320: Comparison of methodologies for Test Reference Year (TRY) generation for Mediterranean sites

Patrizia Ferrante, Maria La Gennusa, Stefania Nicolosi, Gianluca Scaccianoce, Giancarlo Sorrentino*

Dipartimento di Ricerche Energetiche ed Ambientali (DREAM), Università degli Studi di Palermo, Viale delle Scienze, 90148 Palermo, Italy
sorrentino@dream.unipa.it

Abstract

The improvement of the energy efficiency of buildings calls for the availability of tools for evaluating and simulating the thermal behaviour of buildings. These simulation tools generally need a complete input data set concerning the climatic conditions at a given location. In the most cases, this huge mass of data is very complex, so simple aggregation methods of the meteorological data are needed. The test reference year (TRY) is one of the most used methods. In this paper a comparison between two methodologies for compiling TRY is firstly presented: the Belgian and the Sandi method. Both methodologies have a statistical approach to the problem. Then, the two methods were been applied to the city of Palermo, obtaining quite different results, although a particular caution in the choice of the method for generating such reduced sets of data should be suggested.

Keywords: solar radiation; Test Reference Year; energy efficiency.

1. Introduction

In the last decades, the improving of lifestyle of people has determined an increasing of the amount of time spent within confined spaces. This needs, on the one hand, a higher level of the global comfort in indoor environments, and, on the other hand, calls for more detailed evaluations of the energy efficiency of buildings which, of course, directly affects people's comfort conditions. As regard the energy efficiency in buildings, it is important to note that just the building sector of developed countries, mainly referring to residential and commercial buildings, encompasses a large part of the final energy consumptions. In Italy, for example, as far as 35% of the energy uses are utilized in the management of buildings and, mainly, for heating and cooling operations. To address this problem, many developed countries, conscious of the strategic importance of the building sector and according to the new standards released by the European Union, among which the European Directive on the Energy Efficiency of Buildings (EPBD) [1] and the EN 15251:2007 [2] which defines how establish and define the main parameters to be used as input for building energy calculation and long term evaluation of the indoor environment, are engaged in search of actions devoted to the increasing of the indoor performances, to a more rational energy use and to a more clear energy production.

These considerations call for a more detailed computation of the thermal and energy behaviour of buildings, and an accurate prediction of the long-term performance of buildings and, on turn, of all solar systems, such as photovoltaic applications, active and passive heating and cooling. This kind of prediction strongly depends on the long-term climatic features at a location. To address this issue, the availability of tools for evaluating and simulating the thermal behaviour of buildings is needed. In the last years several computer programs and packages for thermal simulation of buildings have been quickly spread. Therefore, most of these simulation tools need a complete input data set and, in particular, meteorological data which strongly affect thermal behaviour of buildings, such as solar radiation, air temperature, wind speed, etc.

As far as meteorological data are concerned, it is important to point out that meteorological data very often are not available because there is only limited number of meteorological sites in the cities where these data are measured. More frequently it is possible to find out these measurements located in the airports that are far from city centres and do not provide us with necessary information about, for example, the state of the boundary layer in the city. The situation becomes even more complicated when a city is located in an area with complex topography. Anyway, if a large amount of meteorological data is available, very often this huge mass of data is very complex and not always useful in that form. To model the long-term average or typical performance, it is necessary to simulate the system behaviour using either many years of real weather data or one year of typical weather data. The first method should give more accurate results, but the simulation will require much longer. The second method will enable results to be obtained much faster, but it may be difficult to select a suitable year.

The need for appropriate meteorological data for long-term prediction of the annual performance of buildings with relatively low computation time led to the development of simple aggregation methodologies of meteorological data. Among these methods, the test reference year (TRY) is one of the most noted and used.

Various TRY generation methodologies are available in the literature: the Danish method by Anderson et al. [3] and by Lund and Eidorff [4], the Sandia National Laboratory method (TMY) presented by Hall et al. [5], the Festa Ratto method [6], the TMY2, which is a modification of the original Sandia method by Marion and Urban [7], the Belgian method by Dogniaux and Sneyers [8].

As it is well known, among climatic parameters, particularly important for the thermal energy balance of buildings is the solar radiation.

In this paper authors present first a brief description of two methodologies for compiling the TRY of the solar radiation: the Belgian method and the Sandia method. Both methods have a statistical approach to the problem. The first one has been previously adopted by the EU and it is based on the normal distribution of the monthly average of each climatic parameter and his variance, while the second one is a more powerful version of the Kolmogorov-Smirnov test, based on the cumulative probability function. Then, authors report a comparison between the two selected methodologies applied to the city of Palermo (Sicily). They give quite different results, suggesting a particular caution in the choice of the method for generating such reduced sets of data.

2. Description of the selected methods

A TRY provides a standard for hourly data for solar radiation and other meteorological parameters for a period of one year, representing climatic conditions considered to be typical over a long time-period. Most of the methodologies for the generation of TRYs proposes to use sequences of real measured hourly values to compose a TRY, such as the Danish method by Lund and Eidorff, the Sandia National Laboratory method and the Festa Ratto method, while other methods propose to use data adjusted to give monthly cumulative distribution like the cumulative distribution of these months in the original multi-year data set (such as the Danish method by Anderson et al.).

The data are in true sequence within each month. The months are selected from a multiple year data set of observations for a given location such that the resulting TRY is typical for the location.

Therefore, it is constituted by a total of 8760 hourly values for each considered climatic parameter.

Several statistical methods have been developed worldwide in order to generate a TRY, most of them utilizing sequences of real, measured data. In the following sub-sections, two methodologies for the generation of TRY of the solar radiation will be analyzed: the “Belgian” method by Dogniaux and Sneyers [8] and the “Sandia” method by Hall et al. [5].

2.1 The Belgian method

The Belgian method [8] was developed in ‘80s within a project of the Commission of the European Communities [9]. This procedure is a statistical method based on the generalized mean square method. All the meteorological parameters can be used for generating a TRY, but, as Dogniaux stated, it would be better to utilise the air temperature and global solar radiation on a horizontal surface. In fact, the introduction of other parameters, such as humidity and wind speed, doesn’t improve the results.

The TRY is obtained by means of the selection of 12 typical months within the available period of time. The selection process for each month consists of 5 steps.

1. For each month of the years analysed (let us suppose 20 years), the monthly mean of the air temperature (*TM*) and its variance (*VTM*) are calculated starting from the daily mean values, as follow

   $$TM = \frac{\sum T_d}{N_m} \qquad VTM = \frac{\sum \left(T_d - TM\right)^2}{N_m - 1}$$

   where T_d is the daily mean air temperature and N_m is the number of days of the month. Therefore, 240 values (12×20) for *TM* and *VTM* are obtained.
2. Taking into consideration the values calculated at point 1, we choose those values related to a same month (for example, the 20 monthly mean values concerning the month of January) and calculate the mean values (*MTM* and *MVTM*) and their variances (V*MTM* and *VMTM*) for this month on the long period.

   $$MTM = \frac{\sum TM}{N_y}$$

   $$MVTM = \frac{\sum VTM}{N_y}$$

   $$VMTM = \frac{\sum \left(TM - MTM\right)^2}{N_y - 1}$$

   $$VMVTM = \frac{\sum \left(VTM - MVTM\right)^2}{N_y - 1}$$

   where N_y is the number of years within the period of time considered (20).

   The procedure is repeated for all months.
3. Assuming that all values of the considered parameters follow a normal distribution, it is possible to calculate the normal standard values of the monthly mean air temperature, X_1, and of the variances, X_2, as follow

   $$X_1 = \frac{TM - MTM}{\sqrt{VMTM}} \qquad X_2 = \frac{VTM - MVTM}{\sqrt{VMVTM}}$$

Even in this case, 240 values (12×20) for X_1 and X_2 are obtained.

4. All the steps, from point 1 to point 3, are repeated for the global solar radiation. The following parameters are determined: GM, VGM, MGM, MVGM, VMGM, VMVGM, X_3 and X_4.
5. Since the joint probability distribution of the 4 normal standard variables before calculated follows a chi-squared distribution with 4 degrees of freedom, we can choose, for a fixed month, the quadrinomial (X_1, X_2, X_3, X_4) which has the higher value of the calculated chi-squared variable. This quadrinomial is linked to a proper year which is, therefore, chosen as the representative one of the long period climatic conditions for that month. The hourly values of the 12 months so selected are put together to have a TRY.

2.2 The Sandia National Laboratories method

The Sandia method was developed in late '70s by Hall et al. [5] at the Sandia National Laboratories of Albuquerke, U.S.A. This is an empirical methodology for selecting individual months of the measuring period. It is a statistical method based on the Finkelstein-Schafer (*FS*) statistic [10], which is, on turn, an improved version of the Kolmogorov-Smirnov test. In this method, nine daily climatic parameters are used, that is maximum, minimum and mean air temperature ($T_{\max}$, $T_{\min}$, $\overline{T}$) and relative humidity ($RH_{\max}$, $RH_{\min}$, $\overline{RH}$), maximum and mean wind speed ($W_{\max}$, $\overline{W}$) and daily global solar radiation (*G*). Depending on the case studied, different sets of weights can be assigned to these parameters.

As in the previous case, the building-up of a TRY requires the selection of 12 typical months. The selection process for each month consists of 3 steps [11]. The procedure is as follows:

1. Considering the nine selected parameters, five candidate months, having the smallest weighted sum of the Filkenstein-Schafer (*FS*) statistics, are selected for each month of the calendar year, according to:

   $$FS_x(y,m)=\frac{1}{N}\sum_{i=1}^{N}\left|CDF_m\left(x_i\right)-CDF_{y,m}\left(x_i\right)\right|$$

   where CDF_m is the long term and $CDF_{y,m}$ is the short term (relative to the year *y*) cumulative distribution function of the daily values of the climatic parameter *x* for month *m*.

   However, due to the consideration of some parameters being more important than others, the weighted sum, *WS*, of the *FS* statistics is calculated according to:

   $$WS\left(y,m\right)=\frac{1}{M}\sum_{x=1}^{M}WF_x\cdot FS_x\left(y,m\right)$$

   where WF_x are the weighting factors, one for each daily index. Of course

   $$\sum_{x=1}^{M}WF_x=1\,.$$

   The months that have the lowest weighted sums are the five candidates.
2. The selected 5 candidate months are then ranked on the basis of their similarity with the month in the long term mean and median using the *FS* (months having minimum *FS* values) statistics. Relative differences are calculated between the mean and median air temperature and global solar radiation of each specific month and the respective mean and median over the long period series. The maximum of the four relative differences is assigned to the month.
3. The persistence of air temperature and global solar radiation is evaluated by means of the determination of the frequency (number of occurrence) and run length (number of consecutive days) above and below fixed long term percentiles. The 67th and the 33th long term percentile are respectively the upper limit and the lower limit for the air temperature. As regard the global solar radiation only a lower limit, the 33th long term percentile, is determined. The persistence criteria exclude the month with the longest run, the month with most runs, and the month with zero runs. The highest ranking month that remains according to the previous step is selected to be part of the TRY.

3. Comparison of methodologies for TRY generation

3.1 Data used in the analysis

For the generation of the two TRYs for the city of Palermo, hourly air temperature and global solar radiation on a horizontal surface were utilized. The data covering a period of 8 years, from 1999 to 2006 are provided by the "Osservatorio Astronomico G. S. Vaiana" of Palermo (Lat. 38° 06' N, Long. 12° 53' E). The observatory is located in the city centre and is equipped with very high accuracy sensors; only a very little amount of data are missing (nearly 0.5%).

Both the methodologies here selected for the application, need complete data sets, so a simple and weighted linear interpolation has been carried out to refill the missing data. When the gaps were larger than 3 hours, no interpolation occurred, and the corresponding month was excluded by the calculations.

3.2 Generated TRYs

In order to better compare the two methodologies, the chosen weights for the Sandia method were all put equal to zero except for air temperature and global solar radiation, both equal to 0.5, as in the Belgian method.

In Table 1, the typical months, selected to be part of the two different TRYs, are reported.

As it is possible to note, only for the month of September the two methods give the same results.

Figs. 1 and 2 illustrate the trend of the air temperature of the obtained TRYs respectively with Belgian and Sandia method.

In Figs. 3 and 4, the global solar irradiance of the obtained TRYs respectively with the Belgian and Sandia method are reported.

Table 1: Selected typical months for Sandia e Belgian TRYs.

Month	Belgian	Sandia
Jan	2000	2005
Feb	2001	2000
Mar	2003	2000
Apr	2002	2001
May	2000	2005
Jun	2004	2001
Jul	2004	2006
Aug	2004	2001
Sep	2003	2003
Oct	2004	2001
Nov	2000	2003
Dec	1999	2002

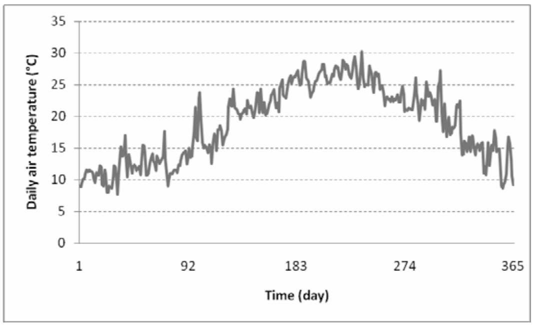

Fig 1. Daily air temperature of the obtained TRY (Belgian method)

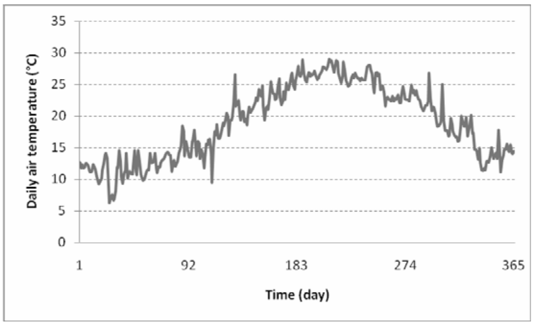

Fig 2. Daily air temperature of the obtained TRY (Sandia method)

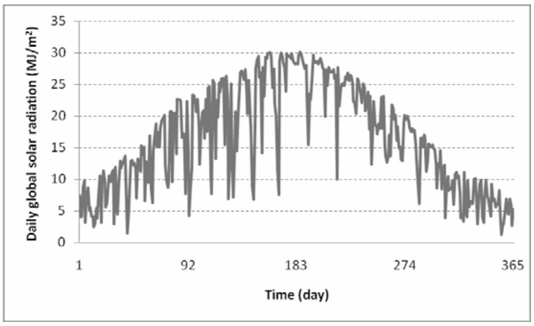

Fig 3. Daily global solar irradiance of the obtained TRY (Belgian method)

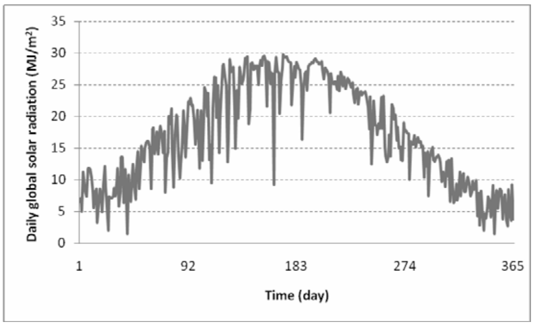

Fig 4. Daily global solar irradiance of the obtained TRY (Sandia method)

3.3 Results and discussion

In order to better evaluate the difference in results, the different priority ranks obtained from the available years have been calculated for each month, depending on the adopted method. These comparisons ranks are reported in Table 2.

Table 2: Different rank obtained using Sandia (S) or Belgian (B) method.

Month	Method	99	00	01	02	03	04	05	06
Jan	S	7	4	8	2	3	6	**1**	5
	B	8	**1**	7	3	2	6	5	4
Feb	S	7	**1**	2	6	8	4	5	3
	B	7	3	**1**	2	8	6	4	5
Mar	S	4	**1**	2	6	3	8	7	5
	B	2	5	6	3	**1**	4	7	8
Apr	S	5	3	**1**	4	7	2	8	6
	B	3	2	6	**1**	4	5	7	8
May	S	-	4	3	5	2	7	**1**	6
	B	-	**1**	5	2	6	7	3	4
Jun	S	5	4	**1**	6	7	3	2	8
	B	5	2	4	3	8	**1**	6	7
Jul	S	5	6	-	4	7	3	2	**1**
	B	3	5	-	6	7	**1**	2	4
Aug	S	3	4	**1**	7	8	2	6	5
	B	2	3	5	4	6	**1**	8	7
Sep	S	3	6	2	-	**1**	7	4	5
	B	7	6	3	-	**1**	2	4	5
Oct	S	2	7	**1**	4	8	6	3	5
	B	7	6	4	2	8	**1**	5	3
Nov	S	5	3	2	4	**1**	-	7	6
	B	6	**1**	7	3	2	-	5	4
Dec	S	2	-	3	**1**	-	-	-	4
	B	**1**	-	3	2	-	-	-	4

As it is possible to note, the two methods are not in good agreement. In fact, if a month ranks high with a method, not always it is the same with the other one.

A simple statistical analysis has been carried out in order to evaluate the ranks correlation for each single month by using the two different methods. The linear coefficient of correlation assumes the value of 0.76, confirming what we expected.

The monthly mean daily values of air temperature and the global, diffuse and beam solar irradiance obtained by means of the Belgian and the Sandia methods, have been compared with the corresponding values included in the UNI 10349 standard (Italian standard) [12]. The comparison is reported in Figs. 5-8.

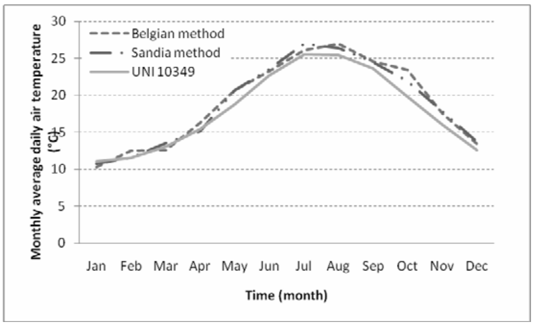

Fig 5. Monthly average daily air temperature of the obtained TRY and UNI 10349

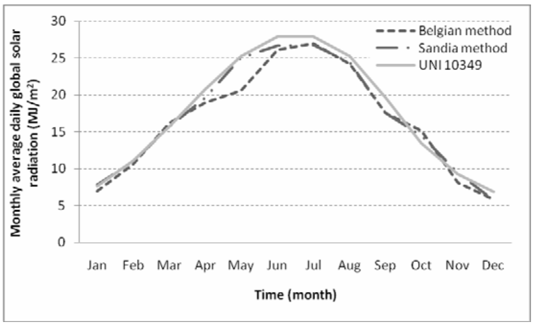

Fig 6. Monthly average daily global solar irradiance of the obtained TRY and UNI 10349

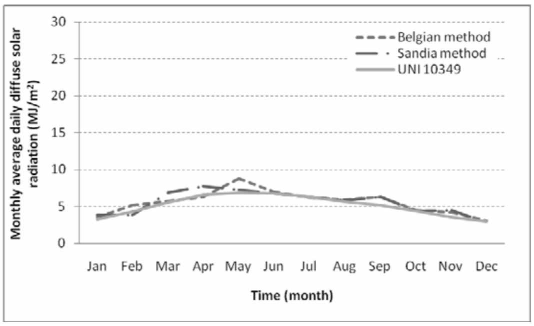

Fig 7. Monthly average daily diffuse solar irradiance of the obtained TRY and UNI 10349

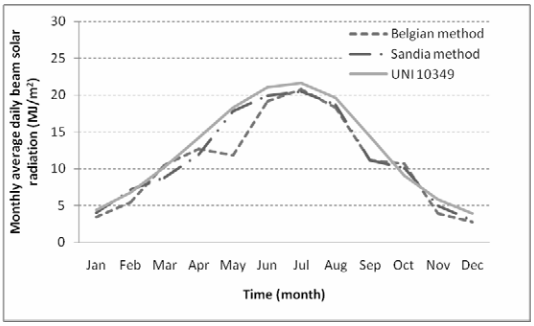

Fig 8. Monthly average daily beam solar irradiance of the obtained TRY and UNI 10349

Once verified the differences between the two methods, further analyses have been carried out in order to estimate the differences in the use of each method for a PV system and energy consumption of buildings.

The energy production generated by a PV system located in Palermo has been calculated, giving as input data the Belgian and Sandia TRYs. The annual solar global irradiance values evaluated by means of the two TRYs are respectively 6017 MJ/(m^2 year) and 6227 MJ/(m^2 year), with a difference of 3.5%. The energy production of a PV field of 1000 m^2, with panels surfaces tilted by an angle of 30°, 22° of azimuth and a peak power of 225 W, has been taken into account. A production of electric energy of 133.0 MWh/year and 138.5 MWh/year has been calculated respectively for the Belgian and Sandia TRYs, with a difference of 4% in the results.

As regards the energy building consumption for heating systems, a simple parameter has been evaluated for both methods: the simplified Heating Degree Day (HDD), that is the difference between a reference value (20°C) and the mean outdoor air temperature for that day, summed up for all days of the heating period (that in Palermo is set from 1 December to 31 March [13]) in which this difference is positive.

It has been determined respectively for the Belgian and Sandia TRYs a value of 874 HDD and 869 HDD, with a difference of only 0.6%. The reference value set by the Italian standard is 751 HDD [13].

In order of evaluating the effectiveness of the method in assessing summer climatic data a very simple parameter, that is a simplified Cooling Degree Days (CDD). This is simply computed as the summation of the day differences between the outdoor air temperature and 26°C that is assumed like comfort indoor temperature. The Belgian method provides a value of 140 for CDD, while the Sandia one provides a value of 135 for CDD: the percentage difference is only 3.0%. Therefore, the global solar irradiance in the cooling season (from 1 June to 30 September) has been evaluated for both methods (2898 MJ/(m2 year) and 2917 MJ/(m2 year)), leading to a difference of 0.7%.

In Table 3 the results of the comparisons has been reported.

Table 3: Comparison of some applications of climatic data obtained with the Belgian and the Sandia statistical methods.

	Belgian	**Sandia**	**Δ%**	**Italian referee rules**
Global irradiance [MJ/year]	6017	6227	3.5%	6427*
Electric energy produced by mean of a PV array [MWh/year]	133.0	138.5	4.1%	
HDD (Heating degree days)	874	869	0.6%	751**
CDD (Cooling degree days)	140	135	3.0%	

* UNI10349 [12]
** DPR 412/93 [13]

4. Conclusions

In this paper, a comparison between two statistical method for generating a TRY has been presented. Hourly air temperature and solar radiation values have been used as meteorological parameters. Both the selected methodologies, the Belgian and the Sandia method, determine the TRY by means of the choose of typical months which are selected from a multiple year data set of observations for a given location.

The comparison showed that only one month (September) was singled out by both methods for generating the respective TRY. Then, the different ranks obtained by all available years have been calculated, for each month, and the results for the two methods have been compared. The comparison showed a very little correlation for the ranks.

The reliability of the two methods has been checked firstly by comparing the mean values of air temperature and global solar irradiance with the Italian regulations values, and then by means of a PV application.

These results showed a low relative difference between the two methodologies. Anyway, a particular caution should be used in the choice of the adopted method for generating a TRY since the results here presented need to be confirmed in different climatic conditions and for different sites.

7. References

1. EPBD, 2002. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings. *Official Journal of the European Communities EN*, 4.1.2003 L 1/65.

2. EN 15251:2007. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Brussels: *European Committee for Standardization*, 2007.

3. Andersen, B., Eidorff, S., Lund, H., Pedersen, E., Rosenorn, S. and Valbjorn, O., (1977). Meteorological Data for Design of Building and Installation: A Reference Year (extract). *Report No 66*, 2nd edition, Thermal Insulation Laboratory, Denmark.

4. Lund, H. and Eidorff, S., (1981). Selection methods for production of test reference years. *Final Report* (short version), contract no. 284-77 ES DK, Report EUR 7306 EN, Thermal Insulation Laboratory, Technical University of Denmark, Lyngby, Denmark.

5. Hall, I.J., Prairie, R.R., Anderson, H.E. and Boes, E.C., (1978). Generation of a typical meteorological year. In: Proceedings of the 1978 *Annual Meeting of American Section of ISES*, Denver, CO.

6. Festa, R. and Ratto, C.F., (1993). Proposal of a numerical procedure to select reference year. *Solar Energy* 50, pp. 9–17.

7. Marion, W. and Urban, K., (1995). User's manual for TMY2's typical meteorological years. National Renewable Energy Laboratory, Golden, CO, USA.

8. Dogniaux, R. and Sneyers, R., (1977). Méthodologie d'analyse statistique des données météorologique en vue de la constitution de périodes-types pour l'application à des problèmes spécifiques. In *Rapport des Journées Internationales d'Etude sur chauffage solaire dans le bâtiment*. Liège, Belgium, September 12-14.

9. Lund et al., (1985). Test Reference Year TRY, Weather data sets for computer simulations of solar energy systems and energy consumptions in buildings. Commission of the European Communities Directorate General XII for Science, Research and Development, Brussels.

10. Finkelstein, J. and Schafer, R., (1971). Improved goodness-of-fit tests. Biometrika, 58(3): p. 641-645.

11. Argiriou, A., Lykoudis, S., Kontoyiannidis, S., Balaras, C. A., Asimakopoulos, D., Petrakis, M. and Kassomenos, P., (1999). Comparison of methodologies for TMY generation using 20 years data for Athens, Greece. *Solar Energy*, 66(1): p. 33–45.

12. UNI 10349, (1994). Heating and cooling of buildings – Climatic data. Milano: *Ente Nazionale Italiano di Unificazione* (UNI), Italy. (*In Italian*)

13. DPR 412, (1993). Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della legge 9 gennaio 1991, n. 10. Italy. (*In Italian*)