The impact of climate change on Building Energy Simulation (BES) uncertainty - Case study from a LEED building in Egypt

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Abstract: Climate change and global warming are two major concerns over the globe today, and the rapid change in climate became more sensible as it impacts diverse industries and disciplines. Buildings share of the global energy use exceeds 40%, and buildings' Green House Gas (GHG) emissions resembles one-third of global GHG emissions; hence, Building Energy Simulation (BES) process became an essential step during building design, to study and minimize whole buildings' energy use, and consequently minimize buildings' carbon footprint. A significant and underestimated input to the BES process is the weather data; BES process normally uses historical weather data in the form of a weather file to simulate the building's outdoor conditions, those outdoor conditions impacts the amount of thermal load on the building, therefore they significantly impact building's estimated thermal comfort and annual energy use. With the rapid change in the outdoor weather conditions year after year, using those historical weather data files must be questioned, as they impact the estimated energy use, and consequently put what's deemed as the "optimum energy use" in question. Using those historical weather data is hence expected to increase BES degree of uncertainty. This paper studies and quantifies the impact of weather data accuracy on building's annual energy performance. The paper follows an empirical research approach by simulating an office building located in Cairo, Egypt. The study relies on using a typical weather data file and real weather files to run and compare two simulations for the same case study. Finally, the paper quantifies the impact of weather data's accuracy on the total annual energy use by comparing both simulation results.

Keywords: *Weather Data, Building Performance Simulation, Uncertainty and Sensitivity, Green Buildings, Energy Efficiency*

1. Introduction

"Only about a decade ago, global warming was just a hypothesis. However, now it is being recognized as leading to climate change and extreme weather conditions."[1]. Climate change impact on hot weather regions causes higher recorded temperatures, and in cold weather regions causes lower recorded temperatures [2], but for a moderate region like Egypt, it's challenging to quantify the impact.

Building Energy Simulation (BES) is a process that aims to predicting the whole building's annual energy consumption, this process enables the user to analyze the building's energy related performance parameters, such as indoor temperatures, internal/external thermal loads, utility reading, and much more, [3], however, the accuracy of those analysis results depends on the accuracy of the input data by the users. One significant BES input is weather data.

Weather data are inserted to the BES tool using weather data files. Weather data files contain numerical values representing one typical year; therefore they do not change from year to another, for example; when defining the year 2003 or 2013 to the simulation tool, both will run the same climatic circumstances, which is not the real case.

As we witness climate change today, Fig. 1, we can no longer depend on a static weather file approach during BES. For example, the metrological data provided by the ETMY (Egyptian Typical Meteorological Year) depends on statistical weather studies that ended in 2003 ([4], while the climate in Egypt do witness annual variations, and each year reports data different from the preceding year. So this static representation – in the simulation process - of a stochastically varying parameter – in the real world - is a source of error in the simulation results, and causes BES uncertainty.

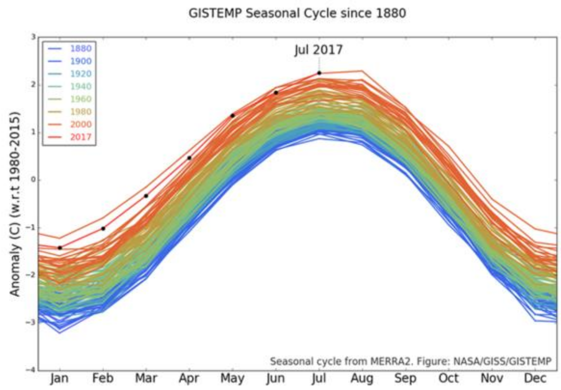


Fig. 1. The GISTEMP monthly temperature anomalies superimposed on a 1980-2015 mean seasonal cycle. Retrieved from [5]

According to [6], there are three ways to represent uncertainty; the most significant is using the Certainty Factor (CF). CF is different than probability since it is the measure of belief in a certain outcome, and not the probability of the outcome itself, therefore each has its own numerical representation; probability is represented as a factor ranging from 0 to 1, while CF ranges from -1 (disbelief) to +1 (belief).

Uncertainty and sensitivity of BES is an uprising concern among BES practitioners today, and related research provided further evidence that: proper weather data sets, which are based on high resolution data are required to empower building engineers and architects with enhanced degrees of certainty [7]; Hence, it's essential to record actual weather data, and study their impact on BES in different climate zones, to be able to quantify uncertainty.

2. Methodology

The research takes an empirical approach; it compares between simulating a building using historic weather file, against simulation using actual weather data. The simulation process is done using eQuest software [8], the actual weather data are collected from a weather station in new Cairo city, that logs actual temperature and Relative Humidity (RH) on a one minute interval, while the weather file is based on the (ETMY), downloaded from DOE - EnergyPlus website [4].

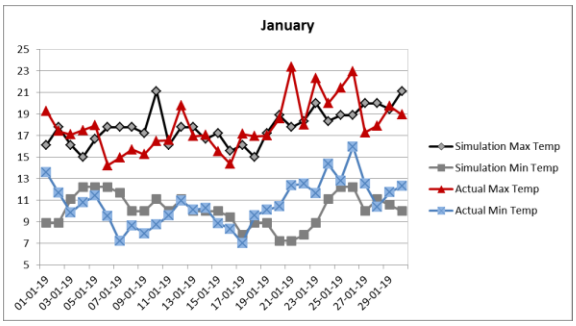
3. Case study

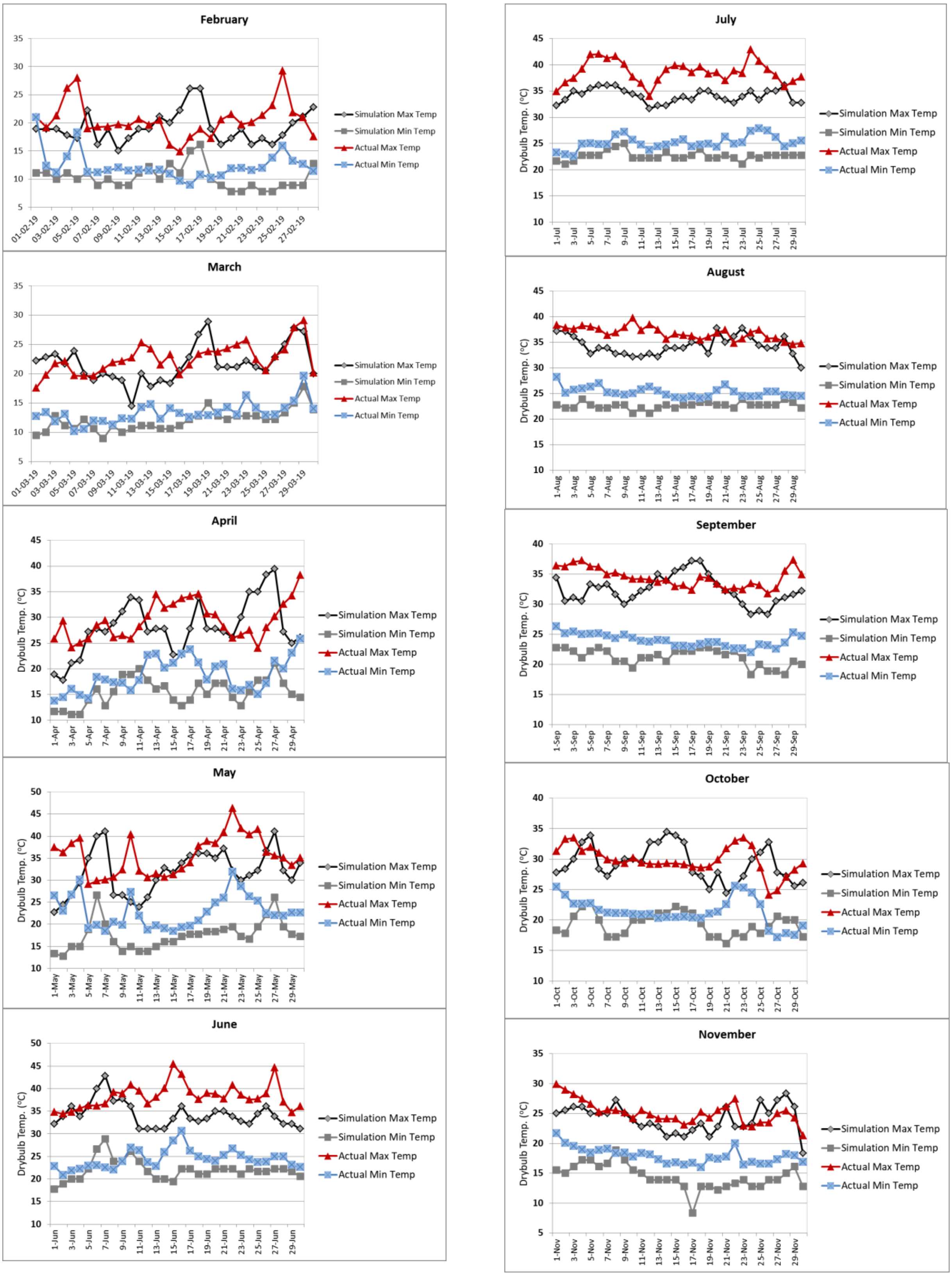
The case is a mid-rise office building located in new Cairo city. The building is awarded LEED Gold certificate in 2018 under LEED V3. The building is equipped with a sensor that measures ambient drybulb temperature and RH, and logs both parameters on minute by minute basis.

3.1. Comparing weather data

The actual weather data were logged starting from April 2018, until March 2019. The data was processed on two steps. The first step was to extract each day's minimum and maximum temperatures, along with the RH that occurred at those temperatures, the temperature data are plotted as shown in Fig. 2.

The second step was to convert the minute by minute log to an hourly log, by automatically extracting a reading every 59 readings of the log. Those data are then inserted to the simulation tool – eQuest – in a weather data file format.




February
Simulation Max Temp
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March
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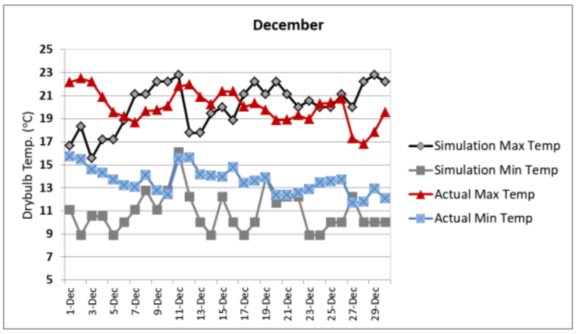

Fig. 2. Annual simulation temperatures (from energy weather file) vs recorded ambient temperatures.

Figures 2 show the contrast between the actual logged weather data, and the DOE weather file data. The weather data is defined in terms of daily maximum and minimum temperatures.

The logged weather data is referred in the graph legend as "*Actual Max/Min Temp*", while the DOE weather file data is referred as "*Simulation Max/Min Temp*".

The DOE weather data file refers to periods of record ranging from 12 to 21 years, which all ends in 2003 [4]. The actual weather data are logged during the period of: April 2018 till March 2019, to represent one full year.

It's noticed from the weather graphs, Fig. 2, that months like May, June, July and August recorded extreme peak temperatures, hitting 45^{o}C once during May, and twice during July, which was never recorded before the year 2003. Peak temperature was also ranging between 35^{o}C and 45^{o}C all along June and July, while historic data of the same months falls almost below 35^{o}C.

3.2. *Simulation limitations*

The logged weather data are only for drybulb temperatures and RH. It's recommended that future research include a full weather station log, including: wet bulb temperature, atmospheric pressure, dew point temperature, global solar radiation (Wh/m^2), normal solar radiation (Wh/m^2), diffuse solar radiation, and wind speed.

4. Results & Findings

First; the building's energy model was run with the weather file data. Results are shown in Fig. 3. Another run, with actual recorded weather data took place, and the results are shown in Fig. 4. Figs. 5, 6, and 7 summarize the variation between both energy simulation runs on monthly and annual basis.

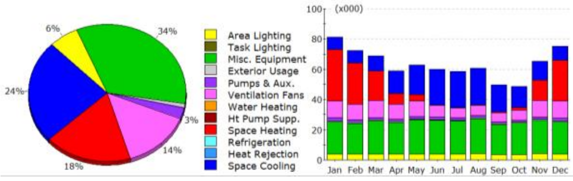

Fig. 3. Annual energy breakdown – case of using historic weather data

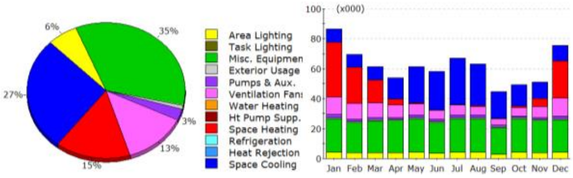

Fig. 4. Annual energy breakdown – case of using actual weather data

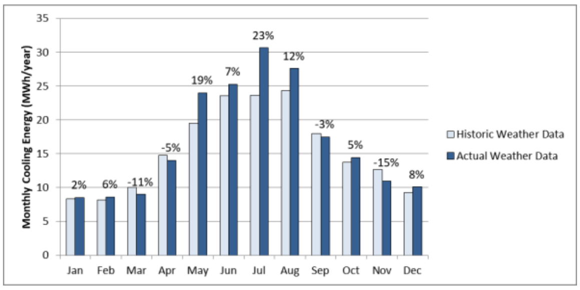

Fig. 5. Comparing monthly cooling energy. Note. The value over each column represents the variation between Historic and Actual weather data.

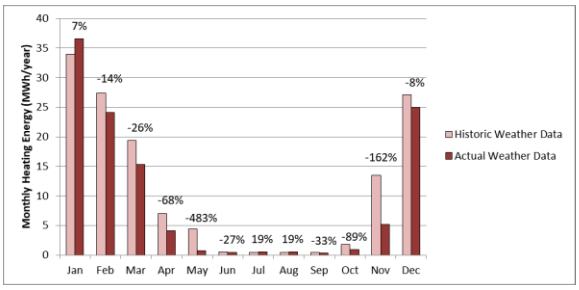

Fig. 6. Comparing monthly heating energy. Note. The value over each column represents the variation between Historic and Actual weather data.

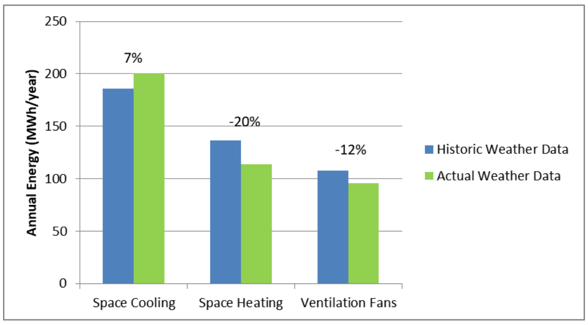

Fig. 7. Summary of both simulation runs' results. Note. The value over each column represents the variation between Historic and Actual weather data.

Results show that: applying actual weather data to the energy model decreased annual energy consumption by 3%. The variation is broke-down as: 7% increase in annual cooling energy, 20% decrease in annual heating energy, and 12% decrease in annual ventilation energy; hence, climate change affected BES uncertainty in some disciplines by 20%, which is a significant impact that must be considered.

5. Discussion

Egypt's climate is changing in terms of high and low temperatures. Global warming seems to affect both; high summer temperatures, which were recorded to get higher (increasing cooling energy), and low winter temperatures which were, unexpectedly, getting higher as well (decreasing heating energy). [9] and [10].

The significance of the presented study is that: the used data are logged from a calibrated weather data logger, which is installed on top of the studied building case; however, the study is limited to logging outdoor temperature and RH only, and is limited to one year data log only.

The calculated uncertainty is considered as a preliminary estimation only, and is based on one case study; though, it showed that using actual weather data do significantly enhance BES certainty. It's recommended for future related research to analyze a dataset of more case studies. It's also recommended that future research quantify the change in uncertainty by following the CF model established by [6], and by following the uncertainty breakdown established by [11].

One of the underestimated sources of uncertainty related to weather files is the representation of the overcast sky percentage in weather files, as weather files assume constant 30% overcast percent all over the year. It's recommended for future research to conduct a sky cover classification analysis, similar to the work of [12], who proved that the clear sky conditions cover 71% of the daylight hours annually.

This research study is expected to impact researchers as well as practitioners. Energy modeling practitioners shall seek actual logged weather data for energy simulation whenever possible, or to assume up to 20% variation in energy predictions of each discipline, and up to 5% in total energy consumption. Future research might follow the same methodology with a bigger dataset; such research is expected to yield metrics that may be used to calibrate BES outcomes.

6. Conclusion

While ASHRAE standard states peak temperature of 38.2^{o}C during August [13], which is followed by the common design practice in Egypt; this research showed repetitive occurrence of a 45^{o}C peak temperature, and showed that the peak occurred in July, not in August. July month recorded the highest variation in peak temperatures (23%), which is one of the significant consequences of climate change on the climate in Egypt, and which, consequently, impacted BES certainty.

It is recommended for BES practitioners in Egypt to consider that using historic weather file data of Egypt's climate zone underestimates cooling energy, and overestimates heating energy.

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