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The influence of different hourly typical meteorological years on dynamic simulation of buildings

Giacomo Chiesa[a]*, Mario Grosso[a]

[a]Politecnico di Torino, Dept. Architecture and Design, Viale Mattioli 39, 10125 Torino, Italy

Abstract

This paper presents a parametric study on the effect of different TMY (Typical Meteorological Year) datasets on the results of energy dynamic simulation. The analysis was carried out running the software *Design Builder* with *EnergyPlus* code on a sample residential building located in three Italian cities and using two different TMY data sets: *EnergyPlus* and CTI (Italian Thermo-Technical Committee). As a support of the simulation results to be confirmed to a larger scale (the whole Italian territory), an analysis on the two TMY data sets was carried out by calculating CDH (Cooling Degree Hours) and HDD (Heating Degree Days) for 21 Italian locations together with annual global horizontal radiation and average annual mean daily wind velocity. The discrepancies found between the software data set and the more updated and locally validated CTI data set undermine the accuracy of simulation results hence flawing the energy performance assessment criteria based on those results.

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Keywords: dynamic simulation; hourly typical meteorological years; building simulations; energy performance

1. Introduction

The use of dynamic energy simulation of buildings is increasing among both design professionals and scientists. Furthermore, the use of dynamic simulation for energy performance evaluation is required in some environmental certification protocols (e.g., LEED US based on ASHRAE 90.1-2013) as well as for design optimisation of innovative passive and hybrid energy saving technologies. Although there are several methods for calculating the indoor temperatures and the energy demand of a building, for complex geometries or special requirements, detailed simulation code are necessary [1]. As a climate data input, dynamic energy simulation codes need TMY based on hourly values,

* Corresponding author. Tel.: +39-0110904371.
E-mail address: giacomo.chiesa@polito.it

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which are not always easily accessible or available. In addition, for a given location, there might be different sources of meteorological databases, whose TMYs, even if elaborated in accordance with international standards (e.g. UNI EN ISO 15927-4), may diverge significantly.

1.1. Methodology and climate sources

This paper focuses on the effect of different TMY datasets on the results of energy dynamic simulation. Firstly, a climate analysis was conducted on 21 Italian Province Capitol Cities by calculating CDH and HDD using different TMY sources (Fig. 1-a) as well as wind velocity and solar radiation monthly-averaged data. Secondly, a test on a sample residential building located in three Italian cities, Novara, Rome and Taranto, was performed to evaluate the effect of TMY divergence on the results of dynamic energy simulations using *Design Builder* with *EnergyPlus* code (Fig. 1-b). The discrepancies found affect significantly the results from dynamic energy performance simulation hence flawing the energy performance assessment criteria based on those results.

Two TMY databases were used: a) the one embedded inside *EnergyPlus* - a code internationally recognised and used worldwide by professionals - and based on different weather data sources; b) a database recently elaborated by CTI with ENEA and the Italian Ministry of economic development for the 110 Italian Province Capitol Cities [2-3]. The *EnergyPlus* weather data for Italian cities refer to two sources: the International Weather for Energy Calculation (IWEC), typical weather files © 2001 ASHRAE [4], and the Italian Climatic data collection "Gianni De Giorgio" (IGDG), based on recorded data from 1951-70 period [5].

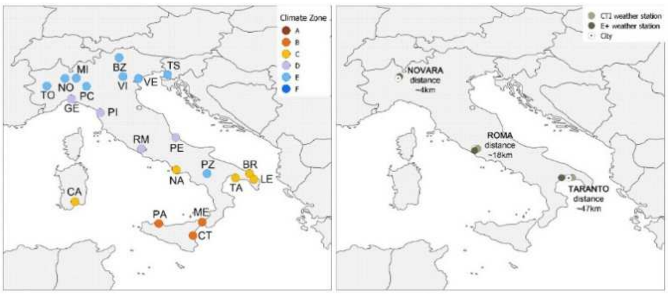

Fig. 1. (a) Considered 21 locations and their specific heating climate zone according to the Italian legislation; (b) selected weather stations for dynamic simulations.

2. Climate analysis

A climate analysis was carried out comparing cooling and heating typical conditions of the 21 locations represented in Fig. 1-a without taking building characteristics into account. The variation of ambient temperature for the different data sets was compared on a hourly basis using the parameters HDD and CDH, representing, respectively, heating and cooling conditions. In addition, monthly-averaged solar radiation and wind velocity data were compared.

2.1. Analysis on ambient temperature data

2.1.1. Heating Degree Days

HDD was calculated for the 21 chosen Italian locations using the two above mentioned TMY data sets and compared as well to HDD values set by law (DPR 412-93, attachment A). *EnergyPlus* data were compared to CTI data for the 21 locations and two to three sources for a smaller sample of cities (Fig. 2). HDD was calculated according to UNI EN ISO 15927-6:2008, on a base temperature (ϑ_b) set to 20°C, using the following equation:

$$HDD_{20} = [\sum_{h=1}^{n} \Delta\vartheta_h(20)]/24 \quad (1)$$

Where:

if ϑ_h<20°C then $\Delta\vartheta_h(20) = (20 - \vartheta_h)$ else $\Delta\vartheta_h(20) = 0$

n = period of the heating season set by law and varying with climate zone (see Fig. 1-a).

Fig. 2 shows a comparison between the HDD values derived from the chosen databases for each location. This comparison highlights some discrepancies as discussed below. Fig. 2 (b) is a zoom on seven locations for three different *EnergyPlus* weather data sources.

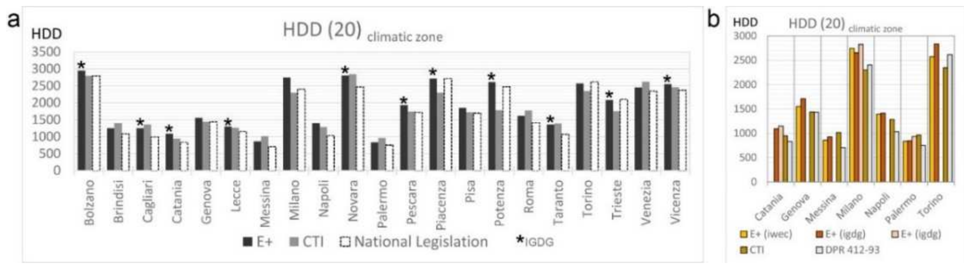

Fig. 2. (a) HDD values for 21 Italian Province Capitol Cities calculated from the *EnergyPlus* and CTI data sources as well as taken from the Italian law; (b) HDD for 7 cities where *EnergyPlus* weather data set can be taken from two or three meteorological stations.

2.1.2. Cooling Degree Hours

The influence of different TMY data sets on simulation for cooling energy analyses was evaluated using the index CDH, calculated by summing the positive hourly differences in temperature between the average hourly environmental DBT (ϑ_h) and a fixed base temperature, assumed as 26°C. Calculation was conducted for a fixed extended summer period from May to October for all considered locations using the following equation:

$$CDH_{26} = \sum_{h=2281}^{7296} (\vartheta_h - 26) \text{ for positive values only} \qquad (2)$$

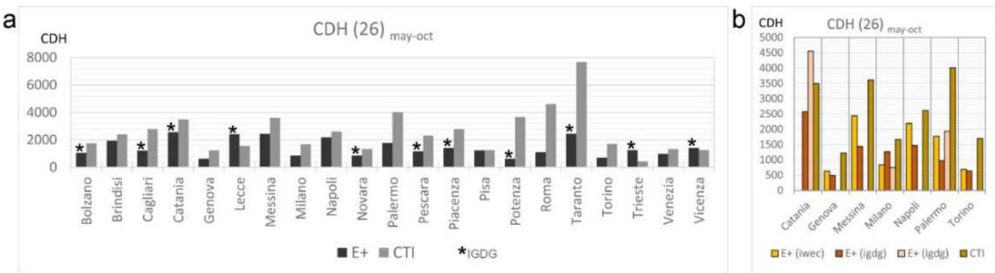

Fig. 3. (a) CDH values for 21 Italian Province Capitol Cities calculated using *EnergyPlus* and CTI data sources; (b) CDH values for 7 cities using CTI data and two or three weather stations available on *EnergyPlus*.

Fig. 3 shows the differences between calculated CDH_{26} based on CTI and *EnergyPlus* data sources for each locality. The two series of data show a discrepancy higher than for HDDs. A drastically reduced cooling need is apparent when using all *EnergyPlus* datasets compared to the CTI's in the majority of considered locations, especially in Southern Italy, where climate is hotter. These differences result to an underestimation of cooling needs by the simulation program due to not updated weather data set which is not taking into account the most recent global warming trend as instead is done by the CTI's.

2.2. Analysis on solar radiation and wind velocity data

Data for the considered locations of total annual global solar radiation intensity on horizontal surface and annual-averaged daily mean wind velocity, compared amid the different weather sources, are shown in Fig. 4, respectively, (a) and (b).

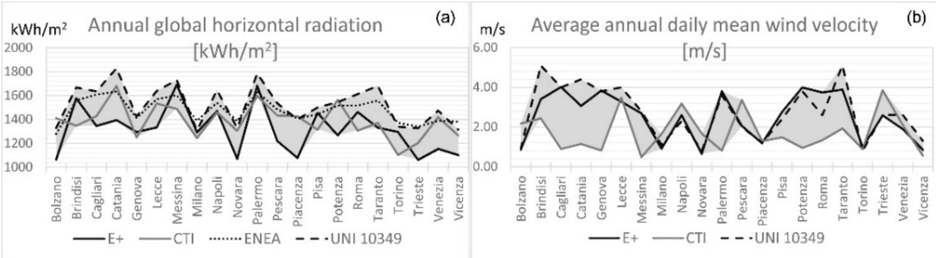

Fig. 4. Comparison amid different weather data sources, in the considered locations: a) total annual global solar radiation on horizontal surface - for the ENEA database see [6]; b) annual-averaged daily mean wind velocity.

2.3. Discussion of results

Results of the climate analysis carried out on ambient temperature data are summarised in Fig. 5, which reports the frequency of relative difference of HDD and CDH values taken from *EnergyPlus* and CTI's data. It is apparent that the higher discrepancy occurs during the cooling period, e.g., in Potenza (621 Vs 3678 CDH) and Taranto (2451 Vs 7665 CDH) . In winter, the majority of differences occurs in a range between ±10% of the reference HDD.

An assessment of the trends related to solar radiation and wind velocity can be inferred from Fig. 4. Regarding solar radiation, data from the *EnergyPlus* source are, in general, underestimated in comparison to the other sources. This can lead to an underestimation of the cooling load, and an overestimation of heating load, in simulation programmes using that code. Data on wind velocity from the *EnergyPlus* source are overestimated in most locations compared to the CTI source, while are closer to the UNI-10349 source. This can lead to an overestimation of the potential reduction of cooling load due to wind-driven controlled natural ventilation in *EnergyPlus* simulations.

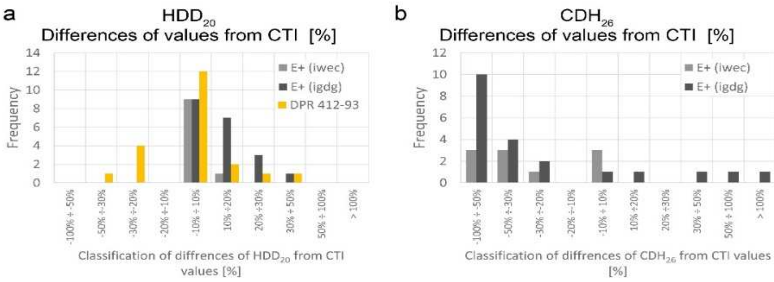

Fig. 5. Percentage differences between index values from *EnergyPlus* and CTI's: (a) heating period; (b) cooling period.

3. Dynamic simulation

In order to check the validity of the above described results when considering building characteristics into account, the influence of different TMY data on dynamic simulation was tested by using a reference residential building on three different Italian locations – Novara, Rome, and Taranto – comparing *EnergyPlus* weather data and CTI TMY elaborated as *.epw files.

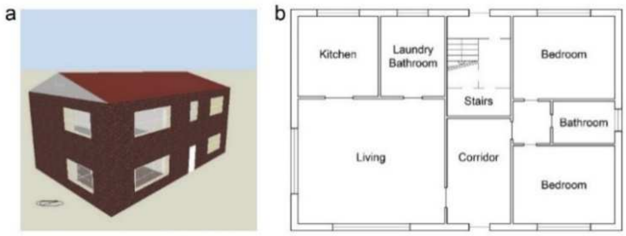

Fig. 6. Reference model: (a) axonometric view; (b) plan of the ground floor.

3.1. Reference model

The reference model is a two-storey residential building with one independent apartment at each floor. Total occupied net floor area is 246 m^2 with four persons per apt. and the net area of unoccupied attic space is 89.7 m^2.

In Fig. 6, an axonometric view and a plan of the ground floor with rooms' layout are shown.

The main input values of the simulation, i.e., related to thermo-physical characteristics of construction elements, environmental control parameters, and schedules are shown in the following tables. The HVAC configuration is of a simple type, i.e., with ideal calculation of energy loads.

Table 1. Thermo-physical parameters.

Element	U_{value} (*W/m²K*)	Internal heat capacity (*kJ/m²K*)	Total solar transmission	Light transmission
Roof slope slab	2.93	4.02		
Top ceiling slab	0.25	32.61		
Ground floor slab	0.34	93.96		
External walls	0.29	134.80		
Partitions	2.29	73.51		
Windows	1.96		0.69	0.62

Table 2. Environmental control parameters

Set-point temperature (°C)		Target illuminance (*lux*)	Lighting energy (*W/m² – 100lux*)	Air flow rate (*l/s -person*)
Heating	Cooling			
20 (12 backup)	26 (28 backup)	150	5	10

Table 3. Schedules.

Activity/space	Period	Occupation (*hours*)	Temperature Heating (*hours*)			Temperature Cooling (*hours*)		
			On	Off	Backup	On	Off	Backup
Living-kitchen-laundry	Weekdays	7÷9; 18÷24	7÷24		24÷7	15÷19	19÷21	12÷15
	Weekends	8÷19; 22÷24	7÷10	10÷20	20÷7		19÷12	12÷19
	Holidays	10÷12	7÷10	10÷20	20÷7		19÷12	12÷19
Bedroom-bathroom	Weekdays	24÷8	19÷24	8÷19	24÷8	12÷17	24÷12	17÷24
	Weekends	24÷10	20÷24	10÷20	24÷10		24÷12	12÷24
	Holidays	24÷10	20÷24	10÷20	24÷10		24÷12	12÷24
Corridor-stairs	Weekdays	9÷10; 18÷19	On during occupation schedule					
	Weekends	10÷11; 23÷24	On during occupation schedule					
	Holidays	9÷10	On during occupation schedule					

3.2. Results

Amid the several simulation output data yielded by *DesignBuilder* with *EnergyPlus*, only the ones related to annual energy use for space heating and cooling were analysed for the purpose of this study. Results show (Fig. 7) that the divergences between *EnergyPlus* and CTI's TMYs, found through the above described climate analysis, affect energy use prediction significantly although with a lower quantitative impact. This was expected, since building envelop and environmental control systems mitigate climate parameters fluctuation over time.

However, the differences found between output data related to the two TMYs reach about 17% for cooling and 39 % for heating. As expected, underestimates of cooling load occur using *EnergyPlus* TMY as compared to the most updated CTI's. Consistently, an overestimate of heating load were found except for the city of Rome, probably due to the different location of the reference meteorological stations.

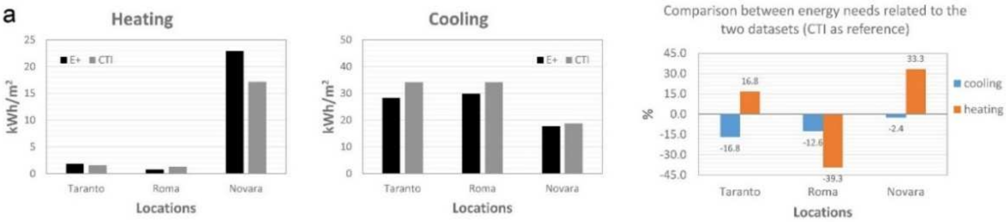

Fig. 7. (a) Annual simulated energy intensity for heating and cooling of the reference model based on the two TMYs; (b) relative differences.

3.3. Limitations of the study

This study has investigated the influence of TMY data on dynamic energy simulation considering two data sources, a wide spectrum of Italian locations for the climate analysis, and three locations for estimating the effect on a building model. However, these limitations do not undermine the study's results although further applications to a larger variety of climate zones and building types could consolidate them, hence reinforcing the need for a climate data harmonisation and their better use in energy dynamic simulation.

4. Conclusion

The results of this paper lead to the useful conclusion that the choice of a given weather file source influences the accuracy of predicted energy needs especially in summer. This outcome suggests an urgent need of developing a consistent uniformly elaborated and periodically updated climate database of TMY data for reference locations, representing all varieties of European as well as World climate zones. Moreover, TMY have to be made interoperable between various simulation codes. This is an important point especially when different building technological choices are compared using dynamic simulation programs for optimising energy performance and cost-effectiveness in various locations and climate zones. In addition, a better fit of simulation output to a real building context could help architects and engineers in their effort to design more energy efficient buildings, hence contributing to global warming mitigation.

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