

# Climatic data quality check and performance assessment of EN ISO 15927-2 Cooling Design Days selection method in Italy

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## A B S T R A C T

Consistent climate data and reliable sizing methods are fundamental for designing Technical Building Systems. This paper addresses both these aspects with reference to the Italian context analyzing 108 different locations. Regarding the climate data, a quality analysis through the application of rules and filters was performed on the locations. The results showed good data quality, with most sites having high percentages of usable material, although highlighting recursive criticalities in the detection of humidity and wind speed parameters. Regarding the sizing methods, a sensitivity analysis was carried on for the European standard EN ISO 15927-2 to evaluate its performances in selecting the Cooling Design Days in the 108 locations. The analysis highlighted great differences in terms of chosen Design Days when using different climatic parameters, showing at the same time a negligible influence of the wind speed on the selection process. Furthermore, a sizing process for a test building applied to the 108 locations was carried on by using the Cooling Design Days. The results highlighted that the Design Days obtained through the EN ISO method often give counterintuitive sizing outputs, even obtaining higher required powers for lower risk levels, the opposite of how it should be. This implies that a designer should be very careful in evaluating which parameters to use in the Design Day selection and if the output sizing powers obtained through them are reliable for its particular sizing process.

## Keywords:

Cooling design day  
Climatic data  
Data quality  
Design  
Cooling systems  
Sizing data

## 1. Introduction

It is widely demonstrated that in the European Union the residential sector accounts for a great part of the total energy usage [1,2], and of Green House Gas emissions [3], covering a 26–28 % percentage for the former and 19 % for the latter. In Italy, this behavior is even more evident with the residential sector accounting for about 36 % of the total national energy consumption [4]. Many researches have been carried out in order to investigate strategies to reduce the impact of this sector on the natural environment and, at the same time, to improve the comfort of the users. Due to the recent climatic changes recorded around the globe, showing an increasing trend of temperatures in all seasons [5], the importance of the cooling performance of the buildings has considerably grown. In fact, if in the recent past the main trend was to insulate the buildings envelope to decrease winter heating energy usage [6], nowadays the designers are more concerned about cooling related problems. With this in mind, it is of the

utmost importance to correctly size the cooling systems, even more in refurbished buildings, where the risk of overheating due to major envelope insulation is higher [7,8]. The cooling load methodologies require the definition of the external boundary conditions, that are a series of data which define the solar and thermohygrometric parameters of the external climate. They affect the heat gain terms and the cooling load results: therefore, weather data is an important factor when sizing an HVAC system [9]. The climate parameters used in the sizing process can be obtained with different statistical methodologies and they represent extreme conditions assessed with risk levels or percentiles.

Considering this, the availability of extensive and reliable climatic data is essential; this necessity could often be a problem because of both poor quantity and/or quality of available material. About the former problem, the data usable for different locations always vary in length, with some sites displaying several years of detected material while for others only few years have been recorded. This could be a serious limitation because of the international standards recommending minimum amounts of detected data to be used [10]. Furthermore, it is very important to have usable material to work with, implying high quality of raw information. Unfortunately, the datasets often present unusable,

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unreadable, or poor data. These deficiencies are due to the operation of meteorological stations, which are subject to black outs, severe working conditions or storage and software failures. Moreover, it often happens that during the data collection and the subsequent post-processing, human and software errors may cause the loss or corruption of some information. Finally, the solar radiation parameter, fundamental for energy calculations, despite being included in nearly all the meteorological stations, remains the most problematic parameter to deal with [11] and usually only the global value is available.

Considered all these critical issues, it is of particular importance to carry out a qualitative analysis of the available raw data in order to determine which one can be used for energy simulations and, for this particular case, in the selection method for the Cooling Design Day, and which one to discard because of low quality. In fact, the use of unchecked climatic data could lead to large differences between the predicted and measured performance of the building systems [12,13].

Many authors have faced these issues using different approaches. Regarding the data availability importance on energy simulations, Murano et al. [14] compared three official climatic databases to highlight the main differences. The datasets were the ones from the national standard UNI 10349-1:1994 [15], the ENEA database [16] and the EPW files from EnergyPlus weather data [17]. A quasi-steady-state analysis performed on an NZEB building case study showed significant discrepancies in energy performances for both heating and cooling by using the different datasets. In order to evaluate the common scarcity of climatic data, Cannistraro et al. [18] approached the problem in a particular way; instead of selecting the widest dataset available and filling the possible gaps with some sort of interpolation, they simply decided to reduce the amount of data to be used. By using the methodology proposed by Erbs et al. [19], they calculated temperature hourly values for 29 European locations starting from the mean monthly temperatures and from the amplitude of diurnal variations leaving unchanged all other climatic parameters. They used the original and modified climatic data for carrying on energy simulations of three sample modules, showing differences below 9 % between the final energy consumption obtained by applying the two climatic datasets to the three modules.

Another approach was carried on by Yang et al. [20] that developed an automated system for climatic data scraping, filtering and displaying, originally developed for climatic analysis applied to agricultural prediction. The tool checks for erroneous information (like relative humidity over 100 %), removes them and treats them as missing and fills the gaps in the dataset using methods like Linear Interpolation, Adjusted Historic Average, Spatial Interpolation, Functional Estimation or Weather Data Generator on the bases of gaps length and parameter to be treated.

In this paper, a qualitative analysis of raw climatic data for 108 meteorological stations throughout Italy is conducted in order to assess which ones present the best raw material and which ones need improvement.

Regarding the hourly data for design cooling load, the reference method for European users is the one proposed by the EN ISO 15927-2 standard [10]. Because of the standard gives the possibility of using different climatic parameters when searching the Cooling Design Days, a sensitivity analysis of the selection method was carried on to assess how the use of different parameters could influence the results of the selection workflow. Moreover, sizing simulations were carried on for a sample building applied to the 108 locations by using the Cooling Design Days selected for said locations through the EN ISO 15927-2 standard method, which will be referred as EN ISO in the following. This allowed to evaluate how the standard method performs when applied to a real sizing procedure, highlighting its behavior in relation to the different risk

levels defined by the standard itself. In order to carry on this research, the EN ISO method has been formally reformulated into a new process, easier to implement in numerical codes and useful to explain some results of the sensitivity analysis, all of this maintaining the theoretical principles of the standard.

This study supports the updating of the national technical standard on climate data for the design of technical building systems. The Italian Thermotechnical Committee Energy & Environment (CTI) [21], a not-for-profit organization which is part of UNI (Italian Certification Body), is in fact currently working on updating the UNI/TR 10349-2 [22] technical report which represents the national reference document which provides climatic input data for the application of technical standards that support the EPBD Directive.

## 2. Qualitative analysis of raw climatic data

Raw climatic data were obtained from local meteorological stations of the Italian regional agencies. The stations are placed in 108 sites throughout Italian territory, as it can be seen in Fig. 1, and record the values of dry-bulb temperature, total solar global radiation, relative humidity and wind speed on hourly bases. Raw climatic data have been measured according to the methods specified in the World Meteorological Organization Guide. However, this material cannot be directly used for energy simulations because of many missing values in the datasets as reported in Table 1; it is in fact clear that days in which there are too many gaps cannot be used as reliable inputs for whatever analysis. Finally, writing and syntax errors were also detected in the climatic sets.

In order to obtain a solid and computable data pool for energy analysis, a data quality treatment is therefore necessary. After a preliminary correcting action on syntax and writing errors, every dataset has been treated through the imposition of four quality rules in order to obtain a pool of valid days for the calculation. The four rules that are to be fulfilled for a day to be considered valid are:

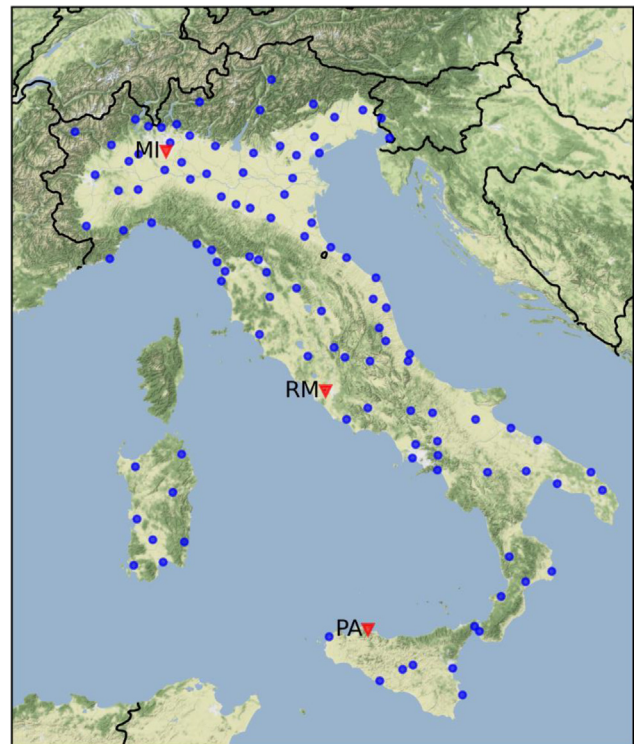


Fig. 1. Location of the analyzed Italian meteorological stations.

**Table 1**

Main features of the analyzed Italian meteorological stations.

| Location          | Label | Lat. [°] | Lon. [°] | Alt. [m] | Rec. Period | Missing Data [%] | Location           | Label | Lat. [°] | Lon. [°] | Alt. [m] | Rec. Period | Missing Data [%] |
|-------------------|-------|----------|----------|----------|-------------|------------------|--------------------|-------|----------|----------|----------|-------------|------------------|
| Agrigento         | AG    | 37.30    | 13.58    | 230      | 2002–2009   | 4.26             | Modena             | MO    | 44.63    | 10.92    | 34       | 2004–2009   | 19.28            |
| Alessandria       | AL    | 44.90    | 8.60     | 95       | 1993–2010   | 0.75             | Massa – Carrara    | MS    | 44.02    | 10.12    | 65       | 1993–2009   | 11.83            |
| Ancona            | AN    | 43.60    | 13.50    | 16       | 2003–2010   | 14.57            | Napoli             | NA    | 40.85    | 14.25    | 17       | 2006–2009   | 1.46             |
| Ascoli Piceno     | AP    | 42.85    | 13.57    | 154      | 2003–2010   | 24.24            | Novara             | NO    | 45.42    | 8.62     | 162      | 1993–2010   | 1.02             |
| L'Aquila          | AQ    | 42.35    | 13.38    | 714      | 2000–2010   | 2.54             | Nuoro              | NU    | 40.32    | 9.32     | 546      | 1997–2006   | 2.98             |
| Arezzo            | AR    | 43.45    | 11.87    | 246      | 2008–2013   | 12.69            | Ogliastra          | OG    | 39.53    | 9.55     | 425      | 1997–2005   | 4.50             |
| Asti              | AT    | 44.88    | 8.20     | 123      | 2005–2010   | 4.91             | Oristano           | OR    | 39.90    | 8.58     | 9        | 2001–2011   | 15.49            |
| Avellino          | AV    | 40.90    | 14.78    | 348      | 2006–2009   | 0.06             | Olbia              | OT    | 40.92    | 9.50     | 10       | 1998–2007   | 11.55            |
| Bari              | BA    | 41.13    | 16.83    | 5        | 2007–2012   | 1.69             | Tempio             |       |          |          |          |             |                  |
| Bergamo           | BG    | 45.68    | 9.67     | 249      | 1997–2008   | 0.97             | Palermo            | PA    | 38.12    | 13.35    | 14       | 2002–2009   | 1.27             |
| Biella            | BI    | 45.55    | 8.05     | 420      | 1993–2010   | 3.79             | Piacenza           | PC    | 45.05    | 9.68     | 61       | 2004–2009   | 21.71            |
| Belluno           | BL    | 46.13    | 12.22    | 383      | 1997–2008   | 1.02             | Padova             | PD    | 45.40    | 11.87    | 12       | 1997–2008   | 3.78             |
| Benevento         | BN    | 41.12    | 14.77    | 135      | 2006–2009   | 0.22             | Pescara            | PE    | 42.45    | 14.20    | 4        | 2007–2010   | 1.68             |
| Bologna           | BO    | 44.48    | 11.33    | 54       | 2004–2009   | 21.18            | Perugia            | PG    | 43.10    | 12.38    | 493      | 2007–2010   | 13.83            |
| Brindisi          | BR    | 40.63    | 17.93    | 15       | 2007–2013   | 11.21            | Pisa               | PI    | 43.70    | 10.40    | 4        | 1990–2009   | 4.85             |
| Brescia           | BS    | 45.53    | 10.20    | 149      | 1998–2008   | 26.50            | Pordenone          | PN    | 45.95    | 12.65    | 24       | 1999–2008   | 0.23             |
| Barletta Andria   | BT    | 41.32    | 16.28    | 15       | 2007–2012   | 6.26             | Prato              | PO    | 43.87    | 11.08    | 61       | 1996–2009   | 8.01             |
| Trani             |       |          |          |          |             |                  | Parma              | PR    | 44.80    | 10.32    | 57       | 2004–2009   | 19.10            |
| Bolzano           | BZ    | 46.48    | 11.35    | 262      | 1997–2008   | 7.68             | Pesaro e Urbino    | PU    | 43.90    | 12.90    | 11       | 1996–2009   | 10.61            |
| Cagliari          | CA    | 39.22    | 9.12     | 4        | 1995–2004   | 4.67             | Pistoia            | PT    | 43.92    | 10.90    | 67       | 2003–2010   | 18.97            |
| Campobasso        | CB    | 41.55    | 14.67    | 701      | 2000–2009   | 9.59             | Pavia              | PV    | 45.18    | 9.15     | 77       | 1998–2008   | 21.22            |
| Caserta           | CE    | 41.07    | 14.32    | 68       | 2006–2009   | 1.33             | Potenza            | PZ    | 40.63    | 15.80    | 819      | 2005–2012   | 8.41             |
| Chieti            | CH    | 42.35    | 14.17    | 330      | 2000–2010   | 19.12            | Ravenna            | RA    | 44.42    | 12.18    | 4        | 2004–2009   | 19.06            |
| Carbonia-Iglesias | CI    | 39.17    | 8.52     | 111      | 1997–2001   | 16.30            | Reggio di Calabria | RC    | 38.10    | 15.63    | 15       | 2002–2009   | 5.29             |
| Caltanissetta     | CL    | 37.48    | 14.05    | 568      | 2002–2009   | 21.29            | Reggio nell'Emilia | RE    | 44.68    | 10.62    | 58       | 2004–2009   | 18.87            |
| Cuneo             | CN    | 44.37    | 7.53     | 534      | 2002–2010   | 1.32             | Ragusa             | RG    | 35.92    | 14.72    | 502      | 2002–2009   | 2.95             |
| Como              | CO    | 45.80    | 9.08     | 201      | 2002–2010   | 19.90            | Rieti              | RI    | 42.40    | 12.87    | 405      | 2006–2010   | 17.06            |
| Cremona           | CR    | 45.13    | 10.02    | 45       | 1996–2008   | 13.16            | Roma               | RM    | 41.88    | 12.47    | 20       | 2005–2013   | 7.50             |
| Cosenza           | CS    | 39.30    | 16.25    | 238      | 2001–2009   | 7.73             | Rimini             | RN    | 44.05    | 12.57    | 5        | 2004–2009   | 23.64            |
| Catania           | CT    | 37.50    | 15.08    | 7        | 2002–2009   | 8.32             | Rovigo             | RO    | 45.07    | 11.78    | 7        | 1997–2008   | 0.49             |
| Catanzaro         | CZ    | 38.90    | 16.58    | 320      | 2001–2009   | 1.72             | Salerno            | SA    | 40.67    | 14.77    | 4        | 2006–2009   | 0.27             |
| Enna              | EN    | 37.55    | 14.27    | 931      | 2002–2009   | 2.19             | Siena              | SI    | 43.32    | 11.32    | 322      | 2003–2013   | 6.87             |
| Ferrara           | FE    | 44.83    | 11.62    | 9        | 2004–2009   | 23.43            | Sondrio            | SO    | 46.17    | 9.87     | 307      | 2001–2008   | 3.29             |
| Foggia            | FG    | 41.45    | 15.55    | 76       | 2004–2009   | 21.31            | La Spezia          | SP    | 44.10    | 9.82     | 3        | 2001–2010   | 14.60            |
| Firenze           | FI    | 43.68    | 11.25    | 40       | 2007–2012   | 6.01             | Siracusa           | SR    | 37.07    | 15.28    | 17       | 2002–2009   | 1.74             |
| Forlì             | FC    | 44.22    | 12.03    | 34       | 2000–2009   | 7.88             | Sassari            | SS    | 40.72    | 8.55     | 225      | 1998–2007   | 2.83             |
| Fermo             | FM    | 43.15    | 13.72    | 319      | 2003–2010   | 42.61            | Savona             | SV    | 44.30    | 8.30     | 4        | 2006–2010   | 22.38            |
| Frosinone         | FR    | 41.63    | 13.33    | 291      | 2001–2010   | 5.11             | Taranto            | TA    | 40.45    | 17.23    | 15       | 2000–2010   | 9.05             |
| Genova            | GE    | 44.42    | 8.88     | 19       | 2003–2010   | 22.19            | Teramo             | TE    | 42.65    | 13.70    | 265      | 2000–2010   | 1.73             |
| Gorizia           | GO    | 45.93    | 13.62    | 84       | 1999–2008   | 0.18             | Trento             | TN    | 46.05    | 11.12    | 194      | 1983–2008   | 3.75             |
| Grosseto          | GR    | 42.75    | 11.10    | 10       | 1989–2009   | 6.43             | Torino             | TO    | 45.12    | 7.72     | 239      | 2002–2013   | 1.20             |
| Imperia           | IM    | 43.88    | 8.02     | 10       | 2010–2013   | 15.03            | Trapani            | TP    | 38.02    | 12.53    | 3        | 2002–2009   | 4.37             |
| Isernia           | IS    | 41.58    | 14.22    | 423      | 2000–2009   | 22.39            | Terni              | TR    | 42.55    | 12.63    | 130      | 2007–2010   | 17.25            |
| Crotone           | KR    | 39.07    | 17.12    | 8        | 2003–2009   | 2.56             | Trieste            | TS    | 45.65    | 13.78    | 2        | 1999–2008   | 0.33             |
| Lecco             | LC    | 45.85    | 9.40     | 214      | 2006–2013   | 9.54             | Treviso            | TV    | 45.67    | 12.23    | 15       | 1997–2008   | 8.27             |
| Lodi              | LO    | 45.30    | 9.50     | 87       | 2000–2010   | 20.45            | Udine              | UD    | 46.05    | 13.23    | 113      | 1999–2008   | 0.23             |
| Lecce             | LE    | 40.35    | 18.17    | 49       | 1994–2009   | 5.70             | Varese             | VA    | 45.82    | 8.82     | 382      | 2003–2012   | 18.45            |
| Livorno           | LI    | 43.55    | 10.32    | 3        | 1998–2008   | 16.42            | Verbania           | VB    | 45.92    | 8.55     | 197      | 1997–2010   | 2.09             |
| Latina            | LT    | 41.45    | 12.90    | 21       | 2001–2010   | 5.63             | Vercelli           | VC    | 45.32    | 8.42     | 130      | 1993–2010   | 2.80             |
| Lucca             | LU    | 43.83    | 10.23    | 19       | 1990–2009   | 14.04            | Venezia            | VE    | 45.43    | 12.33    | 1        | 1997–2008   | 9.64             |
| Monza             | MB    | 45.58    | 9.27     | 162      | 2002–2013   | 27.64            | Vicenza            | VI    | 45.53    | 11.53    | 39       | 1997–2008   | 0.24             |
| Brianza           |       |          |          |          |             |                  | Verona             | VR    | 45.43    | 10.98    | 59       | 1997–2008   | 0.61             |
| Macerata          | MC    | 43.28    | 13.45    | 315      | 2003–2010   | 51.98            | Medio              | VS    | 39.57    | 8.90     | 311      | 1995–2011   | 49.45            |
| Messina           | ME    | 38.18    | 15.53    | 3        | 2002–2009   | 3.48             | Campidano          |       |          |          |          |             |                  |
| Milano            | MI    | 45.45    | 9.18     | 122      | 1996–2007   | 15.95            | Viterbo            | VT    | 42.42    | 12.10    | 326      | 2003–2009   | 15.25            |
| Mantova           | MN    | 45.15    | 10.77    | 19       | 1998–2008   | 14.93            | Vibo Valentia      | VV    | 38.67    | 16.08    | 476      | 2001–2009   | 4.02             |

- **Rule A:** Every climatic parameter has to be valid in at least 18 h during the day. This has to be satisfied in order to have consistent data to be used in the computation and avoid the presence of too many gaps to be filled with interpolation in the following steps [23];

- **Rule B:** The first and last values of the whole dataset have to be valid for all parameters, if not the first and/or last day of the set have to be considered invalid. This condition is necessary because, if interpolation of values is to be taken in the first/last day, a valid data may be required in the first/last hour to compute the interpolated values;

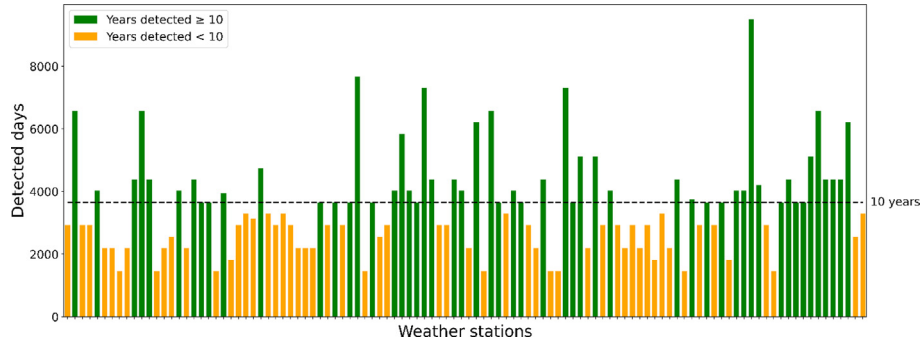


Fig. 2. Italian meteorological stations detected data amount.

- **Rule C:** For every climatic parameter, a maximum of 6 consecutive hours of invalid data is acceptable across two contiguous days. This limitation aims to avoid the problem of interpolating data across too long time intervals as, for example, near stocks of 5 + 5 h of invalid values [23];
- **Rule D:** Solar radiation values have to be valid in all the hours comprised between sunrise and sunset. This rule is the most restrictive one because if solar radiation is invalid in just one hour, the whole day is to be considered unacceptable. This is due to the fact that data gaps are filled through linear interpolation, however, if this approach is consistent for parameters like temperature and relative humidity, it cannot be extended to solar radiation because the latter does not vary on linear bases.

Through the application of these four rules on the 108 Italian locations, the pool of valid data for each one has been obtained. In first instance, it was noted that the number of detected days of each dataset varies greatly, depending on the recording time of the station itself, as it can be seen in Fig. 2, where approximately half of the stations, 55, do not reach ten years of recorded data. Most of these stations, 35, are located in the southern part of Italy, thus highlighting major problems in having long timeframes of recording in this part of the nation. This fact is an additional aspect to be carefully considered when dealing with climatic data, since a minimum amount of recorded days is recommended to obtain reliable datasets in representing the actual climatic situation [24].

The percentage of days rejected because of the quality rules greatly varies between the Italian locations, however three main categories of data quality have been defined. The category with a good behavior displays less than 25 % of rejected days, the acceptable one shows an amount between 25 and 50 % of rejection, while the bad category is characterized by more than 50 % of rejected days. Fig. 3 presents the percentage of locations in each category. It can be noted that the majority of sites present a good data quality, a quarter of them an acceptable behavior and only 5 % of locations falls into the bad category.

The influence of the four quality rules on the rejection process can be observed by inspecting Fig. 4, which reports the relative occurrence of each rule considering the total number of not respected rules in the whole dataset. The first notable feature is that Rule B, related to the first and last days of a dataset, obviously has the lowest effect on the quality check. Generally, rules A, C and D show a similar impact in rejecting values from each dataset, with the latter having a slightly minor impact than the other two.

Once having defined the days that can be used for simulations, the gaps still present in the pool are filled using linear interpolation to obtain continuous sets. The number of interpolated hours for each parameter, solar radiation excluded, are reported in Fig. 5.

At a first glance it is evident that four locations, highlighted in Fig. 5, Aquila (AQ), Bolzano (BZ), Prato (PO) and Trento (TN), have a relevant amount of hours being interpolated, reaching peaks of over one thousand hours in Bolzano and Prato. An interesting feature is that all these four stations are located in hilly or mountain environment, thus highlighting the possibility of a correlation between this kind of environment and the major issues in detecting climatic parameters. All the other locations, however, show a much smaller amount of interpolated hours, with, at worst, three hundred filled gaps. It can then be deduced that, once the invalid days are removed from the dataset, the quality of the remaining ones is fairly high. Furthermore, it can be noted that the majority of the gaps to be filled regards relative humidity and wind speed data, while air temperature usually needs only minor adjustments.

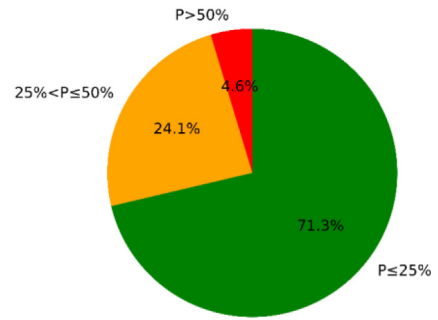


Fig. 3. Percentages of locations having good (green), acceptable (orange) and bad (red) data quality. P: rejected days' percentage. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

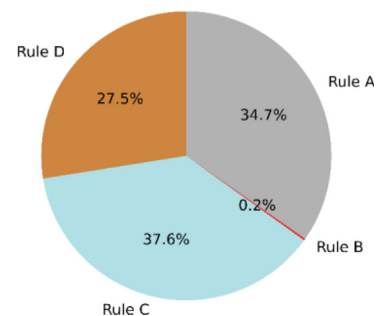
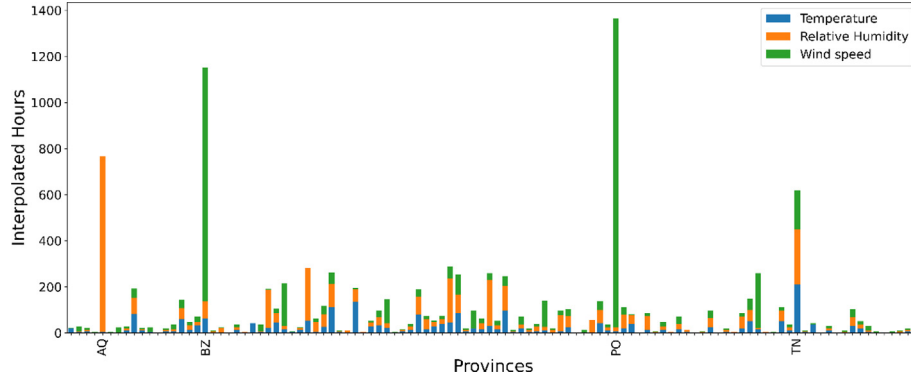


Fig. 4. Average quality rules influence on the rejection of days among all the locations.



**Fig. 5.** Hours of interpolated data for temperature (blue), relative humidity (orange) and wind speed (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

**Table 2**  
EN ISO 15927-2 order (i), parameters, ranges, steps and percentiles.

| i | ID  | Parameter                          | EN ISO range ( $R_i$ )              | EN ISO steps( $s_i$ )               | Percentiles $P_i$ [%] |                 |                 |
|---|-----|------------------------------------|-------------------------------------|-------------------------------------|-----------------------|-----------------|-----------------|
|   |     |                                    |                                     |                                     | RL <sub>1</sub>       | RL <sub>2</sub> | RL <sub>5</sub> |
| 1 | Tmp | Daily mean dry-bulb temperature    | $\pm 0.5$ °C                        | $\pm 0.1$ °C                        | 99                    | 98              | 95              |
| 2 | rad | Daily total global solar radiation | $\pm 0.05$ kWh/(m <sup>2</sup> day) | $\pm 0.01$ kWh/(m <sup>2</sup> day) | 99                    | 98              | 95              |
| 3 | tdp | Daily mean dew-point temperature   | $\pm 0.5$ °C                        | $\pm 0.1$ °C                        | 99                    | 98              | 95              |
| 4 | tsw | Daily dry-bulb temperature swing   | $\pm 0.5$ K                         | $\pm 0.1$ K                         | 1                     | 2               | 5               |
| 5 | vel | Daily mean wind speed              | $\pm 0.5$ m/s                       | $\pm 0.1$ m/s                       | 1                     | 2               | 5               |

The qualitative analysis of raw climatic data then highlighted a heterogeneous behavior throughout the 108 Italian locations. One problem highlighted by this research is the amount of available data, with many locations presenting less than ten years of recorded data, the minimum time length recommended by the EN ISO 15927-2 to apply the Cooling Design Day selection method [10]. On the other hand, more than 70 % of the stations present a good data quality, with less than 25 % of days rejected, showing a good detection and storage capacity of the weather station system.

Finally, the interpolated hours display that major number of gaps are present in relative humidity and wind speed, then highlighting the presence of diffuse and recursive criticalities concerning the instrumentation dedicated to the detection of these parameters.

### 3. The EN ISO 15927-2 cooling design day selection method

The methodology to extract Design Days for cooling systems from measured data is described by EN ISO 15927-2 international standard [10]. It defines a set of parameters to be used to obtain in each calendar month (i.e. all the January data taken together, all the February data taken together, etc.) individual days of hourly data that impose three different risk levels, RL<sub>5</sub>, RL<sub>2</sub> and RL<sub>1</sub>, classified through a cooling load likely to be exceeded by 5 %, 2 % and 1 % of cases. To select the Design Day, two parameters are strictly required: daily mean dry-bulb temperature and daily total global solar radiation. Other parameters can be optionally used, like daily mean dew-point temperature, daily dry-bulb temperature swing and daily mean wind speed.

The first step is to calculate the daily mean values of the analyzed parameters for each day of the dataset. Then, for each calendar month and for each one of the three risk levels, the percentiles of the used parameters and reported in Table 2 must be computed. The method then defines for each parameter an initial neighborhood of the aforementioned percentiles values using the ranges listed in Table 2. For each calendar month, once defined the per-

centiles and the relative ranges, the days for which all parameters fall within the ranges of Table 2 are identified. Following this scheme, three events could happen:

1. Exactly-one day is identified;
2. No day is found;
3. Two or more days are identified with all the parameters within the ranges.

In the first case scenario, the identified day can be directly used as Cooling Design Day with no further selection work. If no day is identified, the initial range for each variable is increased using the steps defined in Table 2 and cyclically following the parameter order there reported, until one day is found. On the other hand, if two or more days are initially identified, the ranges are reduced using the same steps and order of Table 2, until only one day remains.

As a sideline task of this research, a new approach for selecting the Design Days has been developed. The EN ISO method was formally reformulated, while keeping all its theoretical principles. This was done in order to obtain a form of the method easier to implement in numerical codes and to get a clearer view on the process proposed by the EN ISO standard. The new approach has been called Coordinates Method and is described in detail, with applicative examples, in Appendix A. The new selection method was applied to the 108 Italian datasets and, as expected, gave exactly the same results as the ones obtained using the EN ISO 15927-2 method, demonstrating the complete equivalence of the two processes.

### 4. Sensitivity analysis of the cooling design day selection method

Since the standard allows the users to select which parameters to use for searching the Cooling Design Days, it was evaluated how different choices could influence the results. The great flexibility of the aforementioned Coordinates Method has been exploited to carry on different Cooling Design Days selections on the 108 Italian locations by considering all the possible combinations of parame-

|                     |         |             |             |             |                 |                 |
|---------------------|---------|-------------|-------------|-------------|-----------------|-----------------|
| Tmp-rad-tdp         | 21.91   | 100         |             |             |                 |                 |
| Tmp-rad-tsw         | 12.55   | 11.83       | 100         |             |                 |                 |
| Tmp-rad-vel         | 89.92   | 22.02       | 11.63       | 100         |                 |                 |
| Tmp-rad-tdp-tsw     | 5.45    | 26.44       | 46.6        | 5.66        | 100             |                 |
| Tmp-rad-tdp-vel     | 21.71   | 97.94       | 11.52       | 22.74       | 25.62           | 100             |
| Tmp-rad-tsw-vel     | 11.42   | 12.35       | 96.4        | 12.04       | 47.43           | 12.35           |
| Tmp-rad-tdp-tsw-vel | 5.14    | 26.13       | 45.99       | 5.86        | 98.87           | 25.72           |
|                     | Tmp-rad | Tmp-rad-tdp | Tmp-rad-tsw | Tmp-rad-vel | Tmp-rad-tdp-tsw | Tmp-rad-tdp-vel |
|                     |         |             |             |             |                 | Tmp-rad-tsw-vel |

**Fig. 6.** Cooling Design Days matching percentage between all combinations of parameter sets across 108 Italian locations.

ters, leading to eight different sets of results. These have been compared and the percentages of Design Days shared by the different sets across all the locations have been computed. The analysis of the results highlighted some interesting characteristics as it can be deduced by inspecting Fig. 6, which reports the matching percentages for each combination of sets.

The first feature to note is the low percentage of coincident Design Days between each set, with some notable exceptions. Analyzing for instance the case with only two parameters, *Tmp-rad*, including dry-bulb temperature and solar radiation, it shares very few Design Days with every other set, with the exception of the case *Tmp-rad-vel*, where the wind speed is added to the analysis. This consideration leads to another interesting behavior: the wind speed parameter, *vel*, has very little effect on the choice of Design

Days. This is demonstrated by the high matching percentages, generally over 90 %, between the sets where the unique difference is the presence of this parameter.

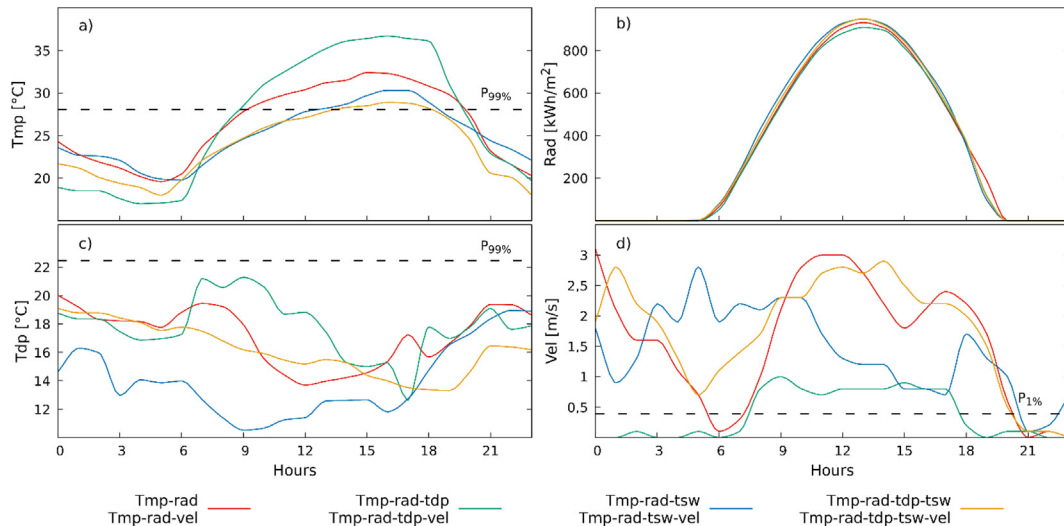
Finally, another interesting behavior is that when adding the dew-point temperature, *tdp*, to an analysis that already includes the dry-bulb temperature swing, *tsw*, the match rate tends to be higher than in other cases, generally amounting to around 45 %.

To further highlight the effects of different parameter sets on the selection of Cooling Design Days, a case study is reported as an example. It considers the location of Rome, risk level  $RL_1$ , and identifies for every parameter set the Design Day for July as reported in Table 3. As it can be noted, the chosen Design Day is the same for the parameter sets where the only difference is the presence of the wind speed in the analysis. This again highlights that wind velocity has a very low impact on the choice of the Design Day. An explanation to this behavior is that generally the wind speed presents daily values near to the reference percentiles. On the other hand, the analysis highlighted that dew-point temperature and temperature swing are the parameters that are more distant from their respective reference percentiles, therefore being the most influential parameters in the selection of the Design Days. These considerations on the behavior of the different parameters can be better understood by exploiting the Coordinates Method, as it is reported in Appendix B, where this example is further described by using the aforementioned method.

The hourly values of the climatic parameters of the Cooling Design Days of the case study, with the exception of the temperature swing, are graphically reported in Fig. 7. For dry-bulb, dew-

**Table 3**  
Rome cooling design days for every parameter set for July and risk level  $RL_1$ .

| Parameter set       | Cooling design day |
|---------------------|--------------------|
| Tmp_rad             | 18/07/2003         |
| Tmp_rad_vel         |                    |
| Tmp_rad_tdp         | 21/07/2006         |
| Tmp_rad_tdp_vel     |                    |
| Tmp_rad_tsw         | 02/07/2003         |
| Tmp_rad_tsw_vel     |                    |
| Tmp_rad_tdp_tsw     | 04/07/2006         |
| Tmp_rad_tdp_tsw_vel |                    |



**Fig. 7.** Hourly values of climatic parameters of Rome Cooling Design Days for every parameter set for July and risk level  $RL_1$ .

point temperature and wind speed the reference percentiles are also reported. As already stated, the results are coincident for the couples of sets where the only difference is the presence of the wind speed in the selection process so only four distributions are presented for the eight sets. As it can be seen in Fig. 7, the selected Design Days for the different sets show different distributions of the parameters, solar radiation excluded. The dry-bulb temperature displays differences up to almost 8 °C between the *Tmp-rad-tdp* and *Tmp-rad-tdp-tsw* sets at 3p.m. as it can be noted in Fig. 7a).

The dew-point temperature also shows remarkable variability, with differences of up to almost 11 °C between the *Tmp-rad-tsw* and *Tmp-rad-tdp* cases, as highlighted in Fig. 7c). Another consideration that can be made by looking at Fig. 7c) and d) is that dew-point temperature and wind speed values are respectively below and above their reference percentile values. In both situations this means being against safety when using the selected Cooling Design Days for sizing.

The sensitivity analysis then highlighted large differences in terms of chosen Design Days when using different sets of parameters in the selection process, thus assessing the importance for the users to carefully evaluate the effects that different choices about the parameters to be analyzed could have on the results and, consequently, on the sizing of a cooling system.

## 5. Output sizing powers: A case study

To further study the behavior of the Cooling Design Days an analysis of the computed sizing powers for a test building applied to the 108 Italian locations has been carried on. According to ISTAT data [25], the 1961–1975 period includes the majority of the existing Italian buildings. Therefore, two versions of the test building, representative of the insulated and uninsulated configurations of

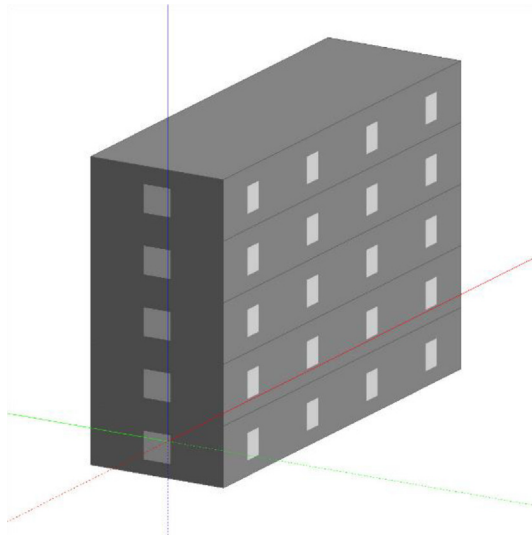


Fig. 8. Test building geometry model.

buildings related to this period was analyzed in this case study. The main characteristics of the test building for both cases were obtained from the Tabula Web Tool of the Tabula Project [26]. The floor area of the building is of 934 m<sup>2</sup>, leading to a heated/cooled air volume of 3,074 m<sup>3</sup>, while the Heat Loss Surface (HLS) accounts for 1,667 m<sup>2</sup>, leading to a Surface Area to Volume Ratio (SV) of 0.54. Finally, the Window-Wall Ratio (WWR) is 9.33 % (Fig. 8). The model was not divided into zones to speed up the calculation, instead a fixed space distribution for each floor was set: 50 % bedrooms, 35 % kitchen and living room and 15 % other areas with no internal gains. No moveable shadings were modeled during simulations to avoid human behavior influences. Opaque constructions, transmittance *U* and surface mass *M*, and windows characteristics Solar heat Gain Coefficient SHGC and transmittance *U<sub>w</sub>*, are reported in Table 4.

Time-varying heat gains were modeled using the time distribution reported in ISO 13790. Electric heat gains can be summarized into a maximum design power of 4.6 W/m<sup>2</sup>. Occupancy was set to a maximum of 0.04 people/m<sup>2</sup> between 5p.m. and 8 a.m. and to 0.01 people/m<sup>2</sup> between 8 a.m. and 5p.m. Cooling system availability was modeled as always-on during the whole year. Heating and cooling systems types were modeled as ideal with 100 % convective effects, therefore air temperature was preferred over the operative one to set the cooling set-points, that were set at 26 °C from 8 a.m. to 10p.m. and at 28 °C for the remaining time.

In order to model an ideal system, object ZoneHVAC: IdealLoadsAirSystem of EnergyPlus software was used. It provides a model for an ideal HVAC system and it supplies cooling or heating air to a zone in sufficient quantity to meet the zone load. Cooling design supply conditions were modeled with 12 °C air temperature and 8 gw/kgda humidity ratio. Since cooling supply air conditions are far below zone internal air saturation conditions, latent gains were considered: the cooling system provides dehumidification even if there is no dehumidification set-point. The ZoneHVAC:IdealLoadsAirSystem object is modeled as an ideal VAV terminal unit with variable supply air temperature and humidity. The supply air flowrate varies between zero and the maximum in order to satisfy the zone cooling load. Outdoor air flowrate, intended as intentionally or inadvertently introduced into the building, was set to 0.3 ACH.

### 5.1. Design day cooling power analysis

Using the climatic data available for the 108 locations, sizing simulations were run, using the EnergyPlus software, for every day of the datasets included in June, July and August months that fulfilled the quality rules described in Paragraph 2, leading to a total of 78,396 sizing simulations which represent the number of valid days for each location and months of the analysis. The simulations were repeated two times to deal with both insulated and uninsulated building. Subsequently, the 95th, 98th and 99th percentiles of the sizing outputs were computed for each of the three analyzed months and for each location, in order to identify the reference values for the three risk levels RL<sub>5</sub>, RL<sub>2</sub>, RL<sub>1</sub>. Then the Cooling Design Days were identified for each of the three months and

Table 4  
Opaque construction and windows characteristics for uninsulated and insulated models.

| Case        | U                      |      |       | M                    |      |       | SHGC  | U <sub>w</sub> |
|-------------|------------------------|------|-------|----------------------|------|-------|-------|----------------|
|             | Wall                   | Roof | Floor | Wall                 | Roof | Floor |       |                |
|             | [W/(m <sup>2</sup> K)] |      |       | [kg/m <sup>3</sup> ] |      |       |       |                |
| Uninsulated | 1.15                   | 1.10 | 0.94  | 194                  | 406  | 478   | 0.700 | 2.2            |
| Insulated   | 0.23                   | 0.21 | 0.21  |                      |      |       | 0.398 | 0.8            |

**Table 5**

Percentage of cases where the sizing power obtained through the Design Day is lower than the reference percentile of the analyzed Risk Level, for the 108 Italian locations.

| Month\Case | Uninsulated     |                 |                 | Insulated       |                 |                 |
|------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|            | RL <sub>1</sub> | RL <sub>2</sub> | RL <sub>5</sub> | RL <sub>1</sub> | RL <sub>2</sub> | RL <sub>5</sub> |
| June       | 98.15           | 96.30           | 87.04           | 96.30           | 93.52           | 84.26           |
| July       | 96.30           | 95.37           | 83.33           | 94.44           | 92.59           | 76.85           |
| August     | 95.37           | 90.74           | 77.77           | 94.44           | 91.66           | 71.30           |

**Table 6**

Percentage of cases where the EN ISO method selects the same Design Day for different Risk Levels, for the 108 Italian locations, the ones having less (U10) and more (O10) than 10 years of recordings.

| Month\Case | Same Design Day for 2 Risk Levels |       |       | Same Design Day for 3 Risk Levels |       |       |
|------------|-----------------------------------|-------|-------|-----------------------------------|-------|-------|
|            | All locations                     | U10   | O10   | All locations                     | U10   | O10   |
| June       | 91.66                             | 46.30 | 45.37 | 50.00                             | 24.07 | 25.92 |
| July       | 91.66                             | 47.22 | 44.44 | 50.00                             | 26.85 | 23.15 |
| August     | 88.88                             | 47.22 | 41.66 | 40.74                             | 20.37 | 20.37 |

**Table 7**

Percentage of cases where the sizing powers obtained through the Design Day for less extreme Risk Levels are greater than the ones computed for more extreme Risk Levels.

| Month\Case | Uninsulated | Insulated |
|------------|-------------|-----------|
| June       | 33.33       | 36.11     |
| July       | 32.40       | 31.48     |
| August     | 39.81       | 43.52     |

locations using the EN ISO method. The sizing powers obtained using the Design Days for each month and each location were then compared with the sizing power percentiles obtained for the same month and location. It was expected that the sizing powers obtained with the Design Days should be equal or higher than the respective percentile, however the inspection of the results revealed a different trend. [Table 5](#) reports, for both the insulated and uninsulated building, the percentage of cases where Design Day powers are lower than the respective percentiles of sizing powers. Results show that the Design Day powers are almost always lower than the percentiles of the three Risk Levels for both uninsulated and insulated configurations. Therefore, it is evident that they do not satisfy the safety limits indicated in the standard for the different Risk Levels. Obviously, this behavior is more marked for cases RL<sub>1</sub> and RL<sub>2</sub>, being these two the most extreme ones.

An additional assessment was performed on the effectiveness of the EN ISO method in appreciating the differences between the three Risk Levels, i.e. its capacity of selecting different Design Days for different RLs. Furthermore, the design powers are expected to be higher for more restrictive risk levels. However, some inconsistencies related to the aforementioned features have been detected as reported in [Tables 6 and 7](#).

As it can be seen in [Table 6](#), the same Design Day was almost always selected for two different Risk Levels, and in half of cases for all three cases. This aspect highlights the difficulty of the EN ISO method to effectively appreciate the differences between the

Risk Levels and to subsequently differentiate the Design Days. As it can be seen, this aspect is not related to a possible scarcity of climatic data to work with, given that this fact happens in equal percentage in stations having more than ten years of data, O10 in [Table 6](#), and less than ten years, U10 in [Table 6](#).

However, the most critical aspect that emerges from this analysis is the one depicted in [Table 7](#). In fact, in approximately one third of cases for both insulated and not insulated configurations of the analyzed building, the sizing powers computed for less extreme Risk Levels, then referring to less extreme percentiles, are greater than the ones computed for more extreme Risk Levels, then referring to higher percentiles. This is the exact opposite of the expected behavior, meaning that the EN ISO method could sometimes give unreliable results in terms of sizing power.

## 5.2. Design days for three sample locations

To further highlight the aforementioned phenomena, the results of the sizing process for the uninsulated and insulated configurations of the building are reported for three sample locations: Milano, Roma and Palermo, respectively localized in North, Central and South Italy, as highlighted in [Fig. 1](#) through red triangles. The analysis, carried on for June, July and August, required 734, 726 and 729 sizing simulations respectively. In [Tables 8 and 9](#) these results are reported as the sizing powers reference percentiles and sizing powers obtained through the Cooling Design Days, identified for every Risk Level for said locations in June, July and August months. The three recursive problems previously highlighted could be identified in these examples as well. First of all, the sizing powers obtained through the Design Days are nearly always lower than their reference percentiles computed for the corresponding Risk Level for both configurations. Moreover, the same Cooling Design Day is often used for different Risk Levels as highlighted by the coincident sizing powers obtained in these cases. Finally, for Milan and Rome in July, the sizing powers obtained with both configurations for less extreme Risk Levels are greater than the ones com-

**Table 8**

Uninsulated building sizing powers, in kW, for three sample locations: Milan (MI), Rome (RM), Palermo (PA).

| ID | June  |       |       |       |       |       | July  |       |       |       |       |       | August |       |       |       |       |       |
|----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|-------|-------|-------|-------|
|    | RL1   |       | RL2   |       | RL5   |       | RL1   |       | RL2   |       | RL5   |       | RL1    |       | RL2   |       | RL5   |       |
|    | 99 %  | CDD   | 98 %  | CDD   | 95 %  | CDD   | 99 %  | CDD   | 98 %  | CDD   | 95 %  | CDD   | 99 %   | CDD   | 98 %  | CDD   | 95 %  | CDD   |
| MI | 52.38 | 50.20 | 51.54 | 47.76 | 48.36 | 47.76 | 50.90 | 40.92 | 49.42 | 40.92 | 46.10 | 42.46 | 45.79  | 44.33 | 44.57 | 44.33 | 41.79 | 44.33 |
| RM | 49.89 | 43.47 | 47.80 | 43.47 | 45.89 | 43.47 | 50.30 | 37.65 | 49.67 | 41.54 | 47.85 | 41.54 | 47.79  | 36.44 | 47.17 | 36.44 | 43.95 | 36.44 |
| PA | 48.21 | 40.98 | 47.16 | 40.98 | 43.35 | 39.38 | 47.57 | 42.91 | 45.23 | 41.04 | 42.54 | 41.04 | 45.09  | 41.85 | 44.60 | 41.85 | 43.56 | 41.85 |

**Table 9**

Insulated building sizing powers, in kW, for three sample locations: Milan (MI), Rome (RM), Palermo (PA).

| ID | June  |       |       |       |       |       | July  |       |       |       |       |       | August |       |       |       |       |       |
|----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|-------|-------|-------|-------|
|    | RL1   |       | RL2   |       | RL5   |       | RL1   |       | RL2   |       | RL5   |       | RL1    |       | RL2   |       | RL5   |       |
|    | 99 %  | CDD   | 98 %  | CDD   | 95 %  | CDD   | 99 %  | CDD   | 98 %  | CDD   | 95 %  | CDD   | 99 %   | CDD   | 98 %  | CDD   | 95 %  | CDD   |
| MI | 25.02 | 25.03 | 24.57 | 25.01 | 23.81 | 25.01 | 23.57 | 20.58 | 23.47 | 20.58 | 22.97 | 21.11 | 23.47  | 22.51 | 22.73 | 22.51 | 22.25 | 22.51 |
| RM | 25.62 | 22.38 | 25.32 | 22.38 | 24.69 | 22.38 | 27.14 | 18.82 | 26.65 | 21.64 | 25.41 | 21.64 | 25.12  | 19.12 | 24.86 | 19.12 | 23.91 | 19.12 |
| PA | 29.77 | 21.61 | 27.57 | 21.61 | 24.76 | 20.32 | 26.61 | 22.87 | 26.08 | 22.86 | 24.55 | 22.86 | 25.92  | 23.91 | 25.52 | 23.91 | 24.70 | 23.91 |

puted for more extreme Risk Levels. These results also highlight that the insulation of the building do not affect the overall behavior of the sizing process.

The analysis of the results suggest that design days should be carefully checked before being used into a sizing process.

A further consideration can be made pertaining the reliability of the process if applied to dataset having few valid data to work with. Surely a minor amount of usable data leads to more unreliable results but the EN ISO standard explicitly indicates that the Cooling Design Day is a “real” day chosen within the dataset. This aspect greatly limits the possibility of using interpolations or other methods to fill data voids. This is also the reason for which in this paper strict quality rules were applied to detect usable days before using interpolation to fill only minor data voids inside the datasets.

## 6. Conclusions

Climatic data are essential to describe the boundary conditions in energy analysis. Weather data usually include the air temperature and humidity, solar radiation and wind speed. These parameters are essential for implementing several physical models such as conductive and convective heat transfer, solar heat gains, sensible and latent loads or ventilation. It is then very important to have consistent and reliable datasets to be used in the simulations. A quality analysis of climatic data must be performed in order to assess this reliability and consistency.

Considering this requirement for the Italian territory, a check of the Italian datasets of climatic parameters has been carried out in order to identify the overall quality level and the most common issues. The analysis displayed a non-uniform behavior among the 108 weather stations, first of all highlighting very different amounts of data between the stations, consequence of variable recording times. However, the overall quality of the data is acceptable, having more than 70 % of the stations displaying less than 25 % of rejected days among the total detected. Only the 5 % of stations display low quality with more than half of the days rejected because of the quality rules not being fulfilled. Moreover, by analyzing the nature of the gaps presents in the datasets, it has been assessed that the main problems are related to the detection of relative humidity and wind speed, while the dry-bulb temperature showed no major problems. This results show that designers must accurately evaluate the nature and accuracy of the climatic data to be used in their simulations, aiming to obtain a reliable dataset to work with.

The quality check here proposed aims to give the designers a workflow to follow when dealing with the analysis of climatic data, with the possibility to adapt it to different situations. However, it has to be considered that this work is focused on the Italian environment, therefore the quality check of the data here reported could not fit as well for case studies located in other countries, because of different issues that could emerge related to different physical and numerical equipment used to record the data. A further development of this research could address this problem by extending the analysis to climatic data across other European

countries to provide a wider application and applicability of the process here reported.

Given the growing importance of buildings cooling performance, the reference cooling sizing method of the EN ISO 15927-2 Design Day selection method, has been applied to the 108 Italian locations to evaluate its performance. In order to do so, an alternative process for the selection of the Cooling Design Day was developed, leading to a simpler and more direct way to proceed, while still applying all the theoretical principles of the standard. The new process, named Coordinates Method, proved to be more direct and easier to be automated than the original one. A comparison between the results of the original and the proposed methods showed a perfect coincidence of results, thus demonstrating the consistence and correctness of the Coordinates Method.

Since the EN ISO allows the choice of the climatic parameters to use for selecting the Cooling Design Days, a sensitivity analysis of the selection method was conducted using the data of the 108 Italian locations, showing large differences in results when using different sets of climatic parameters. The Design Days selected using different parameter sets showed on average less than 20 % of coincident results, with some notable exceptions. Moreover, it has been noted that the wind speed barely affects the results of the selection process, showing coincident results higher than 90 % between the sets where the only difference is the presence of this parameter.

The design days were applied to obtain the sizing powers for a building representative of the Italian building stock, highlighting some critical issues worth to be investigated. The sizing powers obtained through the Design Days for different risk levels proved to be lower than the reference percentile of the risk level itself in the vast majority of cases, therefore decreasing the capability of the designed system to respect the defined level of risk. Moreover, it has been assessed that in the majority of cases the EN ISO method selects the same Design Day for two different risk levels, and in half of cases for all three risk levels. It has also been demonstrated that this behavior is not due to a possible scarcity of climatic data provided by the stations, but it is inherent with the EN ISO approach itself. Finally, in a third of cases, the method selects Design Days that give sizing powers for lower risk levels that are higher than the ones pertaining to the most extreme risk levels, therefore giving counterintuitive results.

This analysis then proved the importance of a careful evaluation of the influence that the choice of parameters has on the selection of the Design Day and, consequently, on the sizing of a cooling system. Moreover, it proved that sometimes the EN ISO standard could give inaccurate or counterintuitive results, therefore leading to the necessity for a designer to accurately evaluate the reliability of the results.

A further development of this work could extend this analysis by studying the correlation between the Design Days and the performances of cooling plants for an extended pool of building-plant systems that can better represent the Italian building environment.

## Data availability

The authors do not have permission to share data.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

The authors thank the institutions that have provided climate data for all Italian locations for the update of the national standards. The complete list is available on the CTI website [27].

## Appendix

### Appendix A

#### The Coordinates Method

The Coordinates Method keeps the calculation of the daily climatic parameters and of the monthly reference percentiles as presented in the EN ISO 15927-2 standard but replaces the concept of ranges and steps with the one of coordinates, which can be interpreted as an alternative description of the range enlargement/shrinkage modification process.

Coordinates represent, for each daily climatic parameter, the difference between its value and the reference percentile, normalized using the step values reported in Table 2. The higher the coordinate, the greater the difference between the daily parameter value and the percentile. The five parameters described in the standard and the reference percentiles for the three risk levels have already been reported in Table 2.

The standard gives the opportunity to use less or more than five parameters, with a minimum of two: dry-bulb temperature and total global solar radiation. In this case, the Coordinates Method described here remains the same; simply it is applied to the required number of parameters. As it is reported in the following procedure, the Design Day refers to each calendar month and each risk level RL.

The first step is to compute the five daily coordinates  $C_i^d$ , referred to the five climatic parameters of Table 2 and identified by the  $i$ -index having values from 1 to 5, computed for every day  $d$  of the analyzed calendar month of the dataset using Eqn. (A.1):

$$C_i^d = \frac{|V_i^d - P_i|}{s_i} \quad d = 1, \dots, n_m \quad (\text{A.1})$$

Where  $V_i^d$  is the value of the  $i$ -th parameter in the analyzed day,  $P_i$  is the monthly reference percentile of the parameter,  $s_i$  is the step defined by the standard and reported in Table 2, and  $n_m$  the total number of days present in the dataset for the analyzed calendar month. The coordinate  $C_i^d$  represent the number of EN ISO enlargement steps required by the standard method to include the  $i$ -th variable of day  $d$ , but starting from a null initial range. A practical example of the application of this step of the process is reported in Example 1 below.

Once computed for each day the coordinates, the selection method proceeds in a two-step phase: first a Reference Coordinate is extracted for every day of the dataset following Eqn. (A.2):

$$C_{ref}^d = \max [C_i^d] \quad d = 1, \dots, n_m \quad (\text{A.2})$$

Then a Selection Coordinate is computed as reported in Eqn. (A.3):

$$C_{sel} = \min [C_{ref}^d] \quad d = 1, \dots, n_m \quad (\text{A.3})$$

The Selection Coordinate represent the minimum numbers of steps required to have at least one day discovered by the iterative enlargement method of the standard assuring that all the variables of Table 2 fall inside the selection ranges of the standard. Therefore, only the days that have the Reference Coordinate equal to the Selection Coordinate, i.e. satisfying Eqn. (A.4), are suitable as Cooling Design Days:

$$C_{ref}^d = C_{sel} \quad d = 1, \dots, n_m \quad (\text{A.4})$$

However, the standard method introduces a precedence in the enlargement of the ranges, following the  $i$ -index order of Table 2. To take into account this imposition the following steps are needed. The first one is to determine for every day selected through Eqn. (A.4) the maximum positional index of the Reference Coordinate, here named as Reference Index, as stated in Eqn. (A.5). This index represents the  $i$ -th variable to be selected last during the final iteration enlargement loop of the standard. This passage accounts also for the possibility that different variables share the same Reference Coordinate.

$$I_{ref}^d = \max(i) : C_i^d = C_{ref}^d \quad d = 1, \dots, s \quad (\text{A.5})$$

Where  $s$  represents the total number of days selected through the imposition of Eqn. (A.4). Similarly to the Selection Coordinate, a Selection Index is then computed, as reported in Eqn. (A.6):

$$I_{sel} = \min [I_{ref}^d] \quad d = 1, \dots, s \quad (\text{A.6})$$

The Design Days are the ones that first satisfy the selection ranges for all the parameters and in the order imposed by the standard, i.e. the ones for which Eqn. (A.7) apply:

$$I_{ref}^d = I_{sel} \quad d = 1, \dots, s \quad (\text{A.7})$$

One or more Cooling Design Days are obtained and can be used to size the cooling systems. Fig. A.1 shows a comparison between the workflow followed by the Coordinate and original methods.

The presented process follows exactly the iterative approach of the standard, but can be easily automated and modified as needed. A practical example of the complete application of the Coordinates Method is reported in Example 2 below.

**Example 1.** *Applicative example of the Coordinates Method for the calculation of the coordinates for a sample day.*

Dataset length: 01/01/2004–31/12/2009.

Sample Day: 15 July 2005.

The climatic parameters for the analyzed day and the reference percentiles for July are computed according to paragraph 4.2.2 and 4.2.3 of EN ISO15927-2 standard respectively and reported in Table A.1.

By applying equation Eqn. (A.1), the coordinates of the analyzed day are computed and reported in Table A.2.

By analyzing Table A.2, a clearer explanation of the coordinate's concept is given. Considering for example risk level RL<sub>1</sub>, the first coordinate states that 40 steps of 0.1 °C are needed to reach  $P_1$  starting from  $V_1$ , as reported in Table A.1, and so on for the others parameters. This means that the maximum coordinate,  $C_3 = 74$ , represents the parameter that is last included in the selection range defined by the standard and, consequently, is the most influential coordinate for the identification of a day suitable as Cooling Design Day.

**Example 2.** *Applicative example of the whole Coordinates Method for the identification of the Cooling Design Day for July for risk level RL<sub>1</sub>. The procedure for the other percentiles is identical.*

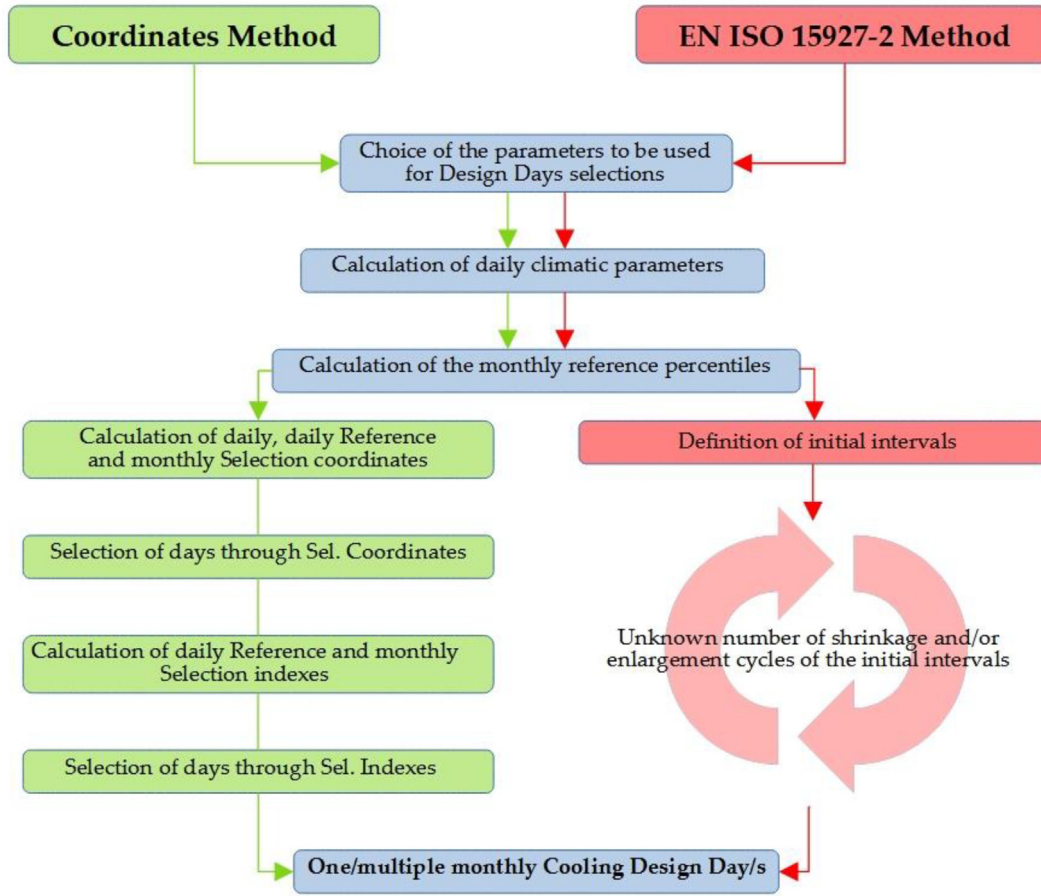


Fig. A1. Workflow of the Coordinates and EN ISO methods.

Table A1

Daily parameters and reference percentiles for 15 July 2005.

| <i>i</i> | <i>Parameter</i>                   | <i>V<sub>i</sub></i> | <i>P<sub>i</sub></i>  |                       |                       |                          |
|----------|------------------------------------|----------------------|-----------------------|-----------------------|-----------------------|--------------------------|
|          |                                    |                      | <i>RL<sub>1</sub></i> | <i>RL<sub>2</sub></i> | <i>RL<sub>5</sub></i> |                          |
| 1        | Daily mean dry-bulb temperature    | 25.39                | 29.32                 | 28.82                 | 28.04                 | °C                       |
| 2        | Daily total global solar radiation | 7.89                 | 8.26                  | 8.25                  | 8.12                  | kWh/(m <sup>2</sup> day) |
| 3        | Daily mean dew-point temperature   | 11.13                | 18.45                 | 17.68                 | 15.97                 | °C                       |
| 4        | Daily dry-bulb temperature swing   | 12.30                | 5.27                  | 5.94                  | 6.60                  | K                        |
| 5        | Daily mean wind speed              | 2.37                 | 1.75                  | 1.82                  | 1.95                  | m/s                      |

Table A2

Coordinates for 15 July 2005.

| <i>i</i> | <i>Parameter</i>                    | <i>C<sub>i</sub></i>  |                       |                       |
|----------|-------------------------------------|-----------------------|-----------------------|-----------------------|
|          |                                     | <i>RL<sub>1</sub></i> | <i>RL<sub>2</sub></i> | <i>RL<sub>5</sub></i> |
| 1        | Daily mean dry-bulb temperature     | 40                    | 35                    | 27                    |
| 2        | Daily total global solar radiation  | 37                    | 36                    | 24                    |
| 3        | Daily mean dew-point temperature    | 74                    | 66                    | 49                    |
| 4        | Daily swing in dry-bulb temperature | 71                    | 64                    | 58                    |
| 5        | Daily mean wind speed               | 7                     | 6                     | 5                     |

Dataset length: 01/01/2004–31/12/2009.

Month: July ->  $m = 7$  (number of months in the dataset).

$n_m = 186$  (total number of days of July in the whole dataset).

$RL_1$  = risk level where the cooling load is likely to be exceeded in 1 % of cases.

After having calculated the coordinates  $C_i^d$  of every July day in the dataset following the procedure reported in Example 1, the

determination of the Reference Coordinate for every day is carried on by applying Eqn. (A.2):

$$C_{ref}^d = \max [C_1; C_2; C_3; C_4; C_5]^d \quad d = 1, \dots, 186$$

After this, it is then possible to compute the Selection Coordinate for July using Eqn. (A.3):

**Table A3**

Days selected through the Selection Coordinate condition.

| d | ID   | Day        | C <sub>1</sub> | C <sub>2</sub> | C <sub>3</sub> | C <sub>4</sub> | C <sub>5</sub> |
|---|------|------------|----------------|----------------|----------------|----------------|----------------|
| 1 | 566  | 20-07-2005 | 58             | 58             | 30             | 36             | 1              |
| 2 | 921  | 10-07-2006 | 47             | 58             | 50             | 49             | 13             |
| 3 | 1277 | 01-07-2007 | 58             | 57             | 54             | 44             | 5              |

**Table A4**

Daily climatic parameters of the Cooling Design Day for July month.

| Parameter                          | Value | U.M.                     |
|------------------------------------|-------|--------------------------|
| Daily mean dry-bulb temperature    | 23.55 | °C                       |
| Daily total global solar radiation | 7.69  | kWh/(m <sup>2</sup> day) |
| Daily mean dewpoint temperature    | 13.14 | °C                       |
| Daily dry-bulb temperature swing   | 9.60  | K                        |
| Daily mean wind speed              | 2.16  | m/s                      |

$$C_{sel} = \min[C_{ref}^d] = 58d = 1, \dots, 186$$

The Selection Coordinate value for July for RL<sub>1</sub> is 58. The first selection of days is now carried on applying the condition reported in Eqn. (A.4):

$$C_{ref}^d = C_{sel}d = 1, \dots, 186$$

There are three days that meet the aforementioned condition, as reported in Table A.3.

As it can be seen in Table A.3, the three selected days all have a Reference Coordinate equal to 58. This means that fifty-eight enlargement cycles would be required to find these days if the method of the standard were used. The final step is to choose, between these selected days, the one that displays the Reference Coordinate at the minimum *i*-index, thus representing the first day to satisfy all the parameters ranges following the modification order given by the standard. The Reference Index for every remaining day is then obtained using Eqn. (A.5):

$$I_{ref}^d = \max(i) : C_i^d = C_{ref}^d d = 1, \dots, 3$$

The result of the application of the equation is also evident by looking at Table A.3, leading to Reference Index equal to 2 for the days with ID 566 and 921 and to 1 for the day with ID 1277. The Selection Index is obtained using Eqn. (A.6):

$$I_{sel} = \min[I_{ref}^d] = 1d = 1, \dots, 3$$

By imposing the condition of Eqn. (A.7) the second and last selection is carried on, leading to the final result of day 1277, 01 July 2007, as the Cooling Design Day for July.

$$I_{ref}^d = I_{sel}$$

In Table A.4 the daily climatic parameters of the selected Cooling Design Day are reported.

## Appendix B

Using the Coordinates Method to explain Rome Cooling Design Days selection example

The Coordinates Method can be used to better understand the features of the Cooling Design Day selection example reported in Table 3. The example considers the location of Rome, risk level RL<sub>1</sub>, and identifies for every parameter set the Design Day for July. The detailed process results, i.e. the Design Days and their coordinates, are reported in Table B.1.

**Table B1**Rome Cooling Design Days coordinates values for every parameter set for July and risk level RL<sub>1</sub>.

| Parameter set       | Cooling Design Day | C <sub>1</sub> | C <sub>2</sub> | C <sub>3</sub> | C <sub>4</sub> | C <sub>5</sub> |
|---------------------|--------------------|----------------|----------------|----------------|----------------|----------------|
| Tmp_rad             | 18/07/2003         | 19             | 25             | \              | \              | \              |
| Tmp_rad_vel         |                    | 19             | 25             | \              | \              | 13             |
| Tmp_rad_tdp         | 21/07/2006         | 15             | 45             | 47             | \              | \              |
| Tmp_rad_tdp_vel     |                    | 15             | 45             | 47             | \              | 1              |
| Tmp_rad_tsw         | 02/07/2003         | 31             | 2              | \              | 57             | \              |
| Tmp_rad_tsw_vel     |                    | 31             | 2              | \              | 57             | 11             |
| Tmp_rad_tdp_tsw     | 04/07/2006         | 44             | 13             | 63             | 61             | \              |
| Tmp_rad_tdp_tsw_vel |                    | 44             | 13             | 63             | 61             | 14             |

As already stated, the chosen Design Day is the same for the parameter sets where the only difference is the presence of the wind velocity *vel* in the analysis, highlighting a very low impact of this parameter on the choice of the Design Day. This can be better understood by looking at the coordinate pertaining the wind speed, i.e. C<sub>5</sub>. As it can be seen, in every case where C<sub>5</sub> is present it never shows low coordinates values meaning that it is one of the parameters that are closest to their reference percentiles. Therefore, it has no influence in the selection of that Design Day.

On the other hand, it was already stated in the text that: “the analysis highlighted that dew-point temperature and temperature swing are the parameters that are more distant from their respective reference percentiles, therefore being the most influential parameters in the selection of the Design Days”. This can again be understood by looking at Table B.1, showing that the coordinates C<sub>3</sub> and C<sub>4</sub>, related to dew-point temperature and temperature swing respectively, have the highest values when they are present. Therefore, these are the most influential parameters in the selection of the Design Days if they are considered in the analysis.

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