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ABSTRACT

Several studies couple simulations of building systems and statistical techniques in order to draw conclusions easy to generalize under given constraints. To this extent, one of the most important input is dealing with climatic conditions: indeed, the weather data and the localities chosen for the analysis can seriously affect the representativeness of the simulation outcomes with respect to other regions. The first question to be answered regards the domain to which one or few reference climates should be representative, which can be related to thermal energy, ventilation, comfort analysis. As a common practice, national guidelines, heating and cooling degree-days scales and worldwide recognized climatic classifications are adopted. However, in some cases, these kinds of categorization are suitable only for specific applications. For example, the well-known and used Köppen-Geiger classification is based on annual or seasonal air temperatures and cumulative precipitation and highlights mainly the relationship between climate and vegetation. Consequently, while this classification can be very effective to distinguish ecological systems, it is expected to be not always suitable for building energy analysis. Similar considerations apply to ANSI/ASHRAE 90.1 and 90.2 classification.

This work proposes a critical discussion of the main climate classification system adopted in Europe and presents a new classification of 66 European climates, based on clustering analysis. The aim is to identify a limited number of climatic zones and, for each one, a reference climate to be used for energy simulations. To this purpose, the hourly weather data of dry bulb temperature, relative humidity and global horizontal irradiation reported in typical and reference years have been considered. The clustering analysis has been performed according to a simplified approach based on the calculated monthly averages of the weather variables and the Kolmogorov-Smirnov non-parametric test has been used to select the most representative city for each cluster. The obtained climatic classes have been compared to Köppen-Geiger traditional ones, underlining the main changes and the impact for building energy simulation analyses.

1. INTRODUCTION

One of the most interesting aspects of building energy simulation is the possibility to explore several scenarios to define energy strategies and energy policies to apply not only to a given case-study but to entire building categories or to the building stock of a given territory. If that is the purpose, the representativeness of the studied configurations and of the boundary conditions is essential in order to achieve meaningful and applicable findings. Among the aspects to consider, on one hand are the buildings' features and, on the other hand, the boundary conditions, both internal, such as the occupancy and the typicality of the building use, and external ones like the climate. When it comes to assess the efficacy of a new potential energy policy for an administrative region, a country or a group of them, it is clearly unfeasible to simulate every climate and it is necessary to identify those, which can be picked as representative for some climatic zones.

There are many approaches to define climatic zones. The most popular worldwide is that developed by W. Köppen and R. Geiger. Köppen published his original climatic classification in 1884 (Köppen, 1884) and made several upgrades until the 40s (e.g., Köppen and Geiger, 1936). Later, Geiger modified furtherly the Köppen classification in the 50s and 60s (Geiger, 1954 and 1961), leading to the current Köppen-Geiger system (Peel et al., 2007). Other authors proposed some changes to the classification system, such as G.T. Trewartha in the 60s (Trewartha, 1968) and the 80s (Trewartha and Horn, 1980). The Köppen-Geiger system (level 1) divides the world into 5 main groups of climates - A (tropical), B (dry), C (temperate), D (continental), and E (polar), which are furtherly subdivided (level 2) according to seasonal precipitations and (level 3) average monthly or seasonal temperature (Table 1). As it can be noticed, the classification is based on:

- the dry bulb temperatures (*DBT*) of the coldest month of the year (*cold*), the hottest month of the year (*hot*) or annual average (*avg*);
- the precipitations (*P*) of the driest month of the year (*dry*), the driest month of the summer season (*sdry*), the driest month of the winter season (*wdry*), the wettest month of the summer season (*swet*), the wettest month of the winter season (*wwet*) or annual average (*avg*);
- the number of months with average *DBT* larger than 10 °C ($n_{DBT>10}$).

Table 1: Criteria for the Köppen-Geiger system. In yellow, the main Köppen-Geiger zones found in Europe.

Level 1	Level 2	Level 3	Criteria
A (Tropical)			$DBT_{cold} \geq 18$ °C
	f (rainforest)		$P_{dry} \geq 60$ mm
	m (monsoon)		$P_{dry} \geq 100 - P_{avg}/25$ mm & Not (**Af**)
	w (savannah)		$P_{dry} < 100 - P_{avg}/25$ mm & Not (**Af**)
B (arid)			$P_{avg} < 10 \cdot P_{threshold}{}^{*}$
	W (desert)		$P_{avg} < 5 \cdot P_{threshold}{}^{*}$
	S (steppe)		$P_{avg} \geq 5 \cdot P_{threshold}{}^{*}$
		h (hot)	$DBT_{avg} \geq 18$ °C
		k (cold)	$DBT_{avg} < 18$ °C
C (Temperate)			$DBT_{hot} < 18$ °C & 0 °C < $DBT_{cold} < 18$ °C
	s (dry summer)		$P_{sdry} < 40$ mm & $P_{sdry} < P_{wwet}/3$
	w (dry winter)		$P_{wdry} < P_{swet}/10$
	f (without dry season)		Not (**Cs**) or (**Cw**)
		a (hot summer)	$DBT_{hot} \geq 22$ °C
		b (warm summer)	Not (**a**) & $n_{DBT>10} \geq 4$ months
		c (cold summer)	Not (**a** or **b**) & $0 < n_{DBT>10} < 4$ months
D (Cold)			$DBT_{hot} > 10$ °C & $DBT_{cold} \leq 0$ °C
	s (dry summer)		$P_{sdry} < 40$ mm & $P_{sdry} < P_{wwet}/3$ mm
	w (dry winter)		$P_{wdry} < P_{swet}/10$ mm
	f (without dry season)		Not (**Ds**) or (**Dw**)
		a (hot summer)	$DBT_{hot} \geq 22$ °C
		b (warm summer)	Not (**a**) & $n_{DBT>10} \geq 4$ months
		c (cold summer)	Not (**a**, **b** or **d**) & $0 < n_{DBT>10} < 4$ months
		d (very cold winter)	Not (**a** or **b**) & $DBT_{cold} < -38$ °C
E (Polar)			$DBT_{hot} < 10$ °C
	T (Tundra)		$DBT_{hot} > 0$ °C
	F (Frost)		$DBT_{hot} \leq 0$ °C

*$P_{threshold}$:

- if 70 % P_{avg} occurs in winter → $P_{threshold} = 2 \cdot DBT_{avg}$;
- if 70% P_{avg} occurs in summer → $P_{threshold} = 2 \cdot DBT_{avg} + 28$;
- otherwise → $P_{threshold} = 2 \cdot DBT_{avg} + 14$.

As it can be observed, besides the dry bulb temperature, there are no other weather variables commonly adopted in building energy simulation as inputs. For example, global solar irradiation on the horizontal plane is not accounted for, nor wind speed and direction. While the latter are strongly affected by local specific configurations and are sometimes neglected also in typical weather data (Pernigotto et al., 2014), the opposite is true of solar irradiation. As regards the air humidity, it is indirectly and partially accounted for by the precipitation, which corresponds to a saturation condition. Indeed, Köppen-Geiger classification focuses on ecological systems and gives no or limited relevance to those quantities which are important for building energy analysis. This aspect has been further stressed in later modifications to the Köppen-Geiger system, which paid more attention to vegetation and genetic characteristics of the different climatic zones, as seen for example in the Trewartha system.

For this reason, when prescribing some constraints for enhancing building energy efficiency in buildings, government bodies and/or authorities use to follow slightly different classifications of climates. Analyzing the literature, climate classification and study is a topic of interest in countries since it represents the first step for the definition of national energy policies for buildings. Recent examples involve China (Lau et al., 2007; Wan et al., 2010), Egypt (Mahmoud, 2011), Saudi Arabia (Alrashed and Asif, 2015), Thailand (Khedari et al., 2002).
As reported by Walsh et al. (2017), around 70 % of the world land surface and world population are subject to climate zoning for building energy efficiency programs. Nevertheless, there is no general consensus about the approach to adopt. In Italy, for example, the Decree of President of the Italian Republic n. 412/1993 has defined 6 climatic zones according to the heating degree days calculated considering a base temperature of 20 °C. In the U.S., a modified Köppen-Geiger system was adopted by ASHRAE (ANSI/ASHRAE 90.1 and 90.2; Briggs et al., 2003) identifying 8 classes using heating and cooling degree-days with base temperatures of 18 °C (HDD_{18}) and 10 °C (CDD_{10}) respectively, furtherly subdivided according 3 humidity classes defined in agreement with the Köppen-Geiger system (A: humid, B: dry; C: marine). Details about this last classification are reported in Table 2.

Table 2: ASHRAE climatic zones.

Names	**Description**	**Criteria**
Climatic Zones **1A** and **1B**	Very Hot – Humid*[1] (1A) or Dry*[2] (1B)	$CDD_{10} \leq 5000$ K d
Climatic Zones **2A** and **2B**	Hot – Humid (2A) or Dry (2B)	3500 K d < $CDD_{10} \leq 5000$ K d
Climatic Zones **3A** and **3B**	Warm – Humid (3A) or Dry (3B)	2500 K d < $CDD_{10} \leq 3500$ K d
Climatic Zone **3C**	Warm – Marine*[3] (3C)	$CDD_{10} \leq 2500$ K d & $HDD_{18} \leq 2000$ K d
Climatic Zones **4A** and **4B**	Mixed – Humid (4A) or Dry (4B)	$CDD_{10} \leq 2500$ K d & $HDD_{18} \leq 3000$ K d
Climatic Zone **4C**	Mixed – Marine (4C)	2000 K d < $HDD_{18} \leq 3000$ K d
Climatic Zones **5A**, **5B** and **5C**	Cool – Humid (5A), Dry (5B) or Marine (5C)	3000 K d < $HDD_{18} \leq 4000$ K d
Climatic Zone **6A** and **6B**	Cold – Humid (6A) or Dry (6B)	4000 K d < $HDD_{18} \leq 5000$ K d
Climatic Zone **7**	Very Cold	5000 K d < $HDD_{18} \leq 7000$ K d
Climatic Zone **8**	Subartic	$HDD_{18} > 7000$ K d

*[1] Humid (A): not dry or marine.
*[2] Dry (B): not marine & $P_{avg} < 20 \cdot (DBT_{avg} + 7)$ mm.
*[3] Marine (C):

- -3 °C < DBT_{cold} < 18 °C;
- DBT_{hot} < 22 °C;
- $n_{DBT>10} \geq 4$ months;
- $P_{sdry} < P_{wwet}/3$ mm

In this work, a preliminary analysis is conducted for 66 European locations, already considered in a previous work about efficient control strategies for mechanical ventilation systems (Tafelmeier et al., 2017). Starting from the hourly weather data of dry bulb temperature, relative humidity and global horizontal irradiation reported in typical and reference years, monthly and annual statistics are calculated and used in clustering analysis to build a few homogeneous groups. Then, the monthly statistics of each group are tested with the Kolmogorov-Smirnov non-parametric test to select the most representative city for each climatic zone.

2. METHODS

In the following sections the considered dataset of European climates is described, followed by the approach adopted for the analysis of European Köppen-Geiger climate zones and by the methodology implemented to cluster the climates and select the representative ones.

2.1 European climates

As it can be seen from the map of the European climates according to the Köppen-Geiger system (Figure 1) and is also highlighted in Table 1, the main European climatic zones are, from the coldest to the warmest one:

- **Dfc** - Cold climate without dry season and with cold summer: in Iceland, in most of Scandinavia, along the coast of the White Sea, in some mountains regions;
- **Dfb** - Cold climate without dry season and with warm summer: in Denmark and southern Sweden, in eastern Europe and in part of the Alpine region;
- **Cfb** - Temperate climate without dry season and with warm summer: in western Europe, in particular in the British islands, in France, in the western German territory, in northern Spain;
- **Csa** - Temperate climate with dry and hot summer: along the Mediterranean coast, in particular in southern Spain, in large part of Italy, Greece and Turkey;

Moreover, in the four Mediterranean peninsulas (Iberia, Italy, Balkans and Anatolia), several sub-classes can be identified, such as:

- **BSk** - Arid cold steppe climate: in centre and eastern Spain;
- **Csb** - Temperate climate with dry and warm summer: in northwestern Spain and part of southern France;
- **Cfa** - Temperate climate without dry season and with hot summer: in the Po Valley and in the coast of the Adriatic Sea in Italy;
- **Dsb** – Cold climate with dry and warm summer: in some regions of Greece and Turkey.

Finally, **ET** climate can be found in some mountain regions.
66 climates have been selected from those available in the EnergyPlus website (https://energyplus.net/weather) and considered in this analysis. Their Köppen-Geiger classes are reported in Table 3.

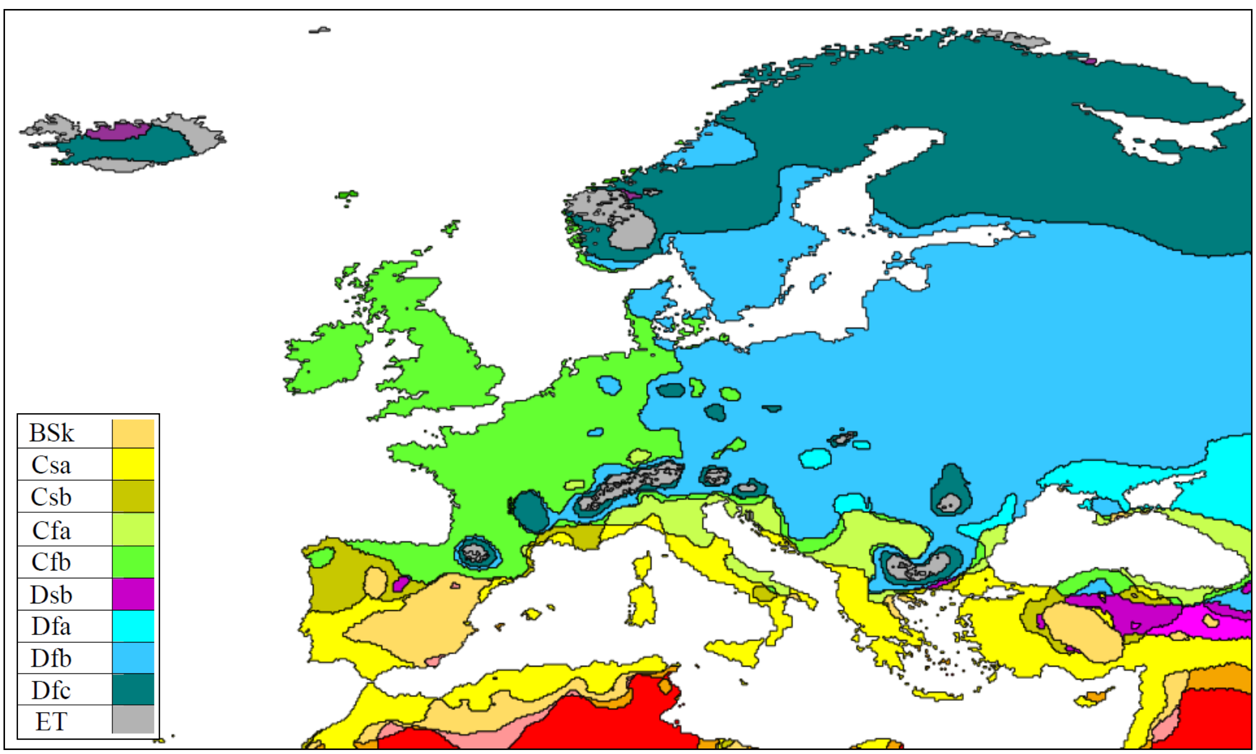

Figure 1: European climates according to the Köppen-Geiger system. Map prepared by the Authors with QGIS v. 2.16.2 based on the Köppen-Geiger GIS climate map by NASA ORNL DAAC.

Table 3. Selected climates.

N	City	Country	Köppen-Geiger Class	N	City	Country	Köppen-Geiger Class
1	Aberdeen	U.K.	Cfb	34	London	U.K.	Cfb
2	Amsterdam	The Netherlands	Cfb	35	Madrid	Spain	BSk
3	Andravida	Greece	Csa	36	Marseille	France	Csa
4	Ankara	Turkey	Dsb	37	Messina	Italy	Csa
5	Arkhangelsk	Russia	Dfc	38	Milan	Italy	Cfa
6	Athens	Greece	Csa	39	Minsk	Belarus	Dfb
7	Barcelona	Spain	Csa	40	Montpellier	France	Csa
8	Bari	Italy	Csa	41	Moscow	Russia	Dfb
9	Belgrade	Serbia	Dfa	42	Munich	Germany	Dfb
10	Bergen	Norway	Cfb	43	Nantes	France	Cfb
11	Berlin	Germany	Cfb	44	Odessa	Ukraine	Dfa
12	Bilbao	Spain	Cfb	45	Oslo	Norway	Dfb
13	Birmingham	U.K.	Cfb	46	Ostersund	Sweden	Dfc
14	Bologna	Italy	Cfa	47	Ostrava	Czech Rep.	Dfb
15	Bordeaux	France	Cfb	48	Paris	France	Cfb
16	Bucharest	Romania	Dfa	49	Pescara	Italy	Cfa
17	Clermont-Ferrand	France	Cfb	50	Porto	Portugal	Csb
18	Copenhagen	Denmark	Cfb	51	Poznan	Poland	Dfb
19	Faro	Portugal	Csa	52	Prague	Czech Rep.	Dfb
20	Finningley	U.K.	Cfb	53	Reykjavik	Iceland	Dfc
21	Frankfurt	Germany	Cfb	54	Rome	Italy	Csa
22	Goteborg	Sweden	Dfb	55	Saint Petersburg	Russia	Dfb
23	Granada	Spain	Csa	56	Sevilla	Spain	Csa
24	Hamburg	Germany	Cfb	57	Sofia	Bulgaria	Dfb
25	Helsinki	Finland	Dfb	58	Stockholm	Sweden	Dfb
26	Istanbul	Turkey	Csa	59	Strasbourg	France	Cfb
27	Kiev	Ukraine	Dfb	60	Tampere	Finland	Dfc
28	Kiruna	Sweden	Dfc	61	Teruel	Spain	BSk
29	Krakow	Poland	Dfb	62	Thessaloniki	Greece	Csa
30	La Coruna	Spain	Csb	63	Venice	Italy	Cfa
31	Larnaca	Cyprus	Csa	64	Vienna	Austria	Dfb
32	Leon	Spain	Csb	65	Warsaw	Poland	Dfb
33	Lisbon	Portugal	Csa	66	Zaragoza	Spain	BSk

2.2 Analysis of the climate dataset

The dataset of 66 climates has been divided according to the Köppen-Geiger Class. For each climate and class, the monthly average values of dry bulb temperature, *DBT* [°C], and water vapour partial pressure, *WVP* [Pa], and the monthly integrals of global solar irradiation on the horizontal plane, *GHI* [kWh m^{-2}] have been used for representing the variation of the climatic conditions along the year. In Figure 2, an example of the representation is reported for the climates belonging to class Dfb.

This type of representation has allowed us to describe first each climate and then each climatic class with two parameters calculated for the three quantities: an annual average value and an annual spread. While averages and spreads have been used to compare the different climatic classes and underline possible overlapping, their standard deviations have been used to comment their homogeneity.

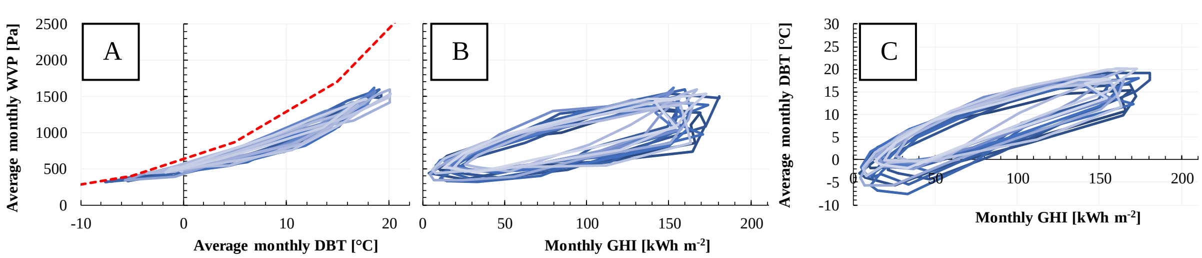

Figure 2: Dfb climates. Graph A: monthly average dry bulb temperatures (*DBT*) against monthly average water vapour partial pressures (*WVP*); Graph B: monthly integrals of global horizontal irradiation (*GHI*) against *WVP*; Graph C: *GHI* against *DBT*. The red dotted line in graph A represents the saturation conditions.

2.3 Development of new climatic classes and selection of representative climates

For the development of new climatic classes from the dataset of 66 European climates, clustering techniques have been adopted. In particular, since this is a preliminary analysis, the hierarchical clustering with Euclidean distances has been selected as approach. For further developments, encompassing much more climates, more statistically robust approaches will be adopted, such as k-means and k-medoids clustering methods. Considering the review by Walsh et al. (2017) about climatic classification systems, it has been chosen to give priority to the annual averages and, among them, larger attention has been paid to the dry bulb temperature. Moreover, Spearman correlation tests have been performed for all annual parameters considering the whole dataset and the results have been taken into account for the definition of the new classification. Even though major relevance has been given to annual averages, homogeneity of spreads has been evaluated and discussed as well.

As concerns the selection of the representative climates for each climatic zone, Kolmogorov-Smirnov tests have been performed. For each new climatic class and each parameter, the monthly values have been used for the calculation of an annual mean profile, which has been taken as reference for Kolmogorov-Smirnov tests. Similarly to the approach used for the definition of a typical year according to EN ISO 15927-4 (CEN, 2005; Pernigotto et al. 2014), representativeness of each city for *DBT*, *WVP* and *GHI* has been assessed separately and, for each, a partial ranking has been prepared. Finally, a global ranking has been developed for each climatic zone and a representative city identified.

3. RESULTS AND DISCUSSION

3.1 Analysis of the climate dataset

As regards the annual averages (Table 4), it can be seen that the minimum values are registered in Dfc class and the maximum ones in Csa, as expected. Nevertheless, BSk, Cfa and Csb have very similar *DBT* averages, as well as Cfb and Dfa. The same can be observed for *WVP* (in BSk, Cfb and Dfa) and for *GHI* (respectively for BSk and Csa and for Cfb and Dfb). Analyzing the spread, a larger variability is found. Csb has the smallest spreads for *DBT* (11.7 °C) and for *WVP* (670 Pa), which are less than half of those observed for Dfa (23.3 °C) and Cfa (1398 Pa), respectively. The spread of *GHI* is quite homogeneous in all the different classes, ranging from 140 to 175 kWh m^{-2}.

Looking at Table 5, it can be noted that Dfa is the most homogenous class, while for the others high values of standard deviations can be observed. In particular, considering the annual averages, standard deviations are often larger than 1 °C for *DBT* and 10 % for *WVP* while better homogeneity is registered for *GHI*. Comparing the standard deviations of averages and spreads, the latter can be seen as affected by larger variability within classes.

Table 4. Annual averages and spreads for the Köppen-Geiger Classes of the dataset of European climates. In red the maximum values and in blue the minimum ones.

	Quantity	**BSk**	**Cfa**	**Cfb**	**Csa**	**Csb**	**Dfa**	**Dfb**	**Dfc**
Annual Average	*DBT* [°C]	13.5	13	10.2	16.4	13.1	10.7	7.4	2.4
	WVP [Pa]	941	1229	1005	1337	1130	1053	863	638
	GHI [kWh m^{-2}]	131	100	86	133	122	110	84	69
Annual Spread	*DBT* [°C]	18.5	21.4	14.8	16.3	11.7	23.3	21.1	21.6
	WVP [Pa]	730	1398	866	1141	670	1278	1057	889
	GHI [kWh m^{-2}]	173	162	143	170	162	164	150	157

Table 5. Standard deviations of annual averages and spreads for the Köppen-Geiger Classes of the dataset of European climates. In red the maximum values and in blue the minimum ones.

	Quantity	**BSk**	**Cfa**	**Cfb**	**Csa**	**Csb**	**Dfa**	**Dfb**	**Dfc**
Annual Average	*DBT* [°C]	1.7	1	1.8	1.6	2	0.7	1.5	2.3
	WVP [%]	11.9	6.9	10.3	13.1	23.9	4.9	7.7	13.8
	GHI [%]	2.7	5.7	12.7	10.6	9.1	6.8	8.8	8.7
Annual Spread	*DBT* [°C]	1.3	2.8	2.5	2.2	4.2	1.4	2.2	6.3
	WVP [%]	10.9	10	17.9	28.8	24.8	7.5	9.9	23.3
	GHI [%]	6.3	8.7	7.4	4.9	7.4	3.2	6.7	7.1

3.2 Definition of the new climatic classification

The hierarchical clustering for *DBT*, *WVP* and *GHI* identified about 5 major groups of climates. The only exception is the clustering according to *DBT*, in which the boreal climate of Kiruna (city 28, in Sweden) has been isolated from the rest of the climates. The dendrogram for *DBT* is showed in Figure 3 as an example. In order to represent in a more straightforward way the climatic zones, they are highlighted in Figures 4-6 on a map. As observed in the dendrograms and in the maps, there is quite an overlapping between the zones obtained with the three hierarchical clusterings. Considering the *DBT* classification, we can distinguish, besides (1) Kiruna climate, (2) the cold Scandinavian, Russian and Icelandic climates, (3) the eastern European climates and those of the countries wetted by the North and the Baltic Seas, (4) the western European climates and the continental Balkans, (5) the warm Mediterranean and Atlantic climates and (6) the hot Mediterranean climates. *WVP* classification is very similar to the *DBT* one. However, some dry Iberic and Anatolian climates are isolated from the surrounding regions. Eventually, the last classification according to *GHI* is generally correlated with the latitude, with some exceptions due to specific meteorological phenomena (e.g., Sofia and Bilbao).

The closeness among the classifications generated with the three annual average quantities has been detected also by means of Spearman correlation tests. Spearman ρ resulted equal to 0.91 between *DBT* and *WVP*, 0.89 between *DBT* and *GHI* and 0.73 between *GHI* and *WVP*. Since ρ is larger than 0.7 for all pairs, the correlations are considered strong: as a consequence, if the annual averages are employed for clustering only one out of those three is sufficient. On the contrary, the same test applied to the spread highlights a certain level of independence of *GHI* with respect to the other quantities (ρ equal to 0.43 between *DBT* and *WVP*; 0.23 between *GHI* and *DBT*; and 0.16 between *GHI* and *WVP*).

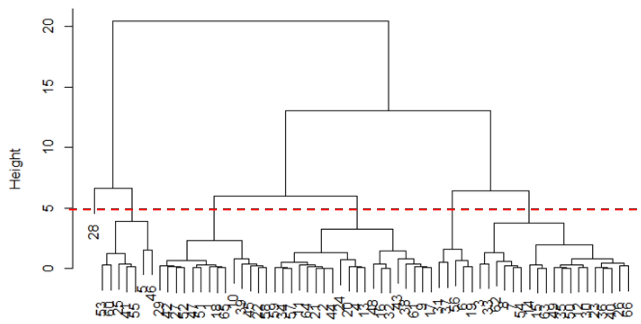

Figure 3: Dendrogram for *DBT* hierarchical clustering. The meaning of the city numbers is indicated in Table 3.

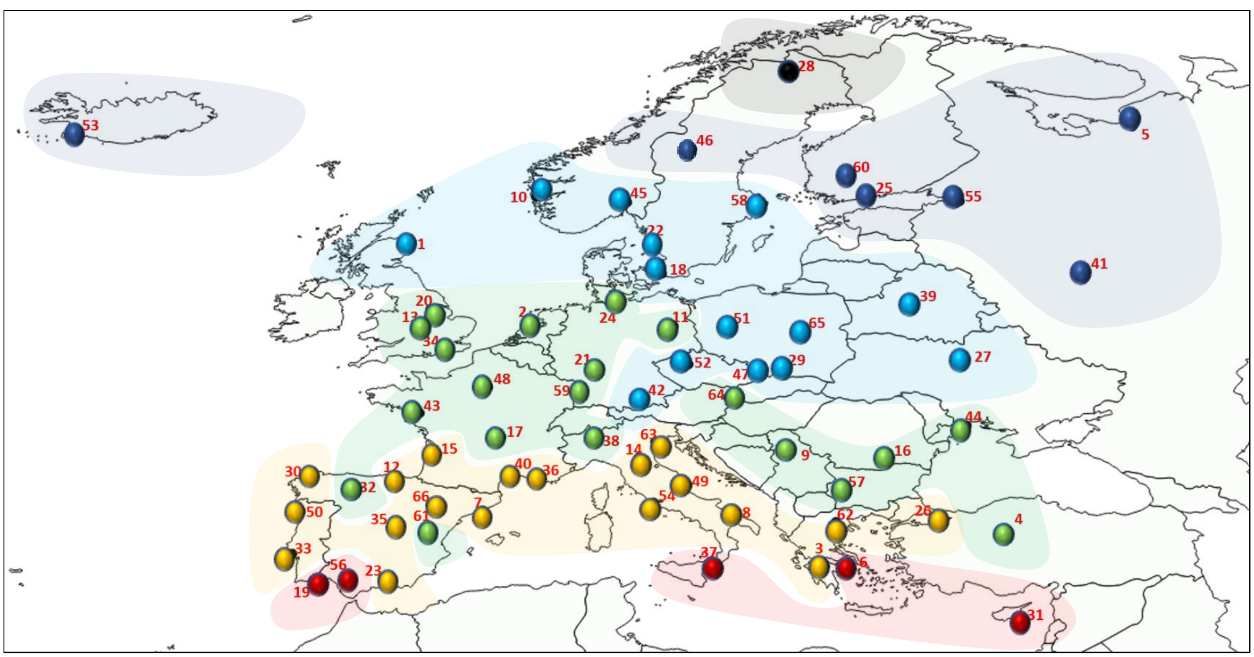

Figure 4: Climatic classification according to *DBT* (Class 1: black; Class 2: dark blue; Class 3: light blue; Class 4: green; Class 5: yellow; Class 6: red).

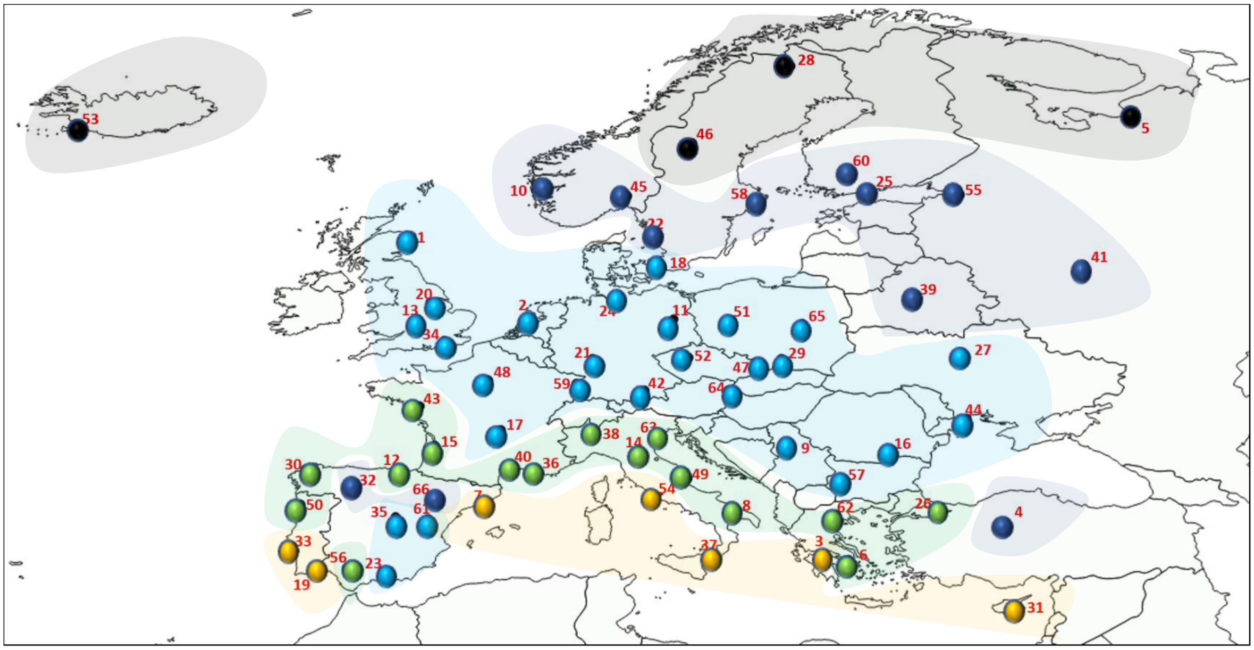

Figure 5: Climatic classification according to *WVP* (Class 1: black; Class 2: dark blue; Class 3: light blue; Class 4: green; Class 5: yellow).

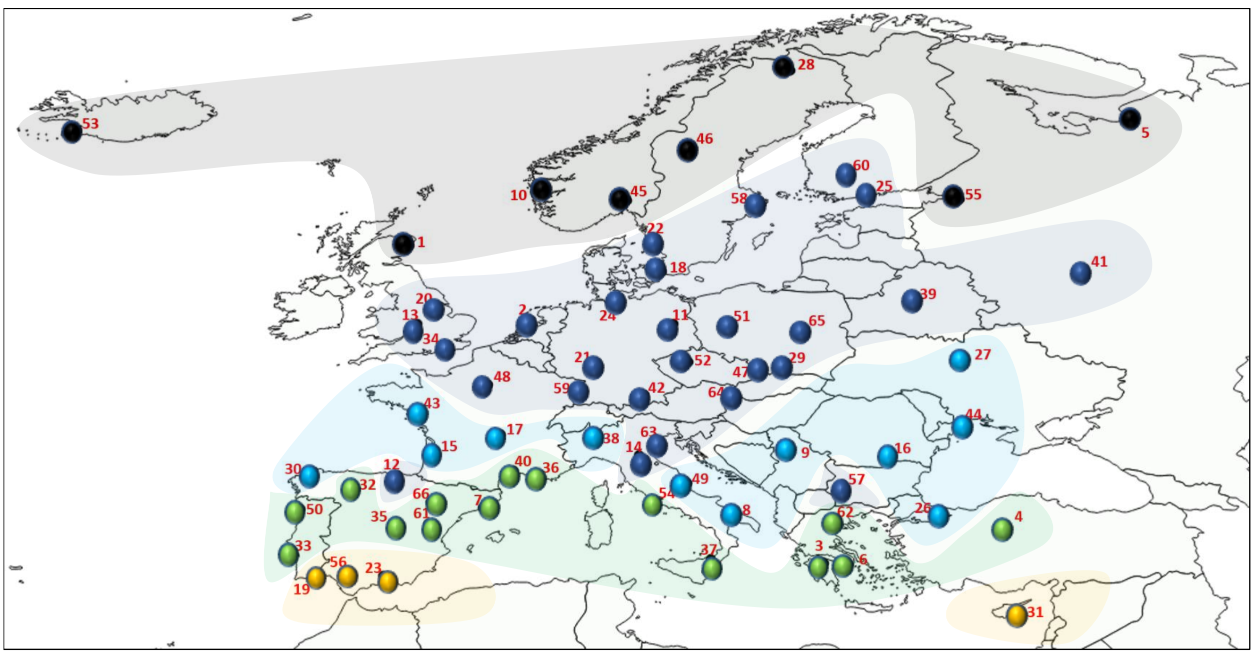

Figure 6: Climatic classification according to *GHI* (Class 1: black; Class 2: dark blue; Class 3: light blue; Class 4: green; Class 5: yellow).

If compared to the Köppen-Geiger system, the maps present several similitudes, especially the one in Figure 4. Nevertheless, they are simpler and with a lower number of sub-classes for southern Europe. Considering all above, the clustering according to *DBT* is selected for further investigations.

3.2.1 Homogeneity of the new classes: Analyzing the annual averages and spreads for the new classes (Figure 7, top), it can be concluded that the differences among the new classes are stronger while the spread is more homogeneous also for *DBT* and *WVP*. As shown in Figure 7 (bottom), standard deviations for averages are reduced for *DBT* and *WVP* while they have been worsened for *GHI*. As regards standard deviations for spreads, they improved for *DBT*, stayed almost the same as for the Köppen-Geiger system for *GHI* but they worsened for *WVP*.

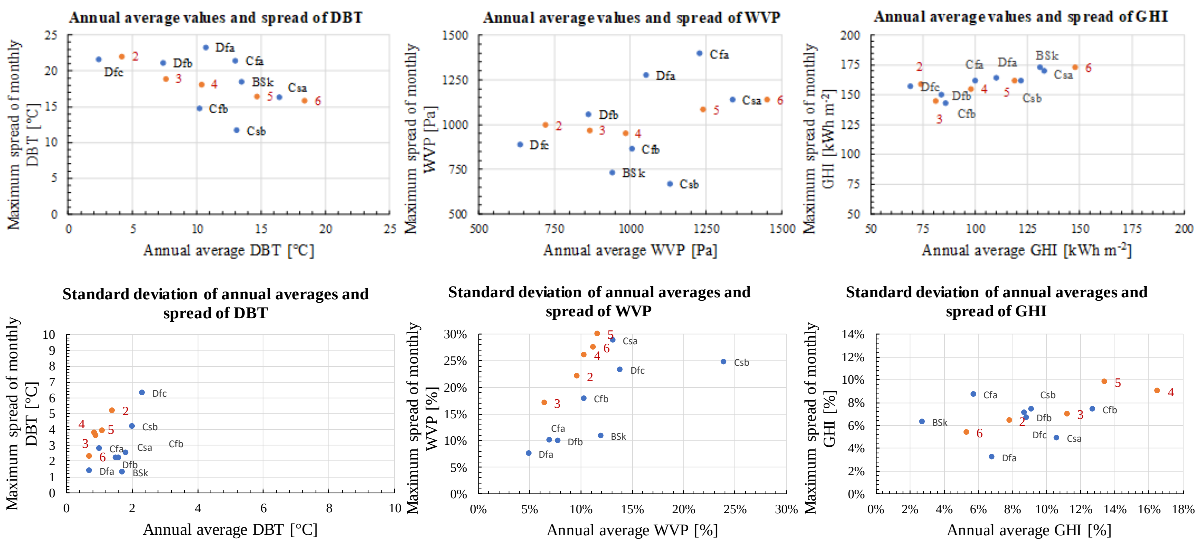

Figure 7: Annual values (top) and standard deviations (bottom) for *DBT*, *WVP* and *GHI*. In blue the Köppen-Geiger classes and in orange the new ones.

3.2.2 Sub-clustering: Due to the worsening of homogeneity in terms of *GHI* parameters for classes 3, 4 and 5, considering their sizes, it has been decided to operate a sub-clustering according to *GHI* in the perspective of generating more homogeneous groups for the selection of representative cities. For class 3, the cities of Kiev, Ukraine, and Munich, Germany, have been identified as outliers and, consequently, discarded from Kolmogorov-Smirnov tests. In class 4, the northernmost localities have been separated from the southernmost ones (e.g., Ankara in Turkey, Belgrade in Serbia, Bucharest in Romania, Leon and Teruel in Spain, Milan in Italy). Because of its lower solar irradiation, as highlighted also in Figure 6, Sofia has been aggregated to the northernmost localities. Finally, in class 5 the sub-clustering brought to separate the Atlantic cities on the Bay of Biscay and the Adriatic regions from the rest of the group. Furthermore, Grenada, Spain, has been highlighted as outlier with respect to class 5, having a *GHI* closer to that typical of class 6.

The updated map with the new climatic sub-classes has been depicted in Figure 8. As a whole, after *GHI* sub-clustering, standard deviations have generally been reduced, even if for some classes with a limited number of cities, the standard deviation of *WVP* is still large.

3.3 Selection of representative cities

None of the Kolmogorov-Smirnov tests resulted statistically significant, confirming that the classification has been able to generate groups with homogeneous annual profiles of *DBT*, *WVP* and *GHI*. The most representative cities are:

- Class 2: Ostersund (Sweden, **Dfc**);
- Class 3: Prague, Ostrava (Czech Republic) or Poznan (Poland), all of them geographically close and characterized by very similar climates (**Dfb**);
- Class 4a: Strasbourg (France, **Cfb**);
- Class 4b: Belgrade (Serbia) or Bucharest (Romania), both belonging to class **Dfa** and representative of Balkans climates. Nevertheless, the number of localities in class 4b is very low and those are quite different each other. For analyses in the Italian and Spanish zones in class 4b (Cfa and Cfb according to Köppen-Geiger), the use of these cities is not recommended;
- Class 5a: Marseille (France, **Csa**);
- Class 5b: Pescara (Italy, **Cfa**). The same consideration drawn for class 4b applies also to class 5b: for specific analyses on the Bay of Biscay, the adoption of this city as reference is discouraged;
- Class 6: Sevilla (Spain), Messina (Italy) or Larnaca (Cyprus), all of them in Köppen-Geiger class **Csa**.

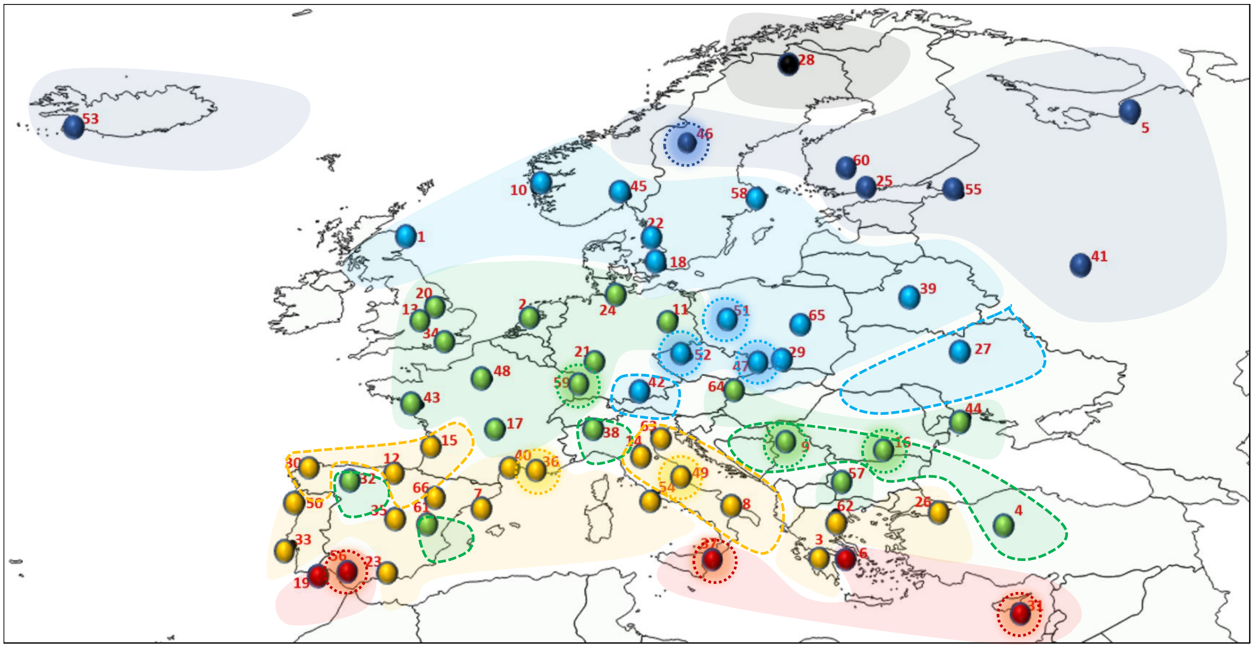

Figure 8: Climatic classification with sub-classes and with representative cities (Class 1: black; Class 2: dark blue; Class 3: light blue; Class 4: green; Class 5: yellow).

6. CONCLUSIONS

In this preliminary work, we analyzed the European climates with the aim of identifying those cities which can be taken as representative in order to allow for robust generalization of building energy simulation findings. To achieve this goal, we discussed the applicability of the most popular climate classification worldwide, the Köppen-Geiger system, which was developed starting from dry bulb temperature and precipitation data and has mainly an ecological perspective. To discuss the topic, a set of 66 European climates were considered and analyzed, both in terms of annual averages and spread among the monthly mean or integral values of dry bulb temperature, water vapour partial pressure and global horizontal irradiation. By means of hierarchical clustering and considered the cross-correlation among climatic parameters, a new classification has been developed based on dry bulb temperature as primary variable and global horizontal irradiation as secondary one. The proposed climatic classes resulted similar to those by Köppen-Geiger but simpler, lower in number, and more homogeneous, facilitating the selection of representative cities through Kolmogorov-Smirnov tests on monthly values.
Further developments are expected to include more climates as inputs, in order to assess more in details the critical aspects identified for sub-classes 4 and 5. Moreover, weekly instead of monthly values, will be considered for the selection of representative months.

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