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Influence of Input Climatic Data on Simulations of Annual Energy Needs of a Building: EnergyPlus and WRF Modeling for a Case Study in Rome (Italy)

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Abstract: The simulation of the energy consumptions in an hourly regime is necessary in order to perform calculations on residential buildings of particular relevance for volume or for architectural features. In such cases, the simplified methodology provided by the regulations may be inadequate, and the use of software like EnergyPlus is needed. To obtain reliable results, usually, significant time is spent on the meticulous insertion of the geometrical inputs of the building, together with the properties of the envelope materials and systems. Less attention is paid to the climate database. The databases available on the EnergyPlus website refer to airports located in rural areas near major cities. If the building to be simulated is located in a metropolitan area, it may be affected by the local heat island, and the database used as input to the software should take this phenomenon into account. To this end, it is useful to use a meteorological model such as the Weather Research and Forecasting (WRF) model to construct an appropriate input climate file. A case study based on a building located in the city center of Rome (Italy) shows that, if the climatic forcing linked to the heat island is not considered, the estimated consumption due to the cooling is underestimated by 35–50%. In particular, the analysis and the seasonal comparison between the energy needs of the building simulated by EnergyPlus, with the climatic inputs related to two airports in the rural area of Rome and with the inputs provided by the WRF model related to the center of Rome, show discrepancies of about (i) WRF vs. Fiumicino (FCO): $\Delta = -3.48\%$ for heating, $\Delta = 49.25\%$ for cooling; (ii) WRF vs. Ciampino (CIA): $\Delta = -7.38\%$ for heating, $\Delta = +35.52\%$ for cooling.

Keywords: energy building analysis; EnergyPlus; weather research and forecasting model; climate data; urban heat island

1. Introduction

The residential building sector accounts for a significant share of energy consumption in each industrialized country, with percentages that exceed one-third of total energy needs. In the more developed countries, the annual amount of energy that air conditioning requires, both for winter and summer, is the most important item of these needs [1]. The process of optimizing the energy consumption of a fragmented sector, such as that of private construction, is not simple to implement. The drive to reduce consumption undertaken in the last three decades could hardly happen spontaneously from below, thanks to an impulse coming directly from the multiplicity of small owners involved.

In Europe, a unified regulatory effort coordinated by the European institutions was necessary [1–3]. These regulations were implemented by the legislation of the European Union countries [4], with the drafting of detailed regulations also at regional and municipal levels, in line with the peculiarities of each geographic area involved. In global terms, therefore, regulatory intervention was carried out from the top (European institutions) to the bottom (individual local institutions). This process took time, but managed to raise awareness among the stakeholders and to stimulate interventions aimed at improving the energy efficiency of building envelopes and systems.

The first step in implementing energy optimization measures on buildings is to analyze their primary energy requirements [5,6]. To this end, technical regulations were issued standardizing the calculation procedures [7–12]. The latter reference allows the assessment of energy needs by introducing some simplifying assumptions, such as expressing the climatic forcing as a function of monthly average data [13,14]. It is necessary to consider the consequence of this simplification on the energy performance of the building, which is influenced by construction characteristics (i.e., technical properties of the enclosure and of the systems [15,16]), and especially by the climatic zone [17].

Depending on the purpose of the energy analysis, and on the importance and complexity of the building, the legislation allows the use of simplified calculation methods or not. In cases where such simplified methods cannot be applied in the quantification of the annual primary energy needs for air conditioning and production of domestic hot water, the legislation requires the use of a software able to simulate the behavior of the "building/plant" system in a dynamic regime [18]. These simulations involve a greater planning effort and a deep knowledge of all the parameters influencing the results. Dynamic calculations are based on input climate data with an hourly frequency, since this time step is considered satisfactory for an annual simulation of the transient thermal behavior of a building. In this way, it is possible to perform a simulation as precise as possible of the energy behavior of the building during a whole standard year [19].

Designers called to perform such calculations must be aware of the importance of using climatic data as close as possible to reality. Usually a great deal of attention is spent on the faithful reconstruction of the building geometry, the description of the thermo-physical properties of materials composing its enclosure [20], and the definition of the energy parameters of the installations serving the building [21]. On the other side, little attention is paid to the implications of climate data on the energy performance. In this regard, one of the first parameters that must be implemented in the software concerns the geographical location of the building, selected by the user. The corresponding climatic database represents a typical year elaborated from data acquired at airport sites near the selected city, because airport sites usually have historical databases. Since airport databases are not representative of the conditions within a big metropolitan area, this approach introduces approximations that can weigh on the quality of the simulation output, albeit theoretically correct.

In the analysis of the energetic behavior of a building located in an urban area (strongly anthropized and with limited green areas), it is necessary to take into account the phenomenon of the urban heat island [22,23]. An urban heat island [24] is defined as the temperature anomaly observed over urban areas with respect to the suburbs [25] and is due to significant changes that urbanization brings to Earth's surface [26]. It heavily affects the local microclimate, influenced by the solar radiation absorbed and retained by traditional construction materials (e.g., cement and asphalt) [27] and released in the form of infrared radiation [28,29]. All this worsens the conditions under which buildings are subjected during the summer, increasing their energy needs; on the other hand, the contribution of the urban heat island effect on the mitigation of the outside temperature during the cold season often does not counterbalance the major energy needs required by the cooling systems during the hot season [30].

Bhandari et al. [31] stressed the importance of having accurate weather files in order to evaluate the actual energy needs with adequate accuracy for buildings analyzed through predictive simulations. Furthermore, in a case study, they found uncertainties up to 90% in the computation of the primary energy. Wang et al. [32] found that the inaccuracies of the weather inputs provided to the models for this type of energy analysis can lead to fluctuations on the order of 10% in the expected annual consumption. These fluctuations can reach 32% according to Andolsun et al. [33].

In order to have more precise predictive simulations, Mustafaraj et al. [34] suggested (when strictly necessary) the use of weather files obtained with data sampled through weather stations placed on site to be included as input to the calculation model. According to Chan [35], the construction of suitable weather files from urban experimental campaigns could be the only method used to calculate energy consumption for buildings subject to the effects of the urban heat island.

In this context, approximations introduced using non-realistic input climate databases is unacceptable for those who need to perform precise calculations and who, for this reason, use a dynamic computation. This would lead to the need for a climate database taking into account these problems, i.e., data sampled within the urban fabric. Often, this solution is not easily achievable due to the difficulty in obtaining such data [36].

This paper aims to be a first approach to the analysis of this problem [37]. The case study of a building located in the (urban) center of a big city was, therefore, considered to investigate the relevance of the climate database used as input for the transitory regime computation of its energy needs [38]. The impact of the choice of a database compared to another was assessed, underlining the need for robust and realistic climate data to ensure an adequate degree of accuracy [39]. To do this, we analyzed the differences in the annual energy performance of the simulated building that arose from using (i) climate data sampled at different airport sites located near the city of Rome (Fiumicino (FCO) and Ciampino (CIA)); and (ii) input climate data sampled in rural areas compared to the city center (characterized by the heat island phenomenon).

2. Modeling Tools

In this work, the EnergyPlus (National Renewable Energy Laboratory (NREL) and U.S. Department of Energy's (DOE), Washington, D.C., U.S.A.) calculation software and the Weather Research and Forecasting (WRF) model were used.

The energetic analysis carried out here can be conducted through various building energy simulation (BES) software, such as DOE-2, EnergyPlus, ESP-r, IDA ICE, IES VE, BLAST, BSim, DeST, EcoTect, Ener-Win, Energy Espress, Energy-10, eQUEST, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE, and TRNSYS [40,41]. However, EnergyPlus is a building energy simulation program recognized by the international scientific community as one of the most comprehensive and detailed computer tools for calculating the thermal behavior of the buildings in a transitory regime [40–42], and the quality of the calculations made by this software is certified by the United States (US) Deparment of Energy (DOE) [43] and by the Pacific Northwest National Laboratory [44], who conducted numerous calibrations and checks on the quality of the results. For this reason, EnergyPlus found wide use in many scientific works [45–47]. Weather data for over 2100 locations (of which 1042 are in the United States, 71 are in Canada, and over 1000 are in 100 countries around the world) are available on the EnergyPlus website [48]. Through this software, the energy needs of a typical building located in the center of Rome (Italy) were estimated. The building was made with a three-dimensional (3D) model designed to characterize its geometry. This geometry was subsequently provided thanks to the OpenStudio computer tool, where the physical parameters characteristic of the thermal zones (in particular, the temperature inside the rooms) were defined within the volume constructed. Subsequently, this file was imported into EnergyPlus, where all the parameters relating to the energy simulation of the building were defined. The characteristics of the envelope (e.g., dimensions, materials, and physical characteristics of the opaque and transparent surfaces of the building), of the present systems, etc. were then defined. In this phase, the annual climate files (often related to airport areas around the city) providing the boundary conditions for the building were selected from the EnergyPlus database with hourly frequency.

The WRF model was designed to be a portable code that is efficient in a massively parallel computing environment. It is suitable for use in a broad spectrum of applications across scales ranging from meters to thousands of kilometers. Such applications include research, operational numerical weather prediction, downscaling climate simulations, and idealized simulations (e.g., boundary-layer eddies and convection) [49]. WRF development started in the 1990s thanks to a collaboration between the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration, and other US institutions. It is based on fully compressible, Euler non-hydrostatic equations, while, in atmospheric applications on large scales, some simplifications in the momentum equation for the vertical component of the velocity lead to the hydrostatic equation. The spatial discretization for the variables in WRF is based on a staggered Arakawa C type: the velocity components are staggered one-half grid length from the thermodynamic variables [49]. The detailed description of the WRF model is beyond the scope of this paper. Information on the scientific and algorithmic approaches (e.g., available physics options, boundary conditions, and grid-nesting techniques) are contained in NCAR's technical notes. In this study, the WRF model was used to simulate the urban heat island [50] in Rome.

Thanks to the coupling between WRF and EnergyPlus, the energy performance computed for the same building using climate databases provided for Rome by EnergyPlus (relating to the two main airports) and data obtained throughout WRF runs (related to the city center) were compared. These differences were also expressed in percentage terms in order to quantify the effect of the climate database on the calculations, considering the approximation introduced using climate files that do not comprise the urban heat island.

This approach, based on a case study in the city of Rome, can also be applied in other metropolitan areas where the extension of cities and the changes in the thermophysical properties of large areas of the land are due to urbanization, contributing to the formation of urban heat islands.

3. The Case Study

To assess the impact of the input climate database on the annual energy performance computed in a transitory regime, a building was designed representing a normal civil residence in Rome built according to construction standards of the early 2000s [51]. It was a building constructed according to traditional techniques that partially take into account the requirements of energy saving for the building envelope, but with margins of improvement both on the performance of the envelope and on the existing plant. To this end, a building placed on a pilot plan, consisting of three floors with three apartments for each floor, was assumed. The staircase was equipped with a lift, acting as a divider for each floor between an isolated apartment and two apartments side by side. A walkable terrace was hypothesized as a roof of the building. The plan of one floor and the 3D model of the stable interior are shown in Figure 1.

For each floor, the internal surface was equal to 320.4 m^2, of which 261.2 m^2 was air-conditioned both during the winter period (heating) and during the summer period (cooling). The total internal area of the building was 1021.44 m^2, of which 783.24 m^2 was air-conditioned. The net height of each floor was 2.8 m, for a total internal volume of 3063.6 m^3, of which 2192.2 m^3 was air-conditioned.

The surface areas (m^2) and the orientation of the boundary surfaces of the building are described in Table 1. The stratigraphy of the boundary surfaces, together with their thermo-physical properties, are described in Table 2.

Table 1. Geographical orientation, and the type and area of the boundary surfaces of the air-conditioned rooms of the building.

Orientation	Type	Surface Area (m^2)
North	Opaque	258.6
	Glass	74.7
East	Opaque	111.6
	Glass	10.8
South	Opaque	184.5
	Glass	120.3
West	Opaque	81.0
	Glass	10.8
Horizontal	Attic	362.3

Table 2. Stratigraphy of the boundary surfaces of the air-conditioned rooms of the building.

Type	Stratigraphy *					Transmittance **
	Material	Thickness	Thermal Conductivity	Density	Thermal Capacity	U
		(m)	($W{\cdot}m^{-1}{\cdot}K^{-1}$)	($kg{\cdot}m^{-3}$)	($J{\cdot}kg^{-1}{\cdot}K^{-1}$)	($W{\cdot}m^{-2}{\cdot}K^{-1}$)
Opaque	Plaster	0.01	0.800	100.00	1000.00	0.656
	Hollow brick	0.15	0.159	693.30	840.00	
	Polyurethane	0.08	0.032	32.00	1400.00	
	Hollow brick	0.15	0.159	693.30	840.00	
	Plater mortar	0.01	0.290	600.00	1000.00	
Coverage	Tiles	0.015	1.300	2300.00	840.00	0.263
	Tar paper	0.002	0.230	1100.00	1000.00	
	Concrete	0.05	0.300	1000.00	1000.00	
	Polyurethane	0.08	0.034	25.00	1400.00	
	Concrete	0.33	0.300	1000.00	1000.00	
	Plaster	0.1	0.400	1000.00	1000.00	
Attic	Tiles	0.015	1.300	2300.00	840.00	0.343
	Concrete	0.33	0.186	400.00	1000.00	
	Polyurethane	0.08	0.034	25.00	1400.00	
	Concrete	0.05	0.300	1000.00	1000.00	
	Aluminum	0.002	160.00	2800.00	880.00	

* Materials are listed from the inside to the outside; ** total heat transfer coefficients: k_i = 10 $W{\cdot}m^{-2}{\cdot}K^{-1}$; k_e = 25 $W{\cdot}m^{-2}{\cdot}K^{-1}$.

In the simulations performed with EnergyPlus, the annual requirements were simulated for (i) the heating with radiators of the apartments and the production of domestic hot water obtained through a condensing boiler (powered by natural gas, with a heating output of 15 kW, a useful return at 100% of the nominal power equal to 104.8%, and a useful return at 30% of the nominal power equal to 107.2%); and (ii) summer cooling through direct expansion split systems (coefficient of performance (COP) = 3.1).

Ventilation of inhabited spaces is natural, with hypothesized air changes equal to 0.5 hourly volumes. The internal heating sources to the building hypothesized according to the regulations were assumed equal to 38 $W{\cdot}m^{-2}$.

Data on the boundary conditions [52] used in the energetic analysis are summarized in Table 3.

Table 3. EnergyPlus boundary condition data for the case study's building.

	Unit	Value
Heating set-point	°C	20
Cooling set-point	°C	26
Sensible heat gain from people	$W \cdot person^{-1}$	70
Latent heat gain from people	$W \cdot person^{-1}$	45
Air change rate (volume per hour)	$m^3 \cdot h^{-1}$	0.5

Figure 1. Plan of one floor and a three-dimensional (3D) model of the building analyzed.

Furthermore, the EnergyPlus set-up includes the Slab EnergyPlus Ground Coupling Auxiliary Model [33,53].

Rome (41° 53′35′ N; 12° 28′58′ E) is a city characterized by a very large territory area of 1287.36 km^2. It is the largest municipality in Italy and one of the largest among the European capitals. The population growth in Rome progressed exponentially in the last century, and consequently, as did urban expansion. The front of the city, in continuous progress, led to the development of extensive suburban areas that accentuated the phenomenon of the heat island. Rome enjoys a typical Mediterranean climate with mild and warm temperatures during the spring and autumn. The summer season is usually hot and humid, and characterized by low rainfall, while the winter tends to be mild and rainy with isolated severe weather events that give rise to low temperatures and snowfall. Most precipitation occurs in the spring and autumn, especially during the months of April and November. According to the Köppen–Geiger classification, the climate of Rome belongs to the Csa category [54,55].

For the city of Rome, the EnergyPlus user can choose in the website among the data sampled in the following airports (Figure 2):

- Fiumicino (41° 48′01″ N; 12° 14′20″ E), an intercontinental airport located in the Municipality of Fiumicino, about 25 km west from the city center of Rome. It is surrounded to the north by cultivated fields, to the east by light wooded hills, to the south by an inhabited area rich in green areas, and to the west by the Tyrrhenian Sea.
- Ciampino (41° 47′58″ N; 12° 35′50″ E), an airport about 16 km southeast of the center of Rome, partly in the territory of Rome and partly in the territory of the Municipality of Ciampino. It is surrounded by an agricultural area to the west and by the city of Ciampino on the remaining three sides.

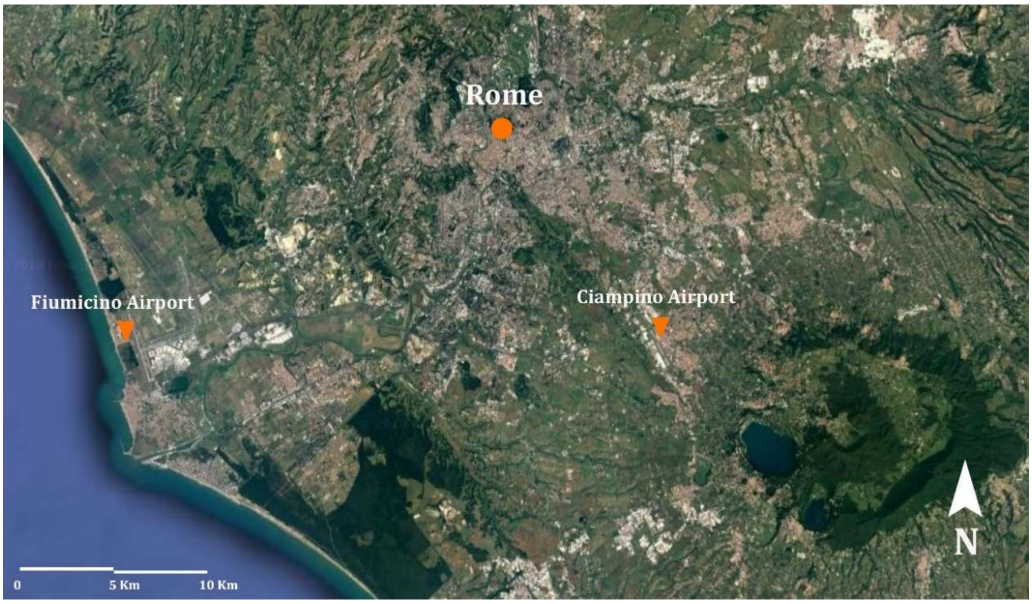

Figure 2. Aerial photo of the Rome metropolitan area and locations of the airports of Fiumicino and Ciampino.

In this study, the choice of the city of Rome allowed the verification of differences in the energy performance of the building analyzed according to the climate database used, as EnergyPlus supplies climate files for two locations. The two airport sites have slightly different climatic characteristics and are not affected by the urban heat island effect. Since this phenomenon influences the climate data employed by EnergyPlus for the calculation of the energy performance of buildings, the WRF model was used for the creation of an input climate file taking into account the built environment of the city. Previous works demonstrated the ability of the WRF model to simulate idealized and real urban heat islands [56,57].

4. Analysis of Climatic Inputs and Evaluation of the WRF Model

Before carrying out the energy simulations of the building described in the previous section, an analysis of the climatic data provided in the official EnergyPlus page for the two airports was carried out.

Data on the dry-bulb air temperature (TBA) and relative humidity were analyzed and plotted for the 8760 h of a standard year (Figure 3). Moreover, for the TBA, the monthly averages were computed and are shown on the graph in Figure 4.

This analysis shows that data relative to Fiumicino and Ciampino are consistent, with slight differences due to their different geographical positions and the different orography of the surrounding land.

In order to generate the input weather file representing the conditions in the center of Rome, focused runs were performed with the WRF model. WRF performances were evaluated before the production of the input file for EnergyPlus (starting from the output of WRF).

The WRF geographic configuration used for this study consisted of three nested domains covering Europe, Italy, and an area in central Italy, with an increasing resolution from 36 km to 4 km. The geographical areas and the land use of the innermost domain are shown in Figure 5, while the number of cells of each domain, together with the resolution, is shown in Table 4. The vertical grid had 33 levels for all domains, with the lowest one at about 23 m and the top at 50 hPa.

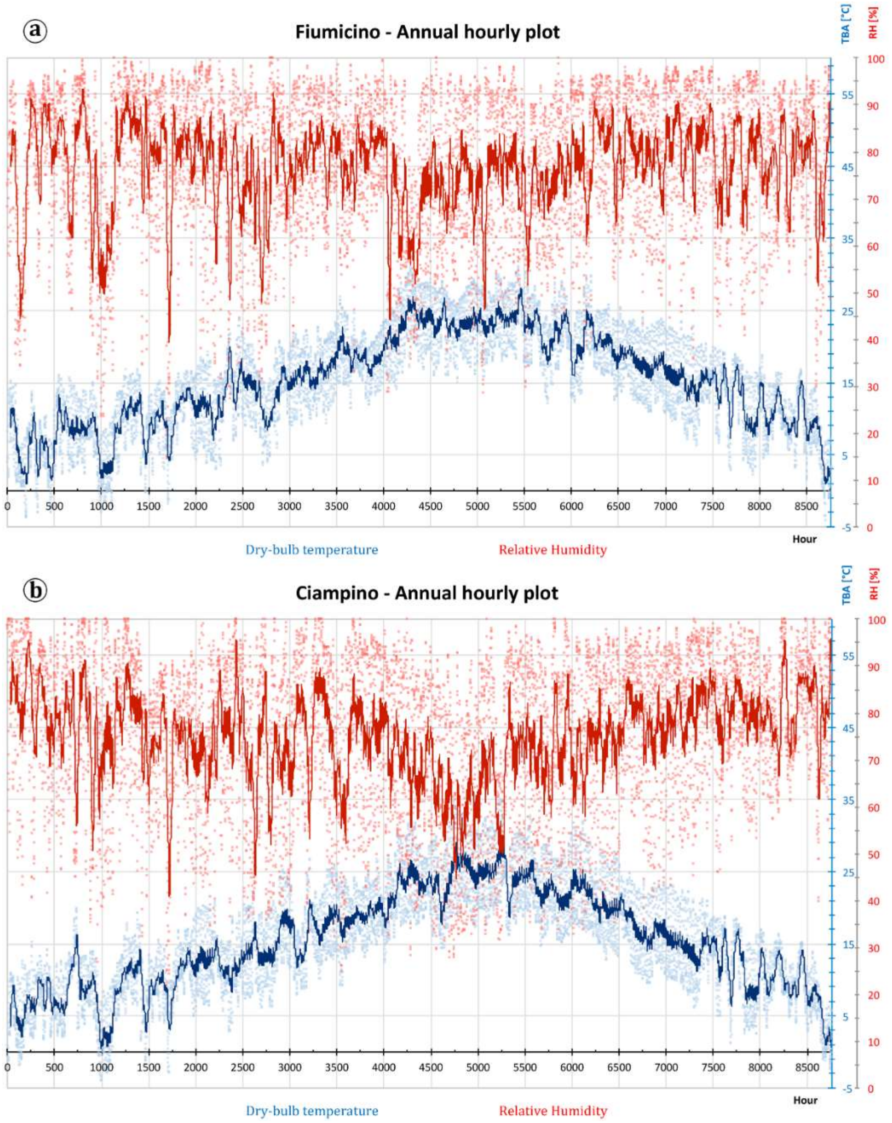

Figure 3. Annual time series of hourly dry-bulb temperature (TBA (°C)) and hourly relative humidity (Ur (%)). Mean (solid lines) and hourly (dotted lines) values are shown. Data were sourced from climate files provided by the EnergyPlus database for Rome, and correspond to the airports of (**a**) Fiumicino, and (**b**) Ciampino.

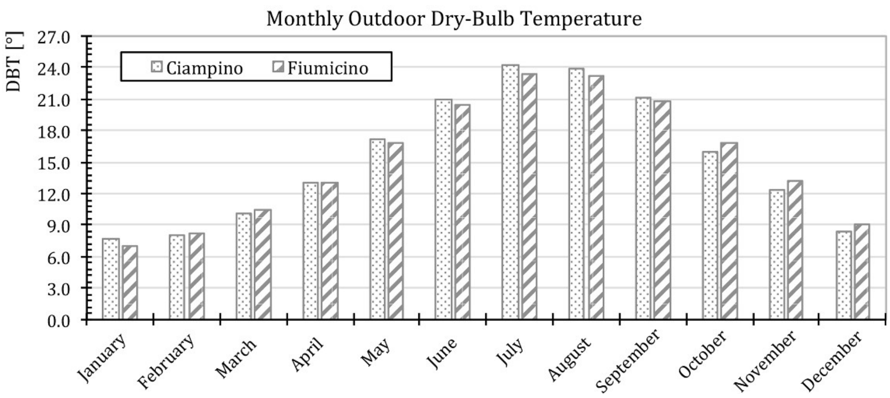

Figure 4. Monthly dry-bulb temperature (TBA (°C)). Data were sourced from climate files provided by the EnergyPlus database for Rome, and correspond to the airports of Fiumicino and Ciampino.

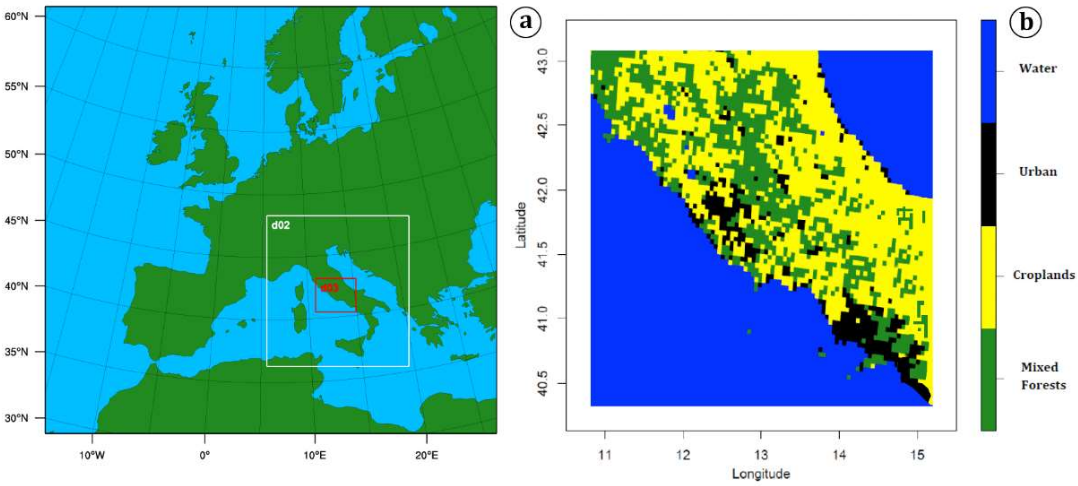

Figure 5. Weather Research and Forecasting (WRF) model domains: (**a**) geographical areas; and (**b**) land-use categories from the moderate resolution imaging spectroradiometer (MODIS) dataset in the innermost domain.

Table 4. Simulation domains for numerical experiments with the Weather Research and Forecasting (WRF) model.

Domain	Geographical Area	Resolution (km)	Cells (Longitude × Latitude)
d01	Europe	36	108 × 102
d02	Italy	12	102 × 108
d03	Central Italy	4	87 × 72

Further details about the method and the physical options can be found in the article by Falasca and Curci [57,58].

Figure 6 shows the comparison between the results of the WRF runs and the observations provided by two urban weather stations in Rome, for a winter month (January) and a summer month (July). Results confirm that the performances of the model were definitely better for the temperature compared to the wind speed intensity, and that the best performances were in the summer for both variables.

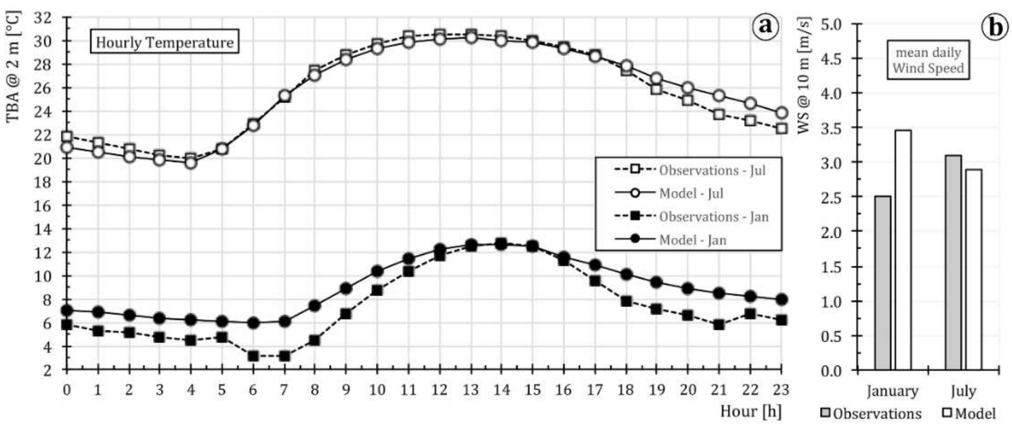

Figure 6. WRF evaluation. Daily cycles of temperature (°C) and of averaged wind speed (m/s) in the urban area of Rome for January and July 2012: (**a**) 2-m temperature; and (**b**) 10-m wind speed.

The standard deviation calculated between modeled and observed values of TBA was equal to 0.44 °C for the month of July and 0.89 °C for the month of January. These results ensured the accuracy of the WRF model, and thus, determined an acceptable approximation for the subsequent energy calculations based on the obtained meteorological inputs.

The following variables were extracted from the WRF output to create the input file for EnergyPlus: dry-bulb temperature, dew-point temperature, relative humidity, atmospheric pressure, and wind speed and direction. Some of these data are shown in Figure 7 for a visual comparison with the Fiumicino and Ciampino airports.

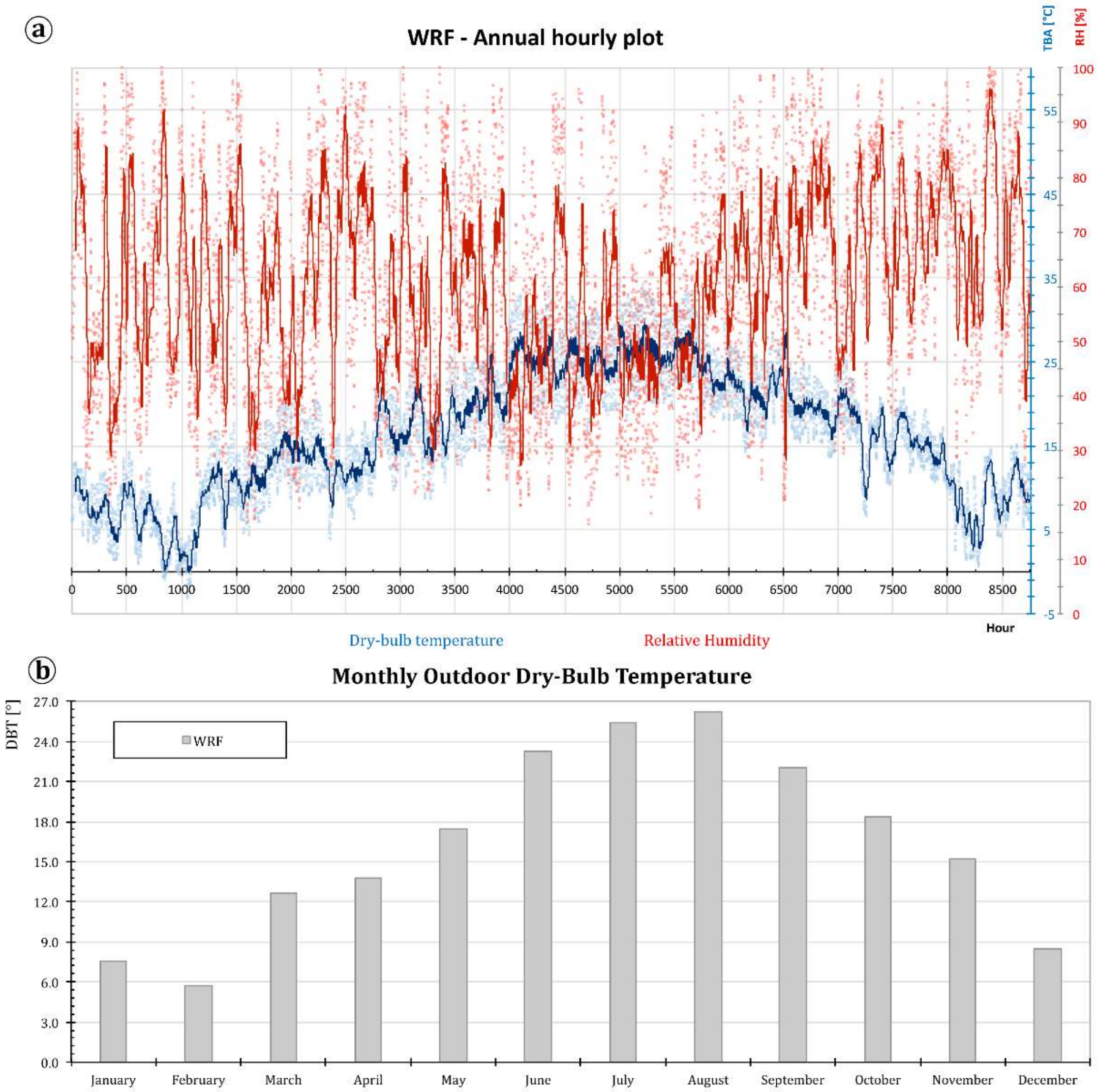

Figure 7. WRF data in the city of Rome: (**a**) time series of hourly dry-bulb temperature (TBA (°C)) and hourly relative humidity (Ur (%)); mean (solid lines) and hourly (dotted lines) values are shown. (**b**) Monthly dry-bulb temperature (TBA (°C)).

5. Analysis of Energy Needs

EnergyPlus simulations were performed using the three different climate files available as input. The hourly energy performance of the studied building was analyzed and plotted monthly for the entire year. These data took into account the characteristics of the plants and their energy efficiency; therefore, the outputs represent the primary energy requirements of the entire "building/plant envelope" system. Figure 8 shows the energy consumption expressed in J on a bar graph: the energy requirements for heating were met by burning methane gas and those for cooling were met using the electrical energy of the city distribution network.

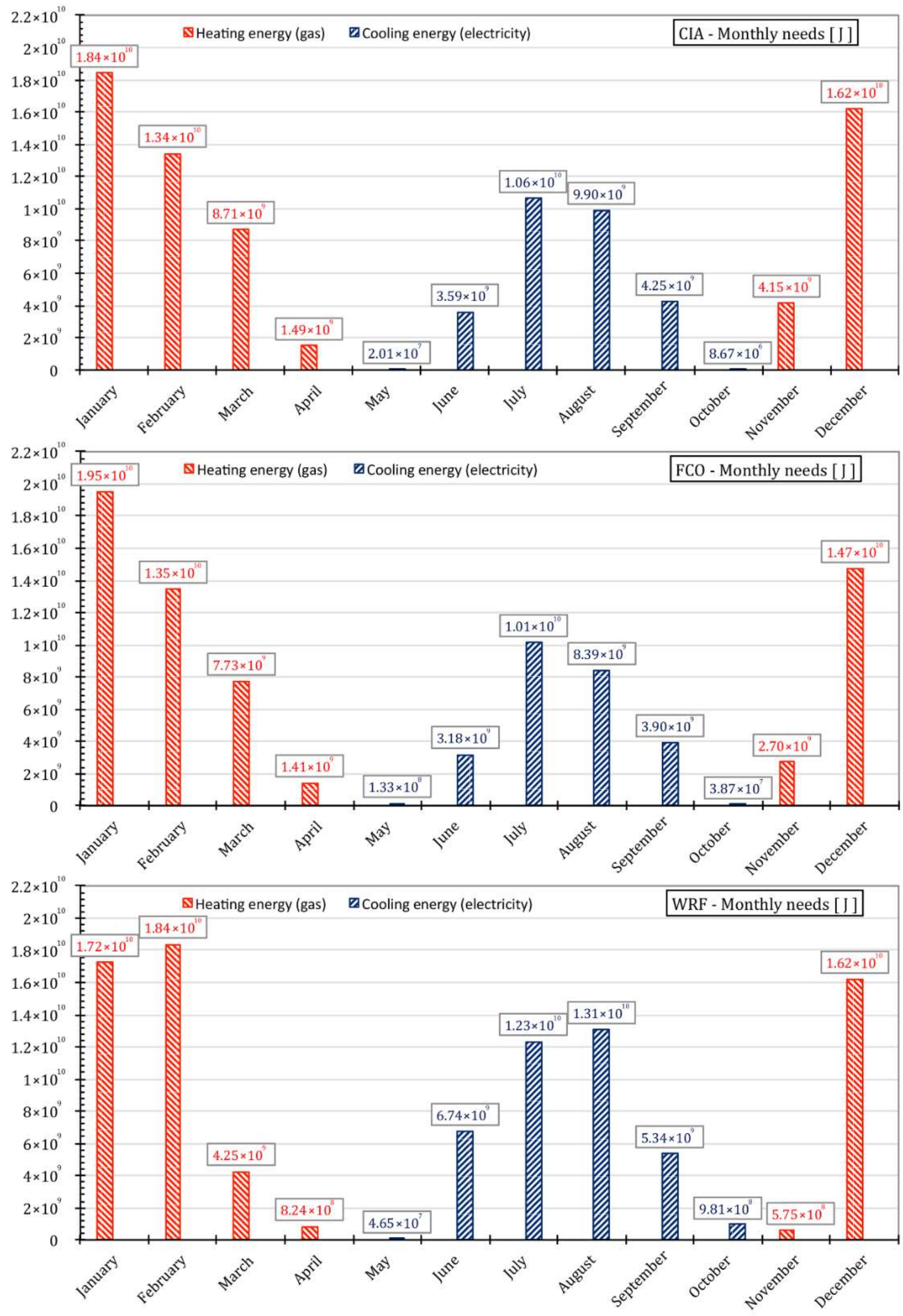

Figure 8. Monthly energy needs of primary energy (gas for heating and electricity for cooling; J) of the system "building envelope/plants" in the case study analyzed for different climate databases used.

The energy consumption obtained with inputs accessible on the EnergyPlus page (related to Fiumicino and Ciampino airports) shows slight differences attributable to the local microclimatic conditions. Energy needs computed with the Ciampino climate file were higher than those computed with the Fiumicino file, because the microclimate at the Ciampino site does not benefit from the proximity of the sea. Figure 9 shows that the consumption for heating was about 4.5% lower when using data related to Fiumicino than when using the data of Ciampino. This difference became greater during the summer period, when the microclimate of Ciampino required about 9.3% more energy than Fiumicino. This shows that a designer who makes calculations of the energy performance of a building in Rome would commit an approximation choosing between the climate files available on the official site of EnergyPlus.

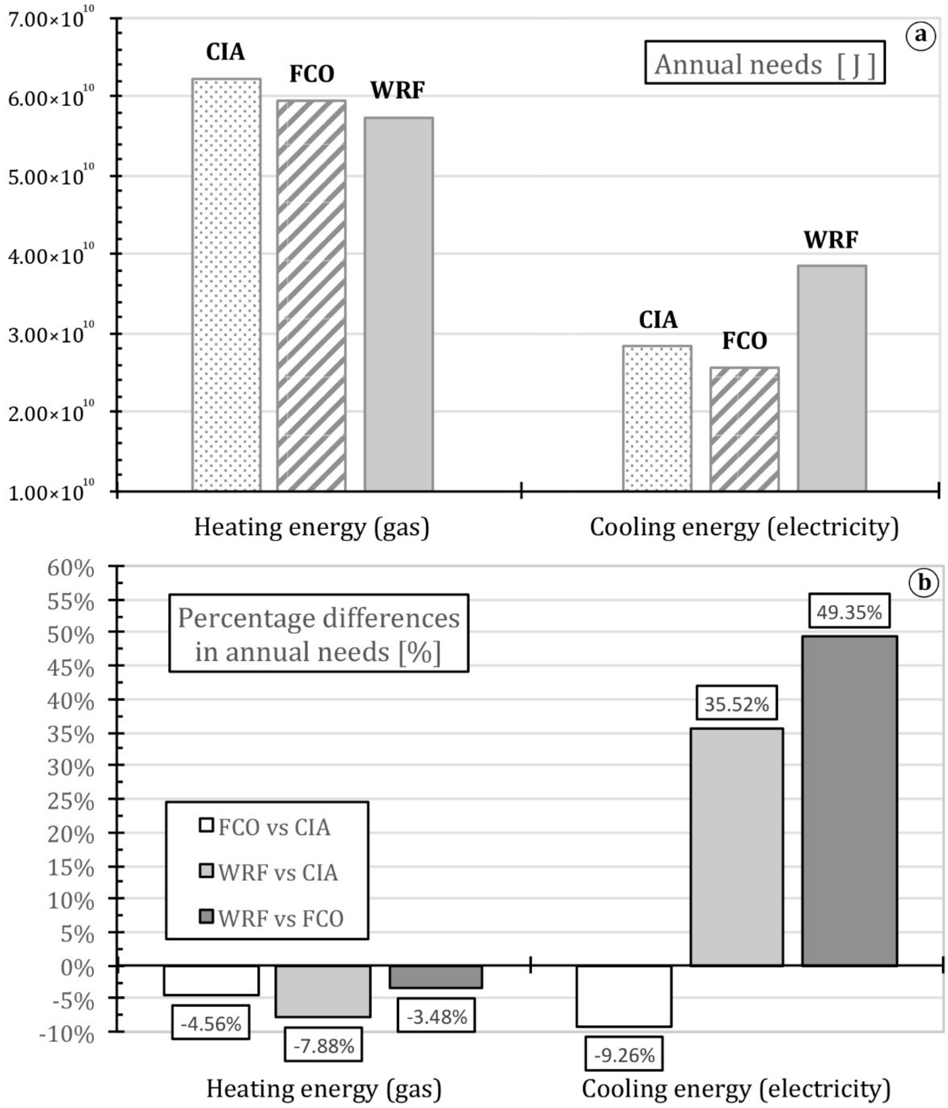

Figure 9. (**a**) Annual primary energy needs (J); and (**b**) percentage differences (%) in the energy consumption of (i) Fiumicino vs. Ciampino; (ii) WRF vs. Ciampino; and (iii) WRF vs. Fiumicino.

This was even more pronounced in comparison with the conditions in the city center. Climatic data of airports concern non-urban areas surrounding Rome; therefore, they do not comprise the urban heat island phenomenon, causing an even greater approximation in the calculation of the energy performance. On the contrary, the urban heat island phenomenon was included in the weather file generated as output by WRF. The percentage differences (relative to annual energy consumption) between each airport file and the one related to the WRF simulations are depicted in Figure 9. Results of the EnergyPlus simulation driven by the WRF output shows that the urban heat island heavily influences the energy behavior of the building. The external climatic forcing obtained effectively affected the building and entailed considerably higher consumption during the cooling period (plus ~35% and ~50% compared to Ciampino and Fiumicino, respectively). The winter energy needs were positively affected by the urban heat island, albeit to a lesser extent compared to the summer (minus ~8% and ~3% compared to Ciampino and Fiumicino, respectively). Therefore, the higher summer energy needs in the city center were not counterbalanced by the decrease in winter energy needs.

6. Conclusions

The analysis of the primary energy needs of buildings (due to the heating and cooling of rooms) is the basis for the optimization processes of consumption in the residential building sector. If the target building has complex architectural peculiarities or a big size, the study of the behavior of its "envelope/plant" system cannot rely on simplified calculation methods based on monthly averaged climatic data. Indeed, it is necessary to simulate the performance in an hourly dynamic regime.

One of the most accredited software by the international scientific community for these purposes is EnergyPlus. EnergyPlus simulations are based on climate files available for all the major cities of the five continents. The complexity of this software requires the user a long time to insert all the inputs related to the three-dimensional model of the building and the information about its plants. For this reason, technicians use this type of software rather than others easier to employ only when the accuracy of the calculations imposes it. The climate data are the only input provided on the software page and they are chosen according to the location of the studied building. Usually, these data refer to measures sampled in airport areas, where long time series of weather data (useful to construct the standard year) are typically available.

Climate files of a (rural) airport area do not take into account the urban heat island phenomenon typical of big cities. In fact, the microclimate of the metropolitan area is especially determined by the interaction of solar radiation with building materials and the replacement of urban green with paved or asphalted areas, and it is very different from that of the rural areas. Furthermore, results present discrepancies when climate files corresponding to different airport sites (but to the same city) are provided as input to EnergyPlus simulations. In support of this thesis, in this work, EnergyPlus simulations were performed for a building located in the center of Rome (Italy), using the following input climate files:

- files provided on the EnergyPlus page and related to the airport areas of the two major airports near Rome, located in Fiumicino (FCO) and Ciampino (CIA);
- a file based on the output of the WRF model and related to the metropolitan area of Rome.

The WRF model allows the reproduction of the urban heat island phenomenon at high resolution through a nesting technique from the continental (over Europe) to the regional scale (over central Italy). Both the climatic inputs provided to EnergyPlus and its outputs were analyzed and compared.

Results show that a technician called to perform an accurate analysis of the energy performance of a building located in the center of Rome would commit approximations depending on the input climate file. These approximations are not negligible and require an explanation with respect to the need of a simulation in a transitory regime. In particular, differences for energy needs were as follows:

- FCO vs. CIA: $\Delta = -4.35\%$ for heating, $\Delta = -9.26\%$ for cooling;
- WRF vs. CIA: $\Delta = -7.38\%$ for heating, $\Delta = +35.52\%$ for cooling;
- WRF vs. FCO: $\Delta = -3.48\%$ for heating, $\Delta = +49.25\%$ for cooling.

As is evident from the entities of these differences, the heat island phenomenon particularly affects energy needs for cooling the building during the summer. In this case study, the main differences are those with the Fiumicino airport, which benefits from the mitigation of the nearby Tyrrhenian sea and of the surrounding large agricultural areas. Therefore, the choice of this climate database would lead to results heavily affected by very different climatic conditions from the city center.

All this shows that, if there is the need to simulate the energy behavior of a building located in a big metropolitan area (rigorously, through software able to perform calculations in a transitory regime), it is necessary to have an input climate database as close as possible to the real local microclimatic conditions. To this end, it is not possible to use data acquired in rural areas located outside the urbanized context, and data sampled in the city center are required. These data are hardly available, but simulations carried out with meteorological models such as WRF, properly evaluated, can be used to create the input annual climate file (with hourly frequency).

Author Contributions: The study was designed by F.S., S.F. and V.C. V.C. and S.F. carried out the numerical simulations. F.S. retrieved the data from yearbooks and websites and reviewed the literature related to the research. The results were then analyzed by F.S., V.C., G.C. and S.F. Model design and English corrections were undertaken by S.F., V.C. and I.G. Finally, F.S., G.C. and M.C. supervised the work related to the paper and the execution of its various phases.

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Nomenclature

CIA	Ciampino airport
FCO	Fiumicino airport
TBA	Dry-bulb temperature (°C)
U	Transmittance ($W \cdot m^{-2} \cdot K^{-1}$)
Ur	Relative Humidity (%)
WRF	Weather Research and Forecasting model
WS	Wind Speed ($m \cdot s^{-1}$)

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