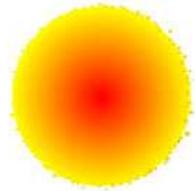# Climatic conditions

# For HVAC calculations
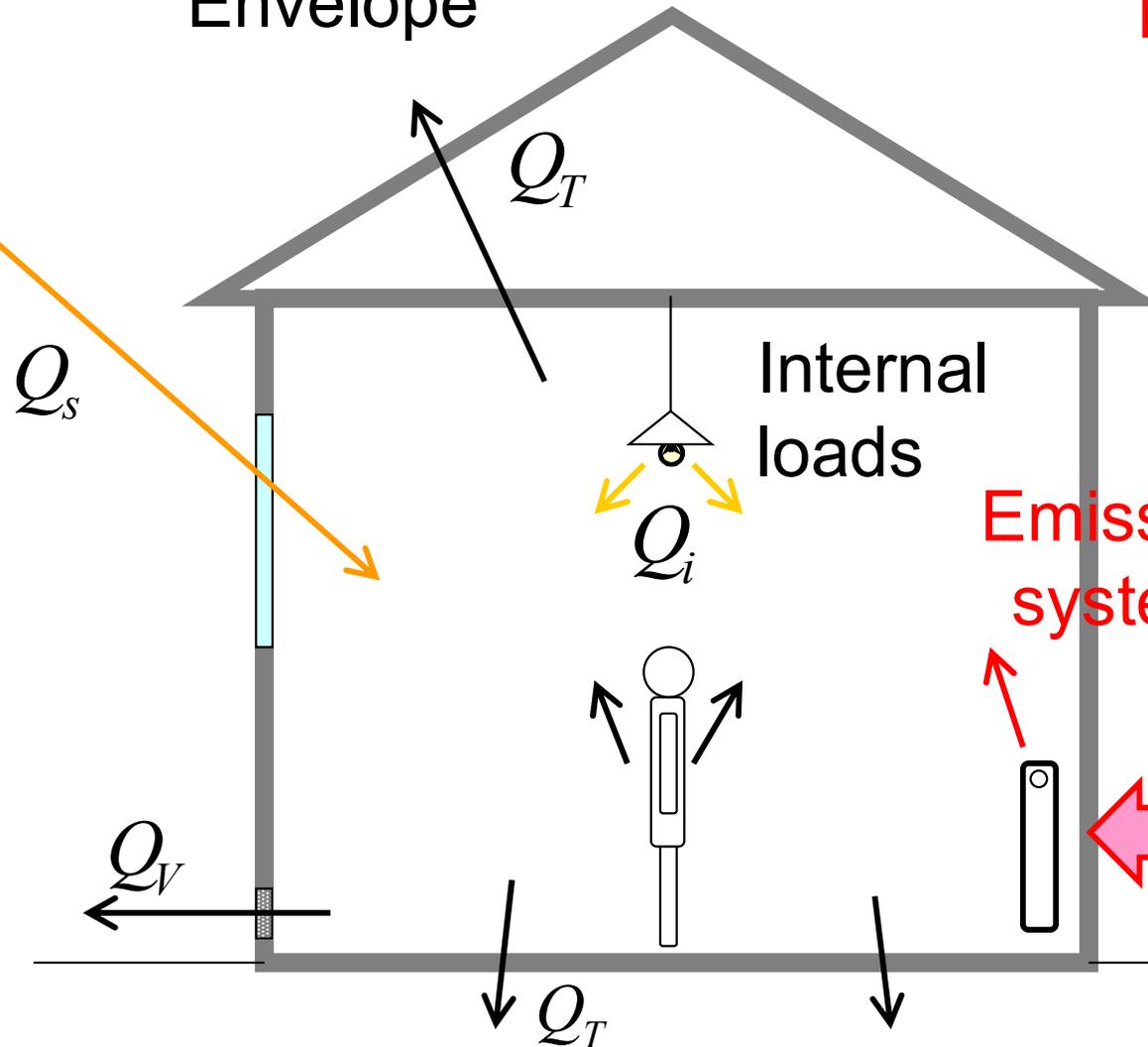
# HVAC plant in heating conditions

Solar radiation

Envelope

Power/energy of the HVAC

$Q_T$

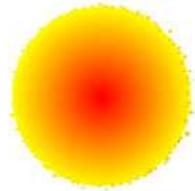Internal loads

$Q_s$

$Q_i$

Emission system

Distribution

Ventilation

$Q_V$

$Q_T$

Generator

# HVAC plant in cooling conditions
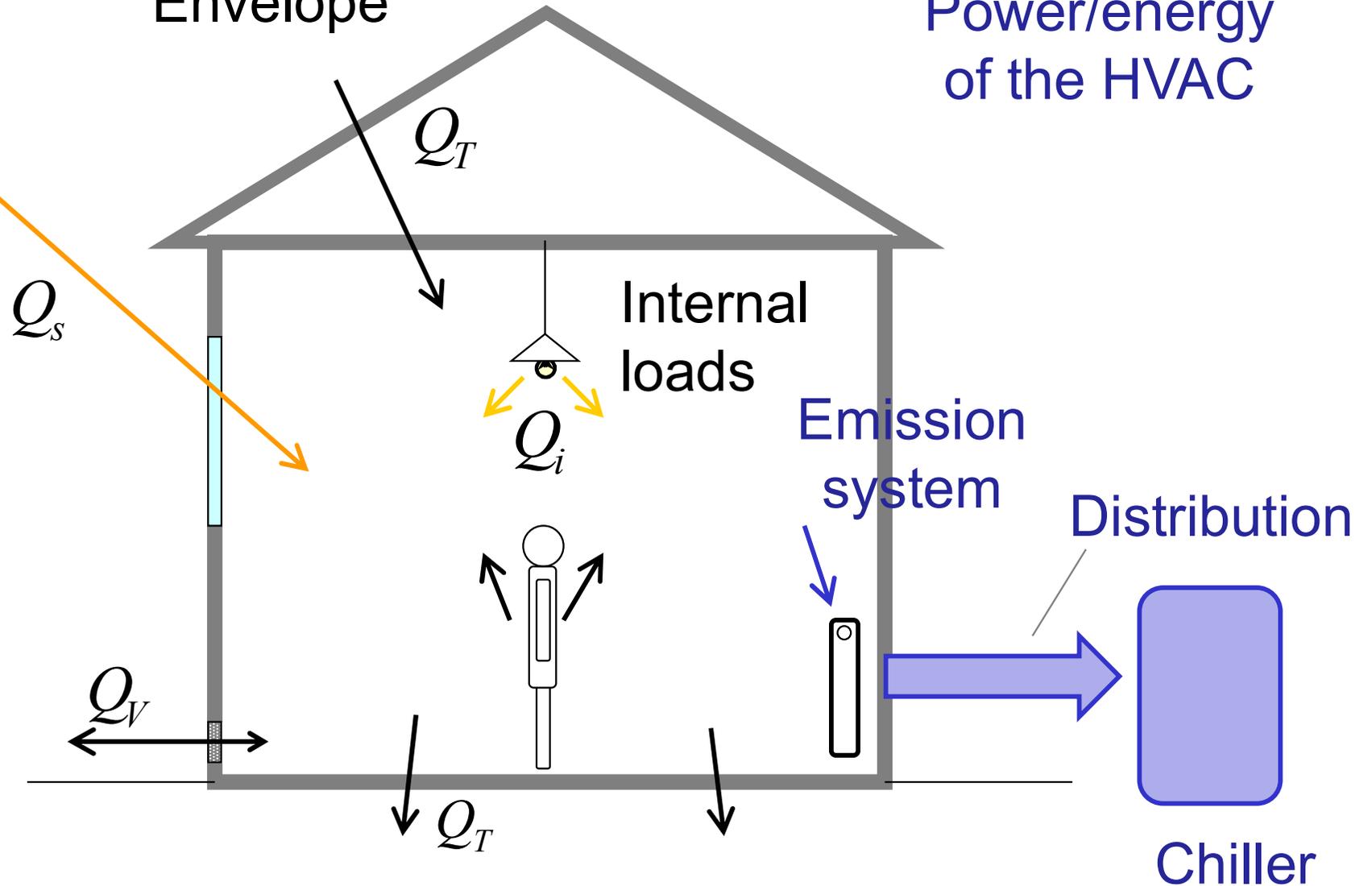
# Are climatic conditions important?



Temperature - Venice, Italy
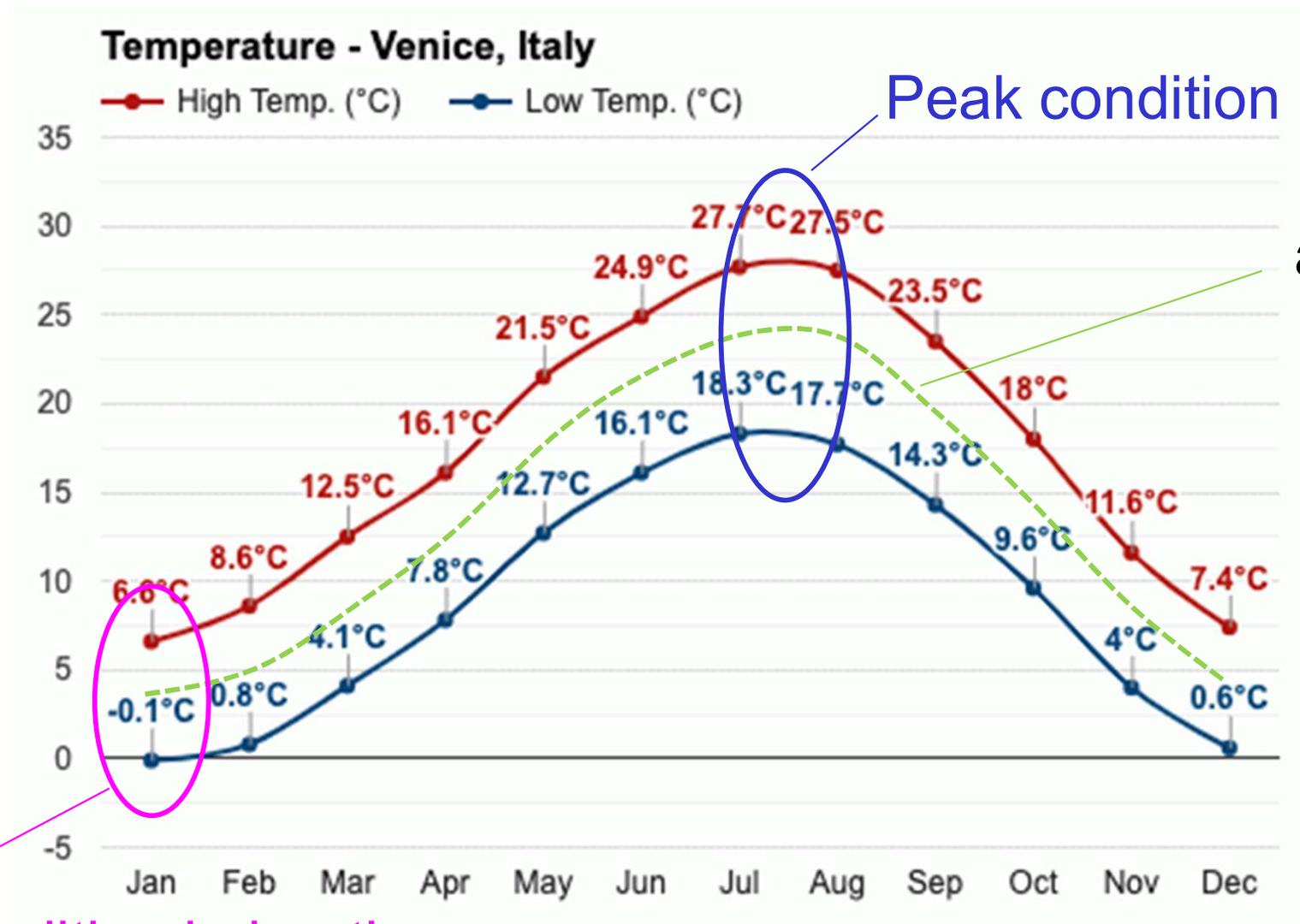
How do they affect the HVAC system?

# Winter design conditions



$t_i = 20°C$

Design temperature
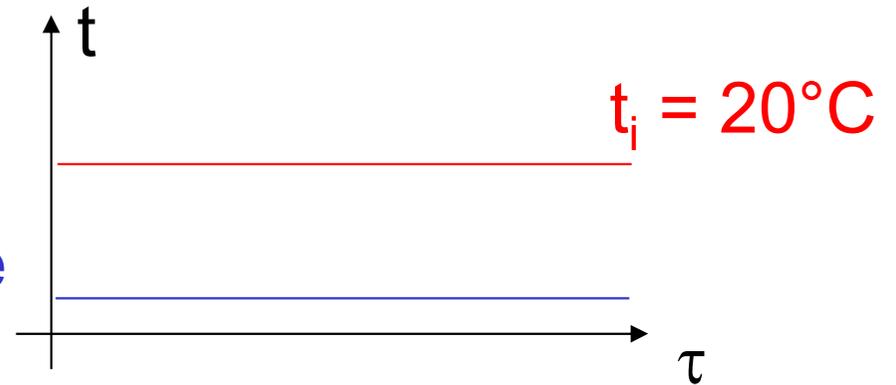
- Outside air temperature constant (coldest day)

- No solar radiation

- No internal gains

Weather conditions
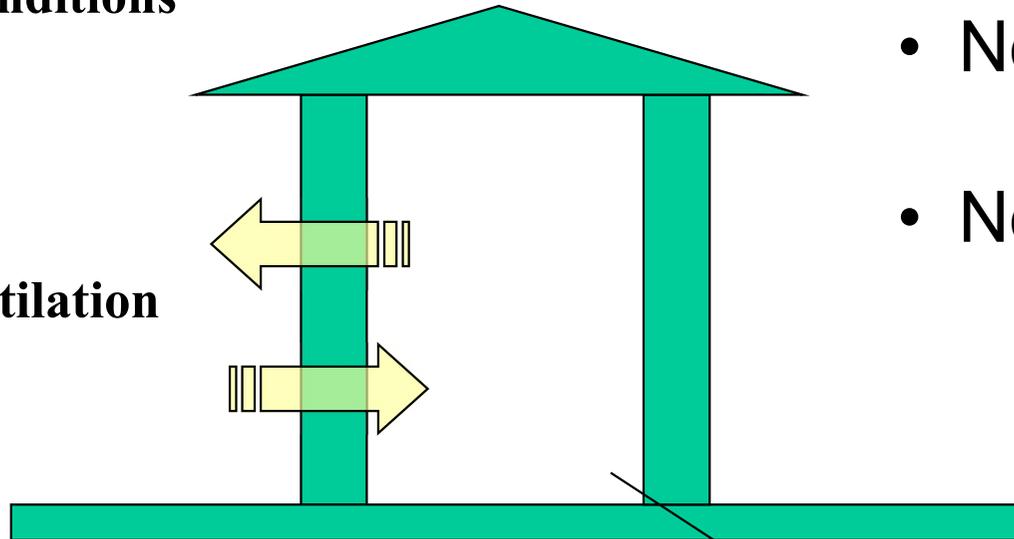
Ventilation

$ti = 20°C$

(RH < 60%)

# Summary design conditions

## 1) Cooling systems

**Weather conditions**
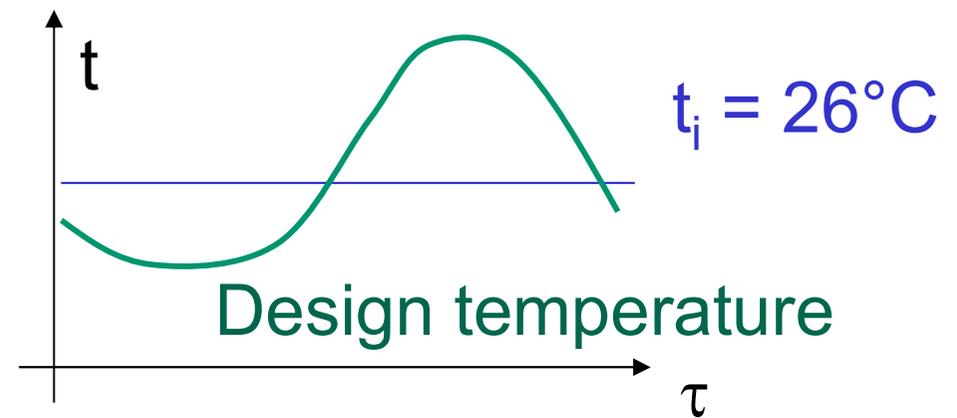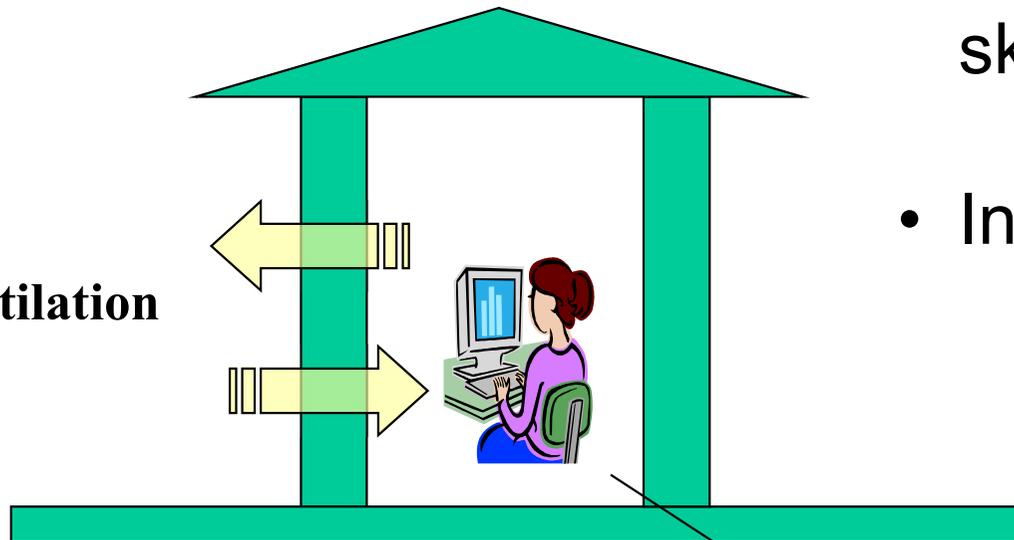
$t_i = 26°C$

Design temperature

**Ventilation**

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

- Internal gains

**ti = 26°C**

**(RH = 50%)**

# Summer design conditions

## 2) Naturally ventilated buildings

### Design temperature
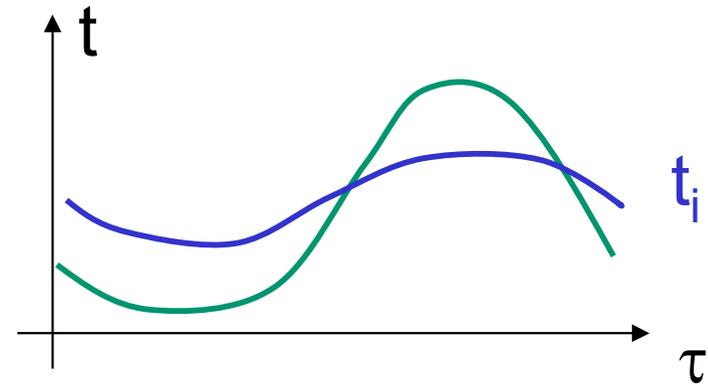
**Weather conditions**
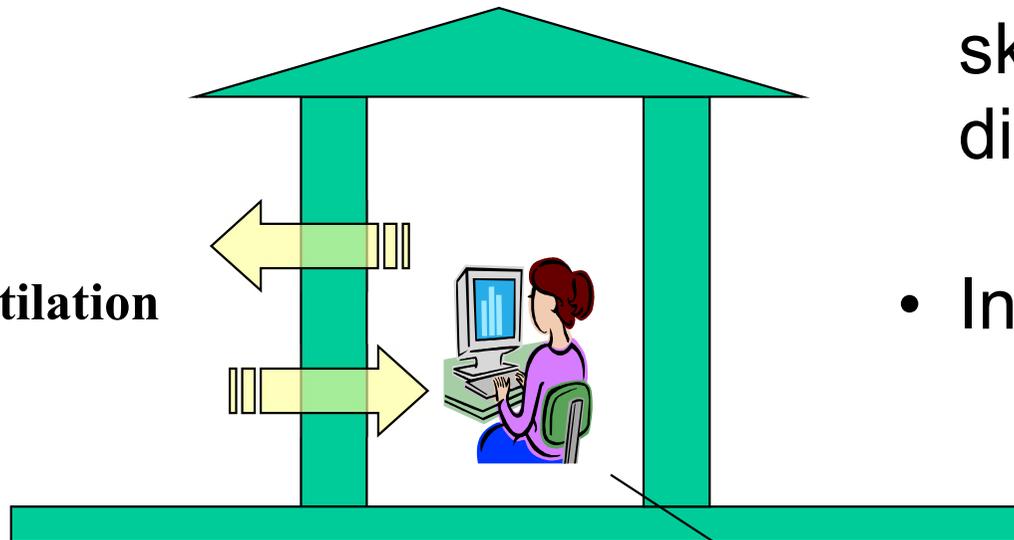


**Ventilation**

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

- Internal gains

$t_i$ = ???

**Negligible effect of RH**

# Energy need of a building for heating in winter
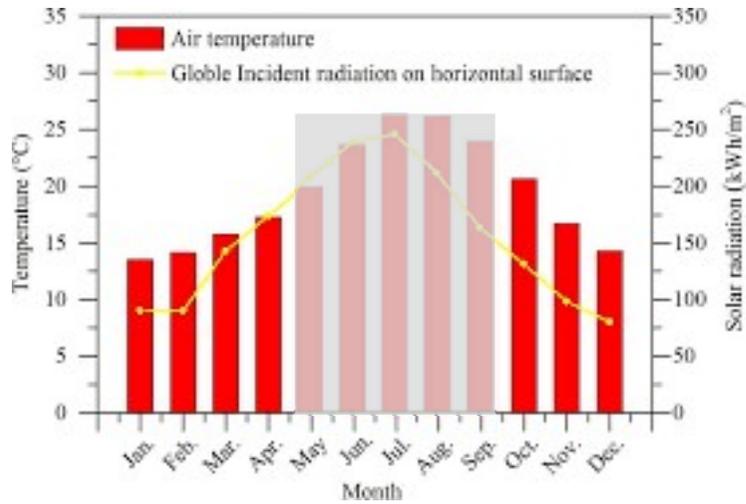


**Weather conditions**

- Outside air temperature and solar radiation over the heating months

- Internal gains
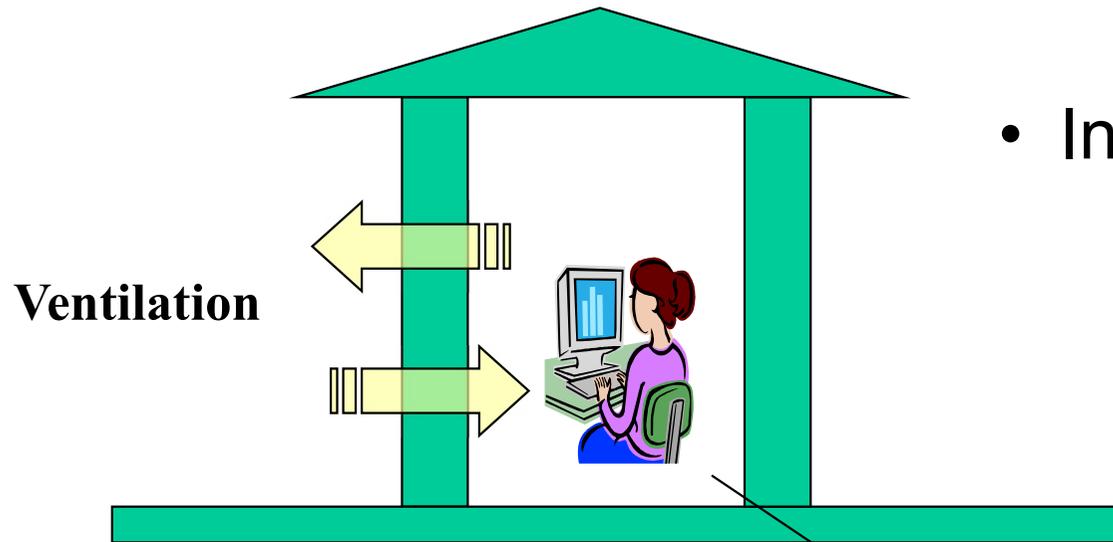
**Ventilation**

$t_i = 20°C$

(RH < 60%)

# Energy need of a building for cooling in summer
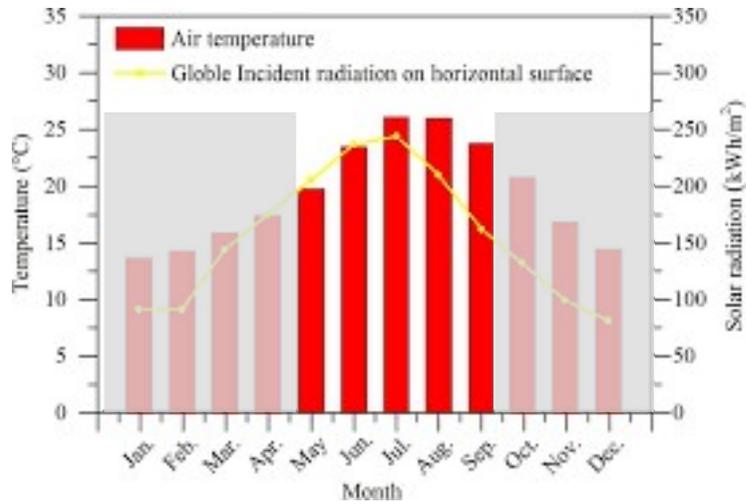


**Weather conditions**

- Outside air temperature and solar radiation over the cooling months

- Internal gains
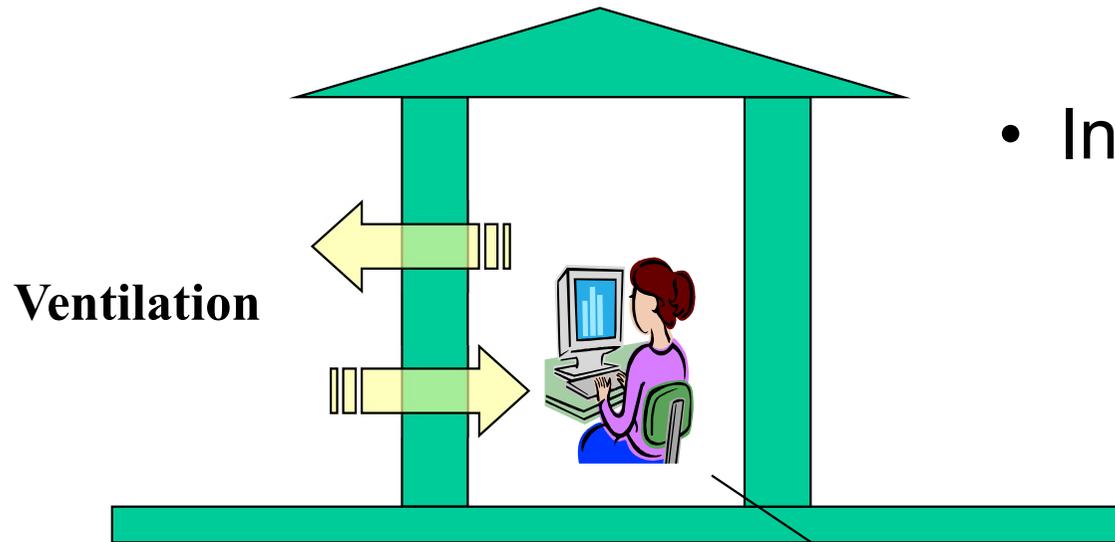
**Ventilation**

$t_i = 26°C$

(RH = 50%)

# Comfort performance of a naturally ventilated building in summer
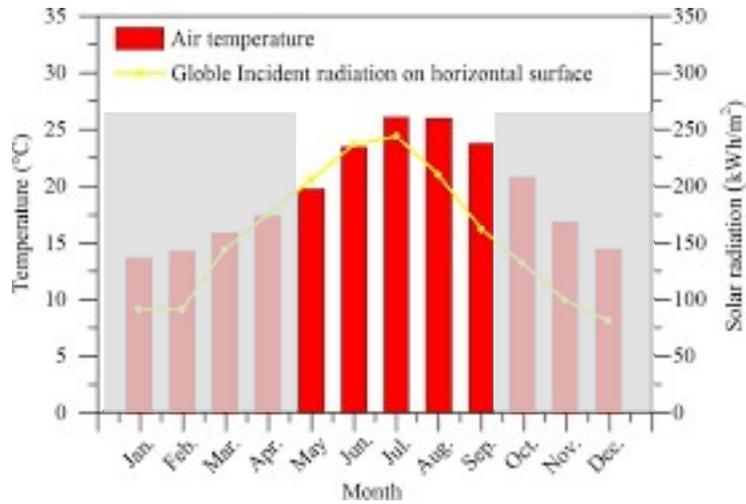


**Weather conditions**

**Ventilation**

- Outside air temperature and solar radiation over the cooling months

- Internal gains

ti = ???
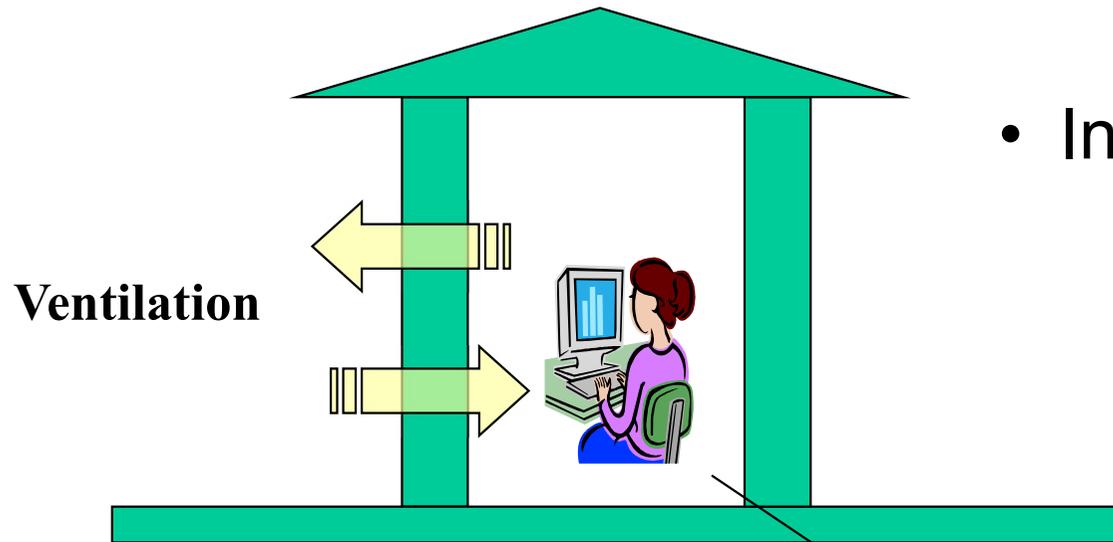
**Negligible effect of RH**

# In summary:

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

Sizing

Peak power in heating

Peak power in cooling

Design

Selection of the plant: emission system, distribution system, generation system

Energy required for heating

Energy required for cooling
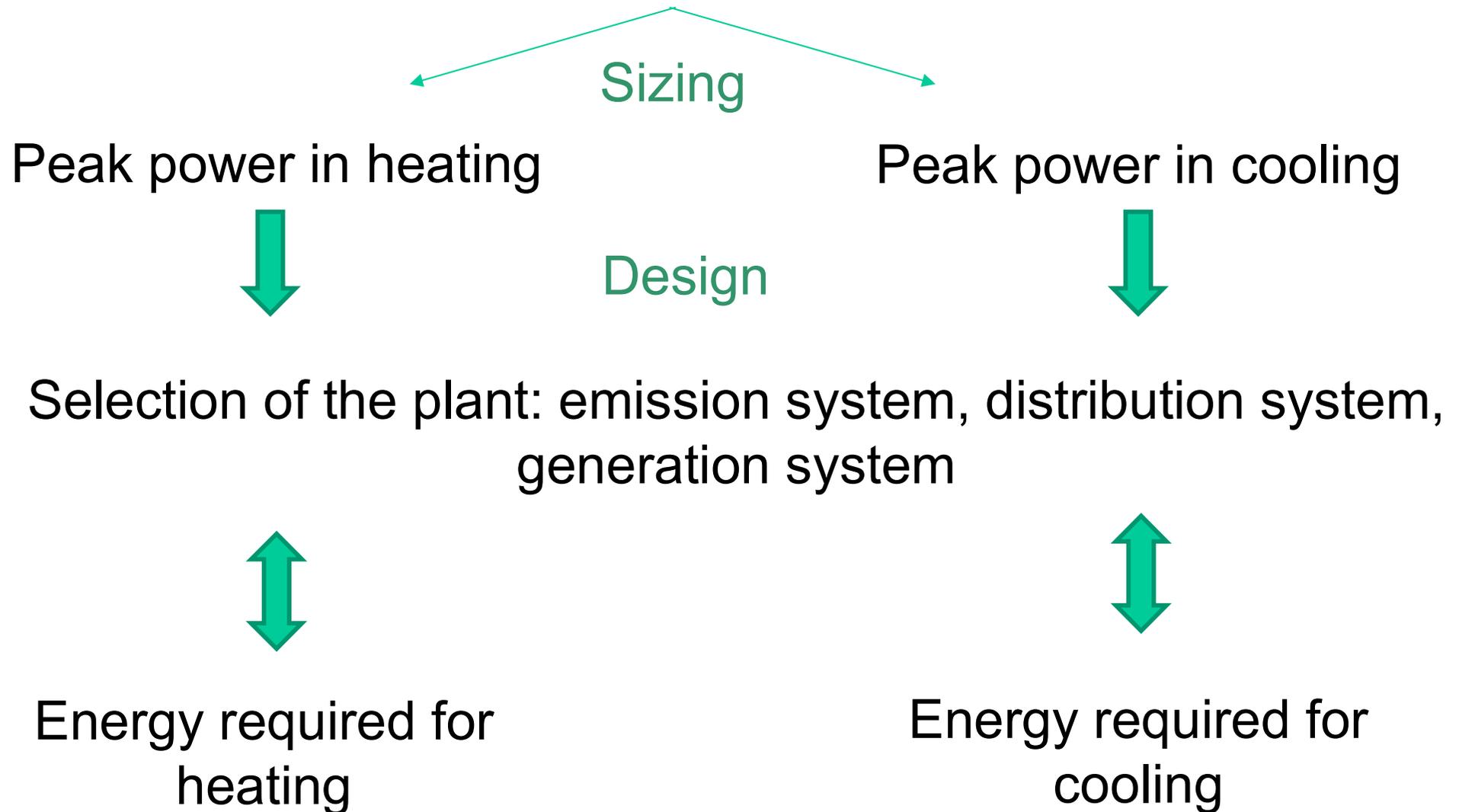
# HOW TO DEFINE THE CLIMATE OF A ZONE

- **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

**Usually defined in standards**

$$t_{amb,h} = t_{amb,\max} - p_h \Delta t_{amb}$$

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 ($\overline{t}_{amb,d,j}$). 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:

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

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

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:

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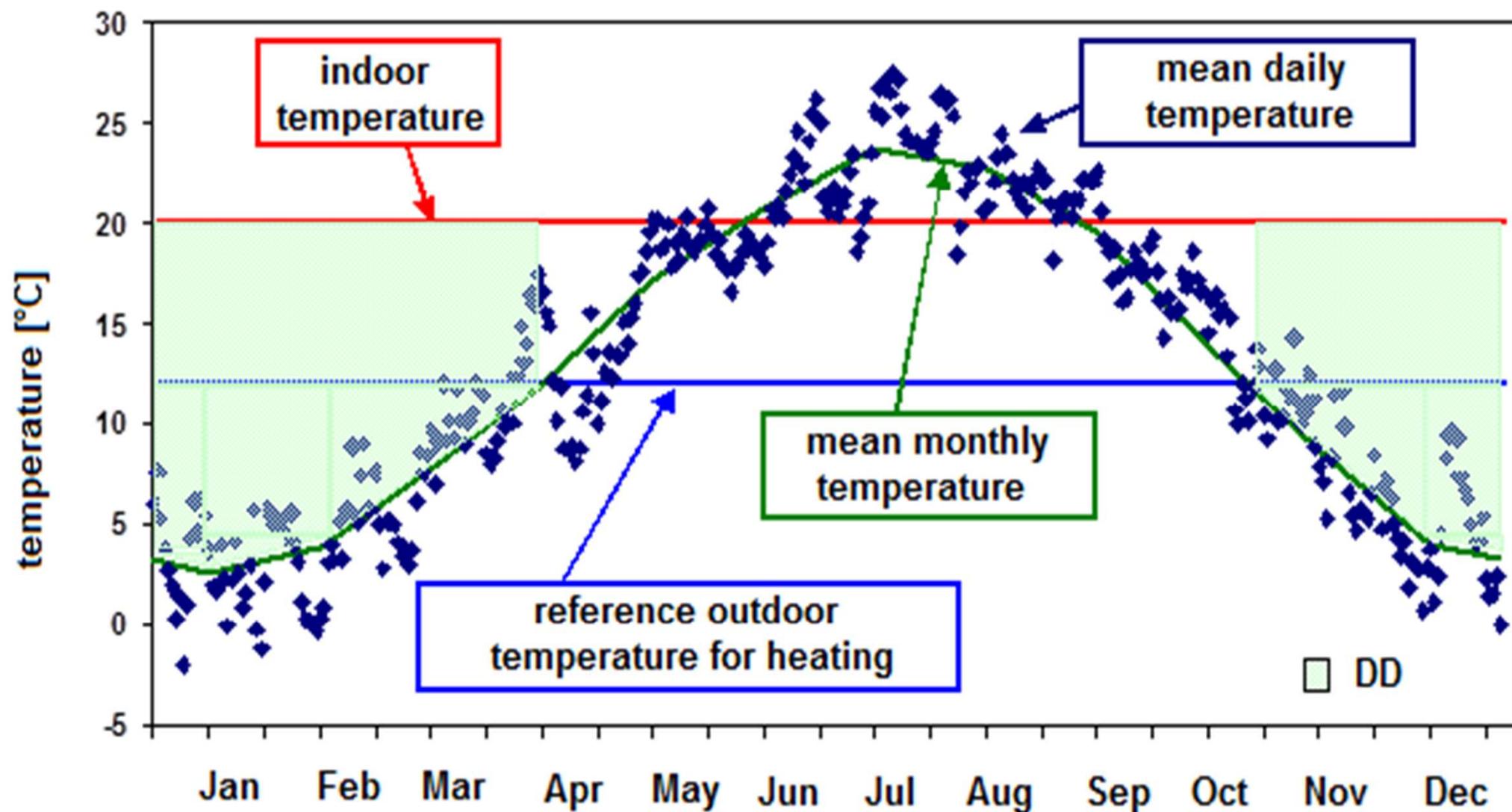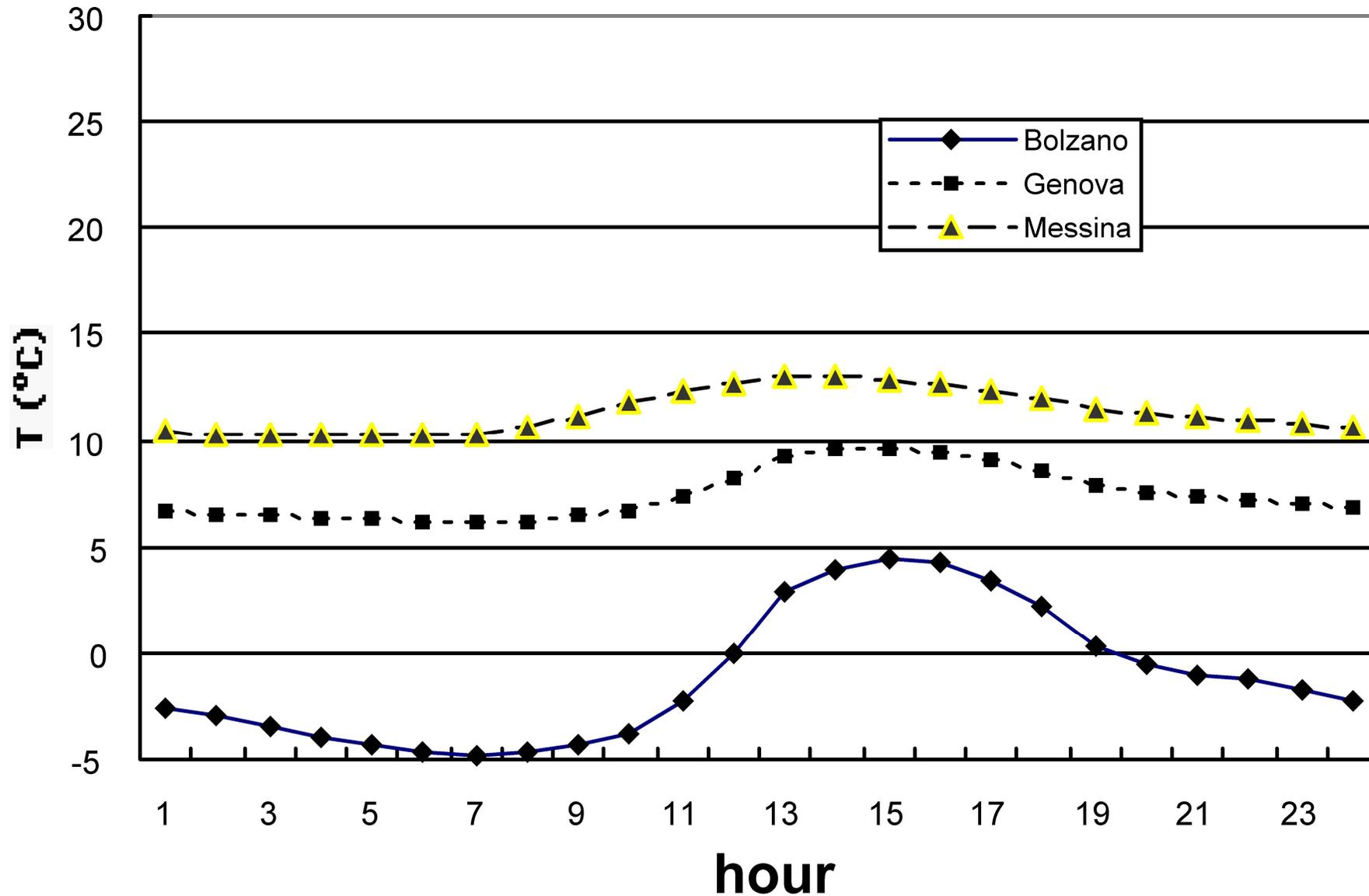
# Monthly average temperature

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 | 14,6 | 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 | 5,8 | 6,8 | 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

**January – Temperature during the average day**

July – Temperature during the average day
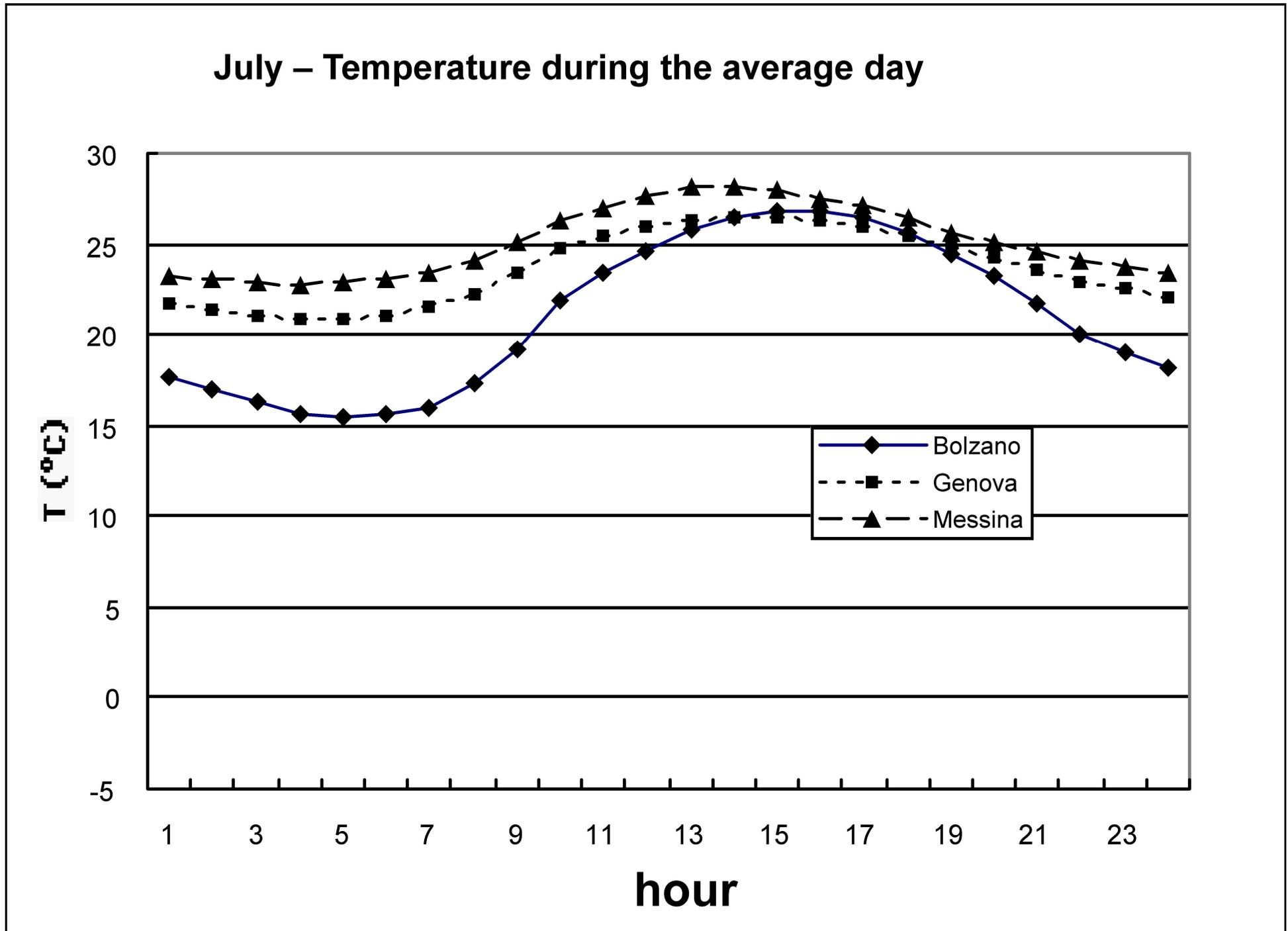
# Test Reference Year (TRY)



try
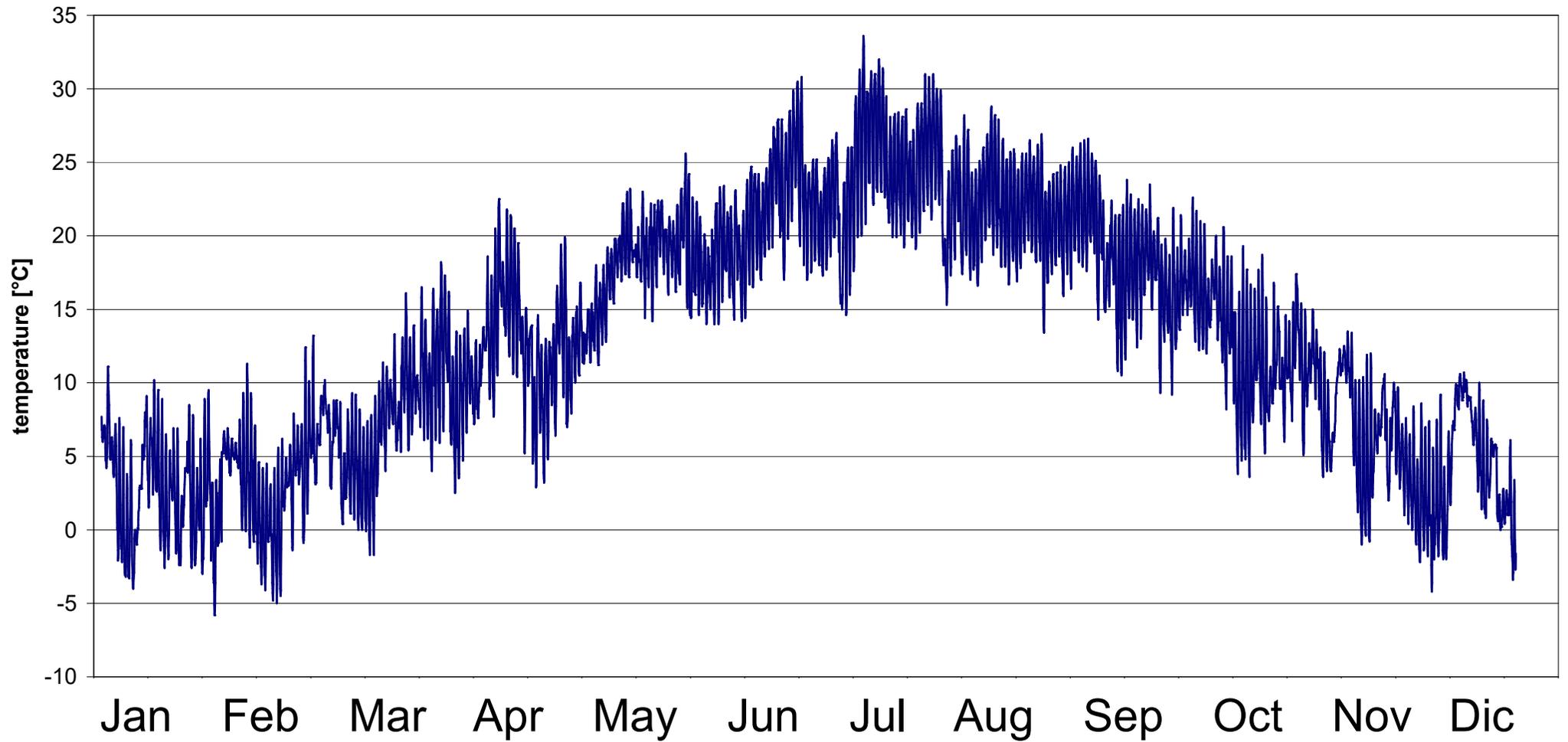
# HOW TO EVALUATE THE SOLAR RADIATION

**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
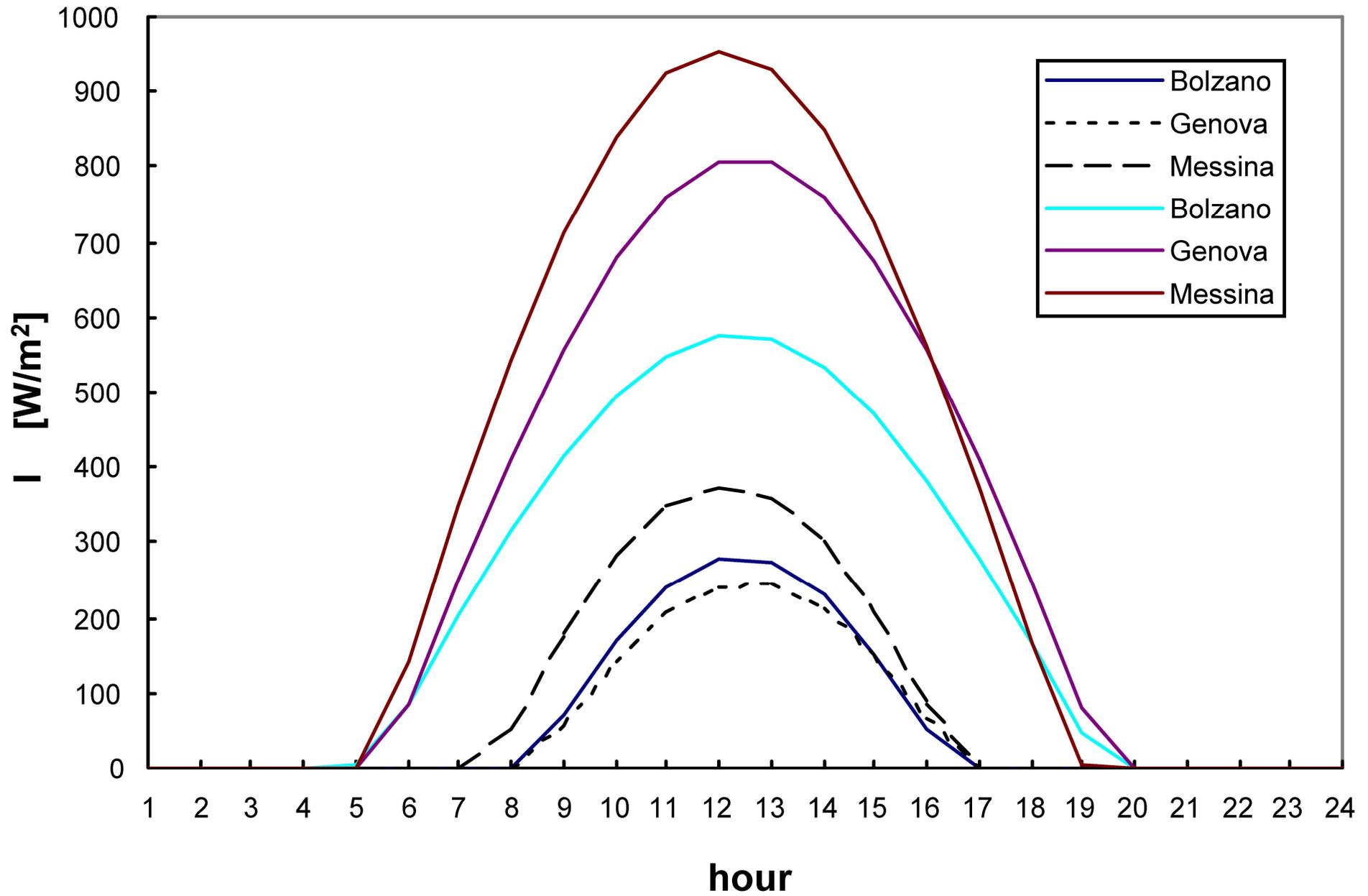
# Consequences of the orientation of the surfaces