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ScienceDirect

Energy Procedia 132 (2017) 640–645

Energy Procedia

www.elsevier.com/locate/procedia

11th Nordic Symposium on Building Physics, NSB2017, 11-14 June 2017, Trondheim, Norway

Critical Analysis of Software Tools Aimed at Generating Future Weather Files with a view to their use in Building Performance Simulation

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Abstract

Two software tools, namely CCWorldWeatherGen and WeatherShift™, are today available on the market and enable individual end-users, to generate future projection weather data that can be used for executing building performance simulation. These software tools have been developed based on different assumptions. Therefore, the outputs of the two tools were generated and compared both graphically and using statistical methods to get to a better understanding of their differences and, hence, to identify possible consequences when applied to building performance simulation. The results suggest that, depending on the purpose of the design, care should be taken in using the above-mentioned tools.

Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics.

Keywords: Future weather generation tools, building performance simulation, climate change, future weather data

1. Introduction

In 1976 National Climatic Data Center (NCDC) [1] provided one of the first weather data sets, called test reference year (TRY) to be used in building performance simulation. Since then many attempts have been made by several organizations to create worldwide weather data sets such as WYEC, TMY, CWEC and CTZ that are readily accessible for users of energy simulation tools [2]. But the increasing recognition of climate change and its impact on built environment [3] has added a new dimension to this challenge, which is the increasing need for future projection

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Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics
10.1016/j.egypro.2017.09.701

weather data sets for the local climates. To tackle this challenge, several methods have been developed. Guan [4] reviewed the methods used to prepare future weather data for the study of the impact of climate change on buildings. One of the practical and frequent used methods is to impose the predicted future climate data generated by a climate model named general circulation model (GCM) on the current typical weather data such as typical meteorological year (TMY) for a specific location. Since the output of GCMs are expressed with a monthly resolution and monthly values are not suitable for building performance simulation (BPS) purposes, Belcher et al. [5] introduced a downscaling method so called morphing. Jentsch et al. [6] discuss the general validity of the morphing method and state that the extensive use of this method in the UK and its acceptance by the Chartered Institution of Building Services Engineers (CIBSE) [7] give some confidence in its principal applicability. However, De Dear [8] questions this method by highlighting its limitations and in general the uncertainties associated with all climatic impact research.

The present study has three purposes. First, it provides users of BPS with the general idea of mentioned concepts and processes on generating future weather data. Second, it presents a comprehensive statistical analysis of the outputs from the two future weather generator tools available today on the market, CCWorldWeatherGen [6] and WeatherShift™ [9], which allows exploring relationships and differences among the data samples. Third, the study warns modellers that, since only a few variables are modified by one of the tools and the other is developed on an older IPCC report, these tools have to be used carefully and consciously.

2. Methodology

In order to give an overview of the two future weather generator tools and estimate the implications of their use in BPS, foremost, the background and calculation assumptions made for their development are described in Section 2.1 and 2.2. Next, three European capitals are used to represent diverse climate conditions in Europe. Accordingly, in Section 2.3, three future projected periods are considered, namely near-term (NT), medium-term (MT) and long-term (LT). The two tools generated the three future projected periods for each of the three selected cities. Finally, Section 2.4 presents the statistical metrics that are used to quantify the changes and differences in the output of the two tools.

2.1. CCWorldWeatherGen tool

In 2000, the Intergovernmental Panel on Climate Change (IPCC) published a special report on the emission scenarios (SRES) that provided projections of possible future climate change. These scenarios were used in the third and fourth assessment reports, respectively mentioned hereby AR3 [10] and AR4 [11]. Based on AR3 and AR4, Jentsch et al. [6] published their work on providing a methodology based on morphing technique for generation of future weather data for worldwide locations. The standard weather file formatted according to the EnergyPlus Weather (EPW) was selected as the baseline weather data for conducting the morphing procedure. EPW files are freely available for worldwide locations, which is as well one of the key attractiveness of this method.

Jentsch et al. [6] reviewed six GCMs under AR3 and 23 GCMs under AR4, which were available on the IPCC online data distribution center [12] by the time. They found that the most suitable GCM for applying their method was HadCM3 [13] for A2 emission scenario [10]. HadCM3 output is expressed as relative changes with respect to the data gathered in the period ranging from 1961 to 1990 that is taken as a timeframe. The tool job is to superimpose this relative change on the meteorological parameters stored in an EPW file format.

In this study, weather files from international weather for energy calculation (IWEC) database are considered. IWEC database has been derived from measured weather data from 1982 to 1999, which is a different timeframe than HadCM3. According to Jentsch [6], this means that morphed weather files created using this EPW data are expected to overestimate the effect of climate change for the given location. Based on the above-mentioned methodology, the Sustainable energy research group (SERG) at Southampton university introduced a Microsoft® Excel based tool called 'The climate change world weather generator (CCWorldWeatherGen)' [14]. The tool is freely available and it allows users to generate future weather files for worldwide locations within three time slices: 2011-2040 ('2020s'), 2041-2070 ('2050s') and 2071-2100 ('2080s') relative to baseline period (1961-1990). It transforms EPW files template into future weather data always in the EPW format ready for use in BPS tools. More details on generation of climate parameters for EPW future weather data can be find in [15] and [5].

2.2. WeatherShift™

In their fifth assessment report, AR5 [16], IPCC identified new "benchmark emission scenarios" referred as representative concentration pathways (RCPs). Based on two of the RCP emission scenarios (4.5 and 8.5), Arup and Argos Analytics has developed a tool named 'WeatherShift™' [17] that applies the morphing procedure on the outcomes of 14 GCMs (out of approximately 40 models) available under AR5 [18]. The tool provides future projection weather data for three time periods – 2026-2045 (referred as '2035s'), 2056-2075 (referred as '2065s'), 2081-2100 (referred as '2090s') relative to the baseline period 1976-2005 – and two emission scenarios – RCP8.5 and RCP4.5 – of the IPCC's AR5. Moreover, WeatherShift™ provides a cumulative distribution function (CDF) that is constructed for each variable using linear interpolation between the model values [9]. This method was introduced earlier from UK Climate Impact Programme (UKCIP) for the UK Climate Projections [19]. The CDF enables users to decide a probability assigned to the projections. In order to make comparable the outcomes of the two weather generation tools, the RCP8.5 is used in the WeatherShift™ that is the highest emission scenario of AR5, which is in accordance with the A2 scenario used by SERG in the CCWorldWeatherGen. For the probability level, we chose 50% value, which means the median or as referred by UKCP09 as central estimate. Table 1 contrasts the different assumptions used in the two tools.

Table 1. Differences between the two tools.

	CCWorldWeatherGen	WeatherShift™
Projected time periods	2020, 2050, 2080	2035, 2065, 2090
IPCC Report	AR3 (2001), AR4 (2007)	AR5 (2014)
GCM(s)	HadCM3	14 models
IPCC emission scenario(s)	A2	RCP4.5, RCP8.5
Downscaling method	Morphing	Morphing
Baseline period	1961-1991	1976-2005

2.3. Projected periods

The two tools use different time slices as described before. For the simplicity of this study, three projection periods – near-term (NT) projection, medium-term (MT) projection and long-term (LT) projection – have been used. The terminology was adopted from IPCC's AR5 (2014), and are used accordingly instead of 2020, 2050, 2080 for CCWorldWeatherGen and 2035, 2065, 2090 for WeatherShift™ tool.

2.4. Statistical analysis

Statistical analysis was carried out on all the parameters contained in the EPW files using the software package IBM® SPSS® Statistics version 24. For the first step of the analysis, all the parameters contained in the EPW file were tested for normality using the Kolmogorov-Smirnov statistic given the sample size. Since the result of the test for all the parameters showed a non-normal distribution for $p \leqslant 0.05$, non-parametric statistic methods were adopted to explore the differences among different sets of data. Secondly, to estimate the statistical significance of the differences between the baseline IWEC files and the generated future weather files, the Mann-Whitney U test was used. This test is the non-parametric test equivalence of the t-test for independent samples. Instead of comparing means of the two groups, as in the case of the t-test, the Mann-Whitney U test actually compares medians. If the significance level (p) provided by the Mann-Whitney U test is higher than 0.05 there is statistically significant difference between the two tested independent samples.

Thirdly, to quantify the magnitude of the differences, the effect size (ES) was calculated. According to Cohen [20], ES is some specific nonzero value and the larger this value, the greater the degree to which the phenomenon under study is manifested, which in our case is a statistically significant difference. The effect size is defined as

$$r = \frac{z}{\sqrt{N}} \qquad (1)$$

Where r is the effect size, z is the statistic's value and N is the sample size. According to Cohen [20], ES is considered large if the value of r is larger than 0.5, medium if it is in the range between 0.5 and 0.1, and low if is lower than 0.1.

The key variables considered for this assessment are dry bulb temperature, relative humidity and global horizontal radiation.

3. Results

The first step aimed at characterizing the data samples. As mentioned before the output of the tools are in EPW format, which contains several meteorological parameters in hourly values for an entire year. All meteorological parameters failed the Kolmogorov-Smirnov normality test and are hence are not normally distributed. For this reason, data is described using the median and the interquartile range instead of using the mean and the standard deviation and is represented graphically using a boxplot. As an example, Figure 1 shows the distribution of the three key variables plotted solely for Paris in the three future projection weather scenarios as generated by the two tools. It allowed us to have a quick scan of the differences.

Figure 2 shows, for the three key variables in the three selected locations, the hourly differences between the values of the long-term projected weather data and the values of the reference IWEC weather file. Pattern of the differences of the two tools emerge and show a substantial different implementation of the morphing method in the two tools. Next, the Mann-Whitney U test was used to estimate quantitatively the magnitude of the difference between the reference IWEC file and the future projection weather files. Table 2 reports the effect size of the changes as a result of this analysis.

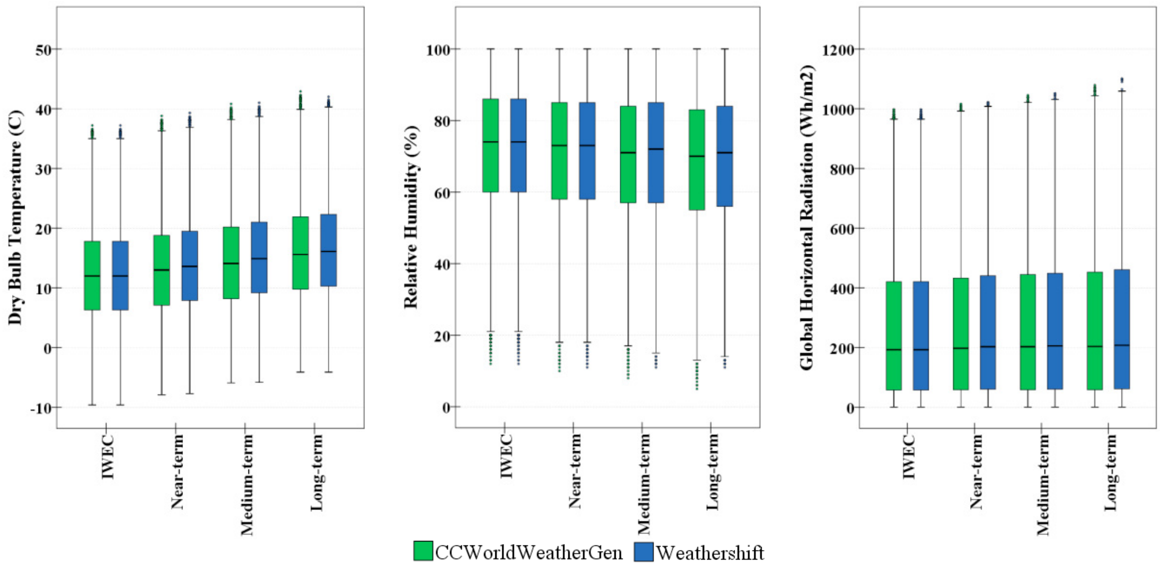

Fig. 1. Comparison of the outcomes of the two weather generation tools for the three meteorological parameters for the city of Paris.

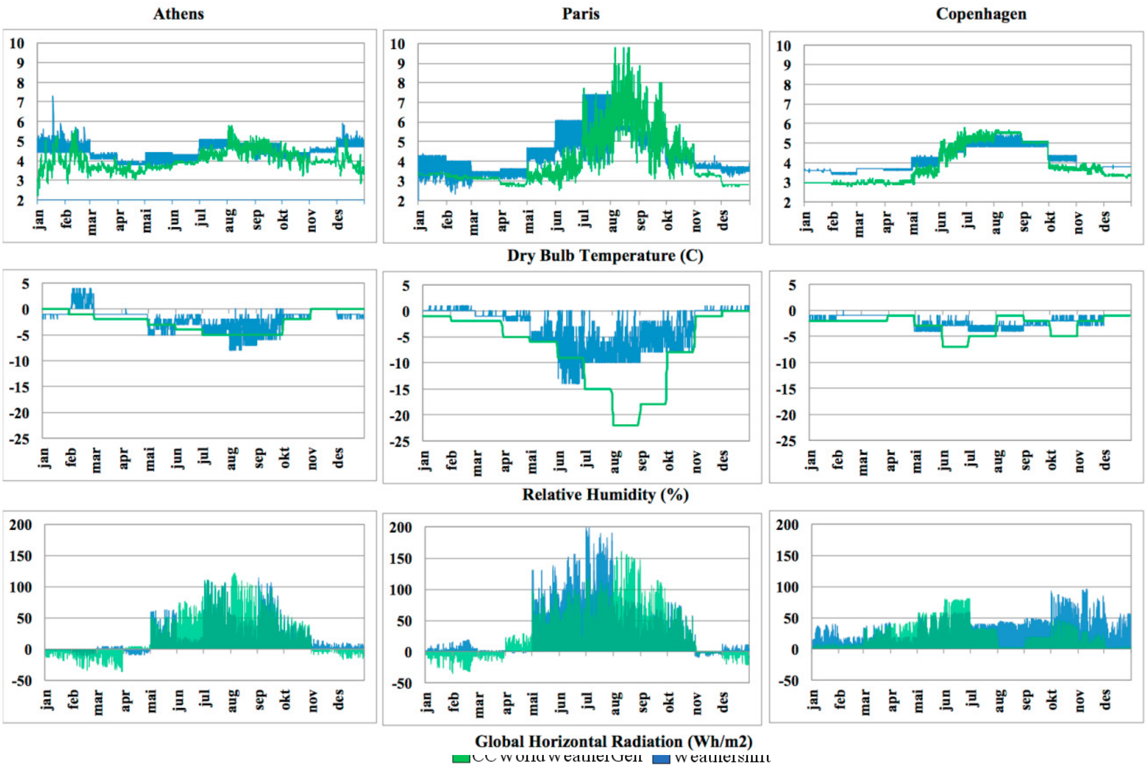

Fig. 2. Hourly differences between the values of the long-term projected weather data and the values of the reference IWEC weather file

Table 1. Comparison of the changes with respect to the reference IWEC file and indication of the effect size (ES) of the change.

EPW Parameters	CCWorldWeatherGen									WeatherShift								
	Near-Term			Medium-Term			Long-Term			Near-Term			Medium-Term			Long-Term		
	Athens	Paris	Copenhagen	Athens	Paris	Copenhagen	Athens	Paris	Copenhagen	Athens	Paris	Copenhagen	Athens	Paris	Copenhagen	Athens	Paris	Copenhagen
Dry Bulb Temperature (°C)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dew Point Temperature (°C)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Relative Humidity (%)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Atmospheric Pressure (Pa)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Extraterrestrial Horizontal Radiation (Wh/m²)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
Horizontal Infrared Radiation Intensity from Sky (Wh/m²)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
Global Horizontal Radiation (Wh/m²)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Direct Normal Radiation (Wh/m²)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Diffuse Horizontal Radiation (Wh/m²)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Global Horizontal Illuminance (lux)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
Direct Normal Illuminance (lux)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
Diffuse Horizontal Illuminance (lux)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
Zenith Luminance (Cd/m2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
Wind Direction (deg)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wind Speed (m/s)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total Sky Cover (.1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
Opaque Sky Cover (.1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
Precipitable Water (mm)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Days Since Last Snow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Liquid Precipitation Depth (mm)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

- No model implemented in the tool
✓ No statistically significant change
✓ Statistically significant change - Small ES
✓ Statistically significant change - Medium ES
✓ Statistically significant change - Large ES

4. Discussion and Conclusion

The direct comparison of the distributions of values generated by the two future weather generation tools displays little differences between them (Figure 1), but, Figure 2 shows very different patterns in application of the morphing method although both tools recur to the same method to downscale the monthly values generated by the GCMs.

After the comparison in Table 2, the two tools demonstrate to be substantially different and Weathershift™ only modifies the most important meteorological parameters (dry bulb temperature, dew point temperature, relative humidity, atmospheric pressure, global horizontal radiation, direct normal radiation, diffuse horizontal radiation, and wind speed). This aspect is of major importance when a modeler (designer, consultant, etc.) want to test the performance of a model that uses one of the other meteorological variables under future weather scenarios. Furthermore, Table 2 shows that a change in a variable might be not statistically significant in the near-term, but becomes statistically significant in medium-term and long-term, for example the global horizontal radiation in case of Paris for CCWorldWeatherGen or in case of Athens for WeatherShift™. The effect size of climate change increases for higher latitudes, that is, although the net increase in temperature in Copenhagen is lower than in Athens, the relative temperature rise will be higher in the former city.

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