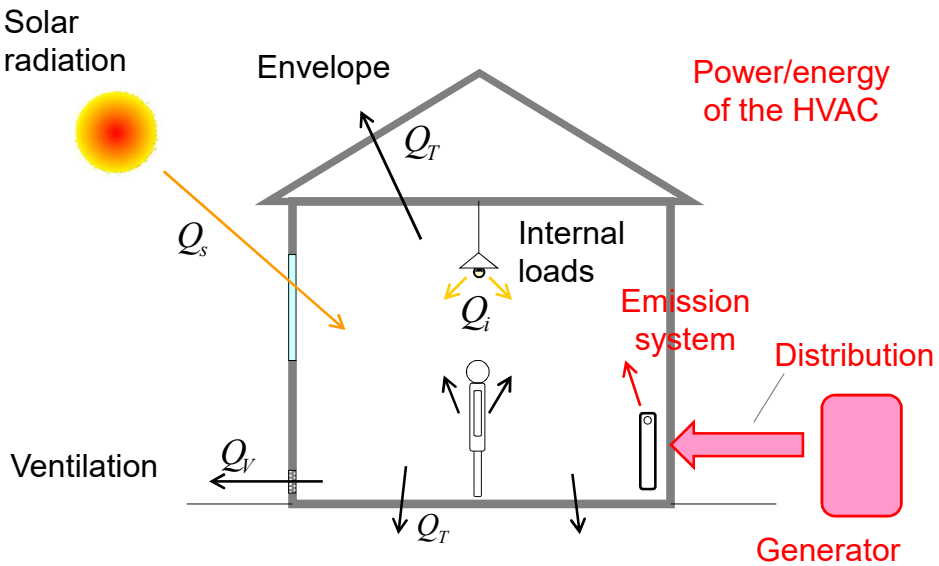
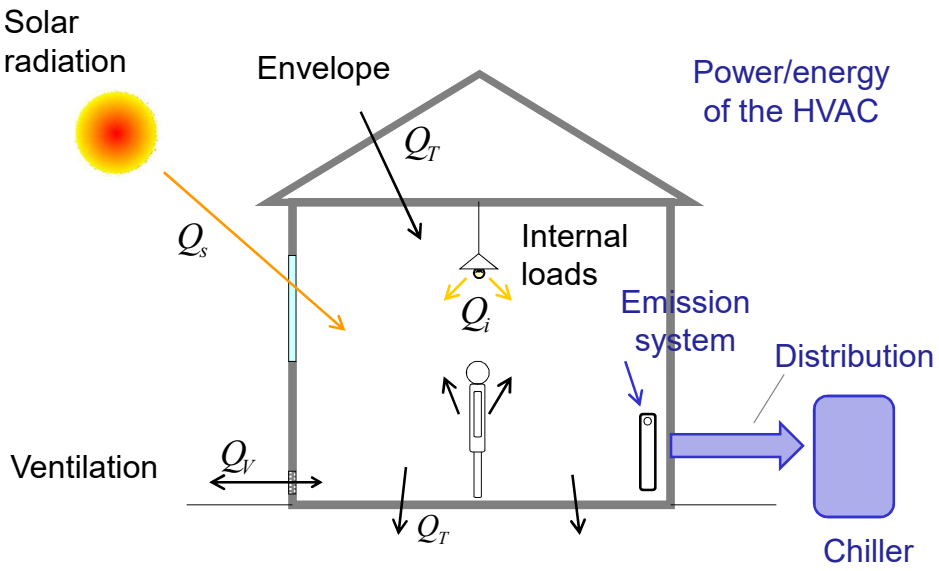
Climatic conditions

For HVAC calculations

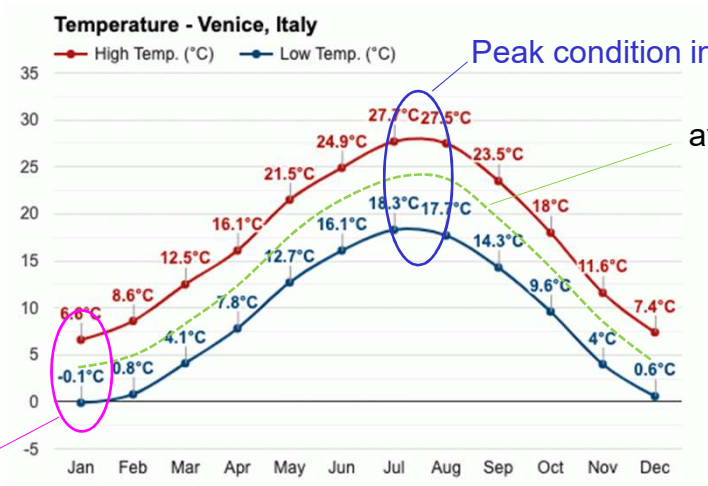
HVAC plant in heating conditions



HVAC plant in cooling conditions



Are climatic conditions important?



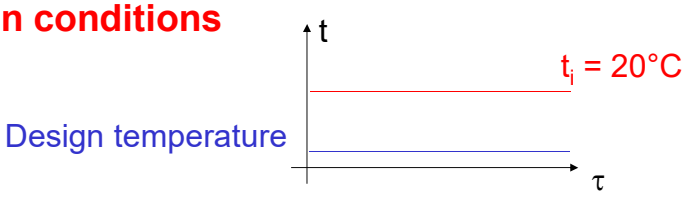
Peak condition in cooling

average

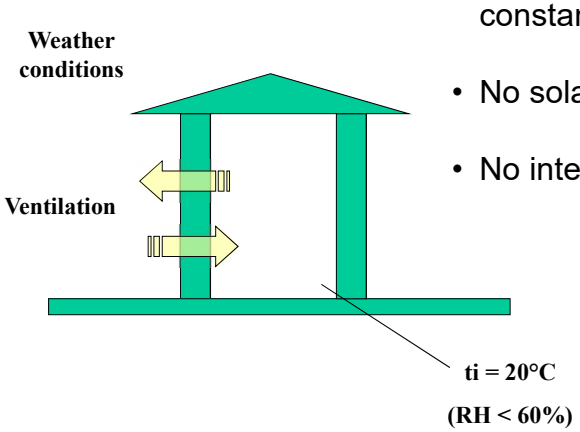
Peak condition in heating

How do they affect the HVAC system?

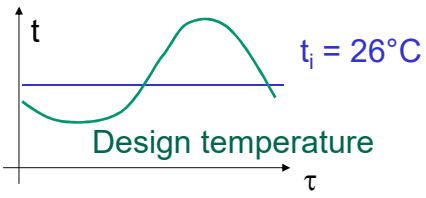
Winter design conditions



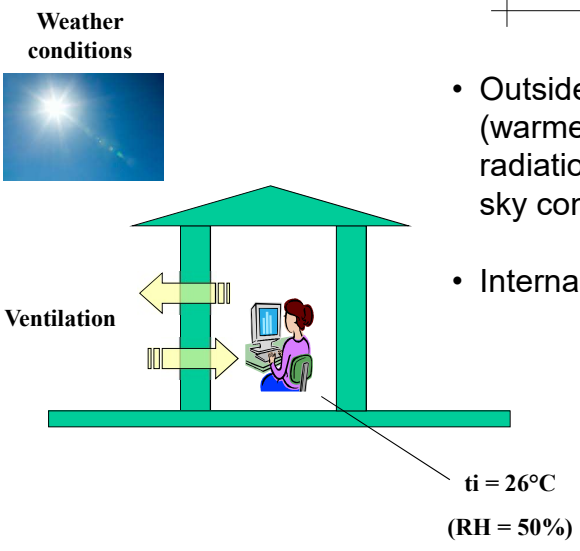
- Outside air temperature constant (coldest day)
- No solar radiation
- No internal gains



Summer design conditions



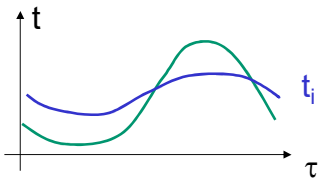
1) Cooling systems



- Outside air temperature (warmest day) and solar radiation over 24 hours (clear sky conditions)
- Internal gains

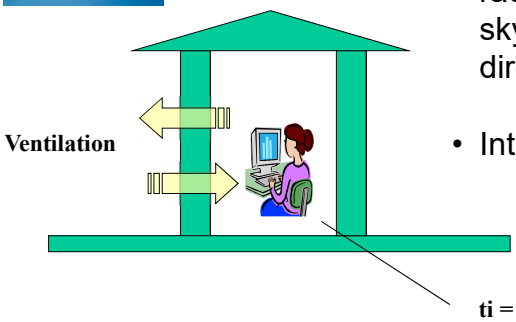
Summer design conditions

2) Naturally ventilated buildings



Design temperature

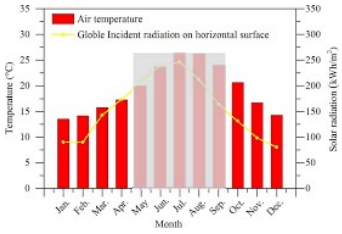
Weather conditions



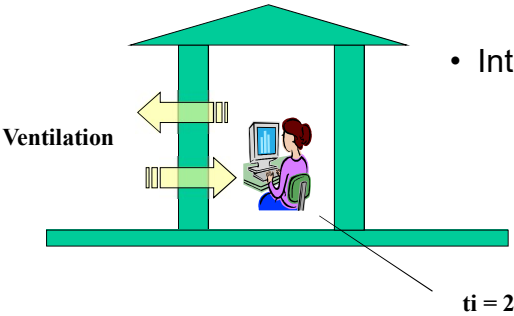
- Outside air temperature (warmest day) and solar radiation over 24 hours (clear sky conditions), wind direction and speed
- Internal gains

Negligible effect of RH

Energy need of a building for heating in winter



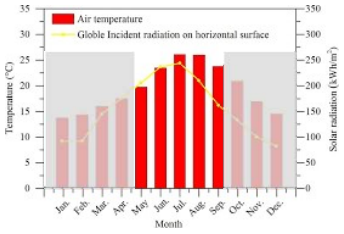
Weather conditions



- Outside air temperature and solar radiation over the heating months
- Internal gains

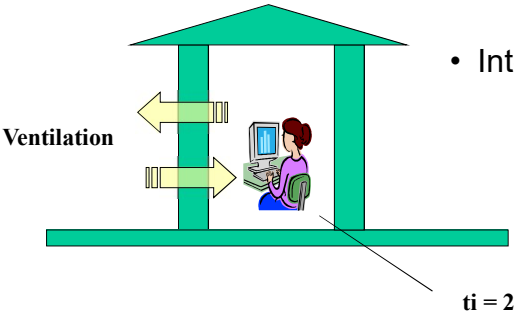
(RH < 60%)

Energy need of a building for cooling in summer



Weather conditions

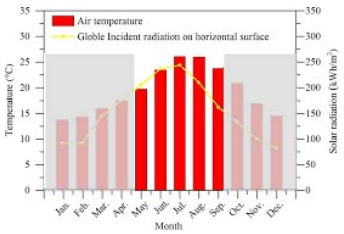
- Outside air temperature and solar radiation over the cooling months
- Internal gains



ti = 26°C

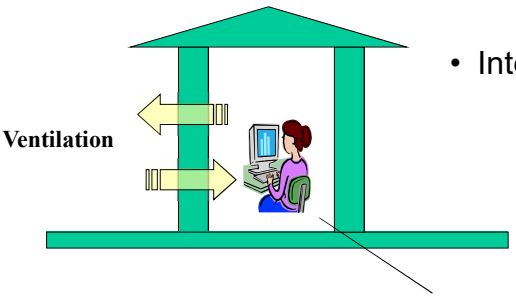
(RH = 50%)

Comfort performance of a naturally ventilated building in summer



Weather conditions

- Outside air temperature and solar radiation over the cooling months
- Internal gains

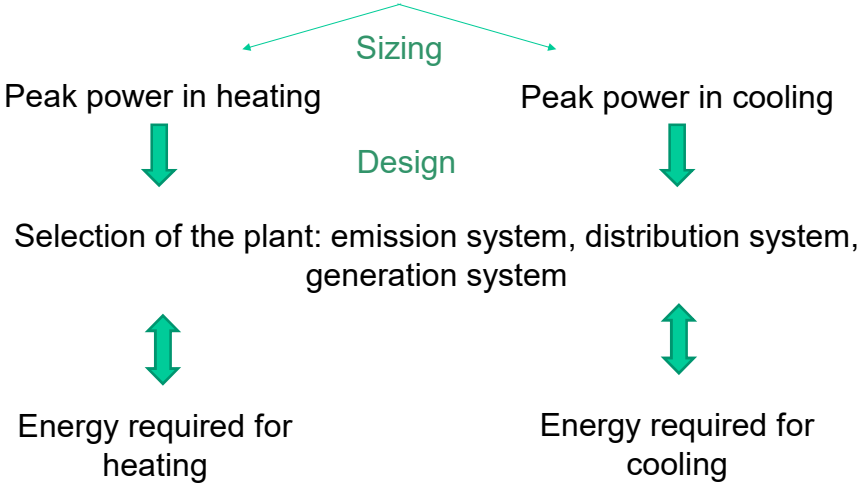


ti = ???

Negligible effect of RH

In summary:

- The HVAC has to work in design conditions, i.e. it has to face the most critical conditions in winter and summer.



HOW TO DEFINE THE CLIMATE OF A ZONE

- **Outside air temperature**
- **Relative humidity**
- **Speed and wind direction**
- **Solar radiation**

HOW TO DEFINE THE TEMPERATURE

- **Design temperature during winter and summer**
- **Average yearly temperature**
- **Degree Day**
- **12 monthly average temperature**
- **12 profiles for the average day of the month (24 hours for 12 months)**
- **TRY (Test Reference Year): 8760 hourly values**

Average yearly temperature

A single value for the average temperature during all the year (ground temperature)

Design temperature in winter conditions

Minimum temperature (conservative condition):

It is used for calculating the peak power for heating:

- **size the emission systems (radiators, radiant floor, fan-coil) room by room**
- **size the generation system (boiler, heat pump, etc.).**

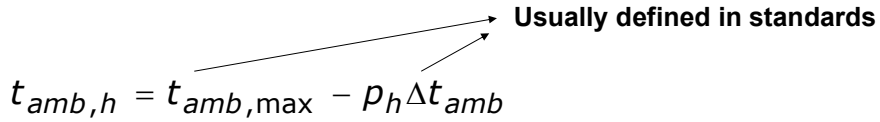
Example of design tempetratures 1/2

	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

Example of design tempetratures 2/2

	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]
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

Design temperature in summer conditions



Values for the term p_h used in the evaluation of the external air temperature according to the 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 (DD)

Degree days (DD): simplified representation of outside air temperature data (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.

DD is the sum, for each day *j*, of the difference between the internal temperature (t_i) and the daily average external (ambient) temperature ($\bar{t}_{amb,d,j}$). The limits of the heating/cooling season are usually defined by a threshold external reference temperature below which there is heating and above which there is cooling:

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

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

There are different ways to choose the inner temperatures and the threshold temperatures since different buildings have different base temperatures

Example of degree days (DD) 1/2

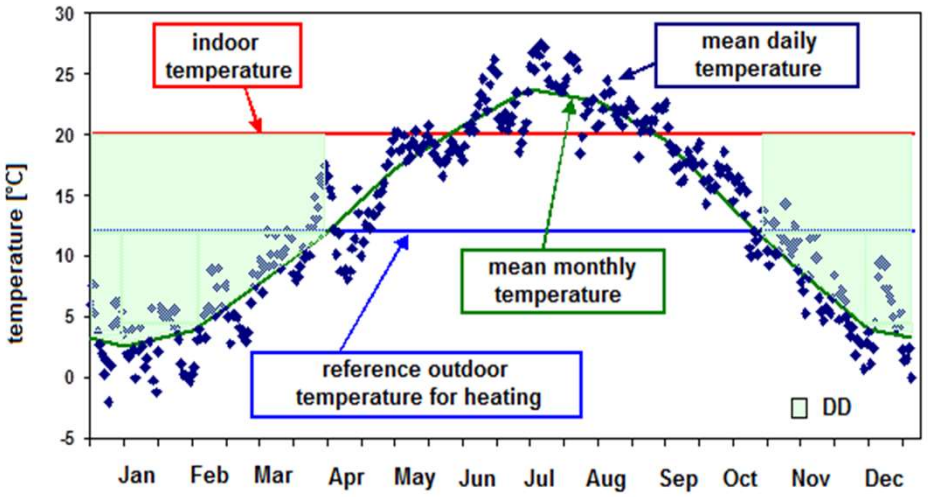
		Heating DD		Cooling DD	
		18°C	10°C	18°C	10°C
1	Abu Dhabi	24	0	6254	3358
2	Athens	1112	82	2966	1076
3	Auckland	1163	0	1909	131
4	Bangkok	0	0	6757	3837
5	Beijing	2906	1420	2199	765
6	Berlin	3156	1191	1125	170
7	Buenos Aires	1189	0	2524	663
8	Cairo	307	0	4472	1859
9	Cape Town	868	0	2388	326
10	Caracas	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

Example of degree days (DD) 2/2

		Heating DD		Cooling DD	
		18°C	10°C	18°C	10°C
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 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:

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



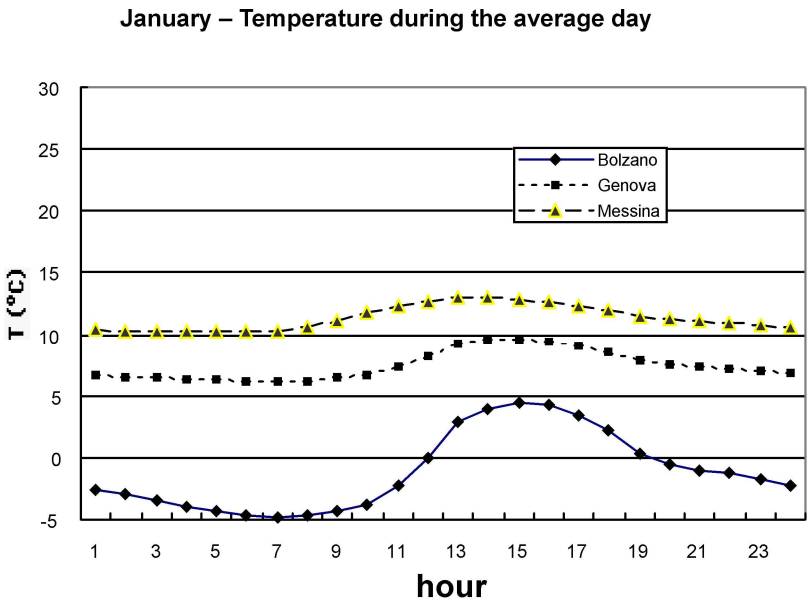
Monthly average temperature

Prospetto VI — Valori medi mensili della temperatura media giornaliera dell'aria esterna

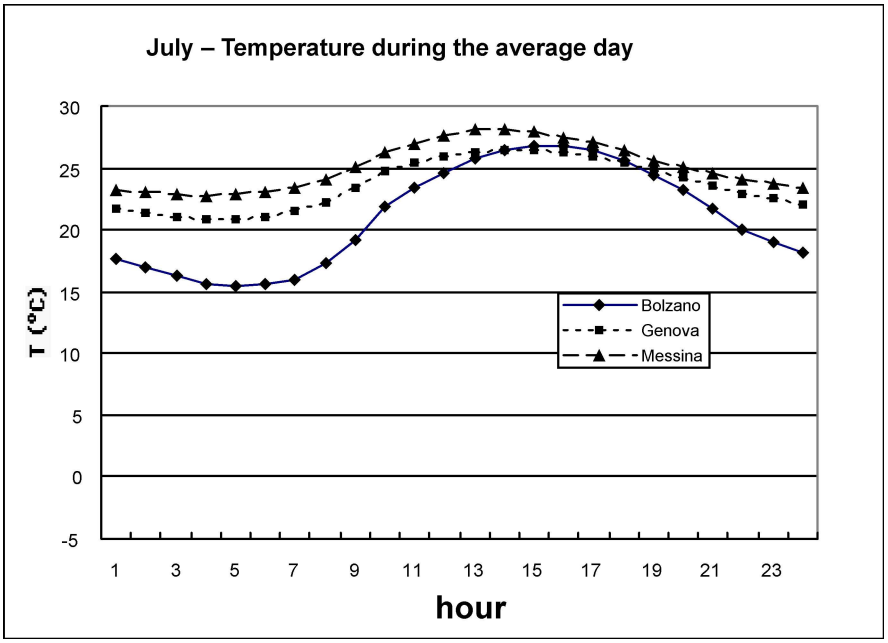
N°	Sigla Provincia	Località	Altitudine m	GEN. °C	FEB. °C	MAR. °C	APR. °C	MAG. °C	GIU. °C	LUG. °C	AGO. °C	SET. °C	OTT. °C	NOV. °C	DIC. °C
1	AG	Agrigento	230	10,4	10,8	12,7	15,6	19,4	24,1	26,9	26,5	24,0	19,9	15,9	12,2
2	AL	Alessandria	95	0,0	2,8	8,1	13,1	17,3	22,0	24,7	23,6	19,9	13,1	6,9	1,9
3	AN	Ancona	16	6,3	7,1	9,9	13,4	17,0	21,8	24,4	24,1	21,3	16,5	12,1	7,8
4	AO	Aosta	583	−0,3	2,6	6,7	11,0	14,7	18,7	20,5	19,4	15,9	10,3	4,8	0,8
5	AP	Ascoli Piceno	154	5,5	6,6	9,5	13,3	17,2	21,7	24,4	24,3	21,1	15,8	10,9	7,0
6	AQ	L'Aquila	714	2,0	3,6	7,1	11,4	15,0	19,1	22,0	21,8	18,6	13,1	8,2	3,8
7	AR	Arezzo	246	5,1	5,9	9,2	12,6	16,4	20,9	24,0	23,4	20,3	15,0	10,2	6,1
8	AT	Asti	123	−0,4	2,7	7,9	13,0	17,0	21,6	24,2	22,9	18,9	12,7	6,1	1,3
9	AV	Avellino	348	5,5	6,5	8,8	12,4	16,0	20,3	23,1	22,6	19,6	14,8	10,4	6,8
10	BA	Bari	5	8,6	9,2	11,1	14,2	18,0	22,3	24,7	24,5	22,0	17,9	14,0	10,2
11	BG	Bergamo	249	3,1	4,9	8,9	13,3	17,0	21,3	23,7	23,2	19,9	14,2	8,6	4,5
12	BL	Belluno	383	0,1	2,3	6,8	11,2	14,9	18,9	21,2	20,8	17,7	12,4	6,5	1,7
13	BN	Benevento	135	6,8	7,7	10,3	13,7	17,5	22,1	24,8	24,3	21,4	16,5	12,1	8,0
14	BO	Bologna	54	2,1	4,6	9,4	14,2	18,2	22,9	25,4	24,9	21,2	14,9	8,7	4,0
15	BR	Brindisi	15	9,3	9,6	11,4	14,2	18,0	22,0	24,5	24,5	22,1	18,3	14,4	10,9
16	BS	Brescia	149	1,5	4,2	9,3	13,5	17,7	22,0	24,4	23,7	19,9	14,0	7,8	3,5
17	BZ	Bolzano	262	1,2	4,2	9,0	13,4	16,9	21,0	22,7	22,0	18,8	12,9	6,7	2,2
18	CA	Cagliari	4	10,3	10,8	12,8	15,1	18,4	22,9	25,5	25,5	23,3	19,4	15,5	11,7
19	CB	Campobasso	701	3,7	4,8	7,3	11,1	14,8	19,6	22,5	22,2	18,9	13,5	9,0	5,0
20	CE	Caserta	68	8,7	9,4	12,0	15,3	19,1	23,5	26,2	26,1	23,0	18,2	13,9	10,3
21	CH	Chieti	330	5,6	6,6	9,6	13,5	17,2	22,0	24,7	24,3	21,2	15,9	11,3	7,2
22	CL	Caltanissetta	568	7,2	7,8	9,9	13,1	17,3	22,5	25,7	25,2	22,1	17,3	12,8	8,9
23	CN	Cuneo	534	1,1	2,9	6,9	11,3	14,8	19,4	21,9	21,0	17,7	11,7	6,2	2,5
24	CO	Como	201	2,9	5,0	8,8	12,7	16,7	21,1	23,6	23,1	19,6	13,7	8,4	4,4
25	CR	Cremona	45	0,7	3,3	8,4	13,3	17,4	21,9	24,3	23,4	19,7	13,4	7,2	2,5
26	CS	Cosenza	238	8,1	8,8	11,3	14,4	18,1	23,1	26,0	25,8	22,7	17,8	13,4	9,4
27	CT	Catania	7	10,7	11,2	12,9	15,5	19,1	23,5	26,5	26,5	24,1	19,9	15,9	12,3
28	CZ	Catanzaro	320	8,3	8,7	10,4	13,4	17,0	21,7	24,4	24,8	22,3	17,9	13,7	10,1
29	EN	Enna	931	4,5	5,1	7,1	10,7	14,9	20,6	23,9	23,2	19,9	14,5	9,8	6,4
30	FE	Ferrara	9	1,4	3,3	7,8	12,8	17,3	21,6	23,9	23,5	20,1	14,0	8,2	3,2
31	FG	Foggia	76	6,4	7,3	10,0	13,8	17,9	23,2	26,0	25,5	22,1	16,9	12,2	7,9
32	FI	Firenze	40	5,3	6,5	9,9	13,8	17,8	22,2	25,0	24,3	20,9	15,3	10,2	6,3
33	FO	Forlì	34	3,0	4,6	9,0	13,7	17,8	22,6	25,3	24,8	21,1	15,1	9,3	4,4
34	FR	Frosinone	291	5,8	6,2	8,0	11,0	15,2	18,5	21,5	20,9	18,8	13,4	9,2	5,0
35	GE	Genova	19	7,9	8,9	11,6	14,7	17,8	21,9	24,5	24,6	22,3	17,1	12,9	9,3
36	GO	Gorizia	84	4,7	5,6	8,2	11,9	16,7	19,9	22,0	22,2	18,6	13,2	9,2	4,7
37	GR	Grosseto	10	6,8	8,1	10,3	13,2	17,1	21,2	24,1	23,9	21,3	16,4	11,7	8,1

(segue prospetto)

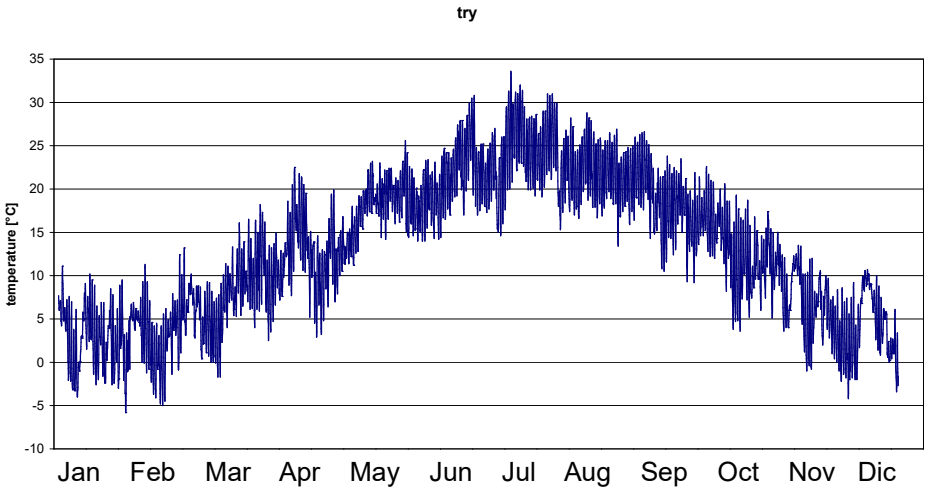
Hourly average temperature during the month 1/2



Hourly average temperature during the month 2/2



Test Reference Year (TRY)



HOW TO EVALUATE THE SOLAR RADIATION

Solar radiation is usually measured on the horizontal plane:

- **Single value to define the annual average incident radiation on the horizontal**
- **12 values for the average monthly incident radiation on the horizontal (split into direct and diffuse)**
- **12 average daily profiles of 24 hours for the incident radiation on the horizontal (split into direct and diffuse) during a month (12 x 24 values)**
- **TRY Test Reference Year: 8760 (365 x 24) values for direct and diffuse radiation on horizontal**

Daily average solar radiation

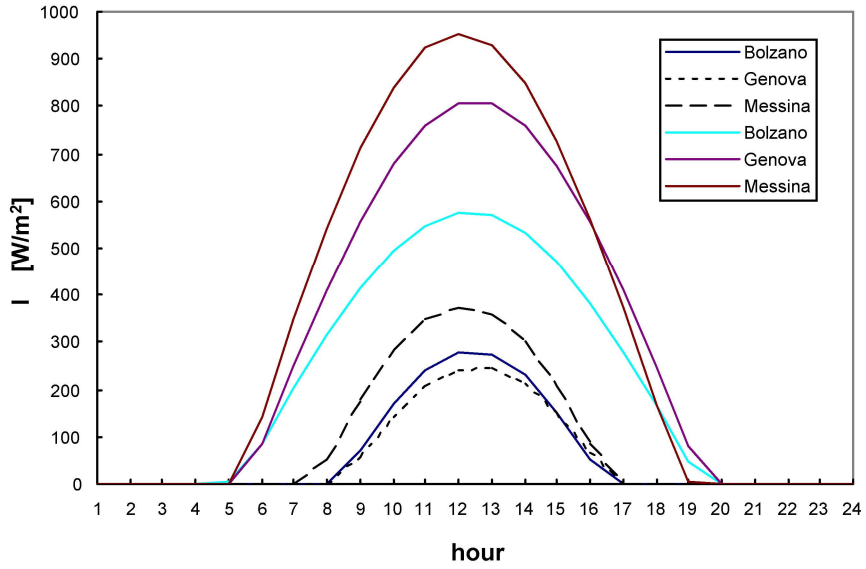
Table 2.6: Daily average total solar radiation on horizontal [kWh/m2] for the locations of Table 2.3

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abu Dhabi	4.22	5.32	5.55	6.51	7.64	7.77	7.40	7.22	6.62	5.71	4.56	3.94
Athens	2.07	2.82	4.01	5.14	6.22	7.48	7.53	6.63	5.42	3.52	2.14	1.81
Auckland	6.80	5.58	4.67	3.38	2.31	1.93	2.06	2.72	4.04	4.83	5.84	6.38
Bangkok	4.71	5.18	5.87	5.59	5.05	5.09	4.79	4.34	4.61	4.40	4.70	4.59
Beijing	2.33	3.05	4.23	5.30	6.01	6.03	5.27	4.87	4.76	3.44	2.36	2.06
Berlin	0.53	1.18	1.93	3.84	4.84	5.04	5.11	4.35	2.74	1.54	0.80	0.41
Buenos Aires	6.84	6.08	4.90	3.60	2.59	2.08	2.29	3.05	4.21	5.29	6.52	6.79
Cairo	2.98	4.01	5.31	6.39	7.39	7.32	6.89	6.24	5.60	4.51	3.37	2.80
Cape Town	7.98	7.20	5.74	4.10	3.04	2.37	2.49	3.52	4.69	6.12	7.51	7.85
Caracas	5.02	5.56	5.94	5.54	5.35	5.85	5.51	6.16	5.88	5.09	4.67	4.36
Chicago	1.76	2.49	3.44	4.39	5.98	6.29	6.18	5.16	4.19	2.94	1.82	1.50
Dakar	4.78	5.45	6.53	6.54	6.66	6.13	5.60	5.29	5.41	5.40	4.68	4.45
Debrecen	0.99	1.89	2.88	4.22	5.49	6.04	6.14	5.34	3.67	2.25	1.19	0.80
Helsinki	0.25	0.91	1.87	3.58	5.31	5.74	5.44	4.02	2.35	1.12	0.31	0.12
Houston	2.83	3.28	4.27	4.92	5.44	5.95	6.18	5.47	5.06	4.25	3.19	2.61
Lima	5.71	5.42	5.85	5.13	3.91	2.78	2.78	2.86	3.30	4.22	4.46	5.08
London	0.71	1.19	2.12	3.64	4.91	4.91	5.02	4.35	2.97	1.75	0.97	0.55
Melbourne	6.94	6.11	4.90	3.33	2.17	1.62	1.94	2.77	4.08	5.33	6.54	6.45
Mexico City	4.13	4.74	5.43	5.70	5.63	5.63	5.52	5.65	5.10	4.66	4.01	3.52

Table 2.6: Daily average total solar radiation on horizontal [kWh/m2] for the locations of Table 2.3

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Montreal	1.66	2.88	4.42	4.56	5.75	6.34	6.01	5.20	4.16	2.57	1.47	1.27
Moscow	0.48	1.20	2.33	3.49	5.04	5.44	5.16	4.12	2.39	1.33	0.58	0.35
Mumbai	4.52	5.31	6.20	6.86	6.56	4.84	3.77	3.84	4.20	5.11	4.74	4.27
Nairobi	6.04	6.56	5.81	4.89	4.34	4.07	4.01	4.74	5.34	5.20	4.72	5.35
New Delhi	3.25	3.68	5.39	6.96	6.61	6.79	5.93	5.10	4.84	4.28	3.92	3.26
New York	1.65	2.60	3.68	4.47	5.53	5.99	5.78	5.95	4.17	3.59	2.04	1.50
Paris	0.78	1.39	2.28	3.63	4.61	5.31	5.36	4.86	3.12	2.03	1.04	0.61
Phoenix	3.29	4.16	5.34	7.09	7.84	8.32	7.62	7.13	6.34	4.82	3.77	3.07
Riyadh	4.28	5.06	5.77	6.41	7.34	8.03	7.82	7.43	6.89	5.99	4.71	3.60
Salt Lake City	1.89	2.92	3.98	5.39	6.32	7.60	7.28	6.37	5.33	3.69	2.30	1.56
San Paulo	5.65	5.39	4.86	4.27	3.34	3.13	3.33	4.15	4.63	5.06	5.58	5.85
Seville	2.53	3.39	4.44	5.49	6.70	7.19	7.56	6.89	5.32	3.97	2.83	2.30
Sidney	6.60	5.63	4.87	3.74	2.66	2.18	2.56	3.56	4.58	5.64	5.99	6.38
Singapore	4.55	4.99	4.80	4.97	4.68	4.47	4.63	4.51	4.57	4.48	4.23	4.12
Stockholm	0.26	0.76	1.77	3.74	5.28	5.36	5.06	3.81	2.32	1.18	0.45	0.20
Strasburg	0.78	1.43	2.75	3.83	4.63	5.40	5.47	4.89	3.30	1.70	0.93	0.66
Tehran	3.06	4.17	5.51	6.48	7.95	8.74	7.99	7.83	6.81	4.98	3.96	2.81
Tokyo	2.52	3.15	3.54	4.61	4.79	4.14	4.39	4.81	3.47	2.93	2.49	2.09
Vancouver	0.80	1.57	2.65	4.55	5.61	5.97	6.56	5.31	3.92	1.79	0.94	0.64
Venice	1.03	1.67	2.97	3.93	4.64	5.39	6.05	4.93	3.21	2.00	1.25	0.76
Washington DC	2.02	2.75	3.88	5.09	5.63	6.46	5.98	5.26	4.30	3.45	2.22	1.83

Horizontal solar irradiance



Consequences of the orientation of the surfaces