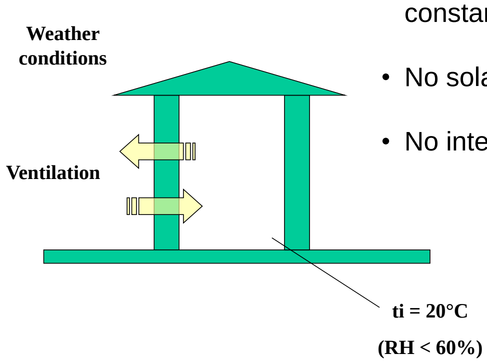
Climatic conditions for HVAC calculations

Winter design conditions

In winter conditions the calculation of the heat load, i.e. the maximum power needed to heat the building is usually performed in steady state conditions, i.e. with fixed temperature outside, constant temperature inside, absence of solar radiation and internal gains (Figure 1). These are the most critical conditions which can be met. This method is the basis of the EN 12831-1 [10]. As for the relative humidity this is usually not fixed, but it is recommended a limit of 60% in order to avoid problems due to condensation.



- Outside air temperature constant (coldest day)
- No solar radiation
- No internal gains

Figure 1 — Boundary conditions and hypotheses for the steady state calculation for the heat load

Summer design conditions

In summer design conditions the calculation has to be done in a dynamic way due to the variation of conditions outside. For the summer design day, a clear sky condition in July is usually considered as most critical condition and as outdoor temperature the hottest average conditions should be considered. In principle you are not obliged to use a cooling system, while usually heating is mandatory in all Europe. Hence there are two possible cases:

a) A cooling system is considered to maintain certain comfort conditions in the rooms (usually 26°C). In this case (Figure 2) the cooling system has to be sized to meet the required goal. As for relative humidity usually this is fixed at 50%, but can be slightly higher if the cooling system risks to be too costly to keep the relative humidity fixed all over the time (e.g. in residential buildings).

b) A cooling system is not present and the building is based on the natural ventilation concept. In this case the temperatures can be slightly higher than 26°C (as it will be shown during the course) and the relative humidity is not considered as parameter affecting the comfort (this is named adaptive comfort). In this case (Figure 3) the temperature and the relative humidity can vary and depend on the energy balance of the room which can be controlled only by the shading devices and level of natural ventilations. Usually for these calculations the calculation of ventilation rates is more difficult and has to be done with specific tools (e.g. LOOPDA [11] or CONTAM [12], COMIS [13]).

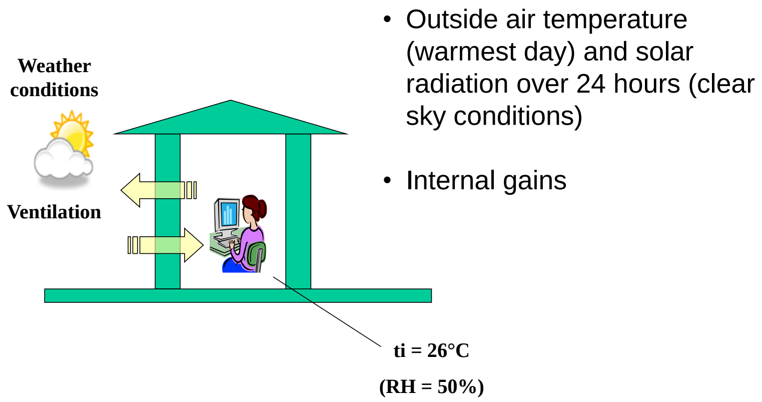


Figure 2 — Boundary conditions and hypotheses for the dynamic calculation for the cooling load in case the air conditioning is present

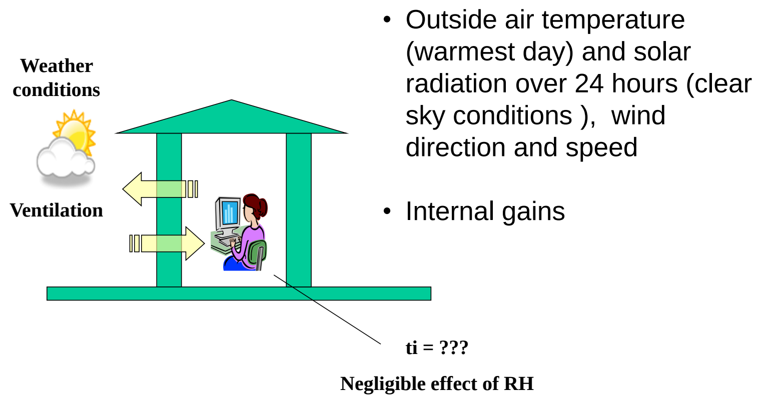


Figure 3 — Boundary conditions and hypotheses for the dynamic calculation for checking the comfort conditions in case of no air conditioning in the building

Energy need for heating and cooling

The energy need of a building can be calculated in dynamic or with monthly based quasi-steady state models. In any case the average climatic conditions have to be considered (TRY or average monthly conditions). The real or standard conditions of the use of the building have to be considered to calculate the energy need for heating and cooling (Figures 7 and 8). Usually the heating season is from October to April and cooling season can be considered from May to September; these time ranges can be longer or shorter depending on the climate, the insulation level of the building envelope and on the internal gains.

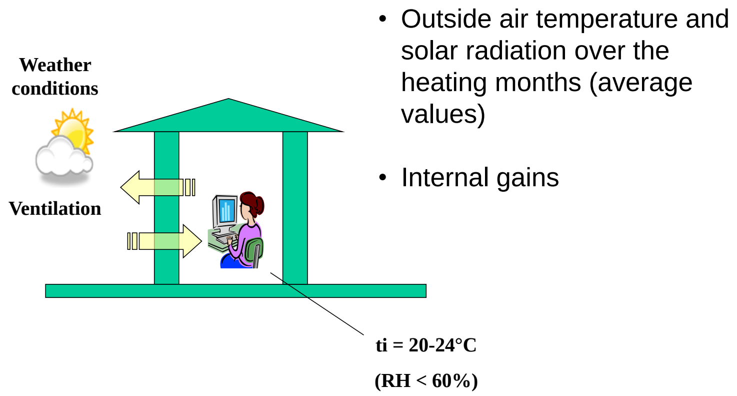


Figure 4 — Boundary conditions and hypotheses for the dynamic or monthly-based calculation for the energy need of building for heating

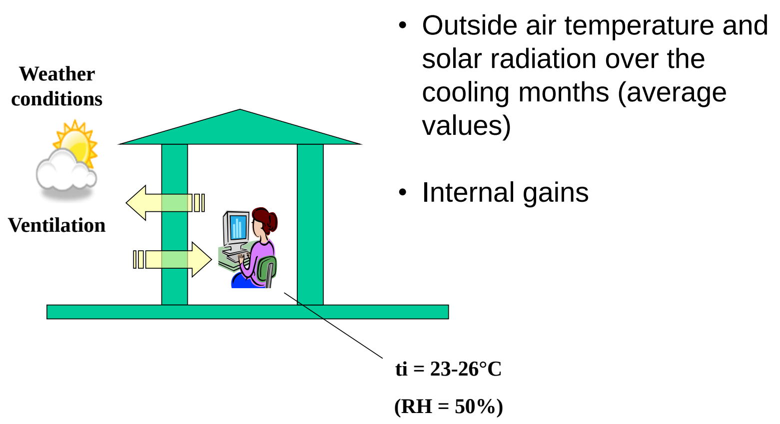


Figure 5 — Boundary conditions and hypotheses for the dynamic or monthly-based calculation for the energy need of building for cooling

Climatic conditions

Weather is the state of the atmosphere, to the degree that it is hot or cold, wet or dry, calm or stormy, clear or cloudy. Most weather phenomena occur in the troposphere, just below the stratosphere. Weather refers, generally, to day-to-day temperature and precipitation activity, whereas climate is the term for the average atmospheric conditions over longer periods of time [1]. For energy uses in buildings weather conditions play an important role. For this reason it is important to define the proper boundary conditions in terms of the different parameters affecting energy and comfort in buildings, which may be different from case to case depending on the particular problem.

Atmospheric temperature is a measure of temperature at different levels of the Earth's atmosphere. It is governed by many factors, including incoming solar radiation, humidity and altitude. When discussing surface temperature, the annual atmospheric temperature range at any geographical location depends largely upon the type of biome, as measured by the Köppen climate classification (see Figure 6):

- GROUP A: Tropical/megathermal climates
- GROUP B: Dry (arid and semiarid) climates
- GROUP C: Temperate/mesothermal climates
- GROUP D: Continental/microthermal climate
- GROUP E: Polar climates
- GROUP H: Alpine climates

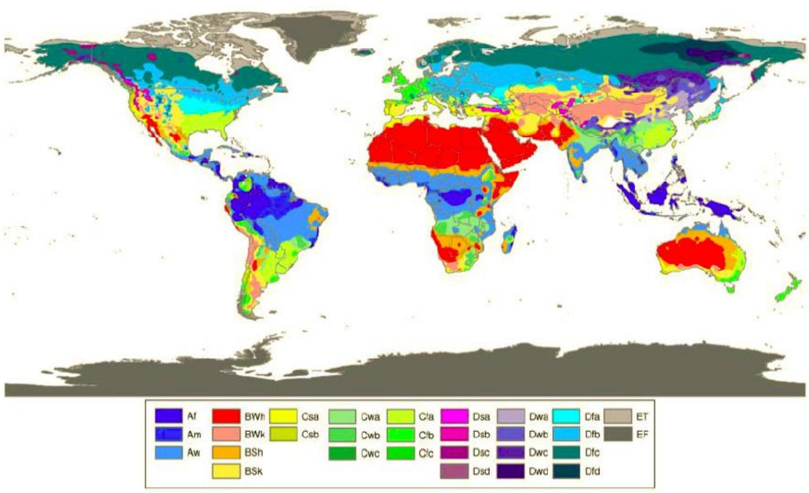


Figure 6: Köppen classification for climates [2]

Nowadays climatic data are available for most of the climates. Weather conditions can be define by the following parameters:

- Design heating temperature
- Design cooling temperature
- Degree day
- Mean monthly temperatures
- Hourly values
- Test Reference Year

Outdoor temperature

Design heating temperature

The design temperature for heating conditions is usually an extreme temperature which might occur in the heating season. Usually the design conditions assume a suitable number of days under constant climatic conditions, i.e. at the design temperature and with no solar radiation, so as to assume steady state conditions through the envelope. In the table 1 the dry-bulb temperatures corresponding to 99.6% and 99.0% annual cumulative frequency of occurrence of some World locations are reported. In the same table the month when the minimum temperature occurs is listed as well.

Design cooling temperature

The design temperature for cooling conditions is usually an extreme temperature which can occur in the cooling season. Usually the design conditions assume a suitable number of days repeating the same climatic conditions. The design day assumes a certain hourly profile of outdoor temperatures with clear sky conditions. In table 1 the dry-bulb temperature corresponding to 0.4%, 1.0%, and 2.0% annual cumulative frequency of occurrence and the mean coincident wet-bulb temperature of some World locations are reported. In the same table the month when the maximum temperature occurs is listed as well. The cyclic conditions of the design day can be calculated, once known the maximum temperature ($T_{amb,max}$) and the temperature difference between the minimum and maximum temperature (Δt_{amb}) by means of the following equation:

$$t_{amb,h} = t_{amb,\max} - p_h \Delta t_{amb} \qquad (1)$$

where p_h is a coefficient depending on the considered time hour; its hourly value is listed in Table 2.

Table 1: Design winter and summer conditions of some cities around the World

	Heating coldest month			Cooling hottest month			
	[n]	DB 99.6% [°C]	DB 99.0% [°C]	[n]	DB Range [°C]	DB 4% [°C]	WB 4% [°C]
Abu Dhabi	1	11.5	12.9	8	12.5	44.9	23.2
Athens	2	1.6	3.1	8	9.1	35.1	21.1
Auckland	7	1.8	2.9	2	6.9	25.2	19.7
Bangkok	12	19	20.4	4	9.2	37.2	26.7
Beijing	1	-10.8	-9.1	7	8.9	34.9	22.2
Berlin	2	-11.8	-10.8	7	9.2	30	18.9
Buenos Aires	7	-0.1	1.3	1	11.8	33.7	22.5
Cairo	1	7.7	8.7	7	11.5	38.1	21.1
Cape Town	7	3.8	5	2	9.5	31	19.4
Caracas	2	20.7	21.2	9	7.2	33.4	28
Chicago	1	-20	-16.6	7	10.5	33.3	23.7
Dakar	2	16.5	16.9	9	5.1	32.1	23.5
Debrecen	1	-13.8	-10.9	7	11.1	7.7	21.3
Helsinki	2	-22.8	-19.1	7	9.5	26.7	17.9
Houston	1	-1.6	0.5	7	10.1	36	24.8
Lima	8	14	14.6	2	6.3	29.3	23.6
London	2	-4.6	-3	7	9.7	27.2	18.7
Melbourne	7	2.8	3.8	2	11.6	34.6	18
Mexico City	1	4.1	5.6	5	13.8	29	13.8
Montreal	1	-23.7	-21.1	7	9.3	30	22.1
Moscow	2	-23.1	-19.8	7	8.3	28.4	20.1
Mumbai	1	16.5	17.8	5	5.6	35.8	23
Nairobi	7	9.8	11	3	11.9	29	15.7
New Delhi	1	6.3	7.3	6	9.7	42	22.2
New York	1	-10.7	-8.2	7	7.4	32.1	23.1
Paris	1	-5.9	-3.8	7	10.1	30.9	20.1
Phoenix	12	3.7	5.2	7	12	43.4	21.1
Riyadh	1	5.9	7.2	7	13.5	44.2	18.7
Salt Lake City	1	-12.6	-9.9	7	14.4	36.3	17.5
San Paulo	7	8.9	10	2	8.2	32.1	20.4
Seville	1	1.3	2.9	7	16.4	39.9	23.8
Sidney	7	6	7	2	6.5	32.8	19.6
Singapore	12	23	23.5	6	5.5	33.2	26.4
Stockholm	2	-17.8	-14.2	7	9.4	27.1	17.5
Strasburg	1	-9.8	-7	7	11.1	31.1	20.9
Tehran	1	-2.8	-1.3	7	10.6	38.5	19
Tokyo	1	-6.9	-5.1	8	7.7	32.1	26
Vancouver	12	-7	-4	8	7.6	25	18.2
Venice	1	-4	-2.8	7	8.8	31.1	23.5
Washington DC	1	-10.6	-8.2	7	10.4	34.4	23.9

Table 2: Values of p_h coefficient to be used in equation (1) for each hour of the day

hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
p_h	0.87	0.92	0.96	0.99	1	0.98	0.93	0.84
hour	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
p_h	0.71	0.56	0.39	0.23	0.11	0.03	0	0.03
hour	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
p_h	0.1	0.21	0.34	0.47	0.58	0.68	0.76	0.82

Degree day

Degree days (DD) are essentially a simplified representation of outside air temperature data. They are widely used for calculating the effect of outside air temperature on building energy consumptions.

Heating Degree Days (HDD) are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific base temperature or balance point. They are often used for calculations related to energy consumption required to heat buildings.

Cooling Degree Days (CDD) are a measure of how much (in degrees), and for how long (in days), outside air temperature was higher than a specific base temperature. They are often used for calculations relating to the energy consumption required to cool buildings.

Weather normalization of energy consumption is one of the most common uses of DD. It enables a comparison of energy consumption from different periods or places with different weather conditions. Depending on the availability of outdoor temperature data, different methods can be used for calculating HDD and CDD. The hourly or ideal method, produces the most accurate estimate, however it requires the availability of very detailed climate data, not always available for each location of interest. According to the ASHRAE daily mean temperature method, the daily degree days are the difference between the daily mean temperature $\bar{t}_{amb,d,j}$ and the internal base temperature T_i, when they are below a certain base outdoor temperature (for heating) or above a certain outdoor temperature (for cooling). The base outdoor temperature named $t_{threshold,heating}$ is the outside temperatures above which the building does not require heating. The base outdoor temperature named $t_{threshold,cooling}$ is the outside temperatures below which the building does not require cooling. Hence the calculations for Heating Degree Days (HDD) and Cooling Degree Days (CDD) are given by equations (2.a) and (2.b):

$$HDD = \sum_{j=1}^{365}(t_i - \bar{t}_{amb,d,j}) \qquad \text{if } \bar{t}_{amb,d,j} < t_{threshold,heating} \qquad (2.a)$$

$$CDD = \sum_{j=1}^{365}(t_i - \bar{t}_{amb,d,j}) \qquad \text{if } \bar{t}_{amb,d,j} > t_{threshold,cooling} \qquad (2.b)$$

There are different ways to choose the inner temperatures and the threshold temperatures since different buildings have different base temperatures [8].

As an example, in Table 3 the *HDD* and the *CDD* considering T_i = 18°C and $T_{threshold}$ = 10°C for both heating and cooling is shown. It has to be underlined that the choice of the inner temperature can be different for heating and cooling as well as the choice for threshold outdoor temperature. As an example, in a recent paper Carnieletto et al. [9] used The inner baseline temperature (T_i) has been settled, for both heating and cooling conditions, equal to 18°C and a threshold for the external temperature (Tt) was set equal to 14°C in HDD calculation and equal to 20°C for the CDD evaluation.

Table 3: Winter and summer degree days of some cities around the World

		Heating DD		Cooling DD	
		18°C	**10°C**	**18°C**	**10°C**
1	**Abu Dhabi**	24	0	6254	3358
2	**Athens**	1112	82	2966	1076
3	**Auckland**	1163	0	1909	131
4	**Bangkok**	0	0	6757	3837
5	**Beijing**	2906	1420	2199	765
6	**Berlin**	3156	1191	1125	170
7	**Buenos Aires**	1189	0	2524	663
8	**Cairo**	307	0	4472	1859
9	**Cape Town**	868	0	2388	326
10	**Caracas**	0	0	6002	3082
11	**Chicago**	3430	1748	506	1743
12	**Dakar**	1	0	5151	2231
13	**Debrecen**	3129	1313	279	1384
14	**Helsinki**	4721	2336	577	33
15	**Houston**	774	134	1635	3915
16	**Lima**	114	0	3541	735
17	**London**	2886	778	864	32
18	**Melbourne**	1733	127	1525	210
19	**Mexico City**	547	0	2503	131
20	**Montreal**	4493	2525	1185	234
21	**Moscow**	4655	2498	862	99
22	**Mumbai**	0	0	6219	3299
23	**Nairobi**	243	0	2870	193
24	**New Delhi**	278	0	5363	2721
25	**New York**	2627	1052	639	1984
26	**Paris**	2644	791	1209	142
27	**Phoenix**	543	28	2661	5066
28	**Riyadh**	305	0	5915	3301
29	**Salt Lake City**	2908	1200	669	1881
30	**San Paulo**	293	1	3483	854
31	**Seville**	927	19	3031	1020
32	**Sidney**	687	5	2871	634
34	**Singapore**	0	0	6374	3454
35	**Stockholm**	4239	1965	683	36
36	**Strasburg**	2947	1054	1162	136
37	**Tehran**	1749	577	1482	3230
38	**Tokyo**	2311	794	1911	508
39	**Vancouver**	3020	901	806	5
40	**Venice**	2262	762	1906	526
41	**Washington DC**	2478	993	730	2164

Usually in most of the European countries the HDD is quite well established, while the CDD definition is not always clear. In many countries (e.g. Italy and Germany) the reference threshold base temperature for heating condition is fixed at 12°C. The indoor reference indoor temperature depends on the building, but usually it can be considered equal to 20°C. The heating degree day (*HDD*) can be calculated in an easier way as the difference between the indoor temperature and the mean outdoor monthly temperature $\bar{t}_{amb,m,z}$ times the number of days of the considered month $n_{d,z}$:, if the considered z_{th} month has an average temperature lower than 12°C:

$$HDD = \sum_{z=1}^{12}\left[\left(t_i - \bar{t}_{amb,m,z}\right) \cdot n_{d,z}\right] \quad (3)$$

In Figure 7 the graphical meaning of the degree day is shown considering 20°C as reference indoor temperature. As can be seen the degree day is the light green area between the indoor temperature and the outdoor mean monthly temperature; the wider the green area (i.e. the higher the degree day), the colder the climatic conditions.

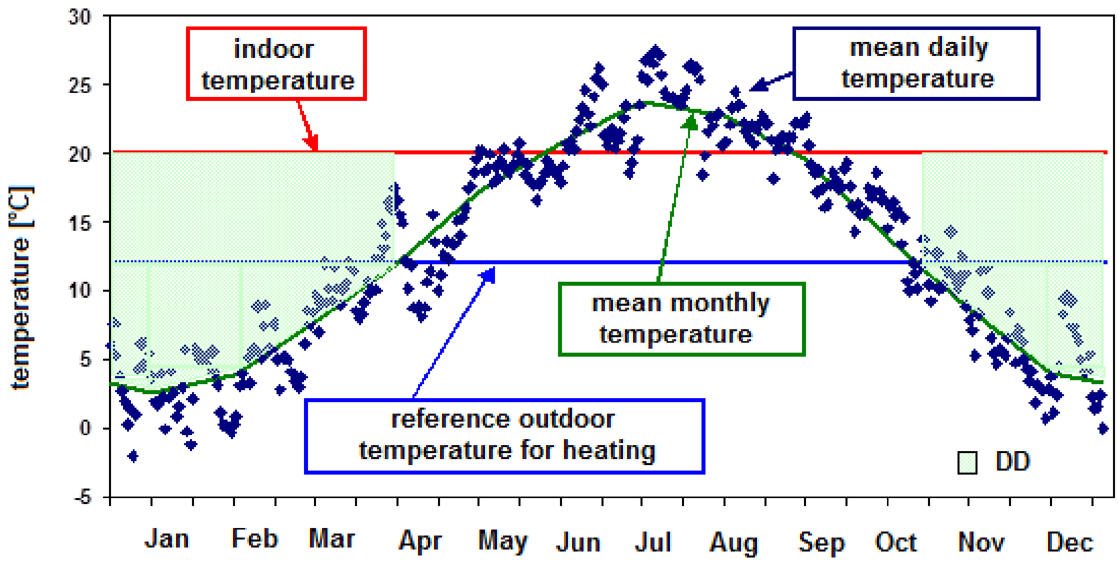


Figure 7: Graphical representation of the Heating Degree Days (HDD) of a typical year in Venice for an indoor temperature of 20°C and a threshold temperature for the outdoor air $T_{threshold,heating} = 12°C$

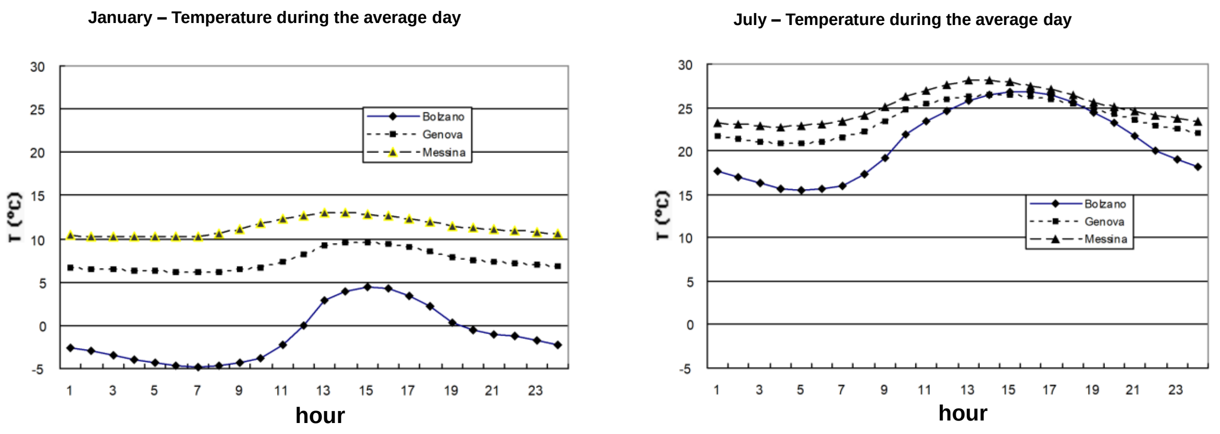
Mean monthly temperatures

Mean monthly temperatures define the mean temperatures of each month of the year. They may be shown together with the maximum mean value and the minimum mean value of the month. In any case, for energy purposes the average outdoor temperature of the month is sufficient to determine many physical phenomena which may happen in a building.
As will be shown afterwards, the average outdoor temperatures may be used for evaluating the net energy demand of a building by means of the quasi-steady state method. The average value of outdoor temperature may be used also for determining the average water vapour content inside a building, as well as for checking moisture problems on internal surfaces of the envelope and interstitial condensation problems inside wall structures.

Profile of hourly average temperatures of the month

The profile of the hourly average temperatures of the month can be used for several purposes. It might be used for determining the energy demand of buildings for both heating and cooling.

If the monthly values are not known the hourly trend of temperatures can be built up by using the average values of the outdoor temperature and the mean values of minimum and maximum temperatures. Please note that the peak loads determined via the mean day hourly patterns do not represent the peak power for heating and cooling, which have to be calculated via design conditions.



a b

Figure 8: Average monthly temperatures for Bolzano (North Italy, mountain area), Genua (North Italy, coast climate), Messina (South Italy, coast) for the coldest month (a) and the warmest month (b) of the year

Test Reference Year

The Test Reference Year (TRY) is the hourly average profile of outdoor temperature of one typical year. The TRY is built up based on at least 20 years. The TRY is built up by calculating the mean outdoor temperature. The real occurred month which presents outdoor conditions which are the closest to the average value of the series is chosen to be representative of real conditions. Real hourly values over the month are used for building the TRY, since the combination of solar radiation and temperature may lead to errors in the evaluation of energy demand of the building. Therefore it is assumed that the most suitable trend of outdoor weather for determining the energy heating/cooling demands is based on real happened conditions. The use of artificial weather data may lead to mistakes, therefore, in case of few data for the climatic conditions, it is preferable to use average monthly data, instead of random profiles reconstructing TRY.

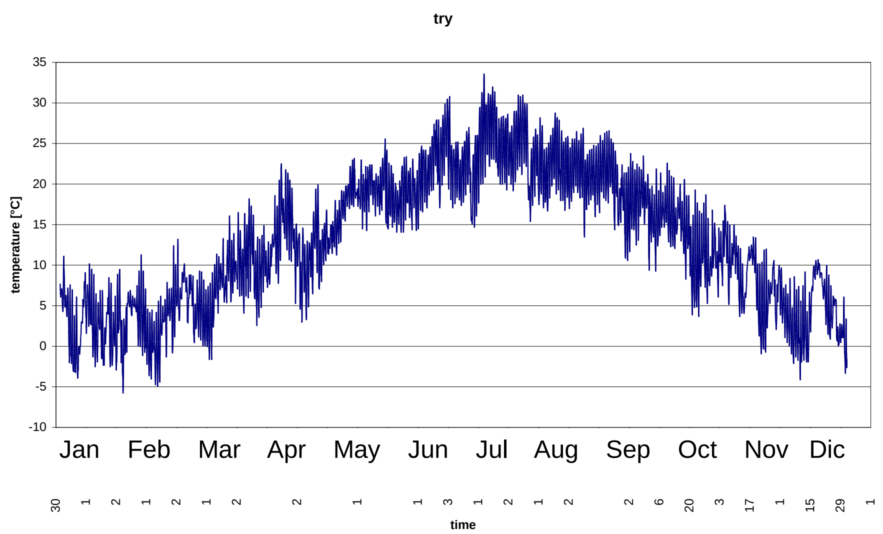


Figure 9: Temperature profile of the Test Reference Year (TRY) of Venice

Solar radiation

Solar radiation in design conditions

As already described, design solar radiation in heating conditions is null. In cooling conditions, instead, the design solar radiation is based on clear sky conditions of the month which has the warmest temperature over the year. The solar radiation depends on the latitude of the considered place.

Overall yearly solar energy radiation

The overall mean energy of the solar radiation which can be expected to impinge a plane during one year can be an important value to understand the available solar radiation energy. Usually, when dealing with a unique value of the solar radiation representing the overall incoming energy, the available data refer to a horizontal plane.

Mean monthly solar energy radiation

Mean monthly solar energy radiation defines the mean radiation of each month of the year. For energy purposes this value may be sufficient to determine the net energy demand of a building by means of the so called quasi-steady state balance, based on an equation which solves the monthly balance of the building.
Usually data are available for the average value measured on an horizontal plane. Depending on details of the meteorological local apparatus the overall solar radiation or its direct and diffused components are available. In Table 4 the daily average total solar radiation on horizontal [kWh/m^2] for some locations is reported.

Table 4: Daily average total solar radiation on horizontal [kWh/m^2] for the locations of Table 3

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	4.22	5.32	5.55	6.51	7.64	7.77	7.40	7.22	6.62	5.71	4.56	3.94
2	2.07	2.82	4.01	5.14	6.22	7.48	7.53	6.63	5.42	3.52	2.14	1.81
3	6.80	5.58	4.67	3.38	2.31	1.93	2.06	2.72	4.04	4.83	5.84	6.38
4	4.71	5.18	5.87	5.59	5.05	5.09	4.79	4.34	4.61	4.40	4.70	4.59
5	2.33	3.05	4.23	5.30	6.01	6.03	5.27	4.87	4.76	3.44	2.36	2.06
6	0.53	1.18	1.93	3.84	4.84	5.04	5.11	4.35	2.74	1.54	0.80	0.41
7	6.84	6.08	4.90	3.60	2.59	2.08	2.29	3.05	4.21	5.29	6.52	6.79
8	2.98	4.01	5.31	6.39	7.39	7.32	6.89	6.24	5.60	4.51	3.37	2.80
9	7.98	7.20	5.74	4.10	3.04	2.37	2.49	3.52	4.69	6.12	7.51	7.85
10	5.02	5.56	5.94	5.54	5.35	5.85	5.51	6.16	5.88	5.09	4.67	4.36
11	1.76	2.49	3.44	4.39	5.98	6.29	6.18	5.16	4.19	2.94	1.82	1.50
12	4.78	5.45	6.53	6.54	6.66	6.13	5.60	5.29	5.41	5.40	4.68	4.45
13	0.99	1.89	2.88	4.22	5.49	6.04	6.14	5.34	3.67	2.25	1.19	0.80
14	0.25	0.91	1.87	3.58	5.31	5.74	5.44	4.02	2.35	1.12	0.31	0.12
15	2.83	3.28	4.27	4.92	5.44	5.95	6.18	5.47	5.06	4.25	3.19	2.61
16	5.71	5.42	5.85	5.13	3.91	2.78	2.78	2.86	3.30	4.22	4.46	5.08

17	0.71	1.19	2.12	3.64	4.91	4.91	5.02	4.35	2.97	1.75	0.97	0.55
18	6.94	6.11	4.90	3.33	2.17	1.62	1.94	2.77	4.08	5.33	6.54	6.45
19	4.13	4.74	5.43	5.70	5.63	5.63	5.52	5.65	5.10	4.66	4.01	3.52
20	1.66	2.88	4.42	4.56	5.75	6.34	6.01	5.20	4.16	2.57	1.47	1.27
21	0.48	1.20	2.33	3.49	5.04	5.44	5.16	4.12	2.39	1.33	0.58	0.35
22	4.52	5.31	6.20	6.86	6.56	4.84	3.77	3.84	4.20	5.11	4.74	4.27
23	6.04	6.56	5.81	4.89	4.34	4.07	4.01	4.74	5.34	5.20	4.72	5.35
24	3.25	3.68	5.39	6.96	6.61	6.79	5.93	5.10	4.84	4.28	3.92	3.26
25	1.65	2.60	3.68	4.47	5.53	5.99	5.78	5.95	4.17	3.59	2.04	1.50
26	0.78	1.39	2.28	3.63	4.61	5.31	5.36	4.86	3.12	2.03	1.04	0.61
27	3.29	4.16	5.34	7.09	7.84	8.32	7.62	7.13	6.34	4.82	3.77	3.07
28	4.28	5.06	5.77	6.41	7.34	8.03	7.82	7.43	6.89	5.99	4.71	3.60
29	1.89	2.92	3.98	5.39	6.32	7.60	7.28	6.37	5.33	3.69	2.30	1.56
30	5.65	5.39	4.86	4.27	3.34	3.13	3.33	4.15	4.63	5.06	5.58	5.85
31	2.53	3.39	4.44	5.49	6.70	7.19	7.56	6.89	5.32	3.97	2.83	2.30
32	6.60	5.63	4.87	3.74	2.66	2.18	2.56	3.56	4.58	5.64	5.99	6.38
34	4.55	4.99	4.80	4.97	4.68	4.47	4.63	4.51	4.57	4.48	4.23	4.12
35	0.26	0.76	1.77	3.74	5.28	5.36	5.06	3.81	2.32	1.18	0.45	0.20
36	0.78	1.43	2.75	3.83	4.63	5.40	5.47	4.89	3.30	1.70	0.93	0.66
37	3.06	4.17	5.51	6.48	7.95	8.74	7.99	7.83	6.81	4.98	3.96	2.81
38	2.52	3.15	3.54	4.61	4.79	4.14	4.39	4.81	3.47	2.93	2.49	2.09
39	0.80	1.57	2.65	4.55	5.61	5.97	6.56	5.31	3.92	1.79	0.94	0.64
40	1.03	1.67	2.97	3.93	4.64	5.39	6.05	4.93	3.21	2.00	1.25	0.76
41	2.02	2.75	3.88	5.09	5.63	6.46	5.98	5.26	4.30	3.45	2.22	1.83

Profile of hourly solar radiation of the month

The profiles of the hourly mean direct and diffuse radiation of the month can be used for determining the energy demand of buildings for both heating and cooling.
In Figure 10 the patterns of the hourly average values of solar radiation can be seen for three locations in Italy.

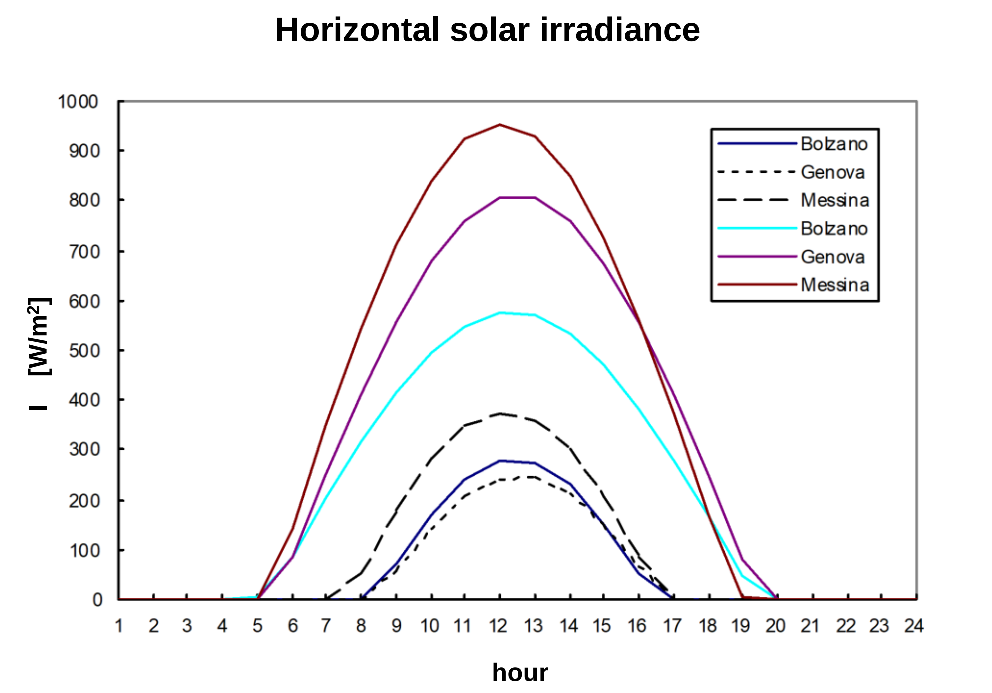


Figure 10: Average monthly solar radiation for Bolzano (North Italy, mountain area), Genua (North Italy, coast climate), Messina (South Italy, coast) for the coldest month (a) and the warmest month (b) of the year

Test Reference Year

The Test Reference Year (TRY) is the hourly average profile of solar radiation of one typical year, as described for the temperature hourly profile over the year. As already discussed, the most suitable trend of outdoor weather for determining the energy heating/cooling demands is based on real happened conditions. The use of artificial weather data may lead to mistakes, hence attention has to be paid on randomized generated data. As an example, in Figure 11 the trend of solar radiation over the year in Venice is shown.

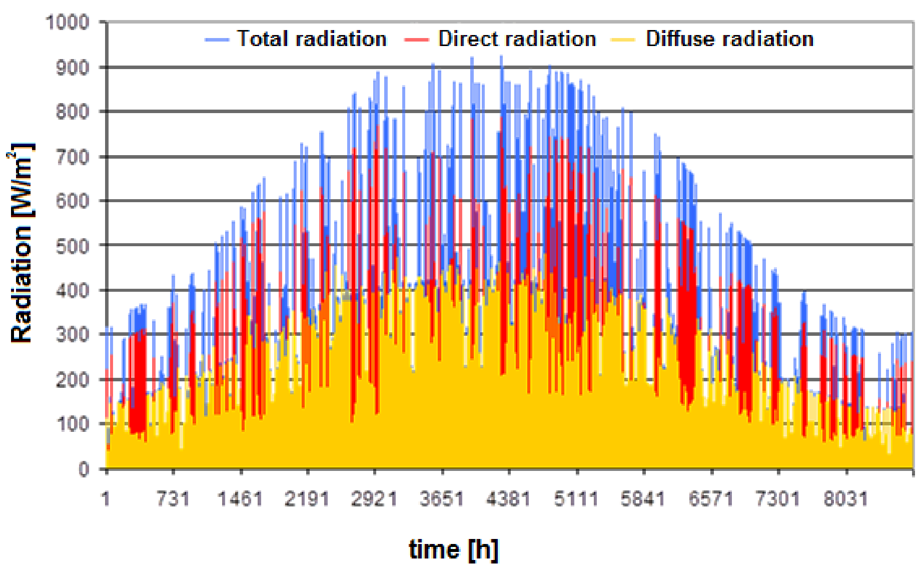


Figure 11: Example of solar radiation distribution over one year for the TRY of Venice

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