Evaluation of stochastically generated weather datasets for building energy simulation

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Abstract

In this study, three different Typical Weather Years (TWYs) generated in Meteonorm using different techniques are compared with each other and with an actual hourly climate dataset of a calendar year. The impact of different hourly weather files on building's annual energy needs is then assessed via dynamic simulations of a typical building. The analysis revealed that Typical Meteorological Months and the corresponding TWYs may vary significantly as different statistical processes have been followed for their development. Comparing the actual monthly average values with the corresponding values of the TWYs revealed peak differences up to 45% during the heating period. Regarding the performance of the three stochastically generated TWYs, differences on annual energy use for heating and cooling purposes were found up to 9.3% and 13%, while the mild actual winter conditions resulted in lower heating energy needs, varying by 42%-47%, depending on the TWY.

1. Introduction

Predicting buildings' heating and cooling loads through dynamic simulation methods requires the input of hourly weather data, so as to represent the typical meteorological characteristics of a specific location. These data, known as typical weather years (TWY), consist of 8760 values of various meteorological parameters and are originally deduced from multi-year sets of annual weather measurements [1]. However, given that long-term hourly time resolution data are rarely available for every site, it is a common practice for engineers to use stochastic weather

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generators, so as to create complete climate data sets for any desired geographic location ([2]-[4]). Stochastic models, such as Meteonorm, allow the user either to use the software’s database for the TWY generation, or to import his own monthly values of the necessary climatic variables, such as dry bulb temperature, solar radiation, relative humidity and wind speed. In the latter case, daily and hourly values are stochastically generated with intermediate data having the same statistical properties as the monthly imported data, i.e. average value, variance and characteristic sequence [5]. The imported monthly values of the climatic variables should correspond to 12 typical meteorological months (TMMs), being representative of the weather conditions of the area in question and issued from various calendar months in a long-term weather database. To date, many different methods have been proposed in order to derive TMMs. One of the most common methods is the one adopted for the creation of the Typical Meteorological Year (TMY) dataset, created by the U.S. National Renewable Energy Laboratory and later updated to the TMY2 and TMY3 dataset ([6], [7]). In this case, the selection of the 12 TMMs is based on the two step procedure of ‘Sandia Method’ and the calculation of Finkelstein-Schafer statistics for each month and each climatic variable [8]; a detailed description of the process is presented in [9]. Another technique for defining 12 TMMs so as to generate hourly weather dataset is the one adopted for the Weather Year for Energy Calculation method (WYEC), initially proposed by [10]; the major differences in comparison with the previous technique relies on the fact that individual months are only selected if the average monthly dry bulb temperature has a difference of 0.2°C of the respective long term monthly average. The complete procedure is described by [11]. Finally, previous studies have been also based on the estimation of monthly long term average values of the meteorological variables so as to define TMMs [3]. Since different statistical procedures are applied in the above mentioned techniques, the issued TMMs and thus, the generated TWY may vary significantly. Indicatively, in an earlier study, six different methods of selecting TMMs for the creation of TWY were tested, including TMY and WYEC; the typical months that were obtained from the various procedures were always different with only two months being the same between TMY and WYEC techniques [9]. In this context and given that the selected hourly weather dataset will strongly influence the building energy simulation results ([12]-[14]), the aim of this study is to provide insight on the following questions: (i) How important is the methodology for defining TMMs, when stochastic models are used for the generation of TWY? (ii) How large is the discrepancy between stochastically generated weather files and an actual weather dataset for a calendar year? (iii) How important is the impact of choosing one weather file or another on the prediction of heating and cooling energy needs of a typical building unit?

2. Methodology

In this study, the investigation of the impact of different ways for selecting TMMs, when stochastic models are used for the creation of typical weather datasets, along with its impact on energy performance calculations, is carried out for the city of Thessaloniki in Northern Greece. Thessaloniki (40° 62’ E, 22° 95’ N), located along the North-East coast of Thermaikos gulf, is the second largest city in Greece with more than a million inhabitants in an area of about 200 km². The climate of the city is characterized by temperate Mediterranean conditions, with generally hot, dry summers, and mild, wet winters; mean temperatures during winter and summer are reported around 7 °C and 25.3 °C, respectively. The analysis comprised of the following three stages:

- First stage: Obtaining climatic records and defining Typical Meteorological Months: The multiyear (i.e. 1993-2003) climatic records of average daily values of air temperature, relative humidity, solar radiation and wind speed, provided by the meteorological station of the Department of Meteorology and Climatology placed in the University Campus, were used as a source of information. The climatic data were firstly filtered so as to detect potential abnormalities and were then subjected to statistical analysis in order to define the TMMs for the city of Thessaloniki. In this study, the following two methodologies were used on the basis of: (i) Monthly averages (i.e. TMM_(10years average)): The long-term average monthly values of the decade 1993-2003, were estimated from the corresponding daily average values of air temperature, wind speed, relative humidity and the monthly total global radiation. The absolute % difference between the average monthly values of each individual month and the corresponding long-term average was defined. The month \( M \) of the year \( Y \) in which simultaneous discrepancy from the long-term average was the minimum for all 4 parameters was selected as typical, (ii) The Weather Year for Energy Calculation method (i.e. TMM_WYEC): provided that there are no abnormalities in the long-term
climatic records, typical months were only selected if the average monthly dry bulb temperature had a difference of ±0.2°C of the respective long term monthly average.

- Second stage: Generation of hourly weather files and comparison of climatic elements: After defining the TMMs, the corresponding average monthly values of air temperature, wind speed, relative humidity and solar radiation were introduced in Meteonorm weather generator and the two hourly weather datasets were stochastically generated (i.e. TWY_10years average, TWY_WYEC). A third weather dataset was also stochastically created using the climate database of the software (i.e. TWY_Meteonorm default). For Thessaloniki, the default climatic records of Meteonorm cover the period of 1991-2009 and 2000-2010 for solar radiation and air temperature respectively and are recorded at the meteorological station of the city airport, situated around 18km from the University campus. Given that the Energy plus simulation tool will be used at the next step for building simulations, the compatible ‘epw’ hourly weather file format was chosen. Finally, in order to identify the discrepancies between stochastically generated weather files and an actual but not typical annual weather dataset, a fourth hourly weather climate file, based on actual hourly measurements of air temperature, wind speed, relative humidity and solar radiation was created (i.e. actual data). The hourly climatic records of the latter dataset were obtained by the meteorological station of the Department of Meteorology and Climatology, for the period Sept. 2015-Aug. 2016.

- Third stage: Building energy analysis: Aiming at the investigation of the impact of weather data on the annual heating and cooling energy demand, dynamic energysimulations with Energy plus tool were performed using the above mentioned four hourly weather datasets and for two residential building units: an insulated one, following the Greek thermal Regulation standards and a non-insulated one. In both cases the urban apartment under investigation (Fig 3.a) has a heated area of 100m² and occupies an entire story of a multi-storey building. The ceiling and the floor are considered as adiabatic surfaces, since the unit represents a middle floor, while external envelope’s U-values are 0.40 W/(m²·K) for the brick-wall, 0.45 for the concrete elements W/(m²·K) and 2.7 W/(m²·K) for the windows. In the not-insulated scenario, these thermal transmittances are 1.9, 3.16 and 3.5 W/(m²·K) respectively. Front and back façades are oriented on the South-North axis and the balcony is extended to façade’s width, as is very common in Green urban buildings. The operational schedules are set according to the Greek building code for residences.

3. Evaluation of climatic variables

As anticipated, the TWYs that emerge from the abovementioned methodologies do not have the same characteristics, since different statistical methods are applied for their development. In this section, the major parameters that strongly influence buildings’ energy demand such as air temperature (Tair), solar radiation (SR) and wind speed (WS), derived from the three stochastically generated hourly weather datasets (i.e. TWY_10years average, TWY_WYEC and TWY_Meteonorm default) are compared with each other and with the corresponding values of the actual measurements of the period September 2015-August 2016.

As depicted in Fig. 1.a, variations among the monthly average Tair of the three stochastically generated weather datasets are rather low; the maximum deviation reaches 16.0%, and is reported in January, between TWY_WYEC and TWY_Meteonorm default. On the other hand, major discrepancies between the stochastically created TWYs and the actual dataset were found during the heating period (except for January when discrepancies are rather minor). More precisely, important deviations were reported for the month of February when the actual mean monthly Tair was 35.6%, 35.5% and 44.4% higher than the corresponding monthly value of the TWY_WYEC, TWY_10years average and TWY_Meteonorm default datasets respectively. For the month of November, these differences were reported up to 20.8%, 20.80% and 23.5%. Yet, deviations on monthly average Tair between actual and stochastically generated data are less significant during the cooling period, with reported deviations varying from 0.1% in August, to 9.8% in September (between actualdata and TWY_Meteonorm default). These extreme winter discrepancies between actual and stochastically generated datasets arise from the fact that the actual recorded data do not correspond to representative climatic conditions for the city of Thessaloniki and are only extreme records of a calendar year. Concerning solar irradiance, TWY_Meteonorm default tends to overestimate solar radiation, given that it shows the maximum discrepancies when compared with the rest of weather files, reported during summer period (Fig.1.c). In terms of the actual dataset, monthly sums follow the normal yearly profile, with values being closer to the corresponding ones of
the TWY_WYEC dataset. Finally, regarding wind speed, considerable differences of monthly means are observed for most of the months between the actual dataset and those created with Meteonorm (Fig.1.b). Once more, this can be attributed to the fact that the calendar year 2015-2016 is not a typical one. Furthermore, when analyzing the monthly wind speed values of the three stochastically generated datasets, it has to be taken into account that the wind speed is a meteorological variable strongly influenced by local features and morphology. Multiyear wind speed records can be significantly diverse in places with different morphological characteristics. The latter remark could explain the fact that TWY_Meteonorm default dataset tends to have higher monthly values of wind speed compared to TWY_10years average and the TWY_WYEC datasets; its creation is based on long-term measurements acquired from a weather station near the airport, which is more exposed compared to the meteorological station, the records of which have been used for the generation of TWY_10years average and the TWY_WYEC datasets.

Fig.1: Monthly profiles of (a) average air temperature, (b) average wind speed and (c) solar radiation sum for the four generated hourly weather datasets.

4. Building energy analysis

Dynamic building energy simulations based on the four developed hourly weather datasets have been carried out with the Energy plus tool, for the two building units described in chapter 2 (bullet 3). The annual profile of heating and cooling energy needs, as a function of weather data, is depicted in Fig.2. As expected, the use of different climate datasets has led to diverse monthly thermal needs, with the non-insulated building unit consistently presenting significantly greater requirements for heating and cooling purposes. Firstly, the energy performance of the examined building units is assessed when the three stochastically created are used. The analysis revealed that the simulated annual heating energy needs may vary up to 3.2% and 9.3% for the insulated and non-insulated apartment respectively, depending on the weather dataset used. The corresponding annual cooling requirements range up to 7.7% and 13.6%. The obtained magnitudes of differences agree with the results reported in [12] and [13], where the absolute maximum difference on annual heating and cooling energy use, due to different TWY datasets, was up to 11% and 5% respectively. The latter results also indicate that the non-insulated building unit is more sensitive to modifications of weather conditions and thus, to the methodology for creating the TWY via weather generators.

At the next step, the actual dataset results are compared with the stochastically created TWYs’ results. In general, for both building units, the higher actual winter dry bulb temperatures contributed in significantly lower heating energy needs, compared to the corresponding requirements derived when the stochastically generated TWYs. Indicatively, for the insulated building, the deviations of the actual annual heating requirements vary from -42.0% (compared to TWY_WYEC results) to -47.0% (compared to TWY_Meteonorm default results).
At the next step, the actual dataset results are compared with the stochastically created TWYs’ results. In general, Dynamic building energy simulations based on the four developed hourly weather datasets have been carried out. The analysis revealed that the simulated annual heating energy needs may vary from 11% and 5% respectively, depending on the weather dataset used. The corresponding annual cooling requirements range up to 7.7% and 13.6%. The obtained magnitudes of differences agree with the results presented significantly.

Fig.2: Monthly values of heating and cooling energy needs for the insulated and non-insulated building unit, as a function of weather.

In the case of the non-insulated building, the corresponding discrepancies range from -22.0% to -33.0%. At this point, it has to be mentioned that the latter magnitudes of deviations, reported for the insulated and non-insulated building unit, could not be easily comparatively assessed, due to the dissimilarities in the interrelations of the thermal energy balance components. As depicted in Fig.3, the increase of thermal protection at the building elements will noticeably reduce sensible heat transfer through wall conduction; infiltration and ventilation are then the major component of heat energy losses, while the phenomenon is different in the case of the non-insulated envelope, where ventilation and wall conduction losses are both important components. Finally, the comparison of actual annual cooling requirements with the corresponding results obtained for the three TWYs showed less noticeable differences with deviations up 4.40% (compared to TWY_WYEC results) and 3.70% (compared to TWY_Meteonorm default results), for the insulated building unit. The less significant variances can be attributed to the lower air temperature differences among the four hourly weather datasets during the cooling period.

Fig.3: Building model and thermal energy balance components for the insulated and non insulated building unit (for the TWY_WYEC dataset).

5. Conclusions

Given that long-term hourly climatic data are not always available for every site, stochastic weather generators such as Meteonorm are commonly used for the creation of TWYs for building energy simulation. In this study, two
different techniques were applied for choosing TMMs as input for TWY generation in Meteonorm. The obtained datasets were then statistically compared with a third typical weather file, the creation of which is based on the default database of Meteonorm and also with an actual hourly climate dataset, corresponding to the calendar year 2015-2016. The analysis revealed rather low variations among the monthly average Tair of the three stochastically generated weather datasets. The estimated values do not exceed 5.0%, while peak differences up to 16% were only reported in January. On the other hand, solar radiation and wind speed data are less consistent as the TWY Default tends to overestimate monthly average values with peak deviations up to 33% and 52% respectively. The deficiency of weather generators to reproduce accurately the wind speed parameter, also mentioned by [4], relies on the fact that this parameter is strongly affected by local features and obstacles and thus, major variations can arise from one site to the other. The comparison of the actual monthly average air temperature with the corresponding values of the TWYs revealed considerably high differences, with peak values ranging from 0.1% to 9% and 10% to 45% during the cooling and the heating period respectively. Even higher deviations were found for the wind speed variable, where the peak underestimation of the average monthly value was approximately 62%. Compared to TWYs, the actual weather dataset is more useful either to model the building energy needs under extreme and not typical weather conditions or to verify its energy performance. The influence of using hourly data, generated with different techniques, on building’s energy performance, was assessed through dynamic energy simulations of an insulated and a non-insulated building. The obtained results indicated that the use of different climate datasets lead to diverse monthly thermal needs, with the non-insulated building unit always requiring higher energy amounts for heating and cooling purposes. When comparing the performance of the three stochastically generated TWYs, differences on annual energy use for heating and cooling were found reaching 9.3% and 13%, respectively with the non-insulated building being more sensitive to different weather files due to different methodologies for generating TWYs. Finally, the mild actual winter conditions of the period 2015-2016, resulted in considerably lower heating energy needs with monthly energy needs varying by 42%-47%, depending on the TWY.

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References