Planning and Installing Photovoltaic Systems)

The condition for the utilization of the solar gain in the heating season is that the energy-collecting surfaces are sunny during the winter months at noon. In the period indicated in Figure 4.1.25, the “solar window” should be “open”, no shadow should fall on that area.

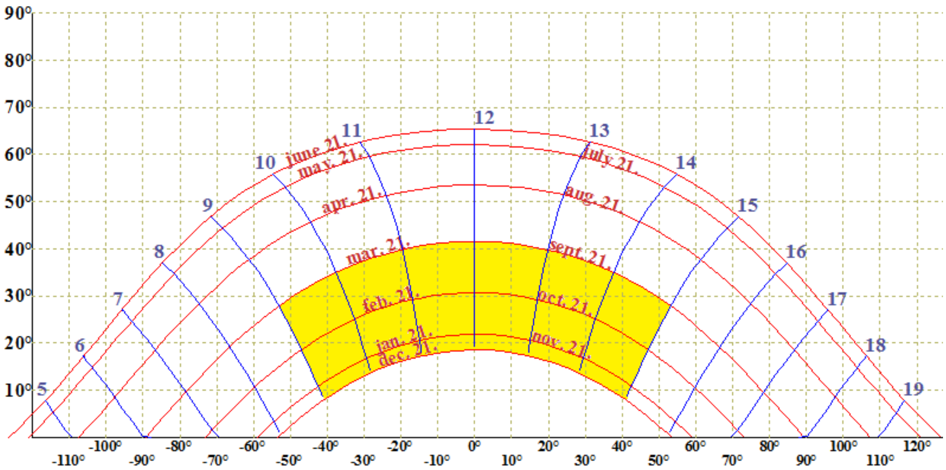

Figure 4.1.25.: Solar window

WIND

Wind is the movement of air relative to the Earth's surface. Generally, wind refers to movement in horizontal direction. If we want to emphasize the vertical movements separately, we are talking about convection.

The wind is a vector quantity, which has direction and speed. The direction of the wind is the quarter from which the wind blows. This vector has an average direction (dominant wind direction) and an average magnitude. Averages with different averaging times give different values.

The deviation of the instantaneous value from the average value can be characterized by the standard deviation of the deviations. This standard deviation is characterized by fluctuations: the level of turbulence. Its value relative to the mean is the turbulence intensity, which is sometimes given as a percentage.

The highest speed that occurs in the register is the so-called peak wind gust speed. The ratio of peak wind gust speed to average speed is called gust factor. Meteorological records show average hourly speeds as an average. It is also good to know about the top speed, that it is not an instantaneous value (since it is difficult to measure and has little effect) but an average of 2 to 3 seconds. The peak speed of an hourly register is thus the highest of the 2 to 3 second averages.

It is usually characterized by the speed of the slice and the frequency of occurrence of each wind speed interval. Being the velocity vector quantity, the previous data are given for different directions (usually for the four main and four secondary quarters), for the whole year, for the seasons, or for each month. The length of the rays is proportional to the frequency of the wind direction, the line thickness within this is proportional to the speed intervals (Figure 4.1.26).

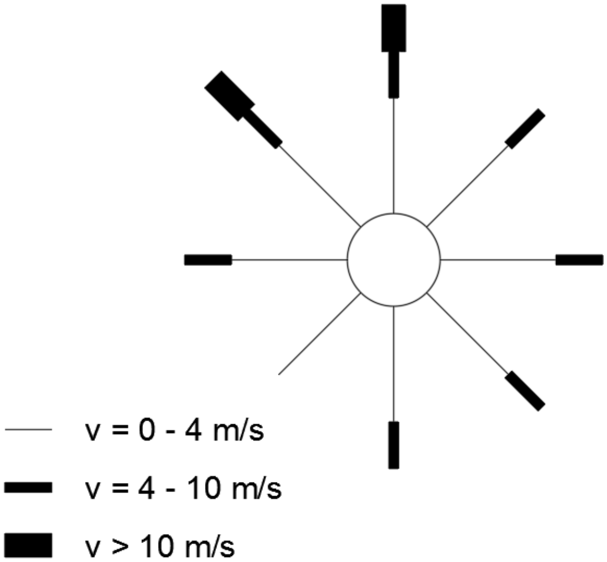

Figure 4.1.26.: Representation of the frequency of wind directions

Wind data are usually measured outside of densely built-up areas (e.g. airports) at an altitude of 10 m. The wind speed varies as a function of soil roughness ("roughness" refers to vegetation, buildings), as a function of height, approximately according to a parabola. In settlements, buildings significantly influence the direction and speed of the wind (Figure 4.1.27).

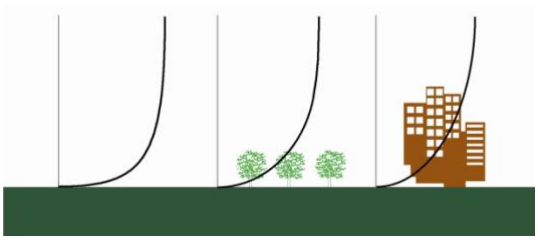

Figure 4.1.27.: A Wind speed in function of height, showing the impact of buildings on wind speed in the function of height

URBAN CLIMATE

A particular consequence of human intervention is the "city heat island." Urban development can be characterized by a significantly different energy balance compared to free areas. The urban climate depends on the structure, topography, geographical location, size, nature of the industry, etc. in the city.

Compared to the undeveloped environment, there is usually less direct radiation to the surface due to air pollution, but the radiation absorbed by the surface also changes due to city-wide roughness (buildings) and artificial coverings, snow removal. Evaporation is lower due to drainage from paved surfaces. Emissions of surfaces to the sky are significantly lower due to air pollution on the one hand and more limited sky visibility on the other. Heat flows from buildings in both winter and summer "heat the street". Because of all this, the temperature is rising towards the city centre. In the periphery, this increase is not significant, it is usually negligible, approaching the centre it can reach 4 °C/km in some sections. The structure of the heat island is strongly influenced by parks, lakes ("cold islands") and densely built-up areas ("warm islands"). The difference between the maximum temperature measured in the city centre and the temperature outside the city is the intensity of the urban heat island. This intensity is maximum (under stable atmospheric conditions) a few hours after sunset and minimal around the middle of the day.

In the winter season, the urban heat island is less of a problem: if the "street" is warmer, the heat loss of the buildings will be lower, if the buildings give off less heat, the intensity of the heat island will decrease, more heat will escape from the buildings. In summer, however, a dangerous self-excitation process develops: the heat leaving the buildings (the heat from the heat loads leaves the building in summer with transmission and ventilation!) heats the already hot street: even higher temperatures inside the building allow the heat to escape from the building if there is mechanical cooling, i.e. the heat extracted from the building will enter the environment through the condensers and cooling towers on the facade or top of the building, which have a higher temperature than the interior of the building. Also the space under the roof layer is warmer, which further increases the cooling demand.

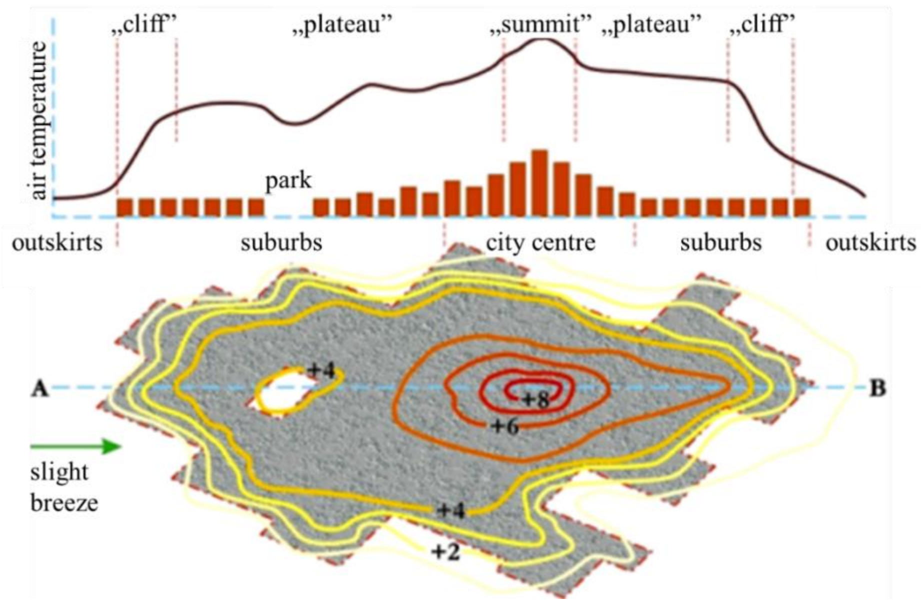

Figure 4.1.28.: The temperature distribution in the urban heat island (Source: Unger, J.: Lokális és mikroklímák. JATE TTK, Éghajlattani és Tájföldrajzi Tanszék, Szeged, 1997, 135–153)

The role of the wind is unclear in determining the heat island effect. In the city centre with a higher temperature, an upflow develops, which induces the so-called urban breeze from the suburban areas towards the city centre. The resulting wind also varies due to the variety of obstructions (buildings, trees etc.): the average speed is lower, but in some cases it is higher in the spaces between the buildings due to the channel effect. In cities both such "canals" and green cooling areas are important to reduce heat in the cities.

HEATING DEMAND FUNDAMENTALS

THERMAL BALANCE OF A ROOM

The energy balance of heating and cooling of buildings can be determined by algebraic summation of several terms. In the following part a short overview is given describing the key elements.

Heat loss in transmission: the sum of the energy flows through the building envelope through heat transfer:

$$\dot{Q}_{tr} = \sum \left(A_j \cdot U_j + l_j \cdot \psi_j \right) \cdot (\Theta_i - \Theta_e) = \sum \left(A_j \cdot U_{j,average} \right) \cdot (\Theta_i - \Theta_e) \; [W] \qquad 2$$

where:

A is the surface area
U is the thermal transmittance of the structural element
Ψ is the linear thermal transmittance for thermal bridges
l is the length of the thermal bridge
Θ is the temperature, i=internal, e=external

Ventilation heat demand: energy flow removed from the room by:

$$\dot{Q}_{vent} = 0.35 \cdot ACH \cdot V \cdot (\Theta_i - \Theta_e) \; [W] \qquad 3$$

where:

0.35 is a constant taking into account the specific heat and density of the air and the necessary unit conversion.
ACH is the air change rate
V is the heated volume of the building
Θ is the temperature, i=internal, e=external

Solar gains through glazed surfaces:

$$\dot{Q}_{sol} = A_g \cdot g_j \cdot I_j \; [W] \qquad 4$$

where:

A_g is the glazing area
g is the glazing's heat transmittance coefficient
I is the incident solar radiation on the surface

Internal heat load: energy flow from non-heating sources (e.g. lighting, household appliances, people): $\dot{Q}_{internal}\;[W]$.

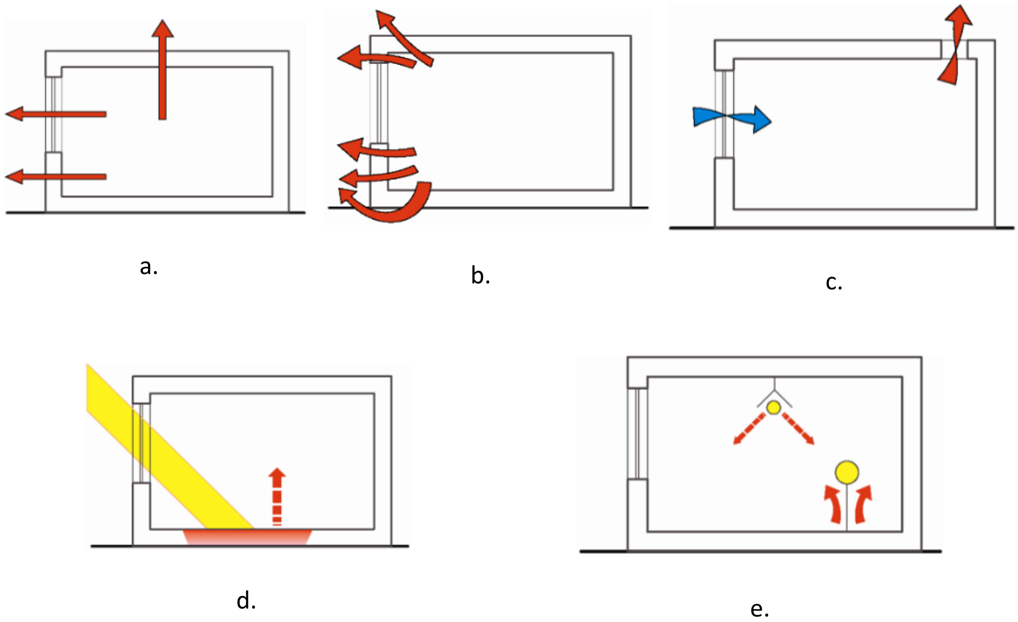

Figure 29.: Heat loss and gain components of a room (Transmission losses (a&b), Ventilation losses (c), Solar gains (d) and Internal gains (e)

Balance condition when there is no heating/cooling in the building:

$$\dot{Q}_{tr} + \dot{Q}_{vent} + \dot{Q}_{sol} + \dot{Q}_{internal} = 0 \; [W] \qquad 5$$

The equation includes an algebraic summation, some components are positive and others are negative, depending on the current weather and operating conditions.

This balance is always formed – the only question is at what internal temperature.

If the building also has cooling or heating, the formula is modified as follows:

$$\dot{Q}_{tr} + \dot{Q}_{vent} + \dot{Q}_{sol} + \dot{Q}_{internal} \ = \dot{Q}_{H/C} \ [W] \qquad 6$$

where

$\dot{Q}_{H/C}$ [W] – the net heating heat demand or cooling load.

Let's go back to the case of the unconditioned space. In this context, two terms ($\dot{Q}_{tr}$ and $\dot{Q}_{vent}$) depend on the difference between the indoor and outdoor temperatures. By writing each term of the equation with the above relations, the difference between the internal and outside temperatures can be expressed:

$$\Theta_i - \Theta_e = \frac{A_g \cdot g_j \cdot I_j + \dot{Q}_{internal}}{\sum(A_j \cdot U_{j,average}) + 0.35 \cdot ACH \cdot V} \qquad 7$$

This results in an expected "spontaneous" internal temperature in a building without heating and cooling in a steady state. It is not suitable for calculating instantaneous values because it does not take heat storage into account, but for calculating the average internal temperature of a day or a few consecutive days (of course, the outdoor temperature is also taken into account with its average value for the same period).

Some of the members of the algebraic sum to the left of Equation 6 are functions of the architectural concept and / or building structure solutions, while others are independent of the building.

Transmission heat loss is not only a matter of building structure (thermal insulation), but also of architecture, as it depends not only on the heat transfer coefficient, but also on the size of the surfaces covering the heated space. In other words, compact or agile mass formation is, among other things, an energy issue. Due to the ratio of the heat transfer coefficients of conventional window and partition structures, of course, the ratio of glazing is also related to the transmission losses.

The linear heat losses caused by thermal bridges depend in part on the design of the junctions, so in this respect it is a question of building structure. At the same time, the mass formation of the building, its facade sections, balconies, loggias, and the internal space distribution determine the length of the corner edges, connecting edges, thermal bridges, so in this respect the problem is also architectural.

The volume flow of the ventilation air – which can also be expressed in other ways by the number of air changes – must not be less than the value determined from the point of view of health, safety and security.

In the winter season, the goal is to provide the required fresh airflow (in other words, the number of air changes) and only that (more air change than necessary would result in higher heating demand). In the summer season, however, the main goal is to increase the ventilation heat loss of the building in the night-time by increasing the air exchange rate (reducing the internal temperature) in order to create a pleasant internal temperature even without artificial cooling.

Spontaneous air exchange (filtration air exchange) when the windows are closed is usually less than required, so manual/mechanical ventilation is needed to ensure the minimal air exchange, i.e. if the air tightness of the building is satisfactory, there is no need to reduce the ventilation energy demand by further improving the air tightness. However, with building construction tools, the air exchange required from the point of view of structural protection and thus the ventilation heat demand can be reduced by creating good junctions, i.e. by reducing the risk of mold formation and condensation.

Since the volume flow of ventilation air cannot be reduced below the minimal air exchange rate, the possibility of energy savings can only be sought from where and from what source we take the energy needed to heat the fresh air with the given volume flow or at least a part of it.

When it comes to architectural tools, preheating fresh air in unheated spaces, buffer zones, solar system components offer such savings. Here, we essentially utilize either the already described "losses" or the energy of solar radiation. This floor plan is related to the organization of the spatial connections, the arrangement of the doors and windows, and the use of the appropriate solar system components.

From a structural point of view, the number and type of glazing, the window division and the shading structures play a decisive role. The latter include movable associated structures as well as fixed shaders and the facade sections and balconies of the building.

Solar gains are a function of many architectural and building structure factors. The mass formation, orientation and glazing ratio of the building are primary. The conditions for solar access also depend on the street lines, the division of land, the surrounding development, the terrain and the vegetation, so there are also issues at the level of urban architecture.

From a structural point of view, the number and type of glazing, the window division and the shading structures play a decisive role. The latter include movable associated structures as well as fixed shaders and the facade sections and balconies of the building.

The issue of radiant heat gain is twofold: the solar gains should cover as much of the heating and lighting energy demand as possible in the winter season, while it is important to reduce the solar gains in the summer to reduce the cooling demand of the building. Thus, during the planning, it is necessary to consider the needs of the winter and summer periods at the same time, to find balanced compromises.

HEATING DEGREE DAYS, BALANCE POINT TEMPERATURE, LENGTH OF THE HEATING SEASON

Figure 4.1.30 shows the outdoor temperature as a function of time for the winter season (not interrupted at the end of the calendar year). The area between Θ_i and Θ_e curves is proportional to the amount of heat leaving the building into the environment. The heat loss is flows are covered by three sources. The internal heat gain can be considered constant throughout the heating season, the solar gains change during the heating season. The utilized fraction of these two covers the losses with a certain (Θ_i – Θ_e) temperature difference so that the internal temperature does not fall below the desired value, it takes the desired value when Θ_e = $\Theta_{balance\ point}$ outdoor temperature at which the heating operation must be started or stopped, i.e. the heating limit temperature. Projecting the intersection points on the horizontal axis gives the length of the heating season. The difference between the outdoor and indoor temperatures is the balance point temperature difference at the moment of the start of heating, which is derived from Equation 7 taking the radiation values from Table 4.1.2.

The value of that temperature in case of poorly insulated buildings is approx. +12 °C in Hungary. In a well-insulated building, this can be significantly lower, even below freezing. In case of heavyweight buildings, due to the large heat storage capacity, the start of the heating season is calculated from the moment when the outside temperature falls below the heating limit temperature for three days.

Subtracting the areas proportional to the gains from the area between the Θ_i and Θ_e curves gives the area proportional to the net heating energy demand (Figure 4.1.31).

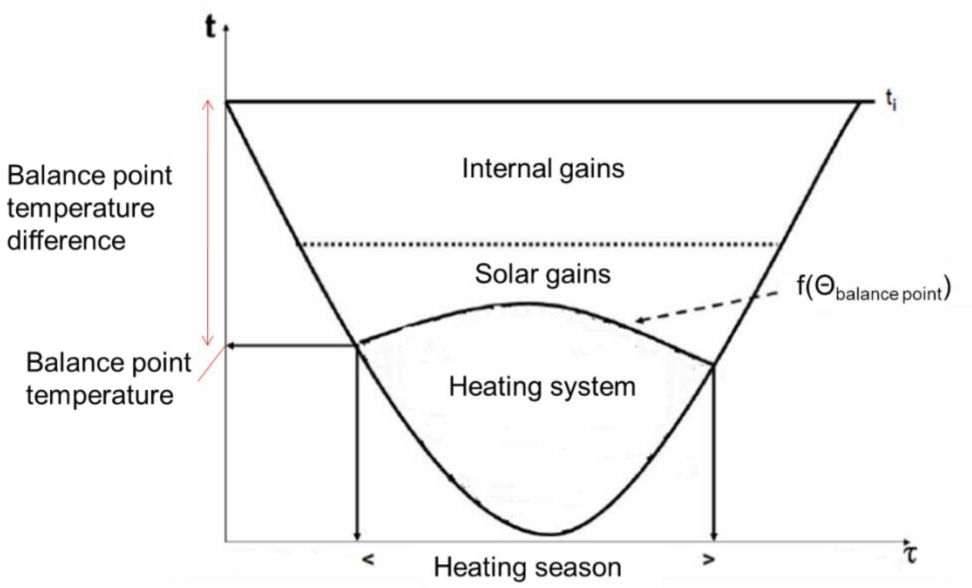

Figure 4.1.30.: The balance point temperature and length of the heating season

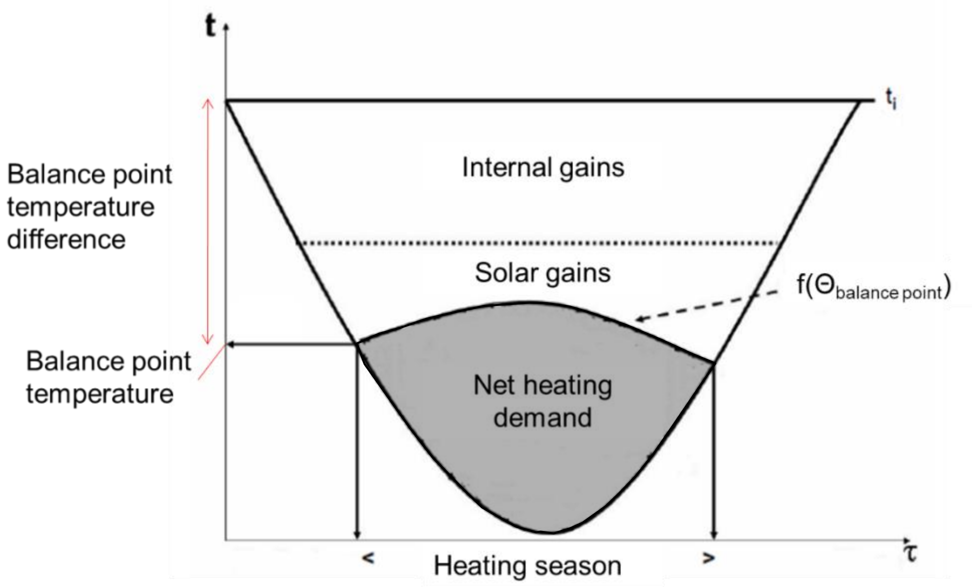

Figure 4.1.31.: Net heating demand of the building (gray area)

If the difference between the required indoor and expected outdoor temperature as a function of time is integrated over the duration of the heating season the heating degree days can be calculated (Equation 8), which can be also shown in the diagram, see Figure 4.1.32. In a similar way, we can interpret the HDD not only for the heating season, but also for a month or a day. The HDD is proportional to the heat loss for the season. The value of the HDD, naturally depends on the internal temperature you want to maintain.

The HDD can be determined by the following formula if the internal temperature is constant:

$$HDD = \sum_{j=1}^{n} \left(\Theta_i - \Theta_{e,j}\right)\ [day°C\ or\ h°C] \qquad 8$$

where

n $[day]$ or $[h]$– the number of days (hours) during the examined period
Θ_i [°C]– the internal temperature (assumed to be constant in this case)
$\Theta_{e,j}$ [°C]– the average of the outside temperature of j. days / hours
In practice, we often use the following formula:

$$HDD = n \cdot (\Theta_i - \bar{\Theta}_e)\ [day°C\ or\ h°C] \qquad 9$$

where

$\bar{\Theta}_e$ [°C] – the average of the outside temperature during the examined period

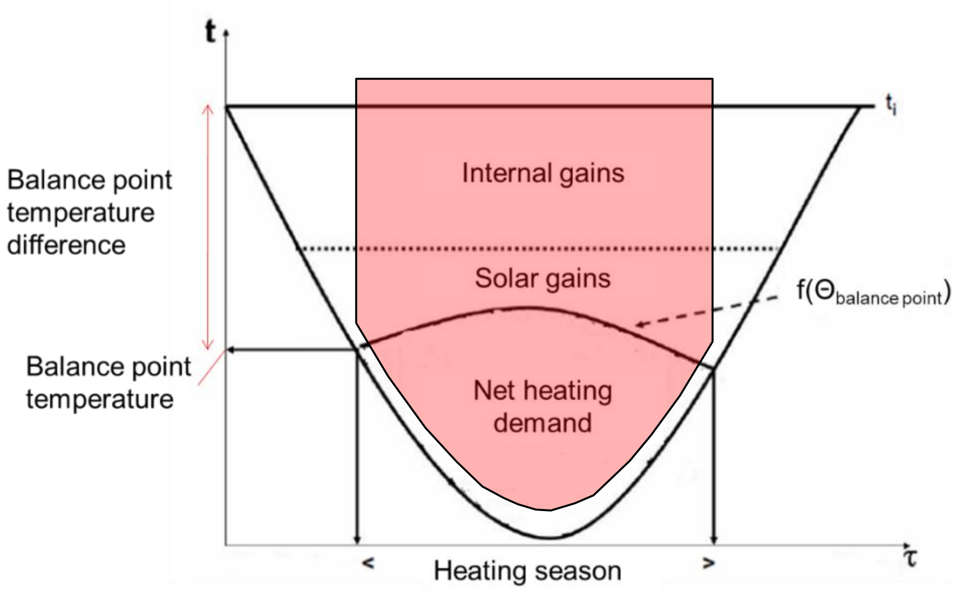

Figure 4.1.32.: Heating degree days (red area)

The difficulty of the calculation is that the length of the heating season, i.e. the value of *n*, is not just meteorological data but a quantity to be determined on the basis of the heat balance. For poorly insulated buildings, it can be assumed 180 days at an internal temperature of 20 °C, but for well-insulated buildings it can be much shorter. This is well illustrated by the following two figures (Figure 4.1.33 and Figure 4.1.34). Figure 4.1.33 shows the heat loss as a function of the outside temperature, which decreases linearly until the outside temperature matches the internal temperature. Heat gain increases slightly with increasing outdoor temperature, as there is more radiation gain in autumn than in winter (longer days, higher radiation intensity) – although this is not linear, but for simplicity we now consider it to be so. The intersection of the two lines gives the balance point temperature (here 12 °C), based on which the length of the heating season can be read from the temperature frequency diagram (approx. 180 days, see Figure 4.1.35). If the building is modernized (e.g. insulating the thermal insulation and replacing windows), losses will be significantly reduced. Due to the window replacement, the heat gain is also slightly reduced due to the lower g value of the high-performance windows. The balance point temperature is much lower (approx. 7 °C), which also means that the heating season is significantly shortened (approx. 120 days, see Figure 4.1.36).

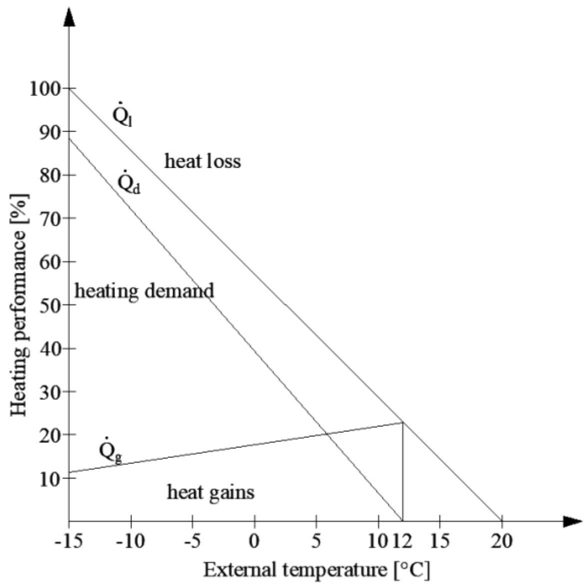

Figure 4.1.33.: Determining the balance point temperature

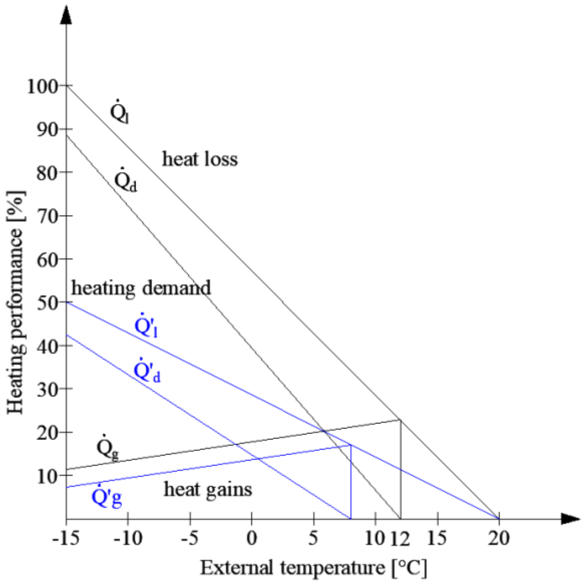

Figure 4.1.34.: Effect of retrofit on the balance point temperature

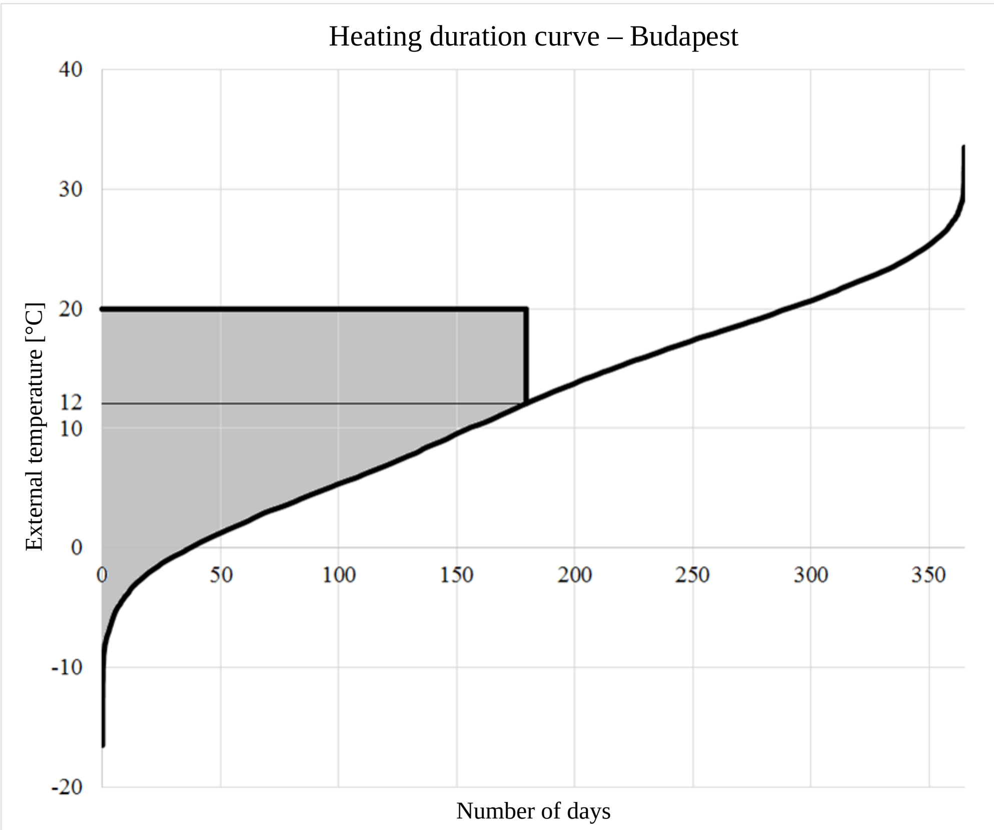

Figure 4.1.35.: HDD in a heating duration curve for 20 °C indoor temperature and 12 °C balance point temperature

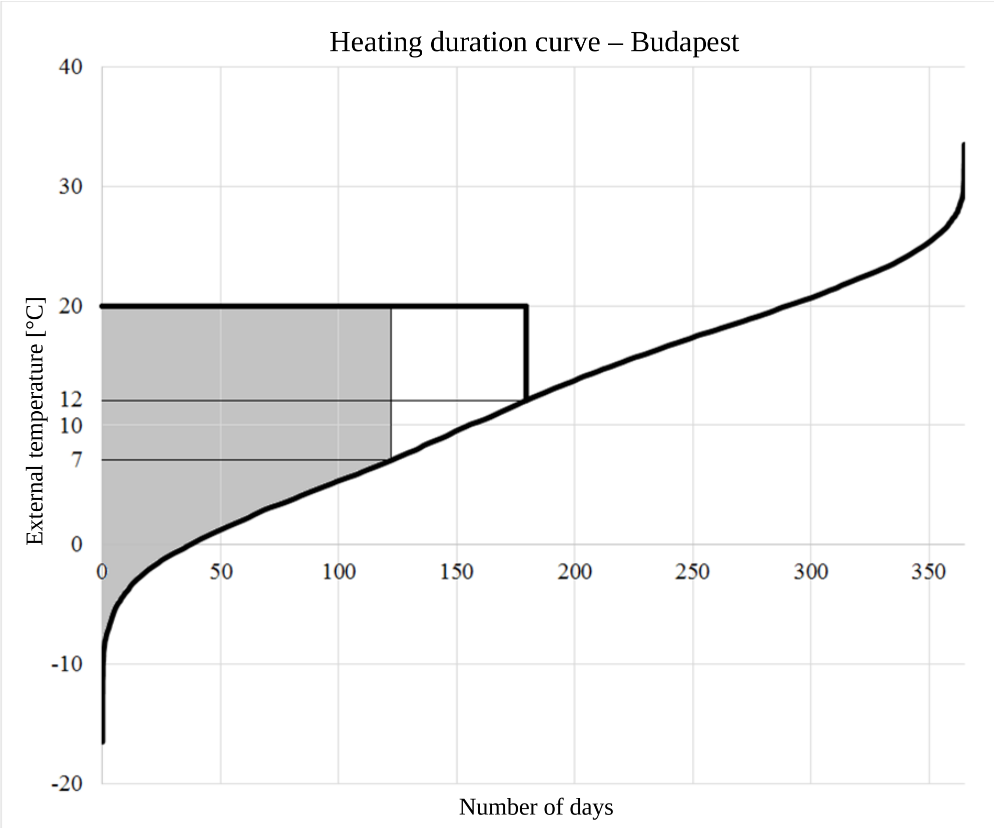

Figure 4.1.36.: HDD in a heating duration curve for 20 °C indoor temperature and 7 °C balance point temperature after retrofit

Nor should it be overlooked that the temperature bridge is significantly dependent on the internal temperature. If the internal temperature is reduced from 20 °C to 19 °C and it is assumed that the average outside temperature during the season is 4 °C, the rate of reduction of the HDD is:

$$\frac{HDD - HDD'}{HDD} = \frac{(20-4)-(19-4)}{20-4} = \frac{1}{16} = 6{,}2\% \qquad 10$$

That is, losses are reduced by this much during the season, which is often mistakenly said to be the rate of reduction in energy demand.

However, the line of reasoning is wrong on two points. On one hand, the length of the heating season also decreases, and on the other hand, the profits do not decrease or only slightly, so the area proportional to consumption decreases more than the HDD. Overall, the reduction in net heating energy demand is thus greater than 6.2%.

4.1.2 ENERGY DEMAND OF A BUILDING

HEATING ENERGY DEMAND – CALCULATION METHOD

SPECIFIC HEAT LOSS COEFFICIENT (Q)

In order to determine the building's specific heat low coefficient the transmission losses and the solar gains has to be determined. The specific heat loss coefficient can be calculated as follows:

$$q = \frac{1}{V}\left(\sum A \cdot U_R + \sum \psi \cdot l - \frac{Q_{sd}}{72}\right)\left[\frac{W}{m^3 \cdot K}\right] \qquad 11$$

where

- V – is the heated volume of the building [m^3]
- A – is the area of the building element using internal measurement [m^2]
- U_R – is the corrected heat loss coefficient [W/m^2K]
- l – is the perimeter of the floor/wall structure connected to the ground [m]
- ψ – is the linear heat loss coefficient of the floor/wall structure connected to the ground [W/mK]
- Q_{sd} – is the solar gains for the heating season [kWh/yr]

Transmission losses

For the group project the heat loss coefficients for different structural elements can be found in the following table:

Table 4.1.5. Requirement heat transfer coefficient values for different structures for new buildings

Building element	Heat transfer coefficient U [W/m^2K]
External wall	0.24
Flat roof	0.17

Building element	Heat transfer coefficient U [W/m²K]
Pitched roof	0.17
Attic slab	0.17
Arcade slab	0.17
Cellar slab	0.26
Glazing	1
Window with wooden or plastic frame (A_g>0.5m²)	1.15
Window with metal frame	1.4
Transparent external wall	1.4
Glass roof	1.45
Skylight	1.25
Facade or door between heated and unheated spaces	1.45
Wall between heated and unheated spaces	0.26
Wall between adjacent heated buildings and parts of buildings	1.5

Heat loss correction for structural elements can be done according to the following equation using the values from the table below:

$$U_R = U \cdot (1 + \chi) \quad 12$$

Table 4.1.6. Thermal bridge correction factors for different building elements

Building element			Correction factor for the thermal bridge effect χ
External wall	with external or intermediate heat insulation	low thermal bridge ratio	0.15
		medium thermal bridge ratio	0.2
		high thermal bridge ratio	0.3
	other	low thermal bridge ratio	0.25
		medium thermal bridge ratio	0.3
		high thermal bridge ratio	0.4
Flat roof		low thermal bridge ratio	0.1
		medium thermal bridge ratio	0.15
		high thermal bridge ratio	0.2
Pitched roof		low thermal bridge ratio	0.1
		medium thermal bridge ratio	0.15

Building element		Correction factor for the thermal bridge effect χ
	high thermal bridge ratio	0.2
Attic slab		0.1
Arcade slab		0.1
Cellar slab	internal heat insulation	0.2
	heat insulation on the bottom side	0.1
Walls between heated and unheated spaces, cellar walls with external insulation		0.05

The thermal bridge ration can be calculated based on the amount of edges compared to the building element's area by using the following table:

Table 4.1.7. Description of thermal bridge ratio for building elements

Amount of thermal bridges (m/m^2)			
Building element	Thermal bridge effect		
	low thermal bridge ratio	medium thermal bridge ratio	high thermal bridge ratio
External wall	< 0.8	0.8 - 1.0	> 1.0
Flat roof	< 0.2	0.2 - 0.3	> 0.3
Pitched roof	< 0.4	0.4 - 0.5	> 0.5

The losses to the ground can be calculated as follows: first the height of the floor (z) relative to the ground has to be determined (Figure 4.1.37.). Than based on the heat resistance value (R) the linear heat loss can be taken from Table 4.1.8 and Table 4.1.9.

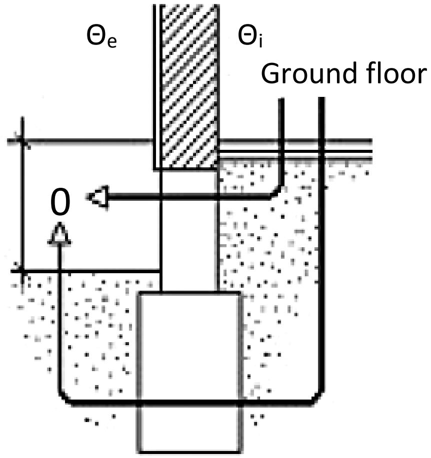

Figure 4.1.37. Position of the floor compared to the ground

Table 4.1.8. Linear heat loss coefficient of a floor connected to the ground

	Heat resistance of the floor structure connected to the ground [m²K/W]										
z [m]	Uninsulated	0,20-0,35	0,40-0,55	0,60-0,75	0,80-1,00	1,05-1,50	1,55-2,00	2,05-3,00	3,05-4,00	4,05-5,00	5,05-6,00	6,05-7,00
...-6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-6.00...-4.05	0.20	0.20	0.15	0.15	0.15	0.15	0.15	0.15	0.00	0.00	0.00	0.00
-4.00...-2.55	0.40	0.40	0.35	0.35	0.35	0.35	0.30	0.30	0.10	0.10	0.00	0.00
-2.50...-1.85	0.60	0.55	0.55	0.50	0.50	0.50	0.45	0.40	0.20	0.15	0.10	0.00
-1.80...-1.25	0.80	0.70	0.70	0.65	0.60	0.60	0.55	0.45	0.30	0.22	0.18	0.13
-1.20...-0.75	1.00	0.90	0.85	0.80	0.75	0.70	0.65	0.55	0.40	0.31	0.25	0.21
-0.70...-0.45	1.20	1.05	1.00	0.95	0.90	0.80	0.75	0.65	0.50	0.40	0.33	0.29
-0.40...-0.25	1.40	1.20	1.10	1.05	1.00	0.90	0.80	0.70	0.60	0.49	0.41	0.37
-0.20...+0.20	1.75	1.45	1.35	1.25	1.15	1.05	0.95	0.85	0.70	0.58	0.50	0.45
0.25....0.40	2.10	1.70	1.55	1.45	1.30	1.20	1.05	0.95	0.75	0.62	0.53	0.48
0.45....1.00	2.35	1.90	1.70	1.55	1.45	1.30	1.15	1.00	0.80	0.66	0.56	0.51
1.05....1.50	2.55	2.05	1.85	1.70	1.55	1.40	1.25	1.10	0.95	0.70	0.60	0.55

Table 4.1.9. Linear heat loss coefficient of a wall connected to the ground

	Heat resistance of the wall structure connected to the ground [m²K/W]								
z [m]	0.30-0.39	0.40-0.49	0.50-0.64	0.65-0.79	0.80-0.99	1.00-1.19	1.20-1.49	1.50-1.79	1.80-2.20
...- 6.00	1.20	1.40	1.65	1.85	2.05	2.25	2.45	2.65	2.80
-6.00...-5.05	1.10	1.30	1.50	1.70	1.90	2.05	2.25	2.45	2.65
-5.00...-4.05	0.95	1.15	1.35	1.50	1.65	1.90	2.05	2.25	2.45
-4.05...-3.05	0.85	1.00	1.15	1.30	1.45	1.65	1.85	2.00	2.20
-3.00...-2.05	0.70	0.85	1.00	1.15	1.30	1.45	1.65	1.80	2.00
-2.00...-1.55	0.55	0.70	0.85	1.00	1.15	1.30	1.45	1.65	1.80
-1.50...-1.05	0.45	0.60	0.70	0.85	1.00	1.10	1.25	1.40	1.55
-1.00...-0.75	0.35	0.45	0.55	0.65	0.75	0.90	1.00	1.15	1.30
-0.70...-0.45	0.30	0.35	0.40	0.50	0.60	0.65	0.80	0.90	1.05
-0.40...-0.25	0.15	0.20	0.30	0.35	0.40	0.50	0.55	0.65	0.74
- 0.40...	0.10	0.10	0.15	0.20	0.25	0.30	0.35	0.45	0.45

Solar gains

To determine the solar gains the orientation and glazing areas of the windows has to be determined. For the g value can be obtained from the window's datasheet. For triple glazed windows it can be assumed to be 0.55. The heat utilization factor (ε) for heavyweight buildings is 0.75, for lightweight structures it is 0.5.

The solar gains can be calculated according to the following equation:

$$Q_{sd} = \varepsilon \cdot \sum A_g \cdot g \cdot Q_{TOT} \left[\frac{kWh}{yr}\right] \quad 13$$

where

ε – is the heat utilization factor for the heating season [1]
Ag – is the glazing area [m2]
g – heat transmittance coefficient for windows [1]
Q_{TOT} – incoming solar radiation on the surface for the heating season [kWh/m2yr]
The incoming solar radiation values for the heating season can be taken from Table 4.1.1.

NET, DELIVERED AND FINAL ENERGY DEMAND FOR HEATING

By calculation the specific heat loss coefficient the net heating demand can be calculated according to the following equation:

$$Q_{H,net} = 72 \cdot V \cdot (q + 0.35 \cdot n) \cdot \sigma - 4.4 \cdot A_N \cdot q_i \left[\frac{kWh}{yr}\right] \quad 14$$

where

V – is the heated volume of the building [m^3]
q – is the specific heat loss coefficient [W/m^3K]
n – is the air change rate, which for residential buildings is 0.5 [1/h]
σ – programmable heating schedule, if applicable 0.9, if not than 1.0 [1]
A_N – is the heated floor area [m^2]
q_i – is the internal heat gain, which for residential buildings is 5 [W/m^2]

The net heating demand shows how much heating energy needs to be supplied to the heated spaces of the heating. However, to supply the demand the following losses have to be calculated for the heating system as well: control (how well the system can respond to the changing demand), distribution and storage (if needed). In order to produce the required delivered energy the heat source's seasonal performance factor (C_k) has to be considered. If there are several heat sources in one heating system, than the share of the heat sources has to be calculated separately. The final energy demand can be calculated according to the following equation:

$$q_{H,final} = \left(q_{H,net} + q_{H,ctr} + q_{H,dist} + q_{H,stor}\right) \cdot \sum C_k \cdot \alpha_k \left[\frac{kWh}{m^2 \cdot yr}\right] \quad 15$$

where

$q_{H,net}$ – is the net heating demand $\left(\frac{Q_{H,net}}{A_N}\right)$ [kWh/m^2]
$q_{H,ctr}$ – is the heat loss due to the control (Table 4.1.10) [kWh/m^2]
$q_{H,dist}$ – is the distributional heat losses (Table 4.1.11 & Table 4.1.12) [kWh/m^2]
$q_{H,stor}$ – is the storage heat losses (Table 4.1.13) [kWh/m^2]
C_k – is the performance factor of the heat supplier (Table 4.1.14, Table 4.1.15 & Table 4.1.16) [1]
α_k – is the heat sources share [1]

The heat loss to the control can be determined based on the following table:

Table 4.1.10. Heating system – control losses

Control method	$q_{H,ctr}$ [kWh/m^{2}yr]	Remarks
Without control	15.0	None
Central controller (e.g. room thermostat)	9.6	
Thermostatic valves (regular)	3.3	
Thermostatic valves (better performing)	1.1	
Electric controller	0.7	Time- and temperature control with PI controller
Electric controller with optimisation	0.4	e.g. window opening / occupancy sensors

The distributional heat losses can be determined based on the following table:

Table 4.1.11. Heating system – distribution losses for different forward and return temperatures A

	Distributional losses when the main horizontal distribution pipe is outside of the heated space [kWh/m^{2}yr]			
A_N [m^2]	90/70 °C	70/55 °C	55/45 °C	35/28 °C
100	13.8	10.3	7.8	4.0
150	10.3	7.7	5.8	2.9
200	8.5	6.3	4.8	2.3

300	6.8	5.0	3.7	1.8
500	5.4	3.9	2.9	1.3
> 500	4.6	3.4	2.5	1.1

Table 4.1.12. Heating system – distribution losses for different forward and return temperatures B

	Distributional losses when the main horizontal distribution pipe is inside of the heated space [kWh/m²yr]			
A_N [m²]	90/70 °C	70/55 °C	55/45 °C	35/28 °C
100	4.1	2.9	2.1	0.7
150	3.6	2.5	1.8	0.6
200	3.3	2.3	1.6	0.6
300	3.0	2.1	1.5	0.5
500	2.8	2.0	1.4	0.5
> 500	2.7	1.9	1.3	0.5

The heat storage losses can be determined based on the following table:

Table 4.1.13. Heating system – storage losses

	The storage tank is placed inside of the heated area		The storage tank is placed outside of the heated area	
A_N [m²]	55/45 °C	35/28 °C	55/45 °C	35/28 °C
100	0.30	0.10	2.60	1.40
150	0.20		1.90	1.00
200	0.20		1.50	0.80
300	0.10	0.00	1.10	0.60
500			0.70	0.40
750			0.50	0.30
1000	0.00		0.40	0.20
1500			0.30	0.20
2500			0.20	0.10
5000			0.20	0.10
10000			0.20	0.10

The performance factors can be taken from the following tables. If the actual heat source is know from the data sheet the seasonal efficiency or the SCOP in case of heat pumps is known, than the performance factor can be calculated as follows:

$$C_k = \frac{1}{\eta_{seasonal}}, or\ C_k = \frac{1}{SCOP}\ [1] \quad 16$$

Table 4.1.14. Gas boiler performance factors

	Performance factor (C_k)					
	Placement outside of the heated zone			Placement inside of the heated zone		
A_N [m^2]	Old boiler	Low temperature boiler	Condensing boiler	Old boiler	Low temperature boiler	Condensing boiler
100	1.38	1.14	1.05	1.30	1.08	1.01
150	1.33	1.13	1.05	1.24		
200	1.30	1.12	1.04	1.21		
300	1.27	1.12	1.04	1.18		
500	1.23	1.11	1.03	1.15		
750	1.21	1.10	1.03			
1000	1.20	1.10	1.02			
1500	1.18	1.09	1.02			
2500	1.16	1.09	1.02			
5000	1.14	1.08	1.01			
10000	1.13	1.08	1.01			

Table 4.1.15. Heat pump performance factors

Heat source / heat transfer medium	Forward/return temperature	Performance factor (C_k)
Water to water	55/45 °C	0.23
	35/28 °C	0.19
Ground to water	55/45 °C	0.27
	35/28 °C	0.23
Air to water	55/45 °C	0.37
	35/28 °C	0.30
Exhaust air to water	55/45 °C	0.30
	35/28 °C	0.24

Table 4.1.16. Biomass boiler performance factors

Old biomass boiler	Wood fired boiler	Pellet boiler	Wood gasifier boiler
1.85	1.75	1.1	1.2

DHW DEMAND – CALCULATION METHOD

NET DHW DEMAND

The net DHW demand for residential buildings can be determined based on the heated floor area. Up to 80 m^2 heated floor area the net DHW demand is 30 kWh/m^2yr, while for the above 80 m^2 heated floor area it is 15 kWh/m^2 year. The net DHW shall be calculated for all individual dwellings in a multifamily building. An example for a 120 m^2 dwelling can be found below:

$$q_{DHW,net} = 80 \cdot 30 + (120 - 80) \cdot 15 = 25 \left[\frac{kWh}{m^2 \cdot yr}\right] \tag{17}$$

The net DHW demand shows how much energy is required by the occupants' DHW usage. However, to supply the demand the distribution and storage losses needed to be considered as well. In order to produce the required delivered energy the heat source's seasonal performance factor (C_k) has to be considered. If there are several heat sources in one heating system, than the share of the heat sources has to be calculated separately. The final energy demand can be calculated according to the following equation:

$$q_{DHW,final} = q_{DHW,net} \cdot \left(1 + q_{DHW,dist} + q_{DHW,stor}\right) \cdot \sum C_k \cdot \alpha_k \left[\frac{kWh}{m^2 \cdot yr}\right] \tag{18}$$

where

$q_{DHW,net}$ – is the net DHW demand [kWh/m^2]
$q_{DHW,dist}$ – is the distributional heat losses (Table 4.1.17) [%]
$q_{DHW,stor}$ – is the storage heat losses (Table 4.1.18 & Table 4.1.19) [%]
C_k – is the performance factor of the heat supplier (Table 4.1.20, Table 4.1.21 & Table 4.1.22) [1]
α_k – is the heat sources share [1]

The distributional heat losses can be determined based on the following table:

Table 4.1.17. DHW system – distribution losses

	With circulation pump		Without circulation pump	
A_N [m^2]	Distribution inside of the heated space	Distribution outside of the heated space	Distribution inside of the heated space	Distribution outside of the heated space
100	28%	24%	13%	10%
150	22%	19%		
200	19%	17%		
300	17%	15%		
500	14%	13%		
750	13%	12%		
>750	13%	12%		

The heat storage losses can be determined based on the following tables:

Table 4.1.18. DHW system – storage losses A

	Storage losses for DHW systems, the storage tank is inside of the heated space			
A_N [m^2]	Externally heated storage	Off-peak electricity based boiler	Electric boiler	Gas fired boiler
100	24%	20%	13%	78%
150	17%	16%	10%	66%
200	14%	14%	8%	58%
300	10%	12%	7%	51%
500	7%	8%	6%	43%
> 500	5%	6%	5%	35%

Table 4.1.19. DHW system – storage losses B

	Storage losses for DHW systems, the storage tank is inside of the heated space			
A_N [m^2]	Externally heated storage	Off-peak electricity based boiler	Electric boiler	Gas fired boiler
100	28%	24%	16%	97%
150	21%	20%	12%	80%
200	16%	16%	10%	69%
300	12%	14%	8%	61%
500	9%	10%	6%	53%
750	6%	8%	5%	49%

A_N [m²]	Storage losses for DHW systems, the storage tank is inside of the heated space			
	Externally heated storage	Off-peak electricity based boiler	Electric boiler	Gas fired boiler
1000	5%	8%	4%	46%
1500	4%	7%	4%	40%
2500	4%	6%	3%	32%
5000	3%	5%	2%	26%
10000	2%	4%	2%	22%

The performance factors can be taken from the following tables. If the actual heat source is know from the data sheet the seasonal efficiency or the SCOP in case of heat pumps is known, than the performance factor can be calculated as follows:

$$C_k = \frac{1}{\eta_{seasonal}}, or\ C_k = \frac{1}{SCOP}\ [1] \qquad 19$$

Table 4.1.20. Gas boiler performance factors

	Performance factor (C_k)				
	Placement outside of the heated zone			Placement inside of the heated zone	
A_N [m²]	Old boiler	Low temperature boiler	Condensing boiler	Combined boiler (without /with small storage)	Combined condensing boiler (without /with small storage)
100	1.82	1.21	1.17	1.27/1.41	1.23/1.36
150	1.71	1.19	1.15	1.22/1.32	1.19/1.28
200	1.64	1.18	1.14	1.20/1.27	1.16/1.24
300	1.56	1.17	1.13	1.17/1.22	1.14/1.19
500	1.46	1.15	1.12	1.15/1.18	1.11/1.15
750	1.40	1.14	1.11		
1000	1.36	1.14	1.10		
1500	1.31	1.13	1.10		
2500	1.26	1.12	1.09		
5000	1.21	1.11	1.08		
10000	1.17	1.10	1.08		

Table 4.1.21. Electric DHW source performance factors

Heat source / heat transfer medium	Performance factor (C_k)
Electric heating cartridge	1.0
Instantaneous water heater, storage	1.0
Heat pump – air source	0.45
Heat pump – water source	0.34
Heat pump – ground source	0.38
Heat pump – exhaust air source	0.38

Table 4.1.22. Biomass boiler performance factors

Old biomass boiler	Wood fired boiler	Pellet boiler	Wood gasifier boiler
2.0	1.9	1.2	1.3

REFERENCES